OPERATIVE TECHNIQUES IN ORTHOPAEDIC SURGERY
ALSO AVAILABLE IN THIS SERIES

OPERATIVE TECHNIQUES IN FOOT AND ANKLE SURGERY
Editor: Mark E. Easley
Editor-in-Chief: Sam W. Wiesel

OPERATIVE TECHNIQUES IN PEDIATRIC ORTHOPAEDICS
Editor: John M. Flynn
Editor-in-Chief: Sam W. Wiesel

OPERATIVE TECHNIQUES IN ORTHOPAEDIC TRAUMA
Editors: Paul Tornetta III
Gerald R. Williams & Matthew L. Ramsey
Thomas R. Hunt III
Editor-in-Chief: Sam W. Wiesel

OPERATIVE TECHNIQUES IN SHOULDER AND ELBOW SURGERY
Editors: Gerald R. Williams & Matthew L. Ramsey
Editor-in-Chief: Sam W. Wiesel

OPERATIVE TECHNIQUES IN SPORTS MEDICINE SURGERY
Editor: Mark D. Miller
Editor-in-Chief: Sam W. Wiesel

OPERATIVE TECHNIQUES IN ADULT RECONSTRUCTION SURGERY
Editors: Javad Parvizi & Richard H. Rothman
Editor-in-Chief: Sam W. Wiesel

OPERATIVE TECHNIQUES IN HAND, WRIST, AND FOREARM SURGERY
Editor: Thomas R. Hunt III
Associate Editor: Scott H. Kozin
Editor-in-Chief: Sam W. Wiesel
OPERATIVE TECHNIQUES IN ORTHOPAEDIC SURGERY

Sam W. Wiesel, MD
EDITOR-IN-CHIEF
Professor and Chair
Department of Orthopaedic Surgery
Georgetown University Medical School
Washington, DC

VOLUME ONE
For Barbara Wiesel—confidante, advisor, best friend, and wife—thank you for a wonderful 39 years. With much love.

SWW
Dedication

To my beloved and inspiring family: Shelly, Yarden, Tom, Nimrod, and Dan —JB

To my family for the unending support of my academic endeavors. —SDB

To my orthopaedic mentors, especially Ed Hanley, John Hall, Jim Kasser, and Peter Waters, who have inspired me to write and teach and give back to orthopaedics, the way they have. —JMF

To Drs. Kenneth C. Francis, Ralph Marcove, and William F. Enneking, three great innovators, pioneers, developers, and critical thinkers in the field of orthopaedic oncology. I had the privilege to work with all three great pioneers and dedicate my work on this project to these world-class surgeons. —MMM

To my last child to leave the nest, Missy. I hope that all of our time together can be “quality time.” —Your loving father, MDM

To my beautiful wife, Fariba, for her fortitude, devotion, and love. —JP

To my dear wife, Marcia, for always believing in and supporting me; to my children, Julia and James, for being my inspirations; to my parents, for always providing for me; and to God, for making it all possible. —JMR

To my mother, Phyllis, who found the best in people, had compassion for all, and whose insight, guidance, and love have always made me believe that anything is possible. —PT

To our wives, Robin and Nancy, and our children, Mark and Alexis and Chelsea, Alex, and Julia. —GRW and MLR

To my wife, Mary Lynne, and my children, Ford, Benson, and Charlotte, for patiently tolerating the time I spent away from them while I pursued this academic endeavor, and to my parents, Barbara and Dennis Easley, whose guidance and support prepared me for a career in academic medicine. —MEE

To my cherished wife Teri and our four extraordinary children, Thomas, William, Caitlin, and Christopher, for their love and understanding, and especially for their endless supply of smiles, laughter, and fun!—TRH
Volume One

PART 1 SPORTS MEDICINE

SECTION I SHOULDER

1 Shoulder Arthroscopy: The Basics
   Elizabeth Matzkin and Craig R. Bottoni 7

2 Arthroscopic Treatment of Anterior Shoulder Instability
   Robert A. Arciero, Augustus D. Mazzocca, and Jeffrey T. Spang 14

3 Arthroscopic Treatment of Posterior Shoulder Instability
   Fotios P. Tjoumakaris and James P. Bradley 24

4 Arthroscopic Treatment of Multidirectional Shoulder Instability
   Steven B. Cohen and Jon K. Sekiya 30

5 Arthroscopic Treatment of Superior Labral (SLAP) Tears
   Brian Cole and John-Paul Rue 38

6 Management of Shoulder Throwing Injuries
   Matthew T. Boes and Craig D. Morgan 44

7 Arthroscopic Treatment of Biceps Tendonopathy
   J. R. Rudzki and Benjamin S. Shaffer 57

8 Arthroscopic Treatment of Subacromial Impingement
   R. Timothy Greene and Spero G. Karas 68

9 Acromioclavicular Disorders
   R. Timothy Greene and Spero G. Karas 75

10 Arthroscopic Treatment of Rotator Cuff Tears
    Robert Z. Tashjian, Jay D. Keener, and Ken Yamaguchi 81

11 Arthroscopic Treatment of Subscapularis Tears, Including Coracoid Impingement
    Christopher R. Adams and Stephen S. Burkhart 91

12 Repair and Reconstruction of Acromioclavicular Injuries
   Amir Mostofi, Augustus D. Mazzocca, and Robert A. Arciero 102

13 Arthroscopic Acromioclavicular Joint Reduction and Coracoclavicular Stabilization: TightRope Fixation
   Michael S. Todd and Winston J. Warme 116

14 Arthroscopic Release of Nerve Entrapment
   Felix H. Savoie, III, and Larry D. Field 122

15 Arthroscopic Capsular Releases for Loss of Motion
   Ryan W. Simovitch, Laurence D. Higgins, and Jon J.P. Warner 125

16 Arthroscopic Treatment of Scapulothoracic Disorders
   Michael J. Huang and Peter J. Millett 134

17 Arthroscopic Débridement and Glenoidplasty for Shoulder Degenerative Joint Disease
   Christian J. H. Veillette and Scott P. Steinmann 138

SECTION II ELBOW

18 Elbow Arthroscopy: The Basics
   John E. Conway 145

19 Arthroscopic Treatment of Chondral Injuries and Osteochondritis Dissecans
   Marc Safran 155

20 Arthroscopic Treatment of Valgus Extension Overload
   Sami O. Khan and Larry D. Field 166

21 Arthroscopic Treatment of Elbow Loss of Motion
   Matthew T. Provencher, Mark S. Cohen, and Anthony A. Romeo 171

22 Arthroscopic Débridement for Elbow Degenerative Joint Disease
   Julie E. Adams and Scott P. Steinmann 179

23 Arthroscopic Treatment of Epicondylitis
   Kevin P. Murphy, Jeffrey R. Giuliani, and Brett A. Freedman 184

SECTION III HIP

24 Hip Arthroscopy: The Basics
   Marc Safran and Matthew A. Stanich 191

25 Arthroscopy for Soft Tissue Pathology of the Hip
   J. W. Thomas Byrd and MaCalus V. Hogan 203

26 Arthroscopic Management of Femoroacetabular Impingement
   Christopher M. Larson and Rebecca M. Stone 213

27 Snapping Hip
   J. W. Thomas Byrd and MaCalus V. Hogan 222

28 Athletic Pubalgia
   Jesse C. Botker, Robert F. LaPrade, and David R. Joesting 231

29 Adductor Longus–Related Groin Pain
   Robert T. Sullivan and William E. Garrett 238

30 Proximal Hamstring Injury
   Robert T. Sullivan and William E. Garrett 243

SECTION IV KNEE

31 Knee Arthroscopy: The Basics
   Steven A. Aviles and Christina R. Allen 248
### CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Authors</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>Arthroscopic Synovectomy</td>
<td>Anne E. Colton, Charles Bush-Joseph, and Jeffrey S. Earhart</td>
<td>256</td>
</tr>
<tr>
<td>33</td>
<td>Arthroscopic Meniscectomy</td>
<td>Frederick M. Azar</td>
<td>263</td>
</tr>
<tr>
<td>34</td>
<td>Meniscal Repair</td>
<td>Nicholas A. Sgaglione and Michael J. Angel</td>
<td>274</td>
</tr>
<tr>
<td>35</td>
<td>Meniscal Transplant</td>
<td>Roland S. Kent, Christopher A. Kurtz, and Kevin F. Bonner</td>
<td>284</td>
</tr>
<tr>
<td>36</td>
<td>Microfracture Chondroplasty</td>
<td>J. Richard Steadman and William G. Rodkey</td>
<td>295</td>
</tr>
<tr>
<td>37</td>
<td>Arthroscopic Meniscectomy</td>
<td>Frederick M. Azar</td>
<td>303</td>
</tr>
<tr>
<td>38</td>
<td>Autogenous Cartilage Implantation</td>
<td>Sean M. Jones-Quaidoo and Eric W. Carson</td>
<td>312</td>
</tr>
<tr>
<td>39</td>
<td>Allograft Cartilage Transplantation</td>
<td>Eric C. McCarty, R. David Rabalais, and Kenneth G. Swan, Jr.</td>
<td>322</td>
</tr>
<tr>
<td>40</td>
<td>Osteochondritis Dissecans and Avascular Necrosis</td>
<td>Mark J. Billante and David R. Diduch</td>
<td>329</td>
</tr>
<tr>
<td>41</td>
<td>Single-Bundle Anterior Cruciate Ligament Repair</td>
<td>Mark D. Miller</td>
<td>341</td>
</tr>
<tr>
<td>42</td>
<td>Anatomic Double-Bundle Anterior Cruciate Ligament Reconstruction</td>
<td>Steven B. Cohen and Freddie H. Fu</td>
<td>350</td>
</tr>
<tr>
<td>43</td>
<td>Revision Anterior Cruciate Ligament Repair</td>
<td>David R. McAllister and David L. Feingold</td>
<td>357</td>
</tr>
<tr>
<td>44</td>
<td>Posterior Cruciate Ligament Repair</td>
<td>Craig S. Mauro, Anthony M. Buoncristiani, and Christopher D. Harner</td>
<td>365</td>
</tr>
<tr>
<td>45</td>
<td>Repair of Acute and Chronic Knee Medial Collateral Ligament Injuries</td>
<td>Christian Lattermann and Darren L. Johnson</td>
<td>375</td>
</tr>
<tr>
<td>46</td>
<td>Management of Posterolateral Corner Injuries</td>
<td>Richard J. Thomas and Mark D. Miller</td>
<td>381</td>
</tr>
<tr>
<td>47</td>
<td>Management of the Multiple Ligament-Injured Knee</td>
<td>Ralph W. Passarelli, Bradley B. Veazey, Daniel C. Wascher, Andrew J. Veitch, and Robert C. Schenck</td>
<td>392</td>
</tr>
<tr>
<td>48</td>
<td>Repair of Acute and Chronic Patella Tendon Tears</td>
<td>Thomas M. DeBerardino and Brett D. Owens</td>
<td>402</td>
</tr>
<tr>
<td>49</td>
<td>Repair of Acute and Chronic Quadriceps Tendon Ruptures</td>
<td>Krishna Mallick</td>
<td>407</td>
</tr>
<tr>
<td>50</td>
<td>Knee Loss of Motion</td>
<td>Gregory C. Fanelli, Justin D. Harris, Daniel J. Tomaszewski, and John A. Scaneli III</td>
<td>413</td>
</tr>
<tr>
<td>51</td>
<td>Arthroscopic Lateral Release of the Knee</td>
<td>Carl H. Wierks and Andrew J. Cosgarea</td>
<td>422</td>
</tr>
<tr>
<td>52</td>
<td>Proximal Realignment of the Medial Patelofemoral Ligament</td>
<td>Donald C. Fithian, Samuel S. Park, and Erik Stark</td>
<td>426</td>
</tr>
<tr>
<td>53</td>
<td>Tibial Tubercle Transfer</td>
<td>John P. Fulkerson</td>
<td>435</td>
</tr>
</tbody>
</table>

### SECTION V LEG

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Authors</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>Chronic Exertional Compartment Syndrome</td>
<td>Jocelyn R. Wittstein, L. Scott Levin, and Claude T. Moorman III</td>
<td>443</td>
</tr>
<tr>
<td>55</td>
<td>Common Peroneal and Lateral Femoral Cutaneous Nerve Injuries</td>
<td>Ivica Ducic and Jeffrey M. Jacobson</td>
<td>453</td>
</tr>
</tbody>
</table>

### PART 2 PELVIS AND LOWER EXTREMITY TRAUMA

### SECTION I PELVIS AND HIP

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Authors</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>External Fixation of the Pelvis</td>
<td>Stephen Kottmeier, John C. P. Floyd, and Nicholas Divaris</td>
<td>462</td>
</tr>
<tr>
<td>2</td>
<td>Open Reduction and Internal Fixation of the Symphysis</td>
<td>Michael S. H. Kain and Paul Tornetta III</td>
<td>476</td>
</tr>
<tr>
<td>3</td>
<td>Open Reduction and Internal Fixation of the Sacroiliac Joint and Sacrum</td>
<td>Henry Claude Sagi</td>
<td>487</td>
</tr>
<tr>
<td>4</td>
<td>Open Reduction and Internal Fixation of the Posterior Wall of the Acetabulum</td>
<td>Jodi Siegel and David C. Templeman</td>
<td>503</td>
</tr>
<tr>
<td>5</td>
<td>Open Reduction and Internal Fixation of Femoral Head Fractures</td>
<td>Darin Friess and Thomas Ellis</td>
<td>514</td>
</tr>
<tr>
<td>6</td>
<td>Open Reduction and Internal Fixation and Closed Reduction and Percutaneous Fixation of Femoral Neck Fractures</td>
<td>Brian Mullis and Jeff Anglen</td>
<td>521</td>
</tr>
</tbody>
</table>

### SECTION II FEMUR AND KNEE

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Authors</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Cephalomedullary Nailing of the Proximal Femur</td>
<td>Thomas A. Russell</td>
<td>533</td>
</tr>
<tr>
<td>8</td>
<td>Open Reduction and Internal Fixation of Peritrochanteric Hip Fractures</td>
<td>Matthew E. Oetgen and Michael R. Baumgaertner</td>
<td>547</td>
</tr>
<tr>
<td>9</td>
<td>Retrograde Intramedullary Nailing of the Femur</td>
<td>Laura S. Phieffer and Ronald Lakatos</td>
<td>558</td>
</tr>
<tr>
<td>10</td>
<td>Anterograde Intramedullary Nailing of the Femur</td>
<td>Bruce H. Ziran, Natalie L. Talboo, and Navid M. Ziran</td>
<td>569</td>
</tr>
<tr>
<td>11</td>
<td>Open Reduction and Internal Fixation of the Distal Femur</td>
<td>Animesh Agarwal</td>
<td>582</td>
</tr>
<tr>
<td>12</td>
<td>Open Reduction and Internal Fixation of the Patella</td>
<td>J. Benjamin Smucker and John K. Sontich</td>
<td>604</td>
</tr>
<tr>
<td>13</td>
<td>Open Reduction and Internal Fixation of the Bicondylar Plateau</td>
<td>Toby M. Risko and William M. Ricci</td>
<td>613</td>
</tr>
<tr>
<td>14</td>
<td>Lateral Tibial Plateau Fractures</td>
<td>Philipp Kobbe and Hans Christoph Pape</td>
<td>622</td>
</tr>
</tbody>
</table>
SECTION III LEG

15 External Fixation of the Tibia
J. Tracy Watson 629

16 Intramedullary Nailing of the Tibia
Mark A. Lee and Brett D. Crist 642

17 Fasciotomy of the Leg for Acute Compartment Syndrome
George Partal, Andrew Furey, and Robert O’Toole 660

SECTION IV FOOT AND ANKLE

18 Open Reduction and Internal Fixation of the Pilon
Cory A. Collinge and Michael Prayson 671

19 Open Reduction and Internal Fixation of the Ankle
Kenneth A. Egol 687

20 Open Reduction and Internal Fixation of the Talus
David E. Karges 697

21 Surgical Treatment of Calcaneal Fractures
James B. Carr 712

22 Open Reduction and Internal Fixation of Lisfranc Injury
Michael P. Clare and Roy W. Sanders 724

23 Open Reduction and Internal Fixation of Jones Fracture
William R. Creevy and Seth P. Levitz 734

PART 3 ADULT RECONSTRUCTION

SECTION I HIP RECONSTRUCTION

1 Cemented Total Hip Arthroplasty
Matthew S. Hepinstall and José A. Rodriguez 744

2 Uncemented Total Hip Arthroplasty
Matthew S. Austin and Brian A. Klatt 756

3 Hip Resurfacing 763
Kang-Il Kim and Ameet Pispati

4 Hemiarthroplasty of the Hip
Hari P. Bezwada, Robert H. Cho, and David G. Nazarian 782

5 Total Hip Arthroplasty for Malignant Lesions
R. Lor Randall 798

6 Revision Total Hip Arthroplasty With Well-Fixed Components
Trevor R. Pickering and Michael E. Berend 808

7 Revision Total Hip Arthroplasty With Femoral Bone Loss: Fluted Stems
Christian P. Christensen and Cale A. Jacobs 815

8 Revision Total Hip Arthroplasty With Femoral Bone Loss: Proximal Femoral Replacement
Javad Parvizi, Benjamin Bender, and Franklin H. Sim 823

9 Revision Total Hip Arthroplasty With Acetabular Bone Loss: Impaction Allografting
Gregg R. Klein, Harlan B. Levine, and Mark A. Hartzband 831

10 Revision Total Hip Arthroplasty With Acetabular Bone Loss: Antiprotrusio Cage
Matthew S. Austin, James J. Purtill, and Brian A. Klatt 836

11 Resection Arthroplasty and Spacer Insertion
Mark J. Spangehl and Christopher P. Beauchamp 843

12 Hip Reimplantation Surgery
Nelson V. Greidanus, Winston Y. Kim, and Bassam A. Masri 853

SECTION II HIP PRESERVATION

13 Periacetabular Osteotomy
Marco Teloken, David Gusmao, and Marcus Crestani 859

14 Femoral Osteotomy
Philipp Henle, Moritz Tannast, and Klaus A. Siebenrock 869

15 Femoroacetabular Impingement and Surgical Dislocation of the Hip
Martin Beck and Michael Leunig 877

16 Treatment of Anterior Femoroacetabular Impingement Through an Anterior Incision
John C. Clohisy 887

SECTION III KNEE RECONSTRUCTION

17 Unicondylar Knee Arthroplasty
Keith R. Berend, Jeffrey W. Salin, and Adolph V. Lombardi Jr. 895

18 Upper Tibial Osteotomy
James Bicos and Robert A. Arciero 905

19 Cemented Total Knee Arthroplasty
S. Mehdi Jafari and Javad Parvizi 918

20 Total Knee Arthroplasty Using Navigation
William J. Hozack, S. M. Javad Mortazavi, and Camilo Restrepo 933

21 Revision Total Knee Arthroplasty With Femoral Bone Loss: Metal Augments
Gwo-Chin Lee 942

22 Revision Total Knee Arthroplasty With Tibial Bone Loss: Metal Augments
Shawn M. Brubaker, William Mihalko, Thomas E. Brown, and Khaled J. Saleh 949

23 Revision Total Knee Arthroplasty With Femoral Bone Loss: Distal Femoral Replacement
B. Sonny Bal 962

24 Revision Total Knee Arthroplasty With Tibial Bone Loss: Bone Grafting
Brian Vannozzi, Gwo-Chin Lee, and Jonathan Garino 969

25 Revision Total Knee Arthroplasty With Removal of Well-fixed Components
Matthew S. Austin, S. Mehdi Jafari, and Benjamin Bender 975

26 Revision Total Knee Arthroplasty With Extensile Exposure: Tibial Tubercle Osteotomy
Anish K. Amin and James T. Patton 980

27 Revision Total Knee Arthroplasty With Extensile Exposure: V-Y Quadroplasty
Ali Oliashirazi 986

28 Revision Total Knee Arthroplasty With Extensor Mechanism Repair
Fabio Orozco and Alvin Ong 989
Volume Two

PART 4 PEDIATRICS

SECTION I TRAUMA

1 Intramedullary Fixation of Forearm Shaft Fractures
   Charles T. Mehlman 1026

2 Open Reduction and Internal Fixation of Displaced Lateral Condyle Fractures of the Humerus
   Kristan A. Pierz and Brian G. Smith 1035

3 Open Reduction and Internal Fixation of Fractures of the Medial Epicondyle
   Brian G. Smith and Kristan A. Pierz 1042

4 Open Reduction of Supracondylar Fractures of the Humerus
   Jennifer J. Winell and John M. Flynn 1046

5 Closed Reduction and Percutaneous Pinning of Supracondylar Fractures of the Humerus
   Paul D. Choi and David L. Skaggs 1050

6 Closed, Percutaneous, and Open Reduction of Radial Head and Neck Fractures
   Jenny M. Frances and Roger Cornwall 1058

7 Percutaneous Joystick and Intramedullary Reduction (Metaizeau) Techniques for Radial Neck Fractures
   Unni G. Narayanan and Fabio Ferri-De-Barros 1066

8 Supracondylar Humeral Osteotomy for Correction of Cubitus Varus
   Yi-Meng Yen, Richard E. Bowen, and Norman Y. Otsuka 1075

9 Pediatric Shoulder Fractures
   Craig P. Eberson 1080

10 Pediatric Hip Fractures
    R. Dale Blasier 1088

11 Closed Reduction and Spica Casting of Femur Fractures
    Matthew R. Garner and John M. Flynn 1095

12 Closed Reduction and External Fixation of Femoral Shaft Fractures
    Stuart M. Myers and John M. Flynn 1099

13 Flexible Intramedullary Nailing of Femoral Shaft Fractures
    Gilbert Chan and John M. Flynn 1106

14 Submuscular Plating of Femoral Shaft Fractures
    Ernest L. Sink 1111

15 Distal Femoral Physeal Fractures
    R. Dale Blasier 1116

16 Pediatric Tibial Fractures
    Craig P. Eberson 1122

17 Open Reduction and Internal Fixation of Tibial Tuberosity Fractures
    Ernest L. Sink 1130

18 Operative Management of Pediatric Ankle Fractures
    Bryan T. Leek and Scott J. Mubarak 1134

SECTION II ARTHROSCOPIC AND SPORTS MEDICINE

19 Elbow Arthroscopy for Panner’s Disease and Osteochondritis Dissecans
   Theodore J. Ganley, Gilbert Chan, Aaron B. Heath, and J. Todd R. Lawrence 1144

20 Patellar Instability
   Eric J. Wall and James R. Romanowski 1149

21 Proximal Patellar Realignment
   Jay C. Albright 1156

22 Arthroscopy-Assisted Management or Open Reduction and Internal Fixation of Tibial Spine Fractures
   Gilbert Chan and Lawrence Wells 1161

23 Anterior Cruciate Ligament Reconstruction in the Skeletally Immature Patient
   J. Todd R. Lawrence and Mininder S. Kocher 1168

24 Arthroscopic Drilling of Osteochondritis Dissecans
   Theodore J. Ganley, Gilbert Chan, and Aaron B. Heath 1177

25 Meniscoplasty for Discoid Lateral Meniscus
   Jay C. Albright 1183

SECTION III RECONSTRUCTION

26 Proximal Femoral Rotational Osteotomy
   Unni G. Narayanan 1187

27 Proximal Femoral Varus Osteotomy Using a 90-Degree Blade Plate
   Tom F. Novacheck 1196

28 Treatment of Congenital Femoral Deficiency
   Dror Paley and Shawn C. Standard 1202

29 Surgical Repair of Irreducible Congenital Dislocation of the Knee
   Matthew B. Dobbs, Noppachart Limpaphayom, and J. Eric Gordon 1224

30 Surgical Management of Blount’s Disease
   Eric D. Shirley and Richard S. Davidson 1230

31 Percutaneous Distal Femoral or Proximal Tibial Epiphysiodesis
   J. Richard Bowen 1238

32 Excision of Physeal Bar
   Anthony A. Stans 1244

33 Repair of Congenital Pseudarthrosis of the Tibia With the Williams Rod
   Perry L. Schoenecker and Margaret M. Rich 1251
CONTENTS

34 Limb Lengthening Using the Ilizarov Method or a Monoplanar Fixator
Roger F. Widmann, Purushottam A. Gholve, and Arkady Blyakher 1258

35 Guided Growth to Correct Limb Deformity
Peter M. Stevens 1270

36 Distal Tibial Osteotomy
Kathryn A. Keeler and J. Eric Gordon 1276

37 Multiple Percutaneous Osteotomies and Fassier-Duval Telescoping Nailing of Long Bones in Osteogenesis Imperfecta
Paul W. Esposito 1284

38 Syme and Boyd Amputations for Fibular Deficiency
Anthony A. Scaduto and Robert M. Bernstein 1295

39 Hemi-Epiphysiodesis for Ankle Valgus
Peter M. Stevens 1304

SECTION IV NEUROMUSCULAR CORRECTION

40 Adductor and Iliopsoas Release
Tom F. Novacheck 1310

41 Rectus Femoris Transfer
Jon R. Davids 1316

42 Proximal Hamstring and Adductor Lengthening
Freeman Miller and Kirk W. Dabney 1322

43 Distal Hamstring Lengthening
Jon R. Davids 1326

44 Gastrocnemius Fascia Lengthening
James J. McCarthy and David A. Spiegel 1334

45 Distal Femoral Osteotomy for Crouch Gait
Tom F. Novacheck 1339

SECTION V CYSTS

46 Benign Bone Cysts
Alexandre Arkader and John P. Dormans 1345

SECTION VI UPPER EXTREMITY

47 Release of Simple Syndactyly
Donald S. Bae 1351

48 Correction of Thumb-in-Palm Deformity in Cerebral Palsy
Thanapong Waitayawinyu and Scott N. Oishi 1358

49 Release of the A1 Pulley to Correct Congenital Trigger Thumb
Roger Cornwall 1366

50 Transfer of Flexor Carpi Ulnaris for Wrist Flexion Deformity
Ann E. Van Heest 1371

51 Radial Dysplasia Reconstruction
Scott N. Oishi and Marybeth Ezaki 1376

52 Forearm Osteotomy for Multiple Hereditary Exostoses
Carla Baldrighi and Scott N. Oishi 1380

53 Modified Woodward Repair of Sprengel Deformity
J. Richard Bowen 1387

SECTION VII SPINE

54 Release of the Sternocleidomastoid Muscle
Gokce Mik and Denis S. Drummond 1392

55 Posterior Cervical Arthrodeses: Occiput–C2 and C1–C2
John P. Dormans, Gokce Mik, and Purushottam A. Gholve 1399

56 Posterior Exposure of the Thoracic and Lumbar Spine
James T. Guille and Reginald S. Fayssoux 1408

57 Segmental Hook and Pedicle Screw Instrumentation for Scoliosis
James T. Guille and Reginald S. Fayssoux 1414

58 Kyphectomy in Spina Bifida
Richard E. McCarthy 1424

59 Anterior Interbody Arthrodesis With Instrumentation for Scoliosis
Daniel J. Sucato 1431

60 Thoracoscopic Release and Fusion for Scoliosis
Daniel J. Sucato 1442

61 Unit Rod Instrumentation for Neuromuscular Scoliosis
Kirk W. Dabney and Freeman Miller 1448

62 Growing Rod Instrumentation for Early-Onset Scoliosis
Victor Hsu and Behroz Akbarnia 1458

63 Hemivertebra Excision 1466
Daniel J. Hedequist and John B. Emans

64 Posterolateral Arthrodesis for Spondylolisthesis
James T. Guille and Reginald S. Fayssoux 1474

65 Decompression, Posterolateral, and Interbody Fusion for High-Grade Spondylolisthesis
Gilbert Chan and John P. Dormans 1480

66 S-Rod Fixation to the Pelvis
Richard E. McCarthy 1489

SECTION VIII HIP

67 Anterior Approach for Open Reduction of the Developmentally Dislocated Hip
Richard M. Schwend 1493

68 Medial Approach for Open Reduction of a Developmentally Dislocated Hip
Lori A. Karol and Jeffrey E. Martus 1502

69 Anterior Drainage of the Septic Hip in Children
Richard M. Schwend 1508

70 Innominate Osteotomy of Salter
Richard E. Bowen and Norman Y. Otsuka 1517

71 Periacetabular Osteotomies of Pemberton and Dega
Tim Schrader and J. Anthony Gonzales, Jr. 1523

72 Labral Support (Shelf) Procedure for Perthes Disease
J. Richard Bowen 1532

73 Triple Innominate Osteotomy
Dennis R. Wenger and Maya E. Pring 1540

74 Chiari Medial Displacement Osteotomy of the Pelvis
Travis H. Matheney and Brian Snyder 1552
75 Bernese Periacetabular Osteotomy
Travis H. Matheney and Michael B. Millis 1559

76 Surgical Dislocation of the Hip
John Frino and Young-Jo Kim 1569

77 Valgus Osteotomy for Developmental
Coxa Vara
Michael B. Millis and Joshua A. Strassberg 1577

78 Valgus Osteotomy for Perthes Disease
Ellen M. Raney 1583

79 Percutaneous In Situ Cannulated Screw
Fixation of the Slipped Capital
Femoral Epiphysis
Richard S. Davidson and Michelle S. Caird 1589

80 Flexion Intertrochanteric Osteotomy for
Severe Slipped Capital Femoral Epiphysis
Young-Jo Kim and John Frino 1595

SECTION IX FOOT AND ANKLE

81 Triple Arthrodesis
Om Prasad Shrestha, David A. Spiegel, and James J. McCarthy 1600

82 Calcaneal Lengthening Osteotomy for the
Treatment of Hindfoot Valgus Deformity
Vincent S. Mosca 1608

83 Open Lengthening of the Achilles Tendon
Anna V. Cuomo, Norman Y. Otsuka, and Richard E. Bowen 1619

84 Split Posterior Tibial Tendon Transfer
David A. Spiegel, Om Prasad Shrestha, and James J. McCarthy 1626

85 Surgical Correction of Juvenile Bunion
B. David Horn 1633

86 Butler Procedure for Overlapping Fifth Toe
B. David Horn 1637

87 Surgical Treatment of Cavus Foot
Richard M. Schwend and Brad Olney 1639

88 Resection of Calcaneonavicular Coalition
David Scher 1650

89 Excision of Talocalcaneal Coalition
David Scher 1655

90 Ponseti Casting
Blaise Nemeth and Kenneth Noonan 1661

91 Posteromedial and Posterolateral Release for the
Treatment of Resistant Clubfoot
Richard S. Davidson 1674

92 Anterior Tibialis Transfer for Residual
Clubfoot Deformity
Karen S. Myung and Kenneth Noonan 1682

PART 5 ONCOLOGY

SECTION I SURGICAL MANAGEMENT

1 Overview of Endoprosthetic Reconstruction
Martin M. Malawer, Robert M. Henshaw, and Kristen Kellar-Graney 1728

4 Expandable Prostheses
Lee Jeys, Adesegun Abudu, and Robert Grimer 1740

5 Surgical Management of Metastatic Bone Disease: General Considerations
Jacob Bickels and Martin M. Malawer 1749

6 Cryosurgical Ablation of Bone Tumors
Jacob Bickels, Isaac Meller, Yehuda Kollender, and Martin M. Malawer 1757

SECTION II SHOULDER GIRDLE AND
UPPER EXTREMITIES

7 Overview of Resections Around the
Shoulder Girdle
James C. Wittig, Martin M. Malawer, and Kristen Kellar-Graney 1766

8 Total Scapular Resections With
Endoprosthetic Reconstruction
Martin M. Malawer, Kristen Kellar-Graney, and James C. Wittig 1776

9 Proximal Humeral Resection With
Allograft Prosthetic Composite
Steven Gitelis, Gregory P. Nicholson, Walter W. Virkus, Martin M. Malawer, and Benjamin J. Miller 1786

10 Proximal Humerus Resection With
Endoprosthetic Replacement: Intra-articular
and Extra-articular Resections
Martin M. Malawer, James C. Wittig, and Kristen Kellar-Graney 1793

11 Distal Humeral Resection With
Prosthetic Reconstruction
James C. Wittig and Martin M. Malawer 1807

12 Surgical Management of Metastatic
Bone Disease: Humeral Lesions
Jacob Bickels and Martin M. Malawer 1816

13 Axillary Space Exploration and Resections
James C. Wittig, Martin M. Malawer, Kristen Kellar-Graney, and Robert M. Henshaw 1825

14 Forequarter Amputation
Jacob Bickels and Martin M. Malawer 1833

15 Above-Elbow and Below-Elbow Amputations
Jacob Bickels, Yehuda Kollender, and Martin M. Malawer 1842

SECTION III SPINE AND PELVIS

16 Primary and Metastatic Tumors of the Spine:
Total En Bloc Spondylectomy
Katsuro Tomita, Norio Kawahara, and Hideki Murakami 1846

17 Overview on Pelvic Resections:
Surgical Considerations and Classifications
Ernest U. Conrad III, Jason Weisstein, Jennifer Lisle, Amir Sternheim, and Martin M. Malawer 1855

18 Surgical Technique for Resection and
Reconstruction of Supra-acetabular
Metastatic Lesions
Martin M. Malawer and Amir Sternheim 1873
CONTENTS

19 Buttockectomy
James C. Wittig and Martin M. Malawer 1876

20 Surgical Management of Metastatic Bone Disease: Pelvic Lesions
Jacob Bickels and Martin M. Malawer 1879

21 Posterior Flap Hemipelvectomy
Martin M. Malawer and James C. Wittig 1891

22 Anterior Flap Hemipelvectomy
Martin M. Malawer and James C. Wittig 1902

23 Hip Disarticulation
Daria Brooks Terrell 1911

SECTION IV LOWER EXTREMITIES

24 Proximal and Total Femur Resection With Endoprosthetic Reconstruction
Jacob Bickels and Martin M. Malawer 1917

25 Distal Femoral Resections With Endoprosthetic Replacement
Jeffrey J. Eckardt, Martin M. Malawer, Jacob Bickels, and Piya Kiatsevi 1929

26 Proximal Tibia Resection With Endoprosthetic Reconstruction
Jacob Bickels and Martin M. Malawer 1953

27 Fibular Resections
Jacob Bickels and Martin M. Malawer 1964

28 The Use of Free Vascularized Fibular Grafts for Reconstruction of Segmental Bone Defects
Eyal Gur, Yehuda Kollender, Isaac Meller, Aharon Amir, Arik Zaretski, and Jacob Bickels 1974

29 Use of Allografts and Segmental Prostheses for Reconstruction of Segmental Bone Defects
Walter W. Virkus, Robert M. Henshaw, Benjamin J. Miller, and Steven Gitelis 1982

30 Quadriceps Resections
Jacob Bickels, Tamir Pritsch, and Martin M. Malawer 1991

31 Adductor Muscle Group (Medial Thigh) Resection
Jacob Bickels, Martin M. Malawer, and Yehuda Wolf 2000

32 Hamstrings Muscle Group (Posterior Thigh) Resection
Jacob Bickels and Martin M. Malawer 2005

33 Overview of Surgical Resection of Space Sarcomas
Amir Sternheim, Tamir Pritsch, and Martin M. Malawer 2011

34 Popliteal Resections
Jacob Bickels and Tamir Pritsch 2018

35 Soleus Resection
Tamir Pritsch, Amir Sternheim, Jacob Bickels, and Martin M. Malawer 2023

36 Surgical Approach and Management of Tumors of the Sartorial Canal
Martin M. Malawer and Amir Sternheim 2028

37 Surgical Management of Metastatic Bone Disease: Femoral Lesions
Jacob Bickels and Martin M. Malawer 2034

38 Foot and Ankle Amputations: Ray Resections
Loretta B. Chou, H. Thomas Temple, Yvette Ho, and Martin M. Malawer 2047

39 Creating an Above-Knee Amputation Stump After Hip Disarticulation
Amir Sternheim, Daria Brooks Terrell, and Martin M. Malawer 2053

40 Above-Knee Amputation
Daria Brooks Terrell 2060

41 Below-Knee Amputation
Daria Brooks Terrell 2067

42 Foot and Ankle Amputations: Lisfranc/Chopart
Loretta B. Chou, H. Thomas Temple, Yvette Ho, and Martin M. Malawer 2072

PEDiatrics Exam Table 1

Volume Three

PART 6 HAND, WRIST, AND FOREARM

SECTION I ANATOMY, APPROACHES, AND ANESTHESIA

1 Anatomy and Surgical Approaches of the Forearm, Wrist, and Hand
Asif M. Ilyas, Neal C. Chen, and Chaitanya S. Mudgal 2093

2 Anesthetic Considerations for Surgery of the Upper Extremity
John A. Dilger and Hugh M. Smith 2102

3 Arthroscopy of the Hand and Wrist
David J. Slutsky 2114

SECTION II RADIUS AND ULNA FRACTURES AND DISLOCATIONS

4 Open Reduction and Internal Fixation of Diaphyseal Forearm Fractures
Michael R. Boland 2127

5 Reduction and Stabilization of the Distal Radioulnar Joint Following Galeazzi Fractures
Michael R. Boland 2139

6 Corrective Osteotomy for Radius and Ulna Diaphyseal Malunions
Vimala Ramachandran and Thomas F. Varecka 2149

7 Operative Treatment of Radius and Ulna Diaphyseal Nonunions
Rena L. Stewart 2156

8 K-Wire Fixation of Distal Radius Fractures With and Without External Fixation
Christopher Doumas and David J. Bozentka 2162

9 Arthroscopic Reduction and Fixation of Distal Radius and Ulnar Styloid Fractures
William B. Geissler 2172

10 Fragment-Specific Fixation of Distal Radius Fractures
Robert J. Medoff 2183

11 Intramedullary and Dorsal Plate Fixation of Distal Radius Fractures
Pedro K. Beredjiklian and Christopher Doumas 2198
12 Volar Plating of Distal Radius Fractures
John J. Fernandez 2206

13 Bridge Plating of Distal Radius Fractures
Paul A. Martineau, Kevin J. Malone, and Douglas P. Hanel 2218

14 Open Reduction and Internal Fixation of Ulnar Styloid, Head, and Metadiaphyseal Fractures
Tommy Lindau and Andrew J. Logan 2224

15 Corrective Osteotomy for Distal Radius Malunion
David Ring, Diego Fernandez, and Jesse B. Jupiter 2234

SECTION III CARPAL FRACTURES AND AVASCULAR NECROSIS

16 Percutaneous Fixation of Acute Scaphoid Fractures
Peter J. L. Jebson, Jane S. Tan, and Andrew Wong 2244

17 Open Reduction and Internal Fixation of Scaphoid Fractures
Asheesh Bedi and Peter J. L. Jebson 2251

18 Percutaneous Treatment of Grade I to III Scaphoid Nonunions
Joseph F. Slade III† and Greg Merrell 2259

19 Volar Wedge Bone Grafting and Internal Fixation of Scaphoid Nonunions
Evan D. Collins 2266

20 Vascularized Bone Grafting of Avascular Scaphoid Nonunions
Alexander D. Mih 2273

21 Partial Scaphoid Excision of Scaphoid Nonunions
Joseph E. Imbriglia and Justin M. Sacks 2277

22 Surgical Treatment of Carpal Bone Fractures, Excluding the Scaphoid
Kenneth R. Means, Jr. and Thomas J. Graham 2284

23 Osteotomy of the Radius for Treatment of Kienböck Disease
Jeffrey E. Budoff 2295

24 Vascularized Bone Grafting and Capitate Shortening Osteotomy for Treatment of Kienböck Disease
Nilesh M. Chaudhari, Mohamed Khalid, and Thomas R. Hunt III 2305

SECTION IV HAND FRACTURES AND DISLOCATIONS

25 Ligament Stabilization of the Unstable Thumb Carpometacarpal Joint
Richard Y. Kim and Robert J. Strauch 2313

26 Operative Treatment of Thumb Carpometacarpal Joint Fractures
John T. Capo and Colin Harris 2320

27 Dislocations and Chronic Volar Instability of the Thumb Metacarpophalangeal Joint
Robert R. Slater, Jr. 2331

28 Arthroscopic and Open Primary Repair of Acute Thumb Metacarpophalangeal Joint Radial and Ulnar Collateral Ligament Disruptions
Alejandro Badia and Prakash Khanchandani 2342

29 Reconstruction of Chronic Radial and Ulnar Instability of the Thumb Metacarpophalangeal Joint
Steven Z. Glickel and Louis W. Catalano III 2349

30 Operative Treatment of Finger Carpometacarpal Joint Fracture-Dislocations
John J. Walsh IV 2358

31 Operative Treatment of Metacarpal Fractures
Christopher L. Forthman and Thomas J. Graham 2365

32 Operative Treatment of Extra-articular Phalangeal Fractures
Timothy W. Harman, Thomas J. Graham, and Richard L. Uhl 2378

33 Open Reduction and Internal Fixation of Phalangeal Condylar Fractures
Greg Merrell, Kerry Bemers, and Arnold-Peter Weiss 2392

34 Dorsal Block Pinning of Proximal Interphalangeal Joint Fracture-Dislocations
Mark Goleski and Jeffrey Lawton 2404

35 Dynamic External Fixation of Proximal Interphalangeal Joint Fracture-Dislocations
Grey Giddins 2410

36 Open Reduction and Internal Fixation of Proximal Interphalangeal Joint Fracture-Dislocations
Brian Najarian and Jeffrey Lawton 2420

37 Volar Plate Arthroplasty
Albert Leung and Philip E. Blazar 2431

38 Hemi-Hamate Autograft Reconstruction of Unstable Dorsal Proximal Interphalangeal Joint Fracture-Dislocations
Thomas R. Kiehhaber, Rafael M. M. Williams, and Soma I. Lilly 2436

39 Operative Treatment of Distal Interphalangeal Joint Fracture-Dislocations
Leo T. Kroonen and Eric P. Hofmeister 2445

40 Corrective Osteotomy for Metacarpal and Phalangeal Malunion
Mohamed Khalid, Nilesh M. Chaudhari, and Thomas R. Hunt III 2452

SECTION V WRIST INSTABILITIES

41 Arthroscopic Evaluation and Treatment of Scapholunate and Lunotriquetral Ligament Disruptions
Alexander H. Payatakes, Alex M. Meyers, and Dean G. Sotereanos 2459

42 Open Scapholunate Ligament Repair and Augmentation
Alex M. Meyers, Alexander H. Payatakes, and Dean G. Sotereanos 2467

43 Capsulodesis for Treatment of Scapholunate Instability
Angel Ferreres, Marc García-Elías, and Andrew Chin 2472

44 Tenodesis for Treatment of Scapholunate Instability
Marc García-Elías and Angel Ferreres 2480

45 Bone–Ligament–Bone Reconstruction of the Scapholunate Ligament
Anthony M. DeLuise, Jr. and Randall W. Culp 2488

† deceased
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Authors</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>Reduction and Association of the Scaphoid and the Lunate for Scapholunate Instability</td>
<td>Richard Y. Kim and Melvin P. Rosenwasser</td>
<td>2495</td>
</tr>
<tr>
<td>47</td>
<td>Lunotriquetral Ligament Repair and Augmentation</td>
<td>Samuel C. Hoxie and Alexander Y. Shin</td>
<td>2501</td>
</tr>
<tr>
<td>49</td>
<td>Arthroscopic and Open Triangular Fibrocartilage Complex Repair</td>
<td>A. Lee Osterman</td>
<td>2520</td>
</tr>
<tr>
<td>50</td>
<td>Intra-articular Radioulnar Ligament Reconstruction</td>
<td>Brian D. Adams and Christina M. Ward</td>
<td>2528</td>
</tr>
<tr>
<td>51</td>
<td>Extra-articular Reconstructive Techniques for the Distal Radioulnar and Ulnocarpal Joints</td>
<td>Christopher J. Oy, E. Anne Ouellette, and Anna-Lena Makowski</td>
<td>2535</td>
</tr>
<tr>
<td>52</td>
<td>Arthroscopic Dorsal Radiocarpal Ligament Repair</td>
<td>David J. Slutsky</td>
<td>2544</td>
</tr>
<tr>
<td>53</td>
<td>Distal Biceps Tendon Disruptions: Acute and Delayed Reconstruction</td>
<td>Robert E. Ivy and Edwin E. Spencer, Jr.</td>
<td>2550</td>
</tr>
<tr>
<td>54</td>
<td>Repair of Acute Digital Flexor Tendon Disruptions</td>
<td>Christopher H. Allan</td>
<td>2555</td>
</tr>
<tr>
<td>55</td>
<td>Tenolysis Following Injury and Repair of Digital Flexor Tendons</td>
<td>Shai Luria and Christopher H. Allan</td>
<td>2561</td>
</tr>
<tr>
<td>56</td>
<td>Staged Digital Flexor Tendon Reconstruction</td>
<td>Kevin J. Malone and Thomas Trumble</td>
<td>2570</td>
</tr>
<tr>
<td>57</td>
<td>Repair Following Traumatic Extensor Tendon Disruption in the Hand, Wrist, and Forearm</td>
<td>David B. Shapiro and Mark A. Krahe</td>
<td>2577</td>
</tr>
<tr>
<td>58</td>
<td>Tendon Transfer and Grafting for Traumatic Extensor Tendon Disruption</td>
<td>John S. Taras and Daniel J. Lee</td>
<td>2587</td>
</tr>
<tr>
<td>59</td>
<td>Extensor Tendon Centralization Following Traumatic Subluxation at the Metacarpophalangeal Joint</td>
<td>Ross J. Richer, Craig S. Phillips, and Leon S. Benson</td>
<td>2594</td>
</tr>
<tr>
<td>60</td>
<td>Flexor and Extensor Tenosynovectomy</td>
<td>Jay T. Bridgeman and Sanjiv Naidu</td>
<td>2603</td>
</tr>
<tr>
<td>61</td>
<td>Tendon Transfers Used for Treatment of Rheumatoid Disorders</td>
<td>John D. Lubahn and D. Patrick Williams</td>
<td>2608</td>
</tr>
<tr>
<td>62</td>
<td>Operative Reconstruction of Boutonnière and Swan-Neck Deformities</td>
<td>Mark Wilczynski, Martin I. Bayer, and Fraser J. Leveredge</td>
<td>2619</td>
</tr>
<tr>
<td>63</td>
<td>Open Treatment of Medial Epicondylitis</td>
<td>Joseph E. Robson and Peter J. Evans</td>
<td>2634</td>
</tr>
<tr>
<td>64</td>
<td>Open and Arthroscopic Treatment of Lateral Epicondylitis</td>
<td>Peter J. Evans</td>
<td>2638</td>
</tr>
<tr>
<td>65</td>
<td>Surgical Treatment for Extensor Carpi Ulnaris Subluxation</td>
<td>David H. MacDonald and Thomas R. Hunt III</td>
<td>2643</td>
</tr>
<tr>
<td>67</td>
<td>Carpal Tunnel Release: Endoscopic, Open, and Revision</td>
<td>Edward Diao</td>
<td>2657</td>
</tr>
<tr>
<td>68</td>
<td>Decompression of Pronator and Anterior Interosseous Syndromes</td>
<td>E. Bruce Toby and Kyle P. Ritter</td>
<td>2666</td>
</tr>
<tr>
<td>69</td>
<td>Decompression of the Ulnar Nerve at Guyon’s Canal</td>
<td>Harris Gellman and Patrick Owens</td>
<td>2671</td>
</tr>
<tr>
<td>70</td>
<td>Surgical Treatment of Cubital Tunnel Syndrome</td>
<td>Catherine M. Curtin and Amy L. Ladd</td>
<td>2677</td>
</tr>
<tr>
<td>71</td>
<td>Radial Nerve Decompression</td>
<td>Mark N. Awantang, Joseph M. Sherrill, Christopher J. Thomson, and Thomas R. Hunt III</td>
<td>2685</td>
</tr>
<tr>
<td>72</td>
<td>Primary Repair and Nerve Grafting Following Complete Nerve Transection in the Hand, Wrist, and Forearm</td>
<td>Randy R. Bindra and Jeff W. Johnson</td>
<td>2691</td>
</tr>
<tr>
<td>73</td>
<td>Surgical Treatment of Nerve Injuries in Continuity</td>
<td>Randy R. Bindra and Jeff W. Johnson</td>
<td>2699</td>
</tr>
<tr>
<td>74</td>
<td>Tendon Transfers for Median Nerve Palsy</td>
<td>Jeffrey B. Friedrich and Scott H. Kozin</td>
<td>2706</td>
</tr>
<tr>
<td>75</td>
<td>Tendon Transfers for Ulnar Nerve Palsy</td>
<td>Michael S. Bednar</td>
<td>2715</td>
</tr>
<tr>
<td>76</td>
<td>Tendon Transfers for Radial Nerve Palsy</td>
<td>Harry A. Hoyen</td>
<td>2722</td>
</tr>
<tr>
<td>77</td>
<td>Metacarpophalangeal Joint Synovectomy and Extensor Tendon Centralization in the Inflammatory Arthritis Patient</td>
<td>Andrew L. Terrono, Paul Feldon, and Hervey L. Kimball III</td>
<td>2729</td>
</tr>
<tr>
<td>78</td>
<td>Proximal Interphalangeal and Metacarpophalangeal Joint Silicone Implant Arthroplasty</td>
<td>Charles A. Goldfarb</td>
<td>2736</td>
</tr>
<tr>
<td>79</td>
<td>Proximal Interphalangeal and Metacarpophalangeal Joint Surface Replacement Arthroplasty</td>
<td>Peter M. Murray and Christopher R. Goll</td>
<td>2744</td>
</tr>
<tr>
<td>80</td>
<td>Distal Interphalangeal, Proximal Interphalangeal, and Metacarpophalangeal Joint Arthrodesis</td>
<td>Charles Cassidy and Jennifer Green</td>
<td>2752</td>
</tr>
<tr>
<td>81</td>
<td>Thumb Metacarpal Extension Osteotomy</td>
<td>Matthew M. Tomaino</td>
<td>2766</td>
</tr>
<tr>
<td>Page</td>
<td>Section</td>
<td>Title</td>
<td>Authors</td>
</tr>
<tr>
<td>------</td>
<td>---------</td>
<td>-------</td>
<td>---------</td>
</tr>
<tr>
<td>82</td>
<td>IX</td>
<td>Thumb Carpometacarpal Joint Arthrodesis</td>
<td>Warren C. Hammert and Matthew M. Tomaino</td>
</tr>
<tr>
<td>83</td>
<td>IX</td>
<td>Thumb Carpometacarpal Joint Resection Arthroplasty</td>
<td>Matthew M. Tomaino</td>
</tr>
<tr>
<td>84</td>
<td>IX</td>
<td>Thumb Carpometacarpal Joint Implant and Resurfacing Arthroplasty</td>
<td>Matthew J. Robon and Matthew M. Tomaino</td>
</tr>
<tr>
<td>85</td>
<td>IX</td>
<td>Wrist Denervation</td>
<td>Carlos Heras-Palou</td>
</tr>
<tr>
<td>86</td>
<td>IX</td>
<td>Open and Arthroscopic Radial Styloidectomy</td>
<td>Bruce A. Monaghan</td>
</tr>
<tr>
<td>87</td>
<td>IX</td>
<td>Proximal Row Carpectomy</td>
<td>Alex M. Meyers, Mark E. Baratz, and Thomas Hughes</td>
</tr>
<tr>
<td>88</td>
<td>IX</td>
<td>Limited Wrist Arthrodesis</td>
<td>Andrew W. Cross and Mark E. Baratz</td>
</tr>
<tr>
<td>89</td>
<td>IX</td>
<td>Complete Wrist Arthrodesis</td>
<td>John C. Elfar and Andrew D. Markiewitz</td>
</tr>
<tr>
<td>90</td>
<td>IX</td>
<td>Wrist Implant Arthroplasty</td>
<td>Joel C. Klena, Andrew K. Palmer, and James W. Strickland</td>
</tr>
<tr>
<td>91</td>
<td>IX</td>
<td>Resection Arthroplasty of the Distal Radioulnar Joint</td>
<td>Jeffrey A. Greenberg</td>
</tr>
<tr>
<td>92</td>
<td>IX</td>
<td>Sauvé-Kapandji Procedure for Distal Radioulnar Joint Arthritis</td>
<td>Robert M. Szabo</td>
</tr>
<tr>
<td>93</td>
<td>IX</td>
<td>Ulnar Head Implant Arthroplasty</td>
<td>Cari Cordell and Randy R. Bindra</td>
</tr>
<tr>
<td>94</td>
<td>IX</td>
<td>Arthroscopically Assisted Triangular Fibrocartilage Complex Débridement and Ulnar Shortening</td>
<td>Daniel J. Nagle</td>
</tr>
<tr>
<td>95</td>
<td>IX</td>
<td>Ulnar Shortening Osteotomy</td>
<td>Lance G. Warhold and Nelson L. Jenkins</td>
</tr>
<tr>
<td>102</td>
<td>X</td>
<td>Surgical Treatment of Septic Arthritis in the Hand and Wrist</td>
<td>Asif M. Ilyas</td>
</tr>
<tr>
<td>103</td>
<td>X</td>
<td>Nail Matrix Repair, Reconstruction, and Ablation</td>
<td>Reuben A. Bueno, Jr. and Elvin G. Zook</td>
</tr>
<tr>
<td>104</td>
<td>X</td>
<td>Soft Tissue Coverage of Fingertip Amputations</td>
<td>Christian Ford and Jeffrey Yao</td>
</tr>
<tr>
<td>105</td>
<td>X</td>
<td>Skin Grafts and Skin Graft Substitutes in the Distal Upper Extremity</td>
<td>James N. Long, Jorge de la Torre, and Luis O. Vasconez</td>
</tr>
<tr>
<td>107</td>
<td>X</td>
<td>Surgical Treatment of Thermal and Electrical Injury and Contracture Involving the Distal Upper Extremity</td>
<td>Edwin Y. Chang and Kevin C. Chung</td>
</tr>
<tr>
<td>108</td>
<td>X</td>
<td>Release of Posttraumatic Metacarpophalangeal and Proximal Interphalangeal Joint Contractures</td>
<td>Christopher L. Forthman and Keith A. Segalman</td>
</tr>
<tr>
<td>109</td>
<td>X</td>
<td>Surgical Treatment of Dupuytren’s Disease</td>
<td>Ghazi Rayan</td>
</tr>
<tr>
<td>110</td>
<td>XI</td>
<td>Surgical Treatment of Vascular Tumors of the Hand</td>
<td>Rimma Finkel and Morton Kasdan</td>
</tr>
<tr>
<td>111</td>
<td>XI</td>
<td>Excision and Coverage of Squamous Cell Carcinoma and Melanoma of the Hand</td>
<td>Mark F. Hendrickson and Benjamin J. Boudreaux</td>
</tr>
<tr>
<td>112</td>
<td>XI</td>
<td>Open and Arthroscopic Excision of Ganglion Cysts and Related Tumors</td>
<td>Mitchell E. Nahra and John S. Bucchieri</td>
</tr>
<tr>
<td>113</td>
<td>XI</td>
<td>Surgical Treatment of Nerve Tumors in the Distal Upper Extremity</td>
<td>Christopher L. Forthman and Philip E. Blazar</td>
</tr>
<tr>
<td>114</td>
<td>XI</td>
<td>Treatment of Enchondroma, Bone Cyst, and Giant Cell Tumor of the Distal Upper Extremity</td>
<td>Edward A. Athanasian</td>
</tr>
</tbody>
</table>

**SECTION VII SHOULDER AND ELBOW**

<table>
<thead>
<tr>
<th>Page</th>
<th>Section</th>
<th>Title</th>
<th>Authors</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I</td>
<td>Anatomy of the Shoulder and Elbow</td>
<td>Joseph A. Abboud, Matthew L. Ramsey, and Gerald R. Williams</td>
<td>3042</td>
</tr>
<tr>
<td>2</td>
<td>I</td>
<td>Surgical Approaches to the Shoulder and Elbow</td>
<td>Joseph A. Abboud, Matthew L. Ramsey, and Gerald R. Williams</td>
<td>3056</td>
</tr>
</tbody>
</table>
Volume Four

PART 8 FOOT AND ANKLE

SECTION I FOREFOOT

1 Distal Chevron Osteotomy: Perspective 1
   Hans-Joerg Trnka and Stefan G. Hofstetter 3481

2 Distal Chevron Osteotomy: Perspective 2
   Paul Hamilton, Sam Singh, and Michael G. Wilson 3488

3 Biplanar Distal Chevron Osteotomy
   Caio Nery 3491
CONTENTS

27 Bone-Block Distraction of the First Metatarsophalangeal Joint
Hans-Joerg Trnka and Stefan G. Hofstaetter  3656

28 Surgical Management of Turf Toe Injuries
Christopher W. Nicholson and Robert B. Anderson  3665

29 Internal Fixation of Sesamoid Fractures
Geert I. Pagenstert, Victor Valderrabano, and Beat Hintermann  3674

30 Tibial Sesamoidectomy
Simon Lee, Johnny Lin, and George B. Holmes, Jr.  3681

31 Flexor-to-Extensor Tendon Transfer for Flexible Hammer Toe Deformity
Emilio Wagner  3688

32 Hammer Toe Correction
Lloyd C. Briggs, Jr.  3696

33 Weil Lesser Metatarsal Shortening Osteotomy
Stefan G. Hofstaetter and Hans-Joerg Trnka  3707

34 Angular Deformity of the Lesser Toes
Adolph S. Flemister, Jr., and Brian D. Giordano  3714

35 Surgical Correction of Bunionette Deformity
Johnny T. C. Lau, W. Bryce Henderson, and Gilbert Yee  3730

36 Rheumatoid Forefoot Reconstruction
Thomas G. Padanilam  3736

37 Morton’s Neuraoma and Revision Morton’s Neuraoma Excision
David R. Richardson  3743

38 Uniportal Endoscopic Decompression of the Interdigital Nerve for Morton’s Neuraoma
Steven L. Shapiro  3751

SECTION II MIDFOOT

39 Plantarflexion Opening Wedge Medial Cuneiform Osteotomy
Jeffrey E. Johnson  3755

40 Tarsometatarsal Arthrodesis
Ian L. D. Le and Mark E. Easley  3761

41 Midfoot Arthrodesis
Mark E. Easley  3766

42 Percutaneous Midfoot Osteotomy With External Fixation
Bradley M. Lamm, Ahmed Thabet, John E. Herzenberg, and Dror Paley  3788

43 Surgical Stabilization of Nonplantigrade Charcot Arthropathy of the Midfoot
Michael S. Pinzur  3794

44 Axial Screw Technique for Midfoot Arthrodesis in Charcot Foot Deformities
Vincent James Sammarco and G. James Sammarco  3802

45 Minimally Invasive Realignment Surgery of the Charcot Foot
Bradley M. Lamm and Dror Paley  3809

SECTION III HINDFOOT

46 Flexor Digitorum Longus Transfer and Medial Displacement Calcaneal Osteotomy
Gregory P. Guyton  3814

47 Lateral Column Lengthening
Donald R. Bohay and John G. Anderson  3823

48 Spring Ligament Reconstruction
Jonathan T. Deland  3832

49 Calcaneonavicular Coalition Resection in the Adult Patient
Aaron T. Scott and H. Robert Tenner  3839

50 Isolated Subtalar Arthrodesis
Aaron T. Scott and Robert S. Adelaar  3843

51 Surgical Management of Calcaneal Malunions
Michael P. Clare and Roy W. Sanders  3849

52 Calcaneal Osteotomy and Subtalar Arthrodesis for Calcaneal Malunions
Michael M. Romash  3859

53 Traditional Triple Arthrodesis
Mark E. Easley  3868

54 Single-Incision Medial Approach for Triple Arthrodesis
Clifford L. Jeng  3879

55 Comprehensive Correction of Cavovarus Foot Deformity
Michael Barnett, Arthus Manoli, Bruce J. Sangeorzan, Gregory C. Pomeroy, and Brian C. Toolan  3885

56 Management of Equinocavovarus Foot Deformity
Wolfram Wenz and Thomas Dreher  3891

57 Plantar Fascia Release in Combination With Proximal and Distal Tarsal Tunnel Release
John S. Gould and Benedict F. DiGiovanni  3911

58 Endoscopic Plantar Fasciotomy
Steven L. Shapiro  3920

59 Transection and Burial of Neuromas of the Foot and Ankle
Stuart D. Miller, Blake L. Ohlson, and Michael Scherb  3925

60 Barrier Procedures for Adhesive Neuralgia
Stuart D. Miller and Venus R. Rivera  3933

SECTION IV ANKLE

61 Distraction Arthroplasty for Ankle Arthritis
Richard E. Gelman and Douglas N. Beaman  3941

62 Supramalleolar Osteotomy With Internal Fixation: Perspective 1
Emmanouil D. Stamatis  3953

63 Supramalleolar Osteotomy With Internal Fixation: Perspective 2
Emmanouil D. Stamatis  3953

64 Supramalleolar Osteotomy With Internal Fixation: Perspective 3
Emmanouil D. Stamatis  3953

65 Supramalleolar Osteotomy With External Fixation: Perspective 1
Austin T. Fragomen and S. Robert Rozbruch  3976

66 Supramalleolar Osteotomy With External Fixation: Perspective 2
Bradley M. Lamm, Shiy John, John E. Herzenberg, and Dror Paley  3995

67 Total Ankle Shell Allograft Reconstruction
Michael E. Brage and Keri A. Reese  4000

68 The STAR (Scandinavian Total Ankle Replacement) Total Ankle Arthroplasty
Mark E. Easley, James A. Nunley II, and James K. DeOrio  4007
69 The HINTEGRA Total Ankle Arthroplasty
Beat Hintermann and Alexej Barg 4022

70 The BOX Total Ankle Arthroplasty
Sandro Giannini, Matteo Romagnoli, Deianira Luciani, Fabio Catani, and Alberto Leardini 4032

71 The Salto and Salto-Talaris Total Ankle Arthroplasty
Michel Bonnin, Brian Donley, Thierry Judet, and Jean-Alain Colombier 4042

72 Mobility Total Ankle Arthroplasty
Pascal F. Rippstein, Mark E. Easley, and J. Chris Coetzee 4056

73 INBONE Total Ankle Arthroplasty
James K. DeOrio, Mark E. Easley, James A. Nunley II, and Mark A. Reiley 4072

74 TNK Total Ankle Arthroplasty
Yasuhito Tanaka and Yoshinori Takakura 4085

75 The Agility Total Ankle Arthroplasty
J. Chris Coetzee and Steven L. Haddad 4093

76 Revision Agility Total Ankle Arthroplasty
Steven L. Haddad 4102

77 Ankle Arthrodesis
Mark E. Easley 4123

78 Transfibular Approach for Ankle Arthrodesis
Alex J. Kline and Dane K. Wukich 4140

79 The Miniarthrotomy Technique for Ankle Arthrodesis
Emmanouil D. Stamatis 4146

80 Arthroscopic Ankle Arthrodesis
James P. Tasto 4154

81 Tibiotalocalcaneal Arthrodesis Using a Medullary Nail
George E. Quill, Jr., and Stuart D. Miller 4161

82 Tibiotalocalcaneal Arthrodesis Using Lateral Blade Plate Fixation
Christopher P. Chiodo and Catherine E. Johnson 4173

83 Tibiocalcaneal Arthrodesis Using Blade Plate Fixation
Richard Alvarez, Delan Gaines, and Mark E. Easley 4179

84 Treatment of Bone Loss, Avascular Necrosis, and Infection of the Talus With Circular Tensioned Wire Fixators
James J. Hutson, Jr., Robert Rochman, and Oladapo Alade 4192

85 Femoral Head Allograft for Large Talar Defects
Bryan D. Den Hartog 4203

86 Posterior Blade Plate for Salvage of Failed Total Ankle Arthroplasty
Mark Ritter, Florian Nickisch, and Christopher W. DiGiovanni 4208

SECTION V SPORTS-RELATED PROCEDURES FOR ANKLE AND HINDFOOT

87 Arthroscopy of the Ankle
Jorge I. Acevedo and Peter Mangone 4216

88 Microfracture for Osteochondral Lesions of the Talus
Hajo Thermann and Christoph Becher 4222

89 Posterior Ankle Impingement Syndrome
Javier Maquirriain 4229

90 Posterior Ankle Arthroscopy and Hindfoot Endoscopy
C. Niek van Dijk and Tahir Öğüt 4234

91 Endoscopic Treatment of Posterior Ankle Impingement Through a Posterior Approach
Phinit Phisitkul and Annunziato Amendola 4243

92 Subtalar Arthroscopy
Carol Frey 4251

93 Osteochondral Transfer for Osteochondral Lesions of the Talus
Mark E. Easley and Justin Orr 4259

94 Anterior Tibial Osteotomy for Osteochondral Lesions of the Talus
G. James Sammarco 4271

95 Osteochondral Lesions of the Talus: Structural Allograft
Mark E. Easley, Samuel B. Adams, Jr., and James A. Nunley II 4274

96 Autologous Chondrocyte Transplantation
Markus Walther 4288

97 Chevron-Type Medial Malleolar Osteotomy
Bruce Cohen 4298

98 Modified Brostrom and Brostrom-Evans Procedures
Paul J. Hecht, Justin S. Cummins, Mark E. Easley, and Dean C. Taylor 4301

99 Anatomic Repair of Lateral Ankle Instability
Gregory C. Berlet, Geoffrey S. Landis, Christopher F. Hyer, and Terrence M. Philbin 4314

100 Hamstring Autografting/Augmentation for Lateral Ankle Instability
Alastair Younger and Heather Barske 4322

101 Lateral Ankle Ligament Reconstruction Using Allograft and Interference Screw Fixation
William C. McGarvey and Thomas O. Clanton 4331

102 Chronic Lateral Ankle Instability
Markus Walther 4340

103 Deltoid Ligament Reconstruction
Eric M. Bluman and Richard J. deAsla 4347

104 Medial Ankle/Deltoid Ligament Reconstruction
Beat Hintermann and Victor Valderrabano 4354

105 Open Achilles Tendon Repair
Sameh A. Labib 4367

106 Limited Open Repair of Achilles Tendon Ruptures: Perspective 1
Mathieu Assal 4374

107 Mini-Open Achilles Tendon Repair: Perspective 2
Mark E. Easley, Marc Merian-Genast, and Mathieu Assal 4380

108 Percutaneous Achilles Tendon Repair: Perspective 1
Karen M. Sutton, Sandra L. Tomak, and Lamar L. Fleming 4387

109 Percutaneous Achilles Tendon Repair: Perspective 2
Nicholas A. Ferran, Ansar Mahmood, and Nicola Maffulli 4393

110 Chronic Achilles Tendon Ruptures Using V-Y Advancement and FHL Transfer
Steven M. Raikin 4398
111 Chronic Achilles Tendon Ruptures Using Hamstring/Peroneal Tendons
Nicholas A. Ferran and Nicola Maffulli 4406

112 Chronic Achilles Tendon Ruptures Using Allograft Reconstruction
Andrew P. Molloy and Mark S. Myerson 4412

113 Soft Tissue Expansion in Revision/Complex Achilles Tendon Reconstruction
Jorge I. Acevedo 4417

114 Retrocalcaneal Bursoscopy
Angus M. McBryde and Fred W. Ortmann 4419

115 Insertional Achilles Tendinopathy
Mark E. Easley and Matthew J. DeOrio 4423

116 Surgical Management of Calcific Insertional Achilles Tendinopathy Using a Lateral Approach
Anthony Watson 4433

117 Flexor Hallucis Longus Tendon Augmentation for the Treatment of Insertional Achilles Tendinosis
William C. McGarvey and Thomas O. Clanton 4437

118 Open Management of Achilles Tendinopathy
Nicola Maffulli and Umile Giuseppe Longo 4443

119 Flexor Hallucis Longus Transfer for Achilles Tendinosis
Bryan D. Den Hartog 4447

120 Proximal Mini-Invasive Grafting of Plantaris Tendon
Geert I. Pagenstert and Beat Hintzmann 4454

121 Repair of Peroneal Tendon Tears
Brad Dresher and Brian Donley 4458

122 Reconstruction of Chronic Peroneal Tendon Tears
Keith L. Wapner, Selene G. Parekh, and Wen Chao 4462

123 Repair of Dislocating Peroneal Tendons: Perspective 1
Sheldon Lin, Karl Bergmann, Vikrant Azad, Virak Tan, Enyi Okereke, and Siddhant Mehta 4468

124 Repair of Dislocating Peroneal Tendons: Perspective 2
Florian Nickisch, Scott B. Shawen, and Robert B. Anderson 4477

125 Reconstruction of Tibialis Anterior Tendon Ruptures
James Santangelo and Mark E. Easley 4484

126 Tendon Transfer for Foot Drop
Mark E. Easley and Aaron T. Scott 4488

PART 9 SPINE

SECTION I APPROACH TO THE SPINE

1 Anterior Cervical Approaches
John Heflin and John M. Rhee 4507

2 Posterior Cervical Approach
Raj Rao and Satyajit V. Marawar 4516

3 Anterior Thoracic Approach
Morgan N. Chen, Sheeraz A. Qureshi, and Andrew C. Hecht 4523

4 Anterior Lumbar Approach
P. Justin Tortolani, Samer Sadey, and Ira L. Fedder 4530

5 Posterior Thoracic and Lumbar Approaches
Thomas Stanley, Michael J. Lee, Mark Dumonski, and Kern Singh 4537

SECTION II CERVICAL SPINE SURGERY

6 Anterior Cervical Discectomy and Fusion With and Without Instrumentation
John M. Rhee, Claude Jarrett, and Sam W. Wiesel 4543

7 Anterior Cervical Corpectomy and Fusion With Instrumentation
Claude Jarrett and John M. Rhee 4554

8 Posterior Cervical Foraminotomy
Jacob M. Buchowski, Ronald A. Lehman, Jr., and K. Daniel Riew 4562

9 Cervical Laminoplasty: Open and French Door
S. Tim Yoon and James S. Kercher 4568

10 Posterior Cervical Fusion With Instrumentation
Raj Rao and Satyajit V. Marawar 4576

11 Occipitocervical and C1–2 Fusion and Instrumentation
Youjeong Kim, Maneesh Bawa, and John G. Heller 4586

SECTION III THORACOLUMBAR SPINE SURGERY

12 Lumbar Discectomy
Bradley K. Weiner and Aristidis Zibis 4595

13 Lumbar Decompression
Bradley K. Weiner and Aristidis Zibis 4603

14 Posterolateral Thoracolumbar Fusion With Instrumentation
Mark Dumonski, Thomas Stanley, Michael J. Lee, Bart Wojewnik, and Kern Singh 4609

15 Transforaminal and Posterior Lumbar Interbody Fusion
Mitchell F. Reiter and Saad B. Chaudhary 4616

16 Anterior Thoracic Corpectomy
Sheeraz A. Qureshi, Morgan N. Chen, and Andrew C. Hecht 4628

17 Anterior Lumbar Interbody Fusion, Disc Replacement, and Corpectomy
P. Justin Tortolani, Paul C. McAfee, and Matthew N. Scott-Young 4634

18 Adult Scoliosis
Andrew P. White, James S. Harrop, and Todd J. Albert 4646

19 Iliac Crest Bone Graft Harvesting
Michael J. Lee, Thomas Stanley, Mark Dumonski, Patrick Cahill, Daniel Park, and Kern Singh 4659

FOOT AND ANKLE EXAM TABLE 1

SPINE EXAM TABLE 1

INDEX I-1
PART 1 SPORTS MEDICINE

Christopher R. Adams, MD
Orthopaedic Surgeon
Advanced Shoulder Orthopaedics
Jupiter, Florida

Julie E. Adams, MD
Assistant Professor of Orthopaedic Surgery
University of Minnesota
Minneapolis, Minnesota

Christina R. Allen, MD
Associate Clinical Professor of Orthopaedic Surgery
University of California
San Francisco, California

Michael J. Angel, MD
Orthopaedic Sports Medicine Fellow
Kerlan Jobe Orthopaedic Clinic
Los Angeles, California

Robert A. Arciero, MD
Professor of Orthopaedics
University of Connecticut Health Center
John Dempsey Hospital
Farmington, Connecticut

Steve Aviles, MD
Department of Orthopaedic Surgery
Iowa Orthopaedic Center
Moline, Iowa

Frederick M. Azar, MD
Professor of Orthopaedic Surgery
University of Tennessee
Residency Program Director
Sports Medicine Fellowship Director
Campbell Clinic
Memphis, Tennessee

F. Alan Barber, MD
Fellowship Director
Plano Orthopedic Sports Medicine and Spine Center
Plano, Texas

Mark J. Billante, MD
Physician
Greater Austin Orthopaedics
Austin, Texas

Matthew T. Boes, MD
Raleigh Orthopaedic Clinic
Raleigh, North Carolina

Kevin F. Bonner, MD
Assistant Professor
Eastern Virginia Medical School
Jordan-Young Institute
Sentara Leigh Hospital
Virginia Beach, Virginia

Jesse C. Botker, MD
Orthopaedic Surgery Chief Resident
University of Minnesota
Minneapolis, Minnesota

Craig R. Bottini, MD
Chief of Surgery
Assistant Chief Medical Officer
Aspetar Orthopaedic & Sports Medicine Hospital
Doha, Qatar

James P. Bradley, MD
Clinical Professor of Orthopaedic Surgery
University of Pittsburgh Medical Center
Pittsburgh, Pennsylvania

Anthony M. Buoncristiani, MD
Orthopaedic Surgeon
St. Luke’s Wood River Medical Center
Ketchum, Idaho

Stephen S. Burkhardt, MD
Director of Orthopaedic Education
The San Antonio Orthopaedic Group
The Orthopaedic Institute
San Antonio, Texas

Charles Bush-Joseph, MD, BA
Professor of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

J. W. Thomas Byrd, MD
Nashville Sports Medicine Foundation
Nashville, Tennessee

Eric W. Carson, MD
Associate Professor
Division of Sports Medicine
Department of Orthopaedic Surgery
University of Virginia
Charlottesville, Virginia

Mark S. Cohen, MD
Professor
Director, Hand and Elbow Section
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Steven B. Cohen, MD
Assistant Professor of Orthopaedic Surgery
Thomas Jefferson University
Rothman Institute Orthopaedics
Philadelphia, Pennsylvania

Brian Cole, MD, MBA
Professor
Section of Sports Medicine
Departments of Orthopaedic Surgery and Anatomy & Cell Biology
Section Head, Cartilage Restoration Center at Rush
Rush University Medical Center
Chicago, Illinois

Anne E. Colton, MD
Premier Orthopaedics
Broomall, Pennsylvania

John E. Conway, MD
Private Practice
Texas Health Harris Methodist Fort Worth Hospital
Fort Worth, Texas

David A. Coons, DO
Multicare Orthopedics and Sports Medicine
Tacoma, Washington

Andrew J. Cosgrove, MD
Professor, Orthopaedic Surgery
Director, Sports Medicine and Shoulder Surgery
Department of Orthopaedic Surgery
Johns Hopkins University
Lutherville, Maryland

Thomas M. DeBerardino, MD
Associate Professor of Orthopaedic Surgery
University of Connecticut Health Center
Farmington, Connecticut

David R. Diduch, MS, MD
Professor of Orthopaedic Surgery
Head Orthopaedic Team Physician
University of Virginia
Charlottesville, Virginia

Ivica Ducic, MD, PhD
Associate Professor
Chief, Peripheral Nerve Surgery
Department of Plastic Surgery
Georgetown University Hospital
Washington, District of Columbia

Jeffrey S. Earhart, MD
Resident
Department of Orthopaedic Surgery
Fenberg School of Medicine
Northwestern University
Chicago, Illinois

Gregory C. Fanelli, MD
Orthopaedic Surgery
Geisinger Sports Medicine
Danville, Pennsylvania

David L. Feingold, MD
Chief, Department of Orthopaedics
Olive View Medical Center
West Hills, California

Larry D. Field, MD
Clinical Instructor
Department of Orthopaedic Surgery
University of Mississippi School of Medicine
Director, Upper Extremity Service
Mississippi Sports Medicine and Orthopaedic Center
Jackson, Mississippi

Donald C. Fithian, MD
Director, San Diego Knee and Sports Medicine Fellowship
Kaiser Permanente, San Diego
El Cajon, California
Matthew T. Provencher, MD
Associate Professor of Surgery
Director, Orthopaedic Shoulder and Sports Surgery
Department of Orthopaedic Surgery
Naval Medical Center San Diego
San Diego, California

R. David Rabalais, MD
Clinical Assistant Professor of Medicine
Department of Orthopaedic Surgery
Louisiana State University Health Science Center
New Orleans, Louisiana

William G. Rodkey, DVM, Diplomate ACVS
Chief Scientific Officer
Steadman Hawkins Research Foundation
Vail, Colorado

Anthony A. Romeo, MD
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

J. R. Rudzki, MD
Clinical Assistant Professor
Department of Orthopaedic Surgery
George Washington University School of Medicine
Washington, District of Columbia

John-Paul Rue, MD, CDR, MC, USN
Assistant Professor
Department of Surgery
Uniformed Services University of Health Sciences
Director of Sports Medicine
National Naval Medical Center
Bethesda, Maryland

Marc Safran, MD
Professor of Orthopaedic Surgery
Stanford University
Stanford, California

Felix H. Savoie, III, MD
Lee C. Schlesinger Professor of Clinical Orthopaedics
Tulane University School of Medicine
New Orleans, Louisiana

John A. Scanelli III, MD
Resident
Department of Orthopaedic Surgery
University of Virginia
Charlottesville, Virginia

Robert C. Schenck, MD
Professor and Chairman
Department of Orthopaedics and Rehabilitation
University of New Mexico
Albuquerque, New Mexico

Jon K. Sekiya, MD
Associate Professor
MedSport—Department of Orthopaedic Surgery
University of Michigan
Ann Arbor, Michigan

Nicholas A. Sgaglione, MD
Associate Clinical Professor of Orthopaedic Surgery
North Shore Long Island Jewish Health System
Great Neck, New York

Benjamin S. Shaffer, MD
Washington Orthopaedics & Sports Medicine
Chevy Chase, Maryland

Ryan W. Simovitch, MD
Palm Beach Orthopaedic Institute
Palm Beach Gardens, Florida

Jeffrey T. Spang, MD
Assistant Professor of Orthopaedics
University of North Carolina
Chapel Hill, North Carolina

Matthew A. Stanich, MD
Resident
University of California, San Francisco
San Francisco, California

Erick S. Stark, MD
Tri-City Orthopedics
Oceanside, California

J. Richard Steadman, MD
Orthopaedic Surgeon and Principal Steadman Hawkins Clinic
Vail, Colorado

Scott P. Steinmann, MD
Professor of Orthopedic Surgery
Mayo Clinic College of Medicine
Rochester, Minnesota

Rebecca M. Stone, MS, ATC
Minnesota Sports Medicine
Twin Cities Orthopedics
Eden Prairie, Minnesota

Robert T. Sullivan, BS, MD
Orthopedic Surgeon/Sports Medicine
United States Air Force Academy
USAF Academy, Colorado

Kenneth G. Swan, Jr., MD
Department of Orthopaedic Surgery
Robert Wood Johnson University Hospital
New Brunswick, New Jersey

Robert Z. Tashjian, MD
Department of Orthopaedics
University of Utah Orthopaedic Center
Salt Lake City, Utah

Richard J. Thomas, MD
OrthoGeorgia Orthopaedic Specialists
Macon, Georgia

Fotios P. Tjoumakaris, MD
Assistant Professor of Orthopaedic Surgery
University of Pennsylvania School of Medicine/Penn Sports Medicine
Philadelphia, Pennsylvania

Michael S. Todd, MC
Orthopaedic Surgery Service
William Beaumont Army Medical Center
El Paso, Texas

Daniel J. Tomaszewski, MD
Department of Orthopaedic Surgery
Geisinger Clinic
Danville, Pennsylvania

Bradley B. Veazey, MD
Assistant Professor
Department of Orthopaedic Surgery and Rehabilitation
Texas Tech University
Lubbock, Texas

Christian J. H. Veillette, MD, MSc, FRCS
Assistant Professor
Division of Orthopaedic Surgery
University of Toronto
Toronto Western Hospital
University Health Network
Toronto, Ontario, Canada

Andrew J. Veitch, MD
Assistant Professor
Department of Orthopaedics and Rehabilitation
University of New Mexico
Albuquerque, New Mexico

Winston J. Warne, MD
Associate Professor of Orthopaedics and Sports Medicine
Chief of Shoulder and Elbow Surgery
University of Washington
Seattle, Washington

Jon J. P. Warner, MD
Professor of Orthopaedic Surgery
Chief of Harvard Shoulder Service
Partner’s Health Care System
Massachusetts General Hospital
Brigham and Women’s Hospital
Boston, Massachusetts

Daniel C. Wascher, MD
Professor
Department of Orthopaedics and Rehabilitation
University of New Mexico
Albuquerque, New Mexico

Carl H. Wierks, MD
Orthopaedic Chief Resident
Johns Hopkins Hospital
Baltimore, Maryland

Jocelyn R. Wittstein, MD
Resident
Department of Orthopaedic Surgery
Duke University Medical Center
Durham, North Carolina

Ken Yamaguchi, MD
Professor of Orthopaedic Surgery
Sam and Marilyn Fox Distinguished Professor of Orthopaedic Surgery
University of Texas Health Science Center at San Antonio
San Antonio, Texas

Jeff Anglen, MD, FACS
Professor and Chairman of Orthopaedics
Indiana University School of Medicine
Indianapolis, Indiana

PART 2 PELVIS AND LOWER EXTREMITY TRAUMA

Animesh Agarwal, MD
Associate Professor of Orthopaedics
Chief, Division of Orthopaedic Trauma
University of Texas Health Science Center at San Antonio
San Antonio, Texas

PART 2 PELVIS AND LOWER EXTREMITY TRAUMA
Michael R. Baumgaertner, MD
Professor
Chief, Orthopaedic Trauma Service
Department of Orthopaedics
Yale University School of Medicine
New Haven, Connecticut

James B. Carr, MD
Associate Clinical Professor
Department of Orthopedic Surgery
University of South Carolina
Columbia, South Carolina

Michael P. Clare, MD
Director of Fellowship Education
Foot and Ankle Fellowship
Florida Orthopaedic Institute
Tampa, Florida

William R. Creery, MD
Vice Chairman and Associate Professor of Orthopaedic Surgery
Boston University School of Medicine
Boston Medical Center
Boston, Massachusetts

Brett D. Crist, MD
Assistant Professor
Department of Orthopaedic Surgery
University of Missouri
Columbia, Missouri

Nicholas Divaris, MD
Assistant Professor
Department of Orthopaedics
State University of New York at Stony Brook
Stony Brook, New York

Kenneth A. Egol, MD
Associate Professor
Department of Orthopaedic Surgery
NYU Hospital for Joint Diseases
New York, New York

Thomas Ellis, MD
Associate Professor of Orthopaedics
The Ohio State University College of Medicine
Columbus, Ohio

John C. P. Floyd, MD
Department of Orthopaedic Trauma
The Medical Center of Central Georgia
Macon, Georgia

Darin Friess, MD
Assistant Professor of Orthopaedics & Rehabilitation
Oregon Health & Science University
Portland, Oregon

Andrew Furey, MSc, MD, FRCSC
Assistant Professor
Department of Surgery
Memorial University of Newfoundland
St. John’s, Newfoundland, Canada

Michael S. H. Kain, MD
Chief Resident, Orthopaedic Surgery
Boston University Medical Center
Boston, Massachusetts

David E. Karges, DO
Associate Professor
Department of Orthopaedic Surgery
St. Louis University
St. Louis, Missouri

Phyllis Kobbe, MD
Department of Orthopaedic Surgery
University of Pittsburgh Medical Center
Pittsburgh, Pennsylvania

Stephen Kottmeier, MD
Associate Professor of Orthopaedics
University Hospital and Medical Center at Stony Brook
Stony Brook, New York

Ronald Lakatos, MD
Assistant Professor of Orthopaedics
The Ohio State University Medical Center
Columbus, Ohio

Mark A. Lee, MD
Associate Professor of Orthopaedic Surgery–Trauma
University of California, San Francisco School of Medicine
San Francisco, California

Seth P. Levitz, MD
Department of Orthopaedic Surgery
NorthShore University Health System
Evaston, Illinois

Brian Mullis, MD
Chief and Assistant Professor, Orthopaedic Trauma Service
Indiana University School of Medicine
Indianapolis, Indiana

Robert O’Toole, MD
Assistant Professor
Department of Orthopaedic Surgery
University of Maryland School of Medicine
Baltimore, Maryland

Matthew E. Oetgen, MD
Clinical Instructor
Department of Orthopaedic Surgery and Sports Medicine
Children’s National Medical Center
Washington, District of Columbia

Hans Christoph Pape, MD
F. Pauwels Professor and Chairman
Department of Orthopaedic Surgery
University of Aachen Medical Center
Aachen, Germany

George Parnal, MD
Department of Orthopaedics
Eastern Maine Medical Center
Bangor, Maine

Laura S. Pfeiffer, MD
Assistant Professor of Orthopaedics
The Ohio State University Medical Center
Columbus, Ohio

Michael Prayson, MD
Associate Professor of Orthopaedic Surgery
Wright State University Boonshoft School of Medicine
Miami Valley Hospital
Dayton, Ohio

William M. Rice, MD
Associate Professor
Department of Orthopaedic Surgery
Washington University School of Medicine
St. Louis, Missouri

Toby M. Risko, MD
Assistant Professor of Orthopaedics
Texas Tech University
Lubbock, Texas

Thomas A. Russell, BS, MD
Professor of Orthopaedic Surgery
Campbell Clinic/University of Tennessee Department of Orthopaedics
Elvis Presley Trauma Center
University of Tennessee
Eads, Tennessee

Henry Claude Sagi, MD
Assistant Clinical Professor
Department of Orthopaedic Surgery and Orthopaedic Trauma Service
University of South Florida
Tampa General Hospital
Tampa, Florida

Roy W. Sanders, MD
Director, Orthopaedic Trauma Service
Florida Orthopaedic Institute
Tampa, Florida

Jodi Siegel, MD
Assistant Professor of Orthopaedics
Department of Orthopaedics and Physical Rehabilitation
University of Massachusetts Medical School
University of Massachusetts Memorial Medical Center
Worcester, Massachusetts

J. Benjamin Smucker, MD
Orthopaedic Resident
Metrohealth Hospital
Cleveland, Ohio

John K. Sontich, MD
Associate Professor of Surgery, Orthopaedics
Metrohealth Medical Center
Cleveland, Ohio

Natalie L. Talbou, MPAS, PA-C
Department of Orthopaedic Surgery
St. Elizabeth Health Center
Youngstown, Ohio

David C. Templeman, MD
Associate Professor of Orthopaedic Surgery
University of Minnesota
Hennepin County Medical Center
Minneapolis, Minnesota

Paul Tornetta III, MD
Professor and Vice Chairman
Department of Orthopaedic Surgery
Boston University Medical Center
Boston, Massachusetts

J. Tracy Watson, MD
Professor of Orthopaedic Surgery
Chief, Division of Orthopaedic Traumatology
St. Louis University School of Medicine
St. Louis, Missouri
PART 3 ADULT RECONSTRUCTION

Anish K. Amin, MBChB, MRCSEd  
Specialist Registrar  
Department of Orthopaedic and Trauma Surgery  
New Royal Infirmary of Edinburgh  
Edinburgh, Scotland

Robert A. Arciero, MD  
Professor and Chief of Sports Medicine  
Department of Orthopaedic Surgery  
University of Connecticut Health Center  
Farmington, Connecticut

Matthew S. Austin, MD  
Assistant Professor of Orthopaedic Surgery  
Thomas Jefferson University Hospital  
Rothman Institute  
Philadelphia, Pennsylvania

B. Sonny Bal, MD, MBA  
Associate Professor  
Department of Orthopaedic Surgery  
University of Missouri  
Columbia, Missouri

Martin Beck, MD, PD, Dr.med.  
Department of Orthopaedic Surgery  
Canton Hospital Lucerne  
Lucerne, Switzerland

Christopher P. Beauchamp, MD  
Associate Professor of Orthopaedics  
Mayo College of Medicine  
Phoenix, Arizona

Benjamin Bender, MD  
Joint Replacement Specialist  
Assuta Hospital  
Tel-Aviv, Israel

Keith R. Berend, MD  
Clinical Assistant Professor  
Department of Orthopaedics  
The Ohio State University  
New Albany, Ohio

Michael E. Berend, MD  
Orthopaedic Surgeon  
Center for Hip & Knee Surgery  
St. Francis Hospital  
Mooresville, Indiana

Hari P. Bezawada, MD  
Assistant Clinical Professor  
Department of Orthopaedic Surgery  
University of Pennsylvania School of Medicine  
Philadelphia, Pennsylvania

James Bicos, MD  
Department of Orthopedics and Sports Medicine  
St. Vincent Medical Center  
Carmel, Indiana

Thomas E. Brown, MD  
Associate Professor of Orthopaedic Surgery  
University of Virginia School of Medicine  
Charlottesville, Virginia

Shawn M. Brubaker, DO  
Staff, Shasta Orthopaedics and Sports Center  
Redding, California

Robert H. Cho, MD  
Orthopaedic Resident  
Department of Orthopaedic Surgery  
Drexel University College of Medicine  
Philadelphia, Pennsylvania

Christian P. Christensen, MD  
Head, Adult Reconstruction  
Lexington Clinic  
Assistant Clinical Professor  
University of Kentucky  
Lexington, Kentucky

John C. Clohisy, MD  
Professor of Orthopaedic Surgery  
Washington University Medical School  
St. Louis, Missouri

Janet D. Conway, MD  
Head of Bone and Joint Infection  
Rubin Institute for Advanced Orthopedics  
Sinai Hospital  
Baltimore, Maryland

Marcus Crestani, MD  
Department of Orthopaedics  
Hospital Moinhos de Vento  
Santa Casa, Brazil

Craig J. Della Valle, MD  
Associate Professor of Orthopaedic Surgery  
Rush University Medical Center  
Westchester, Illinois

Jonathan Garino, MD  
Associate Professor  
Department of Orthopaedic Surgery  
University of Pennsylvania School of Medicine  
Philadelphia, Pennsylvania

Nelson V. Greidanus, MD, MPH, FRCSC  
Assistant Professor  
Department of Orthopaedics  
University of British Columbia  
Vancouver, British Columbia, Canada

David Gusmao, MD  
Department of Orthopaedics  
Hospital Moinhos de Vento  
Santa Casa, Brazil

Mark A. Hartzband, MD  
Senior Attending Director, Total Joint Replacement Service  
Department of Orthopaedic Surgery  
Hackensack University Medical Center  
Hackensack, New Jersey

Philipp Henle, MD  
Resident  
Department of Orthopaedic Surgery  
Inselspital, Bern University Hospital  
Bern, Switzerland

Matthew S. Hepinstall, MD  
Fellow, Adult Reconstruction & Joint Replacement  
Department of Orthopaedic Surgery  
Hospital for Special Surgery  
New York, New York

William J. Hozacl, MD  
Professor of Orthopedics  
Department of Orthopaedic Surgery  
The Rothman Institute  
Thomas Jefferson University Hospital  
Philadelphia, Pennsylvania

Cale A. Jacobs, PhD  
Director of Development  
End Range of Motion Improvement, Inc.  
Assistant Professor, Adjunct Title Series  
College of Health Sciences  
University of Kentucky  
Suwanee, Georgia

S. Mehdi Jafari, MD  
Assistant Professor  
Department of Orthopaedic Surgery  
Tehran University of Medical Sciences  
Shariati Hospital  
Tehran, Iran

Kang-Il Kim, MD, PhD  
Associate Professor and Chief  
Center for Joint Diseases  
Department of Orthopaedic Surgery  
Kyeong Hee University School of Medicine  
East-West Neo Medical Center  
Seoul, Korea

Winston Y. Kim, MBChB, MSc, FRCS  
Lecturer and Consultant Orthopaedic Surgeon  
The Alexandra Hospital  
University of Manchester  
Cheadle, Cheshire, United Kingdom

Brian A. Klatt, MD  
Assistant Professor  
Department of Orthopaedic Surgery  
University of Pittsburgh Medical Center  
Pittsburgh, Pennsylvania

Gregg R. Klein, MD  
Attending Physician  
Department of Orthopaedic Surgery  
Hackensack University Medical Center  
Hackensack, New Jersey

Gwo-Chin Lee, MD  
Assistant Professor  
Department of Orthopaedic Surgery  
University of Pennsylvania School of Medicine  
Philadelphia, Pennsylvania

Michael Leunig, MD, PD, Dr.med.  
Department of Orthopaedics  
Schallthess Clinic  
Zurich, Switzerland

Harlan B. Levine, MD  
Attending Physician  
Department of Orthopaedic Surgery  
Hackensack University Medical Center  
Hackensack, New Jersey

Adolph V. Lombardi, Jr., MD, FACS  
Clinical Assistant Professor  
Department of Orthopaedics  
Department of Biomedical Engineering  
The Ohio State University  
New Albany, Ohio
Roger Cornwall, MD  
Assistant Professor of Orthopaedic Surgery  
University of Cincinnati College of Medicine  
Cincinnati, Ohio

Anna V. Cuomo, MD  
PEDIATRIC ORTHOPAEDIC FELLOW  
Division of Orthopaedic Surgery  
Hospital for Sick Children  
Toronto, Ontario, Canada

Kirk W. Dabney, MD  
Associate Director of the Cerebral Palsy Program  
Alfred I. duPont Hospital for Children  
Wilmington, Delaware

Jon R. Davids, MD  
Chief of Staff  
Director, Motion Analysis Laboratory  
Shriners Hospital for Children  
Greenville, South Carolina

Richard S. Davidson, MD  
Associate Professor  
Division of Pediatric Orthopaedics  
Department of Surgery  
Children’s Hospital of Philadelphia  
University of Pennsylvania School of Medicine  
Philadelphia, Pennsylvania

Matthew B. Dobbs, MD  
Associate Professor of Orthopaedic Surgery  
Washington University School of Medicine  
Saint Louis, Missouri

John P. Dormans, MD  
Chief of Orthopaedic Surgery  
The Children's Hospital of Philadelphia  
Philadelphia, Pennsylvania

Denis S. Drummond, MD  
Professor of Orthopaedic Surgery  
University of Pennsylvania School of Medicine  
Attending Surgeon  
Emeritus Chief of Orthopaedic Surgery  
The Children’s Hospital of Philadelphia  
Philadelphia, Pennsylvania

Craig P. Eberson, MD  
Assistant Professor and Division Chief  
Division of Pediatric Orthopaedics  
Department of Orthopaedics  
Alpert Medical School of Brown University  
Hasbro Children’s Hospital  
Providence, Rhode Island

John B. Emans, MD  
Professor of Orthopedic Surgery  
Children’s Hospital Boston  
Harvard Medical School  
Boston, Massachusetts

Paul W. Esposito, MD  
Professor of Orthopaedic Surgery and Pediatrics  
University of Nebraska Medical Center  
Children’s Hospital and Medical Center  
Omaha, Nebraska

Marybeth Ezaki, MD  
Professor of Orthopaedic Surgery  
Department of Hand Service  
Texas Scottish Rite Hospital for Children  
Dallas, Texas

Reginald S. Fayssoux, MD  
Department of Orthopaedic Surgery  
The Emory Spine Center  
Emory University School of Medicine  
Atlanta, Georgia

Fabio Ferri-De-Barros, MD, FSBOt  
Clinical Fellow, PhD Student  
Department of Orthopaedics  
Hospital for Sick Children  
Toronto, Ontario, Canada

John M. Flynn, MD  
Associate Chief of Orthopaedic Surgery  
The Children’s Hospital of Philadelphia  
Associate Professor of Orthopaedic Surgery  
University of Pennsylvania School of Medicine  
Philadelphia, Pennsylvania

Jenny M. Frances, MD, MPH  
Assistant Professor of Orthopaedic Surgery  
New York University Hospital for Joint Diseases  
New York, New York

John Frino, MD  
Assistant Professor of Orthopaedic Surgery  
Wake Forest University School of Medicine  
Winston-Salem, North Carolina

Theodore J. Ganley, MD  
Associate Professor of Orthopaedic Surgery  
University of Pennsylvania School of Medicine  
Attending Surgeon  
Director of Sports Medicine  
The Children’s Hospital of Philadelphia  
Philadelphia, Pennsylvania

Matthew R. Garner, BS  
The Children’s Hospital of Philadelphia  
Philadelphia, Pennsylvania

Purushottam A. Gholve, MD, MBMS, MRCS  
Assistant Professor of Orthopaedics  
Floating Hospital for Children at Tufts Medical Center  
Tufts University School of Medicine  
Boston, Massachusetts

J. Anthony Gonzales, Jr., BS, MD  
Department of Pediatric Orthopedics  
Children’s Hospital of New Orleans  
New Orleans, Louisiana

J. Eric Gordon, MD  
Associate Professor of Medicine  
Department of Orthopedics  
Washington University School of Medicine/St. Louis Children’s Hospital  
St. Louis, Missouri

James T. Guille, MD  
Division of Spinal Disorders  
Brandywine Institute of Orthopedics  
Pottstown, Pennsylvania

Aaron B. Heath, MD  
Division of Orthopaedic Surgery  
The Children’s Hospital of Philadelphia  
Philadelphia, Pennsylvania

Daniel J. Hedequist, MD  
Associate Professor of Orthopedic Surgery  
Department of Orthopedics  
Children’s Hospital Boston/Harvard Medical School  
Boston, Massachusetts

B. David Horn, MD  
Assistant Professor  
Department of Orthopedic Surgery  
University of Pennsylvania School of Medicine  
Philadelphia, Pennsylvania

Victor Hsu, BA, MD  
Attending Spine Surgeon  
Department of Orthopaedic Surgery  
Orthopaedic Specialty Center  
Willow Grove, Pennsylvania

Lori A. Karol, MD  
Professor of Orthopaedic Surgery  
Texas Scottish Rite Hospital for Children  
Dallas, Texas

Kathryn A. Keeler, MD  
Assistant Professor  
Department of Orthopedic Surgery  
Washington University School of Medicine  
St. Louis, Missouri

Young-Jo Kim, MD, PhD  
Assistant Professor of Orthopaedic Surgery  
Harvard Medical School  
Children’s Hospital Boston  
Boston, Massachusetts

Mininder S. Kocher, MD, MPH  
Associate Director  
Division of Sports Medicine  
Department of Orthopaedic Surgery  
Children’s Hospital Boston  
Associated Professor of Orthopaedic Surgery  
Harvard Medical School  
Harvard School of Public Health  
Boston, Massachusetts

J. Todd R. Lawrence, MD, PhD  
Fellow, Pediatric Orthopaedic Surgery  
The Children’s Hospital of Philadelphia  
Philadelphia, Pennsylvania

Bryan T. Leck, MD  
Fellow  
Department of Orthopedic Surgery  
University of California, San Diego  
San Diego, California

Noppachart Limpaphayom, MD  
Instructor  
Department of Orthopedics  
Chulalongkorn University  
Bangkok, Thailand

Jeffrey E. Martus, MD  
Assistant Professor  
Department of Orthopedics and Rehabilitation  
Vanderbilt Children’s Hospital  
Nashville, Tennessee

Travis H. Matheney, MD  
Instructor in Orthopaedic Surgery  
Harvard Medical School  
Children’s Hospital Boston  
Boston, Massachusetts

James J. McCarthy, MD  
Faculty  
University of Wisconsin School of Medicine and Public Health  
University of Wisconsin Hospital and Clinics  
American Family Children’s Hospital  
Rosemont, Illinois
Richard E. McCarthy, MD
Professor
Chief of Spinal Deformities
Department of Orthopaedics
Arkansas Children’s Hospital
Little Rock, Arkansas

Charles T. Mehlan, DO, MPH
Professor
Department of Pediatric Orthopaedic Surgery
Cincinnati Children’s Hospital Medical Center
Cincinnati, Ohio

Gokce Mik, MD
Department of Orthopaedic Surgery
The Children’s Hospital of Philadelphia
Philadelphia, Pennsylvania

Freeman Miller, MD
Al duPont Hospital for Children
Wilmington, Delaware

Michael B. Millis, MD
Associate Professor of Orthopaedic Surgery
Harvard Medical School
Children’s Hospital Boston
Boston, Massachusetts

Vincent S. Mosca, MD
Associate Professor of Orthopedics
University of Washington School of Medicine
Seattle Children’s Hospital
Seattle, Washington

Scott J. Mubarak, MD
Clinical Professor
Department of Orthopaedics
University of California
San Diego Medical Center
San Diego, California

Stuart M. Myers, MD
Department of Orthopedic Surgery
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Karen S. Myung, MD, PhD
Assistant Professor
Children’s Orthopedic Center
Children’s Hospital of Los Angeles
Los Angeles, California

Unni G. Narayanan, MBBS, MSc, FRCS(C)
Assistant Professor of Surgery
Division of Orthopaedic Surgery
University of Toronto
The Hospital for Sick Children
Toronto, Ontario, Canada

Blaise Nemeth, MA, MS
Assistant Professor (CHS)
Department of Orthopedics
University of Wisconsin School of Medicine and Public Health
Madison, Wisconsin

Kenneth Noonan, MD
Associate Professor
Department of Orthopaedics
University of Wisconsin School of Medicine and Public Health
Madison, Wisconsin

Tom F. Novacheck, MD
Associate Professor
Director, Center for Gait and Motion Analysis
Department of Orthopaedic Surgery
University of Minnesota
Gillette Children’s Specialty Healthcare
St. Paul, Minnesota

Scott N. Oishi, MD
Assistant Professor of Plastic Surgery
Department of Hand Service
Texas Scottish Rite Hospital for Children
Dallas, Texas

Brad Olney, MD
Professor and Chief
Department of Orthopaedics
Children’s Mercy Hospital
Kansas City, Missouri

Norman Y. Otsuka, MD
Clinical Professor
Department of Orthopedic Surgery
University of California, Los Angeles
Shriners Hospitals for Children
Los Angeles, California

Dror Paley, MD, FRSCS
Director
Paley Advanced Limb Lengthening Institute
St. Mary’s Hospital
West Palm Beach, Florida

Kristan A. Pierz, MD
Assistant Professor of Orthopaedics
Connecticut Children’s Medical Center
University of Connecticut School of Medicine
Hartford, Connecticut

Maya E. Pring, MD
Clinical Instructor of Orthopaedic Surgery
University of California San Diego
Rady Children’s Hospital San Diego
San Diego, California

Ellen M. Raney, MD
Clinical Professor of Surgery
Department of Surgery
University of Hawaii John A. Burns School of Medicine
Shriners Hospital for Children
Honolulu, Hawaii

Margaret M. Rich, MD, PhD
Shriners Hospitals for Children—St. Louis
St. Louis, Missouri

James R. Romanowski, MD
Fellow, Orthopaedic Sports Medicine
Department of Orthopaedic Surgery
University of Pittsburgh Medical Center
Pittsburgh, Pennsylvania

Anthony A. Scaduto, MD
Pediatric Orthopaedics
Los Angeles Orthopaedic Hospital
Los Angeles, California

David Scher, MD
Associate Professor of Clinical Orthopaedics
Division of Pediatric Orthopaedic Surgery
Department of Orthopaedic Surgery
Weill Cornell School of Medicine
Hospital for Special Surgery
New York, New York

Perry L. Schoenecker, MD
Professor and Chief of Pediatric Orthopaedics
Washington University School of Medicine
Shriners Hospital for Children
St. Louis, Missouri

Tim Schrader, MD
Medical Director, Hip Program
Children’s Healthcare of Atlanta
Atlanta, Georgia

Richard M. Schwend, MD
Professor
Department of Orthopaedics
Children’s Mercy Hospital
Kansas City, Missouri

Eric D. Shirley, MD
Attending Pediatric Orthopaedic Surgery
Bone and Joint Institute
Naval Medical Center Portsmouth
Virginia Beach, Virginia

Om Prasad Shrestha, MBBS
Clinical Fellow
Division of Orthopaedics
The Children’s Hospital of Philadelphia
Philadelphia, Pennsylvania

Ernest L. Sink, MD
Associate Professor
Department of Orthopaedics
The Children’s Hospital
University of Colorado
Aurora, Colorado

David L. Skaggs, MD
Professor of Orthopaedic Surgery
University of Southern California
Chief of Orthopaedic Surgery
Children’s Hospital Los Angeles
Los Angeles, California

Brian G. Smith, MD
Associate Professor of Orthopaedics and Rehabilitation
Director, Yale Pediatric Orthopaedics and Rehabilitation
Yale School of Medicine
New Haven, Connecticut

Brian Snyder, MD, PhD
Associate Professor
Department of Orthopaedic Surgery
Harvard Medical School
Children’s Hospital Boston
Boston, Massachusetts

David A. Spiegel, MD
Assistant Professor of Orthopaedic Surgery
Children’s Hospital of Philadelphia
University of Philadelphia School of Medicine
Philadelphia, Pennsylvania

Shawn C. Standard, MD
Head of Pediatric Orthopedics
International Center for Limb Lengthening
Rubin Institute for Advanced Orthopedics
Sinai Hospital of Baltimore
Baltimore, Maryland

Anthony A. Stans, MD
Assistant Professor of Medicine
Chair, Division of Pediatric Orthopedics
Mayo Clinic
Rochester, Minnesota
PART 5 ONCOLOGY

Adesegun Abudu, FRCS
Royal Orthopaedic Hospital Oncology Service
Northfield, Birmingham, United Kingdom

Aharon Amir, MD
Attending Surgeon
Department of Plastic Surgery
Tel-Aviv Sourasky Medical Center
Tel-Aviv, Israel

Jacob Bickels, MD
Head, Service for the Management of Metastatic Bone Disease
Attending Surgeon, National Unit of Orthopedic Oncology
Tel-Aviv Sourasky Medical Center
Professor of Orthopedic Surgery
Sackler School of Medicine, Tel-Aviv University
Tel-Aviv, Israel

Loretta B. Chou, MD
Professor of Orthopaedic Surgery
Stanford University
Chief, Foot and Ankle Service
Lucile Packard Children’s Hospital at Stanford
Palo Alto, California

Ernest U. Conrad III, MD
Professor of Orthopaedics
University of Washington
Director, Bone Tumor Clinic
Children’s Hospital and Regional Medical Center
Seattle, Washington

Jeffrey J. Eckardt, MD
Director, Orthopaedic Oncology
UCLA Santa Monica Orthopaedic Center
Santa Monica, California

Steven Gitelis, MD
Professor and Vice Chairman of Orthopaedic Surgery
Director, Section of Orthopaedic Oncology
Rush University Medical Center
Chicago, Illinois

Robert Grimer, FRCS
Consultant Orthopaedic Surgeon
Royal Orthopaedic Hospital
Northfield, Birmingham, United Kingdom

Eyal Gur, MD
Director, Unit of Microsurgery
Department of Plastic Surgery
Tel-Aviv Sourasky Medical Center
Senior Lecturer
Sackler School of Medicine
Tel-Aviv University
Tel-Aviv, Israel

Lee Jeys, MB, ChB, MSc, FRCS
Consultant Orthopaedic Surgeon
Specialist in Hip, Knee, and Oncology Surgery
Midland Hip & Knee Clinic
Royal Orthopaedic Hospital
Northfield, Birmingham, United Kingdom

Robert M. Henshaw, MD
Associate Clinical Professor of Orthopaedic Surgery
Georgetown University Medical Center
Director, Orthopaedic Oncology
Director, Fellowship Program in Orthopaedic Oncology
Washington Cancer Institute
Washington, District of Columbia

Yvette Ho
Research Assistant
Washington Musculoskeletal Tumor Center
Washington Cancer Institute
Washington, District of Columbia

Norio Kawahara, MD, PhD
Clinical Professor
Department of Orthopaedic Surgery
Kanazawa University School of Medicine
Ishikawa, Japan

Kristen Kellar-Graney, MS
Tumor Biologist and Clinical Research Coordinator
Washington Cancer Institute
Washington, District of Columbia

Piya Kiatsiri, MD
Orthopaedic Oncology Unit
Institute of Orthopedics
Lerdos Hospital
Bangkok, Thailand

Yehuda Koller, MD
Attending Surgeon, National Unit of Orthopedic Oncology
Tel-Aviv Sourasky Medical Center
Senior Lecturer
Sackler School of Medicine, Tel-Aviv University
Tel-Aviv, Israel

Jennifer Lisle, MD
Assistant Professor of Orthopedics, Rehabilitation, and Pediatrics
University of Vermont College of Medicine
Vermont Children’s Hospital at Fletcher Allen Health Care
Burlington, Vermont

Martin M. Malawer, MD, FACS
Professor (Clinical Scholar) of Orthopaedics
Professor of Pediatrics (Hematology and Oncology)
Georgetown University Medical Center
Professor of Orthopaedic Surgery
George Washington University
Director of Research and Development
Orthopaedic Oncology
Washington Cancer Institute
Orthopaedic Oncology
Children’s National Medical Center
Washington, District of Columbia
Consultant (Pediatric and Surgery Branch)
National Cancer Institute, National Institutes of Health
Bethesda, Maryland

Isaac Meller, MD
Director, National Unit of Orthopedic Oncology
Tel-Aviv Sourasky Medical Center
Professor of Orthopedic Surgery
Sackler School of Medicine, Tel-Aviv University
Tel-Aviv, Israel

Benjamin J. Miller, MD
Rush Orthopaedic Oncology
Rush University Medical Center
Chicago, Illinois

Hideki Murakami, MD
Professor of Orthopedic Surgery
Tel-Aviv, Israel

Yves van Heest, MD
Professor of Orthopaedic Surgery
University of Minnesota
Minneapolis, Minnesota

Thanapong Waitayawinyu, MD
Assistant Professor of Orthopaedics
Thammasat University
Klonghuang, Pathumthani, Thailand

Eric J. Wall, MD
Director of Orthopaedic Surgery
Cincinnati Children’s Hospital Medical Center
Cincinnati, Ohio

Lawrence Wells, MD
Assistant Professor of Orthopaedic Surgery
University of Pennsylvania School of Medicine
Children’s Hospital of Philadelphia
Philadelphia, Pennsylvania

Dennis R. Wenger, MD
Clinical Professor of Orthopaedic Surgery
University of California San Diego
Rady Children’s Hospital San Diego
San Diego, California

Roger F. Widmann, MD
Associate Professor of Clinical Orthopaedic Surgery
Division of Pediatric Orthopaedic Surgery
Weill Cornell Medical College
Hospital for Special Surgery
New York, New York

Jennifer J. Winell, MD
Assistant Professor of Orthopaedic Surgery
Children’s Hospital of Philadelphia
Philadelphia, Pennsylvania

Yi-Meng Yen, MD, PhD
Instructor in Orthopaedic Surgery
Harvard Medical School
Orthopaedic Surgery/Sports Medicine
Children’s Hospital Boston
Boston, Massachusetts
PART 6 HAND, WRIST, AND FOREARM

Brian D. Adams, MD
Professor of Orthopaedic Surgery and Bioengineering
University of Iowa
Iowa City, Iowa

Christopher H. Allan, MD
Associate Professor of Orthopaedics and Sports Medicine
University of Washington
Seattle, Washington

Edward A. Athanasian, MD
Associate Professor of Clinical Orthopaedic Surgery
Weill Cornell Medical College
Associate Attending Orthopaedic Surgeon
Hospital for Special Surgery
New York, New York

Mark N. Awantang, MD
Orthopaedic Associates
Washington, District of Columbia

Alejandro Badia, MD, FACS
Badia Hand to Shoulder Center
Chief of Hand Surgery
Baptist Hospital
Miami, Florida

Mark E. Baratz, MD
Professor and Executive Vice Chairman
Chief, Upper Extremity Service
Department of Orthopaedic Residency and Upper Extremity Fellowship
Drexel University College of Medicine
Allegheny General Hospital
Pittsburgh, Pennsylvania

Asheesh Bedi, MD
Assistant Professor of Orthopaedic Surgery
University of Michigan Health System
Ann Arbor, Michigan

Michael S. Bednar, MD
Professor of Orthopaedic Surgery and Rehabilitation
Stritch School of Medicine
Loyola University–Chicago
Maywood, Illinois

Kerry Bemers, CHT
University Orthopedics
Providence, Rhode Island

Leon S. Benson, MD
Professor of Clinical Orthopaedic Surgery
University of Chicago Pritzker School of Medicine
Illinois Bone and Joint Institute
Glencoe, Illinois

Pedro K. Beredjiklian, MD
Associate Professor of Orthopaedic Surgery
Thomas Jefferson School of Medicine
Chief, Hand Surgery Division
The Rothman Institute
Philadelphia, Pennsylvania

Randy R. Bindra, MD
Professor of Orthopaedic Surgery
Loyola University Medical Center
Maywood, Illinois

Philip E. Blazar, MD
Assistant Professor of Orthopaedic Surgery
Brigham and Women’s Hospital
Boston, Massachusetts

Michael R. Boland, MBChB, FRCS, FRACS
Assistant Professor of Orthopaedic Surgery
University of Kentucky College of Medicine
Lexington, Kentucky

Benjamin J. Boudreaux, MD
Assistant Clinical Professor of Plastic Surgery
Louisiana State University
Baton Rouge, Louisiana

Martin I. Boyer, MD
Carole B. and Jerome T. Loeb Professor of Orthopaedic Surgery
Department of Orthopaedic Surgery
Washington University School of Medicine
St. Louis, Missouri

David J. Bozentka, MD
Associate Professor of Orthopaedic Surgery
University of Pennsylvania
Chief, Orthopaedic Surgery
Penn Presbyterian Medical Center
Philadelphia, Pennsylvania

Jay T. Bridgeman, MD
Assistant Professor of Orthopaedics
Penn State Hershey Bone and Joint Institute
Hershey, Pennsylvania

John S. Buchieri, MD
Private Practice, Lake Health
Willoughby, Ohio

Jeffrey E. Budoff, MD
Director, Orthopaedic Hand and Upper Extremity Service
Houston VA Medical Center
Southwest Orthopaedic Group
Houston, Texas

Reuben A. Bueno, Jr., MD
Assistant Professor of Plastic Surgery
Southern Illinois University School of Medicine
Springfield, Illinois

John T. Capo, MD
Associate Professor of Orthopaedics
Chief, Division of Hand and Microvascular Surgery
UMDNJ-New Jersey Medical School
Newark, New Jersey

Charles Cassidy, MD
Henry H. Banks Associate Professor and Chairman
Tufts University School of Medicine
Orthopaedist in Chief at Tufts Medical Center
Boston, Massachusetts
Louis W. Catalano III, MD
Assistant Clinical Professor
Columbia University
C. V. Staff
Hand Surgery Center
Roosevelt Hospital
New York, New York

Edwin Y. Chang, MD
Spokane Plastic Surgeons
Spokane, Washington

Nilesh M. Chaudhari, MD
Assistant Professor of Surgery
Department of Orthopaedic Surgery
University of Alabama, Birmingham
Birmingham, Alabama

Neal C. Chen, MD
Clinical Instructor
Department of Orthopaedic Surgery
University of Michigan
Ann Arbor, Michigan

Andrew Chin, MD FRCS
Consultant Hand Surgeon
Hand Surgery Unit
Singapore General Hospital
Singapore

Kevin C. Chung, MD, MS
Professor of Surgery
Section of Plastic Surgery
University of Michigan
Ann Arbor, Michigan

Evan D. Collins, MD
Assistant Professor of Orthopaedics
Weill Cornell Medical College
New York, New York
Staff Physician
Department of Orthopaedics
The Methodist Hospital
Houston, Texas

Cari Cordell, MD
Fellow
Department of Orthopaedics
Loyola University Medical Center
Maywood, Illinois

Andrew W. Cross, DVM, MD
Hand Surgery Specialists, Inc.
Cincinnati, Ohio

Randall W. Culp, MD
Professor of Orthopaedic Hand and
Microsurgery
Department of Orthopaedics
Thomas Jefferson University Hospital
Philadelphia, Pennsylvania

Catherine M. Curtin, MD
Assistant Professor of Plastic Surgery
Stanford University
Pal Alto, California

Leonard L. D’Addesi, MD
Orthopaedic Associates of Reading
Reading Hospital and Medical Center
West Reading, Pennsylvania

Jorge de la Torre, MD
Professor of Surgery
Chief, Plastic Surgery
Division of Plastic Surgery
Department of Surgery
University of Alabama at Birmingham
Birmingham VA Medical Center
Birmingham, Alabama

Anthony M. DeLuise, Jr., MD
Fellow
Department of Orthopaedic Surgery
Thomas Jefferson University Hospital
Philadelphia, Pennsylvania

Edward Diao, MD
Professor Emeritus of Orthopaedic Surgery and Neurosurgery
University of California, San Francisco
San Francisco, California

John A. Dilger, MD
Department of Anesthesiology
Mayo Clinic
Rochester, Minnesota

Christopher Doumas, MD
Clinical Assistant Professor of Orthopaedic Surgery
Robert Wood Johnson Medical School
University of Medicine and Dentistry of New Jersey
New Brunswick, New Jersey

John C. Elfar, MD
Assistant Professor
Department of Orthopaedics
University of Rochester
Rochester, New York

Peter J. Evans, MD, PhD, FRCS
Director, Hand and Upper Extremity
Department of Orthopaedics
Cleveland Clinic
Cleveland, Ohio

Paul Feldon, MD
Clinical Associate Professor of Orthopaedics
Tufts University School of Medicine
New England Baptist Hospital
Boston, Massachusetts

Diego Fernandez, MD
Lindenhof Hospital
Bern, Switzerland

John J. Fernandez, MD
Assistant Professor of Orthopaedic Surgery
Division of Hand, Wrist, and Elbow
Rush University Medical Center
Chicago, Illinois

Angel Ferreres, MD, PhD
Consultant Hand Surgeon
Hand Surgery Unit
Institut Kaplan
Barcelona, Spain

Rimma Finkel, MD
Chandler, Arizona

Christian Ford, MD
Chief Resident
Department of Plastic Surgery
Stanford Hospitals and Clinics
Palo Alto, California

Christopher L. Forthman, MD
Consultant, Curtis National Hand Center
Department of Orthopaedic Surgery
Union Memorial Hospital
Baltimore, Maryland

Jeffrey B. Friedrich, MD
Assistant Professor of Surgery and Orthopedics (Adjunct)
University of Washington
Seattle, Washington

Marc Garcia-Elias, MD, PhD
Consultant Hand Surgeon
Hand Surgery Unit
Institut Kaplan
Barcelona, Spain

William B. Geissler, MD
Professor and Chief
Division of Hand and Upper Extremity Surgery
Chief
Arthroscopic Surgery and Sports Medicine
Department of Orthopaedic Surgery and Rehabilitation
University of Mississippi Medical Center
Jackson, Mississippi

Harris Gellman, MD
Voluntary Professor
Department of Orthopedic and Plastic Surgery
University of Miami
Miami, Florida

Grey Giddins, MBBch, FRCS(Orth), EDHS
Consultant Orthopaedic and Hand Surgeon
Department of Orthopaedics
Royal United Hospital
Bath, England

Steven Z. Glickel, MD
Clinical Professor of Orthopaedic Surgery
C. V. Staff
Hand Surgery Center
Roosevelt Hospital
New York, New York

Charles A. Goldfarb, MD
Associate Professor
Department of Orthopaedic Surgery
Washington University School of Medicine
St. Louis, Missouri

Mark Golemski, MD
Resident of Internal Medicine
UT Southwestern Medical Center
Dallas, Texas

Christopher R. Goll, MD
Heckin Orthopaedics
Jacksonville, Florida

Thomas J. Graham, MD
Associate Professor
Department of Orthopaedic Surgery
Department of Plastic Surgery
Johns Hopkins School of Medicine
Chief, The Curtis National Hand Center
Vice-Chair, Department of Orthopaedic Surgery
Director, MedStar SportsHealth
Founder and Surgeon-in-Chief, Arnold Palmer SportsHealth Center
Union Memorial Hospital
Baltimore, Maryland

Jennifer Green, MD
Hand and Upper Extremity Surgeon
Newton Wellesley Orthopaedic Association
Newton, Massachusetts
Jeffrey A. Greenberg, MD, MS
Clinical Assistant Professor
Department of Orthopedics
Indiana University
Indiana Hand Center
Indianapolis, Indiana

Warren C. Hammert, MD
Associate Professor of Orthopaedic Surgery
Department of Orthopaedic Surgery and Plastic Surgery
University of Rochester Medical Center
Rochester, New York

Douglas P. Hanel, MD
Professor of Orthopaedics and Sports Medicine
University of Washington
Head, Pediatric Hand Surgery Program
Seattle, Washington

Scott L. Hansen, MD
Assistant Professor of Surgery
Division of Plastic and Reconstructive Surgery
University of California, San Francisco
San Francisco, California

Timothy W. Harman, BA, DO
Associate Clinical Professor
Assistant Program Director
Department of Orthopedics
Ohio University
Dayton, Ohio

Colin Harris, MD
Department of Orthopaedics
UMDNJ-New Jersey Medical School
Newark, New Jersey

Mark F. Hendrickson, MD
Section Head, Hand Surgery
Cleveland Clinic
Cleveland, Ohio

Carlos Heras-Palou, MD, FRCS(Trau&Orth)
Pulvertaft Hand Centre
Royal Derby Hospital
Derby, England

Eric P. Hofmeister, MD
Assistant Professor of Surgery
Uniformed Services University of the Health Sciences
Vice Chair and Director, Hand and Microvascular Service
Department of Orthopaedic Surgery
Naval Medical Center, San Diego
San Diego, California

Samuel C. Hoxie, MD
Department of Orthopaedic Surgery
Mayo Clinic
Rochester, Minnesota

Harry A. Hoyen, MD
Assistant Professor of Orthopaedic Surgery
Case Western Reserve University
MetroHealth Medical Center
Cleveland, Ohio

Thomas Hughes, MD
Assistant Professor
Department of Orthopaedic Surgery
Drexel University College of Medicine
Philadelphia, Pennsylvania

Warren C. Hammert, MD
Associate Professor of Orthopaedic Surgery
Department of Orthopaedic Surgery and Plastic Surgery
University of Rochester Medical Center
Rochester, New York

Douglas P. Hanel, MD
Professor of Orthopaedics and Sports Medicine
University of Washington
Head, Pediatric Hand Surgery Program
Seattle, Washington

Scott L. Hansen, MD
Assistant Professor of Surgery
Division of Plastic and Reconstructive Surgery
University of California, San Francisco
San Francisco, California

Timothy W. Harman, BA, DO
Associate Clinical Professor
Assistant Program Director
Department of Orthopedics
Ohio University
Dayton, Ohio

Colin Harris, MD
Department of Orthopaedics
UMDNJ-New Jersey Medical School
Newark, New Jersey

Mark F. Hendrickson, MD
Section Head, Hand Surgery
Cleveland Clinic
Cleveland, Ohio

Carlos Heras-Palou, MD, FRCS(Trau&Orth)
Pulvertaft Hand Centre
Royal Derby Hospital
Derby, England

Eric P. Hofmeister, MD
Assistant Professor of Surgery
Uniformed Services University of the Health Sciences
Vice Chair and Director, Hand and Microvascular Service
Department of Orthopaedic Surgery
Naval Medical Center, San Diego
San Diego, California

Samuel C. Hoxie, MD
Department of Orthopaedic Surgery
Mayo Clinic
Rochester, Minnesota

Harry A. Hoyen, MD
Assistant Professor of Orthopaedic Surgery
Case Western Reserve University
MetroHealth Medical Center
Cleveland, Ohio

Thomas Hughes, MD
Assistant Professor
Department of Orthopaedic Surgery
Drexel University College of Medicine
Philadelphia, Pennsylvania

Emese Kalnoki-Kis, MD
Resident, Plastic Surgery
Phoenix Integrated Surgical Residency
Phoenix, Arizona

Morton Kasdan, BA, MD
Clinical Professor
Division of Plastic Surgery
University of Louisville
Louisville, Kentucky

Mohamed Khalid, MD
Fellow, UAB Hand and Upper Extremity Fellowship
Department of Orthopaedic Surgery
University of Alabama, Birmingham
Birmingham, Alabama

Prakash Khanchandani, MD
Hand Fellow
Miami Hand Center
Miami, Florida

Thomas R. Kiefhaber, MD
Hand Surgery Specialists
Cincinnati, Ohio

Richard Y. Kim, MD
Director of Hand Surgery
Departments of Plastic & Reconstructive Surgery and Orthopaedic Surgery
Hackensack University Medical Center
Hackensack, New Jersey

Hervey L. Kimball III, MD
Clinical Instructor of Orthopaedics
Tufts University School of Medicine
New England Baptist Hospital
Boston, Massachusetts

Joel C. Klena, MD
Director of Hand Division
Department of Orthopaedic Surgery
Geisinger Medical Center
Danville, Pennsylvania

Scott H. Kozin, MD
Professor of Orthopaedic Surgery
Temple University School of Medicine
Hand Surgeon
Shriners Hospital for Children
Philadelphia, Pennsylvania

Mark A. Krahe, DO
Professor of Orthopaedic Surgery
Hamot Hospital
Erie, Pennsylvania

Leo T. Kroonen, MD
Staff Surgeon
Division of Hand and Microvascular Surgery
Department of Orthopaedic Surgery
Naval Medical Center, San Diego
San Diego, California

Amy L. Ladd, MD
Professor of Orthopaedic Surgery
Chief, Chase Hand & Upper Limb Center
Stanford University School of Medicine
Chief of the Children's Hand Clinic
Lucile Packard Children's Hospital
Palo Alto, California

Jeffrey Lawton, MD
Hand and Upper Extremity Surgeon
Department of Orthopaedic Surgery
Cleveland Clinic Foundation
Cleveland, Ohio

Thomas R. Hunt III, MD
Professor of Surgery
John D. Sherrill Endowed Chair of Orthopaedic Surgery
Director, UAB Hand and Upper Extremity Fellowship Director, Division of Orthopaedic Surgery
Surgeon-in-Chief, UAB Highlands Hospital
University of Alabama School of Medicine
Birmingham, Alabama

Asif M. Ilyas, MD
Director, Temple Hand Center
Assistant Professor
Department of Orthopaedic Surgery
Temple University Hospital
Philadelphia, Pennsylvania

Joseph E. Imbriglia, MD
Clinical Professor
Department of Orthopaedic Surgery
University of Pittsburgh Medical Center
Pittsburgh, Pennsylvania

Robert E. Ivy, MD
Knoxville, Tennessee

Peter J. L. Jebson, MD
Associate Professor
Chief, Division of Elbow and Hand Surgery
Department of Orthopaedic Surgery
University of Michigan Health System
Ann Arbor, Michigan

Nelson L. Jenkins, MD
Hand Surgery Fellow
Department of Orthopedics
University of Massachusetts
Worcester, Massachusetts

Jeff W. Johnson, MD
Adjunct Assistant Clinical Professor
Department of Orthopaedic Surgery
University of Arkansas for Medical Sciences
Ozark Orthopaedic Associates
Fayetteville, Arkansas

Marci D. Jones, MD
Associate Professor
Department of Orthopedic Surgery and Rehabilitation
Department of Cell Biology
University of Massachusetts
Worcester, Massachusetts

Neil F. Jones, MD
Professor of Orthopaedic Surgery
Chief of Hand Surgery
University of California
Irvine Medical Center
Orange, California

Jesse B. Jupiter, MD
Hanstorg Wyss/AO Professor of Orthopaedic Surgery
Harvard Medical School
Chief, Hand and Upper Limb Service
Massachusetts General Hospital
Boston, Massachusetts

Joseph E. Imbriglia, MD
Clinical Professor
Department of Orthopaedic Surgery
University of Rochester Medical Center
Drexel University College of Medicine
Philadelphia, Pennsylvania

Emese Kalnoki-Kis, MD
Resident, Plastic Surgery
Phoenix Integrated Surgical Residency
Phoenix, Arizona

Morton Kasdan, BA, MD
Clinical Professor
Division of Plastic Surgery
University of Louisville
Louisville, Kentucky

Mohamed Khalid, MD
Fellow, UAB Hand and Upper Extremity Fellowship
Department of Orthopaedic Surgery
University of Alabama, Birmingham
Birmingham, Alabama

Prakash Khanchandani, MD
Hand Fellow
Miami Hand Center
Miami, Florida

Thomas R. Kiefhaber, MD
Hand Surgery Specialists
Cincinnati, Ohio

Richard Y. Kim, MD
Director of Hand Surgery
Departments of Plastic & Reconstructive Surgery and Orthopaedic Surgery
Hackensack University Medical Center
Hackensack, New Jersey

Hervey L. Kimball III, MD
Clinical Instructor of Orthopaedics
Tufts University School of Medicine
New England Baptist Hospital
Boston, Massachusetts

Joel C. Klena, MD
Director of Hand Division
Department of Orthopaedic Surgery
Geisinger Medical Center
Danville, Pennsylvania

Scott H. Kozin, MD
Professor of Orthopaedic Surgery
Temple University School of Medicine
Hand Surgeon
Shriners Hospital for Children
Philadelphia, Pennsylvania

Mark A. Krahe, DO
Professor of Orthopaedic Surgery
Hamot Hospital
Erie, Pennsylvania

Leo T. Kroonen, MD
Staff Surgeon
Division of Hand and Microvascular Surgery
Department of Orthopaedic Surgery
Naval Medical Center, San Diego
San Diego, California

Amy L. Ladd, MD
Professor of Orthopaedic Surgery
Chief, Chase Hand & Upper Limb Center
Stanford University School of Medicine
Chief of the Children's Hand Clinic
Lucile Packard Children's Hospital
Palo Alto, California

Jeffrey Lawton, MD
Hand and Upper Extremity Surgeon
Department of Orthopaedic Surgery
Cleveland Clinic Foundation
Cleveland, Ohio
CONTRIBUTORS

Ross J. Richer, MD
Orthopaedic Specialty Group, PC
Fairfield, Connecticut

David Ring, MD, PhD
Associate Professor of Orthopaedic Surgery
Harvard Medical School
Orthopaedic Hand and Upper Extremity
Unit
Massachusetts General Hospital
Boston, Massachusetts

Kyle P. Ritter, MD
Hendricks Orthopaedics and Sports
Medicine
Danville, Indiana

Joseph E. Robison, MD
Fayetteville Orthopaedics and Sports
Medicine
Fayetteville, North Carolina

Matthew J. Robon, MD
Proliance Orthopaedics & Sports Medicine
Bellevue, Washington

Melvin P. Rosenwasser, MD
Robert E. Carroll Professor of Orthopedic
Surgery
Chief
Orthopedic Hand and Trauma Surgery
Department of Orthopedic Surgery
Columbia University College of Physicians
and Surgeons
New York, New York

Justin M. Sacks, MD
Assistant Professor
Department of Plastic Surgery
The University of Texas/MC Anderson
Cancer Center
Houston, Texas

Rodrigo Santamarina, MD
Plastic Surgeon
Fellowship-trained Hand Surgeon
Assistant Professor of Surgery
University of Massachusetts
Berkshire Medical Center
Pittsfield, Massachusetts

Keith A. Segalman, MD
Assistant Professor of Orthopaedic Surgery
Johns Hopkins School of Medicine
Baltimore, Maryland
Greater Chesapeake Hand Specialists
Lutherville, Maryland

David B. Shapiro, MD
Section of Hand and Upper Extremity
Surgery
Department of Orthopaedic Surgery
The Cleveland Clinic
Cleveland, Ohio

Joseph M. Sherrill, MD
Chairman of Surgery
Healthsouth Medical Center
Alabama Orthopaedic Institute
Birmingham, Alabama

Alexander Y. Shin, MD
Professor of Orthopedic Surgery
Mayo Clinic
Rochester, Minnesota

Joseph F. Slade III, MD†
Professor of Orthopaedics and Plastic
Surgery
Department of Orthopaedics and
Rehabilitation
Yale University School of Medicine
Guilford, Connecticut

Robert R. Slater, Jr., MD
Associate Clinical Professor
Department of Orthopaedic Surgery
University of California, Davis
Folsom, California

David J. Slutsky, MD, FRCS(G)
Assistant Clinical Professor
David Geffen UCLA School of Medicine
Chief of Reconstructive Hand Surgery
Department of Orthopaedics
Harbor-UCLA Medical Center
The Hand and Wrist Institute
Torrance, California

Hugh M. Smith, MD
Assistant Professor of Anesthesiology
Mayo Clinic
Rochester, Minnesota

Dean G. Sotereanos, MD
Professor of Orthopaedic Surgery
Drexel University College of Medicine
Allegheny General Hospital
Pittsburgh, Pennsylvania

Edwin E. Spencer, Jr., MD
Attending Surgeon
Shoulder and Elbow Center
Knoxville Orthopaedic Clinic
Knoxville, Tennessee

Rena L. Stewart, MD
Assistant Professor
Department of Surgery/Orthopaedics
University Hospital (University of Alabama)
Birmingham, Alabama

Robert J. Strauch, MD
Professor of Clinical Orthopaedic Surgery
Columbia University Medical Center
New York, New York

James W. Strickland, MD
Clinical Professor of Orthopaedic Surgery
Indiana University School of Medicine
Reconstructive Hand Surgeons of Indiana
Carmel, Indiana

Eric Stuffmann, MD
Chief Resident of Orthopaedic Surgery
Stanford University Medical Center
Redwood City, California

Robert M. Szabo, MD, MPH
Professor of Orthopaedic Surgery and
Plastic Surgery
Chief, Hand, Upper Extremity, &
Microvascular Surgery
Department of Orthopaedic Surgery
University of California, Davis School of
Medicine
Sacramento, California

Jane S. Tan, MD
Department of Orthopaedic Surgery
Kaiser Permanente
Denver, Colorado

John S. Taras, MD
Associate Professor
Department of Orthopaedic Surgery
Thomas Jefferson University
Chief, Division of Hand and Surgery
Associate Professor
Department of Orthopaedic Surgery
Drexel University
Philadelphia, Pennsylvania

Andrew L. Terrono, MD
Clinical Professor of Orthopaedics
Tufts University School of Medicine
New England Baptist Hospital
Boston, Massachusetts

Joseph J. Thoder, MD
Professor
Department of Orthopaedic Surgery
Temple University Hospital
Philadelphia, Pennsylvania

Christopher J. Thomson, MD
Birmingham, Alabama

E. Bruce Toby, MD
Department of Orthopaedic Surgery
The University of Kansas Hospital
Kansas City, Kansas

Matthew M. Tomaino, MD
Tomaino Orthopaedic Care for Shoulder,
Hand, & Elbow
Rochester General Health System
Rochester, New York

Thomas Trumble, BA, MD
Professor and Chief, Hand and Upper
Extremity Surgery
Department of Orthopaedics/Sports
Medicine
University of Washington School of
Medicine
Seattle, Washington

Richard L. Uhl, MD
Professor of Surgery
Division of Orthopaedic Surgery
Albany Medical College
Albany, New York

Thomas F. Varecka, MD
Assistant Professor of Orthopaedic Surgery
University of Minnesota
Director, Hand and Microsurgery
Hennepin County Medical Center
Minneapolis, Minnesota

Luis O. Vasconez, MD
Professor of Surgery
Division of Plastic Surgery
University of Alabama at Birmingham
Birmingham, Alabama

John J. Walsh IV, MD
Associate Professor
Department of Orthopaedics
University of South Carolina School of
Medicine
Columbia, South Carolina

Christina M. Ward, MD
Department of Orthopaedic Surgery
University of Minnesota
Minneapolis, Minnesota

† deceased
Lance G. Warhold, MD
Division Director, Upper Extremity
Department of Orthopaedic Surgery
Dartmouth-Hitchcock Medical Center
Lebanon, New Hampshire

Arnold-Peter Weiss, MD
R. Scot Sellers Scholar of Hand Surgery
Professor of Orthopaedics
Associate Dean of Medicine
Brown University Medical School
Providence, Rhode Island

Mark Wilczynski, MD
Department of Orthopaedic Surgery
Washington University School of Medicine
St. Louis, Missouri

D. Patrick Williams, DO
Hand Microsurgery & Reconstructive Orthopaedics
Erie, Pennsylvania

Rafael M. M. Williams, MD
Wilson, Wyoming

Andrew Wong, MD
Private Practice
Arrowhead Orthopaedics
Redlands, California
Assistant Professor—Clinical
Department of Orthopaedic Surgery
Loma Linda University
Loma Linda, California

Jeffrey Yao, MD
Assistant Professor
Department of Orthopaedic Surgery
Stanford University Medical Center
Redwood City, California

Elvin G. Zook, MD
Professor Emeritus
Division of Plastic Surgery
Department of Surgery
Southern Illinois University School of Medicine
Springfield, Illinois

PART 7 SHOULDER AND ELBOW

Joseph A. Abboud, MD
Clinical Assistant Professor of Orthopaedic Surgery
University of Pennsylvania Health System
Philadelphia, Pennsylvania

Aymeric André, MD
Resident
Department of Plastic Surgery
University Hospital Rangueil
Paul-Sabatier University
Toulouse, France

Carl Basamania, MD, FACS
The Polyclinic First Hill
Seattle, Washington

Robert H. Bell, MD
Associate Professor of Orthopaedics
Crystal Clinic
Orthopaedic Surgeons, Inc.
Akron, Ohio

Ryan T. Bicknell, MD, MSc, FRCS(C)
Assistant Professor of Orthopaedic Surgery
Queen’s University
Kingston General Hospital
Kingston, Ontario, Canada

Louis U. Bigliani, MD
Frank E. Stinchfield Professor and Chairman of Orthopedic Surgery
Columbia University
Director of the Orthopedic Surgery Service
New York-Presbyterian Hospital/Columbia University Medical Center
New York, New York

Theodore A. Blaine, MD
Associate Professor of Orthopaedic Surgery
Brown Alpert Medical School
Rhode Island Hospital
Providence, Rhode Island

Kamal I. Bohnsali, MD
Attending Orthopaedic Surgeon, Shoulder and Elbow Reconstructive Orthopaedics
Department of Orthopaedics
Memorial Hospital
St. Luke’s Hospital
St. Vincent’s Hospital
Jacksonville, Florida

Nicolas Bonneville, MD
Clinical Assistant in Orthopedic Surgery
Department of Orthopaedics and Traumatology
University Hospital Purpan
Paul-Sabatier University
Toulouse, France

Christopher T. Born, MD
Professor of Orthopaedic Surgery
The Warren Alpert Medical School of Brown University
Rhode Island Hospital
Providence, Rhode Island

Joanna G. Branstetter, MD
Orthopaedic Surgeon
Madigan Army Medical Center
San Antonio, Texas

Juan Castellanos-Rosas, MD
Orthopaedic Surgeon
Department of Trauma Surgery
Hospital General Regional
Col Girasoles, Coyoacán, Mexico

Michael J. Cossu, MD
Department of Orthopaedic Surgery
University Hospital Rangueil
Paul-Sabatier University
Toulouse, France

Mark S. Cohen, MD
Professor and Director
Section of Hand and Elbow Surgery
Rush University Medical Center
Chicago, Illinois

J. Dean Cole, MD
Medical Director
Florida Hospital Orthopaedic Institute Fracture Care Center
Orlando, Florida

Patrick M. Conner, MD
Clinical Assistant Professor of Orthopaedic Surgery
Brigham and Women’s Hospital
Boston, Massachusetts

Thomas P. Goss, MD
Professor of Orthopaedic Surgery
Department of Orthopaedics and Physical Rehabilitation
University of Massachusetts Medical School
Worcester, Massachusetts
Andrew Green, MD  
Associate Professor of Orthopaedic Surgery  
Brown Alpert Medical School  
Chief, Shoulder and Elbow Surgery  
Providence, Rhode Island  

George Frederick Hatch III, MD  
USC Orthopaedic Surgery Associates  
Los Angeles, California  

Laurence D. Higgins, MD  
Associate Professor  
Chief, Sports Medicine and Shoulder Service  
Department of Orthopedic Surgery  
Brigham & Women’s Hospital  
Boston, Massachusetts  

Joseph P. Iannotti, MD, PhD  
Maynard Madden Professor of Orthopaedic Surgery  
Chairman, Orthopaedic and Rheumatologic Institute  
The Cleveland Clinic  
Cleveland, Ohio  

Asif M. Ilyas, MD  
Director, Temple Hand Center  
Assistant Professor, Orthopaedic Surgery  
Temple University Hospital  
Philadelphia, Pennsylvania  

John M. Itamura, MD  
Associate Professor  
Department of Orthopaedic Surgery  
University of Southern California  
Keck School of Medicine  
Los Angeles, California  

Jesse B. Jupiter, MD  
Hanstorg Wyss/AO Professor of Orthopaedic Surgery  
Harvard Medical School  
Chief, Hand and Upper Limb Service  
Massachusetts General Hospital  
Boston, Massachusetts  

Steven P. Kalandiak, MD  
Assistant Professor of Clinical Orthopaedics  
University of Miami  
Miami, Florida  

Srith Kamieni, MBCh, BSc(Hons), FRCS-Orth  
Associate Professor of Elbow and Shoulder Surgery  
Professor of Bioengineering  
Department of Sports, Orthopaedics, and Trauma  
Kentucky Clinic  
University of Kentucky  
Lexington, Kentucky  

Leonid I. Katolik, MD  
Philadelphia Hand Center  
Philadelphia, Pennsylvania  

Graham J. W. King, MD, MSc, FRCS  
Professor of Surgery  
Division of Orthopaedic Surgery  
University of Western Ontario  
Hand and Upper Limb Centre  
St. Joseph’s Health Centre  
London, Ontario, Canada  

Raymond A. Klug, MD  
Assistant Staff  
Department of Orthopaedic Surgery  
Los Alamitos Medical Center  
Los Alamitos, California  

Thomas J. Kovack, DO  
Department of Orthopaedic Surgery  
Doctors Hospital  
Hillard, Ohio  

Suman G. Krishnan, MD  
Fellowship Director  
Department of Shoulder Service  
The Carrell Clinic  
Dallas, Texas  

John E. Kuhn, MD  
Associate Professor  
Chief of Shoulder Surgery  
Department of Orthopaedics and Rehabilitation  
Vanderbilt University Medical Center  
Nashville, Tennessee  

Phillip Langer, MD, MS  
Assistant Team Physician and Orthopedic Surgeon  
NFL Atlanta Falcons  
NHL Atlanta Thrashers  
Atlanta Sports Medicine & Orthopedic Center  
Atlanta, Georgia  

Jonathan H. Lee, MD  
Fellow in Adult Reconstruction  
Department of Orthopaedic Surgery  
Hospital for Special Surgery  
New York, New York  

William N. Levine, MD  
Vice Chairman and Professor  
Residency Director and Director of Sports Medicine  
Department of Orthopaedic Surgery  
Columbia University Medical Center  
New York, New York  

Steven B. Lippitt, MD  
Professor of Orthopaedic Surgery  
Northeastern Ohio Universities College of Medicine  
Akron General Medical Center  
Akron, Ohio  

Bryan J. Loeffer, MD  
Department of Orthopaedic Surgery  
Carolinas Medical Center  
Charlotte, North Carolina  

John Lunn, FRCSI  
Department of Orthopaedics  
Hermitage Medical Clinic  
Dublin, Ireland  

Pierre Mansat, MD, PhD  
Professor of Orthopedic Surgery  
Department of Orthopedics and Traumatology  
University Hospital Purpan  
Paul-Sabatier University  
Toulouse, France  

Frederick A. Matsen III, MD  
Professor and Chair  
Department of Orthopaedics and Sports Medicine  
University of Washington  
Seattle, Washington  

Jesse A. McCarron, MD  
Associate Professor  
Department of Orthopaedic Surgery  
The Cleveland Clinic  
Cleveland, Ohio  

Michael D. McKee, MD, FRCS(c)  
Professor  
Division of Orthopaedics  
Department of Surgery  
University of Toronto  
Toronto, Ontario, Canada  

Mark A. Migelli, MD  
Associate Director of Shoulder and Elbow Fellowship  
Florida Orthopaedic Institute  
Associate Professor  
Department of Upper Extremity Surgery  
University of South Florida  
Tampa, Florida  

Steven Milos, MD  
Department of Orthopaedics  
Swedish American Hospital  
Rockford, Illinois  

Anthony Miniaci, MD, FRCS  
Professor of Surgery  
Cleveland Clinic Lerner College of Medicine  
Head, Sports Medicine  
Cleveland Clinic Sports Health Center  
Orthopaedic and Rheumatologic Institute  
Garfield Heights, Ohio  

Anand M. Murthi, MD  
Assistant Professor of Orthopaedics  
Chief of Shoulder and Elbow Service  
Department of Orthopaedics  
University of Maryland School of Medicine  
Baltimore, Maryland  

Andrew S. Neviser, MD  
Resident  
Department of Orthopaedic Surgery  
Hospital for Special Surgery  
New York, New York  

Robert J. Neviser, MD  
Professor and Chairman  
Department of Orthopaedic Surgery  
George Washington University  
Washington, District of Columbia  

Daniel D. Noble, BA  
Research Assistant  
Crystal Clinic  
Orthopaedic Surgeons, Inc.  
Akron, Ohio  

Jeffrey S. Noble, MD  
Associate Professor of Orthopaedics  
Crystal Clinic  
Orthopaedic Surgeons, Inc.  
Akron, Ohio
Brett D. Owens, MD  
Assistant Professor  
Department of Orthopaedic Surgery  
Service  
Keller Army Hospital  
West Point, New York

Bradford O. Parsons, MD  
Assistant Professor of Orthopaedic Surgery  
Mount Sinai Medical Center  
New York, New York

Jubin B. Payandeh, MD, FRCS(c)  
Staff Surgeon  
Department of Surgery  
Big Thunder Orthopaedics  
Thunder Bay, Ontario, Canada

Alexander H. Payatakes, MD  
Assistant Professor  
Hand and Wrist Service  
Department of Orthopaedics  
Penn State College of Medicine  
Penn State Milton S. Hershey Medical Center  
Hershey, Pennsylvania

Matthew D. Pepe, MD  
Sports Medicine Surgeon  
The Rothman Institute  
Voorhees, New Jersey

Matthew L. Ramsey, MD  
Associate Professor of Orthopaedic Surgery  
Rothman Institute Shoulder and Elbow Surgery  
Thomas Jefferson University  
Philadelphia, Pennsylvania

Michael A. Rauh, MD  
Clinical Assistant Professor of Orthopaedic Surgery  
State University of New York at Buffalo  
Buffalo, New York

David Ring, MD, PhD  
Associate Professor of Orthopaedic Surgery  
Harvard Medical School  
Department of Orthopaedic Surgery  
Massachusetts General Hospital  
Boston, Massachusetts

Robin R. Richards, MD, FRCSC  
Professor  
Department of Surgery  
University of Toronto  
Sunnybrook Health Sciences Center  
Toronto, Ontario, Canada

Charles A. Rockwood, MD  
Professor and Chairman Emeritus of Orthopaedics  
The University of Texas Health Science Center at San Antonio  
San Antonio, Texas

Anthony A. Romeo, MD  
Associate Professor of Orthopaedic Surgery  
Director, Section of Shoulder & Elbow  
Rush University Medical Center  
Chicago, Illinois

Yishai Rosenblatt, MD  
Orthopaedic Surgeon  
Hand and Upper Limb Surgeon  
The Unit of Hand Surgery and Orthopaedic Surgery  
Tel-Aviv Sourasky Medical Center  
The Sackler Faculty of Medicine  
Tel-Aviv University  
Tel-Aviv, Israel

Joaquin Sanchez-Sotelo, MD, PhD  
Associate Professor  
Department of Orthopedic Surgery  
Mayo Clinic  
Rochester, Minnesota

Shadley C. Schiffern, MD  
Attending Orthopaedic Surgeon  
NorthEast Orthopedics, PA  
Concord, North Carolina

Ryan W. Simovitch, MD  
Shoulder and Elbow Service  
Palm Beach Orthopaedic Institute  
Palm Beach Gardens, Florida

Anshu Singh, MD  
Shoulder and Elbow Surgeon  
Kaiser Permanente  
San Diego, California

Dean G. Sotereanos, MD  
Professor of Orthopaedic Surgery  
Drexel University College of Medicine  
Allegheny General Hospital  
Pittsburgh, Pennsylvania

Edwin E. Spencer, Jr., MD  
Knoxville Orthopaedic Clinic  
Knoxville, Tennessee

Jason A. Stein, MD  
Assistant Professor  
Department of Orthopaedics  
University of Maryland  
Baltimore, Maryland

Scott P. Steinmann, MD  
Professor of Orthopaedics  
Mayo Clinic  
Rochester, Minnesota

Bradford S. Tucker, MD  
Clinical Instructor  
Department of Orthopaedic Surgery  
Thomas Jefferson University Hospital  
Egg Harbor Township, New Jersey

Gilles Walch, MD  
Department of Shoulder Surgery  
Centre Orthopédique Santy  
Hôpital Privé J Mermoz  
Lyon, France

Jon J. P. Warner, MD  
Chief, The Harvard Shoulder Service  
Professor of Orthopaedics  
Massachusetts General Hospital  
Boston, Massachusetts

Brent B. Wiesel, MD  
Chief, Shoulder Service  
Department of Orthopaedic Surgery  
Georgetown University Hospital  
Washington, District of Columbia

Gerald R. Williams, MD  
Professor of Orthopaedic Surgery  
Chief, Shoulder and Elbow Service  
The Rothman Institute  
Jefferson Medical College  
Philadelphia, Pennsylvania

Michael A. Wirth, MD  
Professor of Orthopaedics  
The Charles A. Rockwood, Jr., MD Chair  
University of Texas Health Science Center  
San Antonio, Texas

PART 8 FOOT AND ANKLE

Jorge I. Acevedo, MD  
Associate Clinical Faculty  
Department of Orthopedic Surgery  
University of Miami  
Wellington Regional Medical Center  
Royal Palm Beach, Florida

Samuel B. Adams, Jr., MD  
Resident  
Department of Orthopaedic Surgery  
Duke University Medical Center  
Durham, North Carolina

Robert S. Adelaar, MD  
Medical College of Virginia  
Richmond, Virginia

Oladapo Alade, MD  
Private Practice  
Houston, Texas

Richard Alvarez, MD  
Southern Orthopedic Foot Center  
Chattanooga, Tennessee

Annunziato Amendola, MD  
Professor and Callaghan Chair  
Department of Orthopaedic Surgery  
University of Iowa  
Iowa City, Iowa

John G. Anderson, MD  
Associate Professor  
Michigan State University College of Human Medicine  
Co-Director  
Grand Rapids Orthopaedic Foot and Ankle Fellowship  
Assistant Program Director  
Grand Rapids Orthopaedic Residency Program  
Orthopaedic Associates of Michigan  
Grand Rapids, Michigan

Robert B. Anderson, MD  
Chief, Foot and Ankle Service  
Department of Orthopaedic Surgery  
Carolinas Medical Center, OrthoCarolina  
Charlotte, North Carolina
Michael S. Aronow, MD
Associate Professor
Department of Orthopaedic Surgery
University of Connecticut Health Center
Farmington, Connecticut

Mathieu Assal, MD
Orthopaedic Surgery Service
Geneva University Hospital
Geneva, Switzerland

Vikrant Azad, MD
Research Fellow
Department of Orthopaedics
University of Medicine and Dentistry of New Jersey
Newark, New Jersey

Alexej Barg, MD
Orthopaedic Clinic
Lirstal, Switzerland

Michael Barnett, MD
Assistant Professor of Orthopaedic Surgery
Director of Undergraduate Orthopaedic Education
Wright State University Boonshoft School of Medicine
Dayton, Ohio

Heather Barske, MD
Department of Orthopaedic Surgery
University of Manitoba
Winnipeg, Manitoba, Canada

Douglas N. Beaman, MD
Clinical Assistant Professor
Department of Orthopaedic Surgery
Oregon Health Sciences University
Summit Orthopaedics
Portland, Oregon

Christoph Becher, MD
Department of Orthopaedic Surgery
Hannover Medical School
Hannover, Germany

Karl Bergmann, MD
Department of Orthopaedics
University of Medicine and Dentistry of New Jersey
NJ Medical School
Newark, New Jersey

Gregory C. Berlet, MD, FRCS(C)
Chief, Foot and Ankle Surgery
Orthopaedic Foot and Ankle Center
Ohio State University
Westerville, Ohio

James L. Beskin, MD
Clinical Assistant Professor
Department of Orthopedics
Tulane University
Director, Foot & Ankle Section
Orthopedic Residency Program
Atlanta Medical Center
Atlanta, Georgia

Eric M. Bluman, MD, PhD
Assistant Professor
Department of Orthopaedic Surgery
Harvard University
Brigham and Women’s Hospital
Boston, Massachusetts

Donald R. Bohay, MD
Associate Professor
Department of Orthopaedic Surgery
Michigan State University
Orthopedic Associates of Michigan
Grand Rapids, Michigan

Michel Bonnin, MD
Department of Orthopaedic Surgery
Centre Orthopédique Santy
Lyon, France

Michael E. Brage, MD
Assistant Professor of Clinical Orthopedics
Director, Foot and Ankle Services
Department of Orthopaedic Surgery
University of California, San Diego
South County Orthopaedic Specialists
Laguna Woods, California

Lloyd C. Briggs, Jr., MD
Associate Clinical Professor
Department of Orthopaedic Surgery
Orthopaedic Institute of Ohio
Lima, Ohio

Matteo Cadossi, MD
PhD Student
Department of Human Anatomy and Pathophysiology of Musculoskeletal System
2nd Orthopaedic Department
Istituto Orthopedico Rizzoli
University of Bologna
Bologna, Italy

John T. Campbell, MD
Institute for Foot and Ankle Reconstruction at Mercy Medical Center
Baltimore, Maryland

Fabio Catani, MD
Professor of Orthopaedics
Department of Orthopaedic Surgery
Istituto Orthopedico Rizzoli
University of Bologna
Bologna, Italy

Wen Chao, MD
Department of Orthopaedic Surgery
PennCare—Pennsylvania Orthopaedic Foot and Ankle Surgeons
Philadelphia, Pennsylvania

Timothy Charlton, MD
Assistant Professor of Clinical Orthopaedics
Keck School of Medicine
University of Southern California
USC Orthopaedic Surgery Associates
Los Angeles, California

Christopher P. Chiodo, MD
Brigham Foot and Ankle Center at Faulkner Hospital
Boston, Massachusetts

Thomas O. Clanton, MD
Professor of Orthopaedic Surgery
The University of Texas Medical School at Houston
Director, Foot and Ankle Sports Medicine
The Steadman Clinic
Vail, Colorado

Michael P. Clare, MD
Director of Fellowship Education, Foot & Ankle Fellowship
Florida Orthopaedic Institute
Tampa, Florida

J. Chris Coetzee, MD, FRSCS
Minnesota Orthopedic Sports Medicine Institute
Eden Prairie, Minnesota

Bruce Cohen, MD
Department of Orthopedic Surgery
Carolina Medical Center
Charlotte, North Carolina

Jean-Alain Colombier, MD
Department of Orthopaedic Surgery
Clinique de L’Union
Saint Jean, France

Michael J. Coughlin, MD
Chief of Orthopaedics
St. Alphonsus Regional Medical Center
Clinical Professor of Surgery
Department of Orthopaedics
Oregon Health Sciences University
Boise, Idaho

Justin S. Cummins, MD, MS
Department of Orthopedic Surgery
SMDC Health System
Duluth, Minnesota

Richard J. deAsla, MD
Co-Director, Foot and Ankle Unit
Instructor
Department of Orthopaedic Surgery
Harvard Medical School
Boston, Massachusetts

Bryan D. Den Hartog, MD
Assistant Clinical Professor
Department of Orthopaedics
Sanford School of Medicine
Rapid City, South Dakota

Jonathan T. Deland, MD
Chief, Foot and Ankle Service
Associate Attending Orthopaedic Surgeon
Hospital for Special Surgery
Associate Professor
Department of Orthopaedic Surgery
Weill Cornell Medical College
New York, New York

James K. DeOrio, MD
Associate Professor
Division of Orthopedic Surgery
Department of Surgery
Duke University
Durham, North Carolina

Matthew J. DeOrio, MD
The Orthopedic Center
Huntsville, Alabama

Benedict F. DiGiovanni, MD
Associate Professor of Orthopaedics
University of Rochester Medical Center
Rochester, New York
Christopher W. DiGiovanni, MD
Director and Professor
Brown University Orthopaedic Residency Program
Chief, Foot and Ankle Service
Department of Orthopaedic Surgery
The Warren Alpert School of Medicine
Brown University
Rhode Island Hospital
Providence, Rhode Island

Brian Donley, MD
Director, Center for Foot and Ankle
Department of Orthopaedic Surgery
Cleveland Clinic
Cleveland, Ohio

Thomas Dreher, MD
Orthopaedic Department
University of Heidelberg
Heidelberg, Germany

Brad Dresher, MD
Department of Orthopaedics
Penrose St. Francis Medical Center
Colorado Springs, Colorado

Mark E. Easley, MD
Associate Professor of Orthopaedic Surgery
Co-Director, Foot and Ankle Fellowship
Duke University Medical Center
Durham, North Carolina

Patrick Ebeling, MD
Associate Clinical Instructor
Department of Orthopaedic Surgery
University of Minnesota
Burnsville, Minnesota

Andrew J. Elliott, MD
Assistant Professor
Department of Orthopaedic Surgery
Hospital for Special Surgery
New York, New York

Cesare Faldini, MD
Professor of Orthopaedics
Department of Human Anatomy and Pathophysiology of Musculoskeletal System
2nd Orthopaedic Department
Istituto Ortopedico Rizzoli
University of Bologna
Bologna, Italy

Nicholas A. Ferran, MBBS, MRCSEd
Specialist Registrar
Department of Trauma and Orthopaedics
Lincoln County Hospital
Lincolnshire, United Kingdom

Lamar L. Fleming, MD
Professor and Chairman
Department of Orthopaedics
Emory University School of Medicine
Atlanta, Georgia

Adolph S. Flemister, Jr., MD
Associate Professor
Department of Orthopaedics
University of Rochester
Rochester, New York

Austin T. Fragomen, MD
Limb Lengthening Specialist
Fellowship Director, Director of Education, and Director of Limb Lengthening and Deformity Service
Hospital for Special Surgery
New York, New York

Carol Frey, MD
Assistant Clinical Professor of Orthopaedic Surgery (Volunteer)
University of California, Los Angeles
Manhattan Beach, California

Delan Gaines, MD
Department of Sports Medicine
Southeastern Orthopedic Center
Savannah, Georgia

Richard E. Gellman, MD
Clinical Assistant Professor
Department of Orthopaedic Surgery
Oregon Health Sciences University
Summit Orthopaedics
Portland, Oregon

Sandro Giannini, MD
Professor of Orthopaedics
Department of Human Anatomy and Pathophysiology of Musculoskeletal System
2nd Orthopaedic Department
Istituto Ortopedico Rizzoli
University of Bologna
Bologna, Italy

Brian D. Giordano, MD
Department of Orthopaedics
University of Rochester
Rochester, New York

Jason P. Glover, DPM
Department of Foot and Ankle Surgery
Rutherford Hospital
Rutherfordton, North Carolina

John S. Gould, MD
Professor of Surgery/Orthopaedics
University of Alabama at Birmingham
Birmingham, Alabama

Gregory P. Guyton, MD
Department of Orthopedic Surgery
Union Memorial Hospital
Baltimore, Maryland

Steven L. Haddad, MD
Associate Professor of Clinical Orthopaedic Surgery
University of Chicago Pritzker School of Medicine
Section Head, Foot and Ankle Surgery
NorthShore University HealthCare Systems
Illinois Bone and Joint Institute, LLC
Glenview, Illinois

Sigvard T. Hansen, Jr., MD
Professor
Director, Sigvard T. Hansen, Jr., MD Foot and Ankle Institute
Department of Orthopaedics and Sports Medicine
University of Washington
Seattle, Washington

Paul Hamilton, BMedSci, FRCS(Tr&Orth)
Senior Clinical Fellow
Department of Orthopaedics
Guy’s and St. Thomas’ NHS Foundation Trust
London, England

William G. Hamilton, MD
Clinical Professor
Department of Orthopedic Surgery
Columbia University College of Physicians and Surgeons
New York, New York

Thomas G. Harris, MD
Assistant Professor
Department of Orthopaedics
UCLA-Harbor Medical Center
Torrance, California

Paul J. Hecht, MD
Associate Professor
Department of Orthopaedic Surgery
Dartmouth Hitchcock Medical Center
Lebanon, New Hampshire

W. Bryce Henderson, BS, MD, FRCS
Chief of Orthopedics
Department of Orthopaedic Surgery
Red Deer Hospital, Central Alberta
Alberta, Canada

John E. Herzenberg, MD, FRCS
Director, International Center for Limb Lengthening
Rubin Institute for Advanced Orthopedics
Sinai Hospital of Baltimore
Baltimore, Maryland

Beat Hintermann, MD
Associate Professor of Medicine
Orthopaedic Clinic
University of Basel
Liestal, Switzerland

Stefan G. Hofstaetter, MD
Orthopaedic Senior Resident
Department of Orthopedics
Klinikum Wels-Grieskirchen
Wels, Austria

George B. Holmes, Jr., MD
Assistant Professor
Director, Section of Foot and Ankle
Rush University Medical Center
Westchester, Illinois

Jason M. Hurst, MD
Associate Partner
Joint Implant Surgeons
New Albany, Ohio

James J. Hutson, Jr., MD
Associate Clinical Professor
Department of Orthopedic Surgery
Miller School of Medicine
University of Miami
Miami, Florida

Christopher F. Hyer, DPM, FACFAS
Co-Director, Foot and Ankle Fellowship
Orthopedic Foot & Ankle Center
Westerville, Ohio
Clifford L. Jeng, MD
Institute for Foot and Ankle Reconstruction
Mercy Medical Center
Baltimore, Maryland

Shine John, DPM, AACFAS
Private Practitioner
Foot Specialists
Georgetown, Texas

Catherine E. Johnson, MD
Department of Orthopaedic Surgery
Massachusetts General Hospital
Watertown, Massachusetts

Jeffrey E. Johnson, MD
Associate Professor
Chief, Foot and Ankle Service
Department of Orthopaedic Surgery
Barnes-Jewish Hospital at Washington University Medical Center
St. Louis, Missouri

Kevin L. Kirk, DO
Chief
Orthopedic Surgery Service
San Antonio Military Medical Center
Houston, Texas

Alex J. Kline, MD
Department of Orthopaedic Surgery
University of Pittsburgh Medical Center
Pittsburgh, Pennsylvania

Markus Knupp, MD
Department of Orthopaedics
Kantonsspital Liestal
Liestal, Switzerland

Sameh A. Labib, MD
Assistant Professor of Orthopedic Surgery
Director of Foot and Ankle Service
Emory University
Atlanta, Georgia

Bradley M. Lamm, DPM, FACFAS
Head, Foot and Ankle Surgery
International Center for Limb Lengthening
Rubin Institute for Advanced Orthopedics
Sinai Hospital of Baltimore
Baltimore, Maryland

Geoffrey S. Landis, DO
Tucson Orthopaedic Institute Oro Valley
Oro Valley, Arizona

Johnny T. C. Lau, MD, MSc, FRCS(C)
Assistant Professor of Surgery
University Health Network – Toronto Western Division
Toronto, Ontario, Canada

Ian L. D. Le, MD
Department of Orthopaedic Surgery
Duke University Medical Center
Durham, North Carolina

Alberto Leardini, DPhil
Movement Analysis Laboratory
Istituto Orthopedico Rizzoli
Bologna, Italy

Simon Lee, MD
Assistant Professor
Department of Orthopaedic Surgery
Rush University Medical Center
Westchester, Illinois

Johnny Lin, MD
Assistant Professor
Department of Orthopaedic Surgery
Rush University Medical Center
Westchester, Illinois

Sheldon Lin, MD
Associate Professor
Department of Orthopaedics
University of Medicine and Dentistry of New Jersey
NJ Medical School
Newark, New Jersey

Umile Giuseppe Longo, MD
Consultant
Department of Orthopaedic and Trauma Surgery
Campus Biomedico University
Rome, Italy

Deianira Luciani, MD
PhD Student
Department of Human Anatomy and Pathophysiology of Musculoskeletal System
2nd Orthopaedic Department
Istituto Orthopedico Rizzoli
University of Bologna
Bologna, Italy

Nicola Maffulli, MD, MS, PhD, FRCS(Orth.)
Professor of Orthopaedic and Trauma Surgery
Centre for Sports and Exercise Medicine
Barts and The London School of Medicine and Dentistry
London, England

Ansar Mahmood, MD
Department of Trauma and Orthopaedic Surgery
Keele University School of Medicine
Stoke on Trent, Staffordshire, United Kingdom

Peter Mangone, MD
Department of Orthopaedic Surgery
Mission Hospitals Health System
Asheville, North Carolina
Margaret R. Pardee Hospital
Hendersonville, North Carolina

Jeffrey A. Mann, MD
Private Practice
Oakland, California

Roger A. Mann, MD
Department of Orthopaedic Surgery
Oakland Bone and Joint Specialists
Oakland, California

Arthur Manoli, MD
Department of Orthopedic Surgery
Michigan International Foot & Ankle Center
Pontiac, Michigan

Javier Maquirriain, MD, PhD
Director, Orthopaedic Department
Director, Sports Medicine Research Department
Centro Nacional de Alto Rendimiento Deportivo
Buenos Aires, Argentina

Richard M. Marks, MD, FACS
Assistant Professor
Department of Orthopaedic Surgery
Medical College of Wisconsin
Milwaukee, Wisconsin

William C. McGarvey, MD
Associate Professor
Residency Program Director
Department of Orthopaedic Surgery
University of Texas Medical School at Houston
Houston, Texas

Angus M. McBrayde, MD
Director
Ankle and Foot Fellowship
American Sports Medicine Institute
St. Vincent’s – Birmingham
Birmingham, Alabama

Ronan McKeown, MB, BCh, BA, MD, FRCSI(T&O)
Craigavon Area Hospital
Portadown
Co. Armagh, Ireland

Siddhant Mehta
Research Fellow
Department of Orthopaedics
University of Medicine and Dentistry of New Jersey
NJ Medical School
Newark, New Jersey

Marc Merian-Genast, MD
Clinical Assistant Professor
Department of Orthopedics
University of Saskatchewan
Regina, Saskatchewan, Canada

Stuart D. Miller, MD
Attending
Department of Orthopaedic Surgery
Union Memorial Hospital
Baltimore, Maryland

Andrew P. Molloy, FRCS(Tr & Orth), MR
Department of Trauma and Orthopaedics
University Hospital Aintree
Liverpool, England

Mark S. Myerson, MD
Institute for Foot and Ankle Reconstruction at Mercy
Mercy Medical Centre
Baltimore, Maryland

Caio Nery, MD
Professor of Medicine
Department of Orthopaedics and Traumatology
Federal University of São Paulo, Brazil
São Paulo, Brazil

Christopher W. Nicholson, MD
Department of Orthopedics
The Doctors Hospital of Tatnall
Savannah, Georgia
Michael Scherb, MD
Fellow
Department of Orthopaedics
Union Memorial Hospital
Baltimore, Maryland

Aaron T. Scott, MD
Assistant Professor
Department of Orthopaedic Surgery
Wake Forest University Baptist Medical Center
Winston-Salem, North Carolina

Steven L. Shapiro, MD
Savannah, Georgia

Scott B. Shawen, MD
Assistant Professor
Department of Surgery
Uniformed Services University of Health Sciences
Bethesda, Maryland

Paul S. Shurnas, MD
Director, Foot and Ankle
Columbia Orthopaedic Group
Columbia, Missouri

Sam Singh, MD
Director, CathLab and Continuing Medical Education
San Joaquin Community Hospital
Bakersfield, California

Bertil W. Smith, MD
Department of Orthopaedic Surgery
University of California at San Diego
San Diego, California

Ronald W. Smith, MD
Associate Clinical Professor
Department of Orthopaedic Surgery
University of California at Los Angeles
Balance Orthopaedic Foot and Ankle Center
Long Beach, California

Emmanuel D. Stamatis, Lt Colonel MD, FRCSI, FHCOS, FACS, PhD
Orthopaedic Department
General Army Hospital
Athens, Greece

Michael M. Stephens, MSc(Bioeng.), FRCSI
Associate Professor
Department of Orthopaedic Surgery
Cappagh National Orthopaedic Hospital
Dublin, Ireland

Karen M. Sutton, MD
Assistant Professor
Department of Orthopaedic Surgery
Yale University
New Haven, Connecticut

Yoshinori Takakura, MD
Department of Orthopaedic Surgery
Nara Medical University
Nara, Japan

Virak Tan, MD
Associate Professor
Department of Orthopaedics
University of Medicine and Dentistry of New Jersey
NJ Medical School
Newark, New Jersey

Yasuhito Tanaka, MD
Department of Orthopaedic Surgery
Nara Medical University
Nara, Japan

James B. Tasto, MD
Clinical Professor
Department of Orthopaedic Surgery
University of California at San Diego
Founder, San Diego Sports Medicine & Orthopaedic Center
San Diego, California

Dean C. Taylor, MD
Professor of Orthopaedic Surgery
Co-Director, Sports Medicine Fellowship
Duke University Medical Center
Durham, North Carolina

Ahmed M. Thabet, MD, PhD
Lecturer of Orthopaedic Surgery
Benha University
Benha, Egypt

Hajo Thermann, MD, PhD
Professor
Center for Knee and Foot Surgery/Sports Trauma
ATOS Clinic Center
Heidelberg, Germany

Sandra L. Tomak, MD
Department of Orthopaedic Surgery
New Haven, Connecticut

Brian C. Toolan, MD
Associate Professor of Surgery, Foot and Ankle
Director, Residency Program of Orthopaedic Surgery
The University of Chicago Hospitals
Chicago, Illinois

Hans-Joerg Trnk, Univ. Doz. Dr.
Foot and Ankle Center
Vienna, Austria

H. Robert Tuten, MD
Associate Clinical Professor
Department of Orthopaedic Surgery
Medical College of Virginia
Richmond, Virginia

Vitor Valderrabano, MD, PhD
Professor and Chairman
Orthopaedic Department
University Hospital Basel
Basel, Switzerland

C. Nick van Dijk, MD, PhD
Professor of Medicine
Department of Orthopaedic Surgery
Academic Medical Center
University of Amsterdam
Amsterdam, The Netherlands

Francesca Vannini, MD, PhD
2nd Orthopaedic Department
Istituto Orthopedico Rizzoli
Bologna, Italy

Emilio Wagner, MD
Associate Professor
Department of Orthopedic and Trauma Surgery
Universidad del Desarrollo/Clinica Alemana
Santiago, Chile

Markus Walther, MD, PhD
Professor of Orthopaedic Surgery
Orthopaedic Hospital Munich-Harlaching
Munich, Germany

Keith L. Wapner, MD
Clinical Professor
Department of Orthopedic Surgery
Pennsylvania Hospital
University of Pennsylvania
Philadelphia, Pennsylvania

Anthony Watson, MD
Assistant Professor
Department of Orthopaedic Surgery
Drexel University College of Medicine
Philadelphia, Pennsylvania

Troy Watson, MD
Director, Foot and Ankle Institute
Department of Orthopaedic Surgery
Institute of Orthopaedic Surgery
Las Vegas, Nevada

Wolfram Wenz, MD
Head of Unit for Pediatric Orthopaedics and Foot Surgery
Department of Orthopaedics
University of Heidelberg
Heidelberg, Germany

Michael G. Wilson, MD
Assistant Professor
Department of Orthopaedic Surgery
Harvard Medical School
Brigham and Women’s Hospital
Boston, Massachusetts

Dane K. Wukich, MD
Assistant Professor
Department of Orthopaedic Surgery
UPMC Cancer Center Physicians
Pittsburgh, Pennsylvania

Gilbert Yee, MD, Med, MBA, FRCS
Department of Surgery
The Scarborough Hospital
Toronto, Ontario, Canada

Alastair Younger, MD, ChB, MSc, ChM, FRCS(C)
Ambulatory Care Physician Leader
Providence Health Care
Director, BC Foot and Ankle Clinic
Vancouver, British Columbia, Canada

PART 9 SPINE

Todd J. Albert, MD
Richard H. Rothman Professor and Chairman
Department of Orthopaedic Surgery
Professor of Neurosurgery
Thomas Jefferson University Hospital
Rothman Institute
Philadelphia, Pennsylvania

Maneesh Bawa, MD
Department of Orthopaedics
Emory University School of Medicine
Atlanta, Georgia

Jacob M. Buchowski, MD, MS
Assistant Professor of Orthopaedic and Neurological Surgery
Washington University in St. Louis
St. Louis, Missouri
Patrick Cahill, MD  
Staff Surgeon  
Shriners Hospital for Children  
Philadelphia, Pennsylvania

Saad B. Chaudhary, MD, MBA  
Center for Spine Health  
The Cleveland Clinic  
Cleveland, Ohio

Morgan N. Chen, MD  
Orthopedic Associates of Long Island, LLP  
East Setauket, New York

Mark Dumonski, MD  
Resident  
Department of Orthopaedic Surgery  
Rush University Medical Center  
Chicago, Illinois

Ira L. Fedder, DPharm, MD  
Scoliosis and Spine Center of Maryland  
Towson Orthopaedic Associates  
Towson, Maryland

James S. Harrop, MD  
Associate Professor of Neurological and Orthopedic Surgery  
Thomas Jefferson University  
Philadelphia, Pennsylvania

Andrew C. Hecht, MD  
Co-Chief, Spine Surgery  
Assistant Professor of Orthopaedic and Neurosurgery  
Mt. Sinai Medical Center and School of Medicine  
New York, New York

John Heflin, MD  
Resident  
Department of Orthopaedic Surgery  
Emory University School of Medicine  
Atlanta, Georgia

John G. Heller, MD  
Professor of Orthopaedic Surgery  
Spine Fellowship Director  
The Emory Spine Center  
Emory University School of Medicine  
Emory University Orthopaedics & Spine Hospital  
Atlanta, Georgia

Claude Jarrett, MD  
Resident  
Department of Orthopaedic Surgery  
Emory University School of Medicine  
Atlanta, Georgia

James S. Kercher, MD  
Resident  
Department of Orthopaedic Surgery  
Emory University  
Atlanta, Georgia

Youjeong Kim, MD  
Orthopaedic Consultants of North Texas  
Baylor University Medical Center  
Dallas, Texas

Michael J. Lee, MD  
Assistant Professor  
Department of Sports Medicine and Orthopaedic Surgery  
University of Washington Medical Center  
Seattle, Washington

Ronald A. Lehman, Jr., MD  
Director  
Pediatric and Adult Spine  
Assistant Professor of Surgery, USUHS  
Department of Orthopaedics and Rehabilitation  
Walter Reed Army Medical Center  
Potomac, Maryland

Satyajit V. Marawar, MD  
Fellow in Spine Surgery  
Department of Orthopaedic Surgery  
Medical College of Wisconsin  
Milwaukee, Wisconsin

Paul C. McAfee, MD  
Chief of Spine Surgery  
St. Joseph’s Hospital  
Towson, Maryland

Daniel Park, MD  
Resident  
Department of Orthopaedic Surgery  
Rush University Medical Center  
Chicago, Illinois

Sheeraz A. Qureshi, MD  
Assistant Professor of Orthopaedic Surgery  
Mount Sinai Hospital  
Chief, Spinal Trauma  
Elmhurst Hospital Center  
New York, New York

Raj Rao, MD  
Professor of Orthopaedic Surgery  
Medical College of Wisconsin  
Milwaukee, Wisconsin

Mitchell F. Reiter, MD  
Assistant Professor of Orthopaedic Surgery  
The New Jersey Medical School/UMDNJ  
Summit, New Jersey

John M. Rhee, MD  
Assistant Professor  
Department of Orthopaedic Surgery  
Emory University School of Medicine  
Atlanta, Georgia

K. Daniel Riew, MD  
Mildred B. Simon Distinguished Professor of Orthopaedic Surgery  
Professor of Neurological Surgery  
Chief, Cervical Spine Surgery  
Washington University Orthopedics  
Director, Orthopedic-Rehab Institute for Cervical Spine Surgery  
St. Louis, Missouri

Samer Saiedy, MD  
Department of Surgery  
Towson, Maryland

Matthew N. Scott-Young, MBBS, FRACS, FAOrthA  
Associate Professor  
Faculty of Health Science and Medicine  
Bond University  
Gold Coast, Australia

Kern Singh, MD  
Assistant Professor  
Department of Orthopaedic Surgery  
Rush University Medical Center  
Chicago, Illinois

Thomas Stanley, MD  
Resident  
Department of Orthopaedic Surgery  
Rush University Medical Center  
Chicago, Illinois

Bradley K. Weiner, MD  
Associate Professor  
Chief of Spinal Surgery  
Department of Orthopaedic Surgery  
The Methodist Hospital  
Houston, Texas

Andrew P. White, MD  
Instructor  
Department of Orthopaedic Surgery  
Harvard Medical School  
Beth Israel Deaconess Medical Center  
Boston, Massachusetts

Sam W. Wiesel, MD  
Professor and Chair  
Department of Orthopaedic Surgery  
Loyola University Health System  
Maywood, Illinois

S. Tim Yoon, MD, PhD  
Assistant Professor  
Department of Orthopaedic Surgery  
Emory University  
Atlanta, Georgia

Aristidis Zibis, MD  
Fellow in Spinal Surgery  
Department of Orthopaedic Surgery  
Penn State Hershey Medical School  
Hershey, Pennsylvania
When a surgeon contemplates performing a procedure, there are three major questions to consider: Why is the surgery being done? When in the course of a disease process should it be performed? And, finally, what are the technical steps involved? The purpose of this text is to describe in a detailed, step-by-step manner the “how to do it” of the vast majority of orthopaedic procedures. The “why” and “when” are covered in outline form at the beginning of each procedure. However, it is assumed that the surgeon understands the basics of “why” and “when,” and has made the definitive decision to undertake a specific case. This text is designed to review and make clear the detailed steps of the anticipated operation.

Operative Techniques in Orthopaedic Surgery differs from other books because it is mainly visual. Each procedure is described in a systematic way that makes liberal use of focused, original artwork. It is hoped that the surgeon will be able to visualize each significant step of a procedure as it unfolds during a case.

The text is divided into nine major topics: Adult Reconstruction; Foot and Ankle; Hand, Wrist, and Forearm; Oncology; Pediatrics; Shoulder and Elbow; Sports Medicine; Spine; and Pelvis and Lower Extremity Trauma. Each chapter has been edited by a specialist who has specific expertise and experience in the discipline. It has taken a tremendous amount of work for each editor to enlist talented authors for each procedure and then review the final work. It has been very stimulating to work with all of these wonderful and talented people, and I am honored to have taken part in this rewarding experience.

Finally, I would like to thank everyone who has contributed to the development of this book. Specifically, Grace Caputo at Dovetail Content Solutions, and Dave Murphy and Eileen Wolfberg at Lippincott Williams & Wilkins, who have been very helpful and generous with their input. Special thanks, as well, goes to Bob Hurley at LWW, who has adeptly guided this textbook from original concept to publication.

SWW
January 1, 2010
I would like to acknowledge my wife, Mary, and my children Erin, Colleen, John, and Kelly, who tolerate all the orthopaedic “homework” required to write and teach orthopaedics.

—JMF

I greatly acknowledge the never-ending hard work, dedication, and enthusiasm of Ms. Kristen Kellar-Graney, who has been my right-hand woman for over 12 years.

—MMM

All book projects are a challenge and I certainly could not get as involved with them as I am without a lot of help. To my partners (especially David), my PAs (Jen and Jerry), the residents and fellows, and everyone I have had the pleasure to teach and learn alongside. Thank you!

—MDM

With appreciation to my great mentor, Richard Rothman, MD, PhD, the most amazing human and scholar I have known.

—JP

I acknowledge my mentors and colleagues, Mark Myerson, Lew Schon, Robert Anderson, Hodges Davis, Jim Nunley, and Jim DeOrio, whose tireless commitment to academic orthopaedic surgery continues to inspire me, and the tremendous contributions of the authors who shared their expertise to make this textbook possible.

—MEE
The editors and the publisher would like to thank the resident reviewers who participated in the reviews of the manuscript and page proofs. Their detailed review and analysis was invaluable in helping to make certain this text meets the needs of residents today and in the future.

Daniel Galat, MD
Dr. Galat is a graduate of Ohio State University College of Medicine and the Mayo Clinic Department of Orthopedic Surgery residency program. He is currently serving at Tenwek Hospital in Kenya as an orthopedic surgeon.

Lawrence V. Gulotta, MD
Fellow in Sports Medicine/Shoulder Surgery
Hospital for Special Surgery
New York, New York

Dara Chafik, MD, PhD
Southwest Shoulder, Elbow and Hand Center PC
Tuscon, Arizona

Gautam Yagnik, MD
Attending Physician
Orthopaedic Surgery
DRMC Sports Medicine
Dubois, Pennsylvania

Gregg T. Nicandri, M.D.
Assistant Professor
Department of Orthopaedics (SMD)
University of Rochester
School of Medicine and Dentistry
Rochester, New York

Catherine M. Robertson, MD
Assistant Clinical Professor
UCSD Orthopaedic Surgery—Sports Medicine
San Diego, California

Jonathan Schoenecker, MD
Assistant Professor
Departments of Orthopaedics, Pharmacology and Pediatrics
Vanderbilt University
Nashville, Tennessee
Part 1 Sports Medicine

Chapter 1
Shoulder Arthroscopy: The Basics 7

Chapter 2
Arthroscopic Treatment of Anterior Shoulder Instability 14

Chapter 3
Arthroscopic Treatment of Posterior Shoulder Instability 24

Chapter 4
Arthroscopic Treatment of Multidirectional Shoulder Instability 30

Chapter 5
Arthroscopic Treatment of Superior Labral (SLAP) Tears 38

Chapter 6
Management of Shoulder Throwing Injuries 44

Chapter 7
Arthroscopic Treatment of Biceps Tendonopathy 57

Chapter 8
Arthroscopic Treatment of Subacromial Impingement 68

Chapter 9
Acromioclavicular Disorders 75
Chapter 40
Osteochondritis Dissecans and Avascular Necrosis 329

Chapter 41
Single-Bundle Anterior Cruciate Ligament Repair 341

Chapter 42
Anatomic Double-Bundle Anterior Cruciate Ligament Reconstruction 350

Chapter 43
Revision Anterior Cruciate Ligament Repair 357

Chapter 44
Posterior Cruciate Ligament Repair 365

Chapter 45
Repair of Acute and Chronic Knee Medial Collateral Ligament Injuries 375

Chapter 46
Management of Posterolateral Corner Injuries 381

Chapter 47
Management of the Multiple Ligament–Injured Knee 392

Chapter 48
Repair of Acute and Chronic Patella Tendon Tears 402

Chapter 49
Repair of Acute and Chronic Quadriceps Tendon Ruptures 407
Chapter 50
Knee Loss of Motion 413

Chapter 51
Arthroscopic Lateral Release of the Knee 422

Chapter 52
Proximal Realignment of the Medial Patellofemoral Ligament 426

Chapter 53
Tibial Tubercle Transfer 435

Chapter 54
Chronic Exertional Compartment Syndrome 443

Chapter 55
Common Peroneal and Lateral Femoral Cutaneous Nerve Injuries 453
DEFINITION

- The shoulder is a spheroidal multiaxial joint stabilized not only by its bony anatomy but also by the surrounding muscles and capsular structures.
- Arthroscopy is the process of visualization and examination of a joint using a fiberoptic instrument. All shoulder surgeons must be proficient in diagnostic arthroscopy of the shoulder.

ANATOMY

- The glenohumeral joint consists of the glenoid fossa of the scapula that articulates with the head of the humerus.
- The labrum is a “bumper” of fibrocartilaginous tissue around the rim of the glenoid that acts to deepen and enlarge the glenoid fossa and increase glenohumeral stability. The biceps tendon is anchored at the superior labrum and acts as a humeral head depressor and also aids in glenohumeral stability.
- The static stabilizers of the shoulder include the joint capsule and the glenohumeral ligaments—superior, middle, and inferior glenohumeral ligaments. These will be discussed in greater detail in subsequent chapters.
- The dynamic stabilizers of the shoulder are the rotator cuff muscles—supraspinatus, infraspinatus, subscapularis, and teres minor.
- The scapular stabilizers—rhomboids, levator scapulae, trapezius, and serratus anterior—also contribute to dynamic stability of the shoulder.

PATHOGENESIS

- Shoulder injuries can occur secondary to trauma, microtrauma, or overuse injuries and can be activity- and age-dependent.
- Most patients under age 40 will have symptoms typical of overuse or instability, whereas patients over age 40 present more commonly with rotator cuff, impingement, inflammatory, or degenerative joint disease types of symptoms.

NATURAL HISTORY

- Shoulder injuries can be painful and lead to shoulder dysfunction.
- Recurrent shoulder instability decreases with age.\(^1\)
- The frequency of rotator cuff tears increases with age.\(^2\)
- If shoulder pathology is left unaddressed, pain, motion loss, degenerative changes, loss of function, and inability to participate in sports or work can occur.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The most important part of the physical examination consists of taking an accurate history from the patient.
- Was it a traumatic, nontraumatic, or overuse injury?
- When and how did the injury occur?
- Is the patient’s complaint of pain, loss of motion, weakness, or inability to perform sports, activities of daily living, or work?
- Is there pain at rest, only with activity, or while sleeping?
- Are there any neurologic symptoms?
- Basic physical examination methods are summarized below. More specific examinations for different diagnoses will be described in other chapters in this section.
- Observation of patient with shoulder pain from the front, back, and side
  - Identify any muscle atrophy and asymmetry of muscles, shoulder height, or scapular position.
- Palpation of different parts of shoulder—sternoclavicular joint, acromioclavicular joint, greater tuberosity and rotator cuff, glenohumeral joint, biceps tendon, trapezium—to localize any areas of point tenderness, which may aid in differential diagnosis.
- Passive and active range of motion—forward flexion, abduction, adduction, internal and external rotation
  - Loss of range of motion may indicate adhesive capsulitis, rotator cuff pathology (tendinitis or rotator cuff tear), or degenerative changes.
- Resistive testing of deltoid, supraspinatus, infraspinatus, and subscapularis
  - Weakness of any muscles may indicate nerve injury, torn muscle or tendon, or weakness secondary to pain.
- Rotator cuff and scapular stabilizers: Look for atrophy, scapular winging, weakness with strength testing, and painful range of motion.
- Provocative tests for rotator cuff tear include drop arm sign and lift off or belly press for subscapularis.
- Impingement tests include the Neer and Hawkins tests.
- Labrum: Catching, clicking, popping may indicate a labral tear; check for instability with provocative tests (load shift, apprehension test or crank test, relocation, O’Brien’s).
- Multidirectional instability: Look for increased laxity inferiorly and in one other direction.
  - The sulcus sign demonstrates inferior laxity.
  - Check for the ability to voluntarily subluxate or dislocate the humeral head.
- Acromioclavicular joint: localized tenderness over the acromioclavicular joint and pain with cross-chest adduction and O’Brien’s testing

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs are used to assess different aspects of the shoulder joint.
- Basic radiographs should consist of anteroposterior, axillary, and outlet views.
- Special views may be obtained depending on shoulder pathology and will be discussed in subsequent chapters.
Magnetic resonance imaging (MRI) and MRI arthograms are also commonly obtained to aid in diagnosis because they are highly sensitive and specific in diagnosing many shoulder injuries.

**DIFFERENTIAL DIAGNOSIS**
- Impingement (internal or external)
- Rotator cuff tear
- Adhesive capsulitis
- Acromioclavicular joint injury or arthritis
- Labral tear
- Instability
- Biceps tendon pathology
- Degenerative arthritis
- Scapulothoracic dysfunction
- Cervical or neurologic
- Infection

**NONOPERATIVE MANAGEMENT**
- Nonoperative management for many different diagnoses may first consist of rest, nonsteroidal anti-inflammatories, physical therapy, and diagnostic and therapeutic injections.

**SURGICAL MANAGEMENT**
- A patient who has failed to respond to nonoperative management and continues to have symptoms consistent with his or her diagnosis is a candidate for shoulder arthroscopy.

**Preoperative Planning**
- Patient history and imaging studies are reviewed.
- The surgeon should have a good understanding of what pathology to expect at the time of arthroscopy to ensure that all appropriate equipment and instruments are available.
  - Patient positioning aids (arm holders, weights, beanbag, axillary roll)
  - Arthroscopic pumps or irrigation system
  - Video monitor, 30- and 70-degree arthroscopes
  - Arthroscopic cannulas
  - Shavers, burrs, suture anchors, arthroscopic instruments (probe, grasper, scissors, basket)
  - An examination under anesthesia is performed to assess range of motion and stability.

**Positioning**
- Shoulder arthroscopy may be performed with the patient in either a beach-chair position or the lateral decubitus position (FIG 1).
- The beach-chair position requires a specially designed operating table attachment that ensures that the surgeon has adequate exposure to the patient’s posterior shoulder and the patient’s head is well supported.
  - The advantage of this position is that the shoulder can be freely manipulated throughout the procedure.
  - Commercially available arm holders can also be used to allow glenohumeral distraction and positioning without the need for an assistant.
  - When using the lateral decubitus position (FIG 1B), the patient must be properly padded and the body supported with a beanbag, axillary roll, and pillows.

The operative extremity is placed in a commercially available arm holder in approximately 70 degrees of abduction and 15 to 20 degrees of forward flexion, with 10 pounds of weight for traction. This allows for distraction of the glenohumeral joint and offers excellent visualization.

**Approach**
- The operating room should be set up to allow the surgeon easy access to the entire shoulder and permit optimal visualization of the video monitors and arthroscopic equipment.
  - The typical operating room setup is shown in FIG 2.
  - The entire shoulder, arm, forearm, and hand and the exposed portion of the patient’s hemithorax should be steriley prepared after isolation with a clear U-drape. This will aid in keeping the patient dry in case fluid leaks under the surgical drapes.

**FIG 1**
- **A.** Patient in beach-chair position with standard draping for right shoulder arthroscopy.
- **B.** Patient in right lateral decubitus position with shoulder distraction apparatus to abduct and distract the left upper extremity.

**FIG 2**
- Operating room setup to allow optimal visualization of monitor and arthroscopic equipment.
Chapter 1  SHOULDER ARTHROSCOPY: THE BASICS 9

TECHNIQUES

SETUP AND PORTAL PLACEMENT

- Once the patient is prepared and draped, the bony surface anatomy should be outlined with a surgical marking pen. This includes the clavicle, borders of the acromion (anteriorly, posteriorly, and laterally), the spine of the scapula, the acromioclavicular joint, and the coracoid (TECH FIG 1).

- The posterior portal is created first.
  - A 5-mm skin incision is made using a number 11 scalpel.
  - All shoulder arthroscopy incisions should penetrate only the skin and no deeper to avoid injury to neurovascular structures and possible damage to articular surfaces.
  - The arthroscope sheath and blunt obturator are then inserted into the glenohumeral joint (TECH FIG 2).
  - The trocar should be directed toward the coracoid. One hand can be used to stabilize the shoulder and the index finger used to palpate the coracoid tip.
  - The obturator should be directed just medial to the humeral head and into the space between the head and glenoid. There should be a “pop” once the capsule is penetrated and the cannula is within the glenohumeral joint.
  - Some surgeons prefer first to inject saline with a spinal needle into the glenohumeral joint. This expands the joint and allows a bigger target as well as, with fluid return, confirms that the arthroscope is in the proper place.
  - The irrigation system and pump is turned on and the humeral head, glenoid, and biceps tendon are identified for quick orientation.
  - A brief inspection of the glenohumeral joint can be performed to determine whether modification of the subsequent portals may be required.

- All expected portal sites should next be marked. For a basic diagnostic arthroscopy these should include a posterior, anterior, and if necessary lateral portal. Accessory portal locations required for specific procedures will be discussed in subsequent chapters.
  - Posterior portal: 2 to 3 cm inferior and 1 cm medial to the posterolateral border of the acromion. It is usually located in the “soft spot” of the posterior shoulder that can be palpated between the posterior rotator cuff muscles (infraspinatus and teres minor).
  - Anterior portal: This portal is marked just lateral to the tip of the coracoid process and inferior to the anterolateral acromial border. Care must be taken to ensure that all anterior portals are lateral to the coracoid to avoid damage to the neurovascular structures located medial to the coracoid.
  - Lateral portal: This portal is marked 3 to 5 cm lateral to the lateral margin of the acromial border. The location of this portal may change based on the intra-articular anatomy.
  - Before starting the arthroscopic procedure, the surgeon ensures that all arthroscopic equipment (arthroscope, monitor, pump) is properly functioning.

TECH FIG 1 • Right shoulder with preoperative markings identifying the acromion, clavicle, and expected portal sites.

TECH FIG 2 • Arthroscope insertion. The trocar and arthroscopic cannula are directed toward the coracoid process. It enters the glenohumeral joint just lateral to the posterior glenoid labrum and approximately in the middle of the glenoid from superior to inferior. The surgeon’s index finger is on the tip of the coracoid to help direct the trocar into the joint.
ESTABLISHING THE ANTERIOR PORTAL

- The anterior portal is next created. Depending on the intra-articular shoulder pathology to be addressed, a modified anterior portal may be needed; this is discussed in other chapters.
- For most standard arthroscopic procedures, the anterior portal may be created using either an inside-out or an outside-in technique.

**Inside-Out Technique**

- The arthroscope is placed within the rotator interval just inferior to the biceps tendon and held firmly against the anterior capsule. The camera is then removed while holding the cannula in position.
- A switching stick or Wissinger rod (a long metal rod that fits within the arthroscopic sheath) is inserted into the cannula and used to penetrate the anterior capsule and tent the skin.
- A small skin incision is made over the end of the switching stick.
- A cannula may then be passed over the switching stick and into the glenohumeral joint.

**Outside-In Technique**

- A spinal needle is inserted at the expected site of the anterior portal and into the joint (TECH FIG 3).

**TECH FIG 3** - Spinal needle inserted in rotator interval to establish correct placement of anterior superior portal. The humeral head (H) and the long head of the biceps tendon (B) are clearly identified.

**DIAGNOSTIC ARTHROSCOPY**

**Arthroscope in the Posterior Portal**

- Diagnostic arthroscopy of the shoulder begins with the arthroscope in the posterior portal and a probe through the anterior portal. From this position, the following structures should be visualized and probed:
  - Articular surfaces of the humeral head and glenoid
    - The cartilage surface is evaluated, noting any chondral damage.
    - The glenoid cartilage may have a normal “thinned-out” appearance at its center.
  - Occasionally, the demarcation of the two ossific centers of the glenoid may be identified as a thin line on the chondral surface.
  - Subscapularis tendon and rotator interval
    - The integrity of the superior tendinous edge of the subscapularis and its attachment to the lesser tuberosity is evaluated (TECH FIG 4A).
    - The tissue quality and laxity of the rotator interval (the capsular tissue between the anterior edge of the supraspinatus and the superior edge of the subscapularis) is noted.
  - Superior and middle glenohumeral ligaments
    - The superior ligament is evaluated as it crosses between the subscapularis and biceps tendon and the middle ligament as it crosses the subscapularis tendon (TECH FIG 4B).
  - Variants may include a Buford complex (cord-like middle glenohumeral ligament) or even absence of the ligament altogether.
  - Superior labrum and biceps tendon
    - The biceps tendon is evaluated on both sides, using a probe to pull it into the joint to evaluate for hidden synovitis or fraying that exists as it leaves the joint and enters the bicipital groove (TECH FIG 4C).
  - Rotator cuff
    - The tendons of the rotator cuff are evaluated with the arthroscope looking superiorly. The rotator cuff tendon attachment to the humeral head should be smooth, without any fraying (TECH FIG 4D).
    - As the arthroscope is moved posteriorinferiorly around the humeral head, the normal “bare spot” on the humeral head is easily identified by the lack of articular cartilage and the presence of nutrient foramen in the bone (TECH FIG 4E).
  - Inferior capsule and recess
    - The inferior capsular pouch and the capsular attachment to the humeral head are assessed (TECH FIG 4F).
    - Occasionally a humeral avulsion of the inferior glenohumeral ligament may occur here with or without a fragment of bone.
Chapter 1  SHOULDER ARTHROSCOPY: THE BASICS

TECH FIG 4 • A. Left shoulder in lateral decubitus position with anterior superior and anterior inferior portals established. The biceps tendon (B) is between the two cannulas. The humeral head (H), glenoid (G), and superior edge of the subscapularis (S) are identified. B. Left shoulder in beach-chair position, with subscapularis (S), biceps tendon (B), and middle glenohumeral ligament (M) identified. The anterosuperior labrum is highly variable and in this case presents as a sublabral hole (arrow). C. The long head of the biceps can be pulled into the joint to inspect for synovitis (arrows), as shown in this shoulder. D. The anterior edge of the suprapinatus and the normal rotator cuff insertion are depicted in this image. E. As the arthroscope is swept posteriorly along the rotator cuff, the bare area of the humeral head is identified. This is a normal area devoid of articular cartilage. The transition between the posterior rotator cuff and the inferior capsule is identified (arrow). F. The inferior capsular pouch is seen attaching to the humerus. This is a common area to find loose bodies as they tend to fall to the most dependent aspect of the joint (in the beach-chair position). G. The inferior glenoid labrum can be visualized as the arthroscope is redirected superiorly from the axillary pouch. H,I. The anterior labral attachment is inspected. H. The labrum and capsular attachment are normal. I. There is a disruption in the attachment of the anteroinferior labrum (Bankart lesion). J. The superior labral attachment is probed.
As the arthroscope is directed superiorly, the inferior labral attachment can be examined (TECH FIG 4G).

Anterior band of the inferior glenohumeral ligament
This is the primary static stabilizer to anterior glenohumeral translation.

The anteroinferior labrum should be tightly attached to the glenoid (TECH FIG 4H). Detachment in this area is commonly referred to as a Bankart or Perthes lesion (TECH FIG 4I) and will be discussed in greater detail in Chapter SM-2.

Visualization of this ligament is facilitated when the ligaments and capsular tissues are loose and the arthroscope may easily pass into the anterior recess between the humeral head and glenoid. This is known as a “drive-through” sign and may represent multidirectional laxity.

Biceps anchor
The superior labral attachment to the glenoid is probed to evaluate for a superior labral anterior to posterior (SLAP) lesion.3

Typically the superior labrum is well attached to the superior glenoid (TECH FIG 4J).

Normal variants such as a meniscoid superior labrum and variations of the biceps tendon (bifid tendon) are not uncommon. They must be differentiated from pathoanatomy that requires repair.

**Arthroscope in the Anterior Portal**
- The arthroscope is removed while keeping the sheath in the joint posteriorly. It is placed in the anterior cannula to allow evaluation of the posterior joint and to assess the rest of the joint from another viewpoint.

**SUBACROMIAL ARTHROSCOPY (BURSCOSCOPY)**
- Once the diagnostic glenohumeral arthroscopy is completed, the sheath and obturator are then directed into the subacromial space.
- This is done by placing the obturator tip just beneath the posterior acromion and then inserting it parallel to the acromion.
- If the arthroscope is inserted properly into the subacromial space anterior to the posterior bursal curtain, then the distended bursal space should allow for visualization of the subacromial structures.3
- At the surgeon’s preference, a lateral portal may be created at this time.
- The inferior aspect of the acromion is evaluated and the coracoacromial ligament is identified.
- The lateral and anterior aspects of the acromion are assessed.
- The anterior acromial spur is evaluated if present.
- The arthroscope is oriented to look downward at the greater tuberosity and attachment of the rotator cuff.

- The posterior labrum should be smooth and tightly attached to the glenoid (TECH FIG 5).
- The scope is angled upward to assess posterior capsular attachment to the humeral head. If detached, this represents a reverse humeral avulsion of the glenohumeral ligament.
- Subscapularis and biceps tendon
  - The subscapularis recess and subscapularis attachment to the humeral head can be evaluated.
  - Loose bodies are occasionally found within the subscapularis recess.
  - Integrity and stability of the groove and the synovium of the biceps tendon are evaluated.
PEARLS AND PITFALLS

| Indications | The surgeon should have a clear understanding of patient history, physical examination, imaging studies, and pathology to be addressed. |
| Positioning | Beach-chair or lateral decubitus position is used. The surgeon should ensure that the appropriate equipment is available in the operating room. |
| Portal placement | The surgeon should have a full understanding of pertinent anatomy. Improper portal placement will make visualization and arthroscopic débridement and repair difficult. |
| Equipment | The surgeon must make sure that all necessary equipment and instruments are available, including suture anchors for labral repair or rotator cuff procedures, multiple-size cannulas, sutures and passing instruments, shavers and burrs, and thermal or electrocautery. |
| Approach | It is important to have a systematic, stepwise approach to diagnostic arthroscopy so that all structures are adequately visualized and no pathology is missed. |

POSTOPERATIVE CARE

- The patient is placed in a sling for comfort. Allowable range of motion and exercises are tailored to the specific procedure performed and will be discussed in detail in the following chapters.
- Cryotherapy (a commercial ice unit) may be used.

OUTCOMES

- Shoulder arthroscopy is a safe and effective procedure. It allows for complete visualization of the glenohumeral joint and subacromial space and treatment of identified pathology.
- Outcome data for specific procedures performed are discussed in the following chapters.

COMPLICATIONS

- Failure to address all pathology with thorough diagnostic examination
- Infection
- Loss of motion or adhesive capsulitis

REFERENCES

DEFINITION
- Glenohumeral stability depends on static and dynamic restraints to ensure stable yet unconstrained range of motion.
- Laxity is a physiologic term used to describe the passive translation of the humeral head on or over the glenoid.
- Instability is a pathologic state characterized by abnormal translation of the humeral head on or over the glenoid, leading to frank dislocation, functional impairments, or pain.
- The most common direction of glenohumeral instability is anteroinferior.
- Anterior instability may be traumatic (occurring with the arm in abduction and external rotation), acquired (subtle instability associated with repeated microtrauma), or atraumatic (multidirectional with underlying anatomic contributions).

ANATOMY
- The normal glenoid is broader inferiorly than superiorly (pear-shaped).
- The articulating surface of the humeral head is about three times the size of the corresponding glenoid cavity.
- Static and dynamic stability must be provided by a complex interaction between the capsuloligamentous structures, the rotator cuff, the scapular stabilizers, and the biceps muscle.
- The shallow bony glenoid is deepened by thicker articular cartilage on the periphery and the presence of the ringlike labrum.
- The fibrocartilaginous labrum increases the depth of the socket and prevents the head from rolling anteriorly over the glenoid. The superior labrum provides an attachment for the biceps, whereas the inferior labrum serves as an attachment for the glenohumeral ligaments.
- The capsule and ligaments are intimately related and different geographic areas contribute to stability based on the anatomic position of the arm.
- The inferior glenohumeral ligament complex is the primary static restraint against instability from abduction angles of 45 to 90 degrees. The anterior band is the most important static restraint against anterior instability in the most common position of injury, the abducted and externally rotated arm (FIG 1).
- The superior and middle glenohumeral ligaments limit inferior translation and anteroposterior translation with the arm in abduction.
- The rotator cuff muscles and the long head of the biceps brachii provide critical dynamic stability by increasing joint compression.
- Less important contributors to joint stability include negative intra-articular joint pressure, articular version, and adhesion-cohesion forces.

PATHOGENESIS
- Trauma, especially athletic trauma, plays a significant role in recurrent anterior instability.
- Overhead athletes can present with more subtle instability.
- Repetitive microtrauma contributes to the development of pathologic subluxation.
- Injury may result in subluxation and dislocation with spontaneous reduction or dislocation requiring reduction maneuvers.
- Traumatic anterior instability is most common in the young, athletic population.
- In the 21- to 30-year-old age group the male/female incidence was reported as 9:1.
- The Bankart lesion (detachment of the anterior inferior labrum and capsule) is considered the fundamental pathoanatomic lesion associated with anteroinferior instability. It may be present in about 90% of all traumatic glenohumeral dislocations (FIG 2).
- Recurrent dislocations lead to plastic deformation of the middle and inferior glenohumeral ligaments, contributing to laxity in the “sling” that is designed to restrict translation of the humeral head in abduction.
- Bone injuries to the humerus (such as the Hill-Sachs lesion) and the glenoid (bony Bankart or glenoid erosion) are known to contribute to increased glenohumeral translation, resulting in recurrent instability.
- Extensive soft tissue damage is rare but can include the humeral avulsion of the glenohumeral ligaments or a capsular tear. In addition, the injured labral tissue may heal medially on the glenoid neck (the so-called anterior labroligamentous periosteal sleeve avulsion [ALPSA lesion]) leading to insufficiency of the inferior glenohumeral ligament and labral complex.
- In the older patient with a traumatic dislocation, rotator cuff pathology must be ruled out. A thorough strength examination coupled with appropriate use of soft tissue imaging should alert the examiner to concomitant rotator cuff pathology.
- Other soft tissue injuries (capsular tear and neurovascular injury) as well as glenoid and humeral head defects can occur in this age group.
from posterior to assess any muscular atrophy of the trapezius.

The physical examination should begin with inspection

There are five important questions in the history of instability:
- Did the initial instability episode require a reduction?
- What was the arm position for the first dislocation? The last dislocation?
- What was the disability after the initial incident?
- How many episodes of instability have occurred since the initial event? Were they dislocation or subluxation episodes?
- What was the magnitude of the trauma associated with the initial event? Have subsequent events required similar force, or have they occurred with less provocation?

The physical examination should begin with inspection from posterior to assess any muscular atrophy of the trapezius, supraspinatus, and infraspinatus and teres minor. Muscle atrophy may point out nerve injury.
- Generalized ligamentous laxity should be examined by testing a thumb hyperextension sign and elbow extension.
- Active and passive range of motion in all scapular planes should be recorded and compared with the contralateral shoulder.
- Strength testing should include all important shoulder musculature, with a focus on pain as limiting factor.
- The contralateral side is examined when doing the load and shift examination; positive findings indicate lax anterior stabilizers.
- It is critical to separate feelings of pain from instability relieved with Jobe relocation. A positive relocation maneuver may spotlight subtle instability.
- Axillary nerve function should be assessed by carefully testing motor function of the deltoid and examining sensory distribution.

A positive posterior jerk test with pain and or crepitus illicit with posterior translation of the humeral head over the glenoid rim indicates posteroinferior capsular or labral pathology.
- When examining for the sulcus sign, the clinician should compare the result with the contralateral side. Failure of external rotation to eliminate the sulcus sign may indicate multidirectional instability or global laxity.
- Provocative maneuvers should be employed to evaluate shoulder stability.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Radiographs
  - Standard AP views of the arm with the arm in slight internal rotation: may show greater tuberosity fracture
  - AP views of the glenohumeral joint
  - West Point axillary view: may be used to assess bony avulsions of the inferior glenohumeral ligament, bony Bankart lesions, or anteroinferior glenoid deficiency
  - Stryker notch view: may be used to examine and quantify a Hill-Sachs lesion
- Computed tomography
  - Bone defects are an important cause of failure for instability surgery.
  - Three-dimensional reconstructions have been especially useful to quantify bone loss.
- Indications
  - Instability episodes while asleep
  - Instability episodes with minimal trauma after a primary instability episode that required manual reduction
  - Instability episodes at low degrees of humeral abduction
  - Failure of any prior instability procedure
  - Apprehension on examination at low degrees of humeral abduction
  - Remarkable laxity on load and shift test
  - Any bony lesion on radiographic evaluation
  - When bony deficiencies are identified, operative approaches must be adjusted accordingly. Careful consideration must be given to open instability procedures with bony augmentation in cases of bone involvement (Table 1).
- Magnetic resonance imaging
  - Contrast enhancement improves the ability to detect labral injury, rotator cuff tears, and articular cartilage lesions.
It may identify humeral avulsion of the glenohumeral ligament lesions and capsular tears, allowing recognition of these infrequent but critical injuries (FIG 3C).

**DIFFERENTIAL DIAGNOSIS**
- Osseous lesions, including clavicle fractures, proximal humerus fractures, and scapular and glenoid fractures
- Soft tissue lesions, including deltoid contusions, acromioclavicular joint sprains, and rotator cuff injuries (more common in patients older than 40 years)
- Nerve lesions, including injuries to the axillary nerve, suprascapular nerve, and long thoracic nerve

**NONOPERATIVE MANAGEMENT**
- Nonoperative management has traditionally consisted of a period of immobilization followed by intensive physical therapy to improve proprioception and muscular balance around the shoulder girdle. A recent review noted that recommendations for positioning, length of immobilization, and outcomes are inconsistent at best.\(^3\)
- Recent work by Itoi\(^14\) suggested that immobilization in external rotation will reduce recurrence rates after magnetic resonance imaging demonstrates coaptation of the Bankart lesion with the arm in external rotation.\(^17\) This same author reported a clinical series comparing immobilization in internal rotation versus external rotation after primary dislocation. Immobilization in external rotation reduced the risk of recurrence by 46%.\(^15\)
- Failure of nonoperative management may be manifested in recurrent symptoms of instability (dislocations, subluxations, or pain) despite adequate nonoperative management and activity modification where appropriate.

**SURGICAL MANAGEMENT**
- The guiding basis for the described arthroscopic technique is that restoration of the normal glenoid labrum anatomy and retensioning of the inferior glenohumeral ligament can be accomplished in a manner that mirrors the open method (FIG 4).

---

**Table 1**

**Arthroscopic Versus Open Treatment of Anterior Instability**

<table>
<thead>
<tr>
<th>Arthroscopic</th>
<th>Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal to no bone defects—small, nonengaging Hill-Sachs, no glenoid bone loss</td>
<td>Bone defects—large Hill-Sachs lesions (&gt;25% articular surface), glenoid deficiencies &gt;20%; “inverted pear” large “HAGL” (humeral avulsion of glenohumeral ligament); capsular deficiency or loss (thermal ablation)</td>
</tr>
<tr>
<td>Unidirectional dislocators</td>
<td>Controversial patient populations</td>
</tr>
<tr>
<td>Bankart or anterior labroligamentous peristoeal sleeve avulsion (ALPSA lesion)</td>
<td>Patients with multidirectional instability or hyperlaxity</td>
</tr>
<tr>
<td>Proper surgeon experience</td>
<td>High-demand collision athletes</td>
</tr>
</tbody>
</table>

---

**FIG 3** • A. AP radiograph showing defect in the humeral head. B. CT scan reconstruction showing erosion of the anteroinferior glenoid. C. MRI example of humeral avulsion of glenohumeral ligament lesion.

**FIG 4** • Illustration of a surgical reconstruction with a 180-degree arthroscopic repair with three inferior plication sutures, three anchors repairing the labrum, and a rotator interval closure.
In the senior author’s experience with traumatic anterior instability, a Bankart lesion will typically extend from the 2 o’clock to the 6 o’clock position. To restore anatomy appropriately, the surgeon should be able to instrument and place suture anchors at the inferior aspect of the joint in the 6 o’clock position.

Arthroscopic knots may be sliding, sliding-locking, or simple. Knot selection is less important than the ability to reproduce the desired knot security and tissue tension consistently.

Preoperative Planning
- The indications for arthroscopic stabilization include:
  - Primary anterior dislocation in young, high-demand patients
  - Recurrent, traumatic anterior instability without bone loss
  - Overhead athletes, especially throwing athletes, where preserving motion is important
- Contraindications to arthroscopic stabilization include a large Hill-Sachs lesion (the “engaging” Hill-Sachs) and bony deficiencies of the glenoid that represent more than 20% (the “inverted pear”) (FIG 5).
- Arthroscopic stabilization for collision athletes and patients with osseous Bankart lesions is controversial.
  - However, several recent reports describe favorable results with arthroscopic repair in these groups.3,5,21,22,31
  - The decision to do arthroscopic versus open repair continues to be debated as arthroscopic results are reported (see Table 1).34
- All pertinent radiographic studies should be reviewed to confirm prior hardware, expected soft tissue injuries, and potential bony injuries.
- An examination under anesthesia should confirm anteroinferior instability in the operative shoulder and verify range of motion. It is important to note the normal range of motion in the contralateral shoulder before final positioning.

Positioning
- Both the beach-chair position and the lateral decubitus position may be used for instability surgery. We prefer the lateral decubitus position to allow greater access to the inferior portions of the joint.
- For the lateral decubitus position the patient is stabilized with a beanbag in a 30-degree backward tilt to place the glenoid face parallel to the floor.

- A three-point distraction device that applies longitudinal and vertical traction allows distraction of the humerus.
- Typically 5 pounds of longitudinal traction is combined with 7 pounds of lateral traction or distraction.
- In most cases an interscalene block provides excellent operative and postoperative pain control.
- For the beach-chair position, this may be all that is required.
- For the lateral decubitus position, it is prudent to add general anesthesia for comfort.
- Preoperative antibiotics are administered before the skin incision (FIG 6).

Approach
- A standard posterior portal should be placed in the soft spot at midglenoid level, taking care to be just lateral to the glenoid.
- The blunt arthroscopic trocar and sheath are then inserted into the space between the glenoid rim and the humeral head.
- Using needle localization, the surgeon places the anterior portals. The anterosuperior portal should be as high as possible while staying just inferior to the biceps tendon.
- The anteroinferior portal should enter just above the superior border of the subscapularis.
- The needle used for portal placement should first be navigated throughout the joint to ensure that instrumentation with suture shuttling devices and anchor insertion equipment is feasible.
- The anterosuperior portal is instrumented with a 7.0-mm cannula and the anteroinferior portal is instrumented with an 8.25-mm cannula (FIG 7A–C).

![A. Hill-Sachs lesion on glenoid face. B. Hill-Sachs lesion engaged, with humeral head locked over anterior glenoid. C. Arthroscopic view (right shoulder) of inverted pear: camera anterosuperior, showing anterior glenoid bone loss.](FIG 5)

![Setup for the lateral decubitus position with arm traction device.](FIG 6)
Before beginning the surgical procedure, a thorough diagnostic arthroscopy is performed.

After diagnostic arthroscopy, the arthroscope is brought to the anterosuperior portal and another 8.25-mm cannula is placed in the posterior portal.

With the arthroscope in the anterosuperior portal, visualization of the inferior glenohumeral ligament and labrum is optimized.

A rolled blanket “bump” placed into the axilla provides further gentle distraction and improves exposure of the inferior aspect of the joint (FIG 7D).

---

**Arthroscopy and Glenoid Preparation**

- First, the labral and ligamentous complex must be released off the face of the glenoid.
- Care should be taken to maintain the tissue as one unit, using elevators to adequately release to at least the 6 o’clock position.
- When muscle fibers of the subscapularis are visible, the release is adequate (TECH FIG 1A).
- The glenoid neck must be prepared by either a burr or a shaver to decorticate down to bleeding bone. A meniscal rasp can be a helpful adjunct.
- The bone preparation must be as inferior as the soft tissue release on the glenoid.
- It is critical to begin the repair at the low 6 o’clock position in the capsule.
- Various techniques may be used to ensure that the initial shuttling suture can be placed inferior at the 6 o’clock position. Options include:
  - Arthroscope in anterosuperior portal (our preferred method): suture-passing instrument inserted through posterior cannula (TECH FIG 1B)
  - Arthroscope in anterosuperior portal: suture-passing instrument inserted through anteroinferior cannula (TECH FIG 1C,D)

---

**“Pinch and Tuck”**

- Capsular retensioning and labral repair may be accomplished by the “pinch and tuck” method (TECH FIG 2).
- Using a curved suture-passing device, the capsule is pierced 5 to 10 mm lateral to the labrum.
- The device exits the capsule and pierces the capsule again to re-enter at the lateral base of the labral complex and emerge at the articular margin.
- A monofilament suture is inserted to be used as a shuttle suture. The shuttling suture or device will eventually be used to shuttle the nonabsorbable suture housed in the anchor. Or it may be used to shuttle a nonabsorbable suture being used purely as a plication suture.
- With the introduction of newer ultrastrong suture, subsequent knot tying will combine capsular plication and labral repair.
- All shuttling should be done from the articular side of the labrum out to the soft tissue side and through a cannula.
TECH FIG 1 • Right shoulder. A. Elevator releasing labral and capsular tissue off face of glenoid. B. Pinch of capsular and ligamentous tissue with shuttling instrument coming from posterior portal to place at inferior aspect. C. Shuttling instrument brought through anteroinferior portal and taking tuck of inferior capsule. D. After piercing capsule the needle of the shuttling instrument pierces the labrum. E. Camera in posterior portal with suture passer in anteroinferior cannula. F. Camera in anterosuperior portal with suture passer in anteroinferior cannula.

TECH FIG 2 • Camera in anterosuperior portal with suture passer in posterior cannula.

Anchor Placement

- The initial suture anchor is placed inferiorly on the glenoid, close to the 6 o’clock position.
- Suture anchors should be placed on to the articular face of the glenoid to recreate the “bumper” effect of the normal labrum.
- It is critical to place anchors 5 to 10 mm cephalad to the shuttle suture to accomplish the “superior shift” portion of the procedure (TECH FIG 3A). Subsequent knot-tying will combine capsular re-tensioning and labral repair.
- If appropriate access for anchor placement cannot be gained from the anteroinferior portal, a percutaneous transsubscapular entry may be used.
- In this case, a stab incision is made just inferior to the anteroinferior portal.
- Using needle localization the surgeon confirms appropriate access, and a small trocar may be inserted to place the anchor onto the glenoid (TECH FIG 3B,C).
Capsular Plication

- The process of capsular plication and anchoring is repeated, moving in a superior direction to restore labral anatomy and reposition the inferior gleno-humeral ligament.
- Typically at least four anchors are used in the final construct.

- It may be necessary to return the arthroscope to the posterior portal for placement of the most cephalad anchor (2 o’clock position for the right shoulder) to avoid anterior instrument crowding. A 7.0-mm cannula may be reinserted in the anterosuperior portal for instrumentation. The final repair should re-establish normal positioning of the glenoid labrum over the glenoid rim and reposition the inferior gleno-humeral ligament (TECH FIG 4A,B).

ANCHOR FIRST

- The same general techniques and principles from the suture-first technique apply.
- An anchor is inserted onto the face of the glenoid in an appropriate location.
- Both limbs of the anchor suture are pulled out of a cannula for suture management.

- A tissue penetrator or suture-shuttling device is used to gather the inferior tissue and place a shuttle suture.
- The suture is grasped in the joint and pulled out the anterosuperior cannula.
- A standard suture-shuttle technique is used to pass the anchor suture.

ADDITIONAL ENHANCING TECHNIQUES

Traction Suture

- If access to the inferior capsule and labrum is difficult, a “traction suture” can be used.
- The initial stitch can be placed in the inferior capsule and then brought out the anterosuperior portal.
- Traction on this stitch may allow a more inferior grasp of tissue in the early stages of a repair.

Mattress Suture

- In addition to simple sutures, a mattress suture can be used to position the tissue on the glenoid face.
- For a mattress suture, the process of capsular plication with a suture-passing device and subsequent suture shuttling is repeated so that both limbs of the suture exit the tissue on the tissue side.

- As the arthroscopic knot is tied, a mattress stitch is created to enhance capsular plication and gather additional capsular tissue on the glenoid rim.
- This is particularly useful with a degenerative atrophic labrum or with poor-quality capsular tissue (TECH FIG 5).

Posterior Anchors

- Should the Bankart lesion extend posteriorly past the 6 o’clock point, posterior anchors may be required.
- A percutaneous technique for anchor insertion can be employed using needle localization and a trocar and anchor guide through a postero-inferior stab incision.
- Alternatively, a postero-inferior portal may be established using needle localization and gradually increasing dilators to place an additional cannula for posterior and inferior access.
Plication Stitches

- If the posterior labrum is intact but posterior laxity remains, plication stitches can be placed to better balance the anterior and posterior tension on the inferior glenohumeral ligament.
- Using the pinch-tuck technique, the capsule and ligament can be grasped and connected to the labrum (TECH FIG 7).

Closure of Rotator Interval

- When additional stability is required, the rotator interval can be closed.
- Current recommendations for rotator interval closure include greater than 1/2 sulcus sign, laxity with a posterior component, and a collision athlete.9
- A stitch is passed through a suture passer placed in the anterosuperior cannula through the superior border of the subscapularis or the middle glenohumeral ligament.
- The superior glenohumeral and coracohumeral complex is then pierced with a tissue penetrator to grasp the suture. The suture is then tied and cut with a guillotine knot cutter (TECH FIG 8).
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Patient selection</th>
</tr>
</thead>
</table>
| Major reported reasons for failure of arthroscopic stability procedures include:
| - Failure to appreciate and address excess capsular laxity
| - Failure to evaluate and address bone loss adequately

<table>
<thead>
<tr>
<th>Portal placement pearls</th>
</tr>
</thead>
</table>
| - The posterior portal should be placed so that the camera angle replicates the angle of the glenoid face.
| - The anterosuperior portal should be placed far enough from the anteroinferior portal to maintain a skin bridge and working room.
| - The anteroinferior portal should enter just above the subscapularis so instruments and cannula are not blocked by the subscapularis and may reach the inferior glenoid and pouch.

<table>
<thead>
<tr>
<th>Technical considerations</th>
</tr>
</thead>
</table>
| - The labrum and the inferior glenohumeral ligament complex must be adequately released to at least the 6 o’clock position. The surgeon should visualize muscle fibers of the subscapularis.
| - Soft tissues must be mobilized superiorly on the glenoid to re-establish tension of the inferior glenohumeral ligament complex and decrease inferior capsule space.
| - Suture anchors must be placed 1 to 2 mm on the articular surface to recreate the soft tissue “bumper.”
| - Adequate fixation requires at least four stabilization points.
| - Suture management must be consistent and simple. Sliding, sliding-locking, and simple knots are all acceptable, provided the surgeon can consistently replicate a solid repair.

POSTOPERATIVE CARE

- Goals of postoperative care include controlled mobilization to allow adequate soft tissue healing, adequate motion (external rotation), and successful return to activities.
- Postoperative protocols must respect the biologic repair process.
- Our postoperative protocol includes:
  - Immediate postoperative immobilization in an abduction orthosis
  - Codman exercises and pendulum exercises immediately with assistance
  - Active assisted range-of-motion exercises, including external rotation (0 to 30 degrees) and forward elevation (0 to 90 degrees), for 6 weeks
  - Weeks 6 to 12 include active assisted and active range of motion with the goal of establishing full range of motion.
  - Strengthening exercises begin only after full motion is restored.
  - Sports-specific exercises are begun at 16 to 20 weeks.
  - Final release to full activity is 20 to 24 weeks.

OUTCOMES

- Multiple recent studies using a suture anchor technique similar to the open method have documented clinical success, with recurrent instability rates of 4% to 10%. 5,8,10,18,34
- As arthroscopic techniques and equipment have evolved, the literature indicates decreasing rates of recurrence and results approaching open instability procedures.
- Careful patient selection remains critical for arthroscopic instability procedures and may vary with surgeon experience.

COMPLICATIONS

- The overall rate of recurrent instability from arthroscopic stabilization can safely be placed at 10% to 15%.
- Postoperative glenohumeral noise or squeaking can occur if arthroscopic knots are captured in the glenohumeral joint. This may require later débridement of the knots.
- Loss of external rotation from overtightening can occur.
- Rupture of the repair can occur with aggressive early activities or rehabilitation.
- Injury to the axillary nerve is possible with electrical or mechanical damage.

REFERENCES

DEFINITION
- Posterior shoulder instability results in pathologic glenohumeral translation ranging from mild subluxation to traumatic dislocation. Most patients with this pathologic entity report pain in provocative positions of the glenohumeral joint, a condition referred to as recurrent posterior subluxation.
- Posterior shoulder instability is much less common than anterior instability, representing about 5% to 10% of all patients with pathologic shoulder instability.\(^2,5,10\)
- A decision must be made regarding surgical treatment of this condition when an extended trial of conservative measures, such as physical therapy, has failed.

ANATOMY
- The important stabilizing structures of the glenohumeral joint are the articular surfaces and congruity of the humerus and glenoid, the labral capsule, the labral capsular structures, the labrum, the intra-articular portion of the biceps tendon, and the rotator cuff muscles.
- Pathologies of the posterior capsule and labral complex are believed to be the main contributors to posterior instability.
- With the arm forward-flexed to 90 degrees, the subscapularis provides significant stability against posterior translation, and as the arm is placed in neutral, the coracohumeral ligament resists this force. With internal rotation of the shoulder (follow-through phase of throwing), the posterior capsulolabral complex is the main restraint to posterior translation.\(^1\)
- Histologic evaluation of the posterior capsule shows it to be relatively thin and composed of only radial and circular fibers, with minimal cross-linking.

PATHOGENESIS
- Posterior instability can be the result of trauma in the form of a direct blow to the anterior shoulder or may occur as the result of indirect forces acting on the shoulder, causing the combined movements of shoulder flexion, adduction, and internal rotation.\(^13\)
- Electrocution and seizures are the most common causes of an indirect mechanism resulting in posterior dislocation.
- Patients with recurrent posterior subluxation may present with more vague symptoms, with pain being the chief complaint. Athletes may report that velocity with throwing is diminished, and a sharp pain may accompany the follow-through phase of throwing.
- Other associated injuries such as superior labrum anterior posterior (SLAP) lesions, rotator cuff tears, reverse Hill-Sachs defects, and chondral injuries may be present and contribute to the pathology.\(^4\)

NATURAL HISTORY
- Patients with a history of a chronically locked posterior dislocation are at increased risk for the development of chondral injury and subsequent degenerative arthritis.\(^6\)
- Static posterior subluxations of the humeral head have been correlated with the presence of arthritis in young adults whose instability was left untreated.\(^14\)
- No long-term studies on the arthroscopic treatment of shoulder instability have documented a reduction in the development of osteoarthritis.

PATIENT HISTORY AND PHYSICAL FINDINGS
- A thorough history is obtained, documenting whether a dislocation has occurred (as well as the need for closed reduction) or if the primary symptoms are pain.
- The circumstances regarding pain are documented, namely onset (provocations), severity, ability to participate in sports, and whether symptoms are present at rest.
- Any response to conservative treatment (ie, physical therapy, rest, anti-inflammatory medication) should be noted.
- As with the examination of any joint, the shoulder is palpated to elicit tenderness and range of motion is documented. Any restriction in motion should be compared to the contralateral extremity, and differences between active and passive motion may indicate pain or capsular contracture.
- Impingement signs are tested to determine whether any associated rotator cuff tendinitis is present.
- Other examinations for posterior instability are:
  - Strength testing. Weakness may be the result of deconditioning or may indicate underlying rotator cuff or deltoid pathology.
  - Load and shift test. The degree of pathologic subluxation is assessed, as well as any apprehension or pain experienced by the patient during provocative testing.
  - Jerk test. A positive jerk test indicates pathologic posterior subluxation.
  - Kim test. A positive Kim test suggests a posteroinferior labral tear or subluxation.
  - Circumduction test. A positive test result is highly suspicious of posterior subluxation or dislocation.
  - Sulcus sign evaluation. A positive sulcus sign suggests multidirectional instability.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs, including a glenohumeral anteroposterior view, scapular Y view, axillary lateral view, and supraspinatus outlet view, should be obtained to rule out associated injuries, bone defects (either humeral or glenoid), or degenerative changes (FIG 1A).
- Magnetic resonance (MR) arthrography is currently the best method for imaging the posterior capsulolabral structures.
- Findings on MR suggestive of posterior instability are posterior humeral head translation, posterior labral injury, posterior labrocapsular avulsion, humeral avulsion of the posterior band of the inferior glenohumeral ligament, posterior glenoid bone defects, and anterior humeral head bone defects (FIG 1B).
Differential Diagnosis

- Posterior shoulder dislocation (may be locked)
- Recurrent posterior subluxation
- Multidirectional instability
- Internal impingement
- SLAP tear
- Rotator cuff tear
- Acromioclavicular joint injury
- Fracture (e.g., glenoid, greater tuberosity)

Nonoperative Management

- An extended period of nonoperative management is warranted in most cases of posterior shoulder instability.
- Nonoperative therapy constitutes physical therapy to regain a full and symmetric shoulder range of motion, with later emphasis placed on strengthening the rotator cuff and scapular stabilizing muscles.
- The premise of a conditioning program is to enable the dynamic stabilizers of the shoulder to compensate for the deficient static stabilizers (e.g., capsule, labrum).
- Once full motion and strength are achieved, return to sport is gradually introduced.

Surgical Management

- Surgical management of posterior instability is considered when an exhaustive rehabilitation program has failed to alleviate disabling posterior subluxation, or when instability is the result of a macrotraumatic event.

Preoperative Planning

- All imaging studies are again reviewed and the pathology is determined.
- Any bone deficiencies, loose bodies, and concomitant rotator cuff and SLAP tears should be evaluated and treatment determined before arrival in the operating room.
- An examination under anesthesia is performed before positioning to confirm the diagnosis. This examination should consist of sulcus test, load and shift test, and manual circumduction test or jerk test.

Positioning

- We prefer lateral decubitus positioning because this offers greater exposure than the beach-chair position for evaluating the posterior labrum and capsule.
- An inflatable beanbag and kidney rests hold the patient in the lateral position.
- Foam cushions are used to pad the axilla and all bony prominences, including the fibular head (protection of the peroneal nerve).
- The operative extremity is placed in 10 pounds of traction in 45 degrees of abduction and 20 degrees of forward flexion (FIG 2).

Approach

- We use an all-arthroscopic technique for this procedure, with a posterior portal that is used as the main working portal (through the posterior deltoid) and an anterior portal (placed through the rotator interval) that is used for arthroscopic visualization.

FIG 1 • A. Axillary lateral radiograph that demonstrates glenoid hypoplasia, which predisposes to posterior instability of the shoulder. B. Axial image from an MR arthrogram that demonstrates a posterior labral lesion. Contrast can be seen between the posterior labrum and the articular margin of the glenoid, indicating a labral tear or avulsion.

FIG 2 • A. Lateral decubitus is the preferred position for arthroscopic surgery of the posterior capsule and labrum. B. The arm is placed in 10 to 15 pounds of traction and slightly abducted and forward flexed.
PORTAL PLACEMENT

- The glenohumeral joint is first injected (posteriorly) with 50 mL of sterile saline through an 18-gauge spinal needle.
- A posterior portal is established 1 cm distal and 1 cm lateral to the standard posterior portal that is used for routine shoulder arthroscopy. This portal is often in line with the lateral border of the acromion (TECH FIG 1A).
- Placement of this portal more laterally than typical allows adequate access to the posterior glenoid rim for later anchor placement.
- An anterior portal is established high in the rotator interval via an inside-out technique with a switching stick. As an alternative, this portal can be established with a spinal needle via an outside-in technique (TECH FIG 1B).
- The anterior switching stick is then replaced with an 8.25-mm distally threaded clear cannula.

TECH FIG 1 • A. The posterior portal (PP) is marked in line with the lateral border of the acromion (AC). B. Surface landmarks identify the posterior portal (PP), acromion (AC), anterior portal (AP), and coracoid process (CP).

DIAGNOSTIC ARTHROSCOPY

- With the arthroscope in the posterior portal, a diagnostic arthroscopy is performed.
- The articular surfaces of the glenohumeral joint are inspected for chondral damage. The posterolateral aspect of the humeral head is inspected for any Hill-Sachs lesions (which may indicate combined anterior instability).
- The anterior and inferior labrum is inspected and the glenohumeral ligaments are visualized.
- The biceps tendon and superior labrum are probed to detect any pathology. Concomitant SLAP tears are common with posterior instability.
- The rotator cuff is inspected (including the subscapularis tendon).
- A switching stick is then placed in the posterior portal and replaced with an additional 8.25-mm distally threaded clear cannula. The arthroscope is then replaced into the anterior cannula for viewing; it remains there for the rest of the operation.
- The posterior capsule and labrum are inspected and probed (TECH FIG 2).
- The anterior humeral head surface is inspected for any reverse Hill-Sachs lesions, which may indicate macroinstability.

TECH FIG 2 • A. Arthroscopic view from the posterior portal showing an avulsed posterior labrum. B. A complete avulsion of the labrum off the posterior glenoid is visualized from the posterior portal.
Chapter 3  ARTHROSCOPIC TREATMENT OF POSTERIOR SHOULDER INSTABILITY

PREPARATION OF THE GLENOID AND PLACEMENT OF SUTURE ANCHORS

- Typically the posterior labrum is detached and the capsule attenuated, requiring the placement of suture anchors.
- An arthroscopic rasp or chisel is used to mobilize the labrum from the glenoid rim.
- The rasp is then used to débride the capsule to create an optimal environment for healing.
- A motorized shaver or burr can be used on the glenoid rim to achieve a bleeding surface for healing.
- Suture anchors are placed along the articular margin, not the glenoid neck, for the repair and capsular plication (TECH FIG 3A).
- Typically we use three, 3-mm Bio-Suture Tak suture anchors with no. 2 FiberWire (Arthrex Inc., Naples, FL). A number of other commercially available anchors can be used in a similar fashion.
- The anchor pilot holes are predrilled and the anchor is inserted with a mallet.
- The anchor is placed so that the sutures are perpendicular to the glenoid rim. This facilitates passage of the most posterior suture through the torn labrum.
- The anchors are evenly spaced on the posterior glenoid rim for a symmetric repair (TECH FIG 3B).

![TECH FIG 3 • A. The anchor is placed on the glenoid margin. A drill is used to place a pilot hole before insertion of the anchor. B. The anchors are evenly spaced on the posterior glenoid margin to provide a symmetric and balanced repair.]

LABRAL AND CAPSULAR REPAIR

- A 45-degree Spectrum Hook (Linvatec Corp., Largo, FL) loaded with number 0 PDS suture (Ethicon, Somerville, NJ) is used to shuttle the suture through the capsule and labrum (TECH FIG 4A).
- The suture hook is delivered through the capsule (if a plication is warranted) and under the torn labrum at the articular margin of the glenoid.
- An inferior-to-superior direction is used for this maneuver to achieve a small capsular plication.
- This direction of suture passage is aimed at restoring tension to the posterior band of the inferior glenohumeral ligament.
- Patients with significant instability clinically may require a more aggressive plication than those with isolated pathology to the glenoid labrum.
- The PDS is fed into the glenohumeral joint and the passer is withdrawn.

![TECH FIG 4 • A. A suture hook is used to shuttle the anchor limb through the capsulolabral complex. B. The PDS suture has been passed through the capsule and posterior labrum. C. The anchor limb suture is then shuttled via the PDS suture. D. The sutures are tied using arthroscopic knot-tying techniques through the posterior portal, and the capsulolabral plication is finished.]

PEARLS AND PITFALLS

| Indications                                                                 | ■ A thorough history and examination with correlating radiographic studies help in determining the correct diagnosis.  
|                                                                           | ■ Patients should be counseled extensively on nonoperative therapy. |
| Patient positioning                                                       | ■ Debate exists as to which position allows better exposure of the posterior glenoid.  
|                                                                           | ■ The surgeon should feel comfortable with whichever position is chosen; however, we feel that the lateral decubitus position offers better visualization. |
| Portal placement                                                          | ■ Placing the posterior portal slightly lateral to the standard portal allows for easier placement of the anchors.  
|                                                                           | ■ Placing the anterior portal superior in the rotator interval allows better visualization. |
| Anchor placement                                                          | ■ Placing the anchors perpendicular to the glenoid margin and shuttling the posterior suture is paramount in preventing suture entanglement. |
| Repair                                                                    | ■ The repair should be tailored to the precise pathology of the patient as determined by the history, physical examination, and imaging studies. Patients without labral pathology may require an isolated plication.  
|                                                                           | ■ We prefer suture anchors regardless of which type of repair is necessary (capsule plication, capsulolabral plication, or labral repair). |
| Knot tying                                                                | ■ The surgeon should feel comfortable with both sliding and nonsliding knots before attempting arthroscopic repair techniques. |
**POSTOPERATIVE CARE**
- The patient leaves the operating room in an abduction sling that can be removed for passive range-of-motion exercises at home.
- We allow 90 degrees of forward elevation and external rotation to 0 degrees by 4 weeks after surgery.
- The sling is discontinued 6 weeks after surgery and active-assisted range-of-motion exercises and gentle passive range-of-motion exercises are progressed.
- Pain-free, gentle internal rotation exercises are instituted at 6 weeks.
- At 2 to 3 months after surgery, range of motion is progressed to achieve full passive and active range of motion.
- Stretching exercises can be instituted for any deficiency in motion at this point.
- After 4 months, the shoulder is often pain-free and eccentric rotator cuff strengthening is begun.
- At 5 months, isotonic and isokinetic exercises are advanced.
- At 6 months, throwing athletes undergo isokinetic strength testing.
  - If 80% of the strength and endurance of the contralateral extremity is attained, a throwing program is begun.
  - Full, competitive throwing is typically not attained until 12 months after surgery.
- Nonthrowing athletes are often released to a sport-specific program by 6 months, when 80% of their strength has returned.

**OUTCOMES**
- Arthroscopic posterior stabilization has achieved good results with respect to recurrence of instability and return to sport in athletes.
- Studies have shown rates of recurrence of 0% to 8% and rates of return to sport of 89% to 100%.

**COMPLICATIONS**
- Recurrent instability
- Stiffness
- Infection
- Neurovascular injury

**REFERENCES**
DEFINITION
- Neer and colleagues described the concept of multidirectional instability of the shoulder in detail in 1980.
- This established the difference between unidirectional instability and global laxity of the capsule inferiorly, posteriorly, and anteriorly.
- Subjective complaints of pain and global shoulder instability
- Subluxation or dislocation from traumatic, microtraumatic, or atraumatic injury

ANATOMY
- Stability of the shoulder relies on dynamic and static restraints.
- Static restraints:
  - Inferior glenohumeral ligament
    - Anterior band resists anterior translation in 90 degrees of abduction and external rotation.
    - Posterior band resists posterior translation in forward flexion, adduction, and internal rotation.
  - Middle glenohumeral ligament
    - Resists anterior translation in 45 degrees of abduction
  - Superior glenohumeral ligament
    - Resists posterior and inferior translation with arm at side
  - Rotator interval and coracohumeral ligament
    - Resists posterior and inferior translation with arm at side
- Dynamic restraints
  - Rotator cuff muscles
  - Deltoid
  - Effects of concavity and compression
- Shoulder instability has been found to be a result of several pathologic processes:
  - Capsular laxity
  - Labral detachment and Bankart lesion
  - Rotator interval defects

PATHOGENESIS
- Typically, there is not a history of a traumatic shoulder dislocation, but it may be the inciting event. Most commonly, the instability is due to microtrauma resulting in global capsular laxity.
- There may be a history of recurrent dislocations or repetitive subluxation events.
- Patients are typically young and active and present with the following:
  - Pain
  - Complaints of shoulder shifting
  - Difficulty with overhead activity
  - Inability to do sports
  - Instability while sleeping
  - Trouble with activities of daily living
  - Episodes of “dead arm” sensation
  - Failed prior attempts at physical therapy

NATURAL HISTORY
- Unable to change static restraints
- Stability can be achieved by restoring neuromuscular control through rehabilitation.
- Recurrent dislocations may lead to Hill-Sachs lesions, glenoid erosion, or chondral injury, which may predispose to early degenerative arthritis of the glenohumeral joint.
- Recurrent instability affecting daily activities despite formal physical therapy generally requires surgical treatment.

PHYSICAL FINDINGS
- Infrequent atrophy
- Symmetric range of motion
- Possible scapulothoracic winging
- Loss of active motion may be related to pain.
- Loss of passive motion may be from capsular contracture.
- Normal strength testing
- Loss of strength can indicate rotator cuff pathology or nerve injury.
- Evaluation for ligamentous laxity
  - Frequently positive for generalized ligamentous laxity
  - Predisposed to shoulder instability
- Evaluation for impingement. Impingement may be a sign of rotator cuff tendinitis or internal impingement in throwers.
- Stability testing
  - Positive increased load and shift test for anterior and posterior translation
  - Positive sulcus sign (both in neutral and external rotation) for inferior translation
  - A sulcus sign graded as 3+ that remains 2+ in external rotation is pathognomonic for multidirectional instability.
- Specific tests
  - Apprehension test: Positive result indicates anterior instability.
  - Relocation test: Positive result indicates anterior instability.
  - O’Brien sign: Pain or click indicates a superior labrum anterior posterior (SLAP) tear; anterosuperior pain indicates acromioclavicular joint pathology.
  - Jerk test: Positive result indicates posteroinferior instability.
  - Kim test: Positive result indicates posteroinferior instability.
  - Circumduction test: Positive result indicates posterior instability.
  - Speed’s test: Positive result indicates biceps tendinitis or SLAP tear.

IMAGING AND DIAGNOSTIC STUDIES
- Plain radiographs
- Anteroposterior view
■ Patients with voluntary or habitual instability

Contraindications
■ Patients who have not attempted a formal physiotherapy program should avoid initial surgical treatment.
■ Any patient unable or unwilling to comply with the postoperative rehabilitation regimen

Surgical Planning
■ Patient education is critical in planning surgical treatment for the patient with an unstable shoulder.
■ Patients should have failed a trial at nonoperative treatment and have persistent instability with functional deficits.
■ The goal of surgical treatment is to reduce capsular volume and restore glenoid concavity with capsulolabral augmentation.
■ Decreasing capsular volume may lead to decreased range of motion.
■ It is important to discuss this possibility with the patient because some more active athletic patients such as throwers, gymnasts, and volleyball players may not tolerate losses of motion to maintain participation in their sport.
■ Additional risks should be discussed, including infection, recurrence of instability, pain, neurovascular injury, persistent functional limitations, and implant complications.
■ The surgical planning continues with the evaluation under anesthesia and diagnostic arthroscopy.
■ This may alter the plan to include any combination of the following: capsular plication (anterior, posterior, or inferior), rotator interval closure, anteroposterior labral repair, SLAP repair, biceps tenodesis or tenotomy, and possible conversion to an open capsular shift.
■ Arthroscopic techniques have evolved from capsular shift via transglenoid sutures, Bankart repair and shift with biodegradable tacks or suture anchors, thermal capsulorrhaphy, rotator interval repair, and capsular plication.
■ Standard portals are listed in Table 2.
■ Our current method of treatment for patients with multidirectional shoulder instability who have failed to respond to nonoperative attempts is to perform an arthroscopic capsular shift by reducing capsular volume using capsular plication with a multipleted repair.18

Table 1  MRI Findings

<table>
<thead>
<tr>
<th>Structure</th>
<th>MRI Finding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior labrum</td>
<td>+/- Bankart tear</td>
</tr>
<tr>
<td>Posterior labrum</td>
<td>+/- Labral tear</td>
</tr>
<tr>
<td>Superior labrum</td>
<td>+/- Superior labrum anterior posterior (SLAP) tear</td>
</tr>
<tr>
<td>Inferior capsule</td>
<td>+/- Capsular laxity, enlarged axillary pouch</td>
</tr>
<tr>
<td>Humeral head</td>
<td>+/- Hill-Sachs or reverse Hill-Sachs lesion</td>
</tr>
<tr>
<td>Glenoid</td>
<td>+/- Bony Bankart or glenoid erosion</td>
</tr>
</tbody>
</table>

NONOPERATIVE TREATMENT
■ In many patients with atraumatic multidirectional instability, proper neuromuscular control of dynamic glenohumeral stability has been lost.
■ The goal is to restore shoulder function through training and exercise.
■ Patients with loose shoulders may not necessarily be unstable, as evidenced by examining the contralateral asymptomatic shoulder in patients with symptomatic multidirectional instability.
■ The mainstay of treatment is nonoperative, with attempts to achieve stability using scapular and glenohumeral strengthening exercises.

SURGICAL TREATMENT

Indications
■ Patients who have attempted a dedicated program of physical therapy, have functional problems, and remain unstable may then be candidates for surgical treatment.
■ Patients with a history of multidirectional instability who sustain fractures of the glenoid or humeral head with a dislocation generally require surgical treatment.
■ Patients with significant defects in the humeral head associated with multiple dislocations consistent with Hill-Sachs lesions may require earlier surgical treatment.
■ Glenoid erosion or lip fractures, if significant, can also necessitate surgical intervention if associated with recurrent instability.

Contraindications
■ Patients with voluntary or habitual instability

Table 2  Arthroscopic Portals

<table>
<thead>
<tr>
<th>Portal</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td></td>
</tr>
<tr>
<td>Posterior</td>
<td>2 cm inferior and medial to posterolateral bor-</td>
</tr>
<tr>
<td>Anterosuperior</td>
<td>der of acromion</td>
</tr>
<tr>
<td>Anteroinferior</td>
<td>Lateral to coracoid (external) and just inferior to biceps tendon (internal) in the rotator int-</td>
</tr>
<tr>
<td>Anteroinferior</td>
<td>erval</td>
</tr>
<tr>
<td>Accessory</td>
<td></td>
</tr>
<tr>
<td>Superior</td>
<td>1 cm lateral and anterior to posterolateral bor-</td>
</tr>
<tr>
<td>Interposter</td>
<td>der of acromion</td>
</tr>
<tr>
<td>Neviser</td>
<td>2 cm inferior to standard posterior portal</td>
</tr>
<tr>
<td></td>
<td>In the notch between posterior acromioclavicu-</td>
</tr>
<tr>
<td></td>
<td>lar joint and spine of scapula</td>
</tr>
</tbody>
</table>
Anesthesia and Patient Positioning

- The procedure can be performed under interscalene block or general endotracheal anesthesia with an interscalene block for postoperative pain control.
- The patient is then placed in the lateral decubitus position with the affected shoulder positioned superior.
  - An inflatable beanbag holds the patient in position.
  - Foam cushions are placed to protect the peroneal nerve at the neck of the fibula on the down leg.
  - An axillary roll is placed.
- The operating table is placed in a slight reverse-Trendelenburg position.
- The full upper extremity is prepared to the level of the sternum anteriorly and the medial border of the scapula posteriorly.
- The operative shoulder is placed in 10 pounds of traction and is positioned in 45 degrees of abduction and 20 degrees of forward flexion.
- Alternatively, the beach-chair position can be used. In our experience, however, this position gives limited exposure of the posterior inferior capsule.
- The head of the bed is raised to about 70 degrees with the affected shoulder off the side of the bed with support medial to the scapula.
- The head should be well supported and all bony prominences padded.
- The entire arm, shoulder, and trapezial region are prepared into the surgical field.

ESTABLISHING LANDMARKS AND PORTALS

- The bony landmarks, including the acromion, distal clavicle, acromioclavicular joint, and coracoid process, are demarcated with a marking pen (TECH FIG 1).
- After prepping and draping the patient, the gleno-humeral joint is injected with 50 mL of sterile saline through an 18-gauge spinal needle to inflate the joint.
- A posterior portal can be established 1 cm proximal (high) and 1 cm lateral (humeral) to the standard posterior portal to allow access to the rim of the posterior glenoid for anchor placement if a posterior labral or capsular repair is necessary.
- An anterior portal is then established in the rotator interval via an outside-in technique using a spinal needle.
  - Care should be taken using the switching stick to verify that the low anterior inferior 5 o'clock anchor can be placed through this portal.
  - If two anterior portals are desired, this portal should be placed “high” in the interval to make room for the second “low” portal.
  - Typically, an additional anteroinferior portal is unnecessary using our multipleated technique.

If a second portal is desired, it is created using a spinal needle at the level just superior to the subscapularis tendon lateral to the coracoid and at least 1 cm inferior to the anterior portal.

TEST FIG 1 • Arthroscopic portals.

DIAGNOSTIC ARTHROSCOPY

- The examination under anesthesia is performed on a firm surface with the scapula relatively fixed and the humeral head free to rotate.
  - A “load and shift” maneuver, as described by Murrell and Warren,13 is performed with the patient supine.
  - The arm is held in 90 degrees of abduction and neutral rotation while an anterior or posterior force is applied in an attempt to translate the humeral head over the anterior or posterior glenoid.
  - A “sulcus sign” is performed with the arm adducted and in neutral rotation to assess whether the instability has an inferior component.
  - A 3+ sulcus sign that remains 2+ or greater in external rotation is considered pathognomonic for multidirectional instability.
- Testing is completed on both the affected and unaffected shoulders, and differences between the two are documented.
- Diagnostic arthroscopy of the glenohumeral joint
  - The labrum, capsule, biceps tendon, subscapularis, rotator interval, rotator cuff, and articular surfaces are visualized in systematic fashion.
  - This ensures that no associated lesions will be overlooked.
- Lesions typically seen in multidirectional instability include:
  - Patulous inferior capsule
  - Labral tears (TECH FIG 2) or fraying and splitting
  - Widening of the rotator interval
  - Articular partial-thickness rotator cuff tears
PREPARATION FOR REPAIR

- The arthroscope remains in the posterior portal and the anterior portals serve as the working portal for the anterior repair and vice versa for the posterior repair.
- The side (anterior or posterior) that is least unstable is fixed first. For example, if posterior instability is the most severe direction, the anterior and inferior sides are fixed first and the posterior capsule and labrum is addressed last.
- After viewing the glenohumeral joint from the posterior portal, the arthroscope is switched to the anterior portal to allow improved visualization of the posterior capsule and labrum.
- A switching stick can then be used in replacing the posterior cannula with an 8.25-mm distally threaded or fully threaded clear cannula (Arthrex Inc., Naples, FL), thus allowing passage of an arthroscopic probe and other instruments through the clear cannula to explore the posterior labrum for evidence of tears.
- An arthroscopic rasp or chisel is used to mobilize any torn labrum from the glenoid rim (TECH FIG 3A).
- A motorized synovial shaver or meniscal rasp is used to abrade the capsule adjacent to a labral tear and to débride and decorticate the glenoid rim to achieve a bleeding surface for capsular plication (TECH FIG 3B).

MULTIPLEATED Plication

- A 3.0-mm Bio-Suture Tak anchor loaded with no. 2 FiberWire (Arthrex, Naples, FL) is placed in the 5 o’clock position (right shoulder) for the anterior repair and the 7 o’clock position for the posterior repair and the sutures are brought out through the working portal (TECH FIG 4A,B).19
- A soft tissue penetrator (Spectrum Suture Hook, Linvatec, Largo, FL) or crescent suture passer is passed through the labrum directly adjacent to the anchor and the inferior FiberWire on the anchor is pulled through the labrum (TECH FIG 4C).
- The penetrator is then used to pierce the inferior capsule in the most anteroinferior (5 o’clock anchor) and lateral point or posteroinferior (7 o’clock anchor) and lateral point.
- Once through the capsule, a no. 1 PDS suture (Ethicon, Johnson & Johnson, Somerville, NJ) is shuttled into the joint and the penetrator is removed (TECH FIG 4D).
- A suture grasper is then used to grab both the passed PDS suture and the labral suture and pull them out of the same portal, or the working portal if two portals are used.
- The PDS suture is tied with a simple knot to the FiberWire and then used to shuttle the working suture through the inferior tuck of capsule (TECH FIG 4E).
- This simple process is repeated while moving superiorly up the capsule until adequate capsular tension is restored (TECH FIG 4F). This can be done multiple times until adequate capsular tension is achieved with each suture.
- The suture is checked to ensure it will still slide, and then a locking sliding knot backed with three half-hitches is tied. The remaining suture is then cut (TECH FIG 4G).
- This is begun posteriorly and inferiorly (7 o’clock anchor), working posterior with additional anchors as necessary (TECH FIG 4H), and then anterior and inferiorly (5 o’clock anchor), working up anterior, again using additional anchors as necessary (TECH FIG 4I). This would be the case if anterior instability is the most severe direction. If posterior instability is predominant, then the plication would begin anteriorly and inferiorly and then finish posteriorly.
- The completed multipleated capsular plication reduces volume and improves stability (TECH FIG 4J).
**ARTHROSCOPIC KNOT TYING**

- We prefer the sliding, locking Weston knot, but a number of arthroscopic knot-tying techniques work well.
- What is most important is that the surgeon is familiar with the knot used and skilled in its use.
- The posterior braided suture exiting through the capsule is threaded through a knot-pusher and the end is secured with a hemostat.
- This suture serves as the post, which in effect will advance the capsule and labrum to the glenoid rim when the knot is tightened.
- The knot should be secured posteriorly on the capsule, not on the rim of the glenoid, to prevent humeral head abrasion from the knot.
- Each half-hitch must be completely seated before the next half-hitch is thrown.
- Placing tension on the non-post suture and advancing the knot-pusher "past point" will lock the Weston knot.
- A total of three alternating half-hitches are placed to secure the Weston knot.
- This knot has been found to be biomechanically similar to an open square knot.\(^4\)

**ROTATOR INTERVAL CLOSURE**

- In the setting of multidirectional instability, the rotator interval may not require closure (defined by a 2+/ or greater sulcus sign that does not improve in external rotation) if a multipleated repair is performed both anteriorly and posteriorly to bring up the entire axillary pouch.\(^16\)
- However, if rotator interval closure is required, it is viewed with the arthroscope in the posterior portal.
- A crescent suture passer is advanced from the anterior portal through the anterior capsule just above the superior border of the subscapularis tendon 1 cm lateral to the glenoid.
- It is then passed through the middle glenohumeral ligament at the inferior border of the rotator interval. This makes up the inferior aspect of the rotator interval closure.
- A no. 0 PDS suture is then fed into the joint and retrieved with a penetrator through the superior glenohumeral ligament.
- The PDS suture is then withdrawn out the anterior cannula and exchanged for a no. 2 FiberWire. The knot is then tied blindly in the cannula on the outside of the anterior capsule as the closure is visualized through the posterior portal.

**POSTERIOR PORTAL CLOSURE**

- A crescent suture passer is advanced from the posterior portal through the posterior capsule just above the superior border of the capsular opening of the posterior portal (TECH FIG 5A).
- A no. 0 PDS suture is then fed into the joint and retrieved with a penetrator through the inferior border of the capsular opening in the posterior portal (TECH FIG 5B).
- The PDS suture is then withdrawn out the posterior cannula and exchanged for a no. 2 FiberWire. The knot is tied blindly in the cannula on the outside of the posterior capsule as the closure is visualized through the anterior portal (TECH FIG 5C).

---

**TECH FIG 5**

A. Placing crescent suture passer through posterior capsular and passing PDS suture into the joint.
B. Passing suture grasper through posterior capsule for closure of posterior portal.
C. Completed closure of the posterior portal after capsular plication.
POSTOPERATIVE CARE

■ The patient is discharged home on the day of surgery.
■ The sutures are removed 6 to 8 days later.
■ The arm is immobilized in an Ultrasling (DonJoy, Carlsbad, CA) for 6 weeks (30 degrees abduction in neutral rotation).
■ The sling is removed for bathing and for gentle pendulum and elbow, wrist, and hand range-of-motion exercises.
■ Isometric exercises are started at week 3, passive and active-assisted range-of-motion exercises at week 3.
■ Sling is discontinued at week 6.
■ Active range of motion is started at week 6.
■ Sport-specific exercises are started at 4 months.
■ Overhead sports are started at 6 months.
■ The patient can return to contact sports at 6 to 8 months.

OUTCOMES

■ Table 3 summarizes outcomes of clinical studies.
■ Several studies have investigated the effect of surgical intervention on capsular volume.
■ Comparisons have been made between open capsular shifts using numerous techniques, arthroscopic thermal plications, and arthroscopic suture capsular plications by testing capsular volume in cadaveric specimens before and after procedures.
■ Table 4 summarizes the results and type of shift performed in these studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>Procedure Performed</th>
<th>Follow-up (mo)</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duncan &amp; Savoie, 1993³</td>
<td>Scope inferior capsular shift</td>
<td>12–36</td>
<td>100% satisfactory</td>
</tr>
<tr>
<td>Pagnani et al, 1996¹⁵</td>
<td>Scope stabilization using transglenoid sutures</td>
<td>48–120</td>
<td>74% good or excellent</td>
</tr>
<tr>
<td>McIntyre et al, 1997¹¹</td>
<td>Scope capsular shift</td>
<td>34</td>
<td>95% good or excellent</td>
</tr>
<tr>
<td>Treacy et al, 1999²²</td>
<td>Scope capsular shift</td>
<td>60</td>
<td>88% satisfactory</td>
</tr>
<tr>
<td>Gartsman et al, 2000⁹</td>
<td>Scope labral repair + laser capsulorrhaphy</td>
<td>26–63</td>
<td>92% good or excellent</td>
</tr>
<tr>
<td>Tauro, 2000⁵¹</td>
<td>Scope inferior capsular split and advancement</td>
<td>24–60</td>
<td>88% satisfactory</td>
</tr>
<tr>
<td>Fitzgerald et al, 2002⁶</td>
<td>Scope thermal capsulorrhaphy</td>
<td>36</td>
<td>76% satisfactory</td>
</tr>
<tr>
<td>Favorito et al, 2002⁸</td>
<td>Scope laser-assisted capsular shift</td>
<td>28</td>
<td>81.5% success</td>
</tr>
<tr>
<td>Frostick et al, 2003³</td>
<td>Scope laser capsular shrinkage</td>
<td>26</td>
<td>83% satisfactory</td>
</tr>
<tr>
<td>D’Alessandro et al, 2004²</td>
<td>Scope thermal capsulorrhaphy</td>
<td>38</td>
<td>63% satisfactory</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study</th>
<th>Type of Capsular Shift</th>
<th>Amount of Volume Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miller et al, 2003¹²</td>
<td>Three open (medial, lateral, vertical)</td>
<td>Medial = 37%</td>
</tr>
<tr>
<td>Karas et al, 2004⁹</td>
<td>Three arthroscopic (thermal, suture plication, combined)</td>
<td>Lateral = 50%</td>
</tr>
<tr>
<td>Victoroff et al, 2004²³</td>
<td>Arthroscopic thermal</td>
<td>Vertical = 40%</td>
</tr>
<tr>
<td>Luke et al, 2004¹⁰</td>
<td>Open inferior vs. arthroscopic thermal</td>
<td>Scope thermal = 33%</td>
</tr>
<tr>
<td>Cohen et al, 2005¹</td>
<td>Open lateral vs. arthroscopic plication</td>
<td>Scope plication = 19%</td>
</tr>
<tr>
<td>Sekiya et al, 2007¹⁷</td>
<td>Open inferior vs. arthroscopic multipleated plication</td>
<td>Scope combined = 41%</td>
</tr>
</tbody>
</table>
Chapter 4  ARTHROSCOPIC TREATMENT OF MULTIDIRECTIONAL SHOULDER INSTABILITY

COMPLICATIONS

- Loss of motion
- Recurrence of instability
- Neurovascular injury
- Failure to address missed causes of instability
- Large Hill-Sachs lesions that cause instability and are not addressed at surgery may lead to recurrence.20

REFERENCES

DEFINITION
- Superior labral (SLAP) tears represent injury to the superior aspect of the glenoid labrum, extending from anterior to posterior, including the biceps anchor.14

ANATOMY
- The superior glenoid labrum is composed of fibrocartilaginous tissue between the hyaline cartilage of the glenoid surface and the joint capsule fibrous tissue.13
- The vascular supply of the glenoid labrum does not come from the underlying glenoid, but rather from penetrating branches of the suprascapular, circumflex scapular, and posterior humeral circumflex arteries in the surrounding capsule and periosteal tissue.
- There is histologic evidence that vascularity is decreased in the anterior, anterosuperior, and superior aspects of the glenoid labrum.2

PATHOGENESIS
- The long head of the biceps functions to depress the humeral head and serves as an adjunct anterior stabilizer of the shoulder.5,6
- Disruption of the biceps anchor and the superior labrum, as seen in type II SLAP tears, can result in glenohumeral instability.
- Although SLAP tears are commonly associated with trauma such as traction or compression injuries, up to one third of patients with SLAP lesions have no history of trauma.10
- SLAP tears are commonly classified according to Snyder14 as type I (fraying of superior labrum with intact biceps anchor), type II (detached superior labrum and biceps anchor), type III (bucket-handle tear of the superior labrum with intact biceps anchor), and type IV (bucket-handle tear of the superior labrum with extension into the biceps tendon).
- Other variations have been described that reflect associated injury to the anterior labrum and other structures.8

NATURAL HISTORY
- Conservative nonoperative treatment of SLAP tears is usually unsuccessful.
- Simple débridement of unstable SLAP tears (type II and IV) is generally not recommended because the results are poor.3

PATIENT HISTORY AND PHYSICAL FINDINGS
- Traction and compression are the two primary mechanisms of injury for SLAP tears.
- A SLAP tear should be considered in a patient with a history of a traction or compression injury with persistent mechanical symptoms such as catching or locking.
- Several clinical tests have been described that focus on the examination of the biceps tendon anchor on the superior glenoid. The Speed, Yergason, O’Brien, and load-compression tests are commonly used.
  - Speed and Yergason tests: Pain with the maneuvers suggests a SLAP tear.
  - O’Brien test: Pain with downward pressure applied to the internally rotated arm that is relieved with supination suggests a SLAP tear.
  - Load-compression test: Painful clicking or popping suggests a SLAP tear.
- Type II SLAP tears found in younger patients are commonly associated with instability and a Bankart lesion, whereas type II SLAP tears found in patients older than 40 are often associated with rotator cuff pathology.7
- Although no single clinical test can predictably be used to diagnose a SLAP tear, the examiner should use all of these tests, along with the history and a high clinical index of suspicion, to make the diagnosis of a SLAP tear.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Although conventional radiographs (anteroposterior and supraspinatus outlet and axillary views) are the standard for initial evaluation of a patient with shoulder complaints, magnetic resonance imaging (MRI) is the most sensitive imaging tool for evaluating the superior glenoid labrum, with a sensitivity and specificity of about 90%.1
- The use of contrast arthrography MRI may improve the overall accuracy of MR for diagnosing SLAP tears.9
- Despite advances in imaging techniques, the gold standard for the diagnosis of a SLAP tear is arthroscopy.

DIFFERENTIAL DIAGNOSIS
- Glenohumeral instability
- Rotator cuff pathology
- Acromioclavicular joint pathology

NONOPERATIVE MANAGEMENT
- Physical therapy is the mainstay of nonoperative treatment of most shoulder injuries.
- Selective intra-articular injections with local anesthetic and corticosteroids can be diagnostic and occasionally therapeutic.
- The rehabilitation program should focus on achieving and maintaining a full range of motion and strengthening the rotator cuff and scapula stabilizers.
- Although physical therapy may be useful for regaining range of motion and strength, most patients with SLAP tears will continue to have symptoms despite physical therapy.

SURGICAL MANAGEMENT
- Surgical treatment of SLAP tears should be considered for patients who have persistent symptoms despite appropriate conservative management.
Chapter 5  ARTHROSCOPIC TREATMENT OF SUPERIOR LABRAL (SLAP) TEARS

- Contraindications for SLAP repair include patients who are high-risk surgical candidates (ie, the risk of anesthetic complications outweighs the possible benefits of successful repair).

Preoperative Planning
- Preoperative assessment of glenohumeral instability is paramount to understanding the pathophysiology of a patient’s shoulder complaints.
- Associated instability and any other coexisting pathology must also be addressed at the time of SLAP repair.

Positioning
- Beach-chair position
- Lateral decubitus position
  - May be preferred for cases of suspected labral pathology, especially if associated with posterior instability, because this position allows improved visualization and access with distraction.

- No more than 10 to 15 pounds of traction should be used owing to increased risk of brachial plexus injuries.

Approach
- The primary goal of any SLAP repair is to stabilize the biceps anchor and address any coexisting pathology.
- After a thorough diagnostic evaluation, SLAP lesions are treated according to Snyder14 (see the Techniques section).
  - Standard anterosuperior and anteroinferior portals are established.
  - Accessory portals may also be established depending on the location of the SLAP tear.

**TYPE I SLAP TEARS**
- Type I SLAP tears may be treated using a motorized shaver to simply débride the degenerative or frayed tissue.

- Care must be taken not to detach the biceps anchor from the superior glenoid.

**TYPE II SLAP TEARS**
- Type II SLAP tears are the most commonly encountered SLAP tears (TECH FIG 1).
  - They represent detachment of the biceps anchor from the superior glenoid labrum.
  - As such, the primary goal of any repair should be to securely reattach the superior labral tissue to the superior glenoid.

Glenoid Preparation
- After identifying the detachment by direct probing, a 4.5-mm motorized shaver is used to gently débride any frayed or degenerative tissue.
- A motorized burr is used to débride the superior glenoid to exposed, bleeding bone (TECH FIG 2).

Accessory Portal Placement
- An accessory trans-rotar cuff portal is made using an outside-in technique. No cannula is inserted because this portal will be used only to insert the anchor.

  This portal may be adjusted anteriorly or posteriorly depending on the location of the SLAP tear.
  - A spinal needle is used to ensure that the correct trajectory is achieved to place the anchor at about a 45-degree angle to the glenoid face.
  - A no. 11 blade knife is used to make the skin incision, but a cannula is not inserted because this portal will be used only to insert the suture anchor drill guide and anchor after drilling.

Suture Anchor Placement
- The suture anchor drill guide is placed on the glenoid face at about a 45-degree angle to the face, ensuring that the anchor will be solidly in bone (TECH FIG 3).
  - The suture anchor may be single- or double-loaded with nonabsorbable no. 2 braided suture, depending on preference.
  - If more than one suture anchor is to be used, the surgeon starts the repair posteriorly and works anteriorly to aid in visualization.
  - The anchor is placed in the same trajectory as the drill, ensuring that the drill guide is maintained in its proper orientation and position.

**TECH FIG 1** • Arthroscopic view of type II superior labral anterior posterior (SLAP) lesion.

**TECH FIG 2** • Preparing superior glenoid with burr.
Suture Management

- One limb (limb a) of the suture is retrieved out through the anterior superior cannula, using either a crochet hook or suture grasper.
- A crochet hook is used to capture the other limb (limb b) of the anchor suture and bring it out the anterior inferior cannula (TECH FIG 4).

Suture Passage

- Through the anterosuperior cannula and starting at the posterior edge of the tear superiorly, the surgeon passes a tissue penetrator (Spectrum, ConMed Linvatec, Largo, FL) through the labrum (TECH FIG 5A,B).
  - A 45-degree left-curved tissue penetrator is used for a right shoulder SLAP tear (45-degree right-curved for the left shoulder) loaded with a no. 1 monofilament or Shuttle Relay suture passer (ConMed Linvatec, Largo, FL) as a pull-through suture.
  - An arthroscopic grasper inserted through the anteroinferior cannula is used to grasp the monofilament passing suture as it penetrates the superior labrum, and the free end is pulled out through the anteroinferior cannula (TECH FIG 5C,D).
  - A simple knot is tied in the passing suture (see Tech Fig 5D, inset) and the free end of limb b from the suture an-
Simple débridement of the labral bucket-handle tear is the preferred surgical technique for type III SLAP tears because the biceps anchor is intact.

**TYPE III SLAP TEARS**

- Simple débridement of the labral bucket-handle tear is the preferred surgical technique for type III SLAP tears because the biceps anchor is intact.

**Knot Tying**
- Making sure that the post limb is off the glenoid surface, the surgeon ties the suture using either a sliding knot or a series of half-hitches, taking care to switch posts and alternate directions of the loops.
- The excess suture is cut using an arthroscopic suture cutter.

**Additional Suture Anchor Placement**
- This procedure is repeated until the biceps anchor has been securely reattached to the superior glenoid (TECH FIG 6).
- The surgeon should take care when securing the anterior aspect of the SLAP tears so that a normal labral foramen or an anterosuperior labral variant is not incorrectly identified as a SLAP tear, causing inadvertent tightness and resulting in decreased range of motion.

**Tech FIG 5 (continued)**
- The surgeon firmly pulls the shuttle relay suture through the anterosuperior cannula so that the two ends of the anchor suture are together in the anterosuperior cannula.

**Tech FIG 6**
- Completed superior labral anterior posterior (SLAP) lesion repair.
## Type IV SLAP Tears

- Type IV SLAP tears involve a bucket-handle tear of the superior labrum with a tear of the biceps tendon.
- The biceps anchor may be detached as well.
- Treatment is débridement of the labral tear and biceps tendon tear, with repair of the biceps anchor if needed, essentially converting the tear to a type II and then repairing the anchor detachment.
- In an older patient with significant biceps tendon degeneration, biceps tenodesis should be considered.
- Similarly, in a younger patient with a tear extending into the biceps tendon, repair of any tendon tears should be considered.

## Pearls and Pitfalls

### Indications
- All associated pathology is identified and addressed (eg, instability, rotator cuff pathology, acromioclavicular joint disorders).

### Planning
- Lateral decubitus positioning is considered if posterior labral pathology is suspected.

### Portal Placement
- Proper technique must be used in placing portals at the beginning of the case, with attention to positioning of the portals both in the superoinferior plane and the medial-lateral plane. Improperly placed portals can greatly increase the difficulty of this operation. A spinal needle is used to judge the angle of approach for each portal before making the portal to ensure that the correct trajectory is obtained.

### Suture Management
- When retrieving and handling anchor sutures, the surgeon should not place tension on either limb and should maintain continuous visualization of the anchor–suture interface to ensure that the anchor is not unloaded. The surgeon should take care to avoid twists because these can place increased stress on a suture or knot and lead to breakage. The surgeon should place one anchor at a time and tie each suture or remove and replace the cannula and place the suture outside the cannula for suture storage to prevent tangles during tying.

### Other
- Articular cartilage damage is avoided by firmly seating the drill guide on the edge of the glenoid and avoiding skiving onto the glenoid face.

## Postoperative Care

- 0 to 4 weeks: Sling at all times except for hygiene and exercises. (Active range of motion allowed in all planes except external rotation in abduction starting at 2 weeks.)
- 4 weeks: Discontinue sling. Start passive range of motion with emphasis on posterior capsule stretching.
- 6 weeks: External rotation in abduction allowed. Start strengthening.
- 3 months: Sports allowed except throwing (4 months)

## Outcomes

Table 1 summarizes outcomes from studies of SLAP tear repairs.

### Table 1: Results of Arthroscopic Superior Labral Anterior Posterior (SLAP) Lesion Repair

<table>
<thead>
<tr>
<th>Study</th>
<th>Surgical Procedure</th>
<th>No. of Patients</th>
<th>Average Follow-up</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cordasco et al, 1993</td>
<td>Débridement only</td>
<td>27</td>
<td></td>
<td>89% good or excellent results at 1-year follow-up; 63% excellent results at 2-year follow-up; only 44% return to competition at 2-year follow-up</td>
</tr>
<tr>
<td>Field &amp; Savoie, 1993</td>
<td>Arthroscopic suture repair</td>
<td>20</td>
<td>21 mo</td>
<td>Rowe scale: 100% good or excellent results ASES scores: statistically significant increase in function score, decrease in pain score</td>
</tr>
<tr>
<td>Morgan et al, 1998</td>
<td>Arthroscopic suture repair</td>
<td>102</td>
<td>1 year</td>
<td>97% good or excellent results 4% return to competition among overhead throwers</td>
</tr>
<tr>
<td>O’Brien et al, 2002</td>
<td>Arthroscopic suture repair</td>
<td>31 (type II)</td>
<td>3.7 yr</td>
<td>71% good or excellent, 19% fair results Average postoperative ASES score: 87.2</td>
</tr>
</tbody>
</table>

ASES, American Shoulder and Elbow Society.
■ Failed repair
■ Repeat arthroscopy should be considered with revision repair.
■ Biceps tenodesis should be considered for severely degenerative or intractable cases.

REFERENCES
DEFINITION

- Throwers place unique stress on their shoulder girdles due to the repetitive nature and magnitude of force associated with the activity.
- Throwing athletes are prone to shoulder dysfunction due to chronic fatigue and weakening of the posterior shoulder musculature that over time leads to maladaptive contracture of the posterosuperior glenohumeral joint capsule.\(^5\)
- Posterosuperior capsular contracture alters the biomechanics of the glenohumeral joint during the throwing motion and produces a predictable constellation of injuries in disabled throwers, including superior labral and biceps anchor disruption, undersurface progressing to full-thickness rotator cuff tears, and disruption of the anteroinferior capsule or labrum.\(^3\)
- Symptoms resulting from these injuries have commonly been referred to as the “dead arm syndrome,” where the athlete cannot compete at the premorbid level due to shoulder discomfort with throwing and resultant loss of pitch velocity and control.\(^3\)
- Although most often seen in pitchers, similar shoulder dysfunction may occur in baseball position players as well as athletes in other sports requiring forceful and repetitive overhead activity.

ANATOMY

- Eighteen muscles attach to the scapula and control its position on the chest wall.
  - Scapular position dictates glenoid position and orientation and is critical for normal glenohumeral function.
  - A force of up to 1.5 times body weight is generated during the throwing cycle. The scapular stabilizers and posterior rotator cuff muscles contract violently at ball release and protect the glenohumeral joint from the deceleration force of the arm.
  - The relative position of the glenohumeral ligaments with different arm positions. As the arm is brought into full abduction and external rotation (late cocking phase), the posterior band of the inferior glenohumeral ligament complex (PIGHL) moves from a posterosuperior position to a position directly inferior (6 o’clock) in relation to the glenoid.\(^3\)

PATHOGENESIS

- Posterior shoulder muscle weakness due to chronic, repetitive loading is the inciting lesion causing disability in throwers.
- Posterior muscle weakness leads to shoulder dysfunction as a result of both scapular dyskinesis and PIGHL contracture. One of these pathologic entities may predominate in the disabled thrower, but they are generally intimately related.\(^3\)
- In scapular dyskinesis, the position of the scapula on the chest wall (or “scapular attitude”) is altered owing to loss of scapular elevation and retraction control. The scapula drops (infera), moves lateral from the midline (protraction), and abducts from the midline. The inferior scapular angle may also lift off the chest wall and pitch toward the front of the body (antetilt).
  - The predominant direction of these positional changes will vary depending on which scapular muscles are predominantly affected.
  - Altered scapular position causes abnormal tension on the insertion of scapular stabilizer muscles and over time leads to inflammation and pain (“traction tendinopathy”).\(^5\)
  - PIGHL contracture involves failure of the weakened posterior shoulder muscles to counteract the distraction force of the arm after ball release exposes the PIGHL to abnormal stress due to the forward-flexed and adducted position of the arm at follow-through. Fibroblastic thickening and contracture of the PIGHL occur as a maladaptive response to greater stress (Wolf’s law of collagen).
  - PIGHL contracture can be identified clinically as a scapular-stabilized glenohumeral internal rotation deficit (GIRD) in the throwing shoulder (designated by subscript “ts”) versus nonthrowing shoulder (subscript “nts”).\(^3\)
  - The thickened PIGHL alters the normal biomechanics of the glenohumeral joint, particularly as the arm is brought into abduction and external rotation (late cocking phase). The normal glenohumeral contact point is shifted posteriorly and superiorly due to the thickened and contracted PIGHL occupying a position directly inferior to the humeral head in this arm position (FIG 1A,B).\(^6\)
  - Alteration of the glenohumeral contact point leads to a predictable pathologic cascade with continued throwing.\(^3\)
    - Posterosuperior shift allows greater clearance of the tuberosity over the posterosuperior glenoid rim, enabling pathologic hyperexternal rotation of the arm in the late cocking phase.
    - Increased external rotation of the throwing shoulder is adaptive in these athletes to some extent (used to maximize throwing arc and angular velocity at ball release).\(^3\)
  - However, pathologic hyperexternal rotation leads to:
    - An abnormal posteriorly directed force vector and torsion on the biceps anchor. The biceps anchor ultimately fails and “peels back” medially along the posterosuperior glenoid neck (the “SLAP event”). SLAP tears are typically anterior and posterior or posterior subtypes of type II tears (the “thrower’s SLAP”).\(^8\)
    - Rotator cuff tears occur because of abrasion and torsion of tendon fibers. Torsion failure is most pronounced on the articular side of the tendons, resulting in partial undersurface tears most commonly seen in throwers. These tears may at times progress to full thickness with continued throwing.
    - Posterosuperior shift of the glenohumeral contact point causes relative relaxation and “pseudo-laxity” in the anterior capsule (FIG 1C,D). With continued hyperexternal rotation, tension may ultimately cause anteroinferior capsular fiber attenuation, leading to tertiary anterior glenohumeral instability, which occurs in about 10% of
affected athletes. Discrete “Bankart-type” lesions of the labrum occasionally occur in this group. Anterior instability is a later event in the pathologic cascade, not the primary lesion as previously described.7

**NATURAL HISTORY**

- Athletes manifesting clinical findings of posterior muscle weakness and scapular asymmetry without signs of labral or rotator cuff pathology may correct their shoulder dysfunction with a progressive scapular muscle strengthening program and return to normal function when asymmetry resolves.
- Throwers who have vague shoulder discomfort and demonstrate an internal rotation deficit (GIRD) are started on focused internal rotation stretches (“sleeper” stretches) to alleviate PIGHL contracture and restore normal glenohumeral biomechanics. GIRD reduction to less than 20 degrees removes the athlete from being at risk for shoulder injury and generally allows return to premorbid function.

**FIG 1** • A,B. Depiction of altered glenohumeral biomechanics due to an acquired posterior band of the inferior glenohumeral ligament complex (PIGHL) contracture and the resulting posterosuperior shift in the glenohumeral contact point as the arm is brought from neutral (A) to full abduction and external rotation (B), or late cocking phase. In the fully cocked position, the PIGHL occupies a position inferior to the humeral head, which forces the humeral head superiorly and tethers it posteriorly.
- C,D. Drawings in the axial plane showing relative relaxation of the anterior capsule in the late cocking position as a result of the posterosuperior shift in the glenohumeral contact point in a shoulder with PIGHL contracture.
- In a normal shoulder, the anterior capsule is taut over the cam shape of the humeral head. In PIGHL contracture, the humeral head shifts posteriorly, which decreases tension in the anterior capsule, creating relative laxity. C, center of glenoid.
Pain with throwing is indicative of injury to glenohumeral structures.
- Once actual injury to glenohumeral structures, particularly the labrum, has occurred, mechanical symptoms ensue and the thrower will not be able to return to normal function without surgical repair.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Common early complaints include vague tightness in the shoulder and a difficulty or inability to “get loose” during a warm-up period.
- Pitchers describe a loss of control and decrease in throwing velocity, which early on may be pain-free.
- Pain is most prominent during the late cocking phase of throwing when the peel-back phenomenon of the superior labrum occurs, caused by the posterosuperior glenohumeral shift.4
  - Pain is localized to the posterosuperior shoulder and is described as “deep.”
  - Mechanical symptoms, such as painful popping or clicking, may occur after injury to the superior labrum, particularly during late cocking and early acceleration.
- The surgeon should check for tenderness in the coracoid, the acromioclavicular joint, and the superomedial scapular angle.
- Both shoulder girdles must be completely exposed or subtle asymmetry will be overlooked.
  - Inspection is done with the patient standing in front of fixed vertical and horizontal references (such as window blinds or door frames) so that affected and nonaffected shoulders can be compared for scapular height and malposition (FIG 2).
  - Superior and inferior angles as well as the medial scapular border are marked as a visual reference. Spinous processes are marked for a midline reference.
  - Asymmetry from the unaffected side when in protraction or infera indicates scapular stabilizer muscle weakness.
  - When in abduction or antetilt, increasing magnitude compared to opposite side signifies scapular muscle weakness.
  - Range-of-motion measurements are performed in the supine position with the scapula stabilized by anterior pressure over the glenohumeral joint directed into the examination table, which prevents contribution of scapulothoracic motion. Nonstabilized measurements will be erroneously high and will not reveal the true magnitude of glenohumeral pathology.
- Measurements are made using a special goniometer that incorporates a carpenter’s bubble level to provide a vertical reference point (perpendicular to floor) from which measurements are made.
- External rotation (ER) + internal rotation (IR) = total mobility arch (TMA)
  - IR\textsubscript{as} - IR\textsubscript{ts} = glenohumeral internal rotation deficit (GIRD)
  - TMA\textsubscript{as} \approx TMA\textsubscript{ts} in healthy throwers
  - GIRD\textsubscript{a} > 20 degrees seen in “shoulders at risk” for injury; generally GIRD\textsubscript{a} \approx loss of TMA\textsubscript{ts} vs. TMA\textsubscript{as}
- Scapular relocation tests are performed in the supine position with the arm maximally forward-flexed. A positive test is indicated by pectoralis minor tension that is accentuated with the arm forward-flexed; traction at the coracoid insertion is relieved by scapular repositioning.
  - The specificity of tests for type II SLAP lesions in throwers has been determined as follows:5
    - The modified Jobe relocation test is specific for posterior subtype. In throwers with SLAP tears, their usual pain is reproduced and they will localize to the posterosuperior joint line (“deep”). Pain in the abduction and external rotation (ABER) position is due to an unstable labrum; anterior pressure reduces the labrum and relieves pain.
    - O’Brien’s test is specific for anterior subtype. A positive result is defined as pain with resisted forward flexion and pronation; pain is diminished or relieved with supination.
    - The Speed test is specific for anterior subtype. A positive result is defined as pain with resisted forward flexion.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs: anteroposterior (AP), scapular lateral, and axillary views to detect bone or joint space abnormalities
- Magnetic resonance (MR) arthrography: We routinely order intra-articular contrast material because it improves the ability to detect labral and capsular abnormalities as well as partial-thickness rotator cuff tears (FIG 3).

FIG 2 • Thrower with right scapular dyskinesis. Scapular asymmetry is highlighted by marking the superior and inferior scapular angles as well as the midpoint of the medial border. Affected right side shows scapular infera and protraction compared to the unaffected left side.

FIG 3 • Coronal MRI arthrogram study. The vertically oriented high-signal lesion in the substance of the biceps anchor (circle) suggests a superior labrum anterior-to-posterior (SLAP) tear. In addition, there is evidence of partial undersurface tearing of the supraspinatus tendon.
DIFFERENTIAL DIAGNOSIS
- Subacromial irritation secondary to rotator cuff weakness and dysfunction
- Various forms of anterior shoulder pain, acromioclavicular joint dysfunction, and posterior periscapular pain secondary to scapular dyskinesis and the SICK scapula syndrome (Scapular malposition, Inferior medial scapular winging, Coracoid tenderness, and scapular dyskinesis).5
- Pain with throwing may occur with rare conditions such as bone tumors, stress fractures, and growth plate abnormalities.

NONOPERATIVE MANAGEMENT
- Symptomatic athletes are begun on a scapular reconditioning program combined with internal rotation posteroinferior capsular “sleeper” stretches.
- Scapular reconditioning focuses on regaining scapular elevation and retraction control; progress is assessed by repeat examination for normalization of scapular symmetry.
  - Initially bilateral shoulder shrugs and rolls are combined with retraction “no money” exercises.
  - The patient progresses to closed-chain “table top” movements and wall-washing motions.
  - Finally, prone “Blackburn”-type exercises are instituted.
- “Sleeper” stretches focus on the posteroinferior capsular contracture that initiates the internal derangement in the glenohumeral joint (FIG 4). Response to a course of internal rotation stretching will determine the extent of the PIGHL contracture.
  - 90% of athletes will decrease their GIRD to an acceptable magnitude with 10 to 14 days of focused stretching (less than 20 degrees) with near-normalization of TMA<sub>Ants</sub> and TMA<sub>Ans</sub>.
  - The remaining 10% have recalcitrant PIGHL contracture and will show little or no decrease in GIRD after a period of stretching; they are termed stretch nonresponders. These are generally veteran athletes with longstanding GIRD and may require posteroinferior quadrant capsulotomy to regain internal rotation.

SURGICAL MANAGEMENT
- Athletes presenting with pain and mechanical symptoms during throwing as well as findings suggestive of intra-articular pathology on MR arthrogram are indicated for arthroscopic evaluation and treatment.
- Rarely, posteroinferior capsulotomy is indicated in throwers unresponsive to internal rotation stretching to decrease GIRD. This portion of the procedure is almost never necessary in a young thrower, however.
- Contraindications to the surgical technique below include those similar to other elective arthroscopic shoulder procedures.

Preoperative Planning
- Surgical treatment of the throwing shoulder may involve repair of the superior labrum as well as associated injuries to the rotator cuff and anterior capsulolabral structures, as well as contracture of the posteroinferior capsule.
  - All pathology must be anticipated before beginning the case, and all necessary instruments and materials need to be present on the back table to prevent intraoperative delays.
  - A fluid pump is used during the procedure to distend the joint and limit bleeding to improve visualization (set at 60 mm Hg). Prolonged procedures increase the risk of having to perform the surgery through distended tissue, which makes instrument manipulation in the joint difficult and can severely compromise the procedure.
  - The following order of possible intra-articular repairs is recommended to ease visualization and prevent loss of access to various locations in the joint:
    - Anteroinferior labral repair (if required)
    - Posterior SLAP repair
    - Anterior SLAP repair
    - Anterior capsular redundancy (if present)
    - Posteroinferior capsulotomy (if required)
    - Rotator cuff tear (if present)

Treatment of Associated Injury
- We débride partial-thickness rotator cuff tears that represent less than 50% of the diameter and repair those larger than 50% of the diameter as described in Chapter SM-10.
  - Given the young age and high-level activity of these athletes, strong consideration should be given to repair in borderline cases.
- Anteroinferior capsulolabral injury
  - Throwers may develop stretching and attenuation of the anteroinferior capsule, separation of the anteroinferior labrum from the glenoid rim, or a combination of the two.
  - We perform mini-plication of the anterior capsule in the following circumstances:
    - Evidence of frayed or attenuated anterior capsule with intact anterior labrum
    - A persistent drive-through sign after superior labral repair, or more than 120 degrees of external rotation at 90 degrees of abduction noted during the preoperative examination
    - Posterior capsular release is rarely indicated (about 10% of cases).
  - Response to internal rotation stretching is assessed preoperatively.
Patients displaying little to no response to stretching (unable to attain GIRD less than 20 degrees) are indicated for capsulotomy to allow restoration of full motion and normal glenohumeral biomechanics.

Positioning
- A preoperative intrascalene nerve block is recommended to improve pain control postoperatively.
- Antibiotics for skin flora are administered.
- The patient is in the lateral decubitus position using an inflatable beanbag.
- The arm is secured to a rope and pulley system that is attached to 10 pounds of weight.
- A spring-gated, carabiner-type device is added between the end of the traction cord and the suspension pulley so that an unscrubbed assistant can remove the arm from traction during the procedure for dynamic diagnostic maneuvers (see below).
- Advantages of the lateral decubitus position include:
  - Better visualization of the superior labrum and widening of the superior recess due to gravity for easier anchor placement and knot tying

Approach
- The following arthroscopic portals are used to varying extents in the surgical treatment of disabled throwers:
  - Posterior: established first; main viewing portal
  - Anterior: main working portal: knot tying; anchor placement in anterosuperior glenoid rim
  - Posterolateral ("portal of Wilmington"): anchor placement in the posterosuperior glenoid; passage of sutures through the posterosuperior labrum. No cannulas are used in this percutaneous portal. Only small-diameter anchor insertion devices and suture passers are used to minimize injury to the cuff musculature because this portal traverses the muscular portion of the posterosuperior rotator cuff.
  - Anterosuperior: accessory portal added depending on the nature of the intra-articular pathology; may be used to view the anteroinferior labrum and capsule, or to assist in shuttling sutures through the anteroinferior capsule

## ESTABLISHING PORTALS
- The posterior portal is established by identifying the posterolateral acromial border and making a 5-mm skin incision about 2 cm medial and 2 to 3 cm inferior to the posterior corner of the acromion in the palpated soft spot between the infraspinatus and teres minor portions of the rotator cuff.
  - A blunt trocar is directed from this incision anteriorly with gentle pressure to palpate the space between the rounded humeral head laterally and the glenoid rim medially.
  - The coracoid process is palpated with the opposite index finger and is used as a guide to direct the trocar to the correct plane into the glenohumeral joint.
- The remaining portals are established after arthroscopic examination of the joint using an "outside-in" technique with an 18-gauge spinal needle.
  - The spinal needle creates minimal soft tissue trauma, and multiple passes can be made as needed to determine the proper location of secondary portals to yield unimpeded trajectories to areas of the joint requiring repair (TECH FIG 1).

## DIAGNOSTIC ARTHROSCOPY
- The joint is systematically inspected to ensure that all areas are examined and no pathology is overlooked.
  - Areas requiring particular attention in disabled throwers include superior labrum and biceps anchor, rotator cuff insertion, posterior capsule and recess, and anteroinferior labrum and capsule.
- We routinely perform provocative tests to assess both superior labral integrity and overall stability in the joint.
  - Peel-back test: The posterosuperior labrum is assessed dynamically for evidence of instability in the abducted and externally rotated position (late cocking position). The arm is released from traction and is brought into the full cocking position; an unstable labrum will fall off the glenoid rim and shift medially along the glenoid neck (TECH FIG 2A–D).
  - Drive-through test: Normally, intact capsular and labral restraints appose the humeral head into the glenoid such that easy passage of the arthroscope from posterior to anterior at the midpoint of the glenoid or sweeping of the scope from superior to inferior along the anterior glenoid rim is not possible. When these maneuvers are possible, they are nonspecific evidence of disruption of the labrum or capsular ligaments according to the “circle concept” of glenohumeral stability.3,9
Fraying and disruption of superior labral fibers inserting into the glenoid
Adjacent irritation of the capsule (TECH FIG 2F)
Disruption of the smooth contour of the articular cartilage at the glenoid rim
Superior labral sulcus more than 5 mm or a biceps root that can be displaced medially along the glenoid neck

INTRA-ARTICULAR DÉBRIDEMENT

- A full-radius motorized shaver (Stryker Endoscopy, San Jose, CA) is used to gently remove frayed or flaplike tissue and loose debris from the joint.
- Careful control of suction pressure on the shaver will ensure that only loose tissue is removed and the bulk of the repairable labrum is retained.

SUPERIOR LABRAL REPAIR

Site Preparation

- We briefly outline our steps for SLAP repair because they may differ slightly from elsewhere in this text.
- Regardless of the specific techniques used, the goal is secure fixation of the biceps anchor to the glenoid rim and obliteration of the peel-back phenomenon.
- An arthroscopic rasp (Arthrex, Naples, FL) is used to separate any loose attachments of the labrum to the glenoid rim to mobilize the lesion and free it from medialized scar (similar to a medialized Bankart lesion).
- A rasp is preferred over a sharp elevator, which can skive and injure normal labral tissue.
A spinal needle is used to locate this portal to allow proper insertion angle for anchor placement in the glenoid rim at 45 degrees relative to the glenoid face to ensure secure fixation in bone and prevent skiving under the glenoid articular cartilage or along the glenoid neck (TECH FIG 4B).

A 4-mm skin incision is made and the Spear guide (3.5 mm; Arthrex) with sharp trocar is used to pierce the muscular portion of the posterior rotator cuff as it is advanced into the joint.

Penetration of the Spear guide is done under direct arthroscopic visualization to ensure that the guide enters the joint medial to the rotator cable, which marks the intra-articular location of the musculotendinous junction of the rotator cuff (TECH FIG 4C). Because of its small diameter and passage in the muscular portion of the cuff, there is minimal iatrogenic injury with this approach.

The sharp trocar is removed, and the Spear guide is brought immediately onto the glenoid rim adjacent to the previously prepared bone bed and held firmly in the proper orientation as described above (TECH FIG 4D).

An assistant passes the power drill into the guide and carefully advances the drill bit to the hilt.

Position of the Spear guide is carefully maintained as the drill is removed and the anchor is introduced in the guide and tapped into a fully seated position in the bone.

We insert these anchors to the hilt of the handle of the insertion device.

Gentle twisting inline with the anchor is often needed to remove it in dense bone.

Alternatively, gentle tapping with a mallet inline can be used to remove the inserter.

The Spear guide is removed and the anchor fixation is tested with gentle pulling on the sutures (TECH FIG 4E).

**Suture Passage**

Both suture limbs are brought out the anterior cannula using a looped suture retriever (Arthrex) (TECH FIG 5A).

The medial suture (closest to labrum) is designated for passage through the labrum.
A small-diameter suture-passer device with a retrievable wire loop (Lasso SuturePasser; Arthrex) is used to shuttle the suture through the labrum.

- The suture-passer device is brought into the joint via the same incision and trajectory as the Spear guide (TECH FIG 5B).
- It is used to pierce the labrum from superior to inferior at the location of the anchor to achieve a solid bite of labral tissue (TECH FIG 5C).

- The wire loop is advanced over the glenoid rim and retrieved through the anterior portal (TECH FIG 5D).
- The previously identified suture is threaded into the loop and the suture-passer device is gently removed from the portal of Wilmington while shuttling the “post-limb” suture through the superior labrum.
- Suture passage is done slowly and under visualization so that tangles may be identified and corrected from the anterior portal using the suture retriever (TECH FIG 5E,F).

**TECH FIG 4 • (continued)**

D. Spear guide is carefully positioned on the glenoid rim and held firmly in place during drilling and anchor insertion. Proper insertion angle (45 degrees to the glenoid face) is critical for firm fixation of the suture anchor in bone. E. Spear guide is removed. The suture anchor has been fully inserted in the glenoid rim, and fixation is tested with a steady pull on the sutures. (In this image, the anchor has been rethreaded with no. 1 PDS suture before the start of the case [see text]).

**TECH FIG 5 • A.** Both suture limbs are retrieved through the anterosuperior portal. In this image, the suture anchor has been used with the FiberWire suture that the anchor is normally packaged with (see text). B. The suture-passing device is brought into the joint through the same trajectory as the Spear guide in the previous steps, minimizing the risk of inadvertent damage to the rotator cuff and capsule. C. The suture-passing device is advanced through the superior labrum from superior to inferior to capture the bulk of the labrum and is carefully advanced over the glenoid rim to prevent damage to the articular surface. The wire loop is advanced for retrieval from the anterosuperior portal. D. The wire loop is retrieved from the anterosuperior portal using a gated suture retriever. The previously identified “post-limb” suture (the suture closest to the labrum as they exit the fully seated anchor) is threaded into the wire loop. The suture-passing device and wire loop are then carefully withdrawn out the portal of Wilmington, shuttling the “post-limb” suture through the labrum. E. Passing suture limbs slowly allows for identification of suture tangling, which may occur during suture passage through the labrum. F. Slack sutures are easily untangled using a gated suture retriever to identify and untangle sutures from the anterosuperior portal. (continued)
The extent of capsular plication is subjective. The goal is to obliterate redundant capsule by placing sutures sequentially from inferior to superior to eliminate anterior instability while preventing inadvertent restriction to full external rotation (TECH FIG 7A,B).

The above steps are repeated as needed for additional posterior anchors in the superior labrum.

Anterosuperior Repair

Anterosuperior anchors are placed through the anterior cannula with the same orientation concerns and technique as described for posterior anchors.

Anterior suture limbs are passed and retrieved through the same anchor, which can create tangling of sutures. In addition, given the orientation of passage and retrieval of anterior sutures through the anterior cannula, a “sawing” effect can be created as the suture is drawn through the tissue, which may damage the anterosuperior labrum.

To minimize this risk, we use a tissue-penetrating device with a gated suture-retriever loop (eg, BirdBeak; Arthrex) to retrieve the post-limb suture through the anterosuperior labrum.

Dynamic Assessment of Repair

Peel-back test: The peel-back phenomenon should be obliterated and the labrum should remain firmly fixed to the superior glenoid during full cocking of the arm (TECH FIG 6).

Drive-through test: Advancement through the joint at mid-glenoid should not be possible after SLAP repair; if this test continues to be positive, then additional anteroinferior capsular redundancy is likely (see below).

MINI-Plication OF THE ANTERIOR CAPSule

The extent of capsular plication is subjective. The goal is to obliterate redundant capsule by placing sutures sequentially from inferior to superior to eliminate anterior instability while preventing inadvertent restriction to full external rotation (TECH FIG 7A,B).

A rasp or “whisker” shaver (Arthrex) is used to abrade the capsule to aid in healing of the plication (TECH FIG 7C,D).

no. 1 PDS sutures are placed beginning anteroinferiorly with pointed suture advancement instruments of varying curvatures (Spectrum; Linvatec, Key Largo, FL).

A “bite” capsule is taken laterally and advanced and sutured to the anteroinferior labrum, obliterating a redundant anterior recess (TECH FIG 7E,F).

Placement of sequential sutures allows for repeat examination to ensure anterior stability is restored without creating motion restriction (TECH FIG 7G).

Rarely, a discrete anteroinferior labral avulsion from the glenoid is present that is repaired as described elsewhere in the text. This is most easily accomplished before superior labral repair.

An additional anteroinferior portal may be required to achieve an appropriate anchor insertion angle onto the glenoid rim and to ease suture passage and management.
TECH FIG 7 • A. Multiple anterior plication sutures are used to obliterate redundant anteroinferior capsular tissue. B. Diagram in axial orientation to the glenoid showing accordion-like plication and shortening of the anterior capsule as it is sutured to the labrum. C. An arthroscopic rasp is used through the anterosuperior portal to abrade the capsular tissue and generate a healing response in the tissue after plication. D. Anterior capsule after abrasion and before suture placement. E. Starting anteroinferiorly, a pointed suture-passing device is used to suture a bite of lateral capsule to the labrum, as shown in F. As the knot is tied, this suture effectively shortens and reduces the anterior capsule. G. Multiple no. 1 PDS anteroinferior capsular plication sutures after tying of the final and most superior plication stitch.
POSTEROINFERIOR CAPSULOTOMY

- As stated earlier, a posterior capsulotomy is indicated only in patients unable to attain a GIRD of less than 20 degrees to allow restoration of full motion and normal glenohumeral biomechanics (TECH FIG 8A).
- Arthroscopic findings in these recalcitrant cases include inferior recess restriction and a thickened PIGHL (more than 6 mm thick).
- Two techniques can be used:
  - Arthroscope in anterior portal and instrumentation in standard posterior portal
  - Arthroscope in standard posterior portal and instrumentation in portal of Wilmington. We prefer this method because it allows more direct visualization of the capsular tissue as it is released (TECH FIG 8B). A small-diameter cannula (5.5 mm) may be needed to allow easy passage of the cautery through the portal of Wilmington.
- A hooked-tip arthroscopic electrocautery with long shaft (Meniscal Bovie; Linvatec) is used to create a full-thickness capsulotomy from the 6 o’clock to the 3 or 9 o’clock position in the posteroinferior quadrant.
- The capsulotomy is made approximately a quarter-inch from the labrum.
- Gentle sweeping motions are used to successively divide tissue under direct visualization (TECH FIG 8C-E).
- It is critical to perform the procedure without chemical paralysis induced by the anesthesia staff.
- Muscular twitching will alert the surgeon that the electrocautery is too close to the axillary nerve and causing injury.
- If this occurs, the capsulotomy should be shifted to a more superior and medial position or abandoned altogether if no safe zone is found.
- Posteroinferior capsulotomy typically results in a 50- to 60-degree increase in internal rotation immediately postoperatively.

**TECH FIG 8**

A. Location of the posteroinferior quadrant capsulotomy. B. Intraoperative view showing the instrument placement for posteroinferior quadrant capsulotomy. The arthroscope is in the standard posterior viewing portal and the cautery is in the portal of Wilmington. A small-diameter cannula (5.5 mm) may be required for passage of the hook-tipped cautery device through the portal of Wilmington. C. View of the posteroinferior capsule showing thickening and restriction of the inferior recess. D. The hook-tipped cautery is used to successively divide the capsule about 3 to 5 mm from the labrum under direct visualization. E. Completed capsulotomy. Muscle fibers just posterior to the capsule are visible between the divided edges of the capsule.
POSTOPERATIVE CARE

Follow-up
- Procedures are performed on an outpatient basis.
- Return for dressing change postoperative day 1.
- Ice or cooling pad is encouraged for first 48 hours.
- Sutures are removed at 1 week.
- Starting at 1 week, self-directed range-of-motion exercises are begun under specific guidelines (see below). Patients are seen regularly to assess progress and modify rehabilitation as needed.

Rehabilitation Time Table
- Immediate
  - Passive external rotation with arm at side (not abduction) within specific parameters
  - Elbow flexion and extension
  - Capsulotomy patients are started on “sleeper” stretches on postoperative day 1.
- Weeks 1 to 3
  - Pendulum exercises
  - Passive range of motion using pulley device in forward flexion and abduction to 90 degrees only
  - Start shoulder shrugs and scapular retraction exercises in sling.
  - Sling should be worn when not out for exercises.
- Weeks 3 to 6
  - Sling is discontinued at 3 weeks.
  - Passive range of motion is advanced to full motion in forward flexion and abduction.
  - “Sleeper” stretches are started in patients not having capsulotomy.
- Weeks 6 to 16
  - Stretching and flexibility exercises are continued.
  - Passive external rotation stretching in 90 degrees of abduction is begun.
  - Strengthening for rotator cuff, scapular stabilizers, and deltoit is started at 6 weeks.
  - Biceps strengthening is delayed until 8 weeks.
  - Daily “sleeper” stretches are continued.
- 4 months
  - Interval throwing program on level surface
  - Stretching and strengthening is continued (internal rotation stretches are emphasized).
- 6 months
  - Pitchers begin throwing full speed depending on pain-free progression through interval throwing program.
  - Continue daily internal rotation stretches.
- 7 months
  - Full-velocity throwing from mound
  - “Sleeper” stretches and scapular conditioning are
performed daily indefinitely while the patient continues throwing competitively.

OUTCOMES

- SLAP repair in high-level throwers: 182 pitchers treated over 8 years (one third professional, one third college, one third high school)\(^2\)
  - 92% returned to premorbid performance or better.
  - Average UCLA score was 92% excellent at 1 year and 87% excellent at 3 years.
- 164 pitchers undergoing SLAP repair and posteroinferior capsular stretching:
  - Average GIRD = 46 degrees preoperatively, 15 degrees at 2 years
  - Eight pitchers undergoing SLAP repair and posteroinferior quadrant capsulotomy:
    - Average GIRD = 42 degrees preoperatively, 12 degrees at 2 years
    - Average fastball velocity = 11-mph increase at 1 year

COMPLICATIONS

- Similar to other arthroscopic shoulder reconstructions: rare incidence of infection; failed repair; painful adhesion formation; subacromial irritation; stiffness
- Physicians and therapists must be vigilant about development of postoperative stiffness in overhead athletes. Stiffness can be addressed effectively with modification of the rehabilitation program if it is identified early with regular follow-up and directed therapy.

REFERENCES

1. Burkhart SS. Arthroscopically-observed dynamic pathoanatomy in the Jobe relocation test. Presented at Symposium on SLAP Lesions. 18th Open Meeting of the American Shoulder and Elbow Surgeons, Dallas, TX, Feb. 16, 2002.
DEFINITION
- The long head of the biceps tendon has long been recognized as a potential source of pain and cause of shoulder impairment.\(^1\),\(^{19,20,33}\)
- Although biceps tendon pathology can occur in isolation, it more frequently occurs concomitantly with rotator cuff disease, and its neglect may account for a subset of patients who fail to respond to rotator cuff repair.
- Pathology of the long head of the biceps tendon presents in a spectrum from subtle tendinopathy observed on diagnostic imaging studies to frank tearing or subluxation appreciated intraoperatively.
- Because the functional significance of the biceps tendon long head has been the subject of considerable debate, treatment has often been tailored more to patient symptoms, activity levels, and expectations rather than strict operative criteria.
- The ideal indications and optimal operative technique remain controversial, although recent advances in arthroscopic technology have led to an evolution of surgical strategies.

ANATOMY
- The long head of the biceps brachii originates from the supraglenoid tubercle and the superior aspect of the glenoid labrum.
- Multiple anatomic variants of the long head biceps tendon origin have been described, the most common of which involves an equal contribution from the anterior and posterior labrum.\(^{32}\)
- The tendon travels intra-articularly (but extrasynovially) an average of 35 ± 5 mm toward the intertubercular (bicipital) groove between the greater and lesser tuberosities.\(^{28}\)
- The mean tendon length is 9.2 cm, with greatest width at its origin (about 8.5 × 7.8 mm).\(^{23}\)
- At the site of intra-articular exit lies the annular reflection or biceps pulley, whose fibers are derived from the superior glenohumeral, the coracohumeral ligament, and the superficial or anterior aspect of the subscapularis tendon (FIG 1). Externally this structure’s counterpart is the transverse humeral ligament.
- The bicipital groove has been a topic of significant study in the literature for its relevance to arthroplasty and it has been implicated as a contributing factor to tendinopathy involving the long head of the biceps.\(^{6,26}\)
- The dimensions of the bicipital groove vary along its mean 5-cm length. At its entrance, the width ranges from 9 to 12 mm, and the depth is about 2.2 mm. In its midportion, the groove narrows to a mean width of 6.2 mm and depth of about 2.4 mm, which may contribute to the entrapment of a hypertrophic intra-articular component; this has been referred to as the “hourglass biceps.”\(^{6,15,26}\)
- The bicipital groove internally rotates from proximal to distal with a mean change in rotation of the lateral lip estimated at about 16 degrees.\(^{15}\)
- The biomechanical significance of the biceps tendon long head is controversial. Some authors have advocated a role of the long head of the biceps in contributing to shoulder stability in overhead athletes.\(^{12,22}\) Other authors, in separate studies,
have used electromyographic analysis to conclude that the long head of the biceps tendon does not contribute to shoulder stability.\(^{18,36}\)

- The extent of functional loss of supination and elbow flexion strength after biceps tenotomy has not been clearly established and is a source of controversy in the literature but may be estimated at 10%.\(^{34}\)

**PATHOGENESIS**

- Long head of biceps tendinopathy encompasses a spectrum of pathology, including intratendinous signal change, synovitis of the sheath, partial tearing, and frank tendon rupture (FIG 2).
- The etiology of long head biceps tendinopathy is thought to be multifactorial.
- Identifiable causes include degenerative changes (usually in association with rotator cuff disease),\(^{19,33,34}\) degenerative osteophyte spurring and stenosis within the bicipital groove,\(^{6,26}\) inflammatory disease, traumatic injury, lesions of the biceps pulley complex or subscapularis tendon, and subtle forms of glenohumeral instability or superior labral anterior posterior (SLAP) tears.
- Lesions of the pulley complex (which contributes to stability of the tendon within the intertubercular groove) or tears of the upper subscapularis tendon may permit intra-articular subluxation and mechanical symptoms.
- “Hidden” cuff tears within the rotator interval or compromise of the annular reflection pulley may permit extra-articular long head biceps subluxation, which can lead to pathologic changes to the long head biceps tendon.
- Tears of the superior labrum such as type II SLAP tears and more subtle patterns of instability such as the peel-back mechanism in throwing athletes can also cause bicipital tendinopathy.

**NATURAL HISTORY**

- Little is known about the natural history of biceps tendinopathy, so prediction of a patient’s clinical course is difficult.
- Patients with high-grade tendinopathy, either in isolation or in association with cuff tears, seem to be at risk of subsequent rupture.
- Spontaneous rupture often alleviates the chronic pain preceding the event.\(^{34}\)

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- As for bicipital tendinopathy, patients’ historical presentations vary.
  - Patients may complain of anterior shoulder pain exacerbated by resisted elbow flexion and supination.
  - The history and character of shoulder pain is less helpful in making the diagnosis than the appropriate physical examination and diagnostic imaging findings in a relevant context.
  - Biceps tendon disorders can present either in isolation or in association with other pathology, typically tears of the rotator cuff.
  - Pain due to biceps pathology is often referred to the bicipital groove area.
  - Physical examination findings are variable but typically include focal tenderness to palpation over the course of the biceps long head in the bicipital groove.
  - Examinations and tests to perform include:
    - Speed’s test: low sensitivity and specificity (estimated 32% to 68% and 56% to 75%); may be indicative of biceps tendinopathy in appropriate clinical setting
    - Yergason’s test: A positive result suggests biceps tendinopathy in the appropriate clinical context.
    - Active compression test: Primarily assists in differentiating between symptomatic superior labral pathology and acromioclavicular joint pathology. A positive result may suggest biceps tendinopathy in the appropriate clinical context.
  - Despite these recommendations, few studies have corroborated the sensitivity, reliability, or accuracy of these findings.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Magnetic resonance imaging (MRI) and ultrasound are the primary methods by which biceps tendinopathy is diagnosed.
  - For the diagnosis of subluxation or dislocation of the long head of the biceps, ultrasound has a reported sensitivity of 96% to 100% and specificity of 100%.\(^2\) For the assessment of complete rupture or the determination of a normal tendon, ultrasound has a sensitivity of 50% to 75% and specificity of 100%. Ultrasound is most useful to demonstrate pathology in the intertubercular groove and has been shown to be highly operator-dependent.
  - MRI can identify intratendinous tendon abnormality, bicipital sheath hypertrophy, concomitant superior labral and rotator cuff pathology, the intra-articular course of the tendon, and the relationship of the biceps to the structures of the annular reflection pulley that stabilize it (FIG 3).

**DIFFERENTIAL DIAGNOSIS**

- Long head biceps brachii tendinitis or tenosynovitis
- Long head biceps brachii partial tear
- Long head biceps brachii rupture
- Long head biceps brachii instability or subluxation
Chapter 7  ARTHROSCOPIC TREATMENT OF BICEPS TENDONOPATHY

- SLAP tear
- Acromioclavicular joint pathology
- Anterosuperior rotator cuff tear
- Subcoracoid impingement
- Subscapularis pathology

NONOPERATIVE MANAGEMENT

- Treatment of biceps tendinopathy depends in part on whether it presents in isolation as a primary problem or is associated with other pathology.
- Alternative nonoperative management of suspected biceps pathology includes activity modification, a course of nonsteroidal anti-inflammatory medication, and corticosteroid injections targeted directly into the biceps sheath within the intertubercular groove. Such an injection can be both therapeutic and diagnostic. With respect to tendon involvement, nonscientific relative surgical indications include symptomatic partial-thickness tearing or fraying greater than 25% to 50% of its diameter, or tendon subluxation or dislocation from its normal position within the bicipital groove.
- Patient factors influencing treatment include the patient’s age and activity level, occupation, desired recreational activities, and expectations.
- Because the biceps tendon is a known “pain generator,” its evaluation and inclusion in treatment of cuff disorders is particularly important.
- Preoperative consideration must be given to anticipate operative strategies if encountered.
- Operative alternatives in treating biceps tendon disorders include débridement, tenolysis (release of the biceps tendon long head), and tenodesis, in which the biceps is reattached to either bone or soft tissue of the proximal humerus. Each has advantages and disadvantages (Table 1).

SURGICAL MANAGEMENT

- Surgical decision making includes patient factors, biceps tendon structural compromise, and concomitant shoulder pathology.
- With respect to tendon involvement, nonscientific relative surgical indications include symptomatic partial-thickness tearing or fraying greater than 25% to 50% of its diameter, or tendon subluxation or dislocation from its normal position within the bicipital groove.
- Patient factors influencing treatment include the patient’s age and activity level, occupation, desired recreational activities, and expectations.
- Because the biceps tendon is a known “pain generator,” its evaluation and inclusion in treatment of cuff disorders is particularly important.
- Preoperative consideration must be given to anticipate operative strategies if encountered.
- Operative alternatives in treating biceps tendon disorders include débridement, tenolysis (release of the biceps tendon long head), and tenodesis, in which the biceps is reattached to either bone or soft tissue of the proximal humerus. Each has advantages and disadvantages (Table 1).

The selected surgical approach should take into consideration patient factors, intraoperative findings, and surgeon preference and comfort.

- Patient factors include age, work, recreational and activity demands, expectations, and perspective on influence of cosmesis.
- Intraoperative findings influence decision making in a number of ways, including bone quality, soft tissue quality, the presence of injury to the biceps sling or subscapularis, and the presence of instability.
- Surgeon factors include arthroscopic proficiency and experience and concomitant surgical procedures that may influence the treatment approach (eg, swelling in the subacromial space during concomitant arthroscopic rotator cuff repair).

Few studies have compared surgical alternatives within the same population of patients. Most such comparative studies

---

**Table 1: Indications for Tenodesis and Tenotomy**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenodesis</td>
<td>Better cosmesis</td>
<td>Potential pain at tenodesis site</td>
</tr>
<tr>
<td></td>
<td>Maintenance of length–tension relationship of biceps</td>
<td>Potential failure of tenodesis to heal</td>
</tr>
<tr>
<td></td>
<td>Decreased risk of fatigue-related cramping</td>
<td>Potential persistent tenosynovitis</td>
</tr>
<tr>
<td></td>
<td>Maintenance of forearm supination and elbow flexion strength</td>
<td></td>
</tr>
<tr>
<td>Tenotomy</td>
<td>Typically minimal discomfort</td>
<td>Potential fatigue-related cramping</td>
</tr>
<tr>
<td></td>
<td>No need for placement of implants into proximal humerus</td>
<td>Significant potential for Popeye sign and undesirable cosmetic result</td>
</tr>
<tr>
<td></td>
<td>or bone–tendon healing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High rate of success for pain relief</td>
<td>Potential for slight to mild forearm supination</td>
</tr>
<tr>
<td></td>
<td>Minimal risk of persistent tenosynovitis</td>
<td>and elbow flexion deficit</td>
</tr>
</tbody>
</table>
Preoperative Planning

Clinical evaluation to determine the contribution of the biceps tendon to patient symptoms is an important component of decision making and helps when encountering biceps pathology.

Examinations for cuff pathology, particularly in the rotator interval (“hidden lesions” of the cuff) and for subscapularis integrity (belly press or lift-off test) are necessary components of the preoperative workup.

Accurate preoperative evaluation should include appropriate radiographs to assess bicipital and acromial (outlet view) morphology.

The bicipital groove view permits assessment of groove depth and the presence of osteophytes but may be unnecessary given the typical quality of routine axial MR images.

MR images can be viewed to assess for biceps continuity (sagittal and coronal views) and intratendinous signal change (axial views) as well as tendon subluxation (axial and coronal views).

Attention must be paid when examining MR films to evaluate the appearance of the adjacent subscapularis, whose upper border is an important restraint against inferior biceps subluxation.

Positioning

Positioning is a matter of surgeon preference.

When biceps tendon pathology is perceived to be isolated or a significant component of the patient’s presentation, we have found that beach-chair positioning affords optimal orientation.

Biceps tenodesis or tenolysis can also be easily performed in the lateral decubitus position.

All bony prominences are carefully padded and the neck is maintained in a neutral position, ensuring adequate circumferential exposure to the scapula (posteriorly) and medial to the coracoid (anteriorly).

Alternatively, depending on surgeon preference, the patient may be placed in the lateral position.

Approach

Standard arthroscopic portals for this procedure include the posterolateral portal for initial viewing, an anterior “operative” rotator interval portal, and the direct lateral subacromial portal (operative and viewing).

Additional accessory portals within the antero-supero-lateral aspect of the rotator interval may facilitate work in the subdeltoïd space during tenodesis.

On initial arthroscopic examination, the biceps is carefully inspected along its course from the posterosuperior glenoid labral attachment to its exit within the bicipital sheath.

Examination should include both visualization along the course and down the sheath (enhanced by use of a 70-degree lens) and palpation.

Because only a portion of the biceps tendon long head is visualized within the joint, the biceps tendon must be translated into the joint using a probe, switching stick, or some tissue-safe tool. This enhances the surgeon’s ability to visualize tendinopathic changes that may otherwise go unrecognized.

Meticulous examination of the proximate annular reflection pulley and subscapularis tendon insertion is obligatory.

Biceps long head abnormalities can include:

- Hyperemia, seen in patients with adhesive capsulitis or in biceps instability
- Overt subluxation: Most commonly subluxation is inferior due to injury to its inferior restraints, composed of the upper subscapularis tendon, or bicipital sling, composed of...
the intra-articular extension of the coracoacromial and coracohumeral ligaments.
- Subtle subluxation: Some authors have described a subtle instability pattern in which biceps tendon excursion within the otherwise normal-appearing sheath is greater than normal and deserves “stabilization.”
- Biceps “incarceration”: Some authors advocate the arthroscopic active compression test to assess for this uncommon entity. This test is performed intraoperatively with the arm positioned in forward elevation, slight adduction, and internal rotation.

**BONY TENODESIS**

**Arthroscopic Interference Screws**

- Before release at the superior labral attachment, the biceps long head must be controlled.
  - This is best achieved by the securing suture about 1 to 2 cm distal to the attachment.
  - This can be done either via spinal needle and PDS percutaneously, or by suture passage using a variety of available suture-shuttling instruments.
- The biceps tendon attachment is then released at the anterosuperior glenoid using a bipolar cautery, arthroscopic scissors or basket, or retractable knife.
- The suture tagging the long head of the biceps tendon is then retrieved though an anterior skin incision just outside the arthroscopic cannula and secured with a Kelly clamp.
- The arthroscope is redirected into the subacromial space. Using the direct lateral portal, an arthroscopic bursectomy facilitates adequate visualization within the subdeltoid space and selection of the site of tenodesis.
- Visualization of the anterosuperior proximal humerus in the subdeltoid space may be facilitated by placing the traditional lateral portal slightly more anteriorly, as advocated by Romeo et al.29
  - With the camera repositioned in this lateral portal, the long head of the biceps tendon is identified in the sheath within the intertubercular groove (just lateral to the lesser tuberosity); this can be facilitated by a spinal needle.
- Using the small incision through which the biceps has been retrieved, the bicapital sheath is incised with an arthroscopic scissors, electrocautery device, or retractable arthroscopic knife.
- The release is performed along the lateral aspect of the sheath to minimize any risk to the subscapularis tendon’s insertion.
- The release should also be deep enough only to visualize the groove and tendon within it, because the ascending branch of the anterior humeral circumflex artery (the primary blood supply to the humeral head) lies beneath.
- This incision in the bicipital sheath is carried proximally to the lateral aspect of the rotator interval and the tendon is then retrieved through either the anterior or accessory anterolateral portal and secured with a clamp.
- The proximal end of the tendon is then resected after first placing a nonabsorbable whipstitch just distal to the site of intended tenotomy.
  - Because the interference screw can cause fraying of conventional first-generation sutures, the whipstitch is better composed of a newer second-generation material such as FiberWire or Herculine.
  - The suture should be placed 10 to 20 mm distal to the exposed proximal portion, depending on how much diseased tendon is present, how much was resected intraoperatively, and the intended location of the tenodesis.
  - When using an interference screw, the surgeon must ensure that the length of the suture is sufficient to pass through the cannulated interference screwdriver (TECH FIG 1).
  - Attention to suture management by use of cannulas is critical at this point. They ensure optimal visualization and soft tissue and suture management and minimize iatrogenic trauma to adjacent soft tissues.
- A guidewire for the tenodesis screw is driven into the intertubercular groove about 15 mm distal to the superior aspect of the groove (at the leading edge of the supraspinatus insertion).29 The guidewire is inserted perpendicular to the groove to a depth of 30 mm.
- The scope is repositioned within the lateral (or most anterior lateral) portal and a cannulated 8-mm reamer is drilled to a depth of about 30 mm under direct arthroscopic visualization.
- The guidewire is removed and a screw is selected for tenodesis. Usually an 8-mm bioabsorbable implant is chosen, but this varies depending on bone quality.
- The proximal tendon is then retrieved with its previously placed whipstitch from the subdeltoid space out through the anterolateral portal.
- One limb of the whipstitch is loaded to the tenodesis screwdriver, and the bioabsorbable screw is loaded.
- The suture limb within the screwdriver is secured with a clamp at the top of the driver, thereby fixing the tendon at the tip of the insertion device for delivery to the base of the tunnel.
- The tendon and driver are inserted the full depth of the tunnel, and the interference screw is advanced while maintaining the driver position and suture tension. It should be advanced such that it is flush with the cortical surface of the intertubercular groove.
- The two remaining suture limbs (one exiting the cannulated screw, the other trailing between the screw and the bone tunnel) are arthroscopically tied on the top of the interference screw, providing further reinforcement.
- The arthroscopic portals and subacromial space are irrigated thoroughly and injected with local anesthetic with epinephrine.

**Arthroscopic Suture Anchors**

- Before being released at the superior labral attachment, the biceps long head must be controlled. This is best achieved by securing the suture about 1 to 2 cm distal to the attachment.
An alternative technique involves an intra-articular tenodesis. Advantages include the ability to perform the procedure without requiring movement of the scope from the joint to the subacromial space, or subacromial bursectomy.

- In this procedure, a stay suture is placed at the origin of the biceps sheath just at the anterior margin of the supraspinatus.
- Flexion of the shoulder and use of a 70-degree lens facilitate identification of the most superior aspect of the bicipital groove. This will be the site of tenodesis.
- The biceps tendon is released from its origin, with the stay sutures percutaneous (at the site of spinal needle penetration).
- The anterosuperior portal is used to target the proximal humeral tenodesis site, generating a healing response along the proximal centimeter of the bicipital groove. By rotating and flexing the shoulder, the biceps tendon can be translated to permit good visualization of the tenodesis site and to facilitate subsequent targeting for anchor placement.
- Several alternative fixation techniques exist, the most common of which is anchor insertion, followed by suture passage and knot tying through the proximal tendon stump.
- Alternatively, the surgeon may make multiple passes through the biceps tendon (using a locking stitch of nonabsorbable suture such as FiberWire) and then use a knotless-type anchor (such as the Arthrex “push-lock” or “swivel-lock”) to perform a secure tenodesis in a percutaneous fashion over a previously placed small-diameter cannula. This latter technique is particular good in cases with cuff tears, in which the proximal bicipital groove is so readily accessible.
Arthroscopic Fixation

This technique, in which the biceps tendon is secured to the soft tissues in the rotator interval, is based on the percutaneous intra-articular transtendon (PITT) technique described by Sekiya and Rodosky (TECH FIG 3).

A spinal needle is placed percutaneously through the lateral aspect of the rotator interval proximate to the annular reflection pulley and then through the biceps tendon, about 1 to 2 cm distal to its supraglenoid origin.

TECH FIG 2 • Arthroscopic images showing intra-articular tenodesis of the long head of the biceps tendon at the proximal aspect of the bicipital groove. A. Anchor placement. B. Suture passage. C. Knot tying. D. Completed tenodesis.

SOFT TISSUE TENODESIS

Arthroscopic Fixation

This technique, in which the biceps tendon is secured to the soft tissues in the rotator interval, is based on the percutaneous intra-articular transtendon (PITT) technique described by Sekiya and Rodosky (TECH FIG 3).

A spinal needle is placed percutaneously through the lateral aspect of the rotator interval proximate to the annular reflection pulley and then through the biceps tendon, about 1 to 2 cm distal to its supraglenoid origin.

TECH FIG 3 • Percutaneous transtendinous or soft tissue tenodesis of the long head of the biceps tendon. A. Coronal plane view of suture fixation to secure the long head of the biceps tendon to the adjacent soft tissue structures in the proximal portion of the bicipital groove. B. Sagittal view showing the fixation with the arm in forward elevation and the knots secured in the subdeltoid space.
A 0 PDS suture is then shuttled through the tendon; it is retrieved through the anterior interval portal using a grasper.

This suture is then replaced by shuttling a nonabsorbable suture (such as no. 2 FiberWire or other comparable suture).

This process is repeated 5 to 6 mm distally along the biceps tendon’s course just proximal to the superior aspect of the intertubercular groove. Ideally, this second suture is of a different color so that the first set of suture limbs can be distinguished from the second.

Next, the limb of the no. 2 nonabsorbable suture exiting the cannula is shuttled with the second PDS back through the biceps and annular reflection pulley. A mattress suture is placed in these structures. It exits the skin through two separate punctures made by the spinal needle passages.

A tenotomy is performed via the anterior interval portal using an Arthrocare wand, needle-tip Bovie, arthroscopic scissors, or up-biting narrow meniscal basket.

The intervening residual stump is excised and the arthroscope repositioned within the subacromial space, which is carefully debrided to enhance visualization and retrieval of the two suture sets.

Retrieval of the percutaneous suture pairs is facilitated with an arthroscopic “crochet hook.”

An alternative technique for retrieving hard-to-find sutures involves making a small incision directly over the percutaneous suture exit sites and loading the suture limb within a single-loop knot pusher, which is then pushed through the skin and into the cleared anterior subacromial space. The sutures are then easily identified and grasped, unloading from the knot pusher, which is withdrawn without difficulty.

Upon retrieval, which can be done one at a time, mattress sutures are tied under direct arthroscopic visualization in the anterior subacromial space.

After thorough irrigation, the joint, subacromial space, and arthroscopic portals are infiltrated with 0.25% Marcaine with epinephrine.

**ARTHROSCOPIC BICEPS TENOTOMY**

In the appropriately selected patient, the procedure is carried out by simply releasing the biceps tendon at its attachment site from a rotator interval portal while viewing from posteriorly.

The intervening segment of diseased biceps tendon (in cases of tendinopathy) can be resected.

Distal migration of the tendon can be discouraged by either leaving a residual wider portion of the diseased tendon just proximal to the proximal bicipital groove or by including a small piece of the anterior superior labrum at the time of tenotomy.

Either of these strategies may preclude the tendency for distal translation and formation of a “Popeye” muscle.

**PEARLS AND PITFALLS**

| Indications | Careful assimilation of the preoperative history, physical examination, and imaging data with the findings at surgery is essential to determine which symptomatic lesions require treatment. A thorough discussion with patients about the goals, expectations, and potential complications of tenotomy and tenodesis is a key component of obtaining successful patient-based outcomes. |
| Portal placement | The location of the rotator interval portal will greatly influence the ease with which an arthroscopic tenodesis can be performed. If the initial portal is too medial, establishing an accessory anterolateral portal over the intertubercular groove about 2 cm distal and 1 cm medial to the anterolateral aspect of the acromion will facilitate instrument passage and visualization. The location of the direct lateral portal along the anterior half of the acromion in the sagittal plane will aid in visualization when working in the subacromial space. Portal placement can be optimized by localization and triangulation using a spinal needle. |
| Diagnostic arthroscopy | A key component of the arthroscopic examination is using a probe, switching device, or other instrument to displace the intertubercular portion of the tendon into the glenohumeral joint for adequate assessment. In addition, a careful examination of the fibers of the annular reflection pulley and the subscapularis insertion is essential. When viewing from the standard posterior portal, using a 70-degree lens can enhance visualization of the proximal intertubercular groove when performing an intra-articular tenodesis. |
| Visualization | An adequate bursectomy facilitated by the use of electrocautery for hemostasis will significantly assist in visualization during arthroscopic tenodesis. Attention to accurate portal placement, fluid management (pump pressure), and procedure duration will help limit soft tissue extravasation, which can impair visualization and lead to performing the tenodesis open. |
| Arm position | Manipulating the arm in flexion and extension, as well as rotation, can help in visualization as well as anchor targeting. |
| Suture management | Careful suture management during tenodesis is key to avoid inadvertent soft tissue interposition, leading to inadequate fixation, skin dimpling, or unnecessary soft tissue dissection. |
POSTOPERATIVE CARE

- The postoperative protocols for long head biceps tendon surgery vary according to the specific technique (débridement, tenotomy, or tenodesis).
  - Often the protocol will depend on the concomitant procedures, such as rotator cuff repair, performed.
- In general, after tenotomy, sling immobilization is used for 4 to 6 weeks, with passive elbow flexion and extension as dictated by the surgeon’s preference and comfort level.
  - Forceful, active elbow flexion is prohibited for 6 weeks, by which time it is expected that the biceps tendon will have scarred into the groove or “autotenodesed” sufficiently to begin active motion.23
  - This period of protection also serves to minimize the potential for a Popeye deformity and fatigue-related cramping.
  - To further minimize the risk of distal retraction, some surgeons have described the use of a compressive wrap around the arm.
  - If too tight, however, the effect may be that of a tourniquet, leading to pain, swelling, and ecchymoses.
- After biceps tenodesis, patients are immobilized in a sling for 4 to 6 weeks, with the amount of active-assisted elbow flexion and extension dictated by surgeon preference and comfort.
  - Active elbow flexion is prohibited for about 6 to 8 weeks to allow tenodesis healing.
  - Some surgeons favor limiting the last 15 to 20 degrees of terminal extension for 4 to 6 weeks after surgery to minimize stress at the tenodesis site.
  - Active elbow flexion exercises are then slowly incorporated into the rehabilitation program after 6 to 8 weeks, with strengthening delayed until the third postoperative month.

OUTCOMES

- Outcome interpretation is challenging because of the limited number of studies and the lack of homogeneous patient populations. Surgical procedures to the biceps are typically only one component of surgically treated shoulder pathology in most studies.
- Arthroscopic tenodesis
  - Checchia et al7 reported 93% good and excellent results in 14 of 15 patients, as determined by UCLA scores, who underwent arthroscopic rotator cuff repair and transtendinous soft tissue tenodesis at a mean follow-up of 32 months.
  - Boileau et al5 reported their results of arthroscopic biceps tenodesis with interference screw fixation at mean follow-up of 17 months with a Constant score improvement from 43 preoperatively to 79 at latest follow-up ($P <0.005$).
  - The historical literature regarding biceps tenodesis defines a range of unacceptable or poor results ranging from 6% to 40%.16
  - The results of open biceps tenodesis have been variable and are summarized in Table 2. Briefly, the results of arthroscopic tenodesis to date indicate that the procedure is an effective treatment for refractory biceps tendinopathy in appropriately indicated patients and may be more favorable for patients under 60 years of age.
- Arthroscopic tenotomy
  - Outcomes of arthroscopic tenotomy suggest that in the appropriately selected patient, this procedure can reliably provide pain relief, with minimal functional limitations or functional improvement.
  - Gill et al11 in 2001 reported their results of tenotomy in 30 patients at a mean follow-up of 19 months. These patients scored an average of 82 by the American Shoulder and

### Table 2: Outcomes of Arthroscopic Treatment of Biceps Tendinopathy

<table>
<thead>
<tr>
<th>Author</th>
<th>No. Cases</th>
<th>Technique</th>
<th>Outcome Measure</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Checchia et al, 2005</td>
<td>15</td>
<td>Arthroscopic transtendon tenodesis</td>
<td>UCLA; mean 32-month follow-up</td>
<td>93% good and excellent results</td>
</tr>
<tr>
<td>Elkousy et al, 2005</td>
<td>12</td>
<td>Arthroscopic transtendon tenodesis</td>
<td>Subjective telephone interview; 6-month follow-up</td>
<td>100% subjective assessment of benefit from procedure; 0% incidence of cramping or Popeye deformity</td>
</tr>
<tr>
<td>Kelly et al, 2005</td>
<td>54</td>
<td>Arthroscopic tenotomy</td>
<td>American Shoulder and Elbow Surgeons (ASES) scale, UCLA, L’Insalata, cramping, Popeye, pain; mean 2.7-year follow-up</td>
<td>68% good to excellent results; 38% complained of fatigue discomfort after resisted elbow flexion; 70% Popeye sign</td>
</tr>
<tr>
<td>Walch et al, 2005</td>
<td>307</td>
<td>Arthroscopic tenotomy</td>
<td>Constant score; mean 57-month follow-up</td>
<td>87% satisfied or very satisfied; mean Constant score improvement from 48 preop to 68 postop</td>
</tr>
<tr>
<td>Boileau et al, 2004</td>
<td>43</td>
<td>Arthroscopic interference screw tenodesis</td>
<td>Constant score; mean 17-month follow-up</td>
<td>Mean Constant score improvement from 43 preop to 79 postop</td>
</tr>
<tr>
<td>Gill et al, 2001</td>
<td>30</td>
<td>Arthroscopic tenotomy</td>
<td>ASES; mean 19-month follow-up</td>
<td>Mean ASES score at follow-up was 82 points; 87% satisfactory results</td>
</tr>
<tr>
<td>Berlemann et al, 1995</td>
<td>15</td>
<td>Open keyhole tenodesis</td>
<td>Subjective assessment; mean 7-year follow-up</td>
<td>64% good and excellent results, 29% fair results</td>
</tr>
<tr>
<td>Walch et al, 2005</td>
<td>86</td>
<td>Open tenodesis</td>
<td>Subjective assessment</td>
<td>99% satisfied or very satisfied</td>
</tr>
<tr>
<td>Becker et al, 1989</td>
<td>51</td>
<td>Open tenodesis</td>
<td>Subjective assessment; mean 7-year follow-up</td>
<td>About 48% had moderate to severe pain at mean 7-year follow-up.</td>
</tr>
</tbody>
</table>
Elbow Surgeons (ASES) grading scale (but no preoperative comparison data were available) and a significant reduction in pain and improvement in function. They reported 87% satisfactory results and a complication rate of 13%, including one patient with a painless cosmetic deformity, two patients with loss of overhead function and subacromial impingement, and one patient with persistent pain.

- Kelly et al13 in 1998 reported the results of 307 arthroscopic tenotomies at a mean of 2.7 years of follow-up, with 68% good to excellent results. However, 70% had a Popeye sign, and 38% of patients reported fatigue-related discomfort. They found minimal loss of elbow strength as assessed by biceps curls, and 0% loss for individuals over 60. Fatigue-related discomfort was not present in the patients over 60.

- Walch et al5 in 1998 reported the results of 54 arthroscopic tenotomies at a mean of 2.7 years of follow-up, with 68% good to excellent results. However, 70% had a Popeye sign, and 38% of patients reported fatigue-related discomfort. They found minimal loss of elbow strength as assessed by biceps curls, and 0% loss for individuals over 60. Fatigue-related discomfort was not present in the patients over 60.

- The primary complications of tenotomy are:
  - Persistent pain
  - Fatigue-related cramping
  - Cosmetic deformity in the form of a Popeye sign
  - Potential slight decrease in elbow supination and flexion strength

- The primary complications of tenodesis include persistent pain, failure of the tenodesis, and refractory tenosynovitis.

- Failure of the tenodesis to heal may result in rupture of the tendon with distal retraction. In such cases, as often occurs in patients with spontaneous biceps tendon rupture, symptoms usually resolve with time.

- One study has suggested that the quality of remaining tendon available for tenodesis can significantly affect the success of the procedure.5

- Recent evidence suggests that oral nonsteroidal anti-inflammatory medication may inhibit healing, so this may be a suboptimal postoperative analgesic option.

- The primary complications of tenotomy are:
  - Cosmetic deformity in the form of a Popeye sign
  - Fatigue-related cramping
  - Potential slight decrease in elbow supination and flexion strength

REFERENCES


31. Tuoheti Y, Itoi E, Minagawa H, et al. Attachment types of the long head of the biceps tendon to the glenoid labrum and their relation-


Chapter 8

Arthroscopic Treatment of Subacromial Impingement

R. Timothy Greene and Spero G. Karas

DEFINITION

- Impingement syndrome was originally described by Neer in 1972 as a chronic impingement of the rotator cuff beneath the coracoacromial arch resulting in shoulder pain, weakness, and dysfunction.
- Repetitive microtrauma of the supraspinatus tendon’s hypovascular area causes progressive inflammation and degeneration of the tendon, resulting in tendinopathy and rotator cuff tear.
- Extrinsic compression of the rotator cuff may occur against the undersurface of the anterior third of the acromion, the coracoacromial ligament, or the acromioclavicular (AC) joint.
- In a study of cadaveric scapulae, Neer observed a characteristic ridge of proliferative spurs and excrescences on the undersurface of the anterior acromion overlying areas with evidence of rotator cuff impingement.

ANATOMY

- The scapula is a thin sheet of bone from which the coracoid, acromion, spine, and glenoid processes arise.
- The acromion, together with the coracoid process and the coracoacromial ligament, form the coracoacromial arch. The arch is a rigid structure through which the rotator cuff tendons, subacromial bursa, and humeral head must pass.
- The supraspinatus tendon is confined above by the subacromial bursa and the coracoacromial arch and below by the humeral head in an area referred to as the supraspinatus outlet. There is an average of 9 to 10 mm of space between the acromion and humerus in the supraspinatus outlet. This space is narrowed by abnormalities of the coracoacromial arch. Internal rotation or forward flexion of the arm also decreases the distance between the coracoclavicular arch and the humeral head.
- The subacromial and subdeltoid bursa overlie the supraspinatus and the humeral head. These bursae serve to cushion and lubricate the interface between the rotator cuff and the overlying acromion and AC joint. The bursa may become thick and fibrotic in response to progressive inflammation, further decreasing the volume of the subacromial space.
- The supraspinatus tendon has a watershed area of hypovascularity located 1 cm medial to the insertion of the rotator cuff. This area may predispose the supraspinatus tendon to degeneration, tendinopathy, and tears from overuse, repetitive microtrauma, or outlet impingement.

PATHOGENESIS

- Extrinsic impingement of the rotator cuff is caused by abnormalities of the coracoacromial arch, resulting in an overall decreased area for the rotator cuff tendons within the supraspinatus outlet.
- Acromial morphology most commonly accounts for narrowing of the supraspinatus outlet.
- Bigliani et al. described three types of acromial morphology: the type I acromion is flat, type II is curved, and type III is hooked. They noted that 73% of cadaver shoulders with rotator cuff tears had a type III acromion.
- A type I acromion with an increased angle of anterior inclination may cause impingement of the rotator cuff by narrowing the supraspinatus outlet.
- Other processes that narrow the supraspinatus outlet include osteophytes of the AC joint; hypertrophy of the coracoacromial ligament, or the acromioclavicular joint; clavicle, or acromion; inflammatory bursitis; calcific rotator cuff tendinitis; or a flap from a bursal-sided rotator cuff tear.

NATURAL HISTORY

- Neer classified impingement into three progressive stages:
  - Stage I impingement lesions occur initially with excessive overhead use in sports or work. A reversible process of edema and hemorrhage is found in the subacromial bursa and rotator cuff. This typically occurs in patients less than 25 years old.
  - With repeated episodes of mechanical impingement and inflammation, stage II lesions develop. The bursa may become irreversibly fibrotic and thickened, and tendinitis develops in the supraspinatus tendon. Classically, this lesion is found in patients 25 to 40 years of age.
  - As impingement progresses, stage III lesions may occur, with partial or complete tears of the rotator cuff. Biceps lesions and alterations in bone at the anterior acromion and greater tuberosity may also develop. These lesions are found almost exclusively in patients older than 40.
- Stage I and II lesions typically respond to nonoperative modalities if the offending activity is limited for a sufficient amount of time.
- Refractory stage II lesions and stage III lesions require operative intervention.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with impingement syndrome typically complain of the insidious onset of shoulder pain that primarily occurs with overhead activities. Pain is typically localized to the lateral aspect of the acromion, extending distally into the deltoid.
- Patients may experience pain at night, especially when lying on the affected side.
- Typically, patients with impingement syndrome do not complain of diminished shoulder motion.
- Physical examination methods to identify subacromial impingement include:
  - Palpation of the point of Codman: Tenderness is frequently a sign of supraspinatus tendinitis, tendinopathy, or acute tear of supraspinatus tendon.
  - Range of motion: Patients with impingement may have limited internal rotation from posterior capsular tightness. Active motion is typically more painful than passive motion, especially in the descending phase of elevation.
■ Painful abduction arc: Pain from 60 to 120 degrees (maximally at 90) suggests impingement. Patients may externally rotate at 90 to clear the greater tuberosity from the acromion and increase motion.

■ Neer’s Impingement Sign: This maneuver compresses the critical area of the supraspinatus tendon against the anterior inferior acromion, reproducing impingement pain.

■ Hawkins’ Sign: This maneuver compresses the supraspinatus tendon against the coracohumeral ligament, reproducing the pain of impingement. It has high sensitivity but low specificity.

■ Impingement test: This test has greatly improved specificity for making the diagnosis of subacromial impingement. A positive test is also a predictor of satisfactory outcome after subacromial decompression.14

■ A complete physical examination of the shoulder should be performed to evaluate for associated pathology or other processes in the differential diagnosis.

■ AC arthritis: This may be clinically asymptomatic, but an inferior AC joint osteophyte can contribute to or cause impingement syndrome. If symptomatic, tenderness may be elicited at the AC joint with palpation and the cross-arm adduction test.

■ Rotator cuff tear: The history of traumatic injury is variable. Patients complain of deep shoulder pain at night and may complain of weakness in the affected shoulder. Strength testing will evaluate for rotator cuff tear and tear size. Evaluation for supraspinatus tendon tear is performed at 90 degrees of abduction in the scapular plane with maximally pronated forearms (Jobe test). Infraspinatus and teres minor weakness is assessed with resistance of external rotation. Inability to hold an externally rotated position is indicative of a massive tear (external rotation lag sign). Weakness of the subscapularis tendon is evaluated with resisted internal rotation. Inability to lift the dorsum of the hand from the ipsilateral sacrum (lift-off test) suggests a subscapularis rupture.

■ Glenohumeral instability: Subluxating or dislocating the humeral head anteriorly, posteriorly, or inferiorly while stabilizing the scapula (load and shift test) helps confirm the diagnosis of glenohumeral instability. Throwing athletes may have a complex pattern of pathology that includes anterior laxity and posterior capsular tightness, which may result in internal impingement. Internal impingement occurs during the late cocking phase of throwing and stems from contact of the articular side of the supraspinatus on the posterosuperior glenoid rim. These patients typically have posterior pain with apprehension testing. Internal impingement must be differentiated from extrinsic outlet impingement caused by coracohumeral ligament narrowing. Although a posterior capsule contracture can predispose patients to outlet impingement, classic extrinsic outlet impingement is believed to be rare in throwing athletes.

■ Biceps pathology: Pain is typically in the anterior shoulder. Tenderness may be elicited in the area of the bicipital groove. Pain during resisted flexion of the arm with the elbow in extension and the forearm supinated (Speed’s test) indicates biceps pathology.

■ Glenohumeral arthritis: Pain is associated with movement below 90 degrees of elevation. Patients complain of pain at night. Cogwheel crepitus may be present when loading the glenohumeral joint during resisted arm abduction.

IMAGING AND OTHER DIAGNOSTIC STUDIES

■ Standard anteroposterior (AP) radiographs in internal and external rotation and a supraspinatus outlet view should be taken for the evaluation of impingement syndrome.

■ A supraspinatus or acromial outlet view is a transscapular view taken with the radiographic beam angled 15 to 20 degrees caudally (FIG 1).

■ The outlet view is the best plain radiographic technique to evaluate acromial morphology. With this information, the surgeon may accurately plan the amount of osseous resection required to convert the acromion to type I morphology.

■ Additional views or diagnostic tests may be used to further evaluate the painful shoulder.

■ Axillary lateral radiographs may be helpful in showing an os acromiale.

■ Magnetic resonance imaging, computed tomography scan, arthrography, and ultrasonography should be used for patients whose diagnosis of impingement syndrome is not completely clear from the history, physical examination, and radiographs. These other modalities will also help diagnose biceps, labral, and rotator cuff pathology.

DIFFERENTIAL DIAGNOSIS

■ Rotator cuff pathology

■ AC osteoarthritis

■ Glenohumeral instability

■ Posterior glenoid and rotator cuff (internal) impingement

■ Glenohumeral osteoarthritis

■ Biceps tendon pathology

■ Adhesive capsulitis

■ Cervical spine disease

■ Viral brachial plexopathy

■ Thoracic outlet syndrome

■ Visceral problems (eg, cholecystitis, coronary insufficiency)

■ Neoplasm of the proximal humerus or shoulder girdle

FIG 1 • Supraspinatus outlet view. This view helps the surgeon assess acromial morphology and facilitates preoperative planning for the amount of acromial resection.
NONOPERATIVE MANAGEMENT

- All patients with subacromial impingement syndrome should undergo a course of nonoperative management for 3 to 6 months. In the short term, a graduated physiotherapy program has been shown to be as effective as arthroscopic subacromial decompression.\(^5\)
- Most patients can be successfully treated within 3 to 6 months. Large retrospective studies show that about 70% of patients with impingement syndrome will respond to conservative management.\(^18\)
- The rehabilitation program should start by preventing overuse or re-injury with relative rest and activity modification. Subacromial bursal inflammation may be controlled with nonsteroidal anti-inflammatory medication, hot and cold therapy, ultrasound, and corticosteroid injection when appropriate.
- Therapy is advanced as pain and inflammation subside and is directed at regaining full range of motion and eliminating capsular contractures. In particular, posterior capsular contracture is addressed with progressive adduction and internal rotation stretching.
- As pain continues to decrease and range of motion improves, strengthening of the rotator cuff and periscapular musculature is initiated. This is achieved through progressive resistance exercises with elastic bands or free weights.
- Patients should avoid overhead weight training (military press, latissimus pulldowns) and long lever arms (straight arm lateral raises) because these maneuvers can exacerbate impingement and place undue torque on the glenohumeral joint.

SURGICAL MANAGEMENT

- Operative intervention is indicated if patients continue to have symptoms of impingement syndrome that are refractory to a progressive rehabilitation program of stretching and strengthening over a minimum 3- to 6-month period.
- If the diagnosis is not completely clear, a more extensive diagnostic workup is warranted before surgical intervention.
- The most common cause of failure for arthroscopic subacromial decompression and anterior acromioplasty is error in diagnosis.\(^1\)

Preoperative Planning

- Imaging studies are reviewed to make sure that the preoperative diagnosis is correct.
- Particular attention should be paid to acromial morphology, the status of the AC joint, and evidence of rotator cuff pathology because these disease processes often coexist.
- The preoperative supraspinatus or acromial outlet view gives the surgeon an accurate measurement of the amount of bone that must be resected from the anterior acromion to convert the acromial morphology to type I.\(^16\)
- If the AC joint has developed osteoarthritic changes, the presence of an inferior AC joint osteophyte may contribute to subacromial impingement. The presence of AC arthritis may not be clinically symptomatic; thus, coplaning of the inferior AC joint should be performed with the subacromial decompression. If the AC arthritis is symptomatic, distal clavicle resection should be performed in conjunction with subacromial decompression.
- Preoperative knowledge of a rotator cuff tear is important for surgical planning of equipment, resources, and operative time as well as patient informed consent, recovery time, and time lost from work.
- Failure to recognize associated pathology is a common source of surgical failure.
- Examination under anesthesia of the affected shoulder is done before positioning. Passive range of motion is documented. The patient should be evaluated for a posterior capsule contracture, which can exacerbate impingement symptoms. Release of the posterior capsule with manipulation or arthroscopic cautery can improve a significant posterior capsule contracture.
- Anterior and posterior glenohumeral translation is examined using a modified load and shift test. Inferior translation is evaluated with the sulcus test.

Positioning

- The patient may be positioned in the beach-chair or lateral position.
- Advantages of the beach-chair position include a more customary setup for conversion to open cases such as biceps tenodesis.
- Advantages of the lateral position include better joint distraction for concomitant intra-articular arthroscopic procedures such as labral repair.

Approach

- Standard anterior, posterior, and lateral arthroscopic shoulder portals are used to perform the diagnostic arthroscopy and subacromial decompression.
- The details of these procedures are outlined in the Techniques section.

ARTHROSCOPY

- The bony anatomy of the acromial borders, clavicle, AC joint, and coracoid process is outlined with a skin marker. The proposed site of the posterior, anterior, and lateral portals are marked (TECH FIG 1).
- The posterior portal is located 2 cm medial and 2 to 3 cm distal to the posterolateral aspect of the acromion. This is the “soft spot” in the posterior triangular region of the humeral head, glenoid, and acromion.
- The anterior portal is marked 1 cm lateral and 1 to 2 cm cephalad to the coracoid process.
- The lateral portal is marked 2 to 3 cm distal to the lateral border of the acromion at the junction of the anterior and middle thirds of the acromion.
- The portal sites are infused with a mixture of 1% lidocaine and 1:300,000 dilute epinephrine solution.
- The glenohumeral joint is infused with 50 mL of the dilute lidocaine and epinephrine solution.
- The posterior portal is established with a 5-mm skin incision and a trocar is placed into the glenohumeral joint. Return of the previously injected solution confirms intra-articular placement.
■ The trocar is removed and the arthroscope is placed. Inflow is established through the arthroscope.

■ An 18-gauge spinal needle is used to confirm the anterior portal that was marked preoperatively. A 5-mm skin incision is placed over the site of the needle entry point and a probe is placed through the anterior portal.

■ A diagnostic arthroscopy is performed. All surfaces of the glenohumeral joint, the glenoid labrum, glenohumeral ligaments, biceps tendon, rotator interval, and rotator cuff are thoroughly inspected.

■ Particular attention is paid to the presence of glenohumeral arthritis, labral pathology associated with glenohumeral instability, and rotator cuff tears because they can mimic an impingement syndrome.

**SUBACROMIAL DECOMPRESSION**

■ Twenty milliliters of 1% lidocaine and 1:300,000 diluted epinephrine are injected into the subacromial space before intra-articular diagnostic arthroscopy.

■ A blunt trocar is used to redirect the posterior portal from the intra-articular position to the subacromial space. The correct position is confirmed by palpating the hard undersurface of the acromion with the trocar tip.

■ Once the trocar is felt to be in the subacromial space, it is swept laterally through the subdeltoid bursa to open the subacromial space. Care should be taken to avoid sweeping the trocar medial to the AC joint, which could injure the acromial branch of the thoracoacromial artery.

■ The arthroscope is introduced and an initial assessment of the subacromial bursa and acromial spur is done.

■ A 5-mm skin incision is used to establish the lateral portal 2 to 3 cm distal to the midlateral border of the acromion.

■ A 5.5-mm full-radius resector is introduced through the lateral portal.

■ Visualization is often difficult because of the thickened and inflamed subacromial bursa. Therefore, tri-angulation of the arthroscope and full-radius resector must be done by palpation.

■ Bursectomy cannot be initiated until the cutting flutes of the resector are visualized.

■ The tip of the anterolateral aspect of the acromion is palpated with the resector to confirm the correct subacromial orientation. Bursal resection is completed in an anterio-to-posterior and lateral-to-medial direction (TECH FIG 2A). Care must be taken not to resect the highly vascular bursal tissue medial to the musculotendinous junction of the rotator cuff.

■ A radiofrequency electrocautery device is used to coagulate any bleeding and remove the remaining soft tissue from the undersurface of the acromion, starting at the anterolateral corner of the acromion (TECH FIG 2B).

■ The electrocautery device is used to peel the coracoacromial ligament from the undersurface of the acromion and completely excise the remaining ligament stump. A complete resection of the coracoacromial ligament is confirmed when the undersurface of the deltoid is visualized as it drapes over the acromial edge (TECH FIG 2C).

**TECH FIG 1** • Acromioclavicular anatomy is outlined and the portal sites are marked.

**TECH FIG 2** • A. Arthroscopic bursectomy. The bursa overlying the tendinous portion of the rotator cuff must be thoroughly resected to evaluate the tendons for bursal-side rotator cuff tear. B. Soft tissue on the undersurface of the acromion is denuded with a radiofrequency electrocautery. Removing the soft tissue will expose the bony undersurface of the acromion and facilitate acromioplasty by the burr’s cutting flutes. C. The acromial spur is now completely visualized. The coracoacromial (CA) ligament must be completely resected from the anterolateral acromion. Failure to do so may result in residual impingement by the CA ligament. Visualization of the undersurface fibers of the deltoid indicates a complete CA ligament resection. (continued)
Part 1  SPORTS MEDICINE  •  Section I  SHOULDER

TECH FIG 2  •  (continued)  

D. The acromioplasty begins at the far anterolateral tip of the acromion. The burr's diameter, usually 5 to 6 mm, is used to assess the initial depth of the acromial resection. The acromioplasty proceeds in 5- to 6-mm strips from anterior to posterior and lateral to medial. E. Completed acromioplasty. The undersurface of the acromion is converted to a type I morphology. Any residual ridges or rough edges can be safely smoothed with the burr in the reverse cutting position. F. View of the acromioplasty from the lateral portal. At the procedure's completion, the arthroscope should be placed in the lateral portal to assess the acromion for any residual downslope or unresected bone. The acromioclavicular joint is also well visualized from this portal and may be resected or coplaned via the anterior portal. G. Coplaning of the acromioclavicular joint. The posterior or lateral portal is used for arthroscopic visualization. Coplaning is performed with the burr in the anterior or lateral portal.

- Anterior acromioplasty is performed with a 5.5-mm burr via the lateral portal.
- Resection begins in the anterolateral corner of the acromion. The desired depth of resection, estimated from the preoperative films, is obtained by measuring with the diameter of the burr (TECH FIG 2D).
- This depth of resection is achieved anteriorly from the anterolateral corner of the acromion to the medial acromial facet of the AC joint.
- The depth of resection is then progressively thinned posteriorly to the midportion of the acromion such that there is a smooth zone of transition from the anterior to the midportion of the acromion (TECH FIG 2E).
- Any ridges or rough edges may be smoothed with the burr in the “reverse cutting” position. The reverse position provides a much less aggressive bone resection, which is ideal for smoothing the bone once the acromioplasty is completed.
- The arthroscope is placed in the lateral portal to check the adequacy of resection (TECH FIG 2F). Any residual unresected acromion or impinging osteophytes from the undersurface of the AC joint should be resected.
- Radiofrequency electrocautery should be used to resect the highly vascular soft tissue on the undersurface of the AC joint.
- From the anterior or lateral portal, the 5.5-mm burr is used to coplane the distal portion of the clavicle flush with the acromion (TECH FIG 2G).

CUTTING BLOCK Technique

- Anterior acromioplasty may be carried out using the cutting block technique.
- The arthroscope is placed in the lateral portal and a 5.5-mm burr is placed in the posterior portal.
- The tip of the burr is placed on the undersurface of the anterior acromion. If type I acromial morphology is present, the burr will lie flush with the undersurface of the posterior acromion.
- The undersurface of the posterior acromion is used as a guide for resection of the anterior acromion.
- The anterior acromion is resected until the burr is flush with the undersurface of the posterior acromion, producing type I acromial morphology (TECH FIG 3).

TECH FIG 3 • Completed acromioplasty via the “cutting block” technique. The acromion is viewed from the lateral portal while the burr is used to approach the acromion from the posterior portal. The burr sits flush with the undersurface of the acromion, indicating a type I acromial morphology.
POSTOPERATIVE CARE

- Patients are placed in a sling for comfort postoperatively but are encouraged to discontinue the sling immediately when the interscalene block wears off.
- Patients are initially started on passive range-of-motion exercises. Therapy is advanced to active range of motion with terminal stretching as comfort allows. A rotator cuff and periscapular strengthening program is initiated once full range of motion is achieved. Terminal stretching, especially the posterior capsule, is continued for the next several months postoperatively.
- The therapy regimen is advanced as rapidly as motion and pain allow.
- Wounds are closed subcutaneously with 3.0 Monocryl suture.
- Steri-Strips and a sterile dressing are applied.

OUTCOMES

- The success rate for arthroscopic subacromial decompression ranges from 73% to 95%. 1-8,12,14,15
- The clinical results and predictability of bony resection for arthroscopic subacromial decompression have been shown to be equivalent to those of the open decompression. 13
- The advantages of the arthroscopic procedure far surpass those of the open procedure and include less surgical morbidity, preservation of the deltoid attachment, allowing rapid advancement of rehabilitation, and direct visualization of the glenohumeral joint. It is the senior author’s opinion that open decompression surgery for routine impingement is a dated technique that should be relegated to the status of historical interest.
- Hawkins et al.\textsuperscript{10} found a significant increase in satisfactory outcomes after arthroscopic subacromial decompression by extending the lateral portal 1.5 to 2 cm and assessing the adequacy of decompression by digital palpation.
- This technique is especially effective for surgeons early in their arthroscopic experience, where confirmation by digital palpation can give tactile as well as visual feedback on the adequacy of acromial resection.
- Coplaning impinging osteophytes from the AC joint after subacromial decompression has shown uniformly good results.\textsuperscript{3,6}
- Beveling the inferior 25% to 50% of the distal clavicle and medial acromion has resulted in neither significant AC joint hypermobility nor compromise in the outcome of subacromial decompression.\textsuperscript{3,6}
- With appropriate patient selection, combined arthroscopic subacromial decompression and distal clavicle resection for coexisting impingement syndrome and AC joint symptoms has shown excellent results with long-term follow-up.\textsuperscript{12,15}

**COMPLICATIONS**

- Infection
- Bleeding
- Neurovascular injury
- Fistula formation from excessive drainage
- Acromial fracture\textsuperscript{17}

**REFERENCES**

DEFINITION
- A number of pathologic processes may affect the acromioclavicular (AC) joint, altering anatomy, biomechanics, and normal function.
- The most common of these are primary osteoarthritis, posttraumatic arthritis, and distal clavicle osteolysis.

ANATOMY
- The AC articulation is a diarthrodial joint composed of the medial end of the acromion and the distal end of the clavicle. The joint supports the shoulder girdle through the clavicular strut.
- A fibrocartilaginous intra-articular disc is present in variable shape and size.
- The average size of the AC joint is 9 × 19 mm. The sagittal orientation of the joint surface varies, ranging from an almost vertical orientation to a downsloping medial angulation of 50 degrees.11
- The stability of the AC joint is provided by capsular (AC) ligaments, the extracapsular (coracoclavicular) ligaments, and the fascial attachments of the overlying deltoid and trapezius.
- The AC ligaments are the primary restraint to anteroposterior translation.
- The superior AC ligament, reinforced by attachments of the deltoid and trapezius fascia, resists vertical translation at small physiologic loads. However, the coracoclavicular ligaments are the primary restraint to superior displacement under large loads.

PATHOGENESIS
- Degeneration of the AC joint is a natural part of aging.
  - DePalma11 has shown degeneration of the fibrocartilaginous disc as early as the second decade of life and degenerative changes in the AC joint commonly by the fourth decade.
  - The superficial location of the joint may predispose it to traumatic injury.
  - The clavicle acts as a supporting strut for the scapula, helping maintain its orientation and biomechanical advantage for glenohumeral motion. Large forces may be transmitted from the extremity to the axial skeleton through the small surface area (9 × 19 mm) of the AC joint.
- Repetitive transmission of large forces, such as weightlifting or heavy labor, may result in degeneration of the joint.
- Repetitive microtrauma to the AC joint may cause subchondral fatigue fractures that undergo a subsequent hypervascular response, resulting in reabsorption and osteolysis (distal clavicular osteolysis).

NATURAL HISTORY
- Despite the frequency of radiographically evident AC joint degeneration, symptomatic arthritis of the AC joint is relatively uncommon.
- Studies have shown that 8% to 42% of patients with type I and II AC joint injuries develop chronic AC symptoms from posttraumatic arthritis.2,3
- Distal clavicle fractures may also result in posttraumatic arthritis.
- Patients with symptomatic AC joint degeneration have been successfully treated nonoperatively with activity modification.12

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients with isolated AC pathology typically experience pain over the anterior or superior aspect of the shoulder in an area between the midpart of the clavicle and the deltoid insertion.
- Pain occurs with activities of daily living that involve internal rotation and adduction such as putting on a coat sleeve, hooking a brassiere, or washing the opposite axilla.
- Younger patients may complain of pain with weightlifting, golf swing follow-through, swimming, or throwing.
- Physical examination of the AC joint includes:
  - Palpation: Tenderness on direct palpation suggests AC pathology.
  - Cross-arm adduction test: This test is highly sensitive but not specific for AC pathology; it is often positive with impingement syndrome. Pain should be confirmed anteriorly because this maneuver will cause posterior pain if posterior capsular tightness is present.
  - Paxinos test: Combined with a bone scan, this test was found to be the most predictive factor for AC joint pathology.16
  - Diagnostic AC injection: Elimination of symptoms is diagnostic of AC pathology and prognostic for successful distal clavicle resection.
  - A complete physical examination of the shoulder should be done to evaluate associated pathology and to rule out other differential diagnoses (as described below).
- Impingement syndrome commonly coexists with or may mimic AC pathology, and awareness of this possibility should be used to rule out its existence.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- The AC joint is best evaluated radiologically with a Zanca view. This provides an unobstructed view of the AC joint by tilting the x-ray beam 10 to 15 degrees cephalad of the normal shoulder AP (FIG 1A).
- Characteristic radiographic changes of primary and posttraumatic arthritis of the AC joint include osteophyte formation with trumpeting of the distal clavicle, sclerosis, and subchondral cyst formation. Narrowing of the AC joint will also be present; however, this occurs as a normal part of aging.
Rheumatoid arthritis affecting the AC joint would typically show periarticular erosions and osteopenia with less spurring than osteoarthritis.

Distal clavicle osteolysis characteristically shows osteopenia, cystic changes of the distal clavicle, and widening of the joint space with narrowing of the distal clavicle.

The supraspinatus outlet view may show inferior clavicular osteophytes, which may contribute to an impingement syndrome.

The axillary lateral view of the shoulder may show anterior or posterior displacement of the clavicle, indicative of trauma to the AC joint.

Three-phase technetium bone scan is highly sensitive and specific for AC joint pathology that is not evident with conventional radiography.

Magnetic resonance imaging (MRI) is sensitive in identifying AC pathology but has poor specificity, as AC abnormalities are frequently observed in clinically asymptomatic patients. Reactive edema in the AC joint is more predictive of clinical symptoms than are MRI findings of degenerative changes in the AC joint (FIG 1B).

Differential Diagnosis

- Intrinsic shoulder pathology
- Impingement syndrome
- Rotator cuff tears
- Biceps lesions
- Glenohumeral arthritis
- Early adhesive capsulitis
- Musculoskeletal tumors of the distal clavicle and proximal acromion
- Extrinsic conditions
  - Cervical spine disorder
  - Referred visceral problems (cardiac, pulmonary, or gastrointestinal disorders)

Nonoperative Management

- The initial management of painful AC pathology should be conservative and should include a combination of activity modification, ice or heat therapy, nonsteroidal anti-inflammatory medications, corticosteroid injection, and physical therapy.
- Activity modification should focus on avoiding the inciting painful activities. Some patients may be successfully treated nonoperatively with activity modification.
- Intra-articular corticosteroid injection with 1 mL of 1% lidocaine and 1 mL of corticosteroid is effective in relieving AC joint pain, but the duration of relief is variable. Patients may receive multiple injections.
- Physical therapy consisting of terminal stretching and rotator cuff strengthening may be effective if a concomitant impingement syndrome exists. Isolated AC pathology typically does not respond to physical therapy.
- Patients should undergo 3 to 6 months of conservative management before operative intervention.

Surgical Management

- Patients with continued AC joint symptoms despite adequate conservative management over a 3- to 6-month period are appropriate candidates for surgical intervention.
- Significant pain relief from an AC joint injection should be documented before surgery, as this is prognostic for a good result after distal clavicle excision.

Preoperative Planning

- Preoperative history, physical examination, and imaging studies should be reviewed before operative intervention.
- A lidocaine injection test should be completed preoperatively and the patient should experience significant pain relief.
- If the diagnosis is in doubt and the patient does not receive significant pain relief from the lidocaine injection, a more detailed workup should be completed before surgery.
- Error in diagnosis accounts for a significant number of failures of distal clavicle resections.

Positioning

- The patient may be placed in the beach-chair or lateral decubitus position.
- We prefer the beach-chair position, as it facilitates conversion to an open procedure such as biceps tenodesis. The beach-chair position also places the AC joint in its more customary in vivo orientation, which may aid the surgeon during arthroscopy.

Approach

- There are two methods to resect the distal clavicle: the indirect (subacromial) approach and the direct (superior) approach.
The choice of approach depends on the presence of concomitant shoulder pathology and the status of the AC joint. The indirect approach is used when there is coexisting shoulder pathology, such as an impingement syndrome or a rotator cuff tear, allowing the patient to undergo simultaneous subacromial decompression and rotator cuff repair. The indirect approach is also helpful for markedly narrow AC joints, allowing wider exposure and thus better visualization of the AC joint surfaces.

The direct approach may be used for patients with isolated AC pathology or if there is adequate joint space to place the burr. We prefer the indirect (subacromial) approach to resect the distal clavicle because associated pathology can be addressed, fewer incisions are made, and the joint can be easily and adequately resected from this approach.

### INDIRECT (SUBACROMIAL) DISTAL CLAVICLE RESECTION

- A complete diagnostic arthroscopy of the glenohumeral joint is performed.
- The arthroscope is redirected into the subacromial space through the posterior portal.
- A complete bursectomy and diagnostic subacromial arthroscopy is performed, as described in the previous section on subacromial decompression.
- If an impinging spur from the acromion or an osteophyte from the inferior AC joint is present, subacromial decompression and coplaning of the AC joint are performed, as previously described.
- The AC joint may be difficult to orient due to variations in patient anatomy. An 18-gauge spinal needle may be placed percutaneously into the AC joint to facilitate orientation (TECH FIG 1A).
- If coplaning of the AC joint has not been previously performed with the subacromial decompression, an electrocautery device is used to remove the soft tissue from the undersurface of the AC joint.
- A 5- to 6-mm burr is then inserted in the lateral portal and the acromial side of the AC joint is resected. This will expose the distal aspect of the clavicle (TECH FIG 1B).
- Both the acromial and clavicular sides of the AC joint should be beveled. This maneuver will create more working space and will allow easier access to the AC joint once the burr is introduced into the anterior

**TECH FIG 1** • A. A spinal needle may be placed in the AC joint to help orient the surgeon. B. View of the AC joint from the posterior portal. The burr is in the lateral portal and is used to take down the acromial side of the AC joint. This maneuver will decompress the subacromial space and help expose the distal clavicle. C. Beveling the distal clavicle. With the burr in the lateral portal, the undersurface of the distal clavicle is scored. The surgeon can base the amount of clavicular resection on the length of the burr. D. The arthroscope is placed in the lateral portal and the burr is introduced into the AC joint via the anterior portal. The resection is completed using the landmarks established when previously beveling the distal clavicle. E. The completed AC joint resection is viewed “end on” from the lateral portal. F. The arthroscope is introduced into the anterior portal to view the adequacy of the posterior AC resection. The resection is adequate. The posterior AC joint capsule is left intact.
portal. Inferiorly directed pressure over the distal clavicle will also enhance its visualization.

- The burr tip is about 10 to 12 mm long. Thus, when approaching the distal clavicle from the lateral portal, the length of the burr tip can be used to measure the length of distal clavicle to be resected, typically 8 to 10 mm (TECH FIG 1C).
- Care should be taken to preserve the anterior and posterior AC ligaments if possible. The inferior joint capsule will be resected with the indirect approach.
- The arthroscope is now placed in the lateral portal and the 5.5-mm burr is placed in the anterior portal (TECH FIG 1D).
- The burr is placed in the beveled area previously established via the lateral portal.
- Resection of the remaining dorsal two thirds of the distal clavicle is accomplished starting at the anteroinferior aspect of the distal clavicle and working in a posteroinferior direction.
- Again, care is taken to preserve the superior and posterior AC ligaments and superior joint capsule.
- About 1 cm of the distal clavicle is resected. Again, this can be estimated by comparing the size of the resection with the size of the burr (TECH FIG 1E).
- The arthroscope is then placed in the anterior portal to evaluate the adequacy of resection (TECH FIG 1F).
- The arm may be placed in maximal cross-body adduction with the arthroscope in the anterior portal to confirm that the ends of the acromion and clavicle do not touch.

**DIRECT (SUPERIOR) DISTAL CLAVICLE RESECTION**

- A portal for the arthroscope is placed superiorly, 1 cm posterior to the AC joint. A 5-mm incision is made to introduce the trocar for the arthroscope.
- Once the arthroscope is introduced, the anterior working portal is placed under direct visualization starting superior and 1 cm anterior to the AC joint (TECH FIG 2A).
- A smaller arthroscope (2.7 mm) and soft tissue resector (2.0 mm) may be needed initially if the AC joint is significantly narrowed (TECH FIG 2B).
- An electrocautery device is used to remove the soft tissue on the AC joint undersurface.
- The AC joint is progressively resected until a larger burr (5.5 mm) will fit into the joint space.

**WOUND CLOSURE**

- As much fluid as possible is drained from the subacromial and intra-articular space. Suction may be placed on the arthroscopic cannula's outflow port to speed the extraction of superfluous fluid.
- Wounds are closed subcutaneously with 3.0 Monocryl suture.
- Steri-Strips and a sterile dressing are applied.
**PEARLS AND PITFALLS**

| Diagnostic error | - Diagnostic error is a common cause of failure of distal clavicle resection. A careful history and physical examination must be done before operative intervention. Patients must have significant relief of acromioclavicular (AC) symptoms after the intra-articular lidocaine injection test. A positive injection test is also prognostic for a good outcome after distal clavicle resection.  
- Many patients may have radiographic evidence of AC degeneration, but often these patients have no clinical symptoms. Symptomatic patients frequently have osseous edema on MRI evaluation of the AC joint. |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AC joint orientation</td>
<td>- It may be difficult to discern the orientation of the AC joint from subacromial space. Eighteen-cm of distal clavicle resection is adequate for successful operative treatment; care should be taken to preserve as much of the AC capsular ligaments as possible, especially during orientation. Visualization of the distal clavicle may be enhanced by resecting the medial aspect of the acromion and using inferior-directed pressure over the distal end of the clavicle.</td>
</tr>
</tbody>
</table>
| Inadequate distal clavicle resection | - This is a common technical error resulting in surgical failure.  
- Inadequate resection of the posterior and superior cortical ridge commonly causes residual abutment against the acromion.  
- One centimeter of distal clavicle resection is adequate for successful operative treatment; however, the adequacy of resection should be assessed in each case by dynamic cross-arm adduction with the arthroscope in the anterior portal.  
- If there is any question regarding the adequacy of resection, the anterior portal may be extended 1 cm superiorly and the resection may be assessed by direct digital palpation. |
| AC joint instability | - Care should be taken to preserve as much of the AC capsular ligaments as possible, especially during the superior ligament, which provides the primary resistance to posteriorly directed forces. Inadvertent release of the coracoclavicular ligaments should also be avoided because they resist axial compression of the AC joint. Thus, loss of coracoclavicular ligament function may cause abutment between the distal clavicle and acromion despite adequate bony resection. |

**POSTOPERATIVE CARE**

- Patients are placed in a sling for comfort postoperatively but are encouraged to discontinue the sling immediately when the interscalene block wears off.  
- Patients are started on passive range-of-motion exercises for the first postoperative week. Therapy is advanced to active range of motion with terminal stretching in the second postoperative week. A resisted rotator cuff and periscapular strengthening program is initiated the third week postoperatively. Terminal stretching is continued for the next several months postoperatively, especially posterior capsule stretches.  
- The therapy regimen is advanced as rapidly as motion and pain allow.  
- Patients can typically return to sport in 2 to 3 months. Graduated return is advised. For example, golfers should only chip and putt for the first month postoperatively. Weightlifters can begin training with lighter weights and avoid pressing motions until comfortable.  
- The quicker recovery time is a result of deltoid attachment preservation, which eliminates postoperative protection of the deltoid and allows for rapid advancement of physical therapy.  

**OUTCOMES**

- The published success rates of arthroscopic distal clavicle resection are generally good and parallel the results of open distal clavicle resection.  
- Good or excellent outcomes have been reported in 83% to 100% of patients undergoing arthroscopic distal clavicle resection for primary osteoarthritis, posttraumatic osteoarthritis, or distal clavicle osteolysis. 
- The results of open versus arthroscopic distal clavicle resection have been retrospectively reviewed in the literature.  
- Several authors have found equivalent long-term results of open and arthroscopic distal clavicle resections; however, a significantly quicker recovery time has been observed with the arthroscopic resection.  
- The quicker recovery time is a result of deltoid attachment preservation, which eliminates postoperative protection of the deltoid and allows for rapid advancement of physical therapy.  

**COMPLICATIONS**

- Infection  
- Bleeding  
- Neurovascular injury  
- AC joint instability  
- Painful scar formation  
- Heterotopic ossification at the resection site

**REFERENCES**

DEFINITION

- Rotator cuff disease encompasses a spectrum of disorders ranging from tendinitis to partial and full-thickness tendon tearing.
- It is the most common shoulder disorder treated by an orthopedic surgeon, with over 17 million U.S. individuals at risk for the disabilities caused by the disease.
- The prevalence of full-thickness tearing of the rotator cuff ranges from 7% to 40% across multiple studies.  
- Age-related degenerative change is a primary factor in the development of rotator cuff tears.  
  - Asymptomatic full-thickness tears have been found in 13% of the population between age 50 and 59 and in over 50% of people older than 80 years old.  
  - The risks and benefits of both nonoperative and operative treatment must be considered for each individual patient.
- A number of factors are critical in deciding how to treat full-thickness tears, including a history of trauma, patient age, tear size, degenerative muscle and tendon changes, and functional disability.
- Traditionally, open rotator cuff repair was the standard of care for symptomatic full-thickness rotator cuff tears.
  - Several disadvantages are inherent to open rotator cuff repairs. These include the need for deltoid detachment, difficult visualization of associated glenohumeral joint pathology, larger incisions, more extensive surgical dissection, and potentially a higher infection rate.
- The surgical treatment of full-thickness rotator cuff tears has been revolutionized by the advent of arthroscopic surgery.
  - With the introduction of arthroscopy, rotator cuff repair has moved from mini-open repairs to complete arthroscopic repairs.
  - As techniques of complete arthroscopic rotator cuff repair have advanced, attempts have been made to treat larger tears arthroscopically. To do this, stronger fixation constructs must be used.
  - Single-row suture anchor repairs have been reported with good overall clinical results, but healing rates decrease as tear size increases.  
  - Double-row repair constructs with a medial and lateral row have been shown to provide improved initial biomechanical strength and restoration of the normal anatomic rotator cuff footprint.  
  - In the setting of a full-thickness rotator cuff tear, we now perform a double-row suture anchor repair if technically possible. While the double-row repair is more technically demanding, the potential advantages of anatomic restoration of the tendon insertion, improved biomechanical fixation, and improved healing may lead to improved functional outcomes.

ANATOMY

- The rotator cuff is a complex of four muscles arising from the scapula and inserting onto the tuberosities of the proximal humerus.
  - The supraspinatus and infraspinatus muscles make up two thirds of the posterior cuff. The two tendons fuse together and have a direct bony insertion.
  - When performing a double-row rotator cuff repair, knowledge of the dimensions of the rotator cuff insertion or “footprint” is critical.
  - The supraspinatus averages 25 mm wide and has a medial-to-lateral footprint (tendon attachment) of 12.1 mm at the midtendon (Figure 1).
  - There is a normal sulcus between the articular cartilage and the medial aspect of the supraspinatus footprint; it averages 1.5 mm in width.
  - The infraspinatus has been shown to average 29 mm wide, with a mean medial-to-lateral width of 19 mm.
  - Suture anchor repair constructs using a single row of anchors have been shown to restore only 67% of the original footprint of the rotator cuff.
  - Adding a second row of anchors increases the contact area of the repair 60%.
  - The biomechanical properties of the double-row repair are improved compared to single-row repairs and include decreased strain over the footprint area, increased stiffness, and increased ultimate failure load.

PATHOGENESIS

- The etiology of rotator cuff tears is multifactorial.
  - The major factors are age-related degenerative changes of the tendon and physiologic loading.
  - The theory of age-related accumulative damage is supported by histologic findings of decreased fibrocartilage at the cuff insertion, decreased vascularity, fragmentation of the tendon with cellular loss, and disruption of Sharpey fiber attachments to bone.
  - Clinical studies support the aging theory as a primary cause of rotator cuff disorders.  
    - In a recent review of 586 consecutive patients with unilateral shoulder pain, rotator cuff tears were found to be correlated with increasing age, with an almost perfect 10-year difference between patients with no tear, a unilateral tear, and bilateral tears.
    - The average age of patients presenting with rotator cuff-derived pain with no tear was 48.7 years old; unilateral tear, 58.7 years old; and bilateral tears, 67.8 years old.
  - Physiologic loading of the tendon has also been postulated as a mechanism for cuff tearing.
  - Localized degeneration of the articular region of the tendon, most commonly in the supraspinatus, is indicative of a tendon loading etiology.
NATURAL HISTORY

- Uniform changes throughout the entire tendon, which are not commonly found, would be more suggestive of an age-related degenerative process.
- Age and loading likely have a multiplicative effect, with tendons in an older person both being more susceptible to damage from normal physiologic loading and exhibiting a worse healing response.
- Genetics may also have a significant role in the predisposition for rotator cuff tears.
  - A strong relationship between rotator cuff tearing and family history has been shown.
  - One study found a relative risk of 2.42 for full-thickness rotator cuff tears in siblings of patients with cuff tears versus controls.10
  - This increased risk in siblings implies that genetic factors may play a role in the development of rotator cuff tears.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with rotator cuff disorders often complain of pain, weakness, or both in the shoulder.
- The development of symptoms is often insidious.
  - There may be a recollection of minor trauma (eg, episode of heavy lifting, catching a heavy object).
  - Pain is usually localized to the anterior or anterolateral aspect of the shoulder, often extending down the front or side of the shoulder to the elbow.
  - Pain exacerbated with use, especially with overhead activities, is common.
  - Sleep disruption is also common in patients with symptomatic rotator cuff disease.
- Weakness is a complaint for patients with large full-thickness rotator cuff tears.
  - Pain from tendinitis or small tears may simulate lack of strength, however. Therefore, weakness alone is not diagnostic of a large tear.
  - Similarly, patients with large or massive tears may have very reasonable function.
  - More commonly, however, these patients report overhead weakness and fatigue.
  - If gross weakness is recognized suddenly after a trauma, a rotator cuff injury should be suspected and investigated.
- In the setting of chronic rotator cuff tears, inspection of the shoulder will often reveal atrophy of the supraspinatus and infraspinatus.
  - Prior surgical incisions should be noted. If previous open rotator cuff repair with deltoid detachment was performed, deltoid repair integrity should be assessed, along with axillary nerve function.
  - Range-of-motion testing should be performed both actively and passively.
  - Passive range of motion is often preserved except in the setting of chronic large tears, where static superior head migration leads to limited forward elevation with inferior capsule contracture.
  - Posterior capsular contracture is also a common finding with both small and large tears.
Active motion is often limited in scapular plane elevation. This may be due to either weakness or pain.

Shoulder strength should be evaluated with manual muscle testing.

Various arm positions will isolate the rotator cuff and specifically test these muscles for dysfunction.

The supraspinatus, infraspinatus, and teres minor can be isolated with resisted scapular plane elevation at 90 degrees in neutral rotation, resisted external rotation in full adduction and slight internal rotation, and external rotation in 90 degrees of abduction and 90 degrees of adduction, respectively.

Either the belly-press or lift-off test can be used to test subscapularis function.

Belly-press test: Inability to maintain maximum internal rotation without the elbow dropping posterior to the midsagittal plane of the trunk indicates impaired subscapularis function.

Lift-off test: Inability to maintain active maximal internal rotation with hand off the lumbar spine without extending the elbow indicates impaired subscapularis function.

Electromyographic analysis has shown that the belly-press activates the upper subscapularis while the lift-off activates the lower subscapularis.

Painful limitation of motion may limit the usefulness of the lift-off test.

This information may improve our ability to determine the extent of subscapularis dysfunction.

Special tests have been developed to aid in diagnosis:

The Neer impingement test (forward elevation in internal rotation) and the Hawkins impingement test (elevation to 90 degrees, cross-body adduction and internal rotation) were designed to elicit symptoms by impinging the rotator cuff on the undersurface of the acromion and coracoacromial ligament.

The Hornblower sign indicates teres minor dysfunction or tearing if there is weakness or inability to achieve full external rotation in an abducted position.

A positive result (weakness or pain) in the empty can test (Jobes sign) indicates dysfunction of the supraspinatus tendon.

Weakness with resisted external rotation in adduction represents dysfunction or tearing of the infraspinatus tendon.

External rotation lag sign: Inability to maintain the shoulder in a fully externally rotated position indicates significant dysfunction or tearing of the infraspinatus muscle.

Variable accuracy of these tests has been shown when used in isolation, but accuracy may be improved when used in combination with other provocative examinations.

We do not routinely use these examinations, however. Instead, we base our findings on pain or weakness with resisted strength testing.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

Four standard shoulder radiographs should be taken of every patient evaluated for shoulder pain: anteroposterior (AP), true AP with active shoulder abduction, axillary lateral, and scapular-Y views.

The decision to obtain further imaging studies is based on radiographic findings along with data obtained from the history and physical examination.

In a patient with a small full-thickness rotator cuff tear, radiographs are usually normal.

With increasing tear chronicity, sclerotic and cystic changes of the greater tuberosity are often noted.

With increasing tear size, proximal humeral migration can be found on the AP and true AP views.

Proximal migration is best identified on the true AP view as loss of a concentric reduction of the proximal humeral and glenoid centers of rotation.

Humeral elevation may be static or dynamic depending on the chronicity of the tear. Static elevation occurs with contracture of the inferior capsule.

Narrowing of the acromiohumeral interval on the AP view has also been used to identify large tears.

MRI of the shoulder in patients with rotator cuff tears evaluates both the tendon and muscle quality.

Full-thickness tears show increased signal intensity at the tendon insertion on T2-weighted images.

MRI has been shown to have over 90% sensitivity and specificity in detecting tears without previous surgery.

Fatty infiltration and atrophy of the rotator cuff musculature can also be identified on MRI.

Increased fatty infiltration of the rotator cuff muscles has been correlated with poorer tendon healing and worse final postoperative outcomes after repair.

In the hands of a skilled ultrasonographer, ultrasound has a sensitivity and specificity similar to that of MRI.

Benefits of ultrasound include limited radiation, ability to routinely perform bilateral examinations, and a dynamic component of the examination, which can significantly aid in differentiating scar from tendon.

The most significant limitation of ultrasound is the need for an experienced ultrasonographer.

CT and CT arthrography has been widely used in Europe for the diagnosis of rotator cuff tears.

In patients with pacemakers or aneurysm clips, CT arthrography is a good alternative to MRI. Limitations of CT include increased radiation exposure and poorer soft tissue resolution compared to MRI.

Similar to MRI, muscle quality, including atrophy and fatty infiltration, can be examined and has been shown to be predictive of tendon healing and outcomes after surgery.

**DIFFERENTIAL DIAGNOSIS**

- Rotator cuff tendinitis
- Partial-thickness rotator cuff tear
- Rotator cuff contusion
- Adhesive capsulitis
- Arthritis or chondral injury
- Calcific tendinitis
- Biceps tendon pathology (tendinitis or tearing)
- Suprascapular nerve entrapment or spinoglenoid notch cyst
- Internal impingement

**NONOPERATIVE MANAGEMENT**

The decision to pursue nonoperative management in the setting of a full-thickness rotator cuff tear depends on both patient and tear characteristics. Asymptomatic tears are extremely common, with MRI, ultrasound, and arthrography studies showing a 4% to 13% incidence in subjects 40 to 60 years old and over 50% in subjects older than 80. All asymptomatic
Tears should be treated nonoperatively. In subjects younger than 65, serial monitoring with sequential MRI or ultrasounds is reasonable, given that over 51% of patients with a previously asymptomatic tear and a contralateral symptomatic tear will develop symptoms in the asymptomatic shoulder over an average of 2.8 years.25

For symptomatic tears, nonoperative treatment has shown moderate success, with 45% to 82% satisfactory results.4,11,22 Nonoperative treatment includes anti-inflammatory medications, shoulder stretching, and rotator cuff and scapular stabilizer strengthening exercises. A limited number of subacromial cortisone injections may be performed, especially in patients who are not surgical candidates. Chronic large or massive rotator cuff tears in any age group or any chronic full-thickness tear in patients older than age 70 should undergo an initial trial (at least 3 months) of nonoperative management. Because irreversible changes have already occurred to the cuff or the articular cartilage in most of these patients, it is safe to attempt nonoperative treatment for a period of time. Failure of nonsurgical treatment is an indication for arthroscopic repair.

SURGICAL MANAGEMENT

The decision to proceed with operative treatment of rotator cuff disease requires an evaluation of the risks and benefits associated with both surgical and nonsurgical treatment.

While the risks of surgical management are well known, the risks of nonoperative treatment may not be so obvious.

- Tear progression, muscle fatty infiltration and atrophy, and arthritis are potential irreversible risks of nonoperative treatment of rotator cuff tears.
- Knowledge about these risks can help guide treatment.

Early surgical repair should be considered in all acute tears and any chronic small or medium-sized tears in patients younger than age 65.

These patients are at significant risk for developing the irreversible changes previously mentioned with prolonged nonoperative treatment.

These patients also have the greatest potential for healing. Consequently, the benefits of early surgical treatment combined with the inherent risks of prolonged nonoperative treatment guide us to early surgical repair.

Preoperative Planning

Tear size and chronicity will determine the difficulty of the repair, so careful preoperative imaging evaluation is important in surgical preparation.

- If a tear is very large, the surgeon should make sure that a variety of different suture-passing devices are available to assist in the repair.
- A Banana Suture Lasso (Arthrex, Naples, FL) can be passed through the Neviser portal in large, medially retracted tears to shuttle suture through the tendon.
- Angled Suture Lassos (Arthrex) can be placed through accessory portals to pass sutures from difficult angles not easily approached through the lateral working cannulas.
- Larger anchors should be available if bone quality is poor.
- Assess preoperative motion after the patient is anesthetized but before initiating the surgical procedure. Fixed superior humeral migration in the setting of a large rotator cuff tear will lead to inferior capsular contracture. In these patients, perform preoperative manipulation under anesthesia in forward elevation to increase the subacromial space available, thus facilitating the repair.

Positioning

- Beach-chair position advantages
  - This is an anatomic position that permits better orientation and understanding of shoulder anatomy while performing the repair.
  - Examination under anesthesia is facilitated by stabilizing the scapula in the beach-chair position compared with the lateral position.
  - The arm can be easily manipulated in surgery without the need to unhook it from a traction unit.
  - Traction is not required but can be added in an inferior direction to increase the subacromial working space.
  - Humeral rotational control is easily accomplished. This can be critical when working on different regions (anterior vs. posterior) of the greater tuberosity.
  - Conversion to an open procedure is easily performed without redraping.
- Lateral decubitus position advantages
  - Many surgeons believe that the lateral position improves visualization and maneuverability of the scope due to traction.
  - It significantly improves inferior access to the glenohumeral joint, which makes it less difficult to perform glenohumeral procedures but has little impact on subacromial procedures.
  - Transient and permanent nerve damage has been reported due to traction in the lateral position. Consequently, we prefer to perform all subacromial procedures, including rotator cuff repair, in the beach-chair position.

DOUBLE-ROW ROTATOR CUFF REPAIR WITH “MASON-ALLEN”-TYPE CONSTRUCT USING SCREW-IN SUTURE ANCHORS

Portal Placement and Cannula Insertion

- The camera is placed in the subacromial space through a posterior portal.
- Our preferred starting posterior portal is slightly more lateral than a standard posterior portal. This is done to gain better visualization of the lateral greater tuberosity during repair. Also, a slightly inferior position is preferred, since portals will migrate superiorly with shoulder swelling.
- A lateral working portal is developed under spinal needle localization. Portals should be placed low enough so that cannulas are introduced parallel to the rotator cuff tendon. This allows for easier subacromial instrumentation. The portal should be placed at about the midpoint of the tear in small or medium-sized tears.
- A second lateral portal can be placed in larger tears with cannulas separated by several centimeters. Clear fully threaded 8.25-mm cannulas are placed in these portal sites.
Another large threaded cannula is placed through an anterolateral portal, anterior to the acromion, at the same level as the lateral and posterior portals. Again, maintaining low portal placement is critical so instruments will be passed parallel to the tendon, allowing the greatest excursion of instruments in the subacromial space. The anterolateral portal is mainly used as an accessory portal for suture retrieval and storage.

**Repair Site Preparation**
- A soft tissue ablation device is used through the lateral portal to clear all the soft tissue on the undersurface of the acromion extending posteriorly, including the soft tissue and fat around the scapular spine. This will significantly improve the mobility of the tear. Soft tissue is removed from the greater tuberosity with a shaver, exposing cortical bone.
- Mobility of the torn tendon is assessed with a tissue grasper through the lateral portal.

**Anchor and Suture Placement**
- Once the tear has been determined to be repairable, a medial row of suture anchors (5.5-mm metal screw-in style) is placed. Anchors are loaded with two no. 2 Fiberwire sutures (Arthrex).
- For small and medium-sized tears, we routinely place two medial anchors at the level of the anatomic neck. Each anchor is separated by 1 to 1.5 cm. Anchors are placed through small stab incisions just off the lateral border of the acromion.
- For large and massive tears, we place three medial anchors.
- Sutures from the medial row of anchors are next passed through the tendon. Starting with the most anterior anchor, both strands from one suture are passed through the tendon at the anterior aspect of the tear in a horizontal mattress fashion. Sutures are passed approximately 1 cm medial to the lateral edge of the tear. One strand of the second suture is passed adjacent to the most posterior strand of the first suture. This strand is retrieved out the anterolateral portal along with the two strands of the first suture.
- The steps are repeated for the posterior anchor of the medial row. Two strands of one suture are passed at the posterior aspect of the tear in a mattress fashion. One strand of the second suture is placed just anterior to the previously placed mattress suture and retrieved out the anterolateral portal.
- Both strands of the posterior mattress stitch are retrieved out the lateral portal, tied arthroscopically, and cut. Similarly, both strands of the anterior mattress stitch are retrieved out the lateral portal, tied, and cut.
- The remaining strands passed through the tendon are in the anterolateral cannula and tied to one another outside the shoulder. The tails are cut and the knot is then advanced into the shoulder by pulling on the opposite two strands of the two sutures, creating a large horizontal mattress stitch between the anterior and posterior anchors (TECH FIG 1A).
- A single lateral suture anchor is then placed at the lateral aspect of the rotator cuff footprint on the greater

---

**TECH FIG 1** - A. Arthroscopic picture showing the bridging horizontal mattress stitch between two medial-row anchors. Suture strands on right are the other limbs of the horizontal mattress stitch, which will be tied arthroscopically after the lateral-row stitches have been passed and tied. B. Lateral-row suture anchor placed at the lateral aspect of the greater tuberosity between the two medial-row anchors. C. Passage of lateral-row stitches medial to the bridging medial-row horizontal mattress stitch with a Scorpion suture passer. D. Final repair construct of a double-row repair using two medial and one lateral screw-in suture anchors.
tuberosity, halfway between the medial anchors (TECH FIG 1B). One strand of one suture is retrieved out the lateral portal and passed medial to the horizontal stitch between the anterior and posterior medial anchors.

- This step is repeated with the second suture from the lateral anchor. These stitches are passed using a Scorpion suture passer (Arthrex) (TECH FIG 1C).

- Once the lateral anchor sutures are passed, the remaining strands from the medial sutures are pulled on by an assistant to tension the medial horizontal mattress stitch between the medial anchors while the lateral-row sutures are tied. While tension is applied to the medial row, the lateral simple stitches are tied arthroscopically and cut.

- Finally, the remaining two strands from the medial row anchors are retrieved out the lateral portal and tied arthroscopically.

- The final construct has two medial-row anchors with a mattress stitch between the anchors and one lateral anchor with two simple stitches passed medial to the horizontal mattress between the medial anchors. This creates a “Mason-Allen” type of construct with the lateral simple stitches passed medial to the bridging medial horizontal mattress stitch (TECH FIG 1D).

DOUBLED-ROW ROTATOR CUFF TEAR WITH “MASON-ALLEN”-TYPE CONSTRUCT USING MEDIAL SCREW-IN SUTURE ANCHORS AND LATERAL PUSHLOCK ANCHORS

- This repair technique follows the previous repair technique. After the anterior and posterior medial-row mattress sutures are tied, the tails of these sutures are not cut. Instead, they are retrieved out the anterolateral portal and stored. The bridging horizontal mattress stitch between the two medial anchors is created as described in the previous technique.

- The untied suture strands (one from the anterior anchor and one from the posterior anchor) from the bridging mattress stitch between the anterior and posterior anchors (TECH FIG 2A) are retrieved out the lateral portal.

- Both suture strands are then passed simultaneously medial to the horizontal mattress bridging mattress stitch with the Scorpion suture passer (Arthrex). This creates a Mason-Allen type of locking stitch construct.

- Through one of the accessory lateral portals where the medial-row anchors were placed, a suture retriever is placed. Three strands are grabbed with the retriever: one strand from the tied posterior mattress stitch, one strand from the tied anterior mattress stitch, and one of the strands passed medial to the bridging horizontal mattress stitch.

- All three strands are placed in a PEEK 3.5-mm PushLock knotless suture anchor (Arthrex). The PushLock awl is placed through the same lateral accessory portal and an anchor hole is tapped along the lateral aspect of the greater tuberosity at the posterior aspect of the tear (TECH FIG 2B). After a hole is tapped, the anchor is introduced into the joint through the same portal and impacted into the hole. The PushLock anchor has three strands (one strand from the tied posterior mattress stitch, one strand from the tied anterior mattress stitch, and one of the strands passed medial to the bridging horizontal mattress stitch) (TECH FIG 2C). As the anchor is impacted, all three strands should be tensioned to reduce the rotator cuff to the footprint. All three strands are then cut after final impaction of the PushLock anchor.

- The previous steps are repeated, grabbing the second suture strand from the anterior and posterior mattress stitches and the second strand passed medial to the bridging mattress stitch. All three are placed in a second PushLock anchor and an anchor pilot hole is created at the anterior aspect of the tear along the lateral aspect of the greater tuberosity footprint.

TECH FIG 2 • A. Arthroscopic picture showing the opposite ends of the bridging horizontal mattress stitch shuttled through the cuff tendon medial to the bridging mattress stitch. B. A pilot hole is created using an awl for the posterior PushLock anchor as part of the lateral row. C. The posterior PushLock anchor is placed with one strand of suture from the anterior horizontal mattress stitch, one strand from the posterior horizontal mattress stitch, and one limb of the sutures from the bridging mattress stitch. (continued)
Chapter 10 ARTHROSCOPIC TREATMENT OF ROTATOR CUFF TEARS

After pilot hole creation, the anchor is introduced into the joint. With all three suture strands and while the strands are tensioned, the anchor is impacted (TECH FIG 2D). The tails of all three strands are then cut flush with the PushLock anchor, completing the repair.

The final construct consists of two medial-row anchors and two lateral-row PushLock anchors (TECH FIG 2E,F). Only two arthroscopic knots are required to complete this double-row repair.

PEARLS AND PITFALLS

| Portal placement | ▪ The posterior portal should be placed more lateral than the standard portal site (standard portal site: 2 cm medial and 2 cm inferior to the posterolateral corner of the acromion) for improved access to the lateral aspect of the greater tuberosity.
  | ▪ Portal placement should err low to facilitate instrumentation after shoulder swelling. |
| Surgical anatomy | ▪ Landmarks should be precisely drawn on the shoulder before arthroscopy to ensure accurate portal placement. |
| Preoperative examination under anesthesia and manipulation | ▪ With large, chronic rotator cuff tears, fixed superior humeral migration is often present. Preoperative manipulation in forward elevation will assist in releasing the inferior capsule, thereby allowing improved access to the subacromial space with inferior traction during surgery. |
| Hemostasis | ▪ Preoperative (5 to 10 minutes) subacromial injection of local anesthetic with epinephrine in the subacromial space will significantly reduce bleeding during repair. During soft tissue removal around the scapular spine and coracoacromial ligament release along the anteroinferior acromion, the surgeon must watch for vessels that require coagulation. |
| Passage of lateral low stitches medial to medial horizontal mattress | ▪ During passage of the lateral stitches, any resistance to suture passage may mean impalement of previously placed medial-row sutures. If resistance is met, the suture passer should be removed and reloaded without forcing suture passage. |
| Lateral row PushLock anchor placement | ▪ After PushLock anchors are loaded with suture outside the shoulder, they should be placed through the same fascial defect through which sutures were retrieved, thereby preventing suture entanglement in the deltoid fascia. |
POSTOPERATIVE CARE

- All patients are initially placed in a sling, which is removed only for elbow range-of-motion exercises three or four times per day to limit elbow stiffness and for bathing.
- We use a subacromial pain catheter, infiltrating 0.5% bupivacaine (Marcaine) during the first 48 hours postoperatively.
- Patients remain on antibiotics (cephalexin) while the pain catheter is still in place.
- Dressings are removed on the second postoperative day and showering is allowed the following day.
- Patients are seen at 10 days postoperatively for suture removal.
- When to start physical therapy after rotator cuff repair is debated among orthopedic surgeons. The decision is based on the perceived risks and benefits of early motion.
- The major benefit of early motion is the potential limitation of postoperative shoulder stiffness. The main risks include repair disruption and limited healing.
- Early passive motion has historically been recommended after open rotator cuff repair. With the advent of arthroscopic repairs, scarring from soft tissue dissection is minimized, so limiting early motion is possible.
- Limited early motion may improve tendon healing.
- Several factors, including tear size, tendon and bone quality, and preoperative motion, should be considered in this decision.
- With osteoporotic bone or extremely poor tendon quality, limiting motion initially after repair is recommended.
- Preoperative shoulder motion is an important factor in determining the initiation of motion. Earlier motion may be initiated if preoperative motion is limited and requires manipulation or release at the time of repair.
- In general, tear size is the most important factor in determining the timing of postoperative rehabilitation.
- Limiting early motion in patients with larger tears may provide improved healing potential, given that their overall healing rates are much lower than smaller tears.
- Patients with small or medium-sized tears remain in a sling for the first 6 weeks after surgery.
- Elbow and hand range-of-motion exercises are started immediately.
- No shoulder motion is allowed during the first 6 postoperative weeks.
- If there was a significant preoperative motion deficit requiring surgical release or manipulation at the time of repair, early passive motion is allowed.
- After 6 weeks, the sling is removed and patients are started on passive and active assisted range-of-motion exercises, including forward elevation in the scapular plane, external rotation in full abduction, and pendulum and pulley exercises.
- Internal rotation and shoulder extension is limited and patients are instructed not to perform any lifting, pulling, or overhead activity.
- At 3 months after surgery, strengthening exercises are initiated. These begin with isometric exercises and progress to isotonic exercises, with a stretching program maintained throughout.
- Return to sports and full unrestricted activity is allowed at 4 to 5 months.

- For large or massive tears, patients remain in a sling with no shoulder motion for 6 weeks.
- At 6 weeks, the sling is removed and patients are allowed to lift the arm to shoulder height only.
- Formal physical therapy is not initiated at this time. Instead, a shoulder continuous passive motion (CPM) device (Breg Flexmate S500, Breg, Inc., Vista, CA) is used to regain forward elevation in the scapular plane. CPM use is continued until 3 months postoperatively.
- At this time, formal physical therapy is initiated, including passive and active motion and strengthening as per the protocol for small and medium-sized tears.
- Return to sports and unrestricted activities is allowed at 6 months postoperatively.

OUTCOMES

- Functional outcomes after both open and arthroscopic rotator cuff repair have been reported to be durable at long-term follow-up. A number of factors have been correlated with outcomes after repair, including patient age, tear size, tear acuity, workers’ compensation status, preoperative smoking status, muscle quality, and tendon healing.
- Most series reporting outcomes after complete arthroscopic rotator cuff repair are in single-row repairs. The potential advantage of a double-row repair is improved initial repair fixation strength and restoration of the normal anatomic rotator cuff footprint. Improved initial fixation strength and footprint restoration should lead to improved healing rates. In both open and arthroscopic repairs, tendon healing is correlated with improved outcomes. Therefore, double-row repairs may lead to improved clinical outcomes.
- There are limited series reporting the outcomes of complete arthroscopic double-row rotator cuff repairs.
- Suguya et al compared healing rates and outcomes between single- and double-row repairs in 78 patients an average of 35 months after surgery using MRI. There were significant improvements in UCLA and American Shoulder and Elbow Surgeons (ASES) scores in both repair groups, with no significant difference found between techniques. There was a significant increase in retear rates with single-row repairs.
- Andersson et al recently evaluated 48 patients at a mean of 30 months after double-row repair with ultrasonography. There was a significant improvement in active motion, strength, and outcomes when compared to preoperative values. The overall retear rate was 17%, with no significant difference in outcomes between healed and retorn tendons. Healed shoulders were significantly stronger in elevation and external rotation.
- Overall, double-row repairs appear to have improved healing rates compared to single-row repairs, although functional results are very similar.

COMPLICATIONS

- Several factors can be directly correlated with persistent pain and limited function after repair.
- These factors are broken down into three categories: surgeon-controlled, non-surgeon-controlled, and patient-related factors.
- They include incorrect or incomplete diagnosis, surgical technical error, stiffness, infection, and anesthesia-related complications.
Infection after rotator cuff repair is uncommon.

Continued pain after rotator cuff repair can often occur if a second pathology is not identified and treated.

- Conditions often confused with rotator cuff disease include cervical spine disorders, suprascapular neuropathy, acromioclavicular joint arthritis, biceps tendinopathy, glenohumeral instability or arthritis, labral tears, and frozen shoulder.
- A complete history and physical examination can prevent missing several of these problems, which can often be treated concomitantly at the time of rotator cuff repair.
- Technical problems leading to persistent pain and dysfunction after repair can be grouped into repair failures, deltoid detachment, neurologic injury, excess fluid extravasation, and patient positioning injuries.
- The most likely reason for failure of tendon healing after repair is patient age.
- Poor surgical technique, including poor knot-tying, limited fixation (number of anchors), and poor anchor insertion technique, can all lead to a weak biomechanical construct.
- Deltoid detachment is avoided in the setting of complete arthroscopic repair, but if a mini-open approach is performed, then excess detachment without bony repair can lead to failure of healing.
- Transient neurologic injury can occur secondary to excess traction when the lateral position is used.
- Proper portal placement is critical to avoid axillary (posterior and lateral portals) and musculocutaneous (anterior portal) nerve injury.
- Excess swelling due to fluid extravasation into the deltoid can significantly raise intramuscular pressures. Therefore, pump pressures should be kept below 50 mm Hg, with procedure times less than 2 hours.
- Proper padding around the knees (lateral position) and flexing the hips and knees (beach-chair position) can avoid iatrogenic problems secondary to positioning.
- Postoperative stiffness is another potential complication.
  - With limited surgical dissection associated with complete arthroscopic repairs, the risk of stiffness may be significantly reduced when compared with open repairs.
  - While overall rates of postoperative stiffness have not been clearly reported, more than 5% to 10% of open repairs are complicated by either adhesions in the humeral scapular interface or capsular contracture.
  - We now routinely hold all shoulder motion after arthroscopic repairs for several weeks in an attempt to improve healing rates, with limited concern for developing postoperative stiffness.
  - If significant stiffness does develop that is resistant to therapy, arthroscopic lysis of adhesions in the subacromial space along with capsular release is recommended.
  - Infection after rotator cuff repair is uncommon.
    - Most series report infection rates of 1% to 2% after open or mini-open rotator cuff repairs.
    - While there are few reported studies of infection rates after complete arthroscopic repairs, it appears that infection is less common than after open or mini-open repairs.
    - Diagnosis is often delayed in cases of postoperative infection, and persistent wound drainage is the most consistent examination finding.
    - Cultures will often grow Propionibacterium acnes, Staphylococcus aureus, and coagulase-negative Staphylococcus aureus.
    - P. acnes often takes 7 to 10 days to grow on cultures. Therefore, cultures should be held in the setting of postoperative infections for at least 1 week.
    - Treatment consists of multiple debridements and intravenous antibiotics for usually 6 weeks.
    - Outcomes after infection are satisfactory, although significant delays in diagnosis or treatment can lead to inferior results.
  - Anesthetic complications can occur after rotator cuff repair.
    - If general anesthesia is used, major complications occur less than 1% of the time.
    - More commonly, nausea, inability to void, and severe pain are the complications seen in the setting of outpatient elective shoulder surgery.
    - If an interscalene block is used, inadequate anesthesia is the most common complication.
    - Temporary Horner syndrome, phrenic nerve paralysis, and recurrent laryngeal nerve block are common but usually without significant consequence.
    - Intraneural injection or needle injury to the nerve roots can occur.
    - Symptoms such as persistent paresthesias or numbness can be irritating but usually resolve with time (possibly several months).

**REFERENCES**

DEFINITION
- A subscapularis tendon tear typically occurs at its insertion into the lesser tuberosity of the proximal humerus.
- Although the subscapularis is the largest of the rotator cuff muscles, historically it has received little attention.
- Subscapularis tendon tears are often overlooked and under-diagnosed; therefore, a proper evaluation of the shoulder is of paramount importance.
- Treatment of subscapularis tendon tears can restore the functional stability of the shoulder.

ANATOMY
- The subscapularis muscle originates from the medial two thirds of the anterior scapular fossa. The muscle courses laterally beneath the coracoid and becomes tendinous at the glenoid rim. The subscapularis tendon becomes confluent with the glenohumeral joint capsule deep to it and inserts into the lesser tuberosity of the proximal humerus (FIG 1).
- The normal subscapularis tendon not only intermingles with the fibers of the glenohumeral joint capsule deep to it, but at its insertion it also intermingles with the fibers of the medial sling of the long head of the biceps tendon. The medial sling is composed of fibers from the superior glenohumeral ligament and the coracohumeral ligament complex.
- The tendon insertion is about 2.5 cm long (range 1.5 to 3.0 cm) and is trapezoidal, with the widest portion at its most superior (cephalad) aspect.
- The superior aspect also happens to be the strongest part of the subscapularis insertion.

PATHOGENESIS
- As with the other rotator cuff tendons, intrinsic factors may play a role in the development of a subscapularis tendon tear. Furthermore, extrinsic mechanical factors have also been implicated in the process.
- The normal subcoracoid space (coracohumeral interval) represents the distance from the coracoid tip to the proximal humerus. If this space is stenotic, the coracoid tip will impinge against the insertion of the subscapularis, causing damage to the tendon insertion.
- Anatomic and imaging studies have defined the normal coracohumeral interval to be between 8.4 mm and 11 mm.
- Subcoracoid stenosis is defined as less than 6 mm of space between the coracoid and the proximal humerus (either by magnetic resonance imaging [MRI] or arthroscopy).
- Patients with subscapularis tears often have a significantly reduced coracohumeral interval (5 mm with subscapularis tears vs. 10 mm without subscapularis tears).
- In subcoracoid impingement, the coracoid abuts against the anterior surface of the subscapularis, causing increased articular (under) surface tensile forces that can cause tendon fiber failure.
- Two separate cadaveric studies found that subscapularis tendon tears are often partial-thickness articular tears. Furthermore, they usually begin at the superior aspect of the insertion and are common in the elderly population.
- However, complete tears of the subscapularis tendon often result in medial retraction of the tendon edge to the level of the glenoid.
- The retracted tendon often pulls with it the adjacent medial sling of the biceps tendon (composed of fibers from the superior glenohumeral ligament and coracohumeral ligament).
- The fibers of the medial sling are oriented approximately perpendicular to the fibers of the subscapularis tendon and arthroscopically appear as a comma-shaped soft tissue structure that we refer to as the “comma sign” (FIG 3).
We have found the “comma sign” to be a useful guide for identifying the retracted superolateral edge of the subscapularis tendon.

The loss of the subscapularis tendon results in an unstable glenohumeral fulcrum and abnormal glenohumeral arthrokinematics.\(^{12}\)

### NATURAL HISTORY

- There is little available information on the natural history of subscapularis tendon tears.
- In some patients (especially those with massive rotator cuff tears) the tears can be disabling. Some patients with massive rotator cuff tears never regain functional overhead use of their arms without surgical intervention.

### PATIENT HISTORY AND PHYSICAL FINDINGS

- Although most subscapularis tears in the community are degenerative in nature, the classic scenario for a traumatic tear is forced external rotation.
- Forced external rotation results in an eccentric tensile load, which can be particularly dangerous to a “tendon at risk.”
- In contrast to patients with the typical posterosuperior rotator cuff tear, who have difficulty with overhead tasks, patients with subscapularis tears often have the burden of diminished function with tasks in front of the body and below the level of the shoulder.
- The typical patient complains of chronic pain and loss of arm strength with activities of daily living in front of the body.
- A complete physical examination is necessary, including examination of the cervical spine and both upper extremities. Examinations to perform are:

---

**FIG 2** • Schematic drawing of the roller-wringer effect. In patients with subcoracoid impingement, the prominent coracoid tip indents the superficial surface of the subscapularis tendon. This creates tensile forces on the convex, articular surface of the subscapularis tendon and can lead to failure of the subscapularis fibers. \(C\), coracoid; \(H\), humerus. (From Burkhart SS, Lo IKY, Brady PC. A Cowboy’s Guide to Advanced Shoulder Arthroscopy. Philadelphia: Lippincott Williams & Wilkins, 2006.)

**FIG 3** • **A,B.** Anterior structures from a posterior viewing portal of a right shoulder. The medial sling (\(M\)) of the biceps tendon (\(BT\)) inserts into the lesser tuberosity of the humerus (\(H\)) along with the superolateral margin of the subscapularis (\(SSc\)). **C,D.** Complete subscapularis tendon tear. In this situation, the comma sign (\(,\)) leads to the superolateral border of the subscapularis tendon. \(G\), glenoid; \(C\), coracoid. (From Burkhart SS, Lo IKY, Brady PC. A Cowboy’s Guide to Advanced Shoulder Arthroscopy. Philadelphia: Lippincott Williams & Wilkins, 2006.)
We also routinely obtain an MRI of the affected shoulder.

■ 30-degree caudal tilt, outlet view, and axillary plain films.

We routinely obtain five views of the shoulder: anteroposterior (AP) internal rotation, AP external rotation, AP with 30-degree caudal tilt, outlet view, and axillary plain films.

Evaluation of the plain films may reveal proximal humeral migration (especially with longstanding massive rotator cuff tears), acromial morphology, glenohumeral or acromioclavicular joint degenerative changes, anterior humeral translation (seen with subscapularis tendon disruptions on the axillary view), and so forth.

We also routinely obtain an MRI of the affected shoulder.

■ The MRI can provide important information on the location and extent of the subscapularis tendon tear.

■ It can also determine whether additional pathology in the shoulder coexists (eg, additional rotator cuff tears, medial subluxation or tears of the long head of the biceps tendon, ganglion cysts, labral tears).

■ Tears of the subscapularis tendon are best appreciated on the axillary images of the MRI (Fig 4).

Signal characteristics consistent with fluid may be seen with partial-thickness tears, whereas a loss of part or all of the normal tendon will be seen with full-thickness tears.

DIFFERENTIAL DIAGNOSIS

■ Subscapularis tendinitis or bursitis

■ Posterosuperior rotator cuff tear

■ Biceps tendinitis

■ Labral tear

■ Neurologic impairment

NONOPERATIVE MANAGEMENT

■ The role of nonoperative treatment in patients with symptomatic subscapularis tears is very limited.

■ Most patients who present to orthopedic surgeons with subscapularis tears have had the tear for a long time.  

■ Furthermore, most have attempted and failed nonoperative treatment.

■ However, for patients who are not good surgical candidates (eg, very old, ill), nonoperative treatment is warranted.

■ Nonoperative treatment typically consists of activities as tolerated with gentle stretching and progressive strengthening of the shoulder.

SURGICAL MANAGEMENT

Preoperative Planning

■ The history, physical examination, plain films, and MRI should all be reviewed before operative intervention.

Positioning

■ The anesthesiologist administers general anesthesia with endotracheal intubation and applies protective eyewear to the patient.

■ The patient is rotated into the lateral decubitus position and an axillary roll is placed.

■ The patient is well padded with pillows beneath and between the legs.
- The patient is secured in place with a vacuum beanbag and is tilted back approximately 10 degrees.
- A warming blanket is applied to prevent hypothermia.
- The sterile field must extend posteriorly to a position medial to the scapula and anteriorly just lateral to the nipple.
- After the patient is properly protected, positioned, padded, and draped, the surgeon performs an examination under anesthesia.
- The assistant prepares the operative extremity with a sterile scrub.
- The arm is then placed in 5 to 10 pounds of balanced suspension (Star Sleeve Traction System; Arthrex Inc., Naples, FL) with the shoulder in 20 to 30 degrees of abduction and 20 degrees of forward flexion (FIG 5).

**Approach**

- Successful treatment of subscapularis tears has been documented with both open and arthroscopic techniques.
- We prefer and will present our arthroscopic technique for treatment of a subscapularis tendon tear.

**PORTALS AND VISUALIZATION**

- The surgeon should remember the “6 Ps” for arthroscopic portals: “Proper portal placement prevents poor performance.”
- Our standard posterior viewing portal is placed 4 to 5 cm inferior (caudal) to the posterior border of the acromion and 3 to 4 cm medial to the posterolateral corner of the acromion (TECH FIG 1A).
- A standard diagnostic arthroscopy of the entire glenohumeral joint is performed.
- To fix the tear one must be able to see the tear. This point cannot be emphasized enough, and throughout the procedure special attention is paid to optimize visualization by controlling bleeding.
  - Key factors include minimizing the pressure differential between the patient’s blood pressure and the arthroscopic pump pressure; making use of the Bernoulli principle to achieve turbulence control; and using electrocautery as needed to cauterize specific bleeding points.
- The subscapularis tendon presents a unique problem to visualization. The tendon tear is often in a very confined space that may be unfamiliar to the surgeon (TECH FIG 1B). This space can become even more constricted with soft tissue swelling as the case proceeds, so we recommend repairing the subscapularis tendon before addressing any other problems in the shoulder.
- We have found that examination of the subscapularis tendon for a partial tear is optimized with shoulder flexion and internal rotation (lifts the subscapularis tendon off its footprint on the lesser tuberosity; TECH FIG 1C).
- Visualization is further enhanced with a “posterior lever push” in which an assistant pushes the proximal humerus posteriorly while pulling the distal humerus anteriorly (TECH FIG 1D).
- A 70-degree arthroscope is an extremely helpful additional tool that can improve visualization by providing an “aerial view.”
  - The initial identification and orientation should be done with a 30-degree arthroscope, however, because it is easy to get lost and stray dangerously inferior into the vicinity of neurovascular structures if the 70-degree arthroscope is used initially.
- The primary working portal is the anterosuperolateral portal, which is 1 to 2 cm lateral to the anterolateral corner of the acromion.
  - An 18-gauge spinal needle is introduced into the glenohumeral joint to make a 10-degree angle of approach to the lesser tuberosity.
  - Advantages of the anterosuperolateral portal include a good angle of approach to prepare the lesser tuberosity bone bed; a near-parallel angle of approach to the subscapularis for mobilization and antegrade suture passage; and an angle of approach to the coracoid tip that will allow a coracoplasty to be made in a plane that is parallel to the subscapularis tendon.
  - The next portal created is the anterior portal, which is 4 to 5 cm inferior to the anterior acromion, just lateral to the coracoid tip.
  - An 18-gauge spinal needle is introduced into the glenohumeral joint to determine a 45-degree angle of approach to the lesser tuberosity, and then the portal is established in that line of approach.
- Advantages of the anterior portal include an optimal angle of approach for anchor placement, suture management, and on occasion retrograde suture passage (although we almost always do antegrade suture passage through the subscapularis tendon via an anterosuperolateral portal).
Subscapularis tendon tears are often associated with tearing or medial subluxation of the long head of the biceps tendon. The long head of the biceps tendon should be inspected from its base to the intertubercular groove. It is often helpful to pull the tendon into the glenohumeral joint and to pay particular attention to the medial surface of the tendon for partial tearing.

Also, internal and external rotation of the humerus may reveal subluxation of the tendon. The biceps tendon should never pass posterior to the plane of the subscapularis with rotation of the humerus.

Most of our patients with biceps tendon tearing or subluxation in association with a torn subscapularis receive a biceps tenodesis.

In our view the alternatives are suboptimal:

- Biceps tendon subluxation left alone will result in increased stress to the subscapularis repair and may ultimately cause it to fail.
- Significant biceps tendon degeneration may result in continued shoulder pain and dysfunction.

BICEPS TENDON

- Biceps tenotomy has been shown in the literature to result in decreased elbow flexion and forearm supination strength, and some patients consider it aesthetically undesirable. Therefore, we perform a biceps tenotomy only in elderly patients with low demands and poorly defined arm musculature.

The initial step in the tenotomy is to place two half-racking stitches 1 to 2 cm distal to the base of the long head of the biceps tendon (TECH FIG 2). These sutures tighten and lock against the tendon to securely hold it after it is tenotomized (in preparation for tenodesis).

The tenotomy is made at the base of the biceps with electrocautery or scissors. Care is taken not to damage the superior labrum.

The biceps tendon is then extracted extracorporeally through the anterosuperolateral portal. Pushing on the skin around the tendon’s exit point and flexing the elbow and shoulder aids in presenting the tendon out of the portal.

A no. 2 FiberWire (Arthrex) whipstitch is run with three or four passes on each side of the tendon.
The whipstitch sutures are temporarily pulled through the anterosuperolateral portal outside the cannula so that it will be out of the way until it is time to do the biceps tenodesis.

This temporary tenotomy improves subscapularis visualization and working space. At the end of the case, after the subscapularis tendon has been repaired, we prefer to anchor the biceps tendon to bone using the BioTenodesis screw system (Arthrex) to obtain a secure interference fit of tendon against bone.

Subcoracoid Space

The first step in defining the subcoracoid space is to identify the coracoid tip.

- If the subscapularis tendon is intact or partially torn, the coracoid tip is located just anterior to the upper border of the subscapularis tendon. With internal and external rotation of the humerus the coracoid tip can be seen as a moving bulge in the rotator interval.
- Through the anterosuperolateral portal the electrocautery can be used to create a window in the rotator interval tissue to expose the coracoid tip (the surgeon must take care to preserve the medial sling of the biceps tendon).
- If the subscapularis tendon is completely torn and retracted, the coracoacromial ligament is a useful guide to the coracoid tip.
- The surgeon should use an instrument to palpate and confirm the location of the coracoid tip.

We have found that the best method of measuring the coracohumeral interval is direct visualization during arthroscopy with an instrument of known size through the anterosuperolateral portal (eg, the diameter of a shaver blade). Gentle axial distraction may be necessary to obtain an accurate measurement if there is any proximal humeral migration.

We also routinely place the shoulder in the provocative position of flexion, horizontal adduction, and internal rotation to arthroscopically evaluate if there is any impingement between the coracoid tip and the subscapularis tendon and proximal humerus.

If there is any evidence of subcoracoid stenosis (coraco-humeral interval less than 6 mm) or impingement, we perform a coracoplasty with a goal of creating a coraco-humeral interval of 8 to 10 mm.
The soft tissues on the posterolateral surface of the coracoid are removed ("skeletonizing" the coracoid) with electrocautery and a motorized shaver (the surgeon must be careful not to release the conjoint tendon from the undersurface of the coracoid tip; TECH FIG 3A,B).

The fibers of the coracoacromial ligament may be released for improved visualization.

The anterosuperolateral portal provides a great angle of approach for the high-speed burr to be parallel to the subscapularis tendon for the coracoplasty.

A "posterior lever push" may improve the anterior working space by 5 to 10 mm (TECH FIG 3C,D). A second assistant who is anterior to the patient in a lateral decubitus position provides a posterior force to the proximal humerus with a simultaneous anterior force to the distal humerus.

Alternating between the 30- and 70-degree arthroscopes as needed optimizes visualization.

The coracoplasty improves the anterior working space for the subscapularis repair and prevents future abrasion to protect the repair.

**SUBSCAPULARIS MOBILIZATION**

- We routinely perform a three-sided release for complete, retracted subscapularis tendon tears.
- The three-sided release can be difficult secondary to retraction, scarring, and working in a constricted space.
- The surgeon may be concerned about the proximity of neurovascular structures; however, a cadaveric study found that the axillary nerve, axillary artery, musculocutaneous nerve, and lateral cord of the brachial plexus are all more than 25 mm from the coracoid base. The key is to stay on the posterolateral aspect of the coracoid.
- The first step to mobilizing the subscapularis is to place a traction suture at the junction of the superolateral tendon and "comma tissue" (TECH FIG 4A).
- The comma tissue is a comma-shaped fibrous band of tissue at the superolateral border of the subscapularis tendon; its fibers are oriented at right angles to those of the subscapularis. It is the remnant of the medial sling of the biceps after it pulls loose from its footprint on the lesser tuberosity directly adjacent to the footprint of the upper subscapularis.
- This can be done through the anterosuperolateral portal with a Viper or Scorpion suture passer (Arthrex) loaded with a free no. 2 FiberWire suture (Arthrex). The traction suture can then be held outside the cannula to allow continued use of the anterosuperolateral portal.
- The anterior release (subscapularis from the posterolateral coracoid and deltoid fascia) may be done by alternating the electrocautery with the shaver.
- If a coracoplasty was not performed earlier, the soft tissues are removed from the coracoid ("skeletonizing" the posterolateral coracoid; TECH FIG 4B).
- The release is continued medial along the posterolateral coracoid until the subscapularis muscle belly is visible beneath the arch of the coracoid neck and base.
The superior release (subscapularis from the undersurface of the coracoid neck and base) may then be done with a 30-degree arthroscopic elevator (TECH FIG 4C). The release is done only to the midpoint of the undersurface of the coracoid neck (to prevent damage to the neurovascular structures medial to the coracoid neck). The posterior release (subscapularis from the glenoid neck) may then be done with a 15-degree arthroscopic elevator (TECH FIG 4D). The release is continued medial until the subscapularis is freely mobile. The posterior release is the safest release (because it is in a very safe plane between the subscapularis and the coracoid neck and base). The inferior release is the most dangerous and has not been necessary in our experience.

**BONE BED PREPARATION AND ANCHOR PLACEMENT**

- The anterosuperolateral portal has a great angle of approach for removing the soft tissues off the subscapularis footprint of the lesser tuberosity.
- A ring curette may be used to precisely remove the soft tissues up to the articular margin. Then electrocautery is used to ablate any soft tissue on the footprint (TECH FIG 5A).
- The high-speed burr then removes the “charcoal” (residual of electrocauterization) to a bleeding bone bed without decorticating the bone (TECH FIG 5B).
- To decrease the tension at the repair site, we have found that the subscapularis footprint may be medialized up to 5 mm with no detriment to its function.
One anchor should be placed every centimeter, which typically results in one anchor for a partial tear and two anchors for a complete tear (if a single-row repair is done).
- The anchors should be placed in order from inferior (caudal) to superior (cephalad).
- We use double-loaded anchors to reduce the load on each suture.
- The best angle of approach for anchor placement is typically through the anterior portal (TECH FIG 5C).
- The surgeon’s hand and instruments (eg, punch and anchor inserter) are often close to the patient’s face, which is one reason we place protective eyewear on every patient (TECH FIG 5D,E).

**SUTURE PASSAGE AND KNOT TYING**
- We prefer the Viper or Scorpion suture passers (Arthrex) because they allow antegrade suture passage and retrieval (retrograde suture passage is difficult because the coracoid often blocks a good angle of approach).
- One strand of suture is retrieved from the anchor, pulled out the anterosuperolateral cannula, and loaded in the suture passer.
- Tension is placed on the traction suture (which is inside the anterosuperolateral portal but outside its cannula) and the suture is passed about 10 mm from the lateral edge of the subscapularis tendon (TECH FIG 6A).
- For the superior anchor, the sutures should be passed over the top of the superolateral border of the subscapularis, just medial to the “comma tissue.” This will provide a “ripstop” to prevent lateral cutout of the sutures.
- The process is repeated for the second suture of the same anchor.
- Both the sutures are tied through a clear cannula with a double-diameter knot pusher (Surgeon’s Sixth Finger, Arthrex; TECH FIG 6B).
- We use a six-throw arthroscopic surgeon’s knot, which is composed of a static base knot of three stacked half-hitches followed by three reversing half-hitches on alternating posts (TECH FIG 6C).
- The arthroscopic surgeon’s knot with a double-diameter knot pusher has been found in the laboratory to have the best combination of loop and knot security.\(^\text{11}\)
- To maximize efficiency and visualization, we tie the sutures of the inferior anchor before working on the superior anchor (TECH FIG 6D).
- After completing the subscapularis tendon repair we internally and externally rotate the humerus to be sure that we have achieved secure apposition of the tendon against the bone.
**POSTOPERATIVE CARE**

- An arthroscopic subscapularis tendon repair is usually an outpatient procedure.
- After the arthroscopic portals are closed, a sterile dressing is applied over the shoulder.
- A sling with a small pillow is applied with the arm at the side. The sling is worn full-time for 6 weeks, except when bathing or eating.
- During the first 6 weeks the patient should perform daily active wrist and elbow motion.
  - The patient must not externally rotate past neutral (straight-ahead position) for 6 weeks.
  - There is no overhead motion in the first 6 weeks.
  - At 6 weeks from the operation the sling is discontinued.
  - The patient is started on a passive stretching program that includes passive external rotation with a cane up to 45 degrees and overhead stretches with a rope and pulley.
  - At 12 weeks from the operation the patient is started on a strengthening program with elastic bands.
  - If the subscapularis tear is part of a massive anterosuperior rotator cuff tear, then strengthening is delayed until 16 weeks postoperatively.
  - Progression to light weights is based on the patient’s progress.
  - Rehabilitation focuses on strengthening the scapular stabilizers and deltoid and rotator cuff muscles.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>A complete history, a proper physical examination, full evaluation of the diagnostic studies, and a thorough arthroscopic evaluation of the shoulder are necessary.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portal placement</td>
<td>Proper portal placement is imperative to achieve the correct angle of approach to work in the subcoracoid space.</td>
</tr>
<tr>
<td>Visualization</td>
<td>The key principles include minimizing pressure differentials (hypotensive anesthesia with adequate arthroscopic pump pressure), avoiding turbulence, using the posterior lever push, and using both the 30- and 70-degree arthroscopes freely.</td>
</tr>
<tr>
<td>Secure fixation</td>
<td>The subscapularis tendon must be securely apposed to the bone to optimize healing. Important biomechanical principles include the proper angle of insertion of the suture anchors; use of double-loaded anchors to reduce the load on each suture; use of strong sutures; proper suture placement in the tendon; and optimized loop and knot security.</td>
</tr>
<tr>
<td>Rehabilitation</td>
<td>The patient must clearly understand what he or she can do to protect and optimize healing of the subscapularis tendon repair.</td>
</tr>
</tbody>
</table>
Return to full, unrestricted activities is usually at 6 to 12 months and is based on the patient, the size of the tear, the strength of the repair, and the patient’s rehabilitation progress.

**OUTCOMES**

- The results after arthroscopic subscapularis tendon repair have been quite favorable.²,³,⁹
- The senior author (SSB)³ published his preliminary results in 2002.
- In this series of 25 consecutive patients with a mean follow-up of 11 months, 92% had good or excellent results by the UCLA criteria.
- There was a significant improvement in pain and functional motion.
- Eight of ten patients who had proximal humeral migration preoperatively had reversal of the migration and functional overhead use of their arm.
- Bennett² also found encouraging results in his prospective cohort with 2- to 4-year follow-up.
- The patients had a mean American Shoulder and Elbow Surgeons (ASES) score improvement from 16 preoperatively to 74 postoperatively.
- Visual analogue pain scores improved from 9 preoperatively to 2 postoperatively.
- Kim et al,⁹ in a recent report of patients who had an arthroscopic repair of isolated partial articular-sided tears, found similar improvements in pain and function.
- At a mean follow-up of 27 months, UCLA scores improved from 23 preoperatively to 33 postoperatively, ASES scores improved from 67 to 96, and visual analogue pain scores improved from 5 to 0.3.

**COMPLICATIONS**

- Stiffness
- Retear
- Neuropraxia
- Infection

**REFERENCES**

DEFINITION

- About 9% of shoulder girdle injuries involve damage to the acromioclavicular (AC) joint.
- This is a sequential injury beginning with the AC ligaments, progressing to the coracoclavicular ligaments, and finally involving the deltoid and trapezial muscles and fascia.
- Patients usually report direct trauma to the lateral shoulder or a fall on an outstretched arm driving the humeral head into the AC joint, resulting in a dislocation with pain at the AC joint, in particular with cross-arm adduction.
- Dislocations are classified by severity of injury, radiographic findings, and position of the clavicle (Table 1).

ANATOMY

- The AC joint is a diarthrodial joint that primarily rotates as well as translates in the anteroposterior as well as the superoinferior plane.
- The scapula (acromion) can protract and retract, using the AC joint as a pivot point.
- Normal scapular motion consists of substantial rotations around three axes and plays a major role in the motion at the AC joint.
- The articular surface is made up of hyaline cartilage containing an intra-articular meniscus type of structure, all surrounded by a joint capsule with a synovial lining.
- The AC joint static stabilizers include the acromioclavicular ligaments (superior, inferior, anterior, and posterior), the coracoclavicular ligaments (trapezoid and conoid), and the coracoclomial (CA) ligament.
- The AC joint dynamic stabilizers consist of the deltoid and trapezius muscles.
- Appreciating the location of the coracoclavicular ligament attachment on the clavicle is important. The trapezoid attach to the undersurface of the clavicle at an anterolateral position. The conoid is a broad stout ligament located in a posterior and medial position. Both the trapezoid and conoid are posterior to the pectoralis minor attachment on the coracoid. (FIG 1).
- The AC joint capsule and the capsular ligaments are the primary restraints of the distal clavicle to anterior-to-posterior translation. More specifically, the superior and posterior AC capsule ligaments prevent posterior displacement of the clavicle and abutment against the scapular spine.
- The trapezoid and conoid span the coracoclavicular space (1.1 to 1.3 cm) and contribute to vertical stability, preventing superior and inferior translation of the clavicle.
- The AC and coracoclavicular ligaments all contribute to the prevention of motion in all planes. The conoid ligament has the highest in situ forces with superior loads, regardless of the integrity of the AC ligaments. The AC ligaments are the main restraints to posterior and anterior translation. However, when the AC ligaments are transected, the conoid is the primary restraint to anterior loads and the trapezoid is the primary restraint to posterior loads.
- The AC joint is innervated by the lateral pectoral nerve and the suprascapular nerve.

PATHOGENESIS

- The mechanism of most AC joint injuries is a direct blow to the lateral acromion with the arm adducted.
- Indirect injury occurs by falling on an adducted outstretched hand or elbow, causing the humeral head to translocate superiorly and drive the humeral head into the acromion.

NATURAL HISTORY

- Most patients with type I or II AC joint separations typically have full recovery with no long-term sequelae. However, some patients continue to be symptomatic. In one study, up to 27% of patients with type I and II injuries had persistent pain and required a surgical procedure. Some patients treated nonoperatively continued to have instability and pain with provocative tests (level IV evidence).
- Most patients with type III separations do well with conservative treatment. In a survey of Major League Baseball team physicians, 80% of athletes treated nonoperatively had complete pain relief and normal function (level IV evidence). Studies have failed to show a statistical difference in the return to activity (level IV evidence).
- Type IV, V, and VI AC joint separations do poorly without operative intervention (level V evidence).
- Persistent pain is attributed to a chronically dislocated AC joint with severe soft tissue disruption.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The mechanism of injury is an important history finding that clues one into a possible AC joint injury.
- Pain at the AC joint is difficult to differentiate from glenohumeral pathology because of the dual innervation of the AC joint by the lateral pectoral nerve and suprascapular nerve.
- Because of the innervation by the lateral pectoral nerve, some patients may present with anteromedial pain, further complicating the picture.
- Pain in the trapezius region and anterolateral deltoid is more specific for AC joint injury, whereas pain located only in the lateral deltoid is more indicative of a subacromial process.
- Pathology of the AC joint is identified by a triad of point tenderness, positive pain at the AC joint with cross-arm adduction, and relief of symptoms by injection of a local anesthetic.
- Methods for examining the AC joint include the following:
  - AC joint compression (shear) test: Isolated painful movement at the AC joint in conjunction with a history of direct trauma indicates AC joint pathology.
  - Cross-arm adduction test: Look for pain specifically at the AC joint. Pain at posterior aspect of shoulder or lateral shoulder might indicate other pathology.
Chapter 12  REPAIR AND RECONSTRUCTION OF ACROMIOCLAVICULAR INJURIES 103

Paxinos test\(^\text{16}\) is sometimes done in conjunction with bone scan to assess damage to AC joint.

O’Brien test: Symptoms at the top of the joint must be confirmed by examiner palpating the AC joint. Anterior glenohumeral joint pain suggests labral or biceps pathology.

Local point tenderness at the AC joint while keeping the glenohumeral joint still is suspicious for localized AC joint pathology.

---

**Table 1  Classification of Acromioclavicular (AC) Joint Injuries**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Inspection</th>
<th>Radiographic</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Sprain of the AC joint with all ligaments intact. Mechanism of injury consistent with AC joint injury. No evidence of instability.</td>
<td>Point tenderness at the AC joint and positive provocative tests. Radiographs are normal.</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Rupture of AC ligaments. Sprain of coracoclavicular (CC) ligaments.</td>
<td>Mild subluxation of the AC joint can be observed with stress examination. Radiographs of the lateral end of the clavicle may be slightly elevated, but stress views fail to show a 100% separation of the clavicle and acromion.</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>Complete disruption of both the AC and CC ligaments without significant disruption of the deltoid or trapezial fascia. The clavicle is unstable in both the horizontal and vertical planes.</td>
<td>The upper extremity is usually held in an adducted position with the acromion depressed while the clavicle appears high-riding, but in reality the acromion and the rest of the upper extremity is displaced inferior to the horizontal plane of the lateral clavicle. Radiographs show up to 100% increase in the CC interspace.</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>Complete disruption of both the AC and CC ligaments.</td>
<td>The distal clavicle is posteriorly displaced into the trapezius muscle and may tent the posterior skin. Evaluation of the sternoclavicular (SC) joint is necessary to rule out anterior SC joint dislocation. Posteriorly displaced clavicle can be seen on axillary view, which is always obtained in the standard radiographic evaluation of the AC joint.</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>AC and CC ligaments are disrupted.</td>
<td>Severe droop secondary to anteroinferior translation of the scapula around the thorax, due to the weight of the arm and the geometry of the chest wall. This is considered the third translation of the scapula with loss of the clavicular strut. Reduction of the distal clavicle with shoulder shrug differentiates type III from type V (distal clavicle buttonhole through soft tissue sleeve). Trapezial and deltoid fascia disrupted. Two to three times increase in the CC distance or a 100% to 300% increase in the clavicle-to-acromion radiographic distance.</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>Inferior dislocation of distal clavicle. Reduction may be blocked from interposition of the intact posterosuperior AC ligaments within the AC interval. Mechanism is thought to be severe hyperabduction and external rotation of the arm combined with retraction of the scapula.</td>
<td>The distal clavicle is found in two orientations, either subacromial or subcoracoid, behind the intact conjoined tendon.</td>
<td></td>
</tr>
</tbody>
</table>

---

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standard radiographs include AP, supraspinatus outlet view (FIG 2A), and axillary and Zanca views.
- A Zanca view is made by tilting the x-ray beam 10 to 15 degrees toward the cephalic direction (FIG 2B,C).
- The AC joint is more superficial and surrounded by less soft tissue than the glenohumeral joint.
The AC joint may be better visualized if a reduced penetration strength is used compared to standard radiographs of the glenohumeral joint.

An axial view of the shoulder is important in differentiating a type III from a type IV AC joint injury.

Coracoid base fractures can also be identified on this view.

A normal coracoclavicular interspace, in conjunction with a complete dislocation of the AC joint, may indicate a coracoid fracture, in which case a Stryker notch view is helpful (FIG 2D).

The AC joint width is normally 1 to 3 mm and decreases with age. The width seen on radiographs is influenced by the individual variability of obliquity of the joint in relation to the x-ray beam.

An increase in the coracoclavicular distance (usually 1.3 cm) of 25% to 50% over the normal side indicates complete coracoclavicular ligament disruption.

Although seldom necessary and mainly a historical practice, stress views (5 to 10 pounds placed in the ipsilateral hand) with increased coracoclavicular interspace on the AP view may help differentiate between type II and type III injuries.

Bone scan may help confirm subtle AC joint pathology and arthrosis.

Differential Diagnosis

- Cervical spine pathology
- Trapezial spasm
- Scapular dyskinesia
- Hyperlaxity
- Distal clavicle or acromion fracture
- Coracoid fracture

**FIG 1**

A. Anterior view. The trapezoid is anterolateral, whereas the conoid is a posteromedial structure.

B. Posterior view. The conoid can be seen as a broad ligament that fans out, attaching to the clavicle in a posteromedial position.

**FIG 2**

Positioning for radiographic studies.

A. Supraspinatus outlet view.

B, C. Zanca view. For optimal visualization of the acromioclavicular joint, the x-ray source is directed 10 degrees cephalad with reduced penetration strength compared to a standard radiograph.

D. Stryker notch view. This view helps rule out concomitant injuries. It is helpful when a coracoid fracture is suspected with a normal coracoclavicular interspace.
Glenohumeral pathology (impingement, rotator cuff, Hill-Sachs, Bankart, superior labral anterior posterior [SLAP] lesion, biceps)

Ulnar paresthesias

Thoracic outlet syndrome

NONOPERATIVE MANAGEMENT

The main goals of treatment, whether surgical or nonsurgical, are to achieve a pain-free shoulder with full range of motion and strength and no limitations in activities.

Most type I and type II AC joint separations are treated in a nonoperative fashion.

Treatment begins with a sling, ice, and a brief period of immobilization only for pain control. Rehabilitation is started as soon as tolerated.

The rehabilitation program consists of four phases:
- Pain control, immediate protective range of motion and isometric exercises
- Strengthening exercises using isotonic contractions
- Unrestricted functional participation with the goal of increasing strength, power, endurance, and neuromuscular control
- Return to activity with sports-specific functional drills

Surgical intervention should be considered after rehabilitation if pain persists for greater than 3 months.

Type III injuries:
- These patients are usually evaluated on a case-by-case basis, taking into account hand dominance, occupation, heavy labor, position and sport requirements (quarterbacks, pitchers), scapulothoracic dysfunction, and risk for re-injury.
- In a meta-analysis of 1172 patients, 88% of those treated with surgery and 87% of those treated without surgery had satisfactory outcomes (level IV evidence).
- In patients with type III injuries treated nonoperatively versus operatively, there was no difference in strength at 2 years of follow-up (level IV evidence).
- Schlegel and Burks found that only 20% of patients reported a suboptimal outcome with conservative care. Objective studies showed that patients had no limitation of shoulder motion in the injured extremity and no difference compared with the unaffected extremity in rotational shoulder muscle strength. A finding that may affect heavy laborers was a decrease of 17% in bench press strength at the 1-year follow-up (level IV evidence).
- If symptoms persist for greater than 3 months, including increased pain, impingement due to scapular dyskinesia, decreased strength, inability to get the arm into a cocking position in throwing, and painful instability, especially posterior instability with the clavicle abutting the anterior portion of the spine of the scapula, then operative intervention may be indicated.

SURGICAL MANAGEMENT

Again, the main goals of treatment, whether surgical or nonsurgical, are to achieve a pain-free shoulder with full range of motion and strength and no limitations in activities.

Complete AC joint injuries (type IV, V, and VI) are usually treated operatively because of the significant morbidity associated with persistently dislocated joints and severe soft tissue disruption.

Most surgeons will treat type III injuries conservatively for 12 weeks and consider surgical stabilization if persistent pain and instability exist. In an attempt to return an athlete or high-demand patient to work more rapidly, some will stabilize a type III separation, hoping to decrease painful instability.

Some patients treated nonoperatively will have persistent pain and an inability to return to their sport or job and will require surgical stabilization.

Operative choices:
- AC ligament repair
- Dynamic muscle transfer
- CA ligament transfer
- Coracoclavicular ligament repair
- Distal clavicle resection with coracoclavicular reconstruction
- Distal clavicle resection without coracoclavicular reconstruction
- Anatomic reconstruction of the coracoclavicular ligament
- Arthroscopic variations of the above

In the treatment of chronic AC joint pain with distal clavicle resection, arthroscopy of the glenohumeral joint can be undertaken to rule out concomitant injuries. Missed SLAP lesions and labral pathology have been reported as a cause of failed distal clavicle resection.

The modified CA ligament transfer (Weaver-Dunn) is the gold standard of treatment for the reconstruction of the AC joint and is presented here.

Anatomic reconstruction of the coracoclavicular ligaments (ACCR) attempts to recreate the normal anatomy and biomechanics of the AC joint. This technique has been studied in our biomechanics laboratory and is in clinical trials. The ACCR is our procedure of choice and is also presented here.

Various arthroscopic techniques have been described for fixation of AC separations.
- A description of an arthroscopic procedure using a high-strength suture and endobutton device is provided.
- Although our preferred treatment of acute type III injuries is conservative, this technique may be helpful for surgeons who decide to stabilize and splint acute type III injuries in high-demand patients.

Preoperative Planning

A successful outcome depends on reasonable patient expectations and compliance with the postoperative regimen, including postoperative sling immobilization for 6 weeks.

All radiographs are reviewed.

Reports indicate that concomitant injuries such as SLAP lesions and labral tears are a cause of failure after distal clavicle resection.

Magnetic resonance imaging (MRI) may be obtained to rule out concomitant injuries that also need to be addressed.

If using a modified Weaver-Dunn or ACCR, the surgeon should discuss with the patient the options for autograft or allograft.

Positioning

The patient is placed in the beach-chair position after induction of general anesthesia (FIG 3).

A specialized shoulder table is not used. We prefer a standard table that provides posterior support and stabilization of the scapula.

A small bump is placed on the medial scapular edge to stabilize it and elevate the coracoid anteriorly.
The head is mobile because repositioning is sometimes necessary during medial clavicle drilling. Wide draping is done to expose the sternoclavicular joint and posterior clavicle for complete visualization of the shoulder girdle. The arm is free draped to allow free motion and reduction.

The mean length from the end of the clavicle, or the AC joint, to the coracoclavicular ligaments is $46.3 \pm 5$ mm; the distance between the trapezoid laterally and the conoid medially is $21.4 \pm 4.2$ mm.\textsuperscript{11}

In both the Weaver-Dunn and ACCR procedures, the incision is made to allow exposure of the AC joint and coracoid. The incision for the Weaver-Dunn is more lateral compared to the ACCR because of the exposure necessary for CA ligament acquisition and because the ACCR clavicle preparation is performed slightly more medially.

Again, full exposure of the AC joint and coracoid is necessary in both procedures, and the incision can be extended or curved to allow the necessary exposure.

Although the AC joint and clavicle are superficial structures with little subcutaneous tissue, in our experience large skin flaps can be used to improve visualization without compromising the vascularity of the skin.

Full-thickness flaps of the deltotrapezial fascia during the approach are critical for closure. Tagging sutures can be placed during the approach to allow for quick and effective soft tissue coverage over the repair.

Gelpi retractors are low profile and help retract the deltotrapezial flaps.

Arthroscopy of the glenohumeral joint can be performed to look for concomitant injuries. An incision is made 3.5 cm from the AC joint starting at the posterior clavicle in a curvilinear fashion toward the coracoid along the lines of Langer. The incision is sometimes angled because the key is to have full visualization of the AC joint laterally and the coracoid process medially (TECH FIG 1).

Superficial skin bleeders are controlled down to the fascia of the deltoid with a needle-tip Bovie. Full-thickness flaps are made from the midline of the clavicle both posteriorly and anteriorly, skeletonizing the clavicle.

Tagging sutures are placed in the deltotrapezial fascia. Traction on the tagging sutures or a Gelpi retractor under the flaps is used for visualization. The tagging sutures are used for easy and precise closure of the fascia at the end of the procedure.

Once the approach is complete, a trial reduction is attempted. The distal end of the clavicle may need to be freed from the trapezius muscle, under the acromion, or coracoid. Interposition of soft tissue may prevent anatomic reduction of the AC joint.

A semitendinosus allograft or autograft or an anterior tibialis allograft can be used for this procedure (TECH FIG 2A). (See the Techniques section of Chap. SM-32 for a description of obtaining a semitendinosus autograft.)

A curvilinear incision is made 3.5 cm medial to the acromioclavicular joint along the lines of Langer. Visualization of the acromioclavicular joint as well as the coracoid is possible. The deltotrapezial fascia is split along the midline of the clavicle and elevated as two full-thickness flaps.
Chapter 12 REPAIR AND RECONSTRUCTION OF ACROMIOCLAVICULAR INJURIES

TECH FIG 2 • A. Grafts need tendon-grasping sutures at both ends for ease of passage around the coracoid and through bone tunnels. B. In our alternative method, grafts that are to be fixed to the coracoid are folded so that there is one short limb and one long limb. A no. 2 nonabsorbable suture is placed through the doubled-over tendon graft in a Krakow manner. Tendon ends are bulleted for ease of passage through bone tunnels.

TECH FIG 3 • A. The graft is looped around the coracoid. B. A suture passer can be used to safely loop the graft and a nonabsorbable suture around the coracoid base. C. In the alternative technique, a bone tunnel that approximates the diameter of the graft (usually 6 to 7 mm) is made in the coracoid. One limb of the Krakow suture is placed, and the doubled-over tendon is passed through the PEEK screw and driver (top inset). While traction is held with this suture, the tenodesis driver is advanced to touch the tendon graft (bottom inset), and the entire tendon, driver, and screw complex is placed into the coracoid bone tunnel.

TECHNIQUES

- Tendon ends are bulleted for easy passage through bone tunnels.
- A whipstitch or grasping suture is placed in the two free ends of the tendon for graft passage through bone tunnels.
- The graft is ready for use if the surgeon is performing our preferred looping method. However, an alternative method is interference screw fixation to the coracoid process.
- In this option, the graft is folded with one short limb (about 3 inches) and a limb containing the remaining length of the tendon. A no. 2 ultra-high-strength nonabsorbable suture is placed through the doubled-over tendon graft in a Krakow manner (TECH FIG 2B).

Coracoid Preparation

- Standard looping technique
  - A graft can be looped around the base of the coracoid process using an aortic cross-clamp (Stanitsky clamp) or a suture-passing device (Arthrex, Inc., Naples, FL) for biologic fixation.
  - A heavy no. 2 ultra-strength nonabsorbable suture is also placed around the coracoid for use as a nonbiologic form fixation (TECH FIG 3A,B).
- Alternative technique: interference screw fixation to coracoid (TECH FIG 3C)
Although we currently do not use this method, some may choose to anchor the tendon into the base of the coracoid.

The diameter of the doubled-over portion of the graft is measured with a standard tendon-measuring device. Using this number, the appropriate cannulated reamer is chosen (6 or 7 mm).

The surgeon should use a smaller reamer diameter first and ream up in size if necessary.

Finger palpation of both lateral and medial portions of the coracoid process and drilling into the coracoid base under direct visualization with a cannulated reamer guide pin are completed.

One limb of the Krakow suture is passed through a 5.5 × 8-mm nonabsorbable radiolucent tenodesis screw and driver using a Nitinol wire.

The tenodesis driver is advanced to touch the tendon graft, and the entire tendon, driver, and screw complex is placed into the coracoid bone tunnel until 15 mm of the Krakow suture disappears.

The sutures from the graft are tied together over the existing interference screw, giving both interference screw and suture anchor advantages.

Clavicle Preparation

To recreate the conoid ligament, a cannulated guide pin is placed 45 mm away from the distal end of the clavicle and as posterior as possible, taking into consideration the space needed to not “blow out” the posterior cortical rim during reaming.

A 6-mm cannulated reamer is used to create the tunnel (TECH FIG 4).

If there is a question of what size reamer to use, starting with the smallest reamer necessary is always a good technique; if necessary the surgeon can ream up.

The surgeon reams in under power.

The surgeon disconnects the power driver and pulls the reamer out manually to ensure that the tunnel is a perfect circle and not widened by uneven reaming.

The same procedure is repeated for the trapezoid ligament, which is a more anterior structure than the conoid.

This tunnel is centered on the clavicle, approximately 15 mm lateral of the center portion of the previous tunnel.

Graft Fixation and Reconstruction

The limbs of the graft are crossed over the coracoid and one limb of the biologic graft is placed through the posterior bone tunnel, recreating the conoid ligament.

The other limb is passed through the anterior bone tunnel in the same fashion, recreating the trapezoid ligament (TECH FIG 5).

The no. 2 ultra-high-strength nonabsorbable suture placed around the coracoid is also passed through the tunnels for nonbiologic augmentation of the repair.

Upper displacement of the scapulohumeral complex and the use of a large point-of-reduction forceps placed on the coracoid process and the clavicle by the assistant are used to reduce the AC joint.

Fluoroscopy is used to confirm proper placement of the grafts and reduction of the AC joint.

The graft is pulled on cyclically multiple times and passed through the tunnels back and forth to reduce any displacement that might occur after fixation.

This step is critical to ensure that there is no migration or movement after the fixation is complete.

Nevertheless, we often overreduce the AC joint by 2 to 3 mm with the knowledge that a few millimeters of displacement still occurs.

The graft is positioned so that the graft tail representing the conoid ligament is left 2 cm proud from the superior margin of the clavicle. The long tail of the graft exits the trapezoid tunnel and will later be used to augment the AC joint repair if indicated (see Tech Fig 5).

With traction placed on the graft, ensuring its tautness, a 5.5 × 8-mm nonabsorbable radiolucent screw is placed in the posteromedial tunnel anterior to the conoid ligament graft.

Again, the graft is cyclically loaded multiple times. While holding reduction and tension on the ligament, another 5.5 × 8-mm nonabsorbable radiolucent screw is placed in the lateral trapezoid tunnel anterior to the trapezoid ligament graft.

With both grafts secured, the no. 2 ultra-high-strength nonabsorbable suture is tied over the top of the clavicle, becoming the nonbiologic fixation for the reduced AC joint.

TECH FIG 4 • A. Anatomic reconstruction of the coracoclavicular ligaments. For conoid ligament reconstruction, a guide pin is placed in the clavicle 45 mm from the acromioclavicular joint in a posteromedial position. For trapezoid ligament reconstruction, a guide pin is placed 30 mm from the acromioclavicular joint centered on the clavicle. B. After confirming the positions of the pins, a 5.5-mm cannulated drill is used to drill the clavicle. Care should be taken to place the conoid tunnel as far posterior as possible without violating the posterior cortex during reaming.
For acute injuries, we perform an AC joint repair. The AC joint is exposed. Simple or figure 8 sutures using a no. 0 nonabsorbable suture are used to repair the AC joint capsule and ligaments primarily. The posterior and superior ligaments are key in preventing posterior displacement of the clavicle. The repair can be augmented by using the limbs of the graft used for the coracoclavicular ligament repair. The short limb of the graft exiting the medial tunnel is folded laterally and sewn to the base of the graft exiting the trapezoid tunnel in series (TECH FIG 6A). The long limb exiting the lateral (trapezoid) tunnel is taken laterally and looped on top of the AC joint and used for augmentation of the AC joint capsule repair (TECH FIG 6B,C).

In chronic dislocations, two options exist. One is to repair the AC joint as detailed above for acute AC joint injuries. Alternatively, if arthrosis is a concern, a distal clavicle excision can be performed. An oscillating osteotome is used to remove 1 cm of the distal clavicle. The posterior cortical rim is beveled. The deltoidtrapezial fascia is meticulously closed using interrupted nonabsorbable sutures, taking care to leave the knots on the posterior aspect of the trapezius.

A simple suture can be used to bury the knot if it is prominent. Making clear full-thickness flaps during the approach and using tagging sutures allows for secure coverage of the grafts and clavicle.

A. The short limb of the graft representing the conoid ligament is folded laterally and sewn to the graft base representing the trapezoid ligament. (continued)
The long limb representing the trapezoid ligament can be taken laterally and used to augment the acromioclavicular ligament fixation.

**Biologic Fixation: Coracoacromial Ligament Transfer**
- The CA ligament is dissected out, especially laterally.
- The CA ligament is detached from its footprint that extends posteriorly on the acromion (TECH FIG 8A).

**MODIFIED WEAVER-DUNN PROCEDURE**
- Diagnostic arthroscopy is done if concomitant injuries are suspected.
- An incision is made 1.5 cm from the AC joint starting at the posterior clavicle in a curvilinear fashion toward the coracoid along the lines of Langer.
  - The incision is sometimes angled because the key is to have full visualization of the AC joint laterally and coracoid process medially.
- Superficial skin bleeders are controlled down to the fascia of the deltoid with a needle-tip Bovie.
- Full-thickness flaps are made from the midline of the clavicle both posteriorly and anteriorly, skeletonizing the clavicle (TECH FIG 7).
- Alternatively, a “hockey stick” incision can be made laterally from the acromion along the midportion of the clavicle, ending in a hockey stick fashion down toward the coracoid.
  - Periosteal flaps are elevated and a tagging suture can be placed at the medialmost aspect of the flap for accurate closure.

- Two heavy nonabsorbable sutures are placed at the end of the ligament using a whipstitch.
- The CA ligament is held directly superiorly and the corresponding area is marked on the clavicle.
  - This marks the amount of clavicle that needs to be resected to allow easy passage of the CA ligament without sharp turns.
  - If adequate arthroscopic resection has not already been performed, an oscillating saw is used to make an oblique cut on the clavicle, leaving more bone superiorly rather than inferiorly, at the level of the previously marked site.
- An intramedullary pocket is curetted inside the clavicle for the CA.
- The AC intra-articular disc is resected, leaving the AC ligaments undisturbed.
- A 2.0-mm drill is used to make two drill holes in a cruciate fashion (lateral clavicle anteriorly, medial clavicle posteriorly) 20 mm medial to the distal cut end of the clavicle (TECH FIG 8B).
  - A wire-loop is used to pass each limb of the CA ligament suture through the end of the clavicle and out the drill hole made superiorly.
  - For augmentation of CA ligament transfer, a 3.5-mm drill hole is made into the clavicle medial to the previously made drill holes for the CA ligament.
TECH FIG 8 • A. The ligament is released from the acromion and sutures are placed in the end. B. After a distal clavicle resection, two 2-mm unicortical drill holes are placed in the posterosuperior surface of the distal clavicle, exiting through the intramedullary canal. (Adapted from Galatz LM, Williams GR Jr. Acromioclavicular joint injuries. In: Bucholz RW, Heckman JD, Court-Brown C, eds. Rockwood and Green’s Fractures in Adults, vol 2. Philadelphia: Lippincott Williams & Wilkins, 2006:1354.)

□ For nonbiologic augmentation, a suture cord is constructed.
□ The surgeon takes three no. 1 absorbable sutures clamped at both ends. One clamp is turned clockwise while holding the other end until the sutures are intertwined together for the entire length of the sutures.
□ This is done with two other sets of three sutures.
□ The three sets are intertwined counterclockwise in the same fashion, resulting in a cord of nine total sutures. The suture cord is passed around the coracoid and through the 3.5-mm drill hole in the clavicle.
□ For biologic augmentation an autograft or allograft can be used.

Reduction and Fixation
□ Upper displacement of the scapulohumeral complex and the use of a large point-of-reduction forceps placed on the coracoid process and the clavicle by the assistant are used to reduce the AC joint.
□ Slight overreduction during fixation is recommended.
□ After reduction is achieved, the surgeon pulls the suture limbs of the CA ligament reconstruction, exiting the bone tunnels, and ties them on the superior surface of the clavicle (TECH FIG 9).
□ The pocket for the CA ligament must be long enough so that after anatomic reduction, the graft is nice and taut.
□ If the suture cord was used, the suture cord that was passed around the coracoid and through the clavicle is tied.
□ The surgeon should attempt to place the knot in the least prominent area.
□ The ends of the suture cord are unraveled and each individual suture limb is tied to prevent unraveling of the cable.
□ Finally, all free suture ends are cut.
□ If ligament augmentation was used, the ligament is wrapped in a figure 8 fashion and sutured to itself using heavy nonabsorbable sutures.
□ Closure is the same as the ACCR technique (see Tech Fig 6C).

TECH FIG 9 • Using a curette, a pocket is made inside the clavicle for the coracoacromial (CA) ligament. The CA ligament is transferred to the intramedullary canal. The sutures are placed through the drill holes and tied over the top of the clavicle. This pocket has to be large enough so that after reduction of the joint, the CA ligament can be pulled inside without any impediment. If this is done correctly, the ligament should be taut and not overstuffed inside the pocket. (Adapted from Galatz LM, Williams GR Jr. Acromioclavicular joint injuries. In: Bucholz RW, Heckman JD, Court-Brown C, eds. Rockwood and Green’s Fractures in Adults, vol 2. Philadelphia: Lippincott Williams & Wilkins, 2006:1354.)
ARTHROSCOPIC STABILIZATION

- The patient is placed in a beach-chair position. Draping is similar to the open procedures, with wide exposure and the arm draped free.

Establishing Portals

- A standard posterior portal is made, followed by two anterior portals (TECH FIG 10).
  - An anterosuperior portal is made using an outside-in technique, using a spinal needle to confirm positioning.
  - Débridement of the rotator interval is done until the tip of the coracoid is visualized.
  - Release of the superior glenohumeral ligament and partial release of the middle glenohumeral ligament may be required for adequate exposure.
  - A 7-mm partially threaded cannula is used for the anterosuperior portal.
  - An anteroinferior portal is made near the tip of the coracoid, again with the outside-in technique, using a spinal needle to confirm positioning and ensuring that the base of the coracoid can be reached using this portal. An 8.25-mm twist-in cannula is inserted for this portal.
  - A 70-degree scope may improve visualization of the coracoid base.
  - If the 30-degree arthroscope is used, the arthroscope position is changed to the anterosuperior portal.
  - The coracoid base is exposed using mechanical shavers and radiofrequency devices.
  - Any bursa or periosteum is stripped to obtain a full view of the coracoid base.

Drilling

- The assembled “Adapteur Drill Guide C-Ring with the Coracoid Drill Stop and Graduated Guide Pin Sleeve” (Arthrex, Inc., Naples, FL) is inserted through the anteroinferior portal (TECH FIG 11A).
  - With the drill stop placed at the base of the coracoid (as close to the scapula as possible), the corresponding area is marked on the superior aspect of the clavicle for the guide pin sleeve.
  - This area should be centered on the clavicle and approximately 25 mm from the AC joint.
  - A 1.5-cm incision is made over the clavicle in the lines of Langer, and the surgeon dissects down through the deltopectoral fascia.
Under direct visualization using the arthroscope, the surgeon places a 2.4-mm guide pin through the drill tip guide, clavicle, and coracoid until the drill stop is engaged (TECH FIG 11B,C).
- It is important to place the guide pin centered in the base of the coracoid.
- A 4.0-mm cannulated drill is used to drill the clavicle and coracoid while the drill stop prevents migration of the guide pin. The surgeon should always use the arthroscope for direct visualization and avoid drilling beyond the coracoid base (TECH FIG 11D,E).

**Suture Passage and Tying**
- The power drill is detached, leaving the cannulated drill in place.
- An 18-inch Nitinol suture passing wire is passed down through the cannulated drill and the tip is grasped with the arthroscopic grasper (TECH FIG 12A,B).
  - The drill can now be removed.
- Using the Nitinol passing wire, the two white traction sutures of the oblong button of the TightRope System are passed through the clavicle and coracoid while the blue sutures are kept on the anteroinferior side of the clavicle. (TECH FIG 12C-F).

**TECH FIG 12**
- **A.** The power drill is detached and the cannulated drill is used as a portal to pass an 18-inch Nitinol suture passing wire. **B.** A grasper is used to hold the Nitinol suture while the drill bit is removed. The limb of the Nitinol passing wire is brought out of the anteroinferior portal, leaving the loop superior to the clavicle. **C.** The Nitinol suture passing wire is used to deliver the white traction sutures through the clavicle and coracoid and out of the anteroinferior portal. **D,E.** While holding the blue TightRope suture tails, pulling on one of the white suture tails flips the oblong button to a vertical position, allowing passage of the TightRope through the clavicle and coracoid. **F.** Once past, independent pulling on the white sutures flips the oblong button back to a horizontal position, anchoring it underneath the coracoid. (A,D: Courtesy of Arthrex, Inc.)

**TECH FIG 13**
- Placing the arthroscope into the subacromial space via the posterior portal helps to directly visualize the reduction. After reduction of the clavicle, sequential pulling on the blue TightRope suture tails delivers the round button down to the superior clavicle, holding the reduction firmly. The blue sutures are tied securely. (Courtesy of Arthrex, Inc.)
passed through the clavicle, the coracoid, and the anteroinferior portal (TECH FIG 12C).

- The blue TightRope suture tails of the round button are held firmly with one hand. The surgeon pulls on the white suture tails attached to the oblong button. This flips the oblong button to a vertical position and allows passage through the drill holes (TECH FIG 12D,E).
- The oblong button is pulled through the clavicle and coracoid.
- Once passed, differential pulling on the white sutures flips the button to a horizontal position, preventing it from retracting through the drill holes (TECH FIG 12F).

### Clavicle Reduction

- The surgeon pulls on the blue suture tails to advance the round button down to the clavicle. The sutures are tied over the top of the TightRope, making a surgeon’s knot and two reverse half-hitches.
- Leaving the tails long helps the knot to lie flat (TECH FIG 13).
- All wounds are irrigated and closed.

### Pearls and Pitfalls

<table>
<thead>
<tr>
<th>Positioning and approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>The surgeon should make sure that the patient’s head can be repositioned to the side, allowing room for conoid tunnel drilling.</td>
</tr>
<tr>
<td>An alternative is to displace the clavicle anteriorly with a towel clip to allow access for conoid tunnel drilling.</td>
</tr>
<tr>
<td>The deltoid and trapezial fascia are tagged for good repair.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Graft management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semitendinosus ends are bulleted to allow for easy graft passage.</td>
</tr>
<tr>
<td>Sutures are passed under the coracoid either from medial to lateral or lateral to medial.</td>
</tr>
<tr>
<td>If passing lateral to medial, the surgeon should make sure that the medial coracoid base is exposed and should insert a Darrach retractor on the medial base to “catch” the passing device.</td>
</tr>
<tr>
<td>Once the graft is passed under the coracoid, the limbs are crossed before they are passed through the clavicle tunnels.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tunnel preparation and graft fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>The surgeon should ream in under power. When the power driver is disconnected, the surgeon should pull the reamer out manually to ensure that the tunnel is a perfect circle and not widened by uneven reaming.</td>
</tr>
<tr>
<td>Starting with the smallest reamer necessary is always a good technique. The surgeon can ream up at half-millimeter increments if the graft is too large.</td>
</tr>
<tr>
<td>The tenodesis screw is inserted anterior to the graft to equally recreate posterior coracoclavicular ligaments.</td>
</tr>
</tbody>
</table>

### Postoperative Care

- Postoperative support with a Lerman Shoulder Orthosis (DJO Inc., Vista, CA) or a Gunslinger Shoulder Orthosis (Hanger Prosthetics & Orthotics, Inc., Bethesda, MD) is used for 6 to 8 weeks. These braces are recommended to counter the pull on the shoulder complex by gravity.
- For the first 6 to 8 weeks, the brace may be removed for grooming and supine gentle passive range of motion only.
- Active and passive range-of-motion exercises are started at 8 weeks after surgery.
- If painless range of motion is obtained, strength training is started at 12 weeks.

### Outcomes

- Anatomic coracoclavicular reconstruction: unpublished data from an ongoing study (level IV evidence) at our institution between 2002 and 2006;
  - 427 cases of AC joint dislocations with a surgical rate of 3.7%
  - 16 cases (two revisions)
  - Mean postoperative months: 28.9
  - One failure (noncompliant)
  - To date, preliminary results show a mean Single Assessment Numeric Evaluation (SANE) score of 98.4/100.

Other outcome measures, including American Shoulder and Elbow Surgeons (ASES), Rowe, and Constant scores, are 94.1, 91, and 96, respectively. Patients have a pain rating of less than 1/10 with horizontal adduction and forward elevation and when a posterior force is directed at the AC joint. Postoperative radiographs show that the mean difference in the coracoclavicular distance is 2.1 mm compared to the contralateral side.

- **Weaver-Dunn**
  - Outcomes are difficult to compare due to the variations in the Weaver-Dunn method used and the makeup of the type of patients and severity of injury within study groups.
  - Rauschning et al reported 12 acute and 5 chronic type III AC joint injuries treated by the Weaver-Dunn procedure. At follow-up 1 to 5 years after the operation, all patients had stable and painless shoulders with resumption of full activities and functionally excellent results (level IV evidence).
  - Tienen et al presented 21 patients with Rockwood type V AC joint dislocations who underwent a modified Weaver-Dunn procedure with clavicle reduction and AC joint fixation using absorbable braided sutures. At a mean follow-up of 35.7 months, 18 patients had returned to their sports without pain within 2.5 months after operation; the average Constant score at last follow-up was 97. Radiographs taken at this time showed residual subluxation in two patients.
and, in one patient, redislocation of the joint that occurred because of infection (level IV evidence).

- When chronic and acute repairs of type III AC joint injuries were studied, patients with early repair were significantly better after 3 months. In a study by Weinstein et al., 26 of 27 (96%) patients with early repairs and 13 of 17 (77%) patients with late reconstructions achieved satisfactory results with an average 4-year follow-up (level IV evidence).

- Arthroscopic reconstruction with the TightRope System: preliminary results of an ongoing study:
  - 29 patients with a mean age of 31 years and 6-month follow-up
  - Mean Constant score 91.1
  - Mean ASES score 96.6
  - Return to sports mean of 12 weeks
  - Complications: one hardware failure with revision using TightRope and one patient with transient adhesive capsulitis

COMPlications

- Loss of reduction
- Excessive distal clavicle resection
- Osteolysis due to nonbiologic fixation material
- Coracoid fracture
- Infection

REFERENCES

DEFINITION
- Acromioclavicular (AC) separations are relatively rare injuries that result in disruption of the AC complex.
- Overall incidence of the injury is 3 to 4 per 100,000 in the general population, with up to 52% of cases occurring during sporting events.\(^5\)
- The degree of injury is based on the amount of force transmitted through the acromion to the distal clavicle and the surrounding deltotrapezial fascia.\(^1,12,19\)
- Increased force transmission leads to dissociation of the AC joint and tearing of the coracoclavicular ligaments.
- Determination of the injury type will guide operative versus nonoperative management.\(^12\)

ANATOMY
- The AC joint is a diarthrodial joint composed of the medial acromial margin and the distal clavicle.
- A fibrocartilaginous intra-articular disc between the two bony ends decreases contact stresses.\(^12\)
- Dynamic stability of the AC joint is provided by the trapezial fascia and the overlying anterior deltoid.
- Static stability of the AC joint is provided by:
  - AC ligaments
    - The superior ligament provides the greatest restraint to anterior translation of the distal clavicle.
    - Anterior, posterior, and inferior ligaments add additional horizontal stability to the AC joint.
  - Coracoclavicular ligaments
    - Conoid: arises from the posteromedial aspect of the coracoid and inserts on the posterosmedial clavicle
      - Measures about 2.5 cm long and 1 cm wide
      - Provides primary resistance against anterior and superior loading of the clavicle
    - Trapezoïd: arises from the anterolateral coracoid just posterior to the pectoralis minor and attaches to the lateral or central clavicle
      - Measures about 2.5 cm long and 2.5 cm wide
      - Provides resistance against posterior loading of the clavicle

PATHOGENESIS
- AC separations are the result of a direct force to the lateral aspect of the shoulder with the arm adducted (ie, fall on point of the shoulder).
- The degree of injury to the AC joint, deltopectoral fascia, and coracoclavicular ligaments will determine the resultant deformity.
- Most low-grade injuries involve only the AC joint and are often self-limited.
- Severe arm abduction during the AC separation can result in subacromial or subcoracoid displacement of the distal clavicle.\(^12\)

PATIENT HISTORY AND PHYSICAL FINDINGS
- A complete physical examination of both upper extremities with the patient appropriately attired and in the upright position is standard.
- Evaluation of the neck and a complete neurologic examination are essential, as higher-grade injuries may manifest with brachial plexus compromise.
- Low-grade injuries will be tender to palpation at the AC joint, with mild elevation possible. Increased deformity is commonly seen as the injury grade increases, but acutely the deformity may be masked by swelling.
- Methods for examining the AC joint include:
  - AC joint compression (shear) test: Isolated painful movement at the AC joint in conjunction with a history of direct trauma indicates AC joint pathology.
  - Cross-arm adduction test: Look for pain specifically at the AC joint. Pain at the posterior aspect of the shoulder or the lateral shoulder might indicate other pathology.
  - Paxino test: sometimes done in conjunction with bone scans to assess damage to AC joint
  - O’Brien test: Symptoms at the top of the joint must be confirmed by the examiner palpating the AC joint. Anterior glenohumeral joint pain suggests labral or biceps pathology.
  - Local point tenderness at the AC joint while the glenohumeral joint is kept still suggests localized AC joint pathology.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standard shoulder radiographs can be useful for diagnosis, but overpenetration may result in poor visualization of the AC joint.
- An axillary view should be included to avoid missing a glenohumeral dislocation and to help assess anteroposterior (AP) translation of the clavicle.
A 10- to 15-degree cephalic tilt view (Zanca) avoids superposition of the scapular spine and improves visualization of the AC joint. This also allows evaluation for loose bodies or small fractures that may be missed with standard views of the shoulder (FIG 1).12

- Sling for comfort, range-of-motion exercises, and avoidance of contact sports for 6 to 8 weeks may suffice.
- Padding of the residual deformity for contact athletes may be beneficial. Additional trauma may lead to the development of a higher-grade injury.
- Types IV and VI are routinely treated operatively.

**SURGICAL MANAGEMENT**

- Indication for surgery is an acute Rockwood type III or VI injury in an active patient unwilling to accept the cosmetic deformity and dysfunction of the affected shoulder.
- The TightRope fixation system (Arthrex, Naples, FL) was originally designed for the treatment of syndesmotic injuries. It has two metal fixation buttons with a continuous loop of no. 5 FiberWire running between them.17
- The technique allows for a quick and relatively simple arthroscopic fixation of acute, high-grade AC separations. Chronic injuries should have the coracoclavicular ligaments reconstructed with autologous or allograft tissue.

**DIFFERENTIAL DIAGNOSIS**

- Distal clavicle fracture
- Acromial fracture
- Glenohumeral dislocation
- Sternoclavicular dislocation
- Scapulothoracic dissociation

**CLASSIFICATION**

- Rockwood (modification of Allman, Tossey, and Bannister’s work) described six types of injuries to the acromioclavicular joint (Table 1).1,2,12,29

**NONOPERATIVE MANAGEMENT**

- Types I and II
  - Most authors agree that nonoperative management is the treatment of choice for these incomplete injuries.1,12,16,20
  - A simple sling for comfort is used, with progression to range of motion as tolerated in 1 to 2 weeks.
  - Return to sports is authorized when the patient has pain-free range of motion and normal strength.
- Type III
  - This is more controversial, although conservative treatment is often successful.

- Sling for comfort, range-of-motion exercises, and avoidance of contact sports for 6 to 8 weeks may suffice.
- Padding of the residual deformity for contact athletes may be beneficial. Additional trauma may lead to the development of a higher-grade injury.
- Types IV and VI are routinely treated operatively.

**Table 1**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I and II</td>
<td>Incomplete with no or mild subluxation of the acromioclavicular joint</td>
</tr>
<tr>
<td>III</td>
<td>Complete disruption of the acromioclavicular ligaments and coracoclavicular ligaments Degree of separation is up to 100% of the coracoclavicular interval.</td>
</tr>
<tr>
<td>IV</td>
<td>Posterior displacement of the clavicle through the trapezius muscle</td>
</tr>
<tr>
<td>V</td>
<td>Severe displacement with 100% to 300% increase in coracoclavicular interval (Bannister III-C) Involves injury to the deltotrapezial fascia</td>
</tr>
<tr>
<td>VI</td>
<td>Inferior displacement of the clavicle to a subacromial or subcoracoid position</td>
</tr>
</tbody>
</table>

- Stress radiographs
  - Standing views with 10 to 15 pounds of traction applied to the wrists are recommended by some authors to help distinguish the grade of injury because patients may guard with standard standing views.
  - Recent literature does not support the routine use of stress radiographs.21 They do not affect the decision-making process for operative versus nonoperative management.12,21 However, one AP view with both AC joints visible is helpful to account for normal variants and determine the degree of displacement.

**CLASSIFICATION**

- Rockwood (modification of Allman, Tossey, and Bannister’s work) described six types of injuries to the acromioclavicular joint (Table 1).1,2,12,29
- This classification scheme has proven to be effective for prognosis and treatment.

**NONOPERATIVE MANAGEMENT**

- Types I and II
  - Most authors agree that nonoperative management is the treatment of choice for these incomplete injuries.1,12,16,20
  - A simple sling for comfort is used, with progression to range of motion as tolerated in 1 to 2 weeks.
  - Return to sports is authorized when the patient has pain-free range of motion and normal strength.
- Type III
  - This is more controversial, although conservative treatment is often successful.
ESTABLISHING ANATOMY AND PORTALS

- Anatomy is identified: coracoid, acromion, clavicle (length and width), AC joint.
- Portals are marked: posterior, anterior inferior, and anterolateral.
- The posterior portal is created for viewing 2 cm inferior and 2 cm medial to the posterolateral edge of the acromion in the “soft spot.”
  - Diagnostic arthroscopy with a 30-degree scope of the intra-articular space is routine.20
- The subacromial space is entered from this portal using standard technique.
- We do not find it necessary to move through the rotator interval to identify the coracoid base, although it is recommended in the technique guide.
- A 70-degree scope may be helpful if the trans-interval technique is used.
- The anterolateral portal is made using an “outside-in technique” in line with the lateral edge of the acromion and the coracoid as a working portal.
- A 5- to 7-mm cannula is introduced to assist with pressure control.

CORACOACROMIAL LIGAMENT AND CORACOID PREPARATION

- With the scope in the posterior portal, the anterolateral acromion and the coracoacromial (CA) ligament are identified. The CA ligament is preserved (TECH FIG 1A).
- The CA ligament is followed to its attachment site on the coracoid (TECH FIG 1B).
- Through the anterolateral portal an arthroscopic ablator or chondrotome is used to resect the subcoracoid bursa and allow better visualization of the inferior aspect of the coracoid and its base.
- There is no need to remove soft tissue from the superior aspect of the coracoid (TECH FIG 1C).
- The surgeon should be cautious when placing instruments medial to the coracoid because the scapular notch lies in close proximity. Injury to the neurovascular bundle is a possibility.
- An 18-gauge spinal needle is used for localization and an “outside-in technique” is used to make the anteroinferior portal just lateral and slightly inferior to the coracoid. An 8.25-mm cannula is inserted.
- The Adapter Drill Guide C-Ring and Coracoid Drill Stop (Arthrex) is inserted through the anteroinferior portal under the base of the coracoid (TECH FIG 1D).
- The surgeon should stay as far posterior, near the coracoid base, as possible, and central from a mediolateral standpoint.
- A 1- to 2-cm incision is made over the clavicle in line with the drill guide and the coracoid.

TECH FIG 1 • A. Coracoacromial ligament identification. B. Coracoid identification. C. Soft tissue resection of the coracoid. D. Coracoid drill stop placement. The base is hugged posterior.
GUIDE PIN PASSAGE

- Under arthroscopic visualization with the clavicle reduced, a 2.4-mm guide pin is advanced through the center of the clavicle and coracoid. It is captured by the drill stop (TECH FIG 2A).
- The guide pin is overreamed with a 4-mm cannulated reamer, using the drill stop to prevent plunging. The scope allows visualization of each step (TECH FIG 2B).
- The guide pin is removed and the solid end of the Nitinol wire loop is passed antegrade through the cannulated reamer. It is grasped and removed out the anteroinferior portal with a push-and-pull technique (TECH FIG 2C,D).

SUTURE PASSAGE

- The TightRope comes fixed with two 2-0 FiberWires to lead the suture button through the bone tunnel and flip accordingly.
- These are passed with the wire loop through the clavicle and coracoid and out the anteroinferior portal.
- One suture strand should be colored purple with a marking pen for easier differentiation of the “lead” suture from the “flip” suture (TECH FIG 3A,B).
- The TightRope button is passed and flipped when visualized with the arthroscope (TECH FIG 3C,D).
- The upper extremity is then elevated and the AC joint is overreduced.

TECH FIG 2 • A. Captured 2.4-mm guide pin. B. Captured 4-mm drill bit. C. Nitinol wire passage. D. Retrieval of Nitinol through the anteroinferior portal.

TECH FIG 3 • A. Colored “lead” suture. B. Suture button exits coracoid base. (continued)
POSTOPERATIVE CARE
- A sling is used for comfort and to slow down the patient for 4 weeks.
- Range of motion of the elbow is permitted immediately, as are gentle Codman/pendulum exercises.
- Gentle active motion below the shoulder level is permitted until the 6-week mark, at which time progression to full motion is authorized.
- No heavy work or athletics are permitted for 3 months.
- Postoperative radiographs are compared with radiographs made at the 6-week return visit.

COMPLICATIONS
- Infection
- Loss of reduction
- Coracoid fracture
- Clavicle fracture
- Suprascapular neurovascular bundle injury

OUTCOMES
- The TightRope Fixation System is a relatively new system for treatment of acute AC separations. It is not intended for chronic injuries.
- No long-term studies or prospective randomized trials are available.
- Biomechanical data are available only for its syndesmotic use.\(^{18,19}\)

ACKNOWLEDGMENTS
We thank John Morton, James Willobee, and Jeff Wyman from Arthrex, and the staff of the William Beaumont Army Medical Center Biomedical Research facility.

REFERENCES


DEFINITION

- Suprascapular nerve entrapment may result from constriction within the suprascapular notch, pressure from a ganglion cyst in the floor of the supraspinatus fossa, or a constriction at the spinoglenoid notch.
- The nerve is readily accessible via arthroscopic techniques developed by Thomas Samson and Laurent Lafosse.

ANATOMY

- The suprascapular nerve receives contributions primarily from the C5 root, with additional minor contributions from C4 and C6 nerve roots.
- It exits from the upper trunk of the brachial plexus through the supraclavicular fossa and comes through the suprascapular notch beneath the transverse scapular ligament, dividing into two branches.
- One branch exits medially to the supraspinatus muscle.
- The second continues across the floor of the supraspinatus fossa of the scapula toward the junction of the scapular spine and the posterosuperior neck of the glenoid.
- The nerve makes a short turn around the bone junction under the inconsistently present spinoglenoid ligament and travels medially across the superior aspect of the infraspinatus fossa of the scapula, sending branches into this muscle until terminating into the medial aspect of this muscle.

PATHOGENESIS

- Nerve entrapment usually occurs at the suprascapular notch.
- Trauma, repetitive overhead use requiring hyperretraction and protraction of the scapula (ie, volleyball), and chronic rotator cuff injuries may produce swelling in this area, resulting in pressure on the nerve.
- Congenital V-shaped suprascapular notch orientation has been implicated as a cause of this entrapment.
- Less common areas of entrapment may occur owing to ganglion cyst compression in the middle or posterior aspect of the fossa, and at the spinoglenoid notch.
- A thickened spinoglenoid ligament may cause entrapment at the spinoglenoid notch as well.
- Unusual sources of nerve entrapment include vascular expansion (aneurysm or varices) and tumors.

NATURAL HISTORY

- The natural history of suprascapular nerve entrapment depends on the cause and pathologic changes in the anatomy.
- Spontaneous recovery after rehabilitation treatment has been reported.
- However, if electromyographic nerve conduction studies show evidence of compression, surgical treatment is usually indicated.
- Compression at the suprascapular notch or spinoglenoid area is often the primary problem and is not associated with intra-articular pathology. Compression by ganglion cyst in the supraspinatus fossa is often associated with labral tears that require fixation along with débridement of the cyst. All of these may be managed arthroscopically if nonoperative treatment is ineffective.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient often presents with signs and symptoms of impingement and rotator cuff tearing, overhead weakness, pain on forced flexion, and subacromial crepituation.
- Careful inspection may reveal atrophy in the supraspinatus and infraspinatus fossa compared to the opposite side.
- Weakness to supraspinatus isolation, infraspinatus isolation, and Whipple testing is usually present.
- Palpation of the rotator cuff reveals no defect. However, there is usually no, or only minimal, palpable swelling on the distal supraspinatus tendon.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Most patients will have to undergo magnetic resonance imaging.
- The test should reveal an intact rotator cuff with atrophy of the supraspinatus and infraspinatus musculature.
- Occasionally, there will be tearing of the rotator cuff with atrophy that is not in proportion to the size or duration of the tear.
- Electromyographic nerve conduction studies by a neurologist specializing in proximal entrapment lesions of the upper extremity will be definitive in cases of entrapment at the suprascapular or spinoglenoid notch.

DIFFERENTIAL DIAGNOSIS

- The main confusion in this area is with primary impingement and rotator cuff tears.
- The history and physical examination are often similar, but a careful evaluation and physical examination will reveal the differences as delineated in the prior discussion under physical findings.

NONOPERATIVE MANAGEMENT

- There is a limited role for nonoperative treatment of true entrapment neuropathy.
- Pressure from a cyst may be alleviated by aspiration of the cyst.
- Compression at either the suprascapular or spinoglenoid notch, however, will require release if the nerve conduction study reveals pressure to the nerve in these areas.

SURGICAL MANAGEMENT

- Several approaches to open release have been described (Nicholson, Vastamake, and Post).
- Recently, Samson and Lafosse have each focused interest on techniques of arthroscopic release.

Positioning

- The patient is positioned in the lateral decubitus (preferred) or beach-chair position.
A diagnostic glenohumeral arthroscopy is performed to rule out intra-articular pathology. The arthroscope is then positioned in the lateral portal of the subacromial bursa in line with the anterior acromion, providing a picture of the supraspinatus muscle and tendon (TECH FIG 1A). It is advanced along the anterior edge of the supraspinatus until the base of the coracoid is visualized (TECH FIG 1B).

A switching stick is placed in the lateral Neviaser portal and used to palpate along the anterior edge of the supraspinatus fossa medial to the medial aspect of the base of the coracoid (TECH FIG 1C).

A full-radius shaver can be used from the anterior portal to remove soft tissue as long as it remains lateral to the switching stick, which is functioning as a retractor in addition to a diagnostic tool (TECH FIG 1D).

On encountering the suprascapular artery, a second medial Neviaser portal is created and the retracting switching stick is removed to this portal and used to pull the artery medially and protect it (TECH FIG 1E).

Sliding this retractor along the top of the ligament will also protect any aberrant branches of the nerve that pass superior to the ligament.

**TECH FIG 1**

A. When positioning the arthroscope in the lateral portal of the subacromial bursa in line with the anterior acromion, the supraspinatus muscle and tendon can be seen. B. Advancing the arthroscope along the anterior edge of supraspinatus allows the surgeon to visualize the coracoid. C. Placing a switching stick in the lateral Neviaser portal allows the surgeon to palpate the anterior edge of the supraspinatus fossa medial to the medial aspect of the base of the coracoid. D. A shaver can be used from the anterior portal to remove soft tissue; the surgeon must always remain lateral to the switching stick. E. A second Neviaser portal is established so that the switching stick can be used to pull the artery medially and protect it. F. A blunt probe enters to identify the ligament and protect the underlying nerve. G,H. A side biter or shaver can be used to release the ligament. I. The exposed nerve. J. The suprascapular nerve, artery, and vein are allowed to fall back into a relaxed position.
The primary complication would be inadvertent nerve resection, but this has not been reported to our knowledge.

**REFERENCES**

DEFINITION
- Shoulder stiffness can be a function of soft tissue scarring and contracture or osseous changes.
- The stiff or frozen shoulder has been given the name adhesive capsulitis.
- There are principally two forms of adhesive capsulitis that result in loss of range of motion and can be safely addressed by arthroscopic releases:
  - Primary adhesive capsulitis (idiopathic)
  - Secondary adhesive capsulitis
    - Associated with metabolic disorder (diabetes mellitus, thyroid disorder)
    - Posttraumatic
    - Postoperative
- Shoulder stiffness can result from intra-articular adhesions, capsular contracture, subacromial adhesions, and subdeltoid adhesions.
- The essential tenet of treating the stiff shoulder is recognizing the anatomic region responsible for the stiffness and releasing the specific structures in this region in a controlled fashion.
- An adequate appreciation of anatomy is key to restoring motion and avoiding injury to accompanying tendons and nerves.

ANATOMY
- Shoulder motion occurs principally along two interfaces:
  - Glenohumeral articulation
  - Scapulothoracic articulation
- On average, the normal ratio of glenohumeral motion to scapulothoracic motion is 2:1, with the majority of elevation occurring through the glenohumeral joint.
- Capsuloligamentous structures contribute to stability of the shoulder joint and act as check reins at the extremes of motion in their nonpathologic condition.
- Many areas within the capsule are thickened and contain the glenohumeral ligaments (FIG 1A):
  - Superior glenohumeral ligament
  - Coracohumeral ligament
  - Middle glenohumeral ligament
  - Inferior glenohumeral ligament complex
    - Anterior band
    - Axillary fold
    - Posterior band
- The rotator interval is a triangular region between the anterior border of the supraspinatus tendon and the superior border of the subscapularis. It contains the superior glenohumeral ligament and the coracohumeral ligament.
- During shoulder motion, tightening and loosening of the glenohumeral ligaments and capsule are accompanied by lengthening and shortening of the rotator cuff and deltoid muscles.
  - A plane between the deltoid and humerus (subdeltoid) exists that, when scarred, can limit glenohumeral motion.
  - A plane between the rotator cuff and acromion exists and is occupied normally by a subacromial bursa.
  - Scar tissue and adhesions in this interface can limit excursion of the rotator cuff and thus glenohumeral joint motion (FIG 1B).
- Several structures that are important to preserve are in continuity or proximity to the regions of the capsule that are released arthroscopically in the stiff shoulder.
  - The subscapularis tendon is superficial to the middle glenohumeral ligament. The superior two thirds of the subscapularis is intra-articular.

FIG 1 • A. Thickenings of the capsule are referred to as the glenohumeral ligaments. In their undiseased state they act as physiologic check reins at extreme ranges of motion. B. Fibrous bands can exist in the subacromial space (a) between the acromion and rotator cuff as well as in the subdeltoid space (b) between the deltoid and rotator cuff or humerus. These can restrict excursion of the rotator cuff and thus active and passive range of motion. C. The axillary nerve runs across the superficial surface of the subscapularis and then adjacent to the inferior border of the subscapularis as it heads posteriorly. Anterior capsular release can proceed safely as long as the muscle of the subscapularis is seen inferiorly.
The biceps tendon courses through the rotator interval.
- The axillary nerve runs adjacent to the inferior border of the subscapularis and then is juxtaposed to the inferior glenohumeral ligament and capsule as it exits the quadrangular space (FIG 1C).
- The posterior capsule overlies a distinct layer of rotator cuff muscle posteriorly adjacent to the glenoid.
- The posterior rotator cuff tendons and capsule are juxtaposed and virtually indistinguishable more laterally.
- Release of the posterior capsule should be done adjacent to the glenoid to avoid rotator cuff muscle and tendon disruption.
- Contracture of specific capsular regions and ligaments correlates with specific clinical losses of range of motion. This must be determined preoperatively to guide arthroscopic release.
- These anatomic regions and their influence on shoulder motion are as follows:
  - Rotator interval (superior glenohumeral ligament and coracohumeral ligament) restricts external rotation with the shoulder adducted.
  - Middle glenohumeral ligament restricts external rotation at the midranges of abduction.
  - Inferior glenohumeral ligament (anterior band) restricts external rotation at 90 degrees of abduction.
  - Inferior capsule restricts abduction and forward flexion.
  - Posterior capsule and posterior band of the inferior glenohumeral ligament restrict internal rotation.

PATHOGENESIS
- Shoulder stiffness can be primary or secondary.
  - Secondary stiffness occurs as a result of scar formation and adhesions after trauma or surgery of the shoulder as a result of disruption of soft tissue, release of cytokines, and the body’s inflammatory response seen after injury.
  - Secondary stiffness can also result iatrogenically, as would be the case after a Putti-Platt or Magnuson-Stack procedure.
- Primary stiffness is often termed adhesive capsulitis.
  - Adhesive capsulitis, also referred to as frozen shoulder, can be idiopathic or associated with a secondary cause that is either intrinsic (eg, rotator cuff tears, biceps tendinitis, or calcific tendinitis) or extrinsic (eg, diabetes, myocardial infarction, knee disorders).
- There is no consensus on the definition of frozen shoulder, but it is generally agreed to be a condition with both significant restriction in active and passive range of shoulder motion without an osseous basis for this limitation.
- The pathogenesis of frozen shoulder has been divided into three stages (Table 1). The stages coexist as a continuum and occur over a variable time course in individual patients.

Table 1 Pathogenesis of Frozen Shoulder

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
<th>Time Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freezing or inflammatory</td>
<td>Slow onset of pain, with the shoulder losing motion as the pain</td>
<td>6 weeks to 9 months</td>
</tr>
<tr>
<td>stage</td>
<td>worsens</td>
<td></td>
</tr>
<tr>
<td>Frozen stage</td>
<td>Slow improvement in pain but the stiffness continues</td>
<td>4 to 9 months or more</td>
</tr>
<tr>
<td>Thawing stage</td>
<td>Shoulder motion gradually returns to normal</td>
<td>5 to 26 months</td>
</tr>
</tbody>
</table>

NATURAL HISTORY
- Although the natural history of secondary shoulder stiffness is relatively accepted as protracted and refractory to nonoperative treatment, the time course and end result of adhesive capsulitis (primary and secondary) are more controversial.
- In the absence of operative intervention, recent reports have shown measurable restrictions in range of motion at follow-up in 39% to 76%\(^{3,8,10}\) of patients, in addition to persistent symptoms in up to 50%\(^{2}\) of patients with adhesive capsulitis.
- Adhesive capsulitis can be protracted, with the mean duration of symptoms 30 months.\(^{10}\)
- There is a weak correlation between restricted range of motion and pain.
  - Some patients have severe pain but near-normal range of motion.
  - Some patients have very restricted range of motion but no pain.
  - In one study, restricted range of motion was found in more than 50% of patients with adhesive capsulitis, but functional deficiency was identified in only 7% of the patients.\(^ {10}\)
- The impact of restricted range of motion or pain on an individual patient’s quality of life largely depends on that patient’s functional demands.
- Adhesive capsulitis in diabetics tends to be more protracted and more resistant to nonoperative treatment than idiopathic adhesive capsulitis.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients with idiopathic adhesive capsulitis often deny a traumatic event but complain of the insidious onset of pain that is refractory to physical therapy and predates the loss of motion.
- Patients with secondary adhesive capsulitis often have a history of trauma, surgery, or medical comorbidities.
  - A history of fracture or extended immobilization should be elicited.
  - Previous surgeries including rotator cuff repair, capsular shift, Putti-Platt, Bristow-Latarjet, open glenoid bone grafting, and open reduction and internal fixation of a fracture should be documented as a potential cause of stiffness.
  - Comorbidities, including diabetes mellitus and thyroid disorders, should be recorded because they are associated with adhesive capsulitis.
- Symptoms expressed by patients with shoulder stiffness include:
  - Loss of range of motion that translates into functional limitations
  - Painful arc of motion
  - Pain often radiating to the deltoid area due to “non-outlet” impingement\(^{5}\)
Periscapular pain as a result of transferred pain to the scapulothoracic articulation because of restricted gleno-humeral range of motion

Acromioclavicular joint pain due to increased scapulothoracic motion

A comprehensive examination of the involved shoulder must be done to note any concomitant pathology. Physical examination methods include:

- Passive range-of-motion examinations
  - Assessing the anterosuperior capsule: Results are compared to the contralateral shoulder. A loss of passive range of motion in this position suggests contracture of the anterosuperior capsule in the region of the rotator interval. Loss of passive range of motion should always be compared to loss of active range of motion.
  - Assessing the anteroinferior capsule: A loss of passive external rotation in abduction suggests contracture of the anteroinferior capsule.
  - Assessing the inferior capsule: A loss of passive flexion and abduction suggests contracture of the inferior capsule.
  - Assessing the posterior capsule: Cross-chest adduction can be measured in degrees by recording the angle between an imaginary horizontal to the ground and the axis of the arm. A loss of passive internal rotation suggests contracture of the posterior capsule.
  - Lidocaine injection test: Passive and active range of motion in all planes should be recorded before injection. Once pain is alleviated, the postinjection increase in passive and active range of motion is recorded. The recorded increase in range of motion after the injection indicates the extent to which loss of motion is attributable to adhesions and soft tissue contracture as opposed to pain from non-outlet impingement or a symptomatic acromioclavicular joint.
  - Intra-articular injection: Passive and active range of motion should be recorded in all planes before injection. Passive and active range of motion should be evaluated after the injection to note any improvement after pain relief. A more accurate assessment of range of motion can be made after pain is alleviated. The injection can also be therapeutic in the early stages of adhesive capsulitis when synovitis is present.

- The shoulder should be examined for signs of previous surgery, trauma, deformity, and atrophy.
- Manual motor testing of rotator cuff and deltoid muscles should be done.
- Active and passive range of motion should be noted in all planes both in seated and supine positions. Shoulder motion should be viewed from the front and back of the patient.
  - Assessing range of motion in a supine position controls compensatory scapulothoracic motion and lumbar tilt, yielding a more accurate examination.
  - An equal loss of passive and active range of motion suggests adhesive capsulitis as the cause.
  - Greater loss of active than passive range of motion suggests rotator cuff or nerve injury.
  - Global loss of passive range of motion is typical of adhesive capsulitis, whereas loss of range of motion in one plane is usually attributable to postsurgical scarring or trauma.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Routine radiographic evaluation should include an anteroposterior (AP) view of the shoulder in neutral, internal, and external rotation, as well as scapular-Y and axillary lateral views.
  - Disuse osteopenia is often noted.
  - Concomitant findings may include osteoarthrosis, calcific tendinitis, or hardware signifying a previous surgical procedure (eg, open reduction and internal fixation, Putti-Platt) (FIG 2).
  - Magnetic resonance imaging (MRI) is obtained only if a rotator cuff tear or other soft tissue derangement is suspected.
  - We do not typically order an arthrogram or laboratory studies to confirm the diagnosis of adhesive capsulitis.

**DIFFERENTIAL DIAGNOSIS**

- Glenohumeral arthritis
- Acromioclavicular arthritis
- Rotator cuff tendinitis
- Subacromial or subdeltoid bursitis
- Bicipital tendinitis
- Calcific tendinitis
- Septic arthritis
- Rotator cuff tears
- Gout or crystalline arthropathy

**NONOPERATIVE MANAGEMENT**

- Nonoperative treatment can be attempted but is typically unsuccessful in patients with secondary shoulder stiffness.
  - It is indicated in patients with primary and secondary adhesive capsulitis who have had stiffness for less than 4 to 6 months or no previous treatment.
  - Nonsteroidal anti-inflammatories are used for pain relief but narcotics are avoided because of dependency issues with long-term use.

**FIG 2** • Hardware on radiographs can be helpful in guiding treatment. In this instance, after treatment of a proximal humerus fracture with a blade plate, adhesions would be expected in the subdeltoid space.
■ Injections are helpful in the early stages of adhesive capsulitis to control pain.
  ■ A series of three intra-articular injections can be given for pain relief. An intra-articular injection is often diagnostic as well, with the alleviation of pain but continued restriction in range of motion.7-9
  ■ Paired injections can be given (a subacromial and intra-articular injection).11
  ■ Active-assisted range-of-motion exercises focused on stretching capsular contractures under the supervision of a physical therapist should be done in 5- to 10-minute sessions four or five times a day.6 Other modalities such as ice and heat can provide comfort before and after exercise but are typically not very effective in the inflammatory or freezing phase.

SURGICAL MANAGEMENT
■ Surgical intervention should not be attempted during the early stages of adhesive capsulitis. It may be counterproductive and prohibit an increase in range of motion by abundant scar formation.
■ Surgical intervention is indicated for secondary or primary adhesive capsulitis once pain is present only at the extremes of motion and not through the entire arc of motion.
■ We prefer to continue nonoperative management while motion is increasing. We recommend surgery only when patients plateau.

We prefer to do a manipulation under anesthesia at the conclusion of an arthroscopic release in a controlled fashion rather than as a stand-alone procedure or before an arthroscopic evaluation and release.

Preoperative Planning
■ Imaging is reviewed and concomitant pathology is noted.
  ■ Rotator cuff tears should be noted because a repair will influence postoperative therapy and the timing of surgery.
  ■ Glenohumeral arthritis should be noted. These patients may have some benefit from an arthroscopic release, but their results are influenced by the congruity of the glenohumeral joint.
  ■ Unless contraindicated, we use regional anesthesia (30- to 40-cc bolus of a combination of 1.5% mepivacaine and 0.5% bupivacaine) with an indwelling interscalene catheter that provides muscle paralysis and pain control during the procedure as well as up to 48 hours after arthroscopic capsular release (FIG 3A).
  ■ This is essential to postoperative therapy and was shown to be effective and safe.4,13,14 Patients are admitted for 48 hours of intensive physical therapy under the indwelling interscalene block after surgery.
  ■ An examination under anesthesia is conducted using the range-of-motion principles to assess the anterosuperior, anteroinferior, inferior, and posterior capsules. This guides the emphasis of capsular release (FIG 3B).

Positioning
■ The patient is placed supine on the operating table in the beach-chair position.
■ After an examination under anesthesia, the shoulder is widely prepared and draped well medial to the coracoid anteriorly and to the medial scapular border posteriorly.
■ The entire arm is prepared and then placed into a hydraulic arm holder (Spider Limb Positioner, Tenet Medical Engineering, Calgary, Canada) (FIG 4). This avoids the need for an assistant to hold the arm.

FIG 3 • A. An interscalene catheter is established preoperatively to provide muscle paralysis and pain control during the procedure as well as sustained pain control for 48 hours after the arthroscopic release. B. Passive range of motion is examined under anesthesia to guide the arthroscopic release. The scapula should be controlled with one of the examiner’s hands to avoid scapulothoracic motion.

FIG 4 • We use a hydraulic arm holder (Spider Limb Positioner, Tenet Medical Engineering, Calgary, Canada) to secure the arm and avoid the need for an assistant.
The challenging aspect of arthroscopic capsular release is entering the contracted joint while avoiding iatrogenic articular injury (TECH FIG 1A–C).

- We establish the posterior arthroscopic portal slightly higher than normal (TECH FIG 1D).
- An 18-gauge spinal needle is inserted into the joint and insufflated (usually 10 to 15 cc in a contracted joint) with sterile saline.
  - Entry into the joint can be confirmed by noting backflow of saline from the spinal needle.
  - This step ensures proper portal placement and also distends the joint, thus lessening the risk of iatrogenic articular injury (TECH FIG 1E).

- An incision is made where the needle was inserted using a #11 blade and the arthroscope sheath is advanced into the glenohumeral joint.
- Entry into the joint is confirmed with backflow of saline through the sheath.
- With the arthroscope posteriorly, a spinal needle is inserted lateral to the coracoid through the rotator interval immediately underneath the biceps and above the subscapularis.
- An incision is made with a #11 blade and a 6-mm cannula is then placed through this portal.
- A radiofrequency device is passed through the cannula and used to remove synovium and soft tissue that obscures the view (TECH FIG 1F).

**TECH FIG 1** - It is often difficult to enter a shoulder with significant capsular contraction and scarring. A. Entering at or above the biceps with the anterior cannula is typically possible. B. The biceps can be displaced inferiorly and the rotator interval can be ablated to relax the joint and allow further release inferiorly. C. Forced entry with poor visualization can result in significant osteochondral injury, as depicted in this image. HH, humeral head. D. The posterior portal (a) is established higher than normal to lessen the risk of iatrogenic articular damage. The lateral (b) and anterior (c) portals are established using the outside-in technique with an 18-gauge spinal needle. E. Sterile normal saline is injected into the gleno-humeral joint. This causes distention, which lessens the risk of iatrogenic articular damage and verifies the portal position. Backflow of saline through the spinal needle ensures entry into the joint as opposed to soft tissue. F. The anterior capsule is visualized by the arthroscope from the posterior portal and a radiofrequency device is placed through the cannula anteriorly to remove synovium and create a potential working space.

**ANTERIOR CAPSULAR RELEASE**

- Resection of contracted and thickened capsule can be done with a radiofrequency device, shaver, or arthroscopic punch.
- We prefer to use a hook-tipped radiofrequency device to avoid bleeding, resect in a controlled fashion, and benefit from the feedback of electrical stimulation to nearby muscles and nerves.
- An arthroscopic punch can be used once a leading edge in the capsule has been established (TECH FIG 2A,B).
In adhesive capsulitis, the capsule is often up to 1 cm thick compared with the normal 2 mm.

We resect the anterior capsule systematically.

The rotator interval capsule is noted between the biceps superiorly and the intra-articular subscapularis inferiorly. This comprises the superior glenohumeral and coraco-humeral ligaments (TECH FIG 2C).

We begin by cutting (ablating) the capsular tissue immediately inferior to the biceps tendon (TECH FIG 2D).

The capsular tissue is released inferiorly until the superior border of the subscapularis is identified, thus releasing the rotator interval and its contents (TECH FIG 2E).

A switching stick can then be used to bluntly dissect the capsule from the deep surface of the subscapularis to create a defined interval. This capsule represents the middle glenohumeral ligament (TECH FIG 2F).

The capsule overlying the subscapularis is then divided to the 6 o’clock position (TECH FIG 2G).

Gentle external rotation can place the capsule under additional tension and facilitate its resection.

The axillary nerve is not at risk as long as the subscapularis muscle is seen (see Fig 1C).

The shaver is introduced to resect the capsular tissue medially and laterally to provide a generous interval (10 mm) and discourage the healing of capsular tissue in a contracted position.

**POSTERIOR CAPSULAR RELEASE**

- Release of the posterior capsule is necessary in patients with global capsular contracture or isolated posterior capsular contracture, often seen in patients with “non-outlet” impingement symptoms as described by Warner.¹⁴
- The arthroscope is placed through the anterior 6-mm cannula.
- Inflow is attached to the anterior cannula.
- A switching stick is placed through the arthroscopic sheath posteriorly into the joint (TECH FIG 3A).
- A 6-mm cannula is exchanged for the arthroscope sheath over a switching stick posteriorly (TECH FIG 3B).
- The hook-tipped radiofrequency device is passed through the cannula and is used to release the posterior
capsule from just posterior to the long head of the biceps to the 8 o’clock position (TECH FIG 3C–E).
- In our experience, a release of the inferior capsule from 6 o’clock to 8 o’clock is unnecessary.
- A shaver is introduced and used to further resect tissue medially and laterally, leaving a 10-mm capsule-free interval. The capsule is intimate with the infraspinatus and the release should be terminated at the point at which muscle is encountered.

SUBACROMIAL AND SUBDELTOID BURSOSCOPY
- Subacromial and subdeltoid scarring and adhesions are common after prior rotator cuff repair and fracture fixation.
- In cases of adhesive capsulitis there is often a component of subacromial bursitis.
- The subacromial space and subdeltoid space are always evaluated for bursitis as well as dense adhesions.
- The arthroscope is passed into the subacromial space through the posterior portal immediately inferior to the posterior acromion.
- A 6-mm smooth cannula is placed through the anterior portal (TECH FIG 4A).
- A radiofrequency device is passed through the anterior cannula to meet the arthroscopic lens and a subacromial decompression is initiated until the space adjacent to the lateral deltoid is free of adhesions.
- A spinal needle can then be used to locate the position of a lateral portal.
- A lateral portal is made with a #11 blade and a 6-mm cannula is introduced into the subacromial space.
- The anterior and lateral cannulas can alternately be used to achieve an adequate subacromial decompression.
- It is essential to free the interval between the acromion and rotator cuff as well as laterally in the space between the deltoid and proximal humerus (TECH FIG 4B).
- An acromioplasty can be done if indicated, although it is not usually necessary in cases of primary adhesive capsulitis.
TECH FIG 4 • A. The arthroscope sheath and blunt obturator are passed as a unit through the subacromial space and out the previously made anterior portal. The arthroscope is exchanged for the obturator in the sheath and a 6-mm cannula is placed over the sheath and lens tip. Both are withdrawn into the subacromial together, enabling the radiofrequency device to begin work débriding thick soft tissue within view of the arthroscope. B. Scar and bursa are removed from the subacromial space and the subdeltoid space (*) using a shaver and radiofrequency device. Adhesions are released between the rotator cuff and the acromion and deltoid.

POSTRELEASE MANIPULATION UNDER ANESTHESIA

- Range of motion is evaluated before manipulation under anesthesia to determine which structures need additional release.
- A sterile dressing is applied and the drapes are removed so that the scapula can be stabilized.
- A manipulation after a capsular release requires far less force and therefore carries a lower risk of fracture.
- The scapula is stabilized with one hand while the surgeon’s other hand firmly grasps the humerus above the elbow (TECH FIG 5).
- Sequence of manipulation:
  - External rotation in adduction
  - Abduction
  - External rotation in abduction
  - Internal rotation in abduction
  - Flexion
  - Internal rotation in adduction

TECH FIG 5 • A gentle manipulation under anesthesia is done after arthroscopic release and once the drapes have been removed.

PEARLS AND PITFALLS

| Hemostasis | Visualization is essential during a capsular release. We routinely use epinephrine in our bags of saline. In addition, we rely on the use of a radiofrequency device and limit the use of a shaver and arthroscopic punch. |
| Difficulty entering the glenohumeral joint with the arthroscope | Distention of the joint with sterile normal saline through an 18-gauge spinal needle ensures correct position of the portal. |
| | Typically the joint can be entered superiorly at the level of the biceps and initial release of the interval should relax the joint, allowing improved visualization. |
The following sequence can help gain access to the subacromial space, which facilitates safe decompression and lysis of adhesions:
1. The arthroscope sheath (with obturator) is passed through the posterior portal adjacent to the posterior acromion toward the anterior portal.
2. With the sheath adjacent to the acromion, the sheath and obturator are passed through the existing anterior portal.
3. The obturator is removed and the arthroscope secured in its sheath (lens and tip of scope exiting out of anterior portal).
4. The 6-mm cannula is placed over the tip of the sheath.
5. In a controlled fashion, the arthroscope is withdrawn into the subacromial space while the cannula is maintained on the tip of the sheath and passed into the subacromial space.
6. A radiofrequency device can be placed in the cannula as it is backed off the sheath by 1 to 2 mm.
7. The arthroscope can now visualize the radiofrequency device in a controlled and reproducible fashion to allow safe decompression instead of relying on blind navigation in dense scar and bursa.

POSTOPERATIVE CARE
- Immediately after surgery, the arm is placed in a simple sling and the shoulder in a cryotherapy sleeve.
- The patient is admitted for 48 hours and a continuous infusion of 0.1% bupivacaine is administered through the previously placed interscalene catheter at 10 to 20 cc per hour based on the pain level.
- Passive range of motion in all planes is initiated on the morning of the first postoperative day by the physical therapists. This is done twice a day.
- The patient is discharged on the afternoon of the second postoperative day after the indwelling catheter is removed.
- A simple sling for comfort is worn on discharge, but the patient is encouraged to use the operative arm for activities of daily living.
- After discharge, the patient immediately begins outpatient physical therapy to include stretching and water therapy whenever possible:
  - Five days a week for 2 weeks
  - Three days a week for 2 weeks
  - At 1 month, therapy regimen is transitioned to home program.
- Strengthening is initiated with elastic bands and weights only when range of motion is achieved. We prefer no strengthening until full range of motion is achieved.

OUTCOMES
- Multiple studies have shown the efficacy of arthroscopic capsular release for shoulder stiffness.
- In one study with an average of 33 months of follow-up, final motion at latest follow-up was 93% of the opposite side compared to 41% preoperatively, with a significant improvement in reported health status (SF-36) and ability to use the arm functionally.
- Warner et al11 found significant gains in range of motion (within 7 degrees of the values for the normal contralateral shoulder) in 23 patients with idiopathic adhesive capsulitis treated by arthroscopic release. All patients had either no pain or only occasional mild pain with forceful use of the shoulder.
- Warner et al14 found significant gains in range of motion in all planes in 11 patients with postsurgical stiffness who underwent either an anterior or combined anterior and posterior arthroscopic capsular release after failed nonoperative treatment.
- “Non-outlet” impingement with an associated posterior capsular contracture has been effectively treated by arthroscopic posterior capsular release with an average improvement of internal rotation at 90 degrees of abduction of 37 degrees and alleviation of pain in all but one of the nine patients studied.12

Beaufils et al1 showed that arthroscopic capsular release is effective at improving range of motion regardless of the cause of a stiff shoulder, although releases for postsurgical stiffness are less likely to alleviate pain than those done for adhesive capsulitis.

COMPLICATIONS
- Axillary nerve injury
- Rotator cuff tendon disruption
- Iatrogenic chondral injury
- Fracture or dislocation during manipulation under anesthesia
- Recurrence of stiffness

REFERENCEs
DEFINITION
■ Several terms have been used to describe the elements of scapulothoracic bursitis and crepitus, such as snapping scapula, washboard syndrome, scapulothoracic syndrome, and rolling scapula.
■ The first description of scapulothoracic crepitus is credited to Boinet in 1867.¹
■ By 1904, Mauclaire⁵ had described three subclasses—froissement, frottement, and craquement—depending on the loudness and character of the sound.
■ Milch⁶ and then Kuhn et al⁴ added to the understanding by differentiating sounds of soft tissues (frottement) from those arising from an osseous lesion (craquement or crepitus).

ANATOMY
■ Major bursae
  ▪ Infraserratus bursa located between the serratus anterior muscle and the chest wall
  ▪ Supraserratus bursa located between the subscapularis and the serratus anterior muscles
■ Minor bursae
  ▪ Not consistently identified on cadaveric or clinical studies
  ▪ Adventitial in nature; thought to arise secondary to abnormal biomechanics of the scapulothoracic joint
  ▪ Superomedial angle of the scapula
  ▪ Infraserratus
  ▪ Supraserratus
  ▪ Spine of scapula
  ▪ Trapezioid
  ▪ Inferior angle of scapula
  ▪ Infraserratus

PATHOGENESIS
■ Scapulothoracic bursitis can be caused by atrophied or fibrotic muscle, anomalous muscle insertions, or elastofibroma (rare benign soft tissue tumor located on the chest wall).
■ Osteochondromas and malunited fractures of the ribs or scapula can also cause pathology in this articulation.
■ Infectious causes include tuberculosis or syphilis.
■ The tubercle of Luschka is a prominence at the superomedial aspect of the scapula that can be excessively hooked and can cause altered biomechanics.
■ Scoliosis or thoracic kyphosis can contribute to scapulothoracic crepitus.
■ Unrelated disorders include cervical radiculopathy, glenohumeral pathology, and periscapular strain.

NATURAL HISTORY
■ Scapulothoracic disorders are often associated with repetitive overhead activities or with a history of trauma.
■ Constant motion leads to inflammation and a cycle of chronic bursitis and scarring.
■ Mechanical impingement and pain with motion are a result of tough fibrotic tissue, furthering the inflammatory cycle.

PATIENT HISTORY AND PHYSICAL FINDINGS
■ Repetitive overhead activities or trauma
■ Palpable or audible crepitus over the involved area
■ Occasionally bilateral or positive family history
■ Localized tenderness over the inflamed area is most common.
■ Superomedial border is the most commonly affected area.
■ Inferior pole is also a common site of pathology.
■ Pseudowinging (nonneurologic etiology) may result from fullness over the involved area and compensation of scapular mechanics due to pain.
■ Crepitus alone, without pain, may be physiologic and not warrant treatment.

IMAGING AND OTHER DIAGNOSTIC STUDIES
■ Tangential scapular views to identify bony anomalies
■ Computed tomography is controversial but can be helpful if osseous lesions are suspected and plain radiographs are normal.
■ Magnetic resonance imaging (MRI) is also controversial but can identify the size and location of bursal inflammation.
■ Injection of a corticosteroid and local anesthetic is helpful to confirm the diagnosis.

DIFFERENTIAL DIAGNOSIS
■ Atrophied, fibrotic muscle or anomalous muscle
■ Malunited rib or scapular fracture
■ Mass (eg, elastofibroma, osteochondroma)
■ Infection (ie, tuberculosis, syphilis)
■ Scoliosis or kyphosis
■ Cervical spine radiculopathy
■ Glenohumeral disease

NONOPERATIVE MANAGEMENT
■ Rest
■ Nonsteroidal anti-inflammatory
■ Activity modification
■ Physical therapy
  ▪ Local modalities
  ▪ Periscapular strengthening, emphasizing subscapularis and serratus anterior
■ Postural training
■ Figure 8 harness for kyphosis
■ Injection may be of benefit for both diagnosis and treatment.

SURGICAL MANAGEMENT
■ Indicated for patients who have failed to respond to conservative therapy
■ Open treatment
Chapter 16  ARTHROSCOPIC TREATMENT OF SCAPULOTHORACIC DISORDERS

135

■ Has been used successfully in treatment of both bursitis\(^7,9\) and crepitus\(^6,8\)
■ Requires fairly large exposure and subperiosteal dissection of the medial musculature, with repair back to bone after debridement of pathologic tissue is accomplished
■ Arthroscopic treatment
■ Minimizes morbidity of the exposure and facilitates early rehabilitation and return to function

Preoperative Planning
■ If a bony mass is detected, computed tomography findings will help guide the planned resection.

Positioning
■ The patient is placed in the prone position, with the arm behind the back in extension and internal rotation (the so-called chicken wing position; FIG 1).

Approach
■ Decisions regarding open versus arthroscopic treatment for these disorders should be based on surgeon experience and comfort level.

POSTOPERATIVE CARE
■ Sling for comfort
■ Gentle passive motion immediately
■ Active and active-assisted motion and isometric exercises are started at 4 weeks postoperatively.
■ Periscapular strengthening starts at 8 weeks postoperatively.

OUTCOMES
■ No large series of arthroscopic treatment have been published.
■ Several smaller series have reported favorable outcomes after arthroscopic surgery.\(^2,3\)

COMPLICATIONS
■ Pneumothorax
■ Infection
■ Inadequate resection, recurrence of symptoms

FIG 1 • The arm behind the back in extension and internal rotation: the “chicken wing” position.

Preoperative Planning
• If a bony mass is detected, computed tomography findings will help guide the planned resection.

Positioning
• The patient is placed in the prone position, with the arm behind the back in extension and internal rotation (the so-called chicken wing position; FIG 1).

Approach
• Decisions regarding open versus arthroscopic treatment for these disorders should be based on surgeon experience and comfort level.

POSTOPERATIVE CARE
• Sling for comfort
• Gentle passive motion immediately
• Active and active-assisted motion and isometric exercises are started at 4 weeks postoperatively.
• Periscapular strengthening starts at 8 weeks postoperatively.

OUTCOMES
• No large series of arthroscopic treatment have been published.
• Several smaller series have reported favorable outcomes after arthroscopic surgery.\(^2,3\)

COMPLICATIONS
• Pneumothorax
• Infection
• Inadequate resection, recurrence of symptoms

ARTHROSCOPIC PORTALS

The initial “safe” portal is 2 cm medial to the medial scapular edge at the level of the scapular spine, between the chest wall and serratus anterior (TECH FIG 1A).
• Avoids dorsal scapular nerve and artery
• The space is distended with 150 mL saline via spinal needle and then the portal is created.
• After insertion of a 4.0-mm 30-degree arthroscope into the first portal, a second “working” portal is established under direct visualization (TECH FIGS 1B and 1D).

It is placed about 4 cm inferior to the first portal.
• A 6-mm cannula is inserted into this portal.
• An additional superior portal can be placed as described by Chan et al\(^1\) (TECH FIG 1C).
• Portals superior to the scapular spine place the dorsal scapular neurovascular structures, accessory spinal nerve, and transverse cervical artery at risk, however.

FIG 1 • The arm behind the back in extension and internal rotation: the “chicken wing” position.

Preoperative Planning
• If a bony mass is detected, computed tomography findings will help guide the planned resection.

Positioning
• The patient is placed in the prone position, with the arm behind the back in extension and internal rotation (the so-called chicken wing position; FIG 1).

Approach
• Decisions regarding open versus arthroscopic treatment for these disorders should be based on surgeon experience and comfort level.

POSTOPERATIVE CARE
• Sling for comfort
• Gentle passive motion immediately
• Active and active-assisted motion and isometric exercises are started at 4 weeks postoperatively.
• Periscapular strengthening starts at 8 weeks postoperatively.

OUTCOMES
• No large series of arthroscopic treatment have been published.
• Several smaller series have reported favorable outcomes after arthroscopic surgery.\(^2,3\)

COMPLICATIONS
• Pneumothorax
• Infection
• Inadequate resection, recurrence of symptoms

ARTHROSCOPIC PORTALS

The initial “safe” portal is 2 cm medial to the medial scapular edge at the level of the scapular spine, between the chest wall and serratus anterior (TECH FIG 1A).
• Avoids dorsal scapular nerve and artery
• The space is distended with 150 mL saline via spinal needle and then the portal is created.
• After insertion of a 4.0-mm 30-degree arthroscope into the first portal, a second “working” portal is established under direct visualization (TECH FIGS 1B and 1D).

It is placed about 4 cm inferior to the first portal.
• A 6-mm cannula is inserted into this portal.
• An additional superior portal can be placed as described by Chan et al\(^1\) (TECH FIG 1C).
• Portals superior to the scapular spine place the dorsal scapular neurovascular structures, accessory spinal nerve, and transverse cervical artery at risk, however.

FIG 1 • The arm behind the back in extension and internal rotation: the “chicken wing” position.
**RESECTION**

- A methodical approach to resection is needed because there are minimal anatomic landmarks.
- Radiofrequency ablation and motorized shaving are used (TECH FIG 2A,B).
- The surgeon proceeds medial to lateral and inferior to superior.
- Spinal needles can be used to outline the medial border of the scapula (TECH FIG 2C,D).
- Switching portals and the use of a 70-degree arthroscope may be necessary (TECH FIG 2E,F).
- The superomedial angle of the scapula is identified by palpation through the skin.
- Radiofrequency is used to detach the conjoined insertion of the rhomboids, levator scapulae, and supraspinatus from the bone.
- A partial scapulectomy is performed using a motorized shaver and burr.
- The arm should then be placed through a range of motion to assess the resection.

**TECH FIG 2 • A,B.** Resection and débridement of the scapula. C,D. The spinal needle is used as a guide to the medial border of the scapula. E,F. Final débridement.

**PEARLS AND PITFALLS**

| Portal placement | The surgeon should consider the neurovascular structures and the thoracic structures. |
| Portal placement | The surgeon should enter parallel to the ribs and use a spinal needle to localize the portals. |
| Portal placement | More inferiorly placed portals are safer because the dorsal scapular nerve arborizes terminally. |

| Visualization | Predistention |
| Visualization | Epinephrine for vasoconstriction |
| Visualization | Appropriate pump pressure |
| Visualization | The surgeon should work expeditiously. |

| Bursectomy | Inadvertent thoracotomy is avoided. |
| Bursectomy | A complete bursectomy is performed. |
| Bursectomy | The surgeon should avoid perforating the subscapularis muscle medially (bleeding). |

| Partial scapulectomy | Preoperative planning with computed tomography or three-dimensional computed tomography |
| Partial scapulectomy | Anatomy is localized with a spinal needle. |
| Partial scapulectomy | Adequate resection is performed. |
REFERENCES

Arthroscopic Débridement and Glenoidplasty for Shoulder Degenerative Joint Disease

Christian J.H. Veillette and Scott P. Steinmann

DEFINITION

- Osteoarthritis (OA) is a degenerative disorder of synovial joints characterized by focal defects in articular cartilage with reactive involvement in subchondral and marginal bone, synovium, and para-articular structures.1,10
- Patients with degenerative joint disease (DJD) of the shoulder often have coexisting pathology, including bursitis, synovitis, loose bodies, labral tears, osteophytes, and articular cartilage defects.2,3,9
- Arthroscopic débridement may be a reasonable treatment option in these patients after conservative methods have been unsuccessful and when joint replacement is not desired.1
- Historically, patients who have early OA in whom concentric glenohumeral articulation remains with a visible joint space on the axillary radiograph are candidates for arthroscopic débridement.14
- Patients with severe glenohumeral arthritis for whom shoulder arthroplasty is not ideal, such as young or middle-aged patients and older patients who subject their shoulders to high loads or impact, remain an unresolved clinical problem and are potential candidates for arthroscopic techniques.1
- There are four basic options for arthroscopic treatment in a patient with DJD of the shoulder:
  - Glenohumeral joint débridement
  - Capsular release
  - Subacromial decompression
  - Glenoidplasty
- Choosing which of these four options to perform on a shoulder with DJD depends on the degree of arthritis and the skill, philosophy, and experience of the surgeon.1
- The goal of arthroscopic débridement is to provide a period of symptomatic relief rather than reverse or halt the progression of OA.

ANATOMY

- The normal head shaft angle is about 130 degrees, with 30 degrees of retroversion.4
- The articular surface area of the humeral head is larger than that of the glenoid, allowing for large normal range of motion.4
- Glenoid version, the angle formed between the center of the glenoid and the scapular body, averages 3 degrees and is critical for stability.4
- The glenoid fossa provides a shallow socket in which the humeral head articulates. It is composed of the bony glenoid and the glenoid labrum.4
- The labrum is a fibrocartilaginous structure surrounding the periphery of the glenoid. The labrum provides a 50% increase in the depth of the concavity and greatly increases the stability of the glenohumeral joint.4
- The glenoid had an average depth of 9 mm in the superoinferior direction and 5 mm in the anteroposterior direction with an intact labrum.6,8

PATHOGENESIS

- OA may be classified as primary, when there is no obvious underlying cause, or secondary, when it is preceded by a predisposing disorder.1
- Pathology in patients with glenohumeral OA includes a degenerative labrum, loose bodies, osteophytes, and articular cartilage defects in addition to synovitis and soft tissue contractures.1
- The disease process in OA of the shoulder parallels that of other joints. Degenerative alterations primarily begin in the articular cartilage as a result of either excessive loading of a healthy joint or relatively normal loading of a previously disturbed joint.12
- Progressive asymmetric narrowing of the joint space and fibrillation of the articular cartilage occur with increased cartilage degradation and decreased proteoglycan and collagen synthesis.12
- Subchondral sclerosis develops at areas of increased pressure as stresses exceed the yield strength of the bone and the subchondral bone responds with vascular invasion and increased cellularity.
Physical examination should include the following:

- Cystic degeneration occurs owing to either osseous necrosis secondary to chronic impaction or the intrusion of synovial fluid.
- Osteophyte formation occurs at the articular margin in non-pressure areas by vascularization of subchondral marrow, osseous metaplasia of synovial connective tissue, and ossifying cartilaginous protrusions.
- Fragmentation of these osteophytes or of the articular cartilage itself results in intra-articular loose bodies. In late stages, complete loss of articular cartilage occurs, with subsequent bony erosion.
- Posterior glenoid erosion is predominant, leading to increased retroversion of the glenoid and predisposing to subluxation and reduction of the humeral head, causing symptoms of instability.

**NATURAL HISTORY**

- Information on the natural history of OA in individuals and its reparative processes is limited.
- Progression of OA is considered generally to be slow (10 to 20 years), with rates varying among joint sites.  
- No specific longitudinal studies exist on the progression of shoulder OA.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Typical history for patients with OA is progressive pain with activity over time.
- In early stages, pain is related to strenuous or exertional activities but over time it progresses to activities of daily living. In later stages, pain occurs at rest and at night.
- Pain may be mistaken for impingement syndrome early in the disease process or rotator cuff disease when symptoms occur in the presence of good motion.
- Progression of the disease often leads to secondary capsular and muscular contractures with loss of active and passive motion.
- Mechanical symptoms such as catching and grinding are often reported with use of the shoulder.
- The pain of shoulder OA can be divided into three types:
  - Pain at extremes of motion: due to osteophytes and stretching of the inflamed capsule and synovium
  - Pain at rest: due to synovitis (pain at night is not the same as pain at rest and may be due to awkward positions or increased pressure)
  - Pain in the mid-arc of motion: usually associated with crepitus and represents articular surface damage
- Physical examination should include the following:
  - Range of motion: Loss of both active and passive motion consistent with soft tissue contractures. In patients with preserved passive motion but loss of active motion, rotatory cuff pathology should be ruled out.
  - Compression–rotation test: Pain during mid-arc of motion is a potentially poor prognostic indication.
  - Neer test and Hawkins test: Often patients with OA have positive impingement signs related to articular lesions in the glenohumeral joint or to the synovitis in the joint and subacromial pathology.
  - Supraspinatus evaluation: Weakness may reflect associated supraspinatus tear. Patients with OA may have weakness related to pain inhibition on resistance.

- Infraspinatus and teres minor evaluation: Weakness may reflect associated posterior rotator cuff tear. Patients with OA may have weakness related to pain inhibition on resistance.
- Subscapularis evaluation: Weakness may reflect associated subscapularis tear. Patients with OA may have weakness related to pain inhibition on resistance.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- A standard shoulder series consisting of a true anteroposterior view in the scapular plane, a scapular lateral view, and an axillary view should be obtained on all patients before surgical intervention (FIG 2A,B).
- Classic findings of glenohumeral OA are joint space narrowing, subchondral sclerosis, subchondral cysts, and osteophyte formation.
- Posterior wear of the glenoid is often noted on the axillary view in later stages of the disease.
- Magnetic resonance imaging (MRI) is more sensitive for the diagnosis of early-stage OA than are plain radiographs and can identify concurrent soft tissue pathology.
- Up to 45% of patients with grade IV chondral lesions can have no radiographic (MRI or plain radiograph) evidence of OA on preoperative imaging.  
- Computed tomography (CT) scanning provides improved visualization of the bony glenoid, osteophytes, and loose bodies (FIG 2C).
- Three-dimensional reconstructions provide an excellent visual representation of the biconcave glenoid to assist in preoperative planning (FIG 2D).

**DIFFERENTIAL DIAGNOSIS**

- Impingement syndrome
- Adhesive capsulitis
- Superior labral anterior to posterior (SLAP) lesions
- Rotator cuff tears
- Instability

**NONOPERATIVE MANAGEMENT**

- Standard nonoperative modalities, such as nonsteroidal anti-inflammatory medications, steroid injections, and physical therapy, should be explored before arthroscopic techniques.

**SURGICAL MANAGEMENT**

- Current indications for arthroscopic osteocapsular arthroplasty and glenoidplasty are patients with the following:
  - Moderate to severe glenohumeral OA
  - A biconcave glenoid
  - Moderate to severe pain causing functional impairment that has failed to respond to nonsurgical treatment
  - Painless crepitus with glenohumeral motion during joint compression
- Patient must have a relative contraindication to total shoulder arthroplasty such as age younger than 50 years, excessive physical demands, or unwillingness to consider shoulder replacement.
- Age and prior successful total shoulder arthroplasty on the contralateral shoulder are not contraindications.
Glenoidplasty is performed if there is a biconcave glenoid from posterior wear and involves recontouring the surface to recreate a single concavity.

- The rationale is to restore the position of the humeral head, thus reducing posterior subluxation, increasing the surface area of articulation, decreasing joint pressure, and relaxing the anterior soft tissues.

- Subacromial decompression preoperative examination and intraoperative arthroscopic findings implicate the subacromial space as source of pain.
- A thickened bursa consistent with chronic bursitis has been documented, and several authors advocate a soft tissue decompression, at a minimum.\(^3,15\)
- Bleeding from the undersurface of the acromion may lead to subacromial fibrosis and loss of motion. Therefore, routine subacromial decompression is not recommended.

Preoperative Planning

- The surgeon should review high-quality radiographs, especially the axillary view if glenoidplasty will be performed, to plan the increase in depth of the glenoid required to convert the biconcave glenoid back to a single concavity.
- The surgeon examines the range of motion under anesthesia and compares it to the opposite side.

Positioning

- The patient is placed in the beach-chair or lateral decubitus position after regional anesthesia (interscalene block) or general anesthesia is obtained.
- Unobstructed access to the anterior and posterior aspects of the shoulder is imperative (FIG 3).
- A potential disadvantage of the lateral decubitus position is the need to take the arm out of traction periodically to check the range of motion after capsular resection.

- If working in the area of the axillary nerve, the semi-abducted position used in the lateral decubitus position tends to bring the axillary nerve closer to the capsule.

Approach

- A standard midposterior arthroscopic portal is established in usual fashion.
- A standard anterior portal is made using an 18-gauge spinal needle under direct arthroscopic vision to locate the position in the rotator interval.
- Additional portals that are often required include a midlevel anterior portal (adjacent to the superior border of the subscapularis) for osteophyte removal and a posteromedial portal for placement of a retractor to clear the axillary pouch from the humeral head and neck.
- It is helpful to place both the posterior and anterior portals a bit more inferior than usual to allow easier access to the inferior aspect of the joint.
**DIAGNOSTIC ARTHROSCOPY**

- A standard 15-point assessment of the arthroscopic glenohumeral anatomy as outlined by Snyder\textsuperscript{11} is performed.
- Typical findings include extensive synovitis, especially on the undersurface of the rotator cuff, fraying of the labrum, and fibrillation or loss of articular cartilage.

**SYNOVECTOMY AND DÉBRIDEMENT**

- A complete systematic synovectomy is performed using a combination of an arthroscopic thermal device to minimize bleeding and a full-radius shaver (4.8 or 5.5 mm).
  - The surgeon begins by removing synovium from the anterosuperior aspect of the joint, moving posteriorly and then inferiorly into the axillary recess and finally the posterior inferior synovium.
  - A full-radius shaver is used to débride the fraying labrum and remove loose bodies and unstable chondral flaps.
- Working space in the inferior axillary pouch is markedly increased after removal of the inferior osteophyte and permits improved visibility of the inferior capsule and safer performance of partial capsulectomy.

**CAPSULECTOMY AND RELEASE**

- The surgeon removes impinging osteophytes, especially any inferior osteophyte from the humeral head, and performs appropriate capsular or interval releases to regain passive motion.
  - An efficient way to visualize and remove inferior osteophytes is to view from the anterior portal using a standard 30-degree arthroscope and then establish a posterior inferior working portal. The shaver or burr can then be brought in posteriorly to remove capsule or osteophytes.
  - The inferior humeral osteophyte is removed first through the posterior inferior working portal using a 4.0-mm hooded burr (which protects the inferior capsule and the axillary nerve) beginning posteriorly and moving anteriorly.
  - The humerus can be internally rotated to deliver the osteophyte and improve positioning of the instrument.
- The inferior capsular attachment to the humeral head should be identified and used as a landmark to recreate the normal architecture of the humerus.
  - A 5.5-mm full-radius shaver is useful to débride any loose bony fragments and soft tissues from the burr.
  - Suction on the instruments should be avoided to decrease the likelihood of unintentional damage to the axillary nerve from soft tissue drawn into the instrument.
  - A curved curette may be required to reach around and remove the anterior aspect of the inferior osteophyte.
  - Fine contouring may be done with the shaver or hand rasps as necessary.
  - Working space in the inferior axillary pouch is markedly increased after removal of the inferior osteophyte and permits improved visibility of the inferior capsule and safer performance of partial capsulectomy.
  - A full-radius shaver is placed through the posterior portal and used to create a capsulotomy in the posterior aspect of the inferior capsule (in the right shoulder at the 7 o’clock position) adjacent to the glenoid rim.
  - The plane between the inferior capsule and underlying soft tissues is then developed with a wide duck-billed basket punch moving from a posterior to an anterior direction. The shaver is then used to widen the resection.
  - The capsulectomy should be performed as close to the glenoid rim as possible to minimize the risk to the axillary nerve, which should be identified and protected with a probe after the 6 o’clock position is reached.
  - A partial capsulectomy is then performed anteriorly, ante-rior osteophytes are removed, and the capsule is removed from the rotator interval (TECH FIG 1).

**TECH FIG 1** Osteocapsular arthroplasty. Osteophyte removal is usually best done before resection of the capsule and primarily involves working in the inferior aspect of the glenohumeral joint. A. Inferior osteophytes are best viewed from the anterior portal using a standard 30-degree arthroscope, and then the shaver or burr can be brought in from a posterior inferior working portal to remove capsule or osteophytes. (continued)
This can be done viewing from a posterior portal and using an anterior portal to direct a cautery-radiofrequency device or a shaver to release the anterior capsule from the anterior glenoid surface.

Any residual anteroinferior capsule can be resected from the anterior portal to connect with the inferior capsulectomy.

The direct posterior capsule is not generally removed, just as it is not typically resected during a total shoulder replacement. The posterior capsule is often lax from the posterior subluxation and posterior glenoid wear seen in osteoarthritis.

GLENOIDPLASTY

Anterior and posterior portals are used to perform the procedure, and the biconcave shape of the glenoid can best be visualized by looking inferiorly from the anterior portal (TECH FIG 2A).

A full-radius shaver is used to remove the remaining cartilage from the anterior glenoid facet (TECH FIG 2B).

The central vertical bony ridge is then removed using a 4-mm round burr moving from anterior to posterior in a superior to inferior direction.

The glenoid is divided into quarters and the superior half is contoured first to allow comparison with the prior biconcave glenoid (TECH FIG 2C).

The view of the glenoid can be alternated from front to back, and once a single concave surface has been established, a large hemispherical hand rasp can be used to deepen and smooth the surface (TECH FIG 2D).

The glenoidplasty is assessed intraoperatively by performing a compression-rotation test and palpating for crepitus and assessing the rotation of the humerus on the new glenoid surface arthroscopically.
SUBACROMIAL DECOMPRESSION

- Using standard portals to explore the subacromial space, a shaver or cautery–radiofrequency probe is placed above the rotator cuff, and any thickened bursa is removed.
- Bursal-sided fraying or tearing of the rotator cuff can also be addressed at the same time.
- There is usually no need to perform an acromioplasty, but if a minor spur of the acromion is encountered it can be resected. The corococacromial ligament should be preserved.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Moderate to severe glenohumeral osteoarthritis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Painless crepitus during glenohumeral motion in the midrange with joint compression</td>
</tr>
<tr>
<td></td>
<td>Age younger than 50 years or heavy physical demands on the shoulder</td>
</tr>
</tbody>
</table>

| Preoperative planning | Computed tomography scan with three-dimensional reconstructions to visualize biconcave glenoid from anticipated arthroscopic views |

| Débridement | Complete, systematic synovectomy with removal of all traces of synovitis |
|            | Thermal ablation device is helpful for removal of synovitis and simultaneous control of bleeding. |
|            | Removal of inferior osteophyte on humeral head greatly increases working space for inferior capsulectomy. |
|            | Anterior capsulectomy is performed with arthroscope posterior and instruments anterior. |
|            | Inferior capsulectomy is performed with arthroscope anterior and instruments posterior. |
|            | Capsulectomy should be performed as close to the glenoid rim as possible to minimize the risk to the axillary nerve. |

| Glenoidplasty | The surgeon removes anterior cartilage and defines the central bony ridge. |
|              | Glenoid is divided into four quadrants. Glenoidplasty starts on the inferior half to allow comparison with the biconcave glenoid. |
|              | Assistant must translate the humeral head posteriorly when working on the anterior aspect of the glenoid, and vice versa when working posteriorly. |
|              | A curved hand rasp is used to fine-tune the glenoid contour. |

POSTOPERATIVE CARE

- Full, unrestricted passive and active assisted range of motion is initiated on the first postoperative day.
- Patients with an osteocapsular arthroplasty and glenoidplasty have an indwelling glenohumeral catheter for postoperative analgesia and stay in the hospital overnight.
- Most patients benefit from a structured therapy program supervised by a trained therapist to encourage full passive and active motion.
- The patient begins isometric strengthening immediately and progresses to isotonic exercises as tolerated.
- Patients should be allowed to go back to work as soon as they are comfortable.

OUTCOMES

- Ellman et al\(^1\) showed the benefit of arthroscopic débridement of the glenohumeral joint in 18 patients who underwent initial shoulder arthroscopy for impingement syndrome but were shown at operation to have coexisting glenohumeral DJD that was not evident on preoperative clinical and radiographic evaluation.
- Weinstein et al\(^14\) reported an 80% satisfactory improvement in 25 patients with early OA treated with arthroscopic débridement. Cameron et al\(^2\) reported on 61 patients with grade IV chondral lesions of the shoulder treated with arthroscopic débridement with or without capsular release. Overall, 88% of patients had a satisfactory outcome.
Pain relief is not related to the radiographic stage of arthritis or the location of the lesion. However, return of pain and failure are associated with osteochondral lesions greater than 2 cm in diameter. Kelly et al presented the results on 14 patients with a mean age of 50 years treated with osteocapsular arthroplasty and glenoidplasty. Early follow-up at 3 years showed an 86% rate of improvement, and 92% agreed that the surgery was worthwhile. No complications were reported and there was no evidence of medial migration of the humerus.

COMPLICATIONS

None of the previously published studies on arthroscopic treatment of glenohumeral OA reported complications. Ogilvie-Harris and Wiley reported 15 complications in 439 patients (3%) treated with arthroscopic surgery of the shoulder. Medial migration of the humerus after glenoidplasty and inability to perform glenoid resurfacing during total shoulder replacement has not been encountered.

REFERENCES

DEFINITION
- Elbow arthroscopy involves the use of an arthroscope to examine the interior of the elbow joint and provides the opportunity to perform minimally invasive diagnostic and therapeutic procedures.
- Elbow arthroscopy has evolved to allow the definitive care of more than a dozen complex elbow conditions.
- Despite an expanded understanding of the surrounding neurovascular anatomy, essential portal placement for access to the elbow joint continues to present a level of risk for injury that exceeds that seen in other joints.
- The safe application of this treatment modality requires that the surgeon have a solid grasp of the relative anatomy, fellowship or laboratory training in treatment techniques, experience as an arthroscopist, and an objective assessment of his or her own level of skill.

ANATOMY
- Neurovascular injury risk is relatively high and a three-dimensional grasp of elbow anatomy is essential for safe and successful elbow arthroscopy. Miller et al. showed that the bone-to-nerve distances in the 90-degree-flexed elbow increased with joint insufflation an average of 12 mm for the median nerve, 6 mm for the radial nerve, and 1 mm for the ulnar nerve.
- The capsule-to-nerve distance changes very little with insufflation, however, and the protective effect of insufflation is lost when the elbow is in extension.
- Miller et al. also showed that in the insufflated, 90-degree-flexed elbow, both the radial and median nerves passed within 6 mm of the joint capsule and that the radial nerve was on average 3 mm closer to the capsule than the median nerve. The ulnar nerve was essentially on the capsule.
- Others have also shown the close proximity of the radial nerve to the joint capsule and stressed the greater risk to this nerve during both portal placement and capsular resection.
- Stothers et al. emphasized the importance of elbow flexion during portal placement and showed that the portal-to-nerve distances decreased an average of 3.5 to 5.1 mm laterally and 1.4 to 5.6 mm medially when the elbow was in extension.
- For the distal anterolateral portal, the distance from the sheath to the radial nerve averaged 1.4 mm (range 0 to 4 mm) in extension and 4.9 mm (2 to 10 mm) in flexion.
- Field et al compared three anterolateral portals and reported a statistically significant difference in portal-to-radial nerve distance, with greater safety shown with the more proximal locations.
- Anatomic studies suggest three guidelines for neurovascular safety:
  - Portal placement is safer when the elbow is flexed 90 degrees than when it is in extension.
  - Maximal joint distention before portal placement increases the safety during placement by increasing the nerve-to-portal distance.

FIG 1 • A. Relative anatomy of the medial elbow and the arthroscopic portal sites: 1, standard anteromedial; 2, mid-anteromedial; and 3, proximal anteromedial. B. Relative anatomy of the lateral and posterior elbow and the arthroscopic portal sites: 1, distal anterolateral; 2, mid-antlerolateral; 3, proximal anterolateral; 4, direct posterolateral; 5, posterolateral; and 6, posterior central.
The nerve-to-portal distance is greater for the more proximal anterior portals than for the more distal anterior portals.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- This chapter does not address a specific condition but instead offers a broad view of the basic considerations and setup issues for a surgical treatment that may be applied to many different elbow problems.
- A complete review of the numerous clinical tests described for the diagnostic evaluation of the elbow would exceed the scope of this chapter.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Routine preoperative elbow radiographs should include a true lateral view, a standard anteroposterior (AP) view, and an AP view of both the distal humerus and proximal forearm when joint motion loss prevents full joint extension.
- Additional radiographic views include the cubital tunnel view, the posterior impingement view, the capitellum view, and the radial head view.
- The cubital tunnel view, an AP projection of the humerus with the elbow maximally flexed, provides a clear view of the medial epicondyle and cubital tunnel groove.
- The posterior impingement view is also an AP projection of the humerus with the elbow maximally flexed, but the humerus is rotated into 45 degrees of external rotation. This image offers better assessment of the posterior medial edge of the olecranon tip and the medial epicondyle apophysis.
- The capitellum view, an AP projection of the ulna with the elbow flexed 45 degrees, provides a tangential view of the capitellum for better evaluation of osteochondritis dissecans lesions.
- The radial head view is an oblique view of the 90-degree-flexed elbow with the beam passing between the ulna and the radial head. It allows for clear imaging of both the radial head and the radial-ulna interval.
- Although this point is sometimes argued, computed tomography is often useful when resection of intra-articular bone is considered as a part of contracture release arthroscopy.
- Magnetic resonance (MR) imaging in a closed high-field magnet with thin-section, optimized, high-spatial-resolution sequences may provide exceptional detail of the structures surrounding the elbow joint; however, MR arthrography, with either saline or gadolinium, will improve the assessment of intra-articular structures such as loose bodies.

**SURGICAL MANAGEMENT**

- The indications for elbow arthroscopy include the evaluation and treatment of septic arthritis, lateral synovial plica syndrome, systemic inflammatory arthritis, loose bodies, synovitis, osteochondritis dissecans (OCD), degenerative arthritis, posterior impingement, traumatic arthritis, trochlea chondromalacia, arthrofibrosis, lateral epicondyritis, joint contracture, postero-lateral rotatory instability, and olecranon bursitis.
- Treatment options for these conditions include diagnostic evaluation, loose body removal, synovial biopsy, partial or complete synovectomy, plica excision, extensor carpi radialis brevis tendon débridement, capsule release, capsulotomy, capsulectomy, exostosis excision, ulnohumeral arthroplasty, contracture release, chondroplasty, microfracture chondroplasty, percutaneous drilling or fixation of OCD lesions, capitellum osteochondral transplantation, radial head excision, internal fixation of fractures, lateral ulnar collateral ligament plication, ulnar nerve decompression, and finally olecranon bursctomy.
- The relative contraindications for elbow arthroscopy include recent joint or soft tissue infection, developmental changes, previous trauma or surgery that significantly alters the normal neurovascular, bony, or soft tissue anatomy of the elbow, extensive extracapsular heterotopic ossification, complex regional pain syndrome, and conditions that prevent distention of the elbow capsule.
- Previous ulnar nerve transposition usually requires exposure of the ulnar nerve before the creation of an anteromedial portal.

**Preoperative Planning**

- As with all medical conditions, the importance of the information gained from a careful and complete history and examination for establishing an accurate diagnosis cannot be overemphasized.
- Plain radiographs are also essential, but some authors suggest that computed tomography and MRI offer little in the preoperative assessment.
- In contrast, the exact location of intra-articular, capsular, and extra-articular bone, the thickness of the joint capsule, the integrity of the cartilage covering an OCD lesion, and the presence of stress fractures or loose bodies unseen on radiographs are a few examples of how additional imaging may directly or modify care.
- The surgeon should consider how associated procedures to be performed in conjunction with the arthroscopy will affect patient positioning and the possible need to reposition during the case.
- Fluoroscopy should be available when drilling, pinning, or internal fixation is considered.
- In addition to standard arthroscopic instrumentation, the preoperative plan should also consider the need for specialized instruments such as retractors and special biters for contracture release surgery and small-fragment-fixation devices for OCD or fracture care.
- Elbow arthroscopy may be done using either general or regional anesthesia.
- General anesthesia is typically preferred as it allows for complete muscle relaxation. Regional blockade is reserved for contracture release procedures where repeated manipulation and continuous passive motion is planned during the hospitalization.
- While regional anesthesia may be given before surgery, many surgeons prefer to wait until the status of the neurovascular structures is established in the recovery setting.
- Indwelling catheter regional anesthesia is described and sometimes recommended for contracture release procedures, but not all centers are comfortable or experienced with these techniques, and repeated regional anesthesia during the hospitalization appears to be equally effective.
- The use of ultrasound during injection may decrease the morbidity associated with regional anesthesia.
Positioning

- The four patient positions for elbow arthroscopy are the supine cross-body position, the supine suspended position, the lateral decubitus position, and the prone position.
  - While the latter two positions are most popular today, experience with one of the supine positions still offers advantages. For example, a surgeon who prefers the prone position may elect to use the supine cross-body position when arthroscopic and open procedures are combined, preventing the need for repositioning.

- **Supine cross-body position**
  - Arthroscopy in this position may be done with one of several commercially available arm-holding devices but is performed equally well with an assistant acting as the arm holder (FIG 2A).
  - Because the elbow is not rigidly stabilized in this position, complex procedures may be more challenging and present a greater level of risk for injury.
  - The supine cross-body position is most useful when a less demanding arthroscopic procedure is performed along with an open surgery.

- **Supine suspended position**
  - This position requires the use of a traction device from which the arm is hung. Capture of the hand or wrist is necessary, and finger traps on the index and long fingers work well in this regard (FIG 2B).
  - The elbow is not stabilized against either a post or pad, which allows considerable movement of the elbow beneath the hand.
  - Two potential disadvantages of this position are the unexpected withdrawal of the arthroscope from the freely swinging joint and the almost vertical position of the arthroscope during arthroscopy of the posterior compartment.

- **Lateral decubitus position**
  - This position for elbow arthroscopy is typically set up the same as for shoulder surgery except that the arm is draped across a padded horizontal post attached to the table (FIG 2C).
  - The advantage of this position over the supine positions is that a stable platform is created on which the upper arm rests. There is equal access to the anterior and posterior compartments.
  - The advantage of this position over the prone position becomes apparent when management of the airway is at issue. If prone positioning is a concern, such as in patients with a high body mass index or compromised lung volume, the case is probably best done in the lateral decubitus position.
  - One disadvantage of this position is that small patients, such as gymnasts with OCD lesions, are difficult to position lateral and still maintain full access to the arm.

![FIG 2 • Positioning. A. Left elbow draped in the supine cross-body position. An arthroscope is in the proximal anteromedial portal and a loose body is shown on the monitor. B. Left elbow draped in the supine suspended position. Sterile towels and elastic wrap are used to cover finger traps attached to the index and long fingers. C. Left elbow in the lateral decubitus position. D. Right elbow draped in the prone position. A roll of towels is placed between the upper arm and a shortened armboard aligned with the table. E. Right elbow draped over a shortened padded armboard.](image-url)
Whether the initial anterior portal should be medial or lateral is debatable but usually determined by surgeon preference and patient diagnosis. Good arguments may be made for either approach.\textsuperscript{1,9,13}

The second anterior portal may then be created with either outside-in or inside-out methods. We prefer to make the medial portal first and then create the lateral portal with an outside-in method.

**Instruments**

A standard 4.0-mm, 30-degree offset arthroscope may be used for virtually all elbow arthroscopic procedures. On rare occasion, both a 4.0-mm, 70-degree offset arthroscope and a 2.7-mm arthroscope may be helpful. Because it is often necessary to maintain the tip of the arthroscope just a few millimeters through the capsule, an arthroscope sheath without side flow ports is preferred and minimizes fluid extravasation into soft tissues.

Essential instruments include an 18-gauge spinal needle, a hemostat, a Wissinger rod, switching rods, and both standard and small mechanical shavers (FIG 3A,B).

Specialized instruments have recently become available from several sources and include a series of curved and straight arthroscopic retractors, curettes, and osteotomes. Hand biters, designed to resect the anterior capsule more safely, are very useful during contracture release surgery (FIG 3C).

**Prone position**

Many surgeons, because of the stability and access provided, prefer the prone position. However, careful attention to positioning is essential to avoiding complications (FIG 2D).

The airway must be secure and the face should be well padded.

Chest rolls are used to lift the chest and abdomen from the table, decreasing the airway pressure required for ventilation.

The knees are padded and the feet are elevated.

The nonoperative arm is placed on a well-padded arm board, with attention to the ulnar nerve, and the operative arm is allowed to hang over a shortened, padded armboard positioned along the side of the table (FIG 2E).

Pulses in all four extremities are confirmed.

After draping, a small roll of towels is placed beneath the upper arm to align the humerus in the coronal plane of the body and to allow the elbow to flex to 90 degrees.

**Approach**

The first arthroscopic portal is anterior except when the entire procedure is accomplished through posterior portals. Occult conditions may exist in the anterior compartment, and a complete diagnostic assessment of the joint requires anterior portals.
Chapter 18  ELBOW ARTHROSCOPY: THE BASICS

LIMB PREPARATION

- Setup and portal positions are shown in the supine cross-body position.
- After the administration of general anesthesia, the operative-arm shoulder is relocated to extend just over the edge of the surgical table, affording access to the whole extremity and limiting the reach required for the surgeon.
  - Both the shoulder and the entire arm are prepared and draped and a sterile tourniquet is applied as proximally as possible.
- After limb exsanguination, the tourniquet is elevated and an elastic compression wrap is applied tightly to the forearm, extending from distal to proximal and ending just distal to the radial head.
  - The elastic wrap will limit fluid extravasation into the subcutaneous tissues and the muscle compartments of the forearm and potentially decrease the risk of compartment syndrome.
- Landmarks about the elbow and the proposed arthroscopic portal sites are marked.
- Before portal placement, the joint is distended with saline using an 18-gauge spinal needle passed through the posterolateral “soft spot” (TECH FIG 1).
  - The “soft spot” is located at the center of the triangle formed by the olecranon prominence, the lateral epicondyle prominence, and the lateral margin of the radial head.
- Connector tubing attached to a 60-mL syringe allows an assistant to maintain joint distention during the creation of the initial portal without obstructing the surgeon’s access.

Order of Portal Placement

- Anterior or posterior
  - Neurovascular risk is the most important factor to be considered when determining the order of portal placement.
  - Soft tissue swelling and loss of the capacity to distend the joint would be expected after the creation of the posterior portals and would place both the median and radial nerves closer to the path of the anterior portals.
  - Most surgeons choose to begin the arthroscopy with the anterior portals.

ANTEROMEDIAL PORTALS

- There are three commonly described anteromedial portals: standard, mid, and proximal (TECH FIG 2A).
- The nerve at greatest risk for injury is the medial antebrachial cutaneous nerve. This risk diminishes when the depth of the portal incision avoids cutting the subcutaneous tissues.6
- Dissection to the flexor fascia with a blunt-tipped hemostat allows mobilization of the cutaneous nerves away from the portal for additional protection.
  - Up to six branches are described crossing the medial elbow, and on average at least one branch is within 1 mm (range 0 to 5 mm) of the portal (TECH FIG 2B).
  - Both the median nerve and the brachial artery are at risk during medial portal placement.
- Continuing the hemostat dissection to the medial joint capsule (TECH FIG 2C), introducing the arthroscope sheath with a blunt trocar, and finally penetrating the capsule with a sharp trocar will allow safe medial capsule penetration and avoid extracapsular arthroscopic placement.
- Some authors argue that sharp trocars have no role in elbow arthroscopy; however, blunt trocars are more inclined to penetrate the capsule laterally or, even less desirably, to remain extracapsular. Modifying a sharp trocar by blunting the tip provides a safe and effective compromise.

Medial or lateral

- The order is usually determined by surgeon preference and the nature of the conditions requiring treatment.
- The sheath-to-nerve distance for the mid-anteromedial portal averages 23 mm,5 that for the distal anterolateral portal averages 3 mm,5 and that for the proximal anterolateral portal averages 14.2 mm.5
- Because the nerve-to-sheath distance is greater for the anteromedial portals than for the anterolateral portals, it has been argued that the initial approach to the joint is safer when medial.
- Once the medial portal is established, the lateral portal can be made with an outside-in technique and an 18-gauge spinal needle11,12 or with an inside-out technique and a Wissinger rod.5
- Both methods are relatively safe techniques, but the outside-in method affords greater control of the angle into the joint and potentially greater access to the anterior humerus.
Standard Anteromedial Portal
- Andrews and Carson\(^2\) described the standard anteromedial portal as located 2 cm anterior and 2 cm distal to the prominence of the medial epicondyly. They reported that the median nerve-to-sheath distance was 6 mm.
  - The path of the portal penetrates the common flexor origin, as well as the flexor carpi radialis and the pronator muscles.
  - In some patients, the portal also penetrates the medial border of the brachialis muscle.
- Lynch et al\(^6\) showed that with joint distention and 90-degree elbow flexion, this portal averaged 14 mm from the median nerve. However, Stothers et al\(^1,12\) showed that the median nerve-to-sheath distance averaged only 7 mm (range 5 to 13 mm) and that the brachial artery-to-sheath distance was just 15 mm (range 8 to 20 mm).
- The standard anteromedial portal may be created with either medial (outside-in) or lateral (inside-out) methods. Some authors suggest that it is more safely created using the latter method with a rod exchange technique.
- Although this portal offers excellent visualization of the anterolateral contents of the elbow joint, it is now most commonly recommended as an accessory portal for capsular retractors.

Proximal Anteromedial Portal
- The proximal anteromedial portal, popularized by Poehling et al\(^1,10\) is described as 2 cm proximal to the prominence of the medial epicondyly and just anterior to the medial intermuscular septum.
  - Others have subsequently described this portal as up to 2 cm anterior to the septum.\(^9\)
  - The locations of both the septum and the ulnar nerve must be established before portal placement and the path of the portal must remain anterior to the septum.
  - Arthroscope sheath contact with the anterior humerus is advised to further protect the median nerve.\(^10\)
- In this location, at 90 degrees of flexion and with joint distention, the portal averages 12.4 mm (range 7 to 20 mm) from the median nerve, 18 mm from the brachial artery, 12 mm (range 7 to 18 mm) from the ulnar nerve, and 2.3 mm (0 to 9 mm) from the medial anterolateral cutaneous nerves.
- This portal also provides visual access to the lateral elbow joint structures, but viewing the superior capsular structures, the lateral capitellum, and the radiocapitellar joint space is limited compared to the standard anteromedial portal.\(^1,12\)

Mid-Anteromedial Portal
- A modification of the proximal anteromedial portal was described by Lindenfeld\(^5\) as located 1 cm proximal and 1 cm anterior to the prominence to the medial epicondyle.
  - The portal is directed distally into the center of the joint to preserve the protection afforded by the proximal location and was shown to average 22 mm from the median nerve.

ANTEROLATERAL PORTALS
- While at less risk for injury than the medial anterolateral cutaneous nerve, the anterior branch of the posterior antebibial nerve crosses the lateral elbow and may be injured during portal placement. Limiting the depth of the skin incision and using the arthroscope to cast a silhouette of the nerve may provide reasonable protection.
  - There are three anterolateral portal locations: distal, mid, and proximal (TECH FIG 3).

Distal Anterolateral Portal
- Andrews and Carson\(^2\) were first to describe an anterolateral portal and recommended placement 3 cm distal and
1 cm anterior to the prominence of the lateral epicondyle. Their work documented that the radial nerve averaged 7 mm from the arthroscope sheath when the elbow was flexed 90 degrees.

- Others have reported that the nerve-to-sheath distance was less, averaging only 3 to 4.9 mm,5,11,12 and that in extension this distance was just 1.4 mm.
- Field et al3 showed that Andrew and Carson’s recommendation located the portal near or directly over the radial head in all specimens studied, and that for smaller patients these measurements would potentially place the portal distal to the radial head.
- To lessen the risk of radial nerve injury, landmarks, rather than measurements, are used to determine that the portal is proximal to the radial head.3
- Because of safety concerns, this portal is much less commonly used than the more proximal portals and is typically reserved for a blunt retractor.
- An outside-in method is effective and probably safest.
  - With the elbow at 90 degrees, the forearm in slight pronation, and the joint maximally distended, an 18-gauge spinal needle is placed just anterior to the radial head and directed proximally toward the center of the radiocapitellar joint (TECH FIG 4).
  - A hemostat is then used to dissect through the capsule and a blunt-tipped retractor is introduced to mobilize the anterior capsule.
  - The arthroscope and working instruments are placed in more proximal portals.
  - Superficially, the anterior branch of the posterior antebrachial cutaneous nerve was shown to lie on average 7.6 mm (range 0 to 20 mm) from the portal entry and was in contact with the sheath in 43% of elbows studied.11

Mid-Anterolateral Portal

- The mid-anterolateral portal is safer and used more commonly than the distal anterolateral portal.

Field et al3 compared distal, mid, and proximal anterolateral portals and found that the more proximal portals were statistically farther from the sheath than the distal portal. They described the location of the mid-anterolateral portal as 1 cm anterior to the prominence of the lateral epicondyle and just proximal to the anterior margin of the radiocapitellar joint space.

- At 90 degrees of flexion, the radial nerve-to-sheath distance was reported to average 9.8 mm without joint distention and 10.9 mm with distention. This was more than twice the distance reported for the distal portal.
- Both inside-out and outside-in methods are effective and safe means to establish this portal. This portal is most useful for visualization of the medial elbow and débridement of the anterior radiocapitellar joint surfaces.

Proximal Anterolateral Portal

- Stothers et al11,12 described the location of the proximal anterolateral portal as 1 to 2 cm proximal to the prominence of the lateral epicondyle, with the path of the portal along the surface of the anterior humerus. The sheath is directed toward the center of the elbow joint, penetrating the brachioradialis, brachialis, and extensor carpi radialis muscles before passing through the joint capsule.

- Several studies have shown that the radial nerve-sheath distance averaged 9.9 to 14.2 mm in the 90-degree-flexed and distended elbow.3,11 This represents a statistically significant increase in the distance from the nerve from the sheath compared to either the mid or the distal portal.
- The anterior branch of the posterior antebrachial cutaneous nerve averaged 6.1 mm from the portal, with the trocar in contact with the nerve 29% of the time.11
- The proximal anterolateral portal may be made before or after the anteromedial portal, and an outside-in method is most commonly recommended.
- Although the view of the anteromedial structures was similar for all three anterolateral portals, the proximal anterolateral portal was consistently described as providing a more extensive evaluation of the joint, particularly when viewing the radiocapitellar joint.11,12,14
POSTERIOR PORTALS

- Compared with the anterior portals, all posterior portals are relatively safe\(^1\) (TECH FIG 5).
- Laterally, the posterior antebibrachial cutaneous nerve is at risk, and there are anecdotal reports of injury to the radial nerve branch to the anconal muscle.
- The ulnar nerve is the closest major nerve to any posterior portal and has been described as no closer than 15 to 25 mm from the posterior central portal.\(^1\)
  - This nerve is typically at risk only during posteromedial capsule resection for joint contracture release; however, even with safely performed perineural capsulectomy, recovery of flexion for patients with less than 110 degrees of preoperative elbow flexion still exposes the ulnar nerve to traction injury.
  - In this setting, nerve transposition is advised.
- The posterior portals may be established with the elbow between 45 and 90 degrees of flexion.\(^1,1\)
  - Less flexion is recommended and is thought to decrease the tension in the posterior tissues, expand the olecranon fossa, and provide greater access to the medial and lateral recesses.

Posterior Central Portal

- The posterior central portal, also called the straight posterior portal, has been described by many authors and is usually located 2 to 4 cm proximal to the olecranon prominence and halfway between the medial and lateral condyles.
- This is commonly the initial posterior portal and provides good visualization of the olecranon fossa, the olecranon tip, the posterior trochlea, and the medial recess. The lateral recess, the central trochlea, and the radiocapitellar joint are less well seen.
- Although the ulnar nerve-to-sheath distance is consistently described as 15 mm or more,\(^1\) the nerve should always be palpated and outlined before portal placement.
- Sharp dissection and sharp trocars are often discouraged when establishing anterior portals; however, a no. 11 blade may be used safely to create the posterior central portal and probably limits triceps tendon trauma.
- An 18-gauge needle is first used to confirm the location of the fossa, and the blade is then directed toward the center of the fossa and in line with the tendon fibers.
- For patients with arthrofibrosis, the portal may be more easily created with a sharp trocar.

Posterolateral Portal

- Andrews and Carson\(^2\) described the posterolateral portal as 3 cm proximal to the olecranon and through the lateral border of the triceps tendon.
- More distally, accessory portals may be safely placed anywhere between the proximal posterolateral portal and the soft spot.\(^1,1\) The location of the portal is determined by the intended purpose.
  - For procedures performed in the posteromedial region of the elbow, a more proximal portal will provide greater access and visualization.
  - In contrast, a more distal portal will facilitate procedures confined to the posterolateral recess.
- An 18-gauge needle is used to confirm proper access to the olecranon fossa and the lateral gutter.
- The scope is established in the olecranon fossa while remaining directly on the lateral column of the humerus to avoid capture of the posterior fat pad.
- When properly placed, this portal provides a clear view of the olecranon fossa, the olecranon tip, the posterior and central trochlea, the medial recess, the lateral recess, and the posterior radiocapitellar joint.

Direct Posterolateral Portal

- The direct posterolateral portal is typically the site used for joint inflation before anterior portal placement. The location is defined as the center of a triangle formed by the prominence of the lateral epicondyle, the prominence of the olecranon, and the radial head (see Tech Fig 1).
- Also known as the mid-lateral portal, the dorsal lateral portal, and more commonly the “soft spot” portal, this portal penetrates the anconal muscle and consistently provides the best view of the radiocapitellar joint.
**Lateral Radiocapitellar Portal**

- O’Driscoll and Morrey described the standard mid-lateral portal, also called the lateral radiocapitellar portal, and noted that this portal is difficult to create because of limited space.
- This portal is best used when a very small mechanical shaver blade may be employed in the management of OCD capitellum lesions and radiocapitellar chondral injury.
- An 18-gauge needle is used to determine appropriate portal location (TECH FIG 6).

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Preparation</th>
<th>All bony landmarks and portal sites are outlined before starting.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depth of all skin incisions is limited.</td>
</tr>
<tr>
<td></td>
<td>The elbow joint is maximally distended with fluid before creating the anterior portals.</td>
</tr>
<tr>
<td></td>
<td>The elbow is maintained at 90 degrees during anterior portal placement and capsular resection.</td>
</tr>
<tr>
<td></td>
<td>More proximal portal sites should be used for the anterior portals.</td>
</tr>
<tr>
<td></td>
<td>The location of the medial intermuscular septum must be confirmed, and the surgeon must remain anterior to it while creating the proximal anteromedial portal.</td>
</tr>
<tr>
<td></td>
<td>Retractors are used for visualization and protection during synovectomy and capsulectomy.</td>
</tr>
<tr>
<td></td>
<td>Suction is avoided during mechanical resection of the capsule.</td>
</tr>
<tr>
<td></td>
<td>Ulnar nerve subluxation may reposition the nerve directly beneath the proximal medial portal.</td>
</tr>
<tr>
<td></td>
<td>Postoperative vascular compromise from either direct vascular injury or compartment syndrome is difficult to assess after regional anesthesia.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- Wounds are routinely closed with simple sutures.
- Synovial–subcutaneous and synovial–cutaneous fistulas have been described and most commonly occur in the posterolateral portals along the lateral margin of the triceps tendon.4
  - Deep absorbable sutures placed in the fascia of the lateral triceps along with locking mattress sutures in the skin will minimize the risk for this complication.
  - Unless contraindicated by the procedure performed, the elbow is splinted near full extension to minimize swelling.
  - The arm is elevated overnight and the splint is removed the following day.
  - Passive and active range-of-motion exercises are started as soon as the procedure performed will allow.
  - For patients undergoing contracture release surgery, an axillary regional block is performed early the next day.
  - The elbow is gently taken through a full arc of motion and then placed into continuous passive motion.
  - Based on the extent of the release, the amount of swelling, and the level of pain, the patient is hospitalized for 1 to 3 days.
  - Postoperative static progressive range-of-motion braces and physical therapy are also used to recover motion.

**COMPLICATIONS**

- The incidence of neurologic complications after elbow arthroscopy has been reported to be 0% to 14%.4
  - Transient as well as incomplete and complete permanent nerve palsies, including iatrogenic nerve resection injuries, have also been described for the radial, ulnar, and median nerves.
  - Kelly et al retrospectively reviewed 473 consecutive arthroscopy procedures and found an overall complication rate of 7%.
  - Transient neuropraxia was the most common immediate minor complication and included radial nerve, ulnar nerve, posterior interosseous nerve, anterior interosseous nerve, and medial antebrachial cutaneous nerve palsies.
Risk factors include autoimmune disorder, contracture, capsulectomy, and possibly prolonged tourniquet time.

Prolonged clear or serous drainage from anterolateral and mid-lateral portal sites was the most common minor complication and was reported to occur in 5% of patients.

Deep infection occurred in 0.8% of patients; all the cases occurred in patients who had received intra-articular corticosteroids at the end of the procedure.

Mild postsurgical contracture occurred in 1.6% of patients.¹⁴

REFERENCES

DEFINITION
■ Osteochondritis dissecans (OCD) is a progressive form of osteochondrosis involving focal injury to the subchondral bone or its blood supply. It may occur in many different areas of the adolescent skeleton.
■ The knee is the most common location for OCD, but it may occur in several locations of the elbow, including the radial head, the trochlea, and the capitellum (the most common location within the elbow).
■ The injury to the subchondral bone results in loss of structural support for the overlying articular cartilage. As a result, degeneration and fragmentation of the articular cartilage and underlying bone occur, often with the formation of loose bodies.
■ The histopathology of the subchondral bone in OCD is consistent with osteonecrosis.
■ Articular cartilage injury may also occur anywhere in the elbow, especially after trauma. More common locations of nonarthritic chondral injury include the radial head and capitellum.

ANATOMY
Bony Anatomy
■ The bony anatomy of the elbow allows for two complex motions: flexion–extension and pronation–supination.
■ The ulnohumeral articulation of the elbow is almost a true hinge joint with its constant axis of rotation through the lateral epicondyle and just anterior and inferior to the medial epicondyle. This well-fitted hinge joint allows for little excessive motion or toggle.
■ The radius articulates with the proximal ulna and rounded capitellum of the distal humerus. The radiocapitellar joint and the proximal radioulnar joint allow for pronation–supination (FIG 1A). The ulnohumeral joint allows for flexion–extension of the elbow.
■ The ulnohumeral joint has 11 to 16 degrees of valgus. This results in increased compressive force in the lateral elbow (radiocapitellar joint) with axial loading.

Ligamentous Anatomy
■ The ligaments of the elbow are divided into the radial and ulnar collateral ligament complexes.
■ The lateral or radial collateral ligamentous complex provides varus stability. These ligaments are rarely stressed in the athlete.
■ The ulnar or medial collateral ligament complex consists of three ligaments: the anterior oblique, the posterior oblique, and the transverse.
■ The ulnar collateral ligament complex, particularly the anterior oblique ligament, resists valgus force, such as occurs with throwing, whereas the radiocapitellar joint is a secondary restraint to valgus force (FIG 1B).

Intraosseous Vascular Anatomy
■ There are two nutrient vessels in the lateral condyle of the developing elbow.
■ Each vessel extends into the lateral aspect of the trochlea, with one entering proximal to the articular cartilage and the other entering posterolaterally at the origin of the capsule.
■ Although these two vessels communicate with each other, they do not do so with the metaphyseal vasculature. The rapidly expanding capitellar epiphysis in the developing elbow thus receives its blood supply from one or two isolated trans-chondroepiphysyeal vessels that enter the epiphysis posteriorly.

FIG 1 • A. Cross-section of the elbow showing the round, convex capitellum and the matching concave radial head. B. Anatomy of the medial elbow ligamentous complex. The ulnar collateral ligament complex comprises three ligaments: the anterior oblique, posterior oblique, and transverse ligaments.
These vessels function as end-arteries passing through the cartilaginous epiphysis to the capitellum.

Metaphyseal vascular anastomoses do not make significant contributions to the capitellum until approximately 19 years of age, placing this region at risk for vascular injury.

PATHOGENESIS

The cause of OCD is unclear and controversial.

OCD typically affects the dominant extremity of adolescents and young adults, with onset of symptoms between 11 to 16 years of age.

Most cases are seen in high-level athletes who experience repetitive valgus stress and lateral compression across the elbow (eg, overhead throwing athletes, gymnasts, weightlifters).

The lesion usually affects only a portion of the capitellum.

Genetic factors, trauma, and ischemia have been proposed as causes.

Most authors believe that the primary mechanism of injury is repetitive microtrauma in a genetically predisposed individual’s developing elbow that results in vascular injury due to the tenuous blood supply.

The capitellum is softer than the radial head.

Repeated microtrauma, such as axial loading in the extended elbow or repeated throwing that produces valgus forces on the elbow, results in increased force in the radiocapitellar joint.

The repetitive microtrauma caused by these forces has been proposed to weaken the capitellar subchondral bone and result in fatigue fracture.

Should failure of bony repair occur, an avascular portion of bone may then undergo resorption with further weakening of the subchondral architecture. This is consistent with the characteristic rarefaction often seen at the periphery of the lesion.

The altered subchondral architecture can no longer support the overlying articular cartilage, rendering it vulnerable to shear stresses, which may lead to fragmentation.

The tenuous blood supply of the end-arterioles in the capitellum may become injured with the repetitive microtrauma, resulting in OCD.

Although a genetic predisposition to OCD has been proposed in the literature, convincing scientific evidence of OCD as a heritable condition does not currently exist. Some individuals are more susceptible than others, and this may be genetically based.

NATURAL HISTORY

The natural history of capitellar OCD is unpredictable. No reliable criteria exist for predicting which lesions will collapse with subsequent joint incongruity and which will go on to heal without further sequelae.

If healing is going to take place, it usually occurs by the time of physeal closure.

If healing is not going to take place, repetitive microtrauma and shear stresses to the articular surface of a lesion that has lost its subchondral support may result in further subchondral collapse and deformation with joint incongruity as well as articular cartilage injury, fragmentation, and loose body formation.

In advanced cases, degenerative changes accompanied by a decreased range of motion are likely to develop.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The classic patient with OCD is an adolescent athlete who experiences repetitive valgus stress and lateral compression across the elbow (eg, overhead throwing athletes, gymnasts, weightlifters).
  - The patient usually complains of the insidious onset of poorly localized, progressive lateral elbow pain in the dominant arm.
  - He or she may also note a flexion contracture.
  - The throwing athlete may note a reduction in throwing distance or velocity or both.
  - Prodromal pain is not always present.
  - Typically, pain is exacerbated with activity and relieved by rest.
  - In advanced cases in which a fragment has become unstable or loose body formation has occurred, mechanical symptoms of elbow locking, clicking, or catching may be present.

Physical examination methods

- On examination, there may be tenderness to palpation and crepitus over the radiocapitellar joint.

- Effusion indicates intra-articular irritation and may be consistent with a loose or unstable OCD lesion or loose body.

- Swelling, palpated in the posterolateral gutter (soft spot), may be appreciated.

- Crepitus may be present on range-of-motion testing.

- Loss of 10 to 20 degrees of extension is common and mild loss of flexion and forearm rotation may also be seen. Loss of pronation is less common.

- Provocative testing includes the “active radiocapitellar compression test,” which consists of forearm pronation and supination with the elbow in full extension in an attempt to reproduce symptoms.

- The examiner should rule out radiocapitellar overload as the result of ulnar collateral ligament insufficiency using the milking maneuver, modified milking maneuver, valgus stress test, or moving valgus stress test.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Diagnostic evaluation of the elbow for OCD begins with plain radiographs—an anteroposterior (AP) view, lateral view, oblique views, and a 45-degree flexion AP, which is particularly good at revealing the lesion.

- Radiographs typically show the classic radiolucency (FIG 2A) or rarefaction of the capitellum (FIG 2B) in addition to irregularity or flattening of the articular surface.

- The lesion frequently appears as a focal rim of sclerotic bone surrounding a radiolucent crater with rarefaction located in the anterolateral aspect of the capitellum.

- Radiographs, however, may not reveal the osteochondral lesions in the earlier stages. They are not of much benefit for truly chondral lesions.

- In advanced cases, articular surface collapse, loose bodies, subchondral cysts, radial head enlargement, and osteophyte formation may be seen.

- Further diagnostic imaging of OCD lesions primarily consists of magnetic resonance imaging (MRI), although ultrasonography and bone scintigraphy have been used.

- MRI is especially valuable in assessing the integrity of the articular cartilage overlying the OCD lesion as well as in
diagnosing OCD in its early stages and identifying loose bodies (FIG 2C).

Controversy exists over the utility of contrast-enhanced MR arthrography. This technique, however, can potentially provide additional information regarding the status of the articular cartilage and identification of loose bodies.

Bone scintigraphy is very sensitive for identifying osteoblastic activity or increased vascularity at the site of an OCD lesion. However, it is nonspecific and has limited usefulness in diagnosis.

Computed tomography can help define bony anatomy and identify loose bodies.

Ultrasonography can also help in the assessment of capitellar lesions, including early stages, but ultrasound is technician dependent.

DIFFERENTIAL DIAGNOSIS

- Panner disease
- Infection
- Lateral epicondylitis
- Lateral epicondylar apophysitis
- Radial head osteochondritis dissecans
- Radial head or neck injury
- Radiocapitellar overload and chondromalacia due to ulnar collateral ligament injury
- Posterolateral rotatory instability

NONOPERATIVE MANAGEMENT

- The choice of conservative or surgical management depends on the patient’s age, symptoms, size of the lesion, and stage of the lesion, specifically the integrity of the cartilage surface.
- The goal of treatment for OCD of the elbow is to prevent the progression of the disorder, detachment of the osteochondral lesion, and degenerative changes of the articular cartilage.
- Small, nondisplaced lesions with intact overlying articular cartilage in younger (skeletally immature) athletes are best managed conservatively with relative rest and activity modification, ice, and nonsteroidal anti-inflammatory drugs, particularly if the bone scan shows increased bony activity.
- Activity modification consists of avoiding throwing activities and weight bearing on the involved arm.
- Short-term immobilization (less than 2 to 3 weeks, depending on symptoms) may be considered.
- Serial radiographs, at 10- to 12-week intervals, are obtained to monitor healing.
- Activity modification is continued until the radiographic appearance of revascularization and healing.
- Radiographic findings of OCD may persist for several years. As a result, after conservative management, the most important issue in terms of an athlete’s ability to return to sports is symptom resolution.
- Most patients can return to full activity after 6 months.

SURGICAL MANAGEMENT

- The indications for surgical treatment include persistent symptoms despite conservative management, symptomatic loose bodies, articular cartilage fracture, displacement of the osteochondral lesion, and cold bone scan.
- The surgeon must assess the size, stability, and viability of the fragment and decide whether to remove the fragment or attempt to surgically reattach it.
- Most fragments cannot be reattached and therefore are excised, followed by local débridement.
- Arthroscopic abrasion chondroplasty or subchondral drilling may be performed to encourage healing.
- Although symptoms usually improve, about half of all patients will continue to have chronic pain or limited range of motion.
- In general, many athletes cannot return to their prior levels of competition.
- Surgical indications for operative management of stable lesions with intact articular cartilage include radiographic evidence of lesion progression and failure of symptom resolution despite a 6-month trial of a conservative, nonoperative regimen.
Arthroscopic examination, débridement as needed, and drilling or microfracture of the OCD lesion (with or without in situ pinning) are usually the surgical treatments of choice.

Unstable lesions, characterized by overlying articular cartilage injury and instability as well as collapse or disruption of the subchondral bone architecture, and those with loose bodies are usually managed surgically.

These lesions are frequently flap lesions. They characteristically present with more advanced radiographic changes (including a well-demarcated fragment surrounded by a sclerotic margin).

There is controversy as to whether simple fragment excision or reduction (open or arthroscopic) and internal fixation is the preferred treatment. Many authors advocate excision of displaced fragments, often augmented by drilling or microfracture.

Critical considerations in operative planning include the size and integrity (viability) of the fragment, the subchondral architecture on the fragment and the opposing bony bed, the potential for anatomic restoration of the articular surface, and the method of fixation if attempted.

Internal fixation of the fragment may be performed using metallic screws, bioabsorbable screws or pins, Kirschner wire, bone pegs, and dynamic staple fixation.

There have been a few reports of osteoarticular autograft or allograft plugs in the treatment of more advanced lesions, but experience with this method is limited. The current recommendations are for lesions that involve the lateral column.

Preoperative Planning

Before surgery, an MRI, preferably with contrast, can be used to assess the integrity of the articular cartilage to help determine whether débridement, loose body removal, and drilling may be needed or more advanced techniques, such as reduction and internal fixation or osteochondral transfer, may be needed.

The MRI of the joint is also inspected for loose bodies—their number and location (anterior vs. posterior elbow) (see Fig 2C).

FIG 3 • A. Lateral positioning for elbow arthroscopy, including tourniquet placement. B. Setup in the operating room for the lateral position. C. Prone position of the patient. This is the preferred position, particularly due to the ease of posterior elbow access. The setup of the room is the same and the relative position of the elbow for the surgeon is similar between the prone and lateral positions. D. Supine position of the patient. Some surgeons prefer this position because it is easier to convert to open surgery and easier anesthesia management; however, posterior arthroscopic access is more difficult in this position.
All imaging studies are reviewed.
Examination under anesthesia is performed to assess range of motion and ligamentous stability, particularly valgus laxity, as injury to the ulnar collateral ligament in the athlete may increase the load on the radiocapitellar joint.

**Positioning**
- Elbow arthroscopy can be performed in the supine, lateral, or prone position (FIG 3).
- Prone positioning is preferred because it allows easy access to the elbow, reduces the risk of sterility breaks if the arm needs to be in a finger-trap device, as needed for supine elbow arthroscopy, and arthroscopy.
- The patient is positioned on chest rolls and padding under the knees and feet and ankles.
- The arm is placed on an arm holder.

- A sterile tourniquet is placed after the arm is prepared and draped.

**Approach**
- All cases are approached in the same manner initially.
  - Diagnostic arthroscopy of the elbow is carried out, using a proximal anteromedial portal, a proximal anterolateral portal, and two posterior portals. This allows for assessment of the entire joint to ensure that loose bodies are not missed.
  - The capitellum may be seen from the proximal anteromedial portal (FIG 4A) while the elbow is taken through a full range of motion.
  - A direct lateral portal (sometimes called the soft spot portal) is then used to allow direct access to the radiocapitellar joint and is needed to confirm the extent of the OCD or chondral lesion (FIG 4B).

**ARTHROSCOPIC DÉBRIDEMENT AND LOOSE BODY REMOVAL**
- Elbow arthroscopy is begun in the prone (my preference), lateral, or supine position, using the proximal medial portal to visualize the capitellum.
- Complete elbow examination is mandatory to look for loose bodies:
  - Proximal anteromedial portal
  - Proximal anterolateral portal
  - Posterior central portal
  - Postrolateral portal
  - Direct lateral portal
- Loose bodies tend to hide:
  - In the proximal radioulnar joint anteriorly or the gutters
  - In the olecranon fossa or gutters posteriorly, particularly the lateral gutter
- When looking at the capitellum from the proximal anteromedial portal, instrumentation (shavers, burrs, graspers, and curettes) may be accomplished using the proximal anterolateral portal.
  - Flexion and extension of the elbow allow for enhanced visualization of the capitellum.
- Loose bodies and chondral fragments may be removed via the anterior portals (TECH FIG 1A,B).
- Then the arthroscope is brought in from the posterior portals to look for loose bodies.
The direct lateral (“soft spot”) portal is used for complete evaluation of the capitellum.

This portal is mandatory to fully evaluate the extent of the lesion and to allow for adequate débridement of loose cartilage.

Often loose bodies will be found using this portal. Débridement is performed using shavers, curettes, graspers, and rongeurs to remove loose bodies and any loose, scaly, or fragmented cartilage (TECH FIG 1C).

The direct lateral (“soft spot”) portal is used for complete evaluation of the capitellum.

This portal is mandatory to fully evaluate the extent of the lesion and to allow for adequate débridement of loose cartilage and may allow for a good direction for microfracturing the bed.

Abrasión is carried out from either anterolateral or direct lateral portals to the complete lesion. This may be done with a shaver on high speed or burr.

For chondral lesions, abrasión arthroplasty involves removal of the zone of calcified cartilage, then use of a burr to lightly remove only a partial thickness of the subchondral bone to expose subchondral arterioles to bring blood into the lesion. The key is not to go too deep into the cancellous bone.

For OCD with a cartilage cap that is not intact, abrasion is done lightly to remove only a little bone to allow bleeding into the bony bed.

Microfracture or drilling can also be used to bring blood into the defect when the OCD or chondral lesion results in an exposed bony bed, with the theoretical benefit of microfracturing being that less bone is lost and there is no heat production, which may be seen with drilling.

The bone is pierced every 3 to 4 mm for a 4-mm depth with an awl for microfracture or 0.062 Kirschner wire for drilling (TECH FIG 2).

If the anterolateral or direct lateral portals do not allow for adequate directionality of the drilling or microfracture, an additional outside-in portal may be made based on the known anatomy and using a spinal needle.
**DRILLING FOR INTACT OCD LESIONS**

- When the OCD lesion has an intact overlying chondral surface, then drilling may enhance or stimulate a healing response of the lesion, although this is not frequently needed.
- The key is to try to prevent violation of the OCD cartilage cap, although some surgeons drill from outside-in trying to avoid injury to the articular cartilage and some drill from the joint, which will perforate the articular cartilage.
- Elbow arthroscopy is begun in the prone (my preference), lateral, or supine position, using the proximal medial portal to visualize the capitellum.
  - Complete elbow examination using all four standard portals and the additional direct lateral arthroscopic portals is mandatory to look for loose bodies.
- When looking at the capitellum from the proximal anteromedial portal, instrumentation (shavers, burrs, graspers, and curettes) may be done using the proximal anterolateral portal.
- Flexion and extension of the elbow allow for enhanced visualization of the capitellum.
- Next, the arthroscope is brought in from the posterior portals to look for loose bodies.
- The direct lateral (“soft spot”) portal is then used for complete evaluation of the capitellum.
- OCD lesions with intact articular cartilage, subchondral softening, fibrillated cartilage, or cartilage character change may be identified visually or palpably using a probe (TECH FIG 3) or alternatively using fluoroscopic imaging.
- Drilling through the cartilage and through the sclerotic subchondral bone is done in an effort to promote healing.
- Attempts are made to limit the number of perforations through the intact cartilage, but the subchondral plate should be penetrated multiple times.
- This may be accomplished by redirecting the drill in different directions from the same single (or a few) perforations through the articular cartilage.
- The lesion is pierced with an 0.062 Kirschner wire for drilling.
- If the anterolateral or direct lateral portals do not allow for adequate directionality of the drilling, an additional outside-in portal may be made based on the known anatomy and using a spinal needle.
DRILLING FOR INTACT OCD LESION: OUTSIDE-IN TECHNIQUE

- When the OCD lesion has an intact overlying chondral surface then drilling may enhance or stimulate a healing response of the lesion.
- The key is to try to prevent violation of the OCD cartilage cap, although some surgeons drill from outside in trying to avoid injury to the articular cartilage and some drill from the joint, which will perforate the articular cartilage.
- Elbow arthroscopy is begun in the prone (my preference), lateral, or supine position, using the proximal medial portal to visualize the capitellum.
  - Complete elbow examination using all four standard and the additional direct lateral arthroscopic portals is mandatory to look for loose bodies.
- When looking at the capitellum from the proximal anteromedial portal, instrumentation (shavers, burrs, graspers, and curettes) may be done using the proximal anterolateral portal.
  - Flexion and extension of the elbow allow for enhanced visualization of the capitellum.
- Next, the arthroscope is brought in from the posterior portals to look for loose bodies.
  - The direct lateral (“soft spot”) portal is then used for complete evaluation of the capitellum.
- OCD lesions with intact articular cartilage, subchondral softening, fibrillation of the cartilage, or cartilage character change may be identified visually or palpably (see Tech Fig 3) or alternatively using fluoroscopy.
- Fluoroscopy is then brought in to identify the lesion.
- Using an anterior cruciate ligament tibial guide or posterior cruciate ligament femoral guide can be useful to help aim the drill bit from outside the elbow toward the lesion.
- Depending on the location of the lesion, the drill is brought from proximal and slightly anterior to the lateral epicondyle or posteriorly on the distal humerus.
- A small incision is made at the proposed drilling entry site and blunt dissection is done to bone.
- The lesion is drilled with a 0.062 Kirschner wire for drilling while watching with fluoroscopy or arthroscopy to ensure the articular cartilage is not violated.
- Multiple passes with the Kirschner wire should be performed to enhance healing throughout the lesion.

INTERNAL FIXATION

- When the OCD fragment is partially detached or completely detached but not malformed and there is significant bone on the cartilage fragment, consideration for reattachment is recommended.
- The principle is to stimulate healing and to stabilize the fragment within the bony bed.
- Elbow arthroscopy is begun in the prone, lateral, or supine position, using the proximal medial portal to visualize the capitellum.
- If it is likely the patient will need internal fixation of a partially detached OCD fragment, and there is a possibility that an arthrotonomy is needed, I have found performing the surgery in the lateral position is a bit easier.
- Complete elbow examination using all four standard and the additional direct lateral arthroscopic portals is mandatory to look for loose bodies.
- When looking at the capitellum from the proximal anteromedial portal, instrumentation (shavers, burrs, graspers, and curettes) may be done using the proximal anterolateral portal.
  - Flexion and extension of the elbow allow for enhanced visualization of the capitellum.
- All underlying bone is débrided with an arthroscopic shaver or burr or manually with curettes or pituitary rongeurs.
- Next, the arthroscope is brought in from the posterior portals to look for loose bodies.
  - The direct lateral (“soft spot”) portal is used for complete evaluation of the capitellum.
  - This portal is mandatory to fully evaluate the extent of the lesion and to allow for adequate débridement and preparation of the bed.
- The osteochondral flap or undersurface of the fragment is elevated and the underlying sclerotic bone is curetted and débrided of fibrous tissue (TECH FIG 4A). Drilling of the base is also performed to stimulate healing.
- The abrasion and drilling are carried out from either anterolateral or direct lateral portals to the complete lesion. This may be done with a curette, a shaver on high speed, or a burr and a drill or Kirschner wire to gently débride the bed without removing much bone.
- The flap is then replaced within the bed.
- Retrograde pinning of the lesion with threaded or unthreaded wires can be performed with the wires exiting the lateral epicondyle for later removal (TECH FIG 4B,C).
  - The ends of the pins should be positioned below the articular surface so that the wires do not penetrate the joint space.
  - Bioabsorbable pins and bioabsorbable screws have been used as an alternative (TECH FIG 4D).
- Further, some surgeons will place metallic screws for fixation. These can either be headless variable-pitched screws that are buried beneath the articular surface, or regular-headed screws, which some prefer for better compression but must be removed.
- If the anterolateral or direct lateral portals do not allow for adequate directionality of the drilling or microfracture, an additional outside-in portal may be made based on the known anatomy and using a spinal needle.
- An arthrotomy may be necessary to perform the débride-ment or internal fixation.
When the OCD fragment is loose and it is not possible to fix the lesion back to the bony bed, and there is a large crater, particularly if it involves the lateral column, then consideration is given to inserting osteochondral auto-graft plugs into the defect to eliminate or reduce edge loading and loss of lateral support for the joint.

This is achieved by taking osteochondral plugs from the knee and implanting them into the capitellum.

Elbow arthroscopy is begun in the prone, lateral, or supine position, using the proximal medial portal to visualize the capitellum. Because insertion of the plugs often requires an arthrotomy and the grafts must come from the knee, the supine position is preferred.

Complete elbow examination using all four standard and the additional direct lateral arthroscopic portals is mandatory to look for loose bodies.

When looking at the capitellum from the proximal anteromedial portal, instrumentation (shavers, burrs, graspers, and curettes) may be done using the proximal anterolateral portal.

Flexion and extension of the elbow allow for enhanced visualization of the capitellum.

A posterior or posterolateral approach may be used.

The radiocapitellar joint is approached anteriorly by splitting the intermuscular plane between the extensor digitorum communis and the extensor carpi radialis longus and brevis, exposing the anterior capsule, which is then incised.

The posterior approach uses a posterior longitudinal skin incision with the elbow in full flexion. Then the anconeus and posterior capsule are divided, providing direct access to the OCD lesion.

The posterolateral Kocher approach uses the interval between the anconeus and extensor carpi ulnaris. The lateral collateral ligament complex is protected and preserved, allowing exposure of the posterior radiocapitellar joint.

A commercially available osteochondral graft harvesting system is used.

The size of the lesion is assessed to decide how many grafts and of which size are necessary, although usually less than 100% fill is achieved.

Recipient sockets are created in the lesion with the recipient graft harvesting tool.

Occasionally the sclerotic bed makes it difficult to use the recipient harvesting tool and a cannulated drill is needed to make the recipient bed.

Drilling is carried out at the base of the socket before inserting the graft to allow for marrow stimulation and enhance healing potential.

Osteochondral grafts about 10 mm long are then harvested arthroscopically or with mini-arthrotomy from the knee intercondylar notch or periphery of the non-weight-bearing portion of the lateral femoral condyle.

There are only a few case reports of this technique. Some use multiple 3.5-mm plugs and some use single larger osteochondral plugs.

The depth of the recipient socket is measured with a calibrated depth gauge or alignment stick.

The length of the osteochondral autograft plug is matched to the depth of the recipient socket.

The graft is seated flush with the surrounding intact cartilage.

Complete coverage of the lesion usually is not possible, though coverage of 80% to 90% of the lesion size should be achieved.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Nerve injury</th>
<th>The greatest risk of elbow arthroscopy, for osteochondritis dissecans or any other diagnosis, is nerve injury. Knowledge of elbow neuroanatomy, particularly as it relates to the arthroscopic portals, is of paramount importance. It is safest to use the proximal medial portal and the proximal lateral portals anteriorly. Distending the joint, using the outside-in technique, and using blunt instruments after skin incision only all help to reduce iatrogenic nerve injury.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct lateral portal</td>
<td>Familiarity with the direct lateral portal is critical for the evaluation and treatment of chondral and osteochondral lesions of the capitellum. The posterior radial head and capitellum are best seen with this portal, and loose bodies from osteochondritis dissecans occasionally may only be seen from this portal. Full appreciation of the lesion cannot be made without the use of this portal.</td>
</tr>
<tr>
<td>Converting to an open procedure</td>
<td>Occasionally synovitis or lack of working space makes visualization of the lesion difficult. Further, fixation of the lesion may be difficult arthroscopically. If visualization or fixation is difficult arthroscopically, there should be a low threshold to converting the procedure to open. The threshold of conversion to open should be based on experience and comfort with arthroscopy.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- After elbow arthroscopy for débridement or loose body removal:
  - Early range-of-motion exercises are encouraged to prevent loss of elbow motion. Other early goals include reducing swelling, pain, and muscular atrophy.
  - As motion becomes full and the soft tissues are healing with minimal swelling, rehabilitation concentrates on strengthening and endurance of the joint as well as normalization of arthrokinematics of the elbow. This usually begins after 2 weeks.
  - After 4 weeks, the athlete is prepared to return to functional activities with more strengthening, endurance, and flexibility. However, some believe that individuals with OCD lesions who have a defect should not return to sports activities because of the risk of arthritic change in the elbow.
  - After in situ drilling, return to sports is usually delayed until 3 to 6 months postoperatively, when there is good radiographic evidence of bony incorporation and healing.
  - After microfracture or internal fixation:
    - Range of motion is encouraged, but some clinicians put their patients in a range-of-motion brace positioned in varus to reduce stress over the radiocapitellar joint.
    - Some also consider adding the use of continuous passive motion to help in cartilage nourishment to encourage the microfracture clot or the healing surface of a fixed lesion to reduce adhesions. In these scenarios, strengthening is usually not initiated for at least 6 weeks.
    - Return to gymnastics or throwing sports is delayed until 6 months postoperatively.
  - Following the autograft transfer procedure:
    - The joint is immobilized until 2 weeks postoperatively, when the cast or splint is discontinued.
    - Beginning week 3, range-of-motion exercises are started.
    - Strengthening of the elbow and forearm is begun at 3 months postoperatively, and a throwing program is initiated at 6 months, with full return to participation at 10 to 12 months postoperatively.

OUTCOMES

- Reports in the literature on follow-up of the conservative and surgical management of OCD are difficult to compare and interpret because there is a lack of a universally accepted classification system, the numbers of patients in most series is limited, and there are disparities in age at presentation, symptoms, lesion size, location, stability, and viability. Further, there are differences in the method of diagnostic imaging used, surgical technique, and length of follow-up.
  - A consensus exists in the literature on the need to limit continual high-stress loading of the radiocapitellar joint in patients treated (even successfully) with OCD to prevent the deterioration of the frequently obtained short-term favorable results. As a result, most pitchers are counseled to move to other positions and gymnasts are advised of the difficulty in returning to continued high-level competitive gymnastics.
  - Conservative treatment of OCD does not provide uniformly successful results.
  - Takahara et al6,7 presented the results of nonoperative management of early OCD lesions with an average follow-up of 5.2 years and reported that more than half of these patients had pain with activities, and fewer than half of the lesions showed radiographic improvement.
  - Surgery also does not result in uniformly good outcomes.
  - In one of the longest follow-up studies available in the elbow OCD literature, Bauer et al1 presented the results of 31 patients (23 of whom were treated surgically with lesion or loose body excision) with capitellar OCD followed for an average of 23 years. At follow-up, the most common complaints were decreased range of motion (average 9 degrees of flexion loss, 2 degrees of extension loss, and 6 degrees of pronation–supination loss) and pain with activity. Radiographic evidence of degenerative changes involving the elbow joint was present in 61% and radiolunate enlargement in 58%.
  - McManama et al4 presented data on 14 adolescents with radiocapitellar OCD lesions treated with excision via a lateral arthrotomy with average follow-up of 2 years. Lesions were not sized, but 93% had good or excellent results.
  - Jackson et al13 reported on the roughly 3-year follow-up of OCD lesions in 10 female gymnasts treated primarily with curettage of loose cartilage, drilling, and loose body excision. All of the patients reported symptomatic relief, but only one patient returned to competition, and she did so with discomfort. Average loss of extension at follow-up in this series was 9 degrees, which is consistent with other reports.
  - Ruch et al2 presented the follow-up at an average of 3.2 years after arthroscopic débridement alone for management of elbow
OCD in 12 adolescents. The average flexion contracture improved 13 degrees (23 degrees preoperatively to 10 degrees postoperatively). All patients had capitellar remodeling on follow-up radiographs, and approximately 42% had associated radial head enlargement. Ninety-two percent of the patients in this series were highly satisfied, with minimal symptoms. Of note, five patients (42%) had a triangular lateral capsular avulsion fragment (seen radiographically but not at arthroscopy), which had a statistically significant association with a worse subjective outcome.

Baumgarten et al\(^2\) presented an average 4-year follow-up (range 24 to 75 months) on 17 elbows with OCD treated in 16 patients. Their results showed that the average flexion contracture improved 14 degrees, approximately 24% had pain, seven of nine (78%) throwers and four of five (80%) gymnasts were able to return to sport, and no patient had demonstrable degenerative joint disease.

**COMPLICATIONS**

- The complications seen with OCD treated surgically or not include flexion contracture, elbow pain, arthritis, and inability to return to sports.
- Loose bodies may develop in elbows treated nonoperatively.

Surgical intervention, particularly arthroscopy, has the added risk of nerve injury because the neural structures are so close to the usual elbow arthroscopy portals.

**REFERENCES**

DEFINITION

- Valgus extension overload of the elbow is commonly seen in the overhead throwing athlete and is associated with medial compartment distraction, lateral compartment compression, and posterior compartment impingement.4,6

ANATOMY

- The bony articulation of the elbow joint provides primary stability to varus and valgus force at angles of less than 20 degrees and greater than 120 degrees of flexion.
- Soft tissues are the chief stabilizers between 20 and 120 degrees, where most athletic activity occurs.
- The ulnar collateral ligament (UCL) is the primary restraint to valgus stress.
- It is composed of the anterior band, the posterior band, and the transverse ligament.
- The anterior band is further divided into anterior and posterior bundle, which perform reciprocal functions (FIG 1).
- UCL insufficiency can be subtle, with ligament-sectioning studies showing a 3-degree difference when the anterior band of the UCL is cut.2

PATHOGENESIS

- Valgus extension overload typically occurs in repetitive overhead athletes, most commonly with pitchers. The repetitive pitching motion imparts a large valgus force on the elbow.

Resulting microtrauma and incomplete recovery can lead to attenuation of the UCL.
- Failure of the UCL leads to abnormal valgus rotation of the elbow, affecting the mechanics of the highly constrained articulation of the posterior elbow joint.
- This leads to bony impingement of the posteromedial olecranon and its corresponding fossa.
- Chronic bony impingement can lead to chondral lesions as well as reactive osteophyte formation of the posterior compartment (FIG 2).

NATURAL HISTORY

- Thus far, no studies have been performed documenting the natural history of the disease process.
- It is postulated that chronic impingement and valgus extension overload can lead to posteromedial olecranon osteophyte formation that can cause ulnar nerve irritation and loss of elbow extension as well as posterior compartment elbow arthritis.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient typically complains of loss of extension with posterior or posteromedial elbow pain.
- Pitchers will report pain during the acceleration and follow-through phases of the throwing motion (FIG 3).
Physical examination maneuvers relevant to valgus extension overload include:

- Valgus extension overload test: This maneuver acts to simulate impingement occurring with the throwing motion and to reproduce the symptoms of posterior elbow pain.
- Valgus stress test: Increased medial joint space opening, loss of end point, or pain elicited is significant for UCL insufficiency.
- Milking maneuver: Maneuver eliciting pain, apprehension, or instability indicates UCL insufficiency.
- Posterior olecranon impingement
- Range of motion of elbow: may reveal loose bodies, chondromalacia, or osteophyte formation; flexion contracture may signify either osteophyte impingement or anterior capsular contracture
- Examination of the elbow should also evaluate for other causes of medial-sided elbow problems, such as isolated UCL insufficiency, ulnar neuropathy, medial epicondylitis, and flexor pronator rupture.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Radiographs frequently reveal a posterior olecranon osteophyte on standard lateral or anteroposterior views (FIG 4A).
- Some authors also advocate an olecranon axial view (FIG 4B).
- Because radiographs cannot predict chondral lesions and soft tissue injuries and often underestimate loose body formation, magnetic resonance (MRI) and computed tomography are frequently used.
- MRI can also be important in investigating a potential UCL tear (FIG 4C).

**DIFFERENTIAL DIAGNOSIS**

- Isolated UCL insufficiency
- Medial epicondylitis
- Flexor–pronator rupture
- Ulnar neuropathy

**NONOPERATIVE MANAGEMENT**

- Before recommending surgery, the physician should usually treat the patient nonoperatively for 3 to 6 months.
- Specific goals to be attained during this time are full, nonpainful range of motion; absence of pain and tenderness on physical examination; and satisfactory muscle strength, power, and endurance.
- The patient begins treatment with an initial period of rest (1 to 3 weeks), allowing any synovitis and inflammation to resolve.
- Next, he or she begins wrist and elbow flexor and extensor muscle stretching and strengthening exercises.
- Finally, an interval-throwing program is instituted.

**FIG 3** The pitching athlete with valgus extension overload will often complain of pain during the acceleration and follow-through phases of throwing.

**FIG 4** AP (A) and olecranon axial (B) radiographs showing spur formation along the posteromedial olecranon. C. Coronal section of MRI demonstrating injury to the ulnar collateral ligament.
SURGICAL MANAGEMENT

- Relative contraindications to elbow arthroscopy include severe bony or fibrous ankylosis and previous surgery that has distorted the native anatomy, such as a previous ulnar nerve transposition.

Preoperative Planning

- A thorough history is paramount to planning for arthroscopic elbow surgery.
- The surgeon should confirm that the ulnar nerve is indeed in the groove and cannot be subluxated.
- The surgeon must assess for valgus instability when considering valgus extension overload.
- Failure to address UCL instability in the setting of valgus extension overload may lead to treatment failure.

Positioning

- We prefer the prone position for all elbow arthroscopy because it allows for the elbow to be stabilized as well as giving improved access to the posterior compartment. Posteromedial olecranon spur excision is especially facilitated by the prone position.
- We routinely use a pneumatic tourniquet and a prone arm holder.
- The elbow should be positioned and draped so that the arm is supported by the holder at the proximal upper arm, the elbow rests at 90 degrees of flexion, and the antecubital fossa is free from contact with the holder (FIG 5).

Approach

- Elbow arthroscopy has made open resection of olecranon osteophytes primarily a point of historic interest. However, occasions still exist when an open procedure should be performed.
- The determining factor in the decision-making process is whether a contraindication to elbow arthroscopy is present.
- A posteromedial approach to the elbow is used when concomitant UCL reconstruction, ulnar nerve transposition, or exploration of a previously transposed ulnar nerve is to be accomplished in conjunction with removal of posteromedial osteophytes.

FIG 5 • Intraoperative photograph showing prone positioning for elbow arthroscopy.

Equipment

- General anesthesia is preferred because use of regional anesthesia makes the immediate postoperative motor and sensory examination difficult to interpret.
- A standard 4.0-mm arthroscope, power inflow or pump, standard power débrider, and abraders are required.
- Hand-held instruments as well as only blunt trocars should be used.
- The video monitor is placed on the opposite side of the patient.

Examination Under Anesthesia

- Examination under anesthesia is essential to develop a feel for the character and cause of any extension block.
- A bony block has a hard, sudden stop and a feeling of bony impingement. Anterior capsular contracture often has a slightly softer feel at terminal extension.
- Valgus instability testing throughout the range of motion helps to assess the status of the UCL.

DIAGNOSTIC ARTHROSCOPY

- The medial epicondyle, lateral epicondyle, and ulnar nerve are outlined.
- The surgeon confirms that the ulnar nerve is indeed located within the groove and remains so with range of motion of the elbow.
- The lateral “soft spot” portal location is identified and 20 cc of saline is injected into the elbow joint. Often a slight elbow extension will be seen as the capsule is insufflated.
- Diagnostic arthroscopy must include a complete inspection and evaluation of the elbow.
- An arthroscopic valgus instability test should be performed and medial stability should be documented (TECH FIG 1A,B).
- The posterior compartment should be thoroughly evaluated.
- Examination of the olecranon–olecranon fossa articulation may show osteophyte formation of the posteromedial olecranon (TECH FIG 1C,D).
- The olecranon fossa of the humerus should be evaluated for hypertrophy, chondromalacia, and spur formation.
- A systematic examination of the entire elbow joint is necessary to identify and remove any loose bodies present.
Chapter 20  ARTHROSCOPIC TREATMENT OF VALGUS EXTENSION OVERLOAD


TECH FIG 1 • A. The arthroscopic valgus instability test is performed to assess for significant opening in the ulnohumeral articulation. B. A diastasis in the medial ulnohumeral articulation is noted. C,D. Arthroscopic views of a posteromedial bone spur.

POSTEROMEDIAL OLECRANON SPUR REMOVAL

- First, a viewing portal is established through a posterolateral portal.
- A direct posterior or triceps-splitting portal is established for access of the motorized resector or burr. The posteromedial spur is then resected (TECH FIG 2A,B).
- The ulnar nerve has a close relationship to the medial olecranon. While working medially, the surgeon should minimize the use of suction, use a hooded burr, and always keep the hooded portion oriented toward the ulnar nerve (TECH FIG 2C).

EVALUATION AND TREATMENT OF ARTICULAR CARTILAGE

- After clearing out the olecranon fossa, the articular cartilage is carefully inspected.
- Areas of chondromalacia can be treated by the surgeon’s choice of microfracture, abrasion chondroplasty, or benign neglect.

TECH FIG 2 • A,B. Posterior compartment olecranon spur excision. C. Use of a hooded burr for posteromedial spur resection. The instrument is always pointed away from the ulnar nerve.
DEEPENING OF OLECRANON FOSSA

- Occasionally, hypertrophy of the olecranon fossa necessitates a deepening or fenestration of the olecranon fossa (TECH FIG 3).
- This can be performed using the same instruments and positioning.
- When resection is complete, the surgeon should assess elbow extension and valgus instability with a repeat arthroscopic valgus instability test.

TECH FIG 3 • Arthroscopic views both during (A) and after (B) olecranon fossa fenestration.

POSTOPERATIVE CARE

- Patients with valgus extension overload undergoing isolated spur excision are moved rapidly through the rehabilitation process.5
- A sling is used sparingly for comfort for the first 7 to 10 days.
- After the first week, patients are encouraged to use the elbow normally for activities of daily living, and they can begin strengthening and range-of-motion exercises.
- We include flexor–pronator mass strengthening to improve dynamic valgus instability.
- When patients reach a pain-free plateau, they can be advanced through an interval-throwing program.
- This throwing program typically begins at 6 weeks.
- A target return to competitive pitching is 3 to 4 months.

OUTCOMES

- The study by Wilson et al6 included five patients treated with open biplanar spur excision. One reoperation was required in a patient with severe chondromalacia of the olecranon articular surface.
- Bartz et al1 reported on a series of 24 baseball pitchers treated with a mini-open technique. Nineteen of the 24 obtained complete relief and were able to equal or exceed their preoperative throwing velocity. However, two patients did require reoperation for UCL reconstruction.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Thorough preoperative history and physical examination</th>
<th>Screening for contraindications to elbow arthroscopy can prevent iatrogenic nerve injury. The surgeon should not create a medial portal if the location or orientation of the ulnar nerve is unclear.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arthroscopic valgus instability test</td>
<td>A careful test before and after spur excision helps prevent unrecognized ulnar collateral ligament instability.</td>
</tr>
<tr>
<td>Use of hooded motorized resector</td>
<td>Motorized shavers, even when used properly, present a significant risk of injury to the ulnar nerve.</td>
</tr>
</tbody>
</table>

COMPLICATIONS

- Thus far, no complications of this diagnosis or procedure have been documented.
- Use of a motorized shaver in the medial gutter to débride olecranon osteophytes in close proximity to the ulnar nerve does warrant extreme caution.
- In addition, an unrecognized UCL insufficiency has been a documented cause of reoperation.
- Often this diagnosis is difficult to make in the immediate postoperative period; it may become apparent only when the athlete cannot regain his or her pitching velocity and control.

REFERENCES

**DEFINITION**

- Elbow stiffness can cause significant impairment in function of the upper extremity, especially in performance of the activities of daily living (ADLs).
- A lack of compensatory biomechanical function (ie, the scapula for the shoulder) makes elbow stiffness poorly tolerated.
- A functional arc of 100 degrees (30 to 130 degrees) is required for most ADLs. ¹³
- Posttraumatic elbow motion loss is most common, but osteoarthritis, inflammatory conditions, systemic conditions (head injury), and neurologic problems may also cause contractures.
- Flexion loss is less tolerated than extension loss, but loss of extension is more common. ¹²
- The key to treatment is to determine the functional and occupational impairment and not base treatment decisions solely on the absolute loss of motion of the elbow. ⁷

**ANATOMY**

- The elbow has a predilection for stiffness based on its anatomy: the close relationship of the capsule to the surrounding ligaments and muscles and the presence of three joints within a synovial-lined joint cavity—a hinge (ginglymus) ulnohumeral articulation and rotatory joint (trochoid) of both the radiohumeral and radioulnar joints. ⁷
- The anterior elbow capsule proximally attaches above the coronoid fossa and distally extends to the coronoid (medial) and the annular ligament (lateral). The posterior capsule starts proximally just above the olecranon fossa and inserts at the articular margin of the sigmoid notch and annular ligament (FIG 1).
- The anterior capsule is taut in extension and lax in flexion, with the strength of the capsule provided from the cruciate orientation of the fibers of the anterior capsule.
- Greatest capsular capacity is at 80 degrees flexion. ⁵,¹⁵
  Normal capacity of 25 mL is reduced significantly in a contracture state to 6 mL. ⁵,¹⁵

---

**FIG 1** - Anatomic drawing of elbow capsular structures. The anterior (A) and posterior capsular areas (B) are highlighted. The anterior capsule distally extends to the coronoid medially and annular ligament laterally. C. Lateral diagram of the elbow shows the capsular size and fat pad.
There is loss of joint volume (20 mL to 6 mL) and thickened capsular width (from a normal width of approximately 2 mm). Posttraumatic contractures thicken and tighten variable areas of the elbow capsule, especially the anterior aspect.

**NATURAL HISTORY**

Elbow contracture is frequently posttraumatic. Heterotopic ossification may occur in conjunction with capsular thickening. Patients most at risk are those with combined head and elbow trauma, burn patients, and those who have undergone surgical approaches to the elbow. Classification of the cause of elbow stiffness is important in making treatment decisions (Table 1). Most contractures have mixed elements (both intrinsic and extrinsic factors). Morrey characterized elbow stiffness as static or dynamic, based on tissue involvement (Table 2).

**PATIENT HISTORY AND PHYSICAL FINDINGS**

It is critical to determine the degree of functional impairment for each patient. Management decisions should be based on subjective impairment, not necessarily the amount of motion loss. The surgeon should obtain a history of associated conditions because neurologic, peripheral nerve, or brain injury may influence management decisions.
The surgeon should assess the function of the entire ipsilateral and contralateral upper extremity. The surgeon should determine hand dominance, the patient’s occupation, and the extent of prior therapy, including bracing (both static and dynamic). Physical examination should start with the head, including the cranial and cervical nerves. The surgeon palpates the cervical spine and checks the spine range of motion. The surgeon evaluates the shoulder joint to ensure good strength and range of motion. Careful assessment of the ulnar nerve.

Two-point discrimination: A normal amount of discrimination is less than 6 mm. Froment sign and intrinsic hand muscle function: The patient is asked to grasp a piece of paper between the abducted thumb and index finger. The patient must keep his or her thumb flat against the index finger. If the patient cannot do so, the flexor pollicis longus contributes more to hold paper and indicates weakness of the adductor pollicis and ulnar nerve injury. Decreased grip strength may signify an ulnar nerve problem. Elbow range of motion: Flexion and extension with the humerus flexed to 90 degrees, pronation, and supination can be objectively evaluated with a linear object (pencil) held in a clenched fist and the elbow at the side of the body.

Elbow instability examination: The surgeon should check the ligamentous restraints to varus and valgus stress. Ligaments are assessed with varus and valgus stress at 0 and 30 degrees of flexion if amenable. The cubital tunnel is palpated to assess for tenderness or a positive Tinel’s sign.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Plain radiographs (anteroposterior [AP] and lateral) are usually adequate.
- The AP provides joint line and subchondral bone visualization.
- If an elbow is contracted more than 45 degrees, the AP view of the joint line is usually distorted, but advanced imaging is rarely necessary unless a fracture or malunion is present.
- The lateral view may show osteophytes on the olecranon or coronoid (FIG 3A, B).
- If there is articular incongruity or other joint abnormalities, the surgeon should consider obtaining a computed tomography scan with reformatted images in the coronal and sagittal planes.
- Radiographs can be used to follow the maturation process of heterotopic ossification.
- Arthroscopic treatment is usually not recommended in the presence of heterotopic ossification, which usually signifies multiple extrinsic causes of elbow contracture, not amenable to arthroscopic treatment (FIG 3C).

**DIFFERENTIAL DIAGNOSIS**
- Heterotopic ossification
- Closed head injury
- Burns
- Elbow fracture–dislocation
- Dysplastic radial head (congenital)
- Muscular hypotonia
- Stroke

**NONOPERATIVE MANAGEMENT**
- Nonoperative management should be considered up to 6 months after contracture onset. Response is better if there is a soft “spongy” endpoint during range of motion.
- The goal is to gain motion gradually without causing additional trauma to the capsule and subsequently development of additional capsular contracture (more pain, inflammation, and swelling leads to more contracture).

### Table 1
**Classification of Elbow Stiffness Based on Location of Structure in Relation to the Elbow Joint**

<table>
<thead>
<tr>
<th>Type</th>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic</td>
<td>Within the elbow joint</td>
<td>Articular incongruity after fracture, degenerative changes and loss of cartilage, intra-articular adhesions, loose bodies, synovitis, infection, Soft tissue and capsular contracture, muscle fibrosis (brachialis especially), collateral ligament stiffness, to the elbow joint heterotopic ossification, skin contractures, Stroke, neurologic problems, peripheral nerve disorder, head injury, cerebral palsy</td>
</tr>
<tr>
<td>Extrinsic</td>
<td>Tissues immediately adjacent</td>
<td></td>
</tr>
<tr>
<td>Peripheral</td>
<td>Factors anatomically separate from the elbow</td>
<td></td>
</tr>
</tbody>
</table>


### Table 2
**Characterization of Elbow Stiffness by Tissue Involvement**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Relative Occurrence</th>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>Most common</td>
<td>Tissues in and around the elbow joint</td>
<td>Capsule, ligaments, heterotopic ossification, articular and cartilaginous components Poor muscle tone, nerve injuries, and poor excursion of the muscles that cross the elbow joint</td>
</tr>
<tr>
<td>Dynamic</td>
<td>Less common</td>
<td>Involves muscles around the joint</td>
<td></td>
</tr>
</tbody>
</table>

Edema control is critical, and therapy should focus on this, not exercises that induce inflammation around the elbow. Static and preferably patient-adjusted static progressive splints (turnbuckle splints) have proven valuable and should be used between therapy sessions. Dynamic splinting may be helpful, but care should be taken not to incite an inflammatory process because these provide a constant tension over time. Static progressive splints that allow for stress relaxation of the soft tissues are more effective and better tolerated.

Nonoperative improvements in range of motion vary widely but have been reported anywhere from 10 to 50 degrees or more. O’Driscoll described four stages of elbow stiffness:

- **Bleeding**: minutes to hours
- **Edema**: hours to days. Both bleeding and edema cause swelling within the joint and surrounding tissues, and the tissues become biomechanically less compliant. Early elbow range of motion through an entire range during stages 1 and 2 can prevent stiffness.
- **Granulation tissue**: days to weeks. Splints can be used to regain range of motion.
- **Fibrosis**: Maturation of the granulation tissue further decreases compliance. More aggressive splinting is necessary, along with possible surgical management.

**SURGICAL MANAGEMENT**

- The key is to identify the functional disability of the patient—pain, loss of motion, or both—and what would be most beneficial.
- The indications include a loss of function to preclude the patient from performing ADLs and occupational or vocational activities.
- Arthroscopic treatment of elbow stiffness should be undertaken only if the offending structures can be treated from an arthroscopic approach. Heterotopic ossification is not amenable to arthroscopic treatment.
- Appropriate counseling with the patient should cover realistic expectations of range of motion and functional recovery. Will patients be able to get their hand to their mouth, comb their hair, or reach behind their back, or are more extensive demands required?

**Preoperative Planning**

- The surgeon should assess for heterotopic ossification on plain radiographs. Arthroscopic treatment is not indicated if this is causing the contracture.
- An examination under anesthesia helps to confirm nonmuscle-related pathology and to assess the static component of contraction, which should mirror the in-office examination.
- If the examination documents irritation or neuropathy, the ulnar nerve should be exposed and released.
- We recommend that the ulnar nerve be released before the arthroscopic portion for ease of dissection before fluid distention.
- In patients with elbow flexion of less than 100 degrees and in those with ulnar nerve tension signs or sensitivity to percussion, the nerve should be prophylactically released to prevent compression once flexion is restored postsurgically.
- The surgeon must ensure that the ulnar nerve cannot be subluxated or transposed.
- Contraindications to arthroscopic release are prior surgery that has altered the neurovascular anatomy, joint deformity that would compromise arthroscopic view, prior ulnar nerve transposition, and malunited elbow fractures.

**Positioning**

- Either the lateral decubitus or prone position can be used.
- Lateral decubitus: well-padded pillow at edge of beanbag underneath elbow antecubital fossa
- Prone: adequate chest and arm support, shoulder abducted to 90 degrees
- Well-padded sterile tourniquet for either position
The remainder of the arthroscopic setup has been described elsewhere.

The surgeon should clearly mark the course of the ulnar nerve, portal sites, and bony landmarks with surgical marker (FIG 4C).

**Approach**

- As with any arthroscopy, the surgeon must be able to visualize the joint.
- O’Driscoll states that the single most important factor to improve visualization is the use of arthroscopic retractors.  
- Loss of volume makes this difficult, but it can be facilitated with the use of elbow arthroscopic retractors.
- The key is to avoid nerve injury during the approach and during capsular treatment.
- The surgeon should plan for intraoperative ulnar nerve release if indicated. Nerve decompression is performed before arthroscopy because fluid extravasation distorts the surgical tissue planes (FIG 5).

**PORTAL ESTABLISHMENT IN CONTRACTED ELBOW**

- The joint is distended with saline through the “soft spot” portal (up to 20 mL, less depending on contracture).
- Portals are established.
  - The 4.5-mm, 30-degree arthroscope is used through a proximomedial portal (about 2 cm proximal to the medial epicondyle and just anterior to the medial intermuscular septum) (TECH FIG 1A,B).  
  - The proximolateral portal (1.5 to 2 cm proximal to lateral epicondyle) is identified with either a blunt-tipped Wissinger rod or a spinal needle using an outside-in technique. Retractors are used to improve distention and visualization (TECH FIG 1C).
- Blunt dissection techniques with the Wissinger rod are used to obtain a working space.
- A 4.5-mm shaver (oscillate function) removes more material from the working space, but not yet the capsule.
- A small radiofrequency device can be used to débride the scar tissue within the joint. Inflow should be increased during the use of thermal energy.
- The capsule is not removed until the tissue planes are better defined to minimize nerve injury risk. The capsule is débrided superficially to define it as a structure.
TECH FIG 1 • A. Arthroscopic view of a right elbow joint after first obtaining scope entry into the proximomedial portal, looking laterally. There is synovitis in the joint. B. After the synovitis is gently débrided with an arthroscopic shaver, the bony overgrowth of the coronoid and radial fossa is revealed. There is a lack of concavity in the trochlea and capitellum area. C. Arthroscopic view of elbow joint viewed from the medial portal, showing the increased visualization of the elbow joint that is obtained with the use of intra-articular retractors. C, capitellum; RH, radial head; T, trochlea.

TECH FIG 2 • A. Arthroscopic view of the elbow joint after capsulectomy and deepening of the coronoid and radial fossa. The dissection is carried down to the fibers of the brachialis muscle but does not violate the brachialis (retracted structure). B. View from the lateral portal shows the partially completed release. Bony work and resection are completed before capsulectomy. The concavity in the coronoid and trochlear fossa areas is formed, but anterior capsulectomy is not yet completed. AC, anterior capsule; C, capitellum; RH, radial head; T, trochlea.

ANTERIOR CAPSULAR RELEASE

- Capsulotomy of the anterior capsule is performed with an arthroscopic basket cutter.
- The brachialis muscle can be visualized and the plane between the capsule and brachialis developed from the lateral working portal (TECH FIG 2A).
  - The brachialis protects the median nerve, so the surgeon should avoid penetrating this muscle.
  - The surgeon continues incising the capsule from lateral to medial.
  - The capsulotomy should be continued to the level of the collateral ligaments on each side, but the ligaments are not incised.
- The lateral side is at risk of injuring the radial nerve behind the capsule (just anterior to the radial head).
- Capsulectomy in this area, although it may improve the results, carries a higher risk for radial nerve injury. It may be safest to remove the capsule well proximal to the joint line on the lateral side to avoid this risk.
- The posterior interosseous nerve is the most significant nerve at risk during elbow arthroscopy.16 It is adjacent to the anterolateral capsule (distally).
- The surgeon should view from the lateral portal to ensure adequate medial release (TECH FIG 2B).

POSTERIOR CAPSULAR RELEASE

- The surgeon establishes a posterocentral portal for the arthroscope (4 cm proximal to the olecranon tip through the triceps) and a posterolateral working portal (2 cm proximal to the olecranon tip and lateral to the triceps).
- A shaver is used to débride and open the space and remove loose bodies and osteophytes. Suction is avoided in and along the medial gutter.
- The capsule is elevated from the distal humerus (using a shaver or elevator).
The posterior capsule is released with a basket cutter or arthroscopic elevator on the medial and lateral sides; the surgeon stops before the medial aspect of the olecranon fossa (to avoid injury to the ulnar nerve).

The posteromedial capsule should be resected in the setting of significant flexion loss (posterior band of the medial collateral lateral) and is the floor of the cubital tunnel.

Final inspection from both portals is done to ensure adequate release (TECH FIG 3).

Loose bodies are removed via a 5-mm-smooth cannula.

Subcutaneous transposition or in situ decompression of the ulnar nerve can be performed.

As advocated by O’Driscoll, the ulnar nerve is exposed before performing the arthroscopic release to allow gentle fluid extravasation from the soft tissue posteromedially.

Gentle retraction on the nerve can help protect it while performing arthroscopic releases in this area.

At the end of the case the ulnar nerve can be released using a variety of described techniques.

A drain is placed through the proximal anterolateral portal because accumulation of fluid will compromise range of motion.

Our postoperative dressing is a bulky dressing with Webril, Kerlex, and Ace bandage from wrist to shoulder with material cut out in the antecubital fossa to facilitate immediate continuous passive motion (CPM).

Alternatively, an anterior plaster slab over the elbow is used with the forearm in full extension (TECH FIG 4).

Indwelling catheters or a long-acting regional block may be used to facilitate CPM (from full flexion to extension), which should start in the hospital.

Before starting CPM, the dressing is changed to a soft, noncompressive gauze to prevent skin complications.

Postoperative dressing is applied to the patient after capsular release in the operating room with a drain. Flexion obtained after removing splint material from the antecubital fossa. Immediate continuous passive motion is instituted.
In the medial aspect of elbow joint, the surgeon should retract medially and resect along the radiocapitellar articulation. The surgeon should use care with the capsule just anterior to the midline of the brachialis muscle. Generous retraction and retractors are used inside the joint. Iatrogenic injury is avoided by not penetrating the brachialis muscle.

Prophylactic release if contracture is significant. The surgeon should err on the aggressive side when in doubt.

The surgeon should avoid motorized burrs. No suction should be used on the shaver in risk areas. Generous retraction and retractors are used inside the joint.

The surgeon should use care with the capsule just anterior to the midline of the radiocapitellar articulation. The surgeon should not penetrate the brachialis muscle.

The surgeon should consider prophylaxis of heterotopic ossification with indomethacin.

It is difficult to compare arthroscopic versus open capsular releases.

Compared to open series, Savoie and Field \(^1\) reported on 200 patients with capsular release: there was a mean improvement in extension of −46 degrees to −3 degrees and flexion of 96 degrees to 138 degrees, with a decrease in pain scale score from 6.5 to 1.5.

Radial or posterior interosseous nerve palsy
- Iatrogenic injury can be avoided by avoiding suction in high-risk areas.
- Retractors of soft tissue are used to improve visualization and distention.
- The surgeon should use care when anterior to midline of radiocapitellar articulation in the capsule.

Median nerve
- Iatrogenic injury is avoided by not penetrating the brachialis muscle.
- The surgeon should place portals carefully, avoiding anterior.

Ulnar nerve
- In the medial aspect of joint, the surgeon should use retractors to move the capsule medially.
- Transposition before the case may aid in ulnar nerve protection and also allow fluid extravasation.

Postoperatively it may be transient; there is a much lower incidence if it is transposed during initial surgery.

Excessive bone resection, especially of radial head
- The surgeon should avoid excessive resection.

Ulnar neuritis
- If present preoperatively, ulnar nerve release should be ensured.

References
DEFINITION
- Primary degenerative arthritis of the elbow joint is a relatively rare condition.9,18
- Patients with primary osteoarthritis of the elbow are frequently manual laborers, athletes, and those who rely on wheelchairs or crutches for ambulation.4,15,18,21
- Although total elbow arthroplasty provides pain relief and improved range of motion in patients with inflammatory arthritis and or low demands, use in young active patients has been associated with early loosening and is undesirable in this group. Likewise, elbow arthrodesis is undesirable to many patients who do not wish to sacrifice motion in favor of pain relief.8
- Open débridement procedures have been described and used with good success.3,4,6,9,14,16,22,23
- Arthroscopic procedures have gained acceptance with patients and surgeons for perceived benefits of a minimally invasive nature and better visualization of the joint.
  - More series are confirming results at least equivalent to open procedures, with similar complication rates.
  - Arthroscopic débridement and osteocapsular resection is a procedure that adequately addresses the underlying pathologic processes and is associated with early return to activities, a durable result that does not preclude future reconstructive procedures, and minimal perioperative morbidity.2,10,11,12,17,20

ANATOMY
- At the elbow, the coronoid fossa anteriorly, the trochlea, and the olecranon fossa posteriorly articulate with the coronoid and olecranon. Bony osteophytes may develop, leading to impingement in flexion and extension in degenerative conditions.

PATHOGENESIS
- Three main pathologic processes are involved in primary elbow arthritis. Loss and fragmentation of cartilage lead to loose body formation. Osteophytes arise from reactive bone formation.
  - These two processes cause impingement and contribute to the third process, progressive joint contractures.21,22 The capsule becomes abnormally thickened and contracted.
  - Symptoms include loss of extension, pain at the end points of motion, and mechanical symptoms such as catching or locking.4,9
  - Other commonly associated conditions include cubital tunnel syndrome with paresthesias and weakness in the ulnar distribution and decreased grip strength.4,13

NATURAL HISTORY
- The natural history is one of slowly progressive joint contracture and discomfort. Ulnar neuritis may develop.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The typical patient is a middle-aged male laborer with a painful dominant elbow, worse with use.
  - Less frequently, patients who depend on wheelchairs or crutches for mobility, and who thus put increased forces across their elbow joints, may be afflicted.
  - Progressive loss of motion and pain at the extremes of motion due to impingement of osteophytes are noted.
  - Painful crepitus and catching or locking sensations may be noted with range of motion. Usually pain in the mid-arc of motion is absent.
  - Patients with contracture of the posterior capsule will lack flexion, whereas those with anterior contractures will lack extension.
  - Not infrequently, ulnar nerve irritation is noted. This should be documented and will contribute to decision making regarding the need for decompression or transposition.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Usually plain film radiographs, clinical examination, and history are sufficient to make the diagnosis (FIG 1).
- Radiographs may show joint space narrowing, hypertrophic bony osteophytes, loose bodies, and subchondral sclerosis typical of osteoarthritis.

DIFFERENTIAL DIAGNOSIS
- Usually it is easy to exclude inflammatory arthropathies and posttraumatic arthritis, which may also be treated with this technique.

FIG 1 • AP and lateral radiographs of the typical patient with degenerative arthritis of the elbow. Bony osteophytes are noted with loose body formation.
Physical examination will also exclude other painful elbow conditions, such as tendinitis, instability, or cubital tunnel syndrome.

NONOPERATIVE MANAGEMENT
- Operative treatment should be considered only after exhausting conservative measures, which include activity modification and nonsteroidal anti-inflammatory medications.17

SURGICAL MANAGEMENT
- Patients who have failed to respond to nonoperative management and desire improved range of motion and pain relief may be surgical candidates.

Preoperative Planning
- Careful physical examination with attention to neurovascular status should be documented.
- Routine radiographs are usually all that are necessary.

Positioning
- General endotracheal anesthesia is induced and the patient is placed in the lateral decubitus position.
- The arm is secured in a dedicated arm holder, ensuring free access to the elbow with instruments (FIG 2A).
  - Positioning the elbow just higher than the shoulder allows free access to the elbow.
- A nonsterile tourniquet is applied and the arm is prepared and draped in the usual fashion (FIG 2B).

Approach
- Patients with lack of flexion will need to have the posterior aspect of the joint addressed; patients with lack of extension will require release and débridement anteriorly. Either compartment may be addressed first, depending on the pathology present.
- The standard arthroscopic setup and equipment includes the 4-mm 30-degree arthroscope.
  - A 2.7-mm arthroscope can be used, but in most cases the joint can accommodate a 4-mm arthroscope.
- A 70-degree arthroscope may likewise be used but is usually not necessary and may be awkward unless the surgeon has experience using this arthroscope.
- Only blunt, not sharp, trocars should be used.
- Retractors such as a Howarth elevator or a large blunt Steinmann pin make the procedure easier and enhance visualization. Commercially available retractors are now available.
  - The standard arthroscopic shaver and burr are used.
  - Suction should be placed to gravity only to prevent accidentally shaving objects that may be sucked into the shaver (FIG 3).
- The portal sites and landmarks, including the radial head, medial and lateral epicondyles, capitellum, and olecranon, should be marked before insufflation of the joint, which may obscure landmarks.
- The ulnar nerve should be examined and its location marked; the surgeon should watch for a subluxating ulnar nerve.
  - If prior surgery has been performed or there is any question of the nerve’s location, a small incision may be made to identify and retract the nerve to protect it against inadvertent injury.
ANTERIOR PORTAL PLACEMENT

- The surgical technique for arthroscopic elbow débridement and capsular release involves the standard arthroscopic technique and setup as previously described.  
- The joint is distended with 20 to 30 mL of saline introduced via an 18-gauge needle through the “soft spot” (the center of a triangle formed by the olecranon process, the lateral epicondyle, and the radial head). This makes entry into the joint easier to achieve.
- Portal sites are established according to the order preferred by the surgeon; the procedure described below is our preference.
- Portal sites are made by incising the skin only with a no. 11 blade, and then blunt dissection with a hemostat proceeds to the joint.
  - Capsular entry and joint location is confirmed by sudden egress of fluid.
  - The blunt trocar and sleeve are then placed into the joint and exchanged for the arthroscope.
- The anterolateral portal (TECH FIG 1A) is established first, with care taken to avoid and protect the radial nerve.
  - This portal is established just anterior to the sulcus between the capitellum and the radial head.
  - The anteromedial portal is established using an inside-out technique with direct visualization.
  - The arthroscope is removed and replaced with the blunt trocar, which is pushed directly across the joint until it tents the skin overlying the medial side of the elbow.
  - The skin is incised over this region and the trocar pushed through the remaining soft tissue.
  - A cannula may be placed over the trocar on the medial side, and the trocar is pulled back into the joint and out the lateral side (TECH FIG 1B).
  - A proximal anterolateral retraction portal may be established about 2 cm proximal to the lateral epicondyle.

ANTERIOR PORTAL PLACEMENT

- The anterolateral portal (TECH FIG 1A) is established first, with care taken to avoid and protect the radial nerve.
- This portal is established just anterior to the sulcus between the capitellum and the radial head.
- The anteromedial portal is established using an inside-out technique with direct visualization.
- The arthroscope is removed and replaced with the blunt trocar, which is pushed directly across the joint until it tents the skin overlying the medial side of the elbow.
- The skin is incised over this region and the trocar pushed through the remaining soft tissue.
- A cannula may be placed over the trocar on the medial side, and the trocar is pulled back into the joint and out the lateral side (TECH FIG 1B).
- A proximal anterolateral retraction portal may be established about 2 cm proximal to the lateral epicondyle.

ANTERIOR CAPSULECTOMY AND ARTHROSCOPIC DÉBRIDEMENT

- A 4.8-mm arthroscopic shaver is introduced through the anteromedial portal with retraction via a proximal anterolateral portal.
- Shaving proceeds to gain visualization.
- The anteromedial capsule is then stripped off the humerus to expand space in the contracted joint.
- Loose bodies are removed as they are identified. Osteophytes are removed with the shaver and burr from the coronoid and radial head fossae.
- After completion of the bony débridement, the anterior capsule is completely resected under direct visualization with the arthroscope in the lateral portal site.
- The biter is used to gain a free edge of the anterior capsule, proceeding from medial to laterally and halting when the fat pad anterior to the radial head is encountered.
- The shaver is used to completely resect the anterior capsule.
- The arthroscope is placed in the medial portal and bony débridement and capsulectomy is completed.

POSTERIOR PORTAL PLACEMENT

- After completing the anterior joint débridement and capsulectomy, attention is turned to the posterior aspect of the joint.
- Again, the location of the ulnar nerve is established and marked (see Tech Fig 1B).
- The posterolateral portal is used for visualization.
  - It is made with the elbow in a 90-degree flexed position and is placed at the lateral joint line at a level with the tip of the olecranon.
- The direct posterior portal is the working portal. It is made 2 to 3 cm proximal to the tip of the olecranon. It penetrates the thick triceps, and a knife should be used to establish this portal.
- Optional posterior retractor portals include one placed 2 cm proximal to the direct posterior portal, situated either slightly medially or laterally.
POSTOPERATIVE CARE

- After the procedure, motion is assessed (FIG 4), the portals are closed in the standard fashion with 3-0 nylon or Prolene sutures, and a sterile compressive dressing applied.
- A posterior slab of plaster is used to splint the operative extremity in full extension, and the arm is elevated in the “Statue of Liberty” position overnight.
- On postoperative day 1, the splint is removed and the neurovascular status is evaluated, with particular attention to the radial, median, and ulnar nerves.
- Full active range of motion is initiated. No limitations are placed on use of the arm.
- Continuous passive motion may be initiated using a continuous passive motion device with or without a nerve block; however, in our experience it is not usually necessary.
- In patients who cannot practice motion on their own or in those with severe contractures, it may be of benefit, although a consensus regarding the indications and need for continuous passive motion is lacking.

OUTCOMES

- In our series, outcomes after the described procedure in 41 patients and 42 elbows were reviewed after an average follow-up of 176.3 weeks (minimum 2 years of follow-up).
- Significant improvements in mean flexion (from 117.3 degrees preoperatively to 131.6 degrees, \( P < 0.0001 \)), extension (from 21.4 degrees to 8.4 degrees, \( P < 0.0001 \)), supination (from 70.7 degrees to 78.6 degrees, \( P = 0.0056 \)), and Mayo Elbow Performance Index scores (\( P < 0.0001 \)) were noted, with 81% good to excellent results.
Pain decreased significantly ($P < 0.0001$).
Complications were rare (n = 2; heterotopic ossification and transient ulnar dysthesias).
Cohen et al$^5$ compared outcomes after arthroscopic débridement versus open débridement of the elbow for osteoarthritis, using the Outerbridge-Kashiwagi procedure and an arthroscopic modification.
Both groups showed improved range of elbow flexion, decrease in pain, and a high level of patient satisfaction.
Increases in elbow extension, although improved in both groups, were more modest.
Neither procedure included capsular release.
Comparison between the open and arthroscopic procedures showed that the open procedure might be more effective in improving flexion, whereas the arthroscopic procedure seemed to provide more pain relief.
No differences between overall effectiveness of the two procedures were noted.
From these series and others in the literature, it appears that arthroscopic débridement and capsular release have similar outcomes with respect to pain relief, improved range of motion, and complications. Although the use of arthroscopic procedures is attractive to decrease morbidity, benefits over open procedures have not been proved.

COMPLICATIONS
With any arthroscopic or open procedure about the elbow, the risk of neurovascular injury is a real concern.
In a series from the Mayo Clinic,$^7$ 50 complications were observed after 473 elbow arthroscopies for a variety of interventions.
Most frequently, this included prolonged wound drainage; other complications included infection, nerve injury, and contractures.
No permanent nerve injuries were observed.
Nevertheless, injuries of each of the susceptible nerves about the elbow joint have been observed.
Careful attention intraoperatively, appropriate portal placement, and knowledge of anatomy will help prevent injury.

REFERENCES
Arthroscopic Treatment of Epicondylitis

Kevin P. Murphy, Jeffrey R. Giuliani, and Brett A. Freedman

DEFINITION

- Epicondylitis is overuse tendinosis at the elbow, with pain localized to the origin of the lateral common extensor mass or, much less commonly, the origin of the medial common flexor mass.
- Lateral epicondylitis (LE), also known as tennis elbow, is the most common overuse injury of the elbow, resulting from repetitive microtrauma at the origin of the extensor carpi radialis brevis (ECRB).
- The hallmark clinical finding is pain localized to the lateral aspect of the elbow reproducible with resisted wrist extension and forearm supination.
- Medial epicondylitis results from repetitive valgus forces at the elbow, with tendinosis commonly localized to the origins of the flexor carpi radialis and pronator teres, with tenderness slightly anterior and distal to the medial epicondyle.
- Nonoperative management is the initial treatment of choice for epicondylitis. It is successful in 90% to 95% of patients.3,10 Nonetheless, for the 5% to 10% of LE patients who fail to respond to nonoperative management and develop chronic refractory symptoms, the senior author’s (KPM) treatment of choice since 1995 has been arthroscopic release.
- Cadaveric and anatomic studies have shown that elbow arthroscopy and ECRB release is safe, reliable, and reproducible.7,11
- The treatment of choice for refractory medial epicondylitis is open débridement of pathologic tissue of the flexor pronator origin. This will not be discussed in this chapter.

ANATOMY

- The common extensor tendon origin represents the confluence of four tendons: ECRB, extensor digitorum communis, extensor digiti minimi, and extensor carpi ulnaris.
- The ECRB origin is on the distal anterolateral aspect of the lateral epicondyte. It covers an area of about 1.5 cm and lies deep to the other three muscles of the extensor mass.
- Arthroscopically, the ECRB is the muscle belly and tendon that can be seen lying just superficial to a thinned-out portion of the lateral joint capsule.
- The extensor carpi radialis longus actually originates from the lateral humeral supracondylar ridge, 2 to 3 cm superior to the common extensor tendon, and then passes distally, anterior, and superficial to the ECRB.
- The lateral ulnar collateral ligament is deep to the extensor tendons and originates from the lateral epicondyle, reinforcing the lateral joint capsule as well as inserting onto the annular ligament and supinator ridge of the ulna.

PATHOGENESIS

- The actual pathophysiology of LE is still not completely understood, and minimal advances in our knowledge of the disease process have occurred in the past 2 years.
- Proposed causes include bursitis, synovitis, ligament inflammation, periostitis, tendinitis, tendinosis, and extensor tendon tears.
- It is widely accepted that LE is not an “itis” or inflammatory condition but rather a tendinosis.
- The most commonly accepted cause today is tendinosis as a result of microscopic tearing of the ECRB muscle with repetitive trauma that causes ingrowth of weakened reparative tissue known as angiofibroblastic hyperplasia or angiofibroblastic tendinosis.
- The process of repetitive micro- and macrotearing can ultimately lead to a spectrum of ECRB tendinosis ranging from fraying to complete tendon failure if the condition is not addressed early.6

NATURAL HISTORY

- Epicondylitis responds to conservative management in 90% to 95% of cases.
- If treated in the acute setting with activity modification, in conjunction with other conservative modalities, nonsteroidal anti-inflammatory medication may contribute to the alleviation of symptoms experienced with acute LE.
- With progressive repetitive trauma, fraying of the tendon and microtears can progress to macroscopic tears and fibrillations of the ECRB, which ultimately could lead to complete tendon rupture or avulsion.
- If the lateral joint capsule is involved in chronic LE, it can avulse along with the ECRB tendon and create a lateral synovial cyst or a sense of lateral joint instability.
- Chronic refractory LE originates in the ECRB tendon, but it could extend to involve the anterior portion of the extensor digitorum communis, which may ultimately lead to weakness with wrist extension and supination.
- Baker et al2 have published an arthroscopic classification system for LE that we have found to be reliable (Table 1).
- Rarely, in the chronic setting, treatment may require tendon transfer surgery to restore long extensor function.

Table 1  Arthroscopic Classification of Lateral Epicondylitis

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Fraying of the undersurface of the ECRB without a definitive tear</td>
</tr>
<tr>
<td>II</td>
<td>Linear tears specifically in the undersurface of the ECRB and the lateral capsule</td>
</tr>
<tr>
<td>III</td>
<td>Partial or complete avulsions of the ECRB origin</td>
</tr>
</tbody>
</table>

ECRB, extensor carpi radialis brevis.
PATIENT HISTORY AND PHYSICAL FINDINGS
- The pain associated with LE can be secondary to an acute event, but most commonly it is insidious in onset—the result of repetitive microtrauma.
- Patients typically report pain with resisted wrist extension and supination with the elbow extended.
- It is important to ask the patient about length and type of conservative treatment, history of corticosteroid injections, and response to prior therapy.
- Patients who have had a good or excellent initial response to steroids, followed by reaggravation of symptoms, may have resumed strenuous activities too soon or too abruptly and may respond to an additional trial of nonoperative management.
- A prior surgical history of the involved elbow is extremely important for operative planning and can contribute to the diagnosis. Furthermore, a history of a prior ulnar nerve transposition could place the ulnar nerve at risk when establishing arthroscopic portals and may require an open approach.
- The physical examination should include:
  - Palpation of the lateral epicondyle—common extensor mass; the surgeon should document the exact location of tenderness to palpation, which is critical for differential diagnosis. This is the most predictive examination for LE.
  - Resisted wrist extension: Pain with resisted middle finger extension is commonly present in patients with LE but can also be diagnostic for posterior interosseous nerve (PIN) syndrome.
  - Resisted supination and grip strength: Grip strength is diminished in 78% of patients with LE. Resisted supination elicits pain in 51% of patients. The differential includes bicep tendinitis. Pain with turning a doorknob can also indicate LE.
  - Chair test: The test is positive when a patient refuses or is unable to lift a chair with the arms forward flexed, elbows and wrists in extension, and forearms in pronation.
  - The differential diagnosis for lateral elbow pain is long, so it is pertinent to perform a thorough physical examination of both the ipsilateral and contralateral upper extremity, as well as the cervical spine.
  - The differential diagnosis of lateral elbow pain includes (but is not limited to) the following:
    - Compressive neuropathy of the radial nerve—radial tunnel syndrome or PIN. The point of maximal tenderness in both radial tunnel syndrome and PIN syndrome is more distal than in LE. PIN syndrome presents with a motor palsy, whereas LE is a diagnosis of pain. Radial tunnel syndrome can be tested for specifically with the resisted middle finger extension test. Selective injections and electrodiagnostics can confirm the diagnosis.
    - Posterolateral rotatory instability is caused by an injury to the lateral ulnar collateral ligament. Although posterolateral rotatory instability can be associated with mechanical symptoms, the lateral pivot shift test can clinically differentiate instability from epicondylitis.\(^8,10\)
    - Osteoarthritis, particularly in the radiocapitellar joint
      - The physical examination usually causes mechanical symptoms and decreased range of motion.
      - Radiographs confirm sclerosis, osteophyte formation, loose bodies, and joint space narrowing of the radiocapitellar joint.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographs have been of limited benefit in the diagnosis of LE but should be obtained to rule out other causes of pain or coexisting pathology, especially in recalcitrant cases.
- Radiographic evaluation of the elbow in a patient with lateral elbow pain should be limited to an anteroposterior view in full extension and a lateral view with the elbow flexed at 90 degrees.
- One study reports an incidence of calcification about the ECRB origin from chronic tendinosis in up to 25% of patients (FIG 1A).\(^9\)
- Historically, magnetic resonance imaging (MRI) has had limited utility in the diagnosis of LE.
- MRI can demonstrate ECRB tendon thickening, increased signal on T1 and T2 images, and in advanced disease high T2-signal cystic areas that correspond to partial or complete ECRB avulsions or large areas of mucoid degeneration, which are nonspecific findings for LE (FIG 1B).
- Despite its limited specificity for LE, MRI can be a useful, noninvasive technique to visualize concomitant intra-articular elbow pathology and soft tissue pathology.

DIFFERENTIAL DIAGNOSIS
- Lateral
  - Radiocapitellar chondromalacia
  - Osteochondral loose bodies
  - Radial head fracture
  - Osteochondritis dissecans lesion
  - PIN entrapment
- Medial
  - Inferior cruciate ligament strains or tears
  - Medial epicondyle avulsion fracture
  - Ulnar neuritis
  - Ulnar subluxation
  - Medial epicondylitis
  - Osteochondral loose bodies
  - Olecranon stress fracture
  - Valgus extension overload syndrome
  - Pronator teres syndrome

FIG 1 • A. Standard AP radiograph of the elbow showing calcification of the extensor carpi radialis brevis (ECRB) tendon. B. T1-weighted MRI of the elbow. Arrows show intermediate or high signal intensity of the ECRB tendon at its insertion site on the lateral epicondylitis.
Anterior
- Anterior capsular strain
- Distal biceps tendon strain
- Brachialis strain
- Distal biceps tendon rupture
- Coronoid osteophyte
Posterior
- Valgus extension overload syndrome
- Triceps tendinitis
- Triceps tendon avulsion
- Pronator teres syndrome
- Olecranon stress fracture
- Osteochondral loose bodies
- Olecranon bursitis

NONOPERATIVE MANAGEMENT
- LE responds to conservative management in 90% to 95% of cases.
- Treatment algorithms and modalities are extensive and include rest, activity modification, anti-inflammatory medication, phonophoresis, iontophoresis, massage, stretching, strengthening, counterforce bracing (tennis elbow wraps), sporting equipment modification, acupuncture, extracorporeal shock wave therapy, and corticosteroid injections.
- No single nonoperative protocol has proved to be the best, and there is a severe paucity in empiric support for any modality.
- Realizing that the natural history of LE appears to be one of spontaneous resolution for most patients within 6 to 12 months, rest and removal of the offending overuse activity is probably the most important component in the initial treatment of LE.
- While steroid injections and nonsteroidal anti-inflammatory medications have been recommended in the treatment of LE, there is little to no empiric evidence to support their use.
- A three-stage rehabilitation program with the most widespread acceptance entails rest to reduce pain, counterforce bracing followed by progressive wrist extensor strengthening, and a delayed resumption of inciting activities.
- Extracorporeal shock wave therapy has been the most clinically studied nonoperative modality in the past 2 years.
  - It is difficult to clearly define its role in the treatment of LE given the conflicting results in several studies, along with the relatively short-term follow-up data currently available.
  - We believe extracorporeal shock wave therapy should be considered a possible alternative to surgery for refractory cases only. It is not a first-line therapy at this point.

SURGICAL MANAGEMENT
- Despite 3 to 6 months of nonoperative management, approximately 5% to 10% of patients develop recalcitrant symptoms that may require surgical intervention.
- The surgical options include open, percutaneous, and arthroscopic surgical techniques, with success rates that vary from less to 65% to 95% good or excellent outcomes.
- The pervasive move toward minimally invasive surgical techniques and the desire for a quick return to full activity have resulted in research and development of safe and effective means for performing arthroscopic releases for LE.
- In comparison with open procedures, arthroscopy has several distinct advantages, including the ability to address intra-articular pathology, preservation of the superficial common extensor origin and therefore grip strength, faster return to work and sports-related activities, and lower morbidity.
- Arthroscopy appears to combine the best attributes of the earlier return to activity seen with percutaneous procedures and the decreased recurrence rates commonly reported with open procedures.

Preoperative Planning
- The surgeon must review radiographs and imaging studies for concomitant pathology such as osteochondral loose bodies, radiocapitellar arthritis, fracture, and injury to surrounding soft tissue structures like the lateral collateral ligament complex.
- Under general anesthesia
  - The lateral pivot shift test, described by O’Driscoll, tests the elbow for a lateral ulnar collateral ligament injury by stressing the elbow in supination, and valgus and axial compression as the elbow is moved from full extension over the patient’s head to 20 to 40 degrees of flexion.
  - Posterolateral rotatory instability is diagnosed when the radiocapitellar joint subluxes, creating a sulcus proximal to the radial head.
  - In addition, the surgeon must examine the range of motion of the elbow under anesthesia in full flexion and extension, pronation and supination.
  - Examination findings under anesthesia should always be compared with the contralateral extremity.

Positioning
- The patient is placed in the prone position on the operating table in the standard fashion.
- The operative elbow is flexed at 90 degrees and hangs over the bed to gravity. A sandbag may be placed under the operative extremity to maintain elbow flexion.
- The surgeon is seated for the procedure.

Approach
- As stated previously, LE can be treated with a multitude of well-described open or percutaneous procedures with the goal of débride diseased tissue.
- Techniques include partial epicondylectomies, partial resection of the annular ligament, and lengthening (slides) of the extensor tendons.
- Our bias is toward arthroscopic treatment.
- Numerous arthroscopic portals have been described for elbow arthroscopy, but nine are most commonly used: two medial, four lateral, and three posterior.
- When addressing LE, the surgeon must be able to perform a diagnostic arthroscopy of the anterior compartment of the elbow and be able to visualize, evaluate, and address pathology of the lateral capsule and the undersurface of the ECRB tendon.
- Absolute contraindications to elbow arthroscopy are distortion of normal bony or soft tissue anatomy that precludes safe portal placement, previous ulnar nerve transposition or hardware that interferes with medial portal placement, or local cellulitis.
- Although LE could be addressed through a combination of the different medial and lateral portals, we have had the most success avoiding injury to neurovascular structures and improving visualization with the proximal anteromedial portal as...
Once the patient is positioned, prepared, and draped and the surgical landmarks are drawn, the joint is distended using an 18-gauge needle to inject 20 mL of saline via the direct lateral approach into the joint (TECH FIG 1).

The proximal medial portal is established first. This is the viewing portal and allows for the proximal lateral portal to be created under direct arthroscopic visualization.

The surgeon makes a 2-mm longitudinal skin incision using a no. 11 scalpel blade, 2 cm proximal and 2 cm anterior to the medial epicondyle.

This incision should go no deeper than the skin to protect the cutaneous nerves and veins.

Alternatively, the arthroscope light can be used to transluminate the skin and identify these structures so that they can be avoided before making the skin incision.

A hemostat is inserted through the subcutaneous tissue, onto the medial humeral condylar ridge, and down to the medial capsule, using blunt dissection.

The capsule is robust and a pop should be felt as it is entered.

Some of the normal saline that was previously injected to inflate the joint will now be released through the portal site, further confirming entry into the joint.

Staying anterior to the medial intermuscular septum protects the ulnar nerve from danger.

Next, a blunt trocar is introduced into the joint, followed by the 4-mm, 30-degree arthroscope.

The anterior compartment of the elbow should be diagnosed for pathology (osteoarthritis, loose bodies, capsuloligamentous flaps or redundancies); these will be addressed once the proximal lateral portal is established.

After the anterior compartment has been inspected, attention is directed toward the lateral capsule and ECRB tendon.

An 18-gauge spinal needle is inserted 2 cm proximal and 2 cm anterior to the lateral epicondyle.

Using techniques for skin and soft tissue management similar to those described for the proximal medial portal placement, the proximal lateral portal is made under direct arthroscopic visualization.

The radial nerve is the structure most at risk with this portal.

With the proximal medial portal as the standard viewing portal, the 30-degree scope is advanced just past the radial head to visualize the lateral joint capsule and undersurface of the ECRB origin (TECH FIG 2A).

The capsule often adheres to the undersurface of the ECRB and can have varying degrees of degeneration, presenting as linear tears (type II lesion), fraying, or yellowish fatty infiltration, or it can have a thin, translucent appearance (TECH FIG 2B).

If the capsule is intact, it is débrided using a 4.5-mm synovial shaver inserted in the working portal—the proximal lateral portal.

The capsule and tendon may be completely avulsed and retracted; this is classified as a type III lesion (TECH FIG 2C).

The undersurface of the ECRB is in plain view once the capsule is débrided.

The release of the muscle should begin at the site of degeneration or tear using a 4.5-mm incisor (TECH FIG 2D).
Next, the surgeon progresses proximally to the ECRB origin on the lateral epicondyle.
- Care must be taken to avoid injury to the articular surface of the capitellum or radial head during this process (TECH FIG 2E).
- Just superficial to the ECRB the extensor carpi radialis longus will come into view (TECH FIG 2F).
- A 4.0-mm abrader is placed in the proximal lateral portal to débride the remaining origin of the ECRB and to decorticate the lateral epicondyle and distal lateral condylar ridge to promote healing (TECH FIG 2G).
- The cadaveric model by Kuklo et al? showed that using this technique, an average of 23 mm of ECRB tendon and 22 mm of lateral epicondyle can be safely resected.
- In addition, the 30-degree scope field of visualization avoids injury to the lateral ulnar collateral ligament, which is posterior to an intra-articular line bisecting the head of the radius.¹¹

If needed, a direct lateral portal can be made when the elbow is flexed 90 degrees for access to the posterior compartment.
- This portal enters the soft tissue triangle created by the radial head, the lateral humeral epicondyle, and the olecranon.
- The medial antebrachial cutaneous nerve is the structure at risk with this portal.
- Once the arthroscope is introduced into the joint, the elbow is extended and the scope is advanced into the posterior compartment.
- If a working portal is needed, a direct posterior portal can be placed midline between the medial and lateral epicondyles about 3 cm proximal to the olecranon tip.
- The joint is expressed free of all arthroscopic fluid, portals are closed with figure 8 3-0 nylon sutures, and a soft tissue dressing is applied.
PEARLS AND PITFALLS

| Indications | ■ Indication for arthroscopic release is pain that lasts longer than 3 to 6 months despite a trial of nonoperative methods (rest, counterforce bracing, stretching, and strengthening). |
| Absolute contraindications | ■ Distortion of normal bony or soft tissue anatomy that precludes safe portal placement  
■ Previous ulnar nerve transposition or hardware that interferes with medial portal placement  
■ Osteomyelitis or local cellulitis |
| Neurovascular injury | ■ Neurovascular injury is avoided by using the “nick and spread” technique:  
■ An 11-mm arthroscopic blade placed through the skin is used to pull skin distally for small incision.  
■ A hemostat is used to bluntly dissect to the capsule.  
■ A 2.7-mm arthroscopic blade is used rather than a 4.0-mm arthroscope.  
■ If a 4.0-mm scope is desired, the joint is entered over a switching stick.  
■ A postoperative intra-articular injection is not recommended owing to possible extravasation and transient radial nerve palsy. |
| Complete lateral release | ■ The ECRB insertion site spans 1.5 cm of lateral epicondyle.  
■ Débridement of the ECRB tendon is carried up the lateral flare of the epicondyle.  
■ Lateral epicondyle decortication is best done with an abrader and ensures the entire ECRB tendon is released. |
| Access to posterior compartment | ■ Direct lateral portal for visualization  
■ Direct posterior portal as the working portal  
■ Surgeon is seated with arthroscope draping across his or her thighs. The patient’s wrist should be flexed and the dorsum of the hand should be on the surgeon’s thigh. Raising or lowering the bed allows for the elbow to be extended and flexed, respectively. |
| Iatrogenic lateral collateral ligament complex injury | ■ The surgeon should not decorticate posterior to the lateral epicondyle.  
■ A 30-degree scope prevents injury to the lateral collateral ligament because it does not allow good posterior visualization. |

POSTOPERATIVE CARE
■ Postoperatively the patient is placed into a sling for comfort.  
■ Range of motion is begun immediately with the assistance of a physical therapist.  
■ Rehabilitation goals include edema control with icing, full active range of motion, gradual strengthening, hand exercises, and ergonomic education.  
■ Patients return to full activity as tolerated.  
■ Soldiers undergoing this technique were able to return to full, unrestricted active duty within an average of 6 days (less than 28 days).7,11

OUTCOMES
■ Cadaveric and anatomic studies have shown that elbow arthroscopy and ECRB release is safe, reliable, and reproducible.7,11
■ Two clinical series confirm the long-term subjective and functional improvement, as well as faster return to activity, with arthroscopic treatment.  
■ In 16 patients who underwent an arthroscopic release, the average return time to unrestricted work was 6 days, with no complications or need for further surgery.11
■ In 2000, we evaluated the clinical results of arthroscopic lateral elbow release. Patients rated 95% of the elbows to be “much better” or “better.” Sixty-two percent of the patients were completely pain-free at an average of 2.8 years of follow-up.2
■ Results from open releases have shown time to return to activity as long as 3 to 6 months, with one study reporting that 60% of patients could not return to high-demand sports participation postoperatively.  
■ Arthroscopy, unlike open and percutaneous procedures, gives the surgeon the distinct ability to address concurrent intra-articular pathology.  
■ This may be particularly important because we have found rates of intra-articular pathology from 11% to 18% in our series, and some have reported rates as high as 40%.9

COMPLICATIONS
■ Transient nerve palsy versus direct nerve injury14  
■ Superficial infection  
■ Iatrogenic lateral collateral ligament injury with posterolateral instability7  
■ Hematoma

REFERENCES
DEFINITION

- The hip is increasingly recognized as a source of pain owing to heightened awareness of pathologies, recent research, enhanced imaging techniques, and greater popularity of hip arthroscopy as a diagnostic and therapeutic tool.
- Hip arthroscopy first was performed on a cadaver in the 1930s by Burman, but it was not performed regularly until the 1980s, serving mostly as a tool for diagnosis and simple treatments, such as loose body removal, synovial biopsy, and partial labrectomy.
- With improvements in instrumentation, indications for hip arthroscopy have expanded, because surgeons now are able to do more in the hip with decreased risk of iatrogenic injury. Further, enhanced imaging techniques have allowed noninvasive diagnosis, and research has led to increased understanding of hip pathologies, furthering interest in this procedure.
- Hip arthroscopy can be performed in the central compartment (femoroacetabular joint) and peripheral compartment (along the femoral neck), which also has expanded the indications and success of hip arthroscopy, propagating the popularity of this procedure.

ANATOMY

- The hip joint is a multiaxial ball-and-socket type of synovial joint in which the head of the femur (ball) articulates with the acetabulum (socket) of the hip.
- Articular cartilage covers the head of the femur and acetabulum but is not present at the fovea.
  - The articular cartilage of the femoral head and acetabulum is relatively thin compared with that of the knee.
  - The acetabular labrum is a triangular fibrocartilage that attaches to the rim of the acetabulum at the articular cartilage edge, except at the inferiormost region of the acetabulum, where the transverse acetabular ligament extends the acetabular rim.
- The hip joint is enclosed by a capsule that is formed by an external fibrous layer and internal synovial membrane, and attaches directly to the bony acetabular rim.
- The fibrous layer consists of the iliofemoral, pubofemoral, and ischiofemoral ligaments, which anchor the head of the femur into the acetabulum (FIG 1A).
- The ligamentum teres is extracapsular and travels from the central acetabulum to the foveal portion of the femoral head (FIG 1A).
- The major arteries supplying the hip joint include the medial and lateral circumflex femoral arteries, which branch to provide the retinacular arteries that supply the head and neck of the femur (FIG 1D).
- The artery to the head of the femur also supplies blood and transverses the ligament of the head of the femur (ie, the ligamentum teres).
- The labrum has a relatively low healing potential, because vessels penetrate only the outermost layer of the capsular surface.
  - Pertinent extra-articular neurovascular structures near the hip joint include the lateral femoral cutaneous nerve, femoral nerve, superior gluteal nerve, sciatic nerve, and the ascending branch of the lateral circumflex femoral artery.
  - The lateral femoral cutaneous nerve, formed from the posterior divisions of L2 and L3 nerve roots, supplies the skin sensation of the lateral thigh. It travels from the pelvis just distal and medial to the anterosuperior iliac spine (ASIS) and divides into more than three branches distal to the ASIS.
  - The femoral nerve and artery run together with the femoral vein. They pass under the inguinal ligament midway between the ASIS and the pubic symphysis, with the nerve being most lateral and the vein most medial but being mostly superficial at the level of the hip.
  - The femoral nerve is 3.2 cm from the anterior hip portal, but slightly closer at the level of the capsule.
  - The superior gluteal nerve, formed from the posterior divisions of L4, L5, and S1, passes posterior and lateral to the obturator internus and piriformis muscles, then between the gluteus medius and minimus muscles approximately 4 cm proximal to the hip joint.
- The sciatic nerve, formed when nerves from L4 to S3 come together, passes anterior and inferior to the piriformis and posterior to the deep hip external rotators to supply the hamstrings and lower leg, foot, and ankle.
  - The sciatic nerve is 2.9 cm from the posterior hip arthroscopy portal, but is closest at the level of the capsule.
  - Externally rotating or flexing the hip prior to making the posterior portal brings the nerve dangerously close to the arthroscope.
  - The lateral femoral circumflex artery is a branch of the femoral artery that, along with the medial circumflex artery, forms a vascular ring about the neck of the femur, providing arteriole branches to supply the femoral head (FIG 1D).
  - The lateral femoral circumflex artery is 3.7 cm inferior to the anterior arthroscopy portal; it is much closer at the level of the capsular entry of the arthroscope.

PATHOGENESIS

- Loose bodies can be ossified or nonossified, and can either appear after traumatic hip injury or be associated with conditions such as osteochondritis dissecans and synovial chondromatosis.
- Labral tear often results from hyperextension or external rotation of the hip and is more likely with hip dysplasia.
- Chondral (articular cartilage) damage can result from dislocation or subluxation of the hip or direct impact onto the hip and is associated with labral tears in more than half the cases.
  - Femoroacetabular impingement is a major cause of labral tears and chondral damage.
  - It usually occurs when there is loss of femoral head-neck offset (CAM impingement), excessive acetabular coverage (eg, osteophytes, retroversion, overcorrection with pelvic
osteotomy, protrusio acetabuli, or otto pelvis) (pincer impingement), or both.
- The femoral head–neck junction abuts the acetabulum and labrum, resulting in tearing of the labrum, delamination of the articular cartilage, synovitis, and, eventually, arthritis.
- Ligamentum teres pathology may be due to ligament hypertrophy or partial or complete tearing and may be the result of trauma or degenerative joint disease (DJD).
- Ligamentum hypertrophy or tearing may result in pain as a result of catching of a thickened or torn edge between the joint surfaces.
- DJD may be associated with loose bodies, labrum tears, chondral damage, ligamentum teres pathology, and synovitis.
- Avascular necrosis of the femoral head is primarily idiopathic, but can be associated with corticosteroid use, alcohol consumption, fracture, and deep sea diving (caisson disease), among others.
- Synovial diseases such as pigmented villonodular synovitis (PVNS), synovial chondromatosis, inflammatory arthritis, and osteochondromatosis can be sources of hip pain and joint damage.

**NATURAL HISTORY**
- The natural history of most pathologies about the hip has not been studied; much of the purported natural history is conjecture, therefore.
- Removal of loose bodies alleviates mechanical symptoms and reduces articular cartilage damage.
- Labral tears and chondral lesions that are debrided may result in degenerative arthritis.
- Untreated femoroacetabular impingement may result in degenerative arthritis.
- It has been proposed, but not proved, that labral repair or surgery for femoroacetabular impingement may lower the risk of developing DJD or slow the rate of degeneration.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The patient history should include an investigation of the quality and location of pain, timing and precipitating cause of symptoms, and any referred pain.
- Patients with intra-articular pathology may have difficulty with torsional or twisting activities, discomfort with prolonged hip flexion (eg, sitting), pain or catching from flexion to extension (eg, rising from a seated position), and greater difficulty on inclines than on level surfaces.²
- Intra-articular pathology may be associated with groin pain extending to the knee and mechanical symptoms such as popping, locking, or restricted range of motion (ROM).³
  - The source of intra-articular pathology should be investigated in patients with continuous hip pain for longer than 4 weeks.
- Physical examination methods are summarized later.
  - It is important to follow a systemic approach to examination that includes inspection, palpation, ROM, strength, and special tests.²⁶
- Intra-articular pathologies do not have palpable areas of tenderness, although compensation for longstanding intra-articular problems may result in tenderness of muscles or bursae.
- Motor strength and neurovascular examinations must be performed for the entire lower extremity.
- It is important to rule out other causes of pain referred to the hip.
  - Spinal pain usually is localized at the posterior buttock and sacroiliac region and may radiate to the lower extremity.
  - Injuries to the sacrum and sacroiliac joint are recognized by a positive gapping or transverse anterior stress test.
  - Abdominal injuries are recognized by basic inspection and palpation of the abdomen for a mass or fascial hernia, which can be evaluated by isometric contraction of the rectus abdominis and obliques.
  - Abdominal muscle injury is recognized by pain during contraction of the rectus abdominis and obliques.
  - Herniography may be used to rule out hernias.
    - Particularly difficult to diagnose is the sports hernia (Gilmore’s groin).
  - Genitourinary tract
    - Injuries to the pelvic area, such as pubic symphysis and intrapelvic problems, are recognized by the gapping/transverse anterior stress test.
- Specific tests for the hip include the following:
  - McCarthy test: distinction of internal hip pathology such as torn acetabular labrum or lateral rim impingement
  - Stinchfield and Fulcrum test: diagnosis of internal derangements, primarily of the anterior portion of the acetabulum
  - Scour test: associated with micro-instability or combined anterior anteverision; acetabular anteverision summation; hyperlaxity; or strain of the iliofemoral ligament
  - Thomas test: tests for flexion contracture. Extension to 0 degrees (in line with the body) without low back motion is normal. Less than full extension without rotating the pelvis or lifting the lower back is consistent with a flexion contracture.
  - Ober test: used to evaluate ilioband tightness. The test is positive when the upper knee remains in the abducted position after the hip is passively extended and abducted, then adducted, with the knee flexed. If, when the hip and knee are allowed to adduct while the hip is held in neutral rotation, the knee adducts past midline, the hip abductors are not tight; whereas if the knee does not reach to midline, then the hip abductors are tight.
  - Ely’s test: if on flexion of the knee the ipsilateral hip also flexes, then the rectus femoris is tight.
  - Trendelenburg test: indicative of hip abductor weakness, and may indicate labrum pathology that affects neuromusculo-propriocceptive function. If the pelvis (iliac crest or posterior superior iliac spine) of the ipsilateral hip of the leg that is lifted elevates from the neutral standing position, this is normal. If the pelvis drops below the contralateral pelvis or from the starting position (ie, iliac crest/posterior superior iliac spine) this is considered a positive Trendelenburg sign and indicative of hip abductor weakness of the muscles on the extremity standing on the ground. If the pelvis stays level, then this is indicative of mild weakness and recorded as level.
  - Patrick’s test (FABER test): indicative of sacroiliac abnormalities or iliopsoas spasm. Pain may be felt with downward stress on the flexed knee. Pain in the posterior pelvis may be considered a positive finding that indicates the pain is coming from the sacroiliac joint.
  - Labral stress test: indicative of labral tear. The patient will note groin pain or a click in a consistent position as the hip is being rotated.
  - Piriformis test: pain in the lateral hip or buttock reproduced by this maneuver is consistent with pain from the piriformis.
  - Impingement test: pain in the groin is a positive test and is consistent with femoroacetabular impingement.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Routine anteroposterior (AP) and lateral (usually cross-table lateral) radiographs should be obtained in all patients with hip pain to evaluate variations in bony architecture and visualization of areas that may present with hip pain such as the pubic symphysis, sacrum, sacroiliac joints, ilium, and ischium.
- Radiographs help exclude degenerative joint changes, osteonecrosis, loose bodies, stress fractures, or other osseous pathology, and help assess for acetabular dysplasia and femoral neck abnormalities (hump or cam lesion) and femoroacetabular impingement (FIG 2A,B).
- Bone scan or radionuclide imaging is sensitive in detecting fractures, arthritis, neoplasm, infections, and vascular abnormalities, but has low specificity and poor anatomic resolution.
- MRI is used to detect stress fractures of the femoral neck and to identify sources of hip pain such as osteonecrosis, pigmented villonodular synovitis, synovial chondromatosis, osteochondromas, and other intra-articular pathology.
- MRI arthrography can increase the ability to diagnose and describe labral pathology and articular cartilage loss (FIG 2C).
- MRI combined with the use of intra-articular local anesthetic with gadolinium is used to assess pain relief and provide evidence that intra-articular pathology may be causing pain.
- CT, MRI, and occasionally radioisotope imaging typically are required to help diagnose labral tears, hip instability, iliopsoas tendinitis, inflammatory arthritis, early avascular necrosis, occult fractures, psoas abscess, tumor, upper lumbar radiculopathy, or vascular abnormalities.
- CT scan can be useful to measure ante- and retroversion of the femoral neck and acetabulum, to show the size and shape of the acetabulum and femoral head and neck, to elucidate bony architecture, to confirm concentric reduction after hip dislocation, and to rule out loose bodies.
- Ultrasound is a nonionizing way of evaluating intra-articular effusions and soft tissue swelling.
- Iliopsoas bursography is the choice imaging modality to detect iliopsoas bursitis and internal snapping hip.
- Iliopsoas bursitis and internal snapping hip may be evaluated with real-time dynamic ultrasound.
- Three-dimensional CT is used to assess bony deformities, including oseophytes of the acetabulum and femoral neck bony lesions, which may cause impingement (FIG 2D).

**DIFFERENTIAL DIAGNOSIS**
- Labral tear
- Chondral delamination or degeneration
- Dysplasia
- Femoroacetabular impingement
- Synovitis
- Synovial chondromatosis
- Synovial osteochondromatosis
- Loose bodies
- Ligamentum teres tear
- Ligamentum teres hypertrophy
- Sepsis of the hip
- Arthritis of the hip
- Hip dislocation or subluxation
- Avascular necrosis of the femoral head
- Sacroiliac joint pathology, including ankylosing spondylitis
- Trochanteric bursitis
- Athletic pubalgia
- Femur, pelvic, or acetabular fractures or stress fractures
- Myotendinous strains
- Piriformis syndrome
- Myositis ossification
- Neurologic irritation
- Hamstring syndrome
- Iliotibial band syndrome
- Iliopsoas tendon problems (eg, snapping and tendinitis)
- Tendinitis
- Tendon injuries (iliopsoas, piriformis, rectus, hamstring, or adductor)
- Benign tumors (eg, osteoid osteoma, osteochondroma)
- Occult hernia
- Lumbar spine (mechanical pain and herniated discs)
- Abdomen
- Osteitis pubis

**FIG 2** • AP radiographs of the pelvis (A) and lateral hip (B) of a patient with concomitant developmental dysplasia of the hip and degenerative joint disease. C. MRI arthrogram of patient with femoroacetabular impingement. Note the subchondral edema and chondral lesion. D. Three-dimensional CT scan showing cam impingement with non-union of a superior acetabular stress fracture in a 32-year-old athletic man.
NONOPERATIVE MANAGEMENT
- Conservative therapy includes rest, ambulatory support, nonsteroidal anti-inflammatory drugs, and physical therapy.
- Most pathologies about the hip usually are treated initially with conservative management, including relative rest, NSAIDs, and rehabilitation. Occasionally, use of ambulatory assist devices may be needed.
- However, several intra-articular pathologies do not resolve or heal with nonoperative management, including labral tears, loose bodies, articular cartilage lesions, and femoroacetabular impingement.

SURGICAL MANAGEMENT
- Proper patient selection is essential for a successful surgical outcome.
- Arthroscopy is most successful for patients with recent, symptomatic intra-articular hip joint pathology, particularly those with mechanical symptoms, and minimal arthritic changes.
- Arthroscopy should be considered if hip pain is persistent, is reproducible on physical examination, and does not respond to conservative treatment.
- Pain relief with intra-articular injection of local anesthetic also is a good predictive sign for success.
- Indications for arthroscopy include loose bodies, foreign objects, labral tears, chondral injuries, synovial disease, femoroacetabular impingement, mild degenerative disease with mechanical symptoms, osteonecrosis of femoral head, osteochondritis dissecans, ruptured ligamentum teres, snapping hip syndrome, impinging osteophytes, adhesive capsulitis, iliopsoas tendon release, iliopsoas bursitis, trochanteric bursa, iliobial band resection, crystalline hip arthropathy, hip instability, joint sepsis, osteoid osteoma, osteochondroma, and unresolved hip pain.
- ROM should be evaluated before arthroscopy to determine the presence of contractures.
- Arthroscopy can be a means to delay total arthroplasty for DJD.
- Contraindications include systemic illness, open wounds, soft tissue disorders, poor bone quality (ie, unable to withstand traction), non-progressing avascular necrosis of the femoral head, arthrofibrosis or capsular constriction, and ankylosis of the hip.
- Severe obesity is a relative contraindication that may be circumvented with extra-length instruments.
- Indications for labrectomy include relief of pain with intra-articular injection of anesthetics, no pain relief with physical therapy or nonsteroidal anti-inflammatory drugs, missed time due to delayed diagnosis, and symptoms for longer than 4 weeks.
- Arthroscopy for DJD should be considered for younger patients with mild-moderate disease who present with mechanical symptoms and no deformity.
- Microfracture is indicated for grade IV chondral lesions with healthy surrounding articular surface and intact subchondral bone.
- Treatment of sepsis involves drainage, lavage, débridement, and postoperative antibiotics, and requires early diagnosis.
- Sepsis in the setting of joint arthroplasty requires prompt arthroscopic débridement, well-fixed components, a sensitive microorganism, and patient tolerance to and compliance with antibiotic therapy.15

Preoperative Planning
- A physical examination should be completed and radiographs and other imaging reviewed before arthroscopy.
- A three-dimensional CT scan may be obtained to further assess bony abnormalities (see Fig 2D).
- Arthroscopy usually is performed under general anesthesia.
- If epidural anesthesia is used, it also requires adequate motor block to relax muscle tone.
- Typical instrumentation includes a marking pen; no. 11 blade scalpel; 6-inch 17-gauge spinal needles; 60-mL syringe of saline with extension tubing; a Nitanol guidewire; 4.5-, 5.0-, and 5.5-mm cannulas with cannulated and solid obturators; a switching stick; a separate inflow adaptor; and a modified probe.
- Fluid used can be introduced by gravity or a pump.
- Specialized arthroscopy equipment for the hip is available that is extra-long and extra-strong to withstand the lever arm due to the extra length. These instruments include shavers, burrs, biter, probes, curettes, and loose body retrievers.

Positioning
- The patient may be placed in either the supine or lateral decubitus position on a fracture table or attachment that allows for distraction of the hip joint.
- The lateral decubitus position offers the benefit of directing fat away from the operative site.
- The involved hip joint is in neutral rotation, abducted at 10 to 25 degrees, and in neutral flexion-extension (FIG 3A).
- Flexion of the involved hip during distraction and portal placement increases the risk of injury to the sciatic nerve.
- The nonoperative hip also is abducted and is placed under slight traction to stabilize the patient and allow placement of the image intensifier between the legs and directed over the operative hip.
- A heavily padded perineal post is placed against the pubic ramus and ischial tuberosity, but lateralized against the medial thigh of the operative hip, with care taken to protect perineal structures (FIG 3B).
- It is important to lateralize the traction vector such that it is parallel to the femoral neck to minimize risk of pressure neuropraxia to the pudendal nerve, and to optimize distraction of the joint.
- The surgeon, assistant, and scrub nurse stand on the operative side, facing the arthroscopic monitor on the opposite side of the patient (FIG 3C, D).
- The fluoroscopy monitor is placed at the foot of the fracture table.

Approach
- Portal placement and arthroscopic technique do not differ between the supine and lateral decubitus positions.
- Hip arthroscopy usually is performed through three portals: anterolateral, anterior, and posterolateral.
- A shortened bridge can accommodate the use of 4.5-, 5.0-, and 5.5-mm cannulas.
- Although a 5.0-mm cannula is used for initial entry of the arthroscope, a 4.5-mm cannula permits interchange of the inflow, arthroscope, and instruments, and a 5.5-mm cannula allows entry of larger instruments (eg, shaver blades).
A 30-degree videoarticulated arthroscope provides best visualization of the central portion of the acetabulum, the femoral head, and the superior aspect of the acetabular fossa.

A 70-degree videoarthroscope provides optimal visualization of the periphery of the joint, the acetabular labrum, and the inferior aspect of the acetabular fossa.

The holmium YAG laser and radiofrequency device are used to ablate tissue and can offer increased maneuverability over shavers.

Extra-length convex and concave curved shaver blades are used to remove tissue around the femoral head.

Fragile, extra-length instruments designed for other arthroscopic procedures should be avoided, because these have a greater tendency to break.

**HIP DISTRACTION**

- The patient is prepared with chlorhexidine (Hibiclens) or povidone-iodine (Betadine).
- Traction is applied to distract the joint 7 to 10 mm.
- A tensiometer may be used to monitor traction force (typically 25 to 50 pounds).
- Traction time should be monitored. It is important to limit the time to less than 2 hours to prevent complications such as compression of the pudendal nerve or injury to other nerves.

- The spinal needle is introduced under fluoroscopy at the anterolateral position into the joint capsule to equilibrate the space with the ambient pressure (TECH FIG 1A,B).
- Pressure in the joint may be equilibrated with air or saline (TECH FIG 1C).
- Care should be taken to avoid penetrating the labrum and articular surfaces with the spinal needle.
Portals are established by penetrating the skin with a 6-inch 17-gauge spinal needle and positioning the needle into the respective joint space.

The trocar of the spinal needle is removed and a Nitanol guidewire (Smith & Nephew Endoscopy, Andover, MA) is run through the needle into the joint space (TECH FIG 2A,B).

The needle is removed.

A long cannula sheath with cannulated trocar is advanced over the guidewire into the joint space (TECH FIG 2C–E).

The cannulated obturator should be kept off the femoral head to avoid articu lar damage.

It is important to avoid cannula removal and reintroduction, because this may damage cartilage.

It may be necessary to release the capsule with an arthroscopic knife.

The weight-bearing portion of the femoral head is visualized by using the arthroscope in all three central compartment portals with the 70- and 30-degree lenses or by internally and externally rotating the hip intraoperatively.

The fossa and ligamentum teres typically are visualized from all three portals, particularly using the 30-degree lens.
ANTEROLATERAL PORTAL

- The anterolateral portal is created first because it is the safest, being the most distant from and posing least risk of injury to the femoral and sciatic neurovascular structures.
- The portal penetrates the gluteus medius muscle and is positioned directly over the superior aspect of the greater trochanter at its anterior margin to enter the lateral capsule at its anterior margin (TECH FIG 3).
- When creating the anterolateral portal, it is important to introduce the spinal needle in the coronal plane by keeping it parallel to the floor (see Tech Fig 2A).
- As the cannula is positioned into the intra-articular space, care should be taken to avoid damage to the labrum or articular surfaces.
- The portal provides visualization of most of the acetabular cartilage, labrum, and weight-bearing femoral head within the central compartment, as well as visualization of the peripheral compartment, such as the non-weight-bearing femoral head, the anterior neck, the anterior intrinsic capsular folds, and the synovial tissues beneath the zona orbicularis and the anterior labrum.
- The superior gluteal nerve is the closest neurovascular structure and runs 4.4 cm posterior to the portal.

ANTERIOR PORTAL

- I prefer to establish the anterior portal after the anterolateral portal, although some prefer to establish the anterior portal first.
- Arthroscopic visualization from the anterolateral portal and fluoroscopy facilitate correct portal placement, helping to avoid damage to the labrum or articular surfaces.
- The anterior portal enters at the junction of a line drawn distally from the anterosuperior iliac spine and a transverse line across the superior margin of the greater trochanter (TECH FIG 4A).
- The portal penetrates the sartorius and rectus femoris muscles as it is directed 45 degrees cephalad and 30 degrees medially to enter the anterior capsule (TECH FIG 4B,C).
- As the cannulated obturator enters the joint space, it should be kept off the articular surface and directed underneath the acetabular labrum.
- The portal allows visualization of the anterior femoral neck, the anterior aspect of the joint, the superior retinacular fold, the ligamentum teres, and the lateral labrum.

TECH FIG 3 • The anterolateral portal starts just anterior to the superior aspect of the greater trochanter and pierces the gluteus medius muscle.

TECH FIG 4 • The anterior portal usually is the second portal made and is created under arthroscopic visualization with a 70-degree arthroscopic lens from the anterolateral portal and fluoroscopic visualization. A. Introduction of the spinal needle using the junction of the superior aspect of the greater trochanter and a line drawn inferiorly from the anterior superior iliac spine (ASIS) as the starting point. B. Fluoroscopic view of the arthroscope in the anterolateral portal and spinal needle being introduced from the anterior portal. (continued)
Care should be taken to minimize injury to branches of the lateral femoral cutaneous nerve by directing movement medially, avoiding deep cuts at the entry site, not using vigorous instrumentation, and using a 70-degree arthroscope at the anterolateral portal to guide entry (TECH FIG 4D).

- The femoral nerve is 3.2 cm medial and runs tangential to the portal.
- The ascending branch of the lateral femoral circumflex artery is 3.7 cm inferior to the portal, but terminal branches may be within millimeters of the portal at the capsular level.

POSTEROLATERAL PORTAL

- The posterolateral portal is established after the anterior portal (TECH FIG 5A).
- Arthroscopic visualization and fluoroscopy are used to guide portal placement.
- The portal penetrates the gluteus medius and minimus muscles and is directed over the superior aspect of the greater trochanter at its posterior border to enter the lateral capsule at its posterior margin (TECH FIG 5B).
- The portal is superior and anterior to the piriformis.
- The portal allows visualization of the posterior aspect of the femoral head, the posterior labrum, the posterior capsule, and the inferior edge of the ischiofemoral ligament (TECH FIG 5C).
- The sciatic nerve is 2.9 cm posterior to the portal at the level of the capsule.
  - It is important to maintain the leg in neutral rotation and extension, and to introduce the spinal needle horizontally to avoid injury to the sciatic nerve.

TECH FIG 4 • (continued) C. Schematic depiction of the location of the portal adjacent to the branches of the lateral femoral cutaneous nerve, penetrating the sartorius and rectus femoris muscles. D. Care is taken only to cut the skin when making the anterior portal, to help reduce the risk of laceration of the lateral femoral cutaneous nerve.

TECH FIG 5 • Posterolateral portal. The posterolateral portal usually is the last central portal made, although it can be made before the anterior portal. A. How the posterolateral portal is made, relative to the other portals. (continued)
**TECH FIG 5 • (continued)**

**B.** The posterolateral portal proceeds through the gluteus medius and minimus muscles. Note its relation to the superior gluteal nerve. **C.** View of obturators in all three central compartment portals to allow for complete central compartment hip arthroscopy. Both a 30- and a 70-degree lens are used in all the portals to allow for full visualization of the femoroacetabular joint to perform a complete hip arthroscopy of the central compartment.

---

**DISTAL ANTEROLATERAL PORTAL**

- To access the peripheral compartment–femoral neck region, two portals are used after traction is removed from the extremity.
- Peripheral compartment arthroscopy can be done in hip flexion to relax the anterior capsule or in neutral flexion extension.
- The anterolateral portal is used as one portal.
- A distal anterolateral portal is established 3 to 5 cm distal to the anterolateral portal, just anterior to the lateral aspect of the proximal femoral shaft and neck (**TECH FIG 6**).
- Fluoroscopy is used to guide portal placement.
- The portal penetrates the gluteus medius muscle and upper vastus lateralis.
- The spinal needle should enter the peripheral compartment laterally. The guidewire is brought through the spinal needle and can be gently advanced to the medial capsule—the easy passage until the medial capsule is reached helps confirm that one is in the peripheral compartment.
- The skin incision is made, and the trocar and the sheath are passed over the guidewire.
- The sheath and guidewire are exchanged for the arthroscope or instrumentation.
- Arthroscopy and fluoroscopy can be used together to perform surgery in the peripheral compartment.

**TECH FIG 6 •** Distal anterolateral portal. The distal anterolateral portal allows a second portal for peripheral compartment arthroscopy. This portal is 2.5 to 5 cm distal to the anterolateral portal (**A**). This example shows the hip in neutral flexion–extension, which makes it easier to perform a chielectomy or osteoplasty for cam-type femoroacetabular impingement to maintain orientation while using fluoroscopy to assist with the procedure (**B**). Alternatively, the hip can be flexed, relaxing the anterior capsule, making entry into the joint easier.
PEARLS AND PITFALLS

| Patient selection | • A careful patient history, physical examination, and appropriate imaging should be performed. |
| • Distinguish intra-articular conditions that may require surgery for extra-articular problems that may only require conservative treatment. |
| • Patients should have clear expectations of outcomes. |
| Hip distraction | • Distract the hip with as much force as necessary to safely introduce instruments, typically 8 to 10 mm. |
| • Limit traction time to 2 hours or take a traction break if it is necessary to exceed this time. |
| • Too little traction may result in injury to the articular surfaces. |
| • Too much traction can result in nerve injury or injury to the perineum, knee, foot, or ankle. |
| Patient positioning | • Obtain the correct vector of joint distraction with minimal force necessary to distract the joint. |
| • The perineal post should be adequately padded and lateraledized against the involved hip. |
| Portal placement | • Proper placement of the anterolateral portal is key to successful placement of other portals. |
| • It is important to avoid damaging the labrum or articular surfaces with either the spinal needle or cannula introduction. |
| • Use inflow from the secondary portal to improve fluid dynamics or use a pump. |
| • Use both 30- and 70-degree cannulas in each portal. |
| • Use specialized hip arthroscopy instruments and metal cannulas to reduce risk of instrument breakage and allow proper technique. |
| • Avoid inserting the cannula multiple times to reduce fluid extravasation and the risk of damage to labrum, cartilage, and neurovascular structures. |
| • Maintain systolic blood pressure below 100 mm Hg and use a radiofrequency device to minimize bleeding. |

POSTOPERATIVE CARE

• Traction is released.
• Long-acting local anesthetic is injected into the joint.
• The portals are sutured, and a sterile dressing is applied to the wounds.
• Arthroscopy is an outpatient procedure, and the patient typically leaves recovery after 1 to 3 hours.
• If arthroscopy does not involve bony recontouring of the femoral neck, labral repair, or microfracture of the articular surfaces, then the patient is allowed to walk immediately, although weight bearing should be limited by crutches for 3 to 7 days or until gait pattern is normalized.
• Rehabilitation should take into consideration soft tissue healing constraints, control of swelling and pain, early ROM, limitations on weight bearing, early initiation of muscle activity and neuromuscular control, progressive lower extremity strengthening and proprioceptive retraining, cardiovascular training, and sport-specific training.
• Swelling and pain are controlled by ice and non-aspirin non-steroidal anti-inflammatory drugs.
• The dressing is removed on the first or second postoperative day, and the wound is covered with adhesive bandages.
• Portal sutures are removed a few days after surgery.
• Patients who undergo labrum repairs on the anterior superior region and capsulorraphy should follow specific ROM and weight bearing guidelines.
• Patients who undergo osteoplasty should limit impact activities that increase the risk of femoral neck fracture during the initial several weeks.
• Patients who undergo microfracture should adhere to 8 to 10 weeks of protected weight bearing on crutches.

OUTCOMES

• Record functional and prosthetic survivorship data, as applicable.
• Loose bodies are the clearest indication for arthroscopy, resulting in less morbidity and faster recovery than open surgery.8
• Labral débridement has been shown to result in successful outcomes in 68% to 82% of cases, with positive outcomes associated with isolated tears and poorer prognosis associated with arthritis.2,10,27
• Débridement of ligamentum teres, like labral débridement, has shown best results when lesions are isolated and without associated acetabular fracture or significant osteochondral defect of either the acetabulum or femoral head.
• Treatment of hip DJD by arthroscopy has shown unpredictable results, with a range of 34% to 60% of patients reporting improvement of symptoms after arthroscopic débridement for DJD.11,31
• One study reported that 86% of patients treated for chondral lesions by microfracture showed a successful response at 2-year follow-up.1
• Arthroscopic synovectomy is palliative, and success is based on the integrity of the articular cartilage.
• Treatment of femoroacetabular impingement has shown better outcomes when there is less DJD.
• Treatment of AVN is controversial—the results are better when the articular surface is not disrupted or when treating mechanical symptoms.
• O’Leary23 reported 40% of patients improved at 30-month follow-up.
• More specifics are provided in the chapters describing specific techniques for the different processes treated about the hip.

COMPLICATIONS

• Traction neurapraxia
• Direct trauma to pudendal, lateral femoral cutaneous, femoral, and sciatic nerves
• Iatrogenic labral and chondral damage
• Fluid extravasation
• Vaginal tear
• Pressure necrosis to scrotum, labia and perineum, and foot
• Labia and perineum hematoma
Knee ligament injury
Ankle fracture
Femoral head avascular necrosis
Fracture of femoral neck
Instrument breakage
Portal hematoma and bleeding

REFERENCES
DEFINITION
- Soft tissue pathology of the hip includes labral tears, articular damage, and lesions of the ligamentum teres, all of which share several common features.
- The clinical presentations may be indistinguishable, and these lesions often coexist. They represent significant causes of disabling hip pain that can be elusive to clinical detection.
- The diagnosis sometimes is based just on maintaining an index of suspicion. Often these lesions have gone undiagnosed and untreated, with the patient simply resigned to living within the constraints of their symptoms.

ANATOMY
- The horseshoe or lunate articular surface of the acetabulum surrounds the acetabular fossa (FIG 1).
- The articular surface of the femoral head forms about two thirds of the sphere, with an indentation medially where the ligamentum teres attaches at the fovea capitis.
- The diameter of the femoral neck normally is 65% of the diameter of the femoral head, allowing clearance of the acetabulum during range of motion (ROM).
- The fibrocartilaginous labrum is triangular in cross section, forming a rim around the articular surface of the acetabulum.
- Inferiorly, it is contiguous with the transverse acetabular ligament, which traverses the inferior aspect of the fossa. Its morphology and size can be quite variable, especially anterior and superior.
- The shape of the posterior labrum is the most consistent and least often damaged landmark, representing a useful reference in the arthroscopic assessment of labral pathology.
- Unlike the shoulder, there is no capsulolabral complex; the capsule attaches directly to the acetabulum separate from the labrum. Thus, acetabular labral pathology is not as synonymous with instability as that of the glenoid.
- Konrath et al17 have shown that the labrum has minimal mechanical properties for distributing forces across the acetabular surface. Similarly, Ferguson13 has demonstrated that the labrum has minimal mechanical properties for stabilizing the joint, but its hydraulic seal is important.
- The ligamentum teres has a serpentine course from its acetabular attachment in the posterior fossa to the fovea capitis of the femoral head. Its precise function remains an enigma.

FIG 1 • Macroscopic anatomy of the hip joint. (Courtesy of Delilah Cohn.)
In childhood, its vessel contributes to the blood supply of the femoral head. Its redundant nature implies that it contributes little to joint stability, but it may have nociceptive and proprioceptive functions.

Gray and Villar have postulated that its windshield wiper effect during ROM may facilitate joint lubrication. Its dimensions are variable, and sometimes it is absent in adulthood.

**PATHOGENESIS**

- The etiologies of soft tissue lesions in the hip are numerous and variable. Breakdown may result from supraphysiologic loads on normal tissue, physiologic loads on abnormal tissue, or, commonly, mildly supraphysiologic loads on mildly abnormal tissue.
- Supraphysiologic loads may be the result of macrotrauma or repetitive microtrauma.
- Athletes are especially prone to pushing their bodies beyond the physiologic limits where breakdown occurs.
- Once this point has been passed, reversal of the damage often is incomplete, even with surgical intervention. Variable joint morphology often is a contributing factor.
- Labral tears can occur from compression, commonly associated with impingement; traction associated with excessive translation of the femoral head; and shear forces, typically associated with acetabular dysplasia.
- Articular damage can be caused by acute trauma or degenerative disease. A propensity for acute articular fracture has been identified in physically fit young men, resulting from a direct lateral blow to the trochanter.
- There is little adipose tissue over the trochanter to cushion the blow; and with high bone density fracture does not occur, so the force is delivered directly to the joint surface.
- Lesions of the ligamentum teres can occur from acute trauma or degeneration.
- The ligament is most taut with adduction and external rotation, but acute rupture has been identified with a variety of mechanisms.
- Deterioration of the ligament occurs with degenerative disease, and the ligament is sometimes hypertrophied, making it more susceptible to degenerate rupture.
- Femoroacetabular impingement (both pincer and cam type) has been recognized as a causative factor in the development of soft tissue joint damage. It is the soft tissue damage that then becomes symptomatic, necessitating treatment.
- Pincer impingement is associated primarily with labral pathology due to excessive compression and then secondary development of articular breakdown (FIG 2A).
- Cam impingement is associated with selective articular delamination of the anterolateral acetabulum with a variable amount of associated labral pathology (FIG 2B).
- Dysplasia is associated with breakdown of the labrum, articular surface, and ligamentum teres.
- The labrum often is enlarged, with more weight-bearing responsibility, making it susceptible to a breakdown from shear forces. It also can become inverted within the joint and susceptible to deterioration.
- The reduced surface area of the acetabulum results in increased contact forces, which may exceed the structural integrity of the articular cartilage.
- Hypertrophy of the ligamentum teres occurs in association with dysplasia, and the hypertrophied ligament is more susceptible to degenerative rupture.

**NATURAL HISTORY**

- The natural history of these soft tissue lesions is variable. Some conditions deteriorate quickly, whereas others may remain stable for a protracted period of time, and some become asymptomatic.

---

**FIG 2**

A. Pincer impingement: mechanism of labral breakdown. B. Cam impingement: mechanism of articular delamination.
Labral degeneration has been observed as an unavoidable consequence of age and is found to be uniformly present in persons over 70 years of age.\textsuperscript{18} Abnormal hip morphology, including impingement and dysplasia, may be found even in absence of joint pathology. When symptomatic soft tissue pathology occurs, it is important to assess for predisposing morphology. Some conditions may remain stable for an indefinite period; however, progressive worsening of symptoms usually dictates more proactive intervention.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Examination of the hip joint is fairly straightforward.\textsuperscript{3} Much of the assessment revolves around ruling out other problems. Patients with chronic hip joint pathology will start to develop other conditions secondarily as they compensate for the joint.
- The secondary conditions, such as gluteal pain or trochanteric bursitis, may be more evident, obscuring the underlying diagnosis. In addition, other conditions such as lumbar spine disease may coexist with hip joint disease.
- There is a significant correlation between hip joint pathology and athletic pubalgia in athletes.
- Increased pelvic motion compensates for restricted hip motion, placing more stress on the pelvic stabilizers and resulting in the soft tissue breakdown characterized by athletic pubalgia.
- The history of injury is variable, with some patients describing a major traumatic event. Others may recount an acute episode such as twisting. In these circumstances, however, the clinician should look closely for predisposing factors, because a healthy joint should be able to withstand these forces.
- Some patients simply describe the insidious or gradual onset of symptoms, further indicative of underlying disease.
- A history of a significant traumatic event indicates a more favorable prognosis of a potentially correctable problem.
- Similarly, mechanical symptoms such as sharp stabbing pain, catching, or locking are favorable indicators for surgical intervention.
- Simply having pain, with or without activity, is a poorer prognostic indicator for the success of arthroscopy.
- Numerous characteristic features of hip joint symptoms have been identified.\textsuperscript{3}
  - Straight plane activities, including running, often are well tolerated.
  - Pivoting and twisting maneuvers usually are more troublesome.
  - Squatting and prolonged hip flexion such as sitting often will exacerbate hip symptoms.
  - Patients may experience a catching sensation when rising from a seated position.
  - Ascending and descending stairs or inclines is more troublesome than walking on level surfaces.
  - Entering and exiting an automobile is very characteristic for recreating symptoms, because it loads the hip in a flexed position while introducing a torsional component.
  - Dyspareunia due to hip pain is uniformly present in sexually active individuals.
  - Difficulty getting shoes and socks on and off usually indicates restricted motion and more advanced disease.
- Localization of the symptoms starts with an understanding that the L3 nerve root serves as the principal innervation of the hip.
- Symptoms, therefore, are sometimes referred to the L3 dermatome, explaining the presence of medial-sided thigh and knee pain.
  - The C-sign is very characteristic of hip joint pathology.
  - Describing their symptoms, patients will cup their hand in the shape of a C above the greater trochanter, gripping their fingers into the groin.
  - Most patients describe groin or anterolateral pain.
- Posterior pain rarely is indicative of hip joint pathology, but may occasionally be a presenting feature.
- It is important to record ROM in a consistent fashion for comparing sides as well as for comparison on subsequent examination.
- Recording flexion and extension must take into account the contributing components of pelvic and lumbar motion. Rotational motion is different when measured in extension versus flexion.
- The log roll test is the most specific test for hip joint pathology:
  - The leg is rolled back and forth, rotating only the femoral head in relation to the acetabulum and capsule, without tensioning any of the surrounding soft tissue structures.
  - The impingement test generally has been found positive for virtually any irritable hip joint, regardless of the nature of the pathology.
  - The leg is placed in maximal flexion, adduction, and internal rotation.
  - This maneuver is more sensitive for hip joint pathology, but may be uncomfortable even in a healthy hip. Thus, it is important to compare the symptomatic to the asymptomatic side.
  - It also is important to distinguish whether this test recreates the type of symptoms that the patient experiences with activity, more than simply whether or not it is uncomfortable.
  - Abduction with external rotation also can be sensitive for eliciting hip joint symptoms.
  - It may impinge upon posterior lesions or exacerbate anterior symptoms from translation of the femoral head and, thus, is not especially specific for the location or type of intra-articular pathology.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Radiographs are important for assessing hip morphology.
- A properly centered anteroposterior pelvis radiograph is essential for assessing the morphology of the hip and comparing the affected to the unaffected side (FIG 3).
- The optimal lateral view has yet to be determined, but a standardized reproducible lateral radiograph of the affected hip should be obtained in every case.
- Radiographs usually are normal with regard to specific findings indicative of soft tissue pathology in the hip.
- The soft tissue disease usually is far advanced before any radiographic indices emerge.
- Thus, it is important to scrutinize the radiographs carefully, assessing for subtle indicators of change.
- For example, slight joint space narrowing usually indicates advanced intra-articular disease, and should be viewed
as a cautious indicator in counseling patients on the role of arthroscopy.

- MRI can be useful for the evaluation of hip pathology.
- Low-resolution studies (eg, open magnets and small scanners) are unreliable at detecting hip joint pathology.
- High-resolution scans (eg, 1.5-Tesla magnet, surface coils) are superior but still present limitations.\(^5\)
  - They are best at detecting labral pathology but generally poor at assessing the articular surface or the status of the ligamentum teres.
  - Caution is necessary in assessing labral lesions, because these have been identified in studies of asymptomatic volunteers and occur uniformly as a consequence of age.
  - Indirect findings often are the most reliable.
  - Evidence of an effusion in a symptomatic hip is highly indicative of joint pathology.
  - Paralabral cysts are pathognomonic of labral damage and subchondral cysts are indicative of associated articular damage.
  - Gadolinium arthrography with MRI (MRA) has a greater sensitivity than MRI, but introduces some risk of overinterpreting pathology.\(^5\)
  - A particular challenge is differentiating a labral tear from a normal labral cleft.
  - Assessment of the patient’s symptomatic response to the anesthetic effect of an intra-articular injection is the most reliable diagnostic feature.
  - The intra-articular injection always should include a long-acting anesthetic (eg, bupivacaine).
  - However, this evaluation depends on the patient being able to perform activities that recreate pain prior to injection so that the same activities can be recreated post-injection to assess the amount of pain relief.
  - CT can be superior to MRI for assessing bony architecture.
  - Three-dimensional reconstructions are especially useful in assessing cam impingement.
  - Bone scans are relatively inexpensive, provide a good skeletal survey tool, and can be helpful in assessing osseous homeostasis around the hip.

**DIFFERENTIAL DIAGNOSIS**

- Hip flexor or adductor strain
- Hernia
- Athletic pubalgia
- Nerve entrapment
- Upper lumbar disc
- Referred from visceral origin (eg, gastrointestinal, genitourinary, gynecologic)

**NONOPERATIVE MANAGEMENT**

- Nonoperative management begins with informing the patient on the nature of the disorder; and education regarding warning signs of progressive damage, especially worsening symptoms.
- Activity modification often is necessary to modulate associated discomfort. This may be temporary while managing the acute phase of an injury, or may be long-term for patients coping with a chronic process.
- Distraction mobilization techniques may reduce discomfort and improve function while optimizing ROM.
- Closed-chain stabilization exercises usually are well tolerated and help to protect the joint.
- Trunk and core strengthening are integral to functional recovery.

**SURGICAL MANAGEMENT**

- Surgical intervention is indicated for mechanical symptoms in the presence of clinically suspected joint pathology.
- Conservative treatment may be appropriate for stable, manageable symptoms. A more proactive approach may be indicated if the symptoms are not manageable or demonstrate progressive worsening with time.
- In selecting patients for surgical management, the most important assessment tools are the history and physical examination.\(^5\)
- Imaging studies are helpful only when interpreted in the context of the overall clinical evaluation.
- The surgeon should not be lured by false-positive interpretations or dissuaded by false-negative results.

**Preoperative Planning**

- Numerous intra-articular hip lesions may have similar clinical presentations.
- Imaging studies may only partly reflect the extent of pathology.
- Recent radiographs should be available for review in addition to any other tests that have been performed.
- Radiographic evidence of joint deterioration can occur within a few months; thus, old radiographs are not useful.
- Findings of progressive joint space loss may contraindicate a planned arthroscopic procedure.
- The patient must be properly informed regarding the suspected nature of the joint pathology and also any comorbid conditions that will not be addressed by the procedure.
- The patient should have reasonable expectations of what can be accomplished and the uncertainty regarding what associated pathology may be encountered.

**Positioning**

- Arthroscopy of the intra-articular (“central”) compartment of the hip requires distraction.
Proper positioning is essential to the safety and efficacy of the procedure. A well-padded perineal post should be secured against the ischium but lateralized against the medial thigh (FIG 4A). This keeps the post away from the pudendal nerve and aids in achieving the optimal vector for distraction. Applying slight counter-traction to the nonoperative leg stabilizes the pelvis and keeps the post from shifting as traction is then applied to the operative leg. The amount of abduction of the operative leg can be variable. Less abduction may be necessary with a varus hip to make it possible to introduce the cannulas above the trochanter but enter the joint underneath the lateral lip of the acetabulum. Neutral rotation during portal placement maintains a consistent relationship between the greater trochanter and the joint. Slight flexion (10 degrees) relaxes the capsule and may facilitate distraction (FIG 4B). Excessive flexion should be avoided, because it can place tension on the sciatic nerve and reduce anterior access to the joint. Most standard fracture tables can accomplish the positioning necessary for hip arthroscopy. Specialized positioning devices are more practical for ambulatory surgery centers. These are more affordable and transportable, adapting to standard OR tables. Arthroscopy of the peripheral compartment is performed with traction released and hip flexed (FIG 4C). Traction is released only after the instruments have been removed from the central compartment. Flexion relaxes the capsule, opening the space within the periphery.

Approach
For the intra-articular (“central”) compartment, three standard portals (anterior, anterolateral, and posterolateral) allow access for virtually all procedures (FIG 5A,B). The lateral two portals usually are the easiest to position, but the anterior portal provides the greatest versatility and access to the medial joint space. Eighty percent of the intra-articular pathology resides in the anterior half of the hip and is accessible from the two anteriormost portals. However, the posterolateral portal is important for routine inspection of the posterior recesses as well as access for posteriorly based lesions and the acetabular fossa. Two portals usually are sufficient for the peripheral compartment, but the positioning is widely variable, depending on the nature and location of the pathology to be addressed (FIG 5C,D).
LABRAL DÉBRIDEMENT

- Most symptomatic labral tears are managed with selective débridement of the damaged portion (TECH FIG 1).
- Emphasis is given to preserving healthy tissue, because removal of normal labrum can lead to poorer results.
- A complete joint survey is performed with thorough inspection and palpation of the labrum, identifying its damaged portion.
- Most labral resection is carried out with a power shaver, debulking the damaged tissue.
- Hand instruments and an arthroscopic knife may aid in this resection.
- It is important to preserve the healthy tissue but create a stable transition zone when completing the débridement.
- A radiofrequency device is especially useful for this because of the limited maneuverability imposed by the architecture of the joint.
- Diseased tissue has an increased water content and responds selectively to the thermal device.
LABRAL REPAIR

- Labral repair is best suited for young patients when it is believed that simple débridement may result in inordinate sacrifice of healthy tissue (TECH FIG 2).
- An optimal pattern is a tear at the articulolabral junction where a large segment of otherwise healthy tissue has been detached.
- Labral function is most dependent on its fluid seal. Thus, the goal of repair is to reapproximate the labrum to the adjacent acetabulum.
- The mechanical properties of the labrum are minimal; therefore, the recreation of a bolster effect such as that in the shoulder is not necessary.

TECH FIG 1 • Arthroscopic view of a right hip from the anterior portal. A. A fragmented labral tear with degeneration within its substance is identified. B. Débridement is initiated with the power shaver. C. A portion of the comminuted labral tear is conservatively stabilized with a radiofrequency probe. D. The damaged portion has been removed, preserving the healthy substance of the labrum.

TECH FIG 2 • A. Sagittal MRA image demonstrates an anterior labral tear (arrow). B. Arthroscopy reveals a traumatic detachment of the anterior labrum (indicated by the probe). C. An anchor has been placed with suture limbs passed in a mattress fashion through the detached labrum. D. The labrum has been reapproximated to the articular edge. E. Viewing the peripheral aspect of the labrum, the suture is seen on its capsular surface, avoiding contact with the articular surface of the femoral head. (Courtesy of J. W. Thomas Byrd, MD.)
An anchor should be placed adjacent to the articular edge; it is not necessary for it to be placed on its surface.

The angle created by the articular surface and the bony edge of the acetabulum is more acute than its counterpart in the shoulder, which is created by the articular surface and bony face of the glenoid.

Thus, the direction of anchor entry is more critical, especially to avoid perforation of the articular cartilage. This direction is dictated by the position of the cannula.

The standard portal placements lend themselves well to anchor placement, but if the direction of entry does not seem appropriate, it is best to simply establish another portal with the proper angle for anchor entry.

The anchor is seated adjacent to the articular surface, between it and the detached labrum.

Passage of the suture limbs through the detached labrum can then be accomplished with various suture-passing devices.

It is important that the sutures not be left interposed between the labrum and the articular surface of the femoral head, because this can result in third-body wear on the articular cartilage.

Passing the sutures in a mattress fashion accomplishes reapproximation of the labrum, recreating the seal and avoiding interposed suture in the joint.

CHONDROPLASTY

Chondroplasty of unstable articular fragments is performed in the hip, just as in other joints.

Technical challenges are imposed by the limited instrument maneuverability.

Curved shaver blades aid in navigating the constrained joint architecture (TECH FIG 3A–C).

Radiofrequency devices can further assist in ablating damaged tissue, even within the constraints of the joint. Judicious use is imperative to avoid thermal injury.

Like other joints, microfracture of select grade IV lesions can be performed (TECH FIG 3D–G).

Microfracture is indicated primarily for discrete lesions with healthy surrounding articular surface.

TECH FIG 3 • A. Coronal MRI demonstrates evidence of labral pathology (arrow). B. Arthroscopy reveals extensive tearing of the anterior labrum (*) as well as an adjoining area of grade III articular fragmentation (arrows). C. The labral tear has been resected to a stable rim (arrows), and chondroplasty of the grade III articular damage (*) is being performed. D. Coronal MRI demonstrates evidence of labral pathology (arrow). E. Arthroscopy reveals the labral tear (arrows), but also an area of adjoining grade IV articular loss (*). F. Microfracture of the exposed subchondral bone is performed. G. Occluding the inflow of fluid confirms vascular access through the areas of perforation. (Courtesy of J. W. Thomas Byrd, MD.)
ARTHROSCOPIC REPAIR OF LESIONS OF THE LIGAMENTUM TERES AND PULVINAR

- Disrupted fibers of the ligamentum teres, whether from trauma or degeneration, can be quite painful, creating soft tissue impingement within the joint.
- Associated with this soft tissue impingement, the pulvinar tissue often is hyperplastic or fibrosed and also can create painful symptoms.
- Indiscriminate débridement of the ligamentum teres should be avoided and intact fibers preserved; however, débridement of the disrupted portion can be quite beneficial (TECH FIG 4).

Most of the contents of the acetabular fossa are best accessed from the anterior portal.
- However, a portion of the posterior contents often is best accessed with instrumentation introduced from the posterolateral portal.
- Between these two sites most pathologic processes can be accessed with combinations of straight, curved, and flexible instruments.

TECH FIG 4 • A. Arthroscopic view from the anterolateral portal reveals disruption of the ligamentum teres (*). B. Débridement is begun with a synovial resector introduced from the anterior portal. C. The acetabular attachment of the ligamentum teres in the posterior aspect of the fossa is addressed from the posterolateral portal. (Reprinted with permission from Byrd JWT, Jones KS. Traumatic rupture of the ligamentum teres as a source of hip pain. Arthroscopy 2004;20:385–391.)

PEARLS AND PITFALLS

| Patient selection | Select patients whose clinical circumstances suggest that they could benefit from arthroscopic intervention. Make sure the patient has reasonable expectations of what can be accomplished. Lastly, surgeons should select cases that match their level of experience, which will, of course, evolve over time. |
| Portal placement | Proper portal positioning and placement is essential for a well-performed procedure. Proper orientation within the joint optimizes visualization, access, and instrumentation, despite limitations on maneuverability imposed by the constrained architecture. |
| Avoid iatrogenic damage | Every entry of an instrument into the hip should be performed as carefully as possible. With careful attention to technique, the likelihood of "scope trauma" can be diminished. |
| Avoid excessive labral resection | The damaged tissue must be removed, but avoid resection of healthy labrum, which can lead to poorer results. |
| Avoid advanced disease states | Chondroplasty and débridement in the presence of advanced degenerative disease is unlikely to be successful, despite the appeal of a joint-preserving procedure. |

POSTOPERATIVE CARE

- For most soft tissue procedures, weight bearing is allowed as tolerated, with crutches needed only until the patient’s gait has been normalized, typically 5 or 6 days.
- Home exercises and supervised physical therapy are begun within the first few days.
- Gentle ROM, closed-chain exercises, stabilization, and subsequent functional activities are allowed to progress as dictated by the pathology encountered, the procedure performed, the resources available to the patient, and the patient’s goals for returning to activities.
- For labral repairs, patients are kept on a protective weight-bearing status for 6 weeks, with avoidance of external rotation and maximal hip flexion.
- For microfracture, a strict protective weight-bearing status is maintained for 2 months during early maturation of the fibrocartilaginous healing response.

OUTCOMES

- Successful outcomes from labral débridement range from 68% to 82%.1,12,20
- Diminished results are observed with associated articular damage, which is present in most cases.
• The poorest results are reported in patients with radiographic evidence of arthritis.
• These observations are supported by a recent study reporting 82% continued successful outcomes at 10-year follow-up for patients undergoing labral débridement in absence of arthritis. Among those with associated arthritis, 79% had been converted to total hip arthroplasty.
• Considerable experience has been gained in labral repair, but few outcome data have been published, with preliminary studies reporting success in two thirds of cases.
• These results will improve with a better understanding of patient selection.
• Microfracture of grade IV articular lesions has demonstrated successful outcomes in 86% of properly selected cases.
• Successful results also have been reported with excision of painful unstable fragments caused by macrotrauma.
• Soft tissue impingement due to disrupted fibers of the ligamentum teres tends to be quite painful and responds remarkably well to arthroscopic débridement, with success comparable to loose body removal.
• The results of many of these procedures will continue to improve with better understanding of underlying causative factors such as femoroacetabular impingement.

COMPLICATIONS
• The reported complication rate for hip arthroscopy among large cohorts ranges from 1.3% to 6.4%. Most complications are minor or transient, but a few major problems have been reported.
• Iatrogenic intra-articular damage may be the most common complication. Occasional joint scuffing may not be avoidable, but the concerns can be minimized by use of meticulous technique.
• Traction neuropraxia can be associated with prolonged or excessive traction, but also can occur even when surgery is performed within established guidelines.
• Direct trauma to major neurovascular structures should be avoidable, but, rarely, a partial neuropraxia of the lateral femoral cutaneous nerve can occur in association with the anterior portal.
• Life-threatening intra-abdominal fluid extravasation has been reported, emphasizing the importance of maintaining an awareness of fluid use during surgery.

REFERENCES
DEFINITION

- Femoroacetabular impingement (FAI) is the result of abnormal contact between the proximal femur and the acetabular rim.
- Abnormalities can be identified on either the femoral or acetabular side, but are more commonly seen on both sides.
- This abnormal contact can lead to acetabular chondral lesions and or labral lesions, leading to hip pain and the development of diffuse osteoarthritis of the affected hip if left untreated.\(^1,2,3\)

ANATOMY

- The proximal femur and acetabulum normally articulate without abutment through a physiologic range of motion (ROM).
- The acetabulum normally is anteverted 12 to 16.5 degrees.
- The acetabulum covers the femoral head to a depth that avoids impingement (ie, overcoverage) and instability (ie, dysplasia or undercoverage) with a horizontal, thin, sourcil (ie, the weight-bearing zone).
- The proximal femur has a spherical head-neck contour that allows for impingement-free ROM.
- The normal femoral neck shaft angle is 120 to 135 degrees; the femoral neck typically is anteverted and is 12 to 15 degrees.
- It is important to recognize and respect the location of the retinacular vessels that have been shown to enter the antero- and posterolateral portions of the femoral neck and supply the majority of the femoral head’s blood supply.

PATHOGENESIS

- There are two primary mechanisms of FAI: pincer and cam impingement.\(^1,2,3\)
- Pincer impingement is the result of contact between an abnormal acetabular rim and normal femoral head–neck junction (FIG 1A).
  - Pincer impingement typically is the result of a deep acetabulum (coxa profunda), local anterior overcoverage (acetabular retroversion), or, less commonly, posterior overcoverage.
  - It leads to labral bruising and tearing, and eventually may result in ossification of the labrum and contrecoup posterior acetabular chondral injury.
- Cam impingement is the result of contact between an abnormal femoral head–neck junction and the acetabulum (FIG 1B).
  - The abnormal femoral head neck junction usually is secondary to an aspherical anterolateral head neck junction, but also can be secondary to a slipped capital femoral epiphysis, femoral retroversion, coxa vara, malreduced femoral neck fracture, and, occasionally, posterior femoral head neck abnormalities.
  - Cam impingement results in a shearing stress to the anterosuperior acetabulum, with predictable chondral delamination and labral detachment or tearing in some cases.
Although cam impingement is reported to predominate in young athletic males and pincer impingement in middle-aged women, most patients with FAI have a combination of both cam and pincer impingement.

**NATURAL HISTORY**
- The likelihood of an individual with untreated FAI developing hip osteoarthritis is unknown, because there have been no longitudinal studies prospectively following these patients before the development of symptoms.
- Clinical experience with over 600 surgical dislocations of the hip in patients with FAI has revealed a strong association of this disorder with progressive acetabular chondral degeneration, labral tears, and progressive osteoarthritis.1-3
- It is now well accepted that many patients with FAI will develop progressive chondral and labral injury that can ultimately lead to end-stage hip osteoarthritis.

**PATIENT HISTORY AND PHYSICAL FINDINGS**
- Patients typically are young to middle aged (2nd through 4th decade) with complaints of groin pain exacerbated by physical activity.
- Prolonged sitting, arising from a chair, putting on shoes and socks, getting in and out of a car, and sitting with their legs crossed often exacerbate the symptoms.
- We have found that patients may have a history of siblings, parents, and grandparents with hip pain or osteoarthritis of the hip, and patients may have milder or similar symptoms in the contralateral hip.
- Patients often have had pain for months to years with the diagnosis of chronic low back pathology, hip flexor strains, and sports hernias, and not infrequently have had other surgeries without relief of their pain.
- Physical examinations should include:
  - Evaluation of hip ROM: global ROM restriction indicates advanced osteoarthritis.
  - Anterior impingement test: groin pain indicates anterolateral rim pathology.
  - Posterior impingement test: groin pain or posterolateral pain indicates posterolateral rim pathology.
  - FABER test: FABER means flexion, abduction, and external rotation of the hip. Increased distance from the lateral knee to the examination table can indicate femoroacetabular impingement.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Plain radiographs including an anteroposterior (AP) pelvis, frog lateral, and ideally a cross-table lateral and false profile view are obtained.
- The AP radiograph should have a coccyx to symphyseal distance of 0 to 2 cm with the coccyx centered over the symphysis to properly evaluate acetabular version.
- The following are measured on the AP radiograph (FIG 2A):
  - A lateral center edge angle of 25 to 40 degrees distinguishes deep acetabulum from dysplasia.
  - The presence of a crossover sign indicates local anterior overcoverage (retroversion).
  - The posterior wall sign indicates posterior undercoverage (retroversion).
  - Cam impingement indicates decreased head-neck offset.
  - A femoral neck shaft angle indicates that coxa vara may contribute to impingement.
- The frog-leg lateral and cross-table lateral views with 15 degrees internal rotation ideally evaluate:
  - Alpha angle: normally less than 50 to 55 degrees (anterolateral prominence/aspherical femoral head neck junction; FIG 2B)
  - Femoral head neck cystic changes and sclerosis
  - Femoral neck version: retroversion may contribute to impingement.
- The false profile is used to evaluate:
  - Anterior center edge angle: anterior over- and undercoverage
- An MRI arthrogram is useful to evaluate for labral and chondral pathology, acetabular retroversion, or a prominence of the femoral head neck junction which is best seen on the axial cuts (FIG 2C).
- Synovial herniation pits at the femoral head neck junction are also indicative of FAI.
- An anesthetic agent should be included with the gadolinium to verify the hip joint as the source of pain, which is indicated by temporary pain relief with provocative maneuvers in the first couple of hours after the injection.
- Occasionally it is helpful to obtain a three-dimensional CT study to appropriately map the area of impingement.

**FIG 2**
- **A.** Lateral center edge angle, posterior wall sign, and crossover sign are depicted. **B.** Alpha (α) angle is elevated in cam impingement. **C.** Prominence of the anterolateral femoral head–neck junction is seen on axial MRI images.
This may be done routinely or in cases of subtle FAI or suspected unusual locations of FAI (e.g., posterior femoral head/neck prominences).

**DIFFERENTIAL DIAGNOSIS**
- Sports hernia or athletic pubalgia
- Lumbar spine pathology
- Gynecologic or urologic pathology
- Intra-abdominal pathology
- Hip flexor pathology or iliopsoas snapping
- Iliotibial band pathology or snapping
- Pelvic stress fracture
- Intra-articular pathology not related to FAI

**NONOPERATIVE MANAGEMENT**
- Nonoperative management of FAI consists of avoiding painful activities such as deep hip flexion, aggressive hip flexion–based weight training, and athletic activities that aggravate symptoms.
- Intra-articular pathology often progresses without symptoms early in the disease, and there is concern that without surgical treatment arthritis eventually will develop.
- Nonoperative management may be best employed in the already degenerative hip with joint space narrowing prior to total hip arthroplasty, and consists of activity modification, core trunk strengthening exercises, and occasional intra-articular corticosteroid or hyaluronic acid injections.

**SURGICAL MANAGEMENT**
- Physical examination and imaging studies consistent with FAI
- Pain despite activity modification
- Pain in patient who is unable or unwilling to modify activity
- Minimal to no degenerative changes
- Arthroscopic versus open procedure for FAI (Table 1)
  - There are no strict indications for open versus arthroscopic management of FAI.

**Table 1**

<table>
<thead>
<tr>
<th>Pincer impingement</th>
<th>Cam impingement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral center edge angle</td>
<td>If resection of &gt;30% of the width of the neck is required to restore the alpha angle to normal, consider concomitant osteotomy (severe pistol grip deformity)</td>
</tr>
<tr>
<td>&gt;25 degrees: arthroscopic acetabular rim trimming</td>
<td>If significant femoral head retroversion or coxa vara is present, a concomitant or staged osteotomy is considered when impingement is still present after arthroscopic proximal femoral osteoplasty.</td>
</tr>
<tr>
<td>20–25 degrees: avoid excessive rim trimming laterally</td>
<td>Posterior areas of femoral head–neck impingement can be more challenging, and, depending on the surgeon’s experience, may be better addressed through an open approach.</td>
</tr>
<tr>
<td>&gt;16 to 20 degrees: consider osteotomy</td>
<td></td>
</tr>
</tbody>
</table>

The goal of arthroscopy is to reproduce the open approach for managing FAI.

Although controversial, some higher-level athletes may prefer a less invasive arthroscopic approach with a more predictable return to sports.10

**Preoperative Planning**
- Initially, a fluoroscopic evaluation is done, including anteroposterior, frog lateral, and cross-table lateral evaluation of the acetabulum and proximal femur.
- Dynamic fluoroscopic evaluation by abduction of the hip in flexion, external rotation, and extension with internal and external rotation occasionally reveals impingement of the acetabulum on the proximal femur and results in a vacuum effect in the joint as the proximal femur is levered out of the acetabulum.

**Positioning**
- Arthroscopic management of FAI begins with standard hip positioning in either the supine or lateral position.
- We prefer the supine position with the hip in slight flexion, neutral abduction, and internal rotation (FIG 3).

**Approach**
- Most cases can be performed using the standard anterior paratrochanteric and anterior portals, with occasional use of the posterior paratrochanteric or accessory distal portal (FIG 4).
When pincer impingement is present, the labrum is evaluated, including the acetabular labrum, acetabulum, and femoral head articular cartilage; fovea; ligamentum teres; transverse acetabular ligament; and capsular structures (TECH FIG 1A,B).

The peripheral compartment is evaluated, including the femoral head, labrum, zona orbicularis, medial synovial fold, femoral neck, and peripheral capsular attachments (TECH FIG 1C).

The pathology present helps to define the pathologic mechanisms present, with chondral delamination in the anterior superior acetabulum indicating cam impingement (TECH FIG 1D), and labral ecchymosis, tearing, and linear posterior acetabular chondral wear indicating pincer impingement (TECH FIG 1E).

When pincer impingement is present, the labrum is evaluated, and any tearing is carefully débrided, taking care to preserve the peripheral labrum when possible.

If complex tearing of the labrum is present, the labrum is generously débrided; however, the periphery of the labrum often remains intact and is amenable to repair or refixation (TECH FIG 2A).

If the labrum is amenable to repair or refixation, it is carefully detached from the acetabulum using a Beaver blade and shaver, beginning at the periphery and extending to the articular side of the labrum (TECH FIG 2B).

Care must be taken to detach as much of the labrum as possible without cutting too deep on the articular side, which could result in inadvertent delamination of the acetabular articular cartilage.

The labral detachment usually extends from the anterior portal to the 12:00 position. More or less may be detached further, superiorly and posteriorly, depending on the extent of acetabular overcoverage anterolaterally or posteriorly, and should include detachment of all of the torn or ecchymotic labrum.
The labrum then falls into the joint, creating a bucket handle tear, and a 5.5-mm burr is used to trim the acetabular rim to a depth of 5 to 10 mm (TECH FIG 2C,D). An attempt is made to trim all of the acetabulum with abnormal articular cartilage to a residual lateral center edge angle of 25 to 30 degrees, taking more or less according to the preoperative center edge angles. If areas of grade 4 chondromalacia remain after acetabular rim trimming, microfracture is performed on the exposed bone.

Suture anchors (usually two to four anchors) are then placed just under the acetabular subchondral bone, and the sutures are first passed under the labrum and then pulled over or through the labrum, securing the labrum to the rim with standard knot-tying techniques (TECH FIG 2E–G). Care is taken to place the knot on the capsular or medial side of the labrum to avoid damaging the femoral articular cartilage with prominent suture during weight bearing and ROM.

OS ACETABULI/PINCER IMPINGEMENT

Occasionally an os acetabuli is responsible for local anterior overcoverage and typically is attached to the acetabulum just peripheral to the labrum.

The os is exposed and excised using a burr beyond the fibrocartilage attachment of the native acetabulum with or without labral débridement or detachment and refixation (TECH FIG 3).
Exposure of the femoral head–neck junction can be performed using a generous capsulotomy, capsulectomy, or small capsular window.

We prefer a generous capsulotomy beginning anterior to the anterior portal and extending to the posterolateral portal site (TECH FIG 4A).

Traction is then released, and the hip is flexed to varying degrees, allowing for visualization of the peripheral head–neck junction and the cam lesion.

The normal head–neck junction is spherical (TECH FIG 4B), whereas in cam impingement it appears egg-shaped, flat, or with a prominence at the head–neck junction (TECH FIG 4C).

The cam lesion is covered with healthy-appearing articular cartilage with varying mild degrees of eburnation, progressing very early in the process to a more degenerative peripheral head–neck junction with clefts and intraosseous cysts in more advanced cases (TECH FIG 4D).

A 5.5-mm burr is used to reshape the anterolateral prominence, typically removing 5 to 10 mm and occasionally more, depending on the size of the lesion and thickness of the neck (TECH FIG 4E,F).

A recent cadaveric study recommended resecting no more than 30% of the thickness of the femoral neck to avoid pathologic fractures postoperatively.6

A frog lateral and cross-table lateral view with internal rotation are used to verify restoration of a normal alpha angle (TECH FIG 4G,H).

For more superior and posterior lesions, the hip is slowly extended and internally rotated, and the working and
arthroscopic portals can be exchanged from the anterior and anterior paratrochanteric portals to the anterior and posterior paratrochanteric portals for better visualization.

- Care is taken to avoid aggressive resection down the anterolateral and posterolateral regions of the femoral neck to avoid damage to the retinacular vessels which should be visualized and protected throughout the case.
- The typical pattern of cam impingement extends down the neck on the anterolateral femoral head–neck junction and closer to the articular cartilage margin of the femoral head, more superiorly in the region of the retinacular vessels.

Final confirmation of adequate resection is then verified arthroscopically by flexing the hip more than 90 degrees with maximal internal rotation, external rotation, and abduction.

- Capsular closure is then performed with one or two absorbable sutures passed through one side of the capsule with a looped suture passer and grasped through the other side of the capsule (TECH FIG 4I).
- A knot is then tied blindly at the periphery of the capsule using standard arthroscopic knot-tying techniques.
- The hip is then infiltrated with an anesthetic, and the portals are closed in the usual fashion.

**PEARLS AND PITFALLS**

| Indications                  | History, physical examination, and imaging studies should be consistent with femoroacetabular impingement. |
|                             | Intra-articular anesthetic injection should confirm the hip as the source of pain. |

| Exposure                    | Care should be taken to excise the labrum peripherally and detach on the articular surface without undermining the acetabular chondral surface to allow for adequate tissue for refixation. |
|                            | Adequate capsulotomy or capsulectomy should be performed to allow for exposure of the femoral head–neck junction. |
|                            | Flexion, extension, and rotation allow for complete visualization of the femoral head–neck prominence in cam impingement. |

| Pincer                      | Generally 5 mm of acetabulum is trimmed with more removed based on the extent of chondral damage taking care not to create a dysplastic acetabulum based on preoperative center edge angles. |
POSTOPERATIVE CARE

- Pre- and postoperative radiographs confirm adequate osteoplasty and rim trimming (FIG 5).
- Postoperative restrictions are not consistent from one surgeon to the next and are based on the procedures done.

We impose the following restrictions:
- Proximal femoral osteoplasty is treated with protected weight bearing with crutches for 2 weeks and no high-impact or running activities for 2.5 to 3 months.
- Acetabular rim trimming with labral débridement requires no specific restrictions.
- More complex cases of FAI managed arthroscopically can be lengthy procedures, and alternating between traction and flexion or release of traction can help prevent traction-based neuropraxias.
- Meticulous irrigation of all bony debris and postoperative use of nonsteroidal anti-inflammatories can help to minimize the incidence of heterotopic bone formation.

Acetabular labral repair and refixation is treated with toe-touch weight bearing for 2 weeks and avoidance of the extremes of external rotation for 2 weeks.

Microfracture procedures are treated with 6 to 8 weeks of toe-touch weight bearing.

The first 2 months focus on restoration of ROM, gait and pelvic alignment, and gentle core strengthening.

At 2 months, more aggressive core strengthening is instituted, with resumption of full sporting activities at 3 to 6 months based on functional improvement.

Further research is required to develop the optimal rehabilitation programs after the various procedures that have been discussed.

OUTCOMES

Early and midterm results of open procedures for FAI indicate that reduction in pain and functional improvement directly correlate with the degree of osteoarthritic changes found at the time of surgery.1,2,7,9

Some evidence indicates that repair or refixation of the labrum results in improved outcomes when compared to labral débridement or excision in a consecutive series.2,4

It is unclear, however, whether the improvement is the result of labral preservation or of improved technical skills, because the study was performed in a consecutive series of patients.2,4

Little has been published in the literature with respect to outcomes after arthroscopic management of FAI.

In a review of 45 professional and Olympic level athletes with FAI treated arthroscopically, all had symptomatic improvement and returned to play.10

In another series of 320 patients with FAI treated arthroscopically, 90% had elimination of the impingement sign and were reportedly satisfied with their results.12

Larson and Giveans5 prospectively followed 100 patients with FAI treated arthroscopically for up to 3 years, with a statistically significant improvement in Harris hip, SF-12, and visual analogue pain scoring consistent with that seen after open management of FAI.

No well-designed, long-term, or randomized studies have been done to evaluate outcomes of management of FAI to determine whether osteoarthritis has been delayed or prevented in this patient population. Longer-term follow-up and studies of open versus arthroscopic treatment should better define the optimal indications and procedure for patients with FAI.

COMPLICATIONS

Anterolateral femoral cutaneous nerve neuropraxia

Heterotopic bone or myositis ossificans formation

Iatrogenic acetabular and femoral chondral damage

Rarely postoperative femoral neck fracture

Potential for sciatic or pudendal nerve neuropraxia

Potential for avascular necrosis

REFERENCES

DEFINITION
- *Coxa saltans* is a term popularized by Allen and various co-authors.1
  - Initially they described an internal type (iliopsoas tendon) and an external type (iliotibial band).
  - More recently, they proposed an intra-articular type, which is simply a catch-all for numerous intra-articular lesions.
- Snapping hip syndrome most clearly represents an extra-articular dynamic tendinous phenomenon of either the iliopsoas tendon or iliotibial band.

ANATOMY
- The iliopsoas complex, a powerful hip flexor, is formed from the psoas major and iliacus muscles (FIG 1A).
  - The psoas major originates from the lumbar transverse processes and the sides of the vertebral bodies and intervertebral discs from T12 to L5; the iliacus originates from the superior two thirds of the iliac fossa, the sacral ala, and the anterior sacroiliac ligaments.
  - The tendon forms first from the psoas proximal to the inguinal ligament and then rotates such that its anterior surface comes to lie medial and its posterior surface lateral.
  - The tendon then spreads out to insert over the lesser trochanter.
  - It is joined by an accessory tendon from the iliacus, and the tendons then fuse together before forming the enthesis of the iliopsoas. Some muscle fibers of the iliacus remain separate, attaching directly to bone.
  - In the sagittal plane, as the iliopsoas exits the pelvis, it is redirected 40 to 45 degrees over the pectineal eminence toward its insertion site.
- Iliotibial band (FIG 1B): The fascia lata covers the entire hip region, encasing its three superficial muscles, ie, the tensor fascia lata, sartorius, and gluteus maximus.
  - A confluence of the tensor fascia lata and gluteus maximus forms the iliotibial band.
  - The gluteus maximus also partly inserts into the proximal femur at the gluteal tuberosity.
  - This fibromuscular sheath was described by Henry7 as the “pelvic deltoid,” reflecting on the fashion in which it covers the hip, much as the deltoid muscle covers the shoulder.

PATHOGENESIS
- The snapping occurs as the iliopsoas tendon subluxes from lateral to medial while the hip is brought from a flexed abducted, externally rotated position into extension with internal rotation (FIG 2A,B).
- It is variously proposed that the anterior aspect of the femoral head and capsule, or pectineal eminence, is...
responsible for transiently impeding the tendon and creating the snapping.

- Incidental asymptomatic snapping of the iliopsoas tendon is estimated to be present in at least 10% of a normal, active population.
- Painful snapping may be precipitated by macrotrauma or repetitive microtrauma in patients with a predilection for certain activities such as ballet.
- The exact structural alteration that occurs when symptomatic snapping develops has not been defined.
- The snapping occurs as the iliotibial band flips back and forth across the greater trochanter, and often is attributed to a thickening of the posterior part of the iliotibial tract or anterior border of the gluteus medius (FIG 2C).
- The thickened portion lies posterior to the trochanter in extension and flips forward as the hip begins to flex.
- Coxa vara and reduced bi-iliac width have been proposed as predisposing anatomic factors.
- Tightness of the iliotibial band also may be an exacerbating factor.
- Like snapping of the iliopsoas tendon, snapping of the iliotibial band may be an incidental finding without precipitating cause or symptoms.
- Painful snapping may occur following trauma, but is more commonly associated with repetitive activities, classically being described in the downhill leg of runners training on a sloped roadside surface.
- It also has been reported as an iatrogenic process following surgical procedures that leave the greater trochanter more prominent, or reconstructive procedures around the knee that alter the iliotibial band.

**NATURAL HISTORY**

- For most people, the snapping hip remains asymptomatic, never requiring treatment.
- In patients in whom the snapping hip is symptomatic, the course is variable, but there are no apparent long-term consequences of a chronic snapping hip.
- Spontaneous resolution may occur but is uncommon.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

**Iliopsoas Tendon**

- The history of onset of symptoms is variable and may be insidious, owing to specific repetitive maneuvers or an acute injury.
- The patient typically describes a clicking sensation emanating from deep within the anterior groin, which often is audible enough to be characterized as a “clunk.”
- Although the symptoms typically are referred to the anterior groin, some patients may describe flank or sacroiliac discomfort, reflecting irritation around the origin of the psoas and iliacus muscles.
- The characteristic examination maneuver is performed with the patient lying supine, bringing the hip from a flexed, abducted, externally rotated position down into extension with internal rotation, creating the snap.
- Sometimes this is a dynamic process that the patient can demonstrate actively better than the examiner can produce passively. Although often prominent, it may be subtle, and may occur more as a sensation experienced by the patient rather than one that the examiner can observe objectively.
Applying pressure over the anterior joint can block the tendon from snapping and assist in confirming the diagnosis. Variously, patients may be able to demonstrate this best lying, sitting, or standing, or with walking. However, regardless of the position, the snapping uniformly occurs as the hip goes from a flexed toward an extended position.

Iliotibial Band
- As with the iliopsoas tendon, patients may describe the onset of symptoms as being insidious, due to specific repetitive activities, or in response to acute trauma.
- Whereas snapping of the iliopsoas tendon often can be heard from across the room, snapping of the iliotibial band can be seen from across the room.
- Patients describe a sense that the hip is subluxing or dislocating. This is termed “pseudosubluxation,” because the visual appearance may suggest that the hip is subluxing but radiographs uniformly demonstrate that the hip remains concentrically reduced.
- The patient always relates a snapping or subluxation-type sensation. The symptoms are located laterally, and patients typically can illustrate this while standing.
- As with the iliopsoas, this often is a dynamic process, better demonstrated by the patient than produced by passive examination. It may be detected with the patient lying on the side and then passively flexing and extending the hip.
- The snap can be palpated over the greater trochanter, and its origin is confirmed by applying pressure, which can block the snap from occurring.
- The Ober test evaluates for tightness of the iliotibial band, which may accompany symptomatic snapping.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- The diagnosis of a snapping iliopsoas tendon is based primarily on the history and physical examination.
- Iliopsoas bursography and ultrasonography may be helpful to rule in, but not rule out, the diagnosis (FIG 3).
- These imaging modalities are technically limited because of a significant rate of false-negative interpretation.

Similarly, snapping of the iliotibial band is based on the clinical assessment, and investigative studies offer little aid in substantiating or discounting the diagnosis. Nonetheless, plain radiographs remain an essential tool in the assessment of any hip problem, and other investigative studies such as MRI and magnetic resonance arthrography may be important to evaluate for associated conditions such as intra-articular pathology.

DIFFERENTIAL DIAGNOSIS
- Snapping iliopsoas tendon
- Hip instability
- Snapping iliopsoas tendon
- Intra-articular pathology
- Pelvic instability (eg, sacroiliac joint or symphysis pubis)
- Osteochondroma

NONOPERATIVE MANAGEMENT
- Treatment often involves little more than establishing the diagnosis and assuring the patient that the snapping is not harmful or indicative of future problems.
- Oral anti-inflammatory medications may be helpful in addition to a flexibility and stabilization exercise program.
- For recalcitrant cases:
  - A period of activity modification to diminish symptoms may be necessary.
  - Judicious use of corticosteroid injections may be appropriate, with the goal of providing transient improvement to supplement the effect of other therapeutic modalities.

SURGICAL MANAGEMENT
- Various open procedures have been described for releasing the tendinous portion of the iliopsoas, with generally favorable results. However, superior results have been reported with endoscopic methods. These superior results are due only partly to the less invasive nature of the technique.
- Most cases with a painful snapping iliopsoas tendon also were found to have associated intra-articular pathology, which also was addressed.

FIG 3 • Iliopsoas bursography silhouettes the iliopsoas tendon (arrows) with contrast. A. In flexion, the iliopsoas tendon lies lateral to the femoral head. B. In extension, the iliopsoas tendon moves medial. (Courtesy of J. W. Thomas Byrd, MD.)
Failure to inspect the interior of the hip joint and address associated pathology may be a significant contributing factor to less optimal results with traditional open techniques.

**Iliotibial Band**
- Various techniques have been described for correcting snapping of the iliotibial band.
- One complex procedure is a Z-plasty lengthening, the results of which have ranged from poor to good.2,10,11
- Several techniques have employed a simpler approach, creating a relaxing incision in the portion of the iliotibial band over the greater trochanter, and these have shown to be effective at eliminating the snapping in most cases.3,15
- Violation of the tendon structure is minimized, which diminishes the morbidity of the procedure and facilitates the postoperative recovery.
- Endoscopic methods have been developed that may accomplish this same goal.8

**Preoperative Planning**
- Clinical assessment of the snapping iliopsoas tendon and iliotibial band is relatively straightforward.
- However, careful assessment is necessary to ensure that the snapping is clearly the source of the patient’s symptoms and also to evaluate other associated conditions, especially concomitant intra-articular pathology.
- Perhaps most important is a careful assessment of the patient’s motivation, understanding, and goals of recovery.
- It is important to bear in mind that coxa saltans often is encountered in asymptomatic individuals.
- Surgery is considered only if the patient has exhausted efforts at conservative treatment and demonstrates sufficient motivation for the postoperative recovery.

**Positioning**
- **Iliopsoas tendon**
  - Endoscopic release of the iliopsoas tendon is performed in conjunction with routine arthroscopy of the joint.
  - Arthroscopy can be performed with the patient in either the supine or lateral position.
  - The supine position may provide better access to these structures, and is the method described.
- **Iliotibial band**
  - Open procedures employ the lateral decubitus position, and this also has been the preferred orientation for endoscopic methods.

**Approach**
- **Iliopsoas tendon**
  - Most endoscopic reports have described releasing the tendon from its insertion on the lesser trochanter within the iliopsoas bursa.4,5
  - This is the endoscopic counterpart to the open method described by Taylor and Clarke.12 For the occasional case of a snapping iliopsoas tendon associated with a total hip arthroplasty, it clearly is the preferred approach.
  - Another endoscopic technique, in which the iliopsoas tendon is approached from the peripheral compartment, seems to provide a comparable effect of releasing the tendon.14
  - The method is analogous to the open method described by Allen et al.1 Theoretically, it may have an advantage of reduced morbidity.
- **Iliotibial band**
  - The various open approaches use a common, lateral, longitudinal incision over the greater trochanter.
  - Endoscopic methods employ laterally based portals, approaching the tendon from its superficial subcutaneous surface.

**ENDOSCOPIC ILIOPSOAS RELEASE**

**Lesser Trochanter (Iliopsoas Bursa)**
- After completing routine hip arthroscopy, including intra-articular and peripheral compartments, the leg is repositioned in 20 degrees of flexion and full external rotation.
- Slight flexion partially relaxes the tendon but maintains some tension.
- External rotation brings the lesser trochanter more anterior for access from the laterally based portals (TECH FIG 1A).
- A portal is established distal to the standard anterolateral hip portal at the level of the lesser trochanter, using fluoroscopic guidance (TECH FIG 1B).
  - This exposes the tendon within the iliopsoas bursa, which is the largest bursa in the body.
- Another portal is then placed distally, converging toward the lesser trochanter (TECH FIG 1C).
- The arthroscope and instruments are switched between these two portals for thorough visualization and instrumentation of the iliopsoas tendon (TECH FIG 1D).
- Adhesions within the bursa can be cleared, providing excellent visualization of the iliopsoas tendon.

**Peripheral Compartment**
- After completing arthroscopy of the intra-articular compartment with a standard supine technique, the traction is released, the hip is flexed 45 degrees, and standard portals are established in the peripheral compartment (TECH FIG 2).
- The iliopsoas tendon can be exposed in line with the medial synovial fold, proximal to the zona orbicularis.
  - Occasionally, a communication is present at this location between the joint and the iliopsoas bursa.
  - If no communication is present, a capsular window can be created with a shaver.
- The capsule in this location is thin, and often the tendon is visible or palpable through the thin capsule.
**TECH FIG 1** • Release of right iliopsoas tendon from lesser trochanter. **A.** The hip is flexed approximately 20 degrees and externally rotated. **B.** Initial portal established at level of lesser trochanter. **C.** Ancillary portal is established distally under direct arthroscopic visualization. **D.** The arthroscope has been switched to the more distal portal with a flexible radiofrequency (RF) device introduced proximally. **E.** Arthroscopic illustration shows release of the tendinous portion of the iliopsoas. (Courtesy of J. W. Thomas Byrd, MD.)

**TECH FIG 2** • Arthroscopic view from the peripheral compartment of a right hip. **A.** A window (arrows) has been created through the thin medial capsule, exposing the iliopsoas tendon (*) anterior to the femoral head (FH). **B.** The tendinous portion is released with a basket. **C.** The final fibers are débrided with a power shaver. **D.** Through the capsular window (arrows) the tendon has been completely released, preserving the muscular fibers (*). The relation between the capsular window and the acetabular labrum (AL) and femoral head (FH) is identified. (Courtesy of J. W. Thomas Byrd, MD.)
TENDOPLASTY OF THE ILIOTIBIAL BAND

Open Technique

- A straight, lateral longitudinal incision is centered over the greater trochanter (TECH FIG 3).
- The length is dictated by the amount of exposure needed to precisely accomplish the tenodopasty.
- A smaller incision is more cosmetic and can be accomplished with dissection of the subcutaneous tissues and selective retraction but should not compromise visualization for the procedure.
- Several authors have described variations of a similar method for relaxing the tendon. These are based on an 8- to 10-cm longitudinal incision just posterior to the mid part of the greater trochanter in the thickest portion of the iliotibial band.
- Relaxation of the tendon is completed with paired or staggered 1- to 1.5-cm transverse incisions.
- The field is relatively bloodless, but meticulous hemostasis should be maintained and the subcutaneous tissues closed in layers to avoid formation of a hematoma.

Endoscopic Technique

- Two portals are used: one 3 cm proximal to the tip of the greater trochanter and one 3 cm distal.
- The arthroscope is placed from the distal portal site down to the subcutaneous surface of the iliotibial band.
- Then, with arthroscopic visualization, the proximal portal is established for dissection to release the subcutaneous tissue from the superficial surface of the tendon (TECH FIG 4).
- A 4- to 5-cm longitudinal incision within the tendon is created using a shaver and a radiofrequency (RF) probe.
- An anteriorly based transverse incision is then made and the flaps resected, creating a long, obtuse triangle.
- This provides better visualization to determine the relation of the iliotibial band and the underlying greater trochanter.
- Portions of the trochanteric bursa can be resected as necessary for treatment and clearing the field of view.
- Lastly, a posterior transverse incision is made and the flaps excised, creating a diamond-shaped pattern of resection.
- Hemostasis should be meticulously maintained and a compressive dressing applied to minimize the formation of a hematoma.

If the glistening tendon is not immediately visible, it should come into view after the capsular window is extended laterally.

At the level of the joint, the tendon fibers of the iliopsoas lie on the posterior surface of its muscular portion.

The muscular portion separates the tendon from the femoral nerve, which is the most lateral of the femoral neurovascular structures.

The tendon can be transected with a combination of hand biter instruments, power shaver, and thermal device.

TECH FIG 3 • Our preferred approach includes an 8- to 10-cm longitudinal incision, posterior to the midpoint of the greater trochanter, with two pairs of 1- to 1.5-cm transverse incisions. This relaxes the iliotibial band, eliminating the snapping, without creating any suture repair lines that would necessitate prolonged convalescence. A. Incision pattern. B. Relaxing response to incision. C. Appearance at surgery. (Courtesy of J. W. Thomas Byrd, MD.)
TECH FIG 4 • Endoscopic method of iliotibial band tendoplasty, shown in the right hip. A. After creating the longitudinal incision, the anterior limb is created by a perpendicular incision. B. Resecting the edges creates a triangle that aids in visualization of the underlying structures. C. The posterior limb is then created, and resection completes the diamond pattern of the tendoplasty. (Adapted from Ilizaliturri VM Jr, Martinez-Escalante FA, Chaidez PA, et al. Endoscopic iliotibial band release for external snapping hip syndrome. Arthroscopy 2006;22:505–510.)

PEARLS AND PITFALLS

Visualization
■ With any endoscopic technique, good visualization is essential. Poor visualization will result in a poorly performed procedure. Visualization is facilitated by use of a high-flow fluid management system and control of hemostasis by keeping the systolic blood pressure below 100 mm Hg, adding diluted epinephrine to the fluid, and judicious use of cautery.

Violation of iliopsoas tendon
■ Surgical violation of the iliopsoas tendon carries the risk of heterotopic ossification, in either an open or arthroscopic procedure. It is prudent to use pharmacologic prophylaxis for this condition.

Failure to fully release tendon
■ The iliopsoas tendon forms from the psoas and iliacus muscles. The tendon sometimes may remain bifid all the way to its insertion on the lesser trochanter. Whether addressing the tendon from the peripheral compartment (FIG 4A-G) or from its insertion within the iliopsoas bursa (FIG 4H,I), if the tendon looks inordinately small, search for a separate portion of the tendon. Failure to fully release the tendon fibers may result in incomplete resolution of the snapping.

Inadequate tendoplasty
■ Inadequate tendoplasty of the iliotibial band can result in incomplete resolution of symptoms; but excessive release can compromise the functional integrity of the abductor mechanism, rendering it virtually unsalvageable.

Proper diagnosis
■ With proper diagnosis, the surgical results for snapping of the iliopsoas tendon and the iliotibial band are highly predictable and finite in terms of resolution of the snapping.
■ However, the subjective response to surgery is highly dependent on the patient’s expectations and motivations, which are equally essential in the evaluation process.
POSTOPERATIVE CARE

- After these procedures, the patient is capable of full weight bearing, but crutches are used for about 2 weeks until the gait pattern is normalized.
- Gentle range-of-motion, closed-chain, and stabilization exercises are introduced as symptoms allow.
- For iliopsoas release, aggressive hip flexion strengthening is avoided for the first 6 weeks; for the iliotibial band, aggressive stretching generally is not necessary.
- The patient should not anticipate returning to vigorous activities for at least 3 months.

OUTCOMES

- For endoscopic release of the iliopsoas tendon, several studies have reported highly predictable results in terms of eliminating the snapping and patient satisfaction.\textsuperscript{3,9}
- However, we have observed two cases of heterotopic ossification that occurred following release of the iliopsoas tendon from the lesser trochanter.

These observations are consistent with reports in the literature on open techniques of the iliopsoas tendon that have noted a propensity for heterotopic bone formation.\textsuperscript{13}

- For snapping of the iliotibial band, tendon-relaxing procedures that maintain the structural integrity of the abductor mechanism, whether performed open or endoscopically, have predictably corrected the snapping with minimal morbidity.\textsuperscript{3,8,15}

FIG 4 • A–G. The iliopsoas tendon of the right hip is exposed from the peripheral compartment. A. The initial tendon viewed through a capsular window is fully identified, but is abnormally small. B. This tendon is released with a basket. C. A stump remains. D. This is resected with a shaver. E. Further dissection exposes a more substantial portion of the iliopsoas tendon. F. This is released as well. G. Complete release of the bifid tendon is documented. H, I. Viewing the iliopsoas tendon of a right hip at its insertion on the lesser trochanter within the iliopsoas bursa. H. A bifid iliopsoas tendon is identified with medial (*) and lateral (**) bands separated by a vessel (two white asterisks) coursing perpendicular. I. The lateral band (black asterisks) has been released with a flexible RF device, revealing the medial band (white asterisk) which subsequently is released. (Courtesy of J. W. Thomas Byrd, MD.)

COMPlications

- No reports have been published of complications with endoscopic release of the iliopsoas tendon.
- We have observed two cases of heterotopic ossification, for which the use of pharmacologic prophylaxis is recommended.\textsuperscript{13}
- Potential complication due to damage to surrounding structures (eg, femoral neurovascular bundle)
- No complications have been reported in conjunction with the less extensive tendon-relaxing procedures for a snapping iliotibial band. Careful attention to the precision of the release
can help avoid inadequate or excessive tendoplasty. Inadequate release could result in residual symptoms, whereas excessive release could result in a virtually unsalvageable compromise of the abductor mechanism.

REFERENCES

DEFINITION
- **Athletic pubalgia** refers to a range of groin injuries in athletes. The terms *athletic pubalgia* and *sports hernia* sometimes are used interchangeably.
- Diagnosis of the cause of groin pain is difficult, because the anatomy is complex and two or more injuries may coexist.
  - Intra-abdominal pathology, genitourinary abnormalities, referred lumbosacral pain, and hip joint disorders must first be excluded.
  - Adductor strains are the most common cause of groin pain in athletes.
  - The adductors usually are strained in an eccentric contraction, often one that occurs at the myotendinous junction, but the strain also can occur in the tendon itself or its bony insertion.
  - Other muscles in and around the groin region also can be strained, including the rectus femoris, the sartorius, and the abdominal muscles, as can the conjoint tendon.
- **Sports hernia** is a condition of chronic groin pain that is caused by a tear in the inguinal floor without a clinically obvious hernia.8,12
  - It results in an occult injury that usually is not identified by most examiners. However, with increasing experience, the examiner can feel an abnormal inguinal floor and appreciate abnormal tenderness inside the external ring.
- In contrast, indirect and direct hernias involve easily palpable defects in the inguinal canal or through the anterior abdominal musculature, respectively.
- Duration of symptoms typically is months, and pain is resistant to conservative measures.
- **Osteitis pubis** is characterized by symphysis pain and joint disruption and occurs commonly in distance runners and soccer players.
  - It may be difficult to distinguish from adductor strains, and the two conditions may coincide.
  - Stress fractures are rare injuries that result from repetitive cyclic loading of the bone.
  - The pubic rami are the most common location for stress fractures in the pelvis. These fractures are most common in long distance runners.

ANATOMY
- The anatomy in and around the groin is complex (FIG 1), and a thorough understanding of it is crucial in diagnosing the various groin injuries.
  - Thorough knowledge of the origins and insertions is very helpful during examination and palpation of the area.
  - The posterior inguinal wall consists primarily of the transversalis fascia, along with the conjoint tendon, made up of the internal abdominal oblique and transversus abdominis aponeuroses.8

![FIG 1 • Anatomy of the abdominal (A) and groin (B) musculature.](image)
The conjoint tendon inserts onto the pubic tubercle and along the iliopubic track.
The pubic symphysis is a rigid, nonsynovial, amphiarthrodial joint consisting of layers of hyaline cartilage encasing a fibrocartilaginous disc.

**PATHOGENESIS**
- Adductor strains are most commonly seen in soccer or ice hockey players.
  - Most happen acutely, and the patient recalls a sudden intense pain in the groin.
  - Eventually the medial thigh swells and ecchymosis is noted over the next 2 to 3 days.
  - The pain improves when the muscle warms up.
- Sports hernia is seen in competitive athletes and occasional work injuries and may involve a particular traumatic episode, but most times is insidious and worsens over time with overuse.
  - Patients describe a deep, disabling groin pain.
  - Kicking and endurance running tend to increase the symptoms.
  - Coughing or Valsalva maneuver increases intra-abdominal pressure and can increase tenderness, as can a resisted sit-up.
- The most likely mechanism for osteitis pubis is that of increased forces placed on the symphysis pubis from the pull of the pelvic musculature or repetitive stress from increased shearing forces.
  - Some cases of osteitis pubis probably are secondary to or coexist with a sports hernia.
- Stress fractures of the pubic rami present as an insidious onset of deep pelvic and groin pain that is worsened after high-impact exercises.
  - The pain is worse immediately during and after the activity and improves with rest.
  - These injuries usually occur in conjunction with an acute increase in the intensity of training.

**NATURAL HISTORY**
- Acute adductor strains, if not properly rehabilitated, may progress to chronic strains or tendinopathy.
- Most patients with sports hernia have had a prolonged course of conservative treatment with continued pain and do not get better. A hallmark of sports hernias is that patients have less pain when they are inactive and more pain when active.
- Osteitis pubis is self-limited but may take, on average, about 9 months to heal.
  - If the stress fracture is not addressed, pain will continue to increase and can be debilitating.

**PATIENT HISTORY AND PHYSICAL FINDINGS**
- Patient history is the most important aspect of the evaluation of athletic pubalgia.
  - The patient must be asked for duration of symptoms, any inciting events, relieving and exacerbating factors, and timing of pain.
  - To directly assess for hernia:
    - In men: insert the finger into inguinal ring at level of external opening. Invaginate the loose scrotal skin and gently insert the finger into the external ring (FIG 2). Gently feel the inguinal floor and ask the patient to perform the Valsalva maneuver. One can occasionally feel the tear tighten on one's fingertip. Apply gentle pressure medially and laterally looking for abnormal asymmetric tenderness.
    - In women: palpate the superior aspect of the labia majora and upward to lateral to the pubic tubercle.
    - The groin is examined using these methods:
      - Straight leg raise: In patients with radicular low back pain, this will reproduce the pain they are having.
      - Palpation of insertion of conjoint tendon: tenderness may increase, and a bulge may be felt by having the patient perform a Valsalva maneuver.
      - Palpation of the adductor tendon: helps to diagnose an adductor strain or tear
      - Groin adduction resistance: helps to diagnose an adductor strain or tear
      - Palpation of the pubic symphysis: characteristic of osteitis pubis
      - Hip range of motion (ROM) may isolate a source of pain arising from the hip.
      - Thomas test: tightness in extension is a sign of a tight iliopsoas muscle.
      - Hip extension against resistance tests the strength of the hip extensors.
      - Hip flexion against resistance: tests the strength of the iliopsoas and may detect a strain or tear of this muscle.
      - Ober’s test: patient inability to lower the upper leg completely to the examination table is pathognomonic of a tight iliotibial band.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Radiographs can be helpful in excluding fractures or avulsions.
- Stress fractures usually are not evident on radiographs.
Bone scanning or MRI is most sensitive, especially in the early stages.

MRI can be used to confirm muscle strain or tears, and partial or complete tendon tears (FIG 3A).

MRI has been used to detect sports hernias, although it is not always successful.\(^3\)

Dynamic ultrasound has been found, in certain cases, to detect posterior wall defects but is highly operator dependent.\(^16\)

Radiographs, CT scans, and bone scans can rule out other diagnoses; none are reliable in detecting sports hernias.

Herniography, which involves an intraperitoneal injection of contrast dye followed by fluoroscopy or radiography, has been shown to identify sports hernias but has limited sensitivity and a substantial risk of perforation in up to 5% of patients.\(^2\)

Osteitis pubis has characteristic radiologic findings, including bone resorption, widening of the pubic symphysis, and irregular contour of articular surfaces or periarticular sclerosis (FIG 3B).

A bone scan may show increased uptake in the area of the pubic symphysis in osteitis pubis; however, not all patients who have symptoms show an abnormality.\(^13\)

MRI has become increasingly useful in the diagnosis of osteitis pubis. Findings can include bone marrow edema or symphyseal disc extrusion.\(^15\)

**DIFFERENTIAL DIAGNOSIS**

- Groin disruption or strain
- Osteitis pubis
- Pelvic stress fractures
- Indirect and direct hernia
- Avascular necrosis of the hip
- Labral tear of the hip
- Hip osteoarthritis
- Abdominal muscle tear
- Lumbar radiculopathy
- Nerve entrapment
- Tumors
- Genitourinary problems
- Inflammatory bowel disease
- Endometriosis
- Pelvic inflammatory disease

**NONOPERATIVE MANAGEMENT**

- Acute treatment of adductor strain includes rest, ice, compression, and elevation.
- The next goal is restoration of ROM and prevention of atrophy. Once the patient can tolerate this, the focus should be to regain strength, flexibility, and endurance.\(^9\)
- Nonoperative management of sports hernia includes physical therapy,\(^10\) anti-inflammatory drugs, and corticosteroid injections at the site of pain.\(^1\)
- Osteitis pubis is a self-limiting condition; therapy should focus on hip ROM, as well as adductor stretching and strengthening.
- Corticosteroid injection in osteitis pubis is controversial but may be helpful in select populations of athletic patients.\(^11,15\)
- Treatment in pelvic stress fractures is straightforward and involves 4 to 6 weeks of rest from the activities aggravating the area.

**SURGICAL MANAGEMENT**

- Many approaches have been tried in the surgical management of sports hernias.
- Tissue repairs require longer rehabilitation and pose a greater risk for recurrence, primarily because of collagenases which are currently being described.
- Laparoscopic repairs fail too often because they do not deal with the anterior mechanisms of groin pain.
- Purely anterior repairs fail occasionally because they do not provide adequate posterior support.
- Mesh repairs are standard.
  - Some mesh repairs fail because the mesh chosen is too heavy and tightly woven.
  - Other mesh repairs fail because of surgical technique (eg, metal tackers, permanent sutures in the periosteum, tight sutures involving nerves and causing necrotic tissue).
- The most logical and successful repair is the use of two-layered lightweight mesh, which provides both posterior and anterior support and allows normalization of the torn anatomy.
Preoperative Planning

- Preoperative planning involves extreme care to ascertain that the patient really does have the injury for which surgery is being planned. This requires a complete history and physical examination performed by an examiner who understands the pathophysiology of this injury.
- Imaging is valuable to rule out alternative pathology.
- Preemptive analgesia is important to reduce postoperative pain and to make the anesthetic experience smoother. Also, local anesthesia is bactericidal, reducing the risk of infection.
- We suggest 1/2% lidocaine with epinephrine and sodium bicarbonate.

Positioning
- The patient is positioned supine and draped.

ULTRAPRO HERNIA SYSTEM (JOHNSON & JOHNSON GATEWAY)

Incision, Dissection, and Site Evaluation

- The incision is made along the path of the inguinal ligament, perhaps 1 cm medial and superior to the ligament. A length of 5 to 6 cm is adequate.
- Dissection is performed down to the external oblique tying veins. Too much cautery increases the risk of a subcutaneous infection.
- The external oblique is incised to the external ring, and the fascia is mobilized both medially and laterally.
- The spermatic cord is carefully evaluated and mobilized, looking for an indirect sac.
- The inguinal floor is carefully evaluated, looking for a torn transversalis fascia or a torn transversus abdominis.
- Occasionally, the yellow preperitoneal fat can be seen outlining a tear.
- The inguinal floor is palpated. The disruption often can be felt.

TECH FIG 1 • A, B. The anterior pocket is developed under the external oblique to optimize placement of the onlay patch and dissected out laterally to ensure the onlay patch will lie flat. C. After the posterior wall has been opened, visual confirmation is made of location in the preperitoneal space by identifying the yellow preperitoneal fat and by visualizing Cooper’s ligament. D. Then, using the forefinger, sweep circumferentially medial, then lateral to actualize the preperitoneal space. (continued)
TECH FIG 1 • (continued) E,F. With the onlay patch grasped down to the connector with sponge forceps, insert the device completely into the defect and deploy the underlay with forceps or finger. (Courtesy of Ethicon Surgery, a Johnson & Johnson company.)

### Positioning the Patches
- The preperitoneal space is opened and prepared. Dissection is extended out laterally so the onlay patch will lie flat (TECH FIG 1A,B).
  - It should be possible to clearly feel under the rectus, the pubis, Cooper’s ligament, and up along the iliofemoral vessels (TECH FIG 1C,D).
- The posterior (round) patch of the UHSL is positioned in the space that has been prepared (TECH FIG 1E,F).
- The transversalis and transversus abdominis are closed around the connector with an absorbable suture tied loosely (an air knot). The technique is evolving, and in the near future, the mesh probably will be attached with tissue glue.

### Affixing the Patches
- The onlay patch is attached to the fascia overlying the pubic tubercle, to the internal oblique fascia medially and to the iliopubic track laterally.
  - A lateral slit is made in the mesh for the spermatic cord, attaching the mesh to the shelving edge of the inguinal ligament. Excess mesh is trimmed away.
  - The mesh should never be tight, and fewer sutures are better than many, as long as the mesh is anatomically placed (TECH FIG 2A–C).
- Marcaine is injected thoroughly, and the external oblique, Scarpa’s fascia, and skin are closed with an absorbable suture (TECH FIG 2D,E).

TECH FIG 2 • A,B. Sutures are used to fixate the onlay patch over the pubic tubercle (essential) and to the mid-portion of the transverse aponeurotic arch (optional). A slit is created in the onlay patch to accommodate the spermatic cord, and the mesh is sutured to close the slit. C. The spermatic cord comes through the onlay patch. (continued)
SPORTS MEDICINE • Section III HIP

TECH FIG 2 • (continued) D. Schematic drawing of where the patch will lie. E. Finished position of the mesh. (Courtesy of Ethicon Surgery, a Johnson & Johnson company.)

PEARLS AND PITFALLS

Operate only if the patient has a good mechanism of injury, a good history, and clear indications on physical examination.

- If the patient’s pain does not improve with rest, he or she probably does not have a sports hernia.

Tight sutures, tacks, or tight mesh may cause chronic postoperative pain.

- For the best results, both the anterior and posterior mechanisms of pain must be addressed.

The principle of this surgery (and all abdominal wall hernia surgery) is to normalize the tissue and reinforce the normalized tissue with lightweight, flexible mesh.

POSTOPERATIVE CARE

- Standard post-inguinal hernia surgery care is advised.
- It is important to emphasize a rapid return to normal nonphysical activity (starting the day after surgery) and a progressive incremental return to sports and working out in preparation for sports. This is best accomplished with the help of a trainer.
- The goal of rehabilitation is to establish a full and normal ROM and flexibility followed by incremental increases in resistance for strength training.
- Contact athletes should be able to return to competition in 3 to 4 weeks.
- Runners should be running in 2 weeks and golfers golfing in 1 week.

OUTCOMES

- With appropriate indications and surgical technique, success rates in sports hernia repair have been as high as 97% to 100% in high-performance athletes, with success measured as a return to previous levels of performance and freedom from pain.

COMPlications

- Recurrence
- Thigh pain in the early postoperative period
- Infection
- Hematoma
- Continued pain

REFERENCES

DEFINITION
- Groin injuries are common among athletes, accounting for 2% to 5% of all athletic injuries.  
- A broad spectrum of pathology can cause groin pain in the athlete, and the differential diagnosis is critical.
- Adductor longus–related pain is the most common entity, particularly in athletes participating in kicking sports, such as soccer, and in sports requiring rapid directional changes such as ice hockey and American football.
- Most acute adductor-related groin pain represents strain at the muscle–tendon junction. Although rare, complete avulsions of the adductor longus origin from the pubis can occur.
- Chronic adductor pain typically occurs as an isolated enthesopathy or in concert with athletic pubalgia or pre-hernia complex.

ANATOMY
- The adductor longus is a large, fan-shaped muscle that originates from the anteromedial aspect of the superior pubic ramus just inferior to the pubic tubercle and inserts on the linea aspera of the femur.
- Innervated by the anterior division of the obturator nerve, the origin of the adductor longus consists of direct attachment of both muscle fibers and tendon to the pubis. The proximal tendon has a narrow cross-sectional area.
- The proximal tendon is readily identified on the anterior surface of the muscle with an oblique muscle–tendon junction. The proximal posterior surface usually is entirely muscular in origin.
- A common anomaly is muscle fibers forming the lateral 5 to 11 mm of the anterior origin.
- In maturity, the fibrocartilage of the symphysis pubis develops a small, central fluid-filled cavity or cleft. This cleft manifests as a central focus of high signal intensity at T2-weighted and fat-suppressed short T1 inversion recovery (STIR) imaging.

PATHOGENESIS
- The pathogenesis of chronic adductor strains and frequently associated sports hernias or athletic pubalgia is poorly understood.
- The problem usually is seen in athletes using powerful and ballistic muscle action involving a rapid change from a trunk rotated posteriorly to the plant foot with simultaneous hip extension and abduction followed by a sudden anterior trunk rotation with hip flexion and adduction.
- Examples are an in-step kick in soccer or a fast gait in hockey when the trailing leg is pulled forward, where these actions create strong muscle activity around the lower abdominal muscles and hip adductors and flexors.
- Many of these conditions are chronic or acute on chronic.
- The possibility of a subtle degree of pelvic instability has been considered, but it is difficult to prove.
- Hip adductor involvement is more likely an abnormality at the insertion than a chronic tendinitis or tendinosis.

NATURAL HISTORY
- Acute adductor strains at the musculotendinous junction, like other muscle strain injuries, vary considerably in time to recovery based on the severity of the injury. These are almost always managed without surgery.
- Prior adductor strain has been shown to be a significant risk factor for injury.
- An adductor-to-abductor muscle strength ratio of less than 80% is predictive for a future adductor strain as well. Preventive hip strengthening regimens can lower the incidence of adductor strains.
- In the rare instance of a complete adductor longus avulsion, nonoperative management is preferred.
- Chronic adductor pain presenting as an enthesopathy may occur simultaneously with athletic pubalgia or may follow an acute strain. Enthesopathy can lead to resistant, chronic groin pain, warranting operative intervention.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The diagnosis of an acute adductor strain is relatively straightforward, because the athlete typically presents with a sudden injury to the groin incurred during athletic competition.
- There is tenderness to palpation at the muscle tendon junction. This pain is exacerbated with resisted adduction and passive abduction. Imaging rarely is required for acute strains, but is more commonly obtained for professional athletes.
- In the setting of a more severe acute injury or avulsion, edema and ecchymosis are present and a defect may be palpated.
- The diagnosis of chronic groin pain is not as straightforward because of the broad spectrum of clinical entities that can cause pain in this region and their similar presentations.
- There is no current diagnostic gold standard for chronic groin pain.

FIG 1 • Muscle fibers forming the most lateral aspect of the adductor longus origin.
The differential diagnosis is critical owing to the possibility of other serious disorders; thus, a comprehensive history and physical is warranted in the patient with chronic groin pain.

The physical findings of chronic adductor pain are similar findings to those of an acute strain, but the examiner is more likely to elicit pain with palpation of the pubic symphysis and is more reliant on imaging, coupled with the examination, for a definitive diagnosis.

Involvement of the symphysis pubis detected by physical and even radiographic examination is common.

Chronic adductor-related pain often occurs in conjunction with athletic pubalgia. Sports hernias can present with complaints of vague and migratory lower abdominal pain radiating to the medial thigh.

Sports hernia findings are pain with a sit-up maneuver or resisted internal rotation of a flexed hip. Tenderness to palpation is found above the inguinal ligament and superior to the pubic tubercle. Tenderness may be more focal, involving the external inguinal ring without a palpable hernia or in the vicinity of the conjoint tendon.

Physical examination should include:
- Squeeze test. The presence or absence of pain is noted. Strength is graded as follows: mild—minimal loss of strength; moderate—clear loss of strength; severe—complete loss of strength. Pain with or without a strength deficit implies adductor-related groin pain.
- Passive stretch of adductors. Pain localized to the adductor implies adductor-related groin pain.
- Palpation of external inguinal ring. Pain in the absence of a palpable hernia implies a sports hernia.
- Sit-up against resistance. Adductor pain implies a concomitant or isolated sports hernia.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Imaging studies are most effective when selected on the basis of a thorough history and physical examination.
- MRI is the imaging modality of choice to evaluate chronic adductor-related pain.
- Muscle strains have high T2 signal at the muscle–tendon junction, which can extend along the epimysium.
- Enthesopathy, an overuse injury, reveals signal change within the adductor origin and, often, the pubic marrow.
- We believe that osteitis pubis, ie, marrow changes within the pubis, is a radiologic sign rather than a diagnosis, because these changes are most often present in the setting of adductor-related symptoms.
- Robinson demonstrated that patient symptoms and MRI abnormalities within the pubis correlated significantly and reproducibly with symptomatic adductor enthesopathy or chronic myotendinous strain. Thus, pubic marrow changes should alert the clinician to consider an adductor or lower abdominal wall injury.
- Additionally, Cunningham demonstrated pubic marrow changes are frequently associated with adductor injury, but adductor enthesopathy is also commonly identified in the absence of pubic marrow changes. This suggests adductor dysfunction most likely precedes pubic marrow changes.

In addition to signal changes within the adductor origin, muscle tendon junction, or pubis, a secondary cleft sign may be present.

- Brennan et al defined the abnormal secondary cleft as an extension of the normal hyperintense signal seen within the central symphyseal cleft to a location lateral to the midline or inferior to the joint.
- The secondary cleft is best visualized on a coronal STIR image (FIG 2). This secondary cleft, like pubic marrow changes, is thought to be a consequence of prolonged traction on the pubic rami and common aponeurosis anterior to the symphysis.
- Chronic injury leads to a communication between the central and secondary clefs owing to a microtare or partial avulsion of the adductor longus from the pubis.

**DIFFERENTIAL DIAGNOSIS**

- Athletic pubalgia (sports hernia)
- Inguinal hernia
- Acetabular labral tear
- Hip arthritis
- Femoral neck stress fracture
- Hip synovitis
- Referred testicular pain
- Gynecologic pathology
- Coxa saltsans
- Iliopsoas strain
- Intra-abdominal disorders

**NONOPERATIVE MANAGEMENT**

- Adductor-related acute strains and overuse injuries are all initially managed with rest, ice, compression, and elevation (the RICE method) and a brief period of nonsteroidal anti-inflammatory drugs (NSAIDs). Differentiation between a strain and an enthesopathy is critical, because musculotendinous strains are managed much more aggressively with early, active therapy.
- Early on, active and passive range of motion without pain is initiated.
- Once full, painless range of motion has been achieved, a progressive strengthening regimen is started. Increased emphasis is placed on core stabilization and strengthening of the pelvic musculature.
- Resistance training consists predominantly of eccentric exercise for the hip and pelvic musculature.
Holmich et al\textsuperscript{5} demonstrated that an active strengthening and coordination program for the pelvic musculature was significantly better than conventional physical therapy in treating chronic athletic-related groin pain.

- Nonoperative therapy is completed with sport-specific training and eventual return to play.
- Early return to play is not advised because of the high risk of recurrent injury. Tyler et al\textsuperscript{14,15} showed the best predictor of a future groin strain was an adductor-to-abductor muscle strength ratio of less than 80%.
- Acute adductor avulsions are best managed with nonoperative means, despite reports of successful repair.\textsuperscript{8,11}
- Schlegel et al\textsuperscript{11} reported on 19 acute avulsions in NFL players, where those managed nonoperatively had good outcomes and a markedly shorter recovery time.
- Verall\textsuperscript{16} reported on a specific nonoperative regimen for sports-related groin pain with MRI-documented pubic stress changes. Twenty-seven athletes were rested for 12 weeks, followed by an active therapy regimen. When evaluated by return to sport criteria, outcomes were excellent.
  - However, results were satisfactory only if the criterion of ongoing symptoms was used, because nearly a third of individuals remained symptomatic during their second season post–nonoperative treatment.
  - Additionally, 26\% of these athletes were participating at a lower level of competition.
- Holmich et al\textsuperscript{5} reported on 23 of 29 athletes with chronic adductor-related groin pain returning to symptom-free play at 19 weeks as a result of an active therapy program. Long-term follow-up was not obtained, and these injuries were not stratified regarding strain versus enthesopathy versus avulsion.

**SURGICAL MANAGEMENT**

- Chronic adductor-related groin pain that has failed nonoperative measures, including an active therapy program focused on strengthening of the pelvic musculature and core stabilization, can be successfully treated with tenotomy of the adductor longus.\textsuperscript{1} Although adductor tenotomy previously was reserved for patients with spasticity, it clearly has a role in the management of chronic and disabling groin pain in the athlete. Tenotomy is performed as an isolated procedure or in conjunction with a sports hernia repair.
- Individuals suspected of having a concomitant sports hernia are referred to a general surgeon for definitive management.

**Preoperative Planning**

- Surgical planning consists primarily of an extensive history and physical examination to confirm that the pain is isolated to the adductor and that all appropriate nonoperative measures have been exhausted.
- Additionally, a confirmatory MRI revealing enthesopathy or chronic strain with associated pubic marrow changes or cleft sign is warranted.

**Positioning**

- The patient is placed in the supine position with the operative extremity in an abducted and externally rotated position (FIG 3). The adductor origin is easily palpated in this position. Only the ipsilateral groin is prepped and draped.

**Approach**

- The adductor longus is superficial and proximal to the adductor brevis and adductor magnus origins.
- A 3-cm incision is marked about 1 cm inferior and parallel to the inguinal crease. This incision is centered over the palpable tendinous mass.

**FIG 3** • The operative thigh is flexed, abducted, and externally rotated to provide excellent exposure and easy palpation of the adductor origin.

**OPEN ADDUCTOR LONGUS TENOTOMY**

- The skin is incised in line with the previous mark down to the underlying fascia (TECH FIG 1A). The fascia is incised in a similar fashion, parallel to the skin incision, revealing the underlying adductor longus proximal tendon.
- The tendon is readily identified, and care is taken to identify the medial and lateral borders, noting that the lateral aspect often is composed of muscle fibers without a true tendinous component.
- Once the borders are defined, the tendon is elevated from the underlying adductor brevis and divided with cautery about 1 cm from its pubic origin while protecting the underlying adductor brevis (TECH FIG 1B). Note that the undersurface of the adductor longus is entirely muscular.
- Remaining proximal also protects the anterior division of the obturator nerve as it runs its course along the anterior aspect of the adductor brevis.
- Although some have reported suturing the distal stump of the cut tendon to the overlying fascia, this is not necessary; no distal retraction or deformity has been encountered in our experience.
- The fascia is repaired with an absorbable suture, and the overlying skin is approximated.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Surgical release or tenotomy of the adductor longus has a role in sports medicine for chronic and recalcitrant adductor-related groin pain.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concomitant pathology</td>
<td>Adductor-related groin pain often is associated with athletic pubalgia. A general surgery evaluation is warranted before considering an isolated adductor tenotomy.</td>
</tr>
<tr>
<td>Anatomy</td>
<td>Muscle fibers often make up the lateral 5 to 11 mm of the adductor longus origin. The presence or absence of these fibers must be confirmed to ensure a complete tenotomy is accomplished.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Immediate ambulation is permitted without assistive devices. Stretching is avoided until the incision has healed.
- Once the incision has healed, a progressive strengthening and stretching routine is initiated, with an emphasis on core stabilization.

OUTCOMES

- Akermark performed isolated adductor tenotomy in 16 athletes with chronic adductor-related groin pain. All patients reported significant improvement. Fifteen of 16 returned to sporting activities within 6 to 8 weeks, and 12 of 16 returned to competitive sports by 14 weeks. Only 10 athletes returned to full athletic competition; five returned to a reduced level of competition.
- As one might expect, patients had decreased isokinetic testing relative to the nonoperative side. However, these patients were reported to maintain functional sports activity despite the measured deficit.
- A definitive recommendation to proceed with adductor tenotomy is difficult, particularly in the high-performance athlete. Therefore, adductor tenotomy is reserved as a last-ditch effort to return the chronically disabled athlete to competitive sports with the possibility of participation at a reduced level of performance.
- Additional study investigating nonoperative and surgical intervention of adductor-related groin pain clearly is warranted.

COMPLICATIONS

- We suspect that persistent groin pain attributed to an incorrect diagnosis or an untreated concomitant sports hernia is the most prevalent complication from adductor-related surgery.

REFERENCES


DEFINITION
- Stretch-induced proximal hamstring injury is common among athletes.
- These injuries represent a continuum including strain at the musculotendinous junction (MTJ), partial tear of the tendon, or complete avulsion of the hamstring muscle complex from the ischial tuberosity.\(^1,9\)

ANATOMY
- The hamstring muscle group consists of three muscles: the biceps femoris (long and short heads); the semitendinosus; and the semimembranosus. All three muscles, except for the short head of the biceps femoris, originate from the ischial tuberosity of the pelvis.
- The biceps femoris and semitendinosus have a common origin.
- The hamstrings are biarticular muscles bridging the hip and knee.
- The proximal tendons of the biceps femoris and semimembranosus have been shown to extend for about 62% and 73%, respectively, of their muscle bellies.\(^9,11\)
- The sciatic nerve lies immediately lateral to the hamstring origin.

PATHOGENESIS
- Eccentric activation while under stretch, as seen in a flexed hip and extended knee when the hamstrings attempt to decelerate the leg during knee extension in high-speed sports-related activity, is thought to be the principal mechanism of injury.\(^2,21\)
- An additional, but rare, mechanism for hamstring injury is extreme stretch with an uncertain amount of muscle activation. This may occur in situations such as waterskiing or when the knee is extended and there is sudden hip flexion.\(^1,9,11,18\)

NATURAL HISTORY
- The natural history of these injuries varies considerably, with a more proximal injury resulting in a longer time for recovery to pre-injury status and a greater likelihood of surgical intervention due to the persistent and significant disability associated with hamstring avulsion.\(^1\)
- Partial or complete hamstring avulsions should not be confused with strain at the musculotendinous junction. Avulsions can be extremely disabling and, unlike strain at the musculotendinous junction, may warrant surgical intervention. Avulsions cause symptoms of weakness and loss of muscle control, especially during fast-paced running.
- Fortunately, most proximal hamstring injuries are strains at the musculotendinous junction that are best managed non-operatively. Strains most often occur in the biceps femoris, and the most common location is near the muscle–tendon junction. Recovery time has been correlated directly with the percentage of muscle involved by measuring the cross-sectional area or the longitudinal length of abnormal muscle signal on MRI.\(^1,5,13,20\)
- Injuries involving over 50% of the cross-sectional area result in a recovery period longer than 6 weeks, whereas normal imaging findings result in a recovery period of approximately 1 week.\(^13\)
- The greatest risk factor for injury to the hamstring muscle complex is a history of previous injury to the same place.\(^16,21\)
- Peterson\(^17\) reported the recurrence rate for hamstring injury to be 12% to 31%. Whether the reinjury is attributed to insufficient rehabilitation and early return to sport or the persistence of pre-existing risk factors, the treating physician must have the ability to assess the degree of injury, a knowledge of the reparative process of healing muscle, and an understanding of the rehabilitative and preventive measures for hamstring injury.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Proximal hamstring injury typically results in sudden onset of pain in the posterior proximal thigh during athletic competition or training.
- Severe injury, such as an avulsion, may present with a visible deformity, swelling, ecchymosis, and a palpable defect. Focal tenderness to palpation and pain on provocation with resisted knee flexion are consistent findings.
- With the patient lying prone and the hamstrings activated, palpation of proximal hamstring origin is undertaken.
  - A palpable defect implies proximal avulsion.
  - Pain without a defect suggests partial avulsion.
- Obvious increase in apparent hamstring flexibility of the injured extremity implies proximal avulsion.
- The current classification of muscle injuries identifies mild, moderate, and severe injuries, based on the degree of clinical impairment.
  - Mild muscle injury is minimal to no loss of strength, whereas moderate injury is a clear loss of strength.
  - Severe injury is the complete absence of muscle function. In severe injury, neurogenic symptoms may be present secondary to direct compression or a traction neuritis on the adjacent sciatic nerve.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs are useful in evaluating for a bony avulsion.
- MRI is the imaging of choice to confirm the existence of a muscle injury or avulsion, particularly when a discrepancy exists between the examiner’s findings and the patient’s symptoms.
In separate investigations Connell, Kouloris, Askling, and Slavotinek correlated rehabilitation time to the percentage of muscle involved by measuring the cross-sectional area or the longitudinal length of abnormal muscle signal on MRI. Kouloris stated injuries involving greater than 50% of the cross-sectional area resulted in a greater than 6 week recovery period, whereas normal imaging resulted in a recovery period of approximately 1 week.1,5,13,20 Schneider-Kolsky et al19 questioned the ability of MRI to predict rehabilitation time for minor and moderate injury. Despite a limitation of variable methods of rehabilitation, they concluded MRI to be useful in predicting the duration of convalescence for moderate and severe injury. Conversely, they determined clinical assessment to be slightly better than MRI for minor injury. Verall reported on a subset of patients with a clear clinical diagnosis of hamstring strain, but an MRI negative for muscle injury. Like Schneider-Kolsky’s findings, Verall reported patients with hamstring muscle strain injuries demonstrable by MRI had a poorer prognosis than those whose posterior thigh injury was not MRI-positive. Askling also demonstrated a correlation between the location of injury by MRI and time to recovery. He found longer recovery times for injuries in close proximity to the hamstring origin. In other words, the more cranial the injury the longer the recovery time. Interestingly, the prediction of recovery time was equally good using the point of highest pain on palpation, established within 3 weeks of the injury.

MRI is most useful in the setting of moderate or severe injury to predict recovery time based on injury location or percentage of involved muscle or to detect an avulsion imperceptible on physical exam due to a massive hematoma or swelling (FIG 1).

**DIFFERENTIAL DIAGNOSIS**
- Referred lower back pain (discogenic, arthropathy, etc.)
- Radiculopathy (HNP, spinal stenosis)
- Sciatica
- Tumor
- Piriformis syndrome
- Apophysitis
- Pelvic stress fracture

**NONOPERATIVE MANAGEMENT**
- The vast majority of proximal hamstring injuries involve strain at the musculotendinous junction and are managed with nonoperative measures focusing on restoration of flexibility and muscle strength.8,10
- Treatment of a proximal hamstring injury is predicated on the grade or severity of the injury and an understanding of the balanced progression of muscle regeneration and scar formation.10
- Proximal hamstring strains are typically treated with a few days of rest based on the grade of injury followed by early active and passive mobilization within the limits of pain.
- Ice and compression are useful adjuncts to diminish bleeding and inflammation as large hematomas may adversely influence scar formation.
- Sport specific training usually starts approximately 2 weeks post injury.
- If there is no improvement by 3 to 4 weeks, an MRI should be obtained.
- Once athletes return to their sports, they should continue an in-season strengthening and stretching program, as prevention of reinjury is critical due to the high rate of recurrence.2,6,17,21,22

**FIG 1** • A.B. Hamstring strain reveals increased T2 signal along the entire length of the left hamstrings, particularly along the musculotendinous junction, involving the biceps femoris and to a lesser degree the semitendinosus and semimembranosus. C. Surgical exposure reveals complete avulsion of the proximal tendon from the ischial tuberosity. (C: Courtesy of Gary Fetzer, MD, and Brad Nelson, MD, Minneapolis.)
Chapter 30 PROXIMAL HAMSTRING INJURY

REPAIR OF HAMSTRING COMPLETE AVULSION

The posterior femoral cutaneous nerve and its proximal branches are identified running deep to fascia down the back of the thigh obliquely crossing the long head of the biceps femoris.

- Branches of the posterior femoral cutaneous nerve are the inferior cluneals and perineals.
- The inferior cluneal nerves, three or four in number, turn upward around the lower border of the gluteus maximus.
- The perineal branches are distributed to the skin at the upper and medial side of the thigh.
- The inferior border of the gluteus maximus muscle is mobilized by dividing the posterior fascia and retracting the muscle superiorly in order to expose the ischial tuberosity and avulsed tendon stumps.
- Starting distally from normal anatomy, the sciatic nerve is identified lateral to the ischium.
- If required, a careful sciatic neurolysis is performed in chronic cases.
- Care is taken to identify and protect the branches to the semimembranosus.

The avulsed tendon stumps are identified and tagged with a grasping suture using a no. 2 high strength suture (TECH FIG 1A).

Mobilization of the tendon stumps and proximal musculature is carefully performed in order to minimize tension on the repair and limit the amount of knee flexion, if any, required to approximate the tendons to their origin on the lateral aspect of the ischial tuberosity. In chronic cases, a distal hamstring lengthening may be necessary.

If there is an adequate residual, proximal tendon stump, a direct repair is performed. Otherwise the repair is performed using suture anchors after clearing the soft tissue from the anatomic footprint on the ischial tuberosity (TECH FIG 1B).

If a tendon cannot be mobilized to its anatomic origin on the ischium other authors have reported tenodesing the tendon to the adjacent myotendinous complex.

The fascia and overlying skin are then approximated in separate layers.
POSTOPERATIVE CARE

- The knee is held in the minimal amount of flexion to limit tension on the repair for approximately 3 to 4 weeks.
- Range of motion is initiated thereafter in order to obtain a normal gait by 6 weeks post surgery.
- A progressive strengthening regimen is initiated after 6 weeks with a return to sports related activity no earlier than 3 months after surgery.

OUTCOMES

- Klingele\(^{13}\) reported on suture anchor fixation in 11 individuals (average age 41.5 years) with complete proximal avulsion injuries. There were 7 acute and 4 chronic (>4 weeks) injuries treated with a 78% return to sport by 6 months and a 91% satisfaction after a minimum 2 year follow-up. Varying degrees of hamstring mobilization and fractional lengthening were performed in the chronic cases. However, for patients who underwent repair of chronic injuries the average hamstring muscle strength was 89% of the uninjured extremity by Cybex testing at an average 34-month follow-up.
- Chakravarthy performed either direct or suture anchor repair in 4 patients, 1 acute and 3 chronic, with all patients obtaining normal strength and near-normal flexibility at an average 15 months of follow-up.\(^4\) Three of these four patients returned to their preinjury level of sport.
- Cross performed repairs on 9 patients (average age 34 years) with chronic, complete avulsions at an average of 36 months post injury.\(^7\) These patients were held at 90 degrees of knee flexion for 8 weeks after surgery with full knee range of motion obtained by 14 weeks in all cases. At an average 4 year follow-up, hamstring strength was 60% of the unaffected side with 7 of 9 patients having returned to a lower level of sports.
- Brucker performed surgical repair in 8 complete avulsions, 6 acute and 2 chronic, also immobilizing the operative extremity at 90 degrees of knee flexion for 6 weeks post surgery.\(^3\) Full range of motion was obtained in all patients by 16 weeks. At 33 months follow-up all patients were satisfied and 7 had returned to sports. The minimum time to return to sports was 6 to 8 months with 2 individuals delayed more than 24 months. Objective measures revealed no difference in hamstring flexibility relative to the contralateral extremity. Cybex dynamometer testing revealed an average peak torque of the operated hamstring muscles of 88.8% compared to the opposite limb.
- Orava described surgical intervention in 8 patients, 5 acute and 3 chronic, with complete or incomplete proximal avulsions using suture anchors, drill holes, or tenodesis of the avulsed hamstring to an adjacent and intact hamstring.\(^{15}\) Hip and knee flexion were avoided for 1 month with full weight bearing initiated at 1 month. All 5 acute patients exhibited normal strength and full range of motion at 5.7 year follow-up. However, those patients surgically treated 3 or more months from their injury had inferior outcomes.
- Lempainen recently described surgical repair of 48 MRI confirmed partial proximal hamstring avulsions or tendon tears in athletes who failed to respond to nonsurgical measures.\(^{14}\) Forty-three of these injuries were operated on more than 4 weeks from the time of injury with an average delay of 13 months. No immobilization was performed and full weight bearing was initiated at 2 weeks after repair. Eighty-eight percent of these patients reported good or excellent results and 87% returned to their preinjury level of sport at a mean follow-up of 36 months. However, this population predominantly consisted of patients who had failed conservative treatment. There are no reports on the number of patients successfully managed with nonoperative measures for partial avulsions.
Despite variable technique, degree of chronicity, and heterogeneous patient populations, these reports indicate repair of acute and chronic complete or partial proximal hamstring avulsion can improve patient outcomes. Early surgical intervention for complete tears is preferred in order to limit hamstring retraction and muscle atrophy and to obtain a better functional outcome. Whether or not surgical treatment should be considered in the acute setting for partial injuries remains unclear. The delay in return to sport and the persistent functional impairment associated with partial avulsions as reported by Sallay and Lempainen suggests further study is warranted regarding the indications and timing of surgical intervention in this population.

COMPLICATIONS

- Surgical repair of proximal hamstring avulsions have resulted in satisfactory outcomes; however, several authors have reported on several patients with persistent pain and/or spasm associated with strenuous exercise.
- Brucker reported on a loss of fixation for a single suture anchor from the ischial tuberosity. The anchor was removed in a second surgical procedure due to pain in a sitting position.
- Others have reported on persistent sciatica mandating a neurolysis to address postoperative scarring.

REFERENCES

Knee arthroscopy is a video-assisted surgical intervention for intra-articular disease of the knee.

**ANATOMY**

- The knee can be divided into three compartments: the patellofemoral joint, the lateral tibiofemoral joint, and the medial tibiofemoral joint.
- The patellofemoral compartment is composed of the suprapatellar pouch, the patella bone, its femoral articulation (called the trochlea), the medial and lateral femoral condyles, and the medial and lateral patellofemoral ligaments.
- The suprapatellar pouch is a potential space that develops when the knee joint is insufflated with fluid. Within this area, adhesions, plicae, and loose bodies may be found. Adhesions are commonly found with revision surgery.
- Synovial plicae are bands of synovium that are remnants from fetal development. Their location and size may contribute to snapping sensations and inflammation within the joint. In the suprapatellar pouch, however, they most commonly provide a location for loose bodies to hide.
- Suprapatellar plicae may partition an entire compartment within the pouch, leaving only a centralized hole by which loose bodies may gain entrance. These holes are called porta.
- The patella is one of the sesamoid bones of the body. It has a medial and a lateral facet that articulate with its respective condyles. Centrally, there is an apex of the bone that sits in the trochlea.
- The patella has the thickest cartilage in the body, which is used to withstand forces up to five times body weight.
- With normal articulation of the patella on the femur, the cartilage of the medial facet touches the medial femoral condyle. This can be visualized with arthroscopy.
- The patella begins to engage the trochlea at approximately 20 degrees and fully engages at 45 degrees. Lack of contact of the medial facet with the medial femoral condyle at these points in the range of motion suggests malalignment.
- The medial and lateral patellofemoral ligaments are thickenings of the medial and lateral retinaculum respectively. They originate centrally on the patella and insert onto the medial and lateral epicondyles of the femur.
- The medial patellofemoral ligament may become disrupted or attenuated with patellar dislocations. This may predispose to further dislocations, necessitating operative repair.
- The lateral patellofemoral ligament and retinaculum are often released in efforts to restore patellofemoral alignment.
- The medial tibiofemoral compartment is composed of the medial gutter and the tibiofemoral articulation.
- The medial gutter is a fold of synovium in the posteromedial aspect of the joint where loose bodies may hide. Ballooning of this space is essentially to ensure that no potential sources of pain exist within this region.
The popliteus tendon inserts onto the posterior body of the lateral meniscus and provides stability to the meniscal body. It attaches to the meniscus by means of three popliteomeniscal fascicles: the anteroinferior, posterosuperior, and posteroinferior fascicles. Anterior and posterior to the insertion of the tendon on the lateral meniscus is a recess of the joint capsule that does not insert onto the periphery of the meniscus. This makes the lateral meniscus more mobile than the medial meniscus.

Along the posterior horn of the meniscus originate two ligaments that insert into the femur. The ligament of Wrisberg travels posterior to the posterior cruciate ligament (PCL) to insert onto the femur; the ligament of Humphrey travels anterior to the PCL and inserts onto the femur.

Between the medial and lateral articulations is the intercondylar notch. It is a nonarticular portion of the knee that extends distally and posteriorly from the trochlea.

In the most anterior aspect of the notch lies the transverse meniscal ligament. This is a ligament that originates at the anterior horn of the medial meniscus away from the anterior root and inserts on the anterior horn of the lateral meniscus anterior to the anterior root of the lateral meniscus.

This space between the transverse ligament and the anterior horn of the medial and lateral menisci is often mistaken for a tear of the menisci on magnetic resonance imaging (MRI).

There is significant bony variation in terms of the width of the intercondylar notch; this may contribute to the decision to perform a notchplasty or notch widening when performing an anterior cruciate ligament (ACL) reconstruction.

The ACL and PCL reside within the intercondylar notch.

- The ACL originates at the posterolateral position (about 10:30 on a right knee and 1:30 on a left knee) of the inner wall of the notch and inserts centrally and anteriorly on the tibia. In the sagittal plane, it inserts slightly posterior to the anterior horn of the lateral meniscus and about 7 mm anterior to the PCL fibers.

- The PCL originates from the anterior aspect of the medial wall of the notch and has a broad origination that begins at about 12 o’clock and ends around 3:30 (on a right knee). This ligament travels posterior to the ACL and inserts centrally on the posterior aspect of the tibial plateau about 10 to 15 mm inferior to the joint line. The fibers run quite close to the posterior root of the medial meniscus and one must be careful not to deviate medially when débriding PCL remnants in this region during a PCL reconstruction.

**SURGICAL MANAGEMENT**

**Preoperative Planning**

- Each patient is unique and the equipment needed for each surgery will vary. The surgeon must review the case specifics and studies before surgery and ensure that all necessary equipment is available when the surgery begins.

- On the day of surgery, the surgeon should reconfirm with the patient the laterality of the procedure, “sign your site,” and verify that there has been no change in the signs and symptoms of the injury since the last office visit.

- The surgeon performs an examination under anesthesia to reconfirm the diagnosis because this is crucial to understanding the nature of the injury. With sedation, the patient is more relaxed and able to give a more sensitive examination.

**Positioning**

- The patient should be supine and close to the edge of the bed.

- The surgeon should verify that he or she will be able to get proper flexion of the leg should it be necessary to drop the foot of the bed.

- The contralateral leg can be placed in a well-padded leg holder or secured to the bed with circumferential padding.

- The use of a thigh holder versus a lateral post for arthroscopy is based on surgeon preference.

- The thigh holder can be used with the foot of the bed dropped to 90 degrees, or the leg may be abducted and brought over the side of the bed (Fig 2A).

- Commercial knee holders may not be capable of holding very large knees or pediatric knees. In these cases, a lateral post is preferred (Fig 2B).

**Approach**

- The approach largely depends on what arthroscopic knee procedure is going to be performed.

- Regardless, portal placement is the key to successful knee arthroscopy.
PORTAL PLACEMENT

- TECH FIG 1 shows the locations of the far lateral, anterolateral, anteromedial, and far medial portals and their relationships to landmarks of the knee.

Anterolateral Portal
- Most arthroscopic visualization is performed through this portal.
- It is created just lateral to the patella tendon. The incision is usually placed just inferior to the inferior aspect of the patella. Alternatively, the incision can also be referenced from the tibia.
- The incision should measure 1 cm long.
- Typically the incision is made vertically, but some surgeons prefer a horizontal incision, which may aid in preventing inadvertent laceration to the infrapatellar branch of the saphenous nerve.

Anteromedial Portal
- This is the primary working portal.
- Its position is highly dependent on the work that needs to be done.
- Traditionally, it is slightly more inferior than the anterolateral portal and just medial to the patella tendon, but the surgeon should be liberal about moving the location of this portal to optimize the surgical goals of the arthroscopy (ie, meniscal surgery versus mosaicplasty).
- The surgeon can use a spinal needle to localize the optimal portal placement before making the anteromedial portal incision.

Superomedial or Superolateral Portal
- A superior portal can be placed either medial or lateral to the quadriceps tendon.
- We prefer a superolateral portal because it results in less vastus medialis oblique inhibition.
- This portal can be used as an inflow or outflow portal or to perform procedures in the suprapatellar pouch (ie, loose body removal, medial retinaculum plication, synovectomy, or evaluation of patella tracking).
- This portal is placed about 2.5 cm proximal to the superior pole of the patella at the edge of the quadriceps tendon.

Central (Transpatellar) Portal
- This portal uses a vertical incision through the central third of the patellar tendon at the level of the joint line.
- It is mostly used to facilitate access to the intercondylar notch.

TECH FIG 1 • Artist’s rendition (A) and anterior view (B) of the right knee showing portal placement of far lateral, anterolateral, anteromedial, and far medial portals and their relationships to the inferior pole of the patella, the medial and lateral joint line, and the patellar tendon. C. Medial view of right knee showing anteromedial, far medial, and posteromedial portal placement and their relationships to the medial tibial plateau and medial femoral condyle. D. Lateral view of right knee far lateral, anterolateral, and posterolateral portal placement and their relationships to the lateral tibial plateau, lateral femoral condyle, fibula, and biceps tendon.
Occasionally, this portal may be required when performing a modified Gillquist maneuver (examination of the posterior horns of the menisci through the intercondylar notch) in a patient with a stenotic intercondylar notch.

**Posteromedial Portal**
- When pathology presents in the posteromedial knee, this portal may be used as a working portal.
- To assess the proper placement of this portal, the surgeon performs a modified Gillquist maneuver through the anterolateral portal (technique details are given in the Diagnostic Arthroscopy section) and uses the 70-degree arthroscope to transilluminate the skin overlying the posteromedial capsule.
  - A spinal needle is placed at the center of the transilluminated skin. This position should be about 1 to 2 cm above the joint line.
  - When comfortable with the position of the needle, the surgeon makes a 1-cm skin incision with a no. 11 blade and places a cannula with a blunt obturator to penetrate the capsule. This helps to protect the soft tissues in this area from damage and reduces fluid extravasation into the surrounding soft tissues.

  ![Tech FIG 2](https://example.com/techfig2.png)  
  *Arthroscopic view of the suprapatellar pouch showing adhesion running obliquely.*

**Posterolateral Portal**
- The indications and technique for this portal are similar to those for the posteromedial portal.
- The surgeon perform the modified Gillquist maneuver through the anterolateral portal and transilluminates the skin overlying the posterolateral capsule of the knee with the 70-degree arthroscope as described above.
- A spinal needle is used to confirm proper portal placement. This portal should be at the lateral aspect of the posterolateral compartment to avoid the large neurovascular structures.
- Before making the skin incision, the surgeon should ensure that the planned incision is anterior to the biceps tendon to avoid the peroneal nerve.

**Far Lateral and Far Medial Portals**
- These portals are made 2 cm either lateral or medial to their respective anterior portals.
- They can be used to aid in work that needs to be done posterior to the femoral condyles.

**Anterolateral Portal**
- Using a no. 11 blade knife, the surgeon places a vertically oriented 1-cm incision just lateral to the patellar tendon and inferior to the patella with the knee at 60 to 90 degrees of flexion.
- The bevel of the knife is buried (blade facing away from the meniscus) to ensure the capsule has been penetrated.
- The knife is angled toward the intercondylar notch to prevent damage to the lateral femoral condyle.

**Anteromedial Portal**
- Creation of an anteromedial portal is necessary to complete a thorough diagnostic arthroscopy.
- The surgeon may use a probe placed through this portal to palpate the cartilage for injury and perform a complete evaluation of the menisci once the arthroscope has been inserted.
- The position of this portal varies depending on the work being performed. Typically, it is 1 cm medial to the patellar tendon and slightly inferior to the anterolateral portal.

**Introduction of Obturator and Sheath**
- With the knee flexed at 60 to 90 degrees, the arthroscope sheath is placed with a blunt obturator through the anterolateral portal, aiming toward the intercondylar notch.
- Intra-articular position is confirmed by palpating the obturator anterior to the medial compartment.
- By dropping his or her hand, the surgeon pulls the obturator and sheath back slightly.
- As the knee is brought to an extended position, the obturator and sheath is gently advanced in the suprapatellar pouch.

**Visualization of Suprapatellar Pouch**
- The camera is placed in the suprapatellar pouch (Tech FIG 2).
- The size of the pouch is evaluated.
- The surgeon looks for adhesions and loose bodies.

**Visualization of the Patella**
- The camera is aimed anteriorly (toward the ceiling) to visualize the patella.
Assessment of Patellar Tracking
- The arthroscope is retracted further and the knee is ranged from flexion to extension to assess patellar tracking.
- The medial facet of the patella should engage the medial aspect of the trochlea at 20 degrees and fully engage in the trochlea at 45 degrees.
- Lateral facet overhang may suggest a tight lateral retinaculum and maltracking.

Lateral Gutter
- The arthroscope is advanced up into the suprapatellar pouch so the tip is proximal to the patella.
- With the patient's knee extended, the surgeon brings the arthroscope over the lateral femoral condyle. The surgeon's hand is raised so that the camera is angling down toward the floor, and the light source is turned so that it is looking distally (TECH FIG 4A).
- The lateral gutter (located between the lateral femoral condyle and the lateral capsule of the knee joint) will be visualized.
- By pushing posteriorly, the insertion of the popliteus tendon and its three popliteomeniscal fascicles of the lateral meniscus may be visualized (TECH FIG 4B,C).

Visualization of the Lateral Meniscocapsular Junction and the Anterior Knee
- The arthroscope is retracted to visualize the attachment of the lateral meniscus to the capsule. This is best performed with the knee in 20 degrees of flexion.

Visualization of the Trochlea and Condyles
- The arthroscope is aimed toward the femur, and the trochlea and anterior aspects of the medial and lateral femoral condyles are inspected.
- The probe is used to palpate the cartilage for evidence of softening, fissures, and unstable cartilage flaps.
- The arthroscope is retracted until the patella comes into view (TECH FIG 3).
- Pictures of the medial and lateral facets are taken.
- The surgeon's free hand can be used to mobilize the patella for better visualization.
- The cartilage of the patella is probed for evidence for softening, chondral flaps, or fissures.

Lateral Gutter
- The arthroscope is advanced up into the suprapatellar pouch so the tip is proximal to the patella.
- The lateral gutter (located between the lateral femoral condyle and the lateral capsule of the knee joint) will be visualized.
- By pushing posteriorly, the insertion of the popliteus tendon and its three popliteomeniscal fascicles of the lateral meniscus may be visualized (TECH FIG 4B,C).
A varus stress is applied to the knee at 30 degrees of flexion.

The lens of the arthroscope is turned medially to visualize the anterior horn of the lateral meniscus.

The anterior horn of the medial meniscus may also be seen more medially if the view is not blocked by synovium or the anterior fat pad.

**Medial Gutter**

The arthroscope is returned to the suprapatellar pouch, and then the surgeon migrates over the medial femoral condyle to the medial gutter.

By lifting his or her hand and aiming the light source so that the arthroscope is angling toward the floor again, the surgeon can visualize the medial gutter (space between the medial femoral condyle and the medial capsule of the knee joint).

Ballottement is performed to check for loose bodies.

A medial meniscal cyst and displaced meniscal flap tears may be visualized using this view as well.

**Medial Compartment**

From the medial gutter, the medial compartment is entered by bringing the arthroscope toward the midline until the medial femoral condyle is viewed (TECH FIG 5).

The knee is moved through a range of motion from full extension to full flexion. The entire medial femoral condyle is evaluated for cartilage defects.

The surgeon probes for softening, fissures, and flaps and checks for plica snapping over the condyle as well.

The posterior portion of the medial compartment is usually best visualized with the leg at 30 degrees, with a valgus stress applied to the knee.

The medial compartment may widen abnormally with valgus stress so that significant space between the medial tibial plateau and medial femoral condyle exists.

The surgeon should suspect a medial collateral ligament injury when this occurs. This is especially true if the meniscus lifts up off the tibial plateau, indicating significant tibial-sided medial collateral ligament laxity.

The tibial plateau is visualized and probed for chondral abnormalities. The surgeon should visualize the posterior root, posterior horn, body, anterior horn, and anterior root of the meniscus.

The undersurface of the meniscus is probed and inspected. The meniscus is tested with a hoop stress test.

The perimeter of the tibial plateau is probed for flipped flap tears of the meniscus.

In patients who are not ligamentously lax, the posterior horn periphery may be difficult to visualize.

In this case a modified Gillquist maneuver may allow better visualization of the posterior horn of the medial meniscus.

Instruments angled up work best in the medial compartment because the tibial plateau is a convex surface.

**Posteromedial Knee**

The surgeon performs the modified Gillquist maneuver.

The arthroscope is removed from the sheath and the blunt obturator is placed in the sheath. The knee should not be placed in 70–90 degrees of flexion.

The blunt obturator and sheath is placed into the anterolateral portal and advanced into the space between the medial aspect of the intercondylar notch and the posterior cruciate ligament (TECH FIG 6A).

Gentle pressure is applied until the obturator slides posteriorly.
The blunt obturator is replaced with the 70-degree arthroscope and camera, and the surgeon visualizes the posterior horn of the medial meniscus, the posterior medial femoral condyle, the posterior meniscal root and the capsular attachment, and the insertion of the PCL on the back of the tibial plateau (TECH FIG 6B). The surgeon can check for loose bodies as well.

**Intercondylar Notch**
- The leg is relaxed and allowed to dangle at the side of the bed.
- The cruciate ligaments are inspected in the intercondylar notch and their competency and laxity are tested (TECH FIG 7).

**Lateral Compartment**
- The arthroscope and probe can be situated in the intercondylar notch near the medial aspect of the lateral femoral condyle.
- The leg is placed in a figure 4 position with the knee flexed to 90 degrees while varus stress is applied. Ninety degrees of flexion is the optimal position for visualizing the posterolateral compartment of the knee.
  - When using a leg holder, varus stress can produce similar results.
- When the lateral compartment opens up so there is significant space between the lateral tibial plateau and lateral femoral condyle, the surgeon should suspect a posterolateral corner injury.
- The knee is moved through a range of motion from full extension to full flexion and the entire lateral femoral condyle and lateral tibial plateau are evaluated for cartilage defects (TECH FIG 8).

**Tech FIG 7** • Arthroscopic view of the intercondylar notch. The anterior cruciate ligament is well visualized on the left, with the posterior cruciate ligament on the right more obscured by fat and synovial tissue.

**Tech FIG 8** • Arthroscopic view of the lateral compartment, including the lateral femoral condyle, lateral tibial plateau, lateral meniscus, and popliteus tendon.

- The surgeon should probe for softening, fissures, and flaps.
- The meniscus is inspected and probed on its surface and undersurface.
- The popliteus tendon is checked for tears.
- The popliteal hiatus is checked for abnormal instability.
- The surgeon should visualize the posterior root, posterior horn, body, anterior horn, and anterior root of the meniscus.
- The undersurface of the meniscus is probed and inspected, and the meniscus is tested with a hoop stress test.
- The perimeter of the tibial plateau is probed for flipped flap tears of the meniscus.
- The surgeon should inspect the posterior horn of the lateral meniscus. This may require a variation of the modified Gillquist maneuver (mentioned previously).

**Modified Gillquist Maneuver for the Posterolateral Compartment**
- The arthroscope is removed from the sheath and the blunt obturator is placed in the sheath. The knee should not be placed in 70–90 degrees of flexion.
- The blunt obturator and sheath is placed into the anteromedial portal and advanced into the space between the lateral aspect of the intercondylar notch and the ACL.
- Gentle pressure is applied until the obturator slides under the ACL next to the lateral femoral condyle posteriorly to the posterolateral compartment.
- The blunt obturator is replaced with the 70-degree arthroscope and camera. The posterior horn of the lateral meniscus, the posterior lateral femoral condyle, the posterior meniscal root, and the capsular attachment are visualized. The surgeon can check for loose bodies as well.

**Pearls and Pitfalls**

- **Preoperative planning**
  - The surgeon should be sure to have all instruments and implants available that will be helpful to the surgery. A 70-degree arthroscope can be useful in most cases. Shoulder arthroscopy instrumentation and cannula systems can be helpful with more complex surgeries as well. The surgeon should talk to the patient before the surgery and perform an examination under anesthesia to confirm the pathology necessitating surgery.

- **Proper portal placement**
  - Surgical portal incisions should be tailored to the needs of the case. If a portal is not adequate or optimal, the surgeon should make a new portal. Larger or heavier patients may require larger portals for better maneuvering.
### POSTOPERATIVE CARE

- Once the procedure has ended, postoperative care has begun.
- Excess fluid is eliminated from the knee with suction.
- Although there is some variation in portal closure, we prefer a simple skin closure with a nonabsorbable monofilament suture.
  - Regardless of suture type or technique, the surgeon should obtain a tight closure.
- Intra-articular and portal injection of local anesthetic may help with postoperative pain management.
- Deep vein thrombosis prophylaxis may be accomplished with a compression dressing from the toes to the thigh, elevation, mobilization, and ankle pumps.
- Regardless of postoperative weight-bearing status, most patients will require crutches for mobility.
- Cryotherapy has been shown to improve pain scores after knee arthroscopy and is recommended.
- Motion and weight-bearing status are determined by the procedure performed and the patient’s needs.
- Pain control with narcotics will likely be necessary for the first few weeks.

### COMPLICATIONS

- Iatrogenic cartilage injury
- Nerve injury: saphenous nerve, peroneal nerve, femoral nerve, sciatic nerve
- Vascular injury
- Deep vein thrombosis
- Compartment syndrome
- Arthrofibrosis
- Reflex sympathetic dystrophy
- Persistent hemarthrosis

### REFERENCES

DEFINITION
- Synovitis is inflammation of the synovial membrane. The synovial lining undergoes hyperplasia, most prominent in rheumatoid arthritis. A mononuclear infiltration often makes up the sublining. Redundant synovial folds and villae may be present.
- Synovitis secondary to inflammatory conditions can lead to painful, swollen, and stiff knees.
- After medical management has been exhausted, surgery is indicated if the patient experiences continued pain, swelling, and mechanical symptoms.
- Conditions associated with knee synovitis include rheumatoid arthritis, pigmented villonodular synovitis (PVNS), synovial osteochondromatosis, psoriatic arthritis, osteoarthritis, lupus arthropathy, gout, synovial hemangiomas, plicae, intra-articular adhesions, fat pad fibrosis, postruumatic synovitis, hemophilic synovitis, and fibrous ligamentum muscosum.1–4,6,9,14,15

ANATOMY
- Synovial tissue is a specialized mesenchymal lining of joints.
- Normal synovium supplies nutrients for the articular cartilage and produces lubricants that bathe the joint surfaces to allow smooth gliding. It is a specialized mesenchymal tissue.
- Histologic hallmarks of chronic synovitis include hyperplasia of the intimal lining, lymphocyte infiltration, and blood vessel proliferation.
- Patients with chronic synovitis can have localized or diffuse disease, depending on their underlying condition. When localized, imaging studies such as magnetic resonance imaging (MRI) can help direct arthroscopy. With diffuse disease, it is vital to visualize all aspects of the knee.

PATHOGENESIS
- In chronic synovitis, the synovial lining undergoes hyperplasia, angiogenesis, and increased cellularity (inflammatory cells such as lymphocytes and macrophages).
- Rheumatoid arthritis is one of many immunoinflammatory diseases. It presents as an insidious onset of morning stiffness with multiple joint involvement. The synovitis that ensues is likely an acute autoantibody-mediated inflammatory response.
- PVNS is a proliferation of nodules and villi in the synovium of joints. Typically it is monoarticular, most commonly affecting the knee.
- Hemophilia is an X-linked deficiency of clotting factors, leading to bleeding of varying severity.
  - The knee is the most common site of hemarthrosis. The repeated hemarthroses can lead to a chronic, progressive synovial hyperplasia.

NATURAL HISTORY
- Repeated bouts of acute synovitis or chronically inflamed synovium can lead to chronic pain, limited range of motion, and ultimately joint degeneration and arthrosis.

PATIENT HISTORY AND PHYSICAL FINDINGS
- A full personal and family history of rheumatologic and hematologic disorders should be elicited, including involvement of other joints and episodes of knee or other joint swelling in the past.
- The patient may have a history of recurrent swelling, pain, warmth, stiffness, and mechanical symptoms (FIG 1).
- Patients may have the stigmata of psoriasis or lupus.
- PVNS can cause mechanical symptoms such as locking, not unlike a meniscal tear. A palpable mass may be present.
- Intermittent symptoms are more common with localized PVNS; diffuse PVNS has more of a chronic presentation.
- In rheumatoid arthritis, the cervical spine is commonly involved and must be evaluated before surgical intervention. Also, the disease is often not limited to the musculoskeletal system: patients can also have vasculitis, subcutaneous nodules, and pericarditis.
- During the physical examination the surgeon should look for effusion, tenderness, warmth, mass, and synovial thickening.
  - Range of motion: Loss of flexion or extension may indicate arthrofibrosis.
  - Lachman test: assesses competence of anterior cruciate ligament
  - Posterior drawer test: assesses competence of posterior cruciate ligament
  - Varus stress test: assesses competence of lateral collateral ligament
  - Valgus stress test: assesses competence of medial collateral ligament
- Malalignment and ligamentous insufficiencies are noted and will likely preclude arthroscopic synovectomy, given their association with joint destruction.
- Joint aspiration can be therapeutic and diagnostic.
- Synovial fluid analysis should include documentation of fluid color (ie, brownish in PVNS, indicating recurrent...
bleeding), testing for rheumatoid factor, complement levels, cell count, Gram stain, culture, and crystal analysis.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Radiographs are important to document the extent of joint destruction.
  - The surgeon should look for the characteristic rheumatologic signs of periarticular erosions and osteopenia.
  - Radiologic signs of PVNS and gout include cystic, sclerotic, or erosive lesions.
  - Synovial chondromatosis is often visible.
  - Advanced degenerative disease is associated with a poorer prognosis after arthroscopy.12
- MRI is helpful to assess the scope of joint involvement before surgery (FIG 2).
  - Nodular PVNS can be readily seen as low signal on both T1 and T2 images.

**DIFFERENTIAL DIAGNOSIS**
- Synovial disorders
- Infection
- Degenerative joint arthrosis

**NONOPERATIVE MANAGEMENT**
- Conservative treatment includes medical management of the underlying disease.
  - Oral anti-inflammatory medications may be used, as well as intra-articular corticosteroid injections.
  - Gentle physical therapy can aid in maintenance of range of motion.

**SURGICAL MANAGEMENT**
- Arthroscopic synovectomy allows the identification and management of synovial lesions that may be missed with open procedures and also allows re-evaluation after the index procedure with a low morbidity.7,13
  - For more chronic or recurring conditions such as rheumatoid arthritis or hemophilic synovitis, this surgery can reduce the severity of pain and dysfunction commonly associated with these pathologies. It can reduce the number of recurrences and may slow the progression of joint arthrosis.7

**Preoperative Planning**
- Preoperative flexion and extension cervical spine radiographs are necessary to rule out instability in rheumatoid patients.
- Appropriate medical clearance is necessary to keep perioperative complications to a minimum.
- General anesthesia rather than local anesthesia is recommended because the procedure can be lengthy. An epidural may also be used when medically indicated and may aid in postoperative pain relief. A Foley catheter may be used in anticipation of prolonged anesthesia.

**Positioning**
- The patient is placed supine and brought to the edge of the bed to ensure that the leg may be easily hung over the side.
  - An arthroscopic leg holder is not used because it may prohibit the use of the superomedial and superolateral portals.
  - A well-padded thigh tourniquet is placed high on the operative leg.
  - The contralateral leg is placed in a well-padded leg holder, flexing the hip and knee, with the hip in slight abduction. Compressive wrapping or sequential compression stockings should be used on the contralateral leg owing to the length of the procedure (FIG 3).
  - The foot of the bed is dropped, allowing the operative leg to hang free. The bed is also flexed to produce slight hip flexion, decreasing the chance of femoral nerve palsy that may be associated with excessive hip extension and leg traction.
An arthroscopic lateral post may be placed midthigh on the side of the operative bed.
- A suction canister trap should be set up for biopsy collection.

**Approach**
- Portals are marked on the skin; five or six are generally needed for a complete synovectomy (FIG 4).

**DIAGNOSTIC ARTHROSCOPY**
- The operative limb is exsanguinated and the tourniquet is inflated to 250 to 300 mm Hg (TECH FIG 1A).
- The procedure is begun with outflow in the superomedial portal because this is rarely used as a viewing portal (TECH FIG 1B).
- An incision is made in the inferolateral portal. The arthroscope is placed into the suprapatellar pouch with the knee in extension. A superolateral working portal is established (TECH FIG 1C,D).

**SYNOVECTOMY**

**Suprapatellar Pouch, Medial and Lateral Gutter, and Intercondylar Notch**
- With the arthroscope in the inferolateral portal, the shaver is placed in the superolateral portal. The synovium is resected from the suprapatellar pouch and the lateral gutter (TECH FIG 2A,B).
- The shaver is moved to the inferomedial portal. The synovium is excised from the medial gutter and the medial aspect of the suprapatellar pouch (TECH FIG 2C,D).
Retropatellar Pouch, Inferolateral and Inferomedial Gutters

- The arthroscope is moved to the superolateral portal and the shaver is placed in the inferolateral portal. This enables synovial resection from the inferolateral gutter and the retropatellar space (TECH FIG 3A,B).
- The shaver is placed in the inferomedial portal to complete the synovectomy of the retropatellar space and the inferomedial gutter (TECH FIG 3C,D).

Intercondylar Notch

- The arthroscope is returned to the inferolateral portal and the shaver is maintained in the inferomedial portal (TECH FIG 4A,B).
- Resection of synovium in the intercondylar notch and around the cruciate ligaments is carefully performed (TECH FIG 4C).
- This establishes adequate working space within the notch to allow visualization of the posterior compartments of the knee.
- Care must be taken to distinguish synovium from ligament.

**TECH FIG 3** • A. The arthroscope is moved to the superolateral portal, and the shaver is placed in the inferolateral portal. B. Arthroscopic view of the resection in the retropatellar space and lateral gutter. C. The arthroscope is moved to the inferomedial portal, and the shaver is placed in the inferolateral portal. D. Arthroscopic view of inferomedial gutter synovial resection.
Posteromedial Compartment

- For access to the posteromedial compartment, a blunt-tipped trocar is placed in its arthroscopic sheath and inserted through the inferolateral portal.
- Alternatively, a switching stick can be placed through the inferolateral portal under direct visualization with the arthroscope placed in the inferomedial portal.
- The medial femoral condyle is palpated with the tip and the trocar is pushed posteriorly in the interval between the medial femoral condyle and the posterior cruciate ligament, raising the hand to accommodate the posterior slope of the tibia.
- The trocar should push into the posteromedial compartment without too much force.
- If this proves difficult to accomplish, a central patellar tendon portal may allow easier access to the posterior compartment.

- The trocar is removed and the arthroscope is inserted. From this position, the posterior aspect of the medial femoral condyle and the posterior horn of the medial meniscus can be visualized.
- While looking medially, a posteromedial working portal is developed under direct visualization.
- A spinal needle is inserted anterior to the medial head of the gastrocnemius to avoid the neurovascular structures (TECH FIG 5A).
- Once in the appropriate position, a small, longitudinal incision is made through the skin.
- Using a hemostat, the soft tissue is spread until the capsule is reached.
- Using a blunt-tipped trocar and arthroscopic cannula, the hemostat is replaced to establish a working portal.
- The surgeon inserts the shaver after removing the trocar and proceeds with resection of the synovium in the posteromedial compartment (TECH FIG 5B,C).

**TECH FIG 4**

A. The arthroscope is returned to the inferolateral portal, and the shaver is in the inferomedial portal. B. Arthroscopic photograph shows the resection of synovectomy in the notch. C. Arthroscopic photo shows complete resection of synovium in the notch. The anterior cruciate ligament is now apparent.

**TECH FIG 5**

A. Arthroscopic photograph showing establishment of the posteromedial portal. B. Arthroscopic photograph showing placement of the arthroscope and shaver in the posteromedial compartment. C. Synovial resection in the posteromedial compartment.
Posterolateral Compartment

- With a blunt trocar in the arthroscopic cannula, the trocar is placed in the inferomedial portal.
- The lateral femoral condyle is palpated with the trocar and pushed along the notch between the condyle and the anterior cruciate ligament (TECH FIG 6A).
  - This can also be done with a switching stick, as described in the previous section.
  - Again, the hand is raised to accommodate the posterior slope of the tibial plateau.
- The trocar should give way, indicating passage into the posterolateral compartment. It is important not to push through any great resistance to avoid penetrating the capsule and damaging the neurovascular structures.
- The arthroscope is placed into the cannula. The posterior aspect of the lateral femoral condyle as well as the posterior horn of the lateral meniscus should be seen.
- A posterolateral portal is made by inserting a spinal needle into the compartment under direct visualization (TECH FIG 6B,C).
  - The needle should be inserted posterior to the fibular collateral ligament and anterior to the lateral head of the gastrocnemius.
  - The soft spot anterior to the biceps femoris muscle and posterior to the iliotibial tract will ensure protection of the peroneal nerve.

When making the posterolateral and posteromedial portals, the surgeon should make sure that the instruments can be directed in the coronal plane behind the corresponding femoral condyle.

- In a manner similar to the posteromedial portal, the skin is incised with a scalpel and the surgeon dissects to and then through the posterior capsule with a hemostat under direct visualization.
- Maintaining the same angle, the surgeon replaces the hemostat with a blunt trocar in an operative cannula.
- The surgeon inserts the shaver and proceeds with débridement of the posterolateral compartment (TECH FIG 6D,E).
- Hypertrophied synovium on the posterior capsule and posterior septum should be resected.
- The suction must be monitored carefully because the posterior capsule may be penetrated, placing the neurovascular structures at risk.
- After completion of the synovectomy, the tourniquet is released and hemostasis is achieved with electrocautery.
- The entire suction canister should be sent for pathology and microbiology testing (TECH FIG 6F).
- A suction drain is typically used for 24 hours postoperatively to minimize hemarthrosis.
- Light compressive dressing and cryotherapy are used to minimize swelling and encourage early joint motion.
Regaining and maintaining full knee range of motion and quadriceps function is critical. Cannulas should be used when possible to ensure atraumatic entry and exit of instruments, avoiding soft tissue injury.

At the end of the procedure, hemostasis must be obtained. Failure to do so may result in hemarthrosis and maintaining range of motion.

The surgeon must be prepared to view the knee from multiple portals.

Enough tissue must be obtained for pathologic evaluation and diagnosis.

Portals must be placed under direct visualization to protect neurovascular structures.

POSTOPERATIVE CARE

- The patient is weight bearing as tolerated.
- Continuous passive motion is advised in cases of complete synovectomy, advancing as tolerated over 1 to 3 days.
- Physical therapy is initiated after removal of the suction drain. Closed-chain exercises are emphasized.

OUTCOMES

- When comparing arthroscopic synovectomy to open synovectomy, the arthroscopic technique is associated with lower morbidity and more rapid return of function and lower rates of recurrence in rheumatoid, hemophilia, and other inflammatory arthropathies. In addition, synovectomy can be more complete with accurate visualization of the posterior compartments.
- One study of 96 rheumatoid arthritic knees found significant decreases in pain and synovitis at an average of 4 years after arthroscopic synovectomy.
- Along with the use of rheumatoid medications, arthroscopic synovectomy can reduce inflammation and help preserve range of motion.
- Success rates in the relief of pain and swelling have been as high as 80% in the treatment of rheumatoid arthritis.
- Arthroscopic synovectomy has been used successfully in the treatment of PVNS.
- In the past, open synovectomies led to stiffness and pain after the procedure. In a series of 18 patients with diffuse PVNS, one third of the patients had a recurrence after open synovectomy, and in most patients the knee was manipulated in an attempt to decrease stiffness.
- Recurrence rates with arthroscopic synovectomy of PVNS have been as low as 11%, with improved range of motion.
- Localized PVNS has responded best to arthroscopic treatment.
- Multiple series have reported no recurrences at follow-up after excision of the lesion.
- The procedure allows improved visualization of lesions and facilitates the discovery of small, localized forms of PVNS.
- Hemophilic synovitis, also associated with aggressive joint destruction, has responded well symptomatically to arthroscopic synovectomy.
- Unlike most forms of synovitis, this usually requires a short period of hospitalization because of the underlying systemic disorder.
- The procedure has been effective in reducing recurrent hemarthrosis and maintaining range of motion.

However, joint deterioration continues to occur, although probably at a slower rate.

COMPLICATIONS

- Recurrent hemarthrosis, often requiring repeat aspirations or surgical irrigation and débridement
- Loss of range of motion
- Joint stiffness and flexion contracture can be challenging to treat.
- Dynamic bracing can be used.
- Rare complications include infection, either superficial or intra-articular, neurovascular injury, rapid onset of joint arthrosis, or cruciate ligament damage.

REFERENCES

DEFINITION

- Irreparable meniscal tears are those for which no healing response is possible.
  - This may include all or part of a meniscus, prompting partial, subtotal, or total meniscectomy.
- Meniscal injuries in the “white zone” (central avascular portion; FIG 1) most often require partial meniscectomy.
  - This usually involves the inner two thirds of the meniscus.
- Symptomatic tears of discoid lateral menisci also may require partial or subtotal saucerization of the meniscus.
- Numerous classifications of tears of the meniscus have been proposed based on location or type of tear, etiology, and other factors; most of the commonly used classifications are based on the type of tear found at surgery (FIG 2).
  - Longitudinal tears
  - Transverse and oblique tears
  - A combination of longitudinal and transverse tears
  - Tears associated with cystic menisci
  - Tears associated with discoid menisci
- The most common type of tear is the longitudinal tear, usually involving the posterior segment of either the medial or lateral meniscus.
- More lateral meniscal tears have been diagnosed than medial tears.
  - Although no definitive study comparing the incidence of medial to lateral tears has been reported, the two types are believed to occur with almost equal frequency.
  - Most partial-thickness tears involve the inferior rather than the superior surface of the meniscus.

- Certain patterns of meniscal tears are associated with mechanical locking.
  - Small longitudinal tears limited to the posterior horn usually are not capable of producing locking but rather cause pain, recurrent swelling, and subjective instability.
  - Extensive longitudinal tears can cause locking by displacing into the intercondylar notch.
  - A pedunculated fragment may result if either the posterior or anterior attachment of the bucket-handle fragment becomes detached.
- Transverse, radial, or oblique tears can occur in either meniscus but are more common in the lateral, usually at the junction of the anterior and middle thirds.
- Transverse tears also can result from degenerative changes that make the meniscus less mobile.
- Complex transverse and longitudinal tears may occur with degeneration or repeated traumatic episodes.
- Meniscal cysts frequently are associated with tears and are nine times more common on the lateral than on the medial side.
- Discoid menisci are abnormal in terms of both mobility and tissue bulk, making them vulnerable to compression and rotary stress.

ANATOMY

- The menisci are crescents that are roughly triangular in cross section.
- They cover one half to two thirds of the articular surface of the corresponding tibial plateau.
- They are composed of dense, tightly woven collagen fibers arranged in a pattern providing great elasticity and ability to withstand compression.
  - The major orientation of collagen fibers in the meniscus is circumferential.
  - Radial fibers and perforating fibers also are present (FIG 3A).
  - The arrangement of these collagen fibers determines to some extent the characteristic patterns of meniscal tears (FIG 3B,C).
- When meniscal samples are tested by applying a force perpendicular to the fiber direction, the strength is decreased to less than 10% because collagen fibers function primarily to resist tensile forces along the direction of the fibers.4
  - The circumferential fibers act in a similar manner as metal hoops placed around a pressurized wooden barrel; the tension in the hoops keeps the wooden staves in place (FIG 3D,E).
  - Hoop tension is lost when a single radial cut or tear extends to the capsular margin.
- The peripheral edges of the menisci are convex, fixed, and attached to the inner surface of the knee joint capsule, except where the popliteus is interposed laterally; the peripheral edges also are attached loosely via coronary ligament to the borders of the tibial plateaus.
- The inner edges are concave, thin, and unattached.
The menisci are largely avascular except near their peripheral attachment.

The inferior surface of each meniscus is flat, whereas the superior surface is concave, corresponding to the contour of the associated bony anatomy.

The medial meniscus is a C-shaped structure larger in radius than the lateral meniscus, with the posterior horn being wider than the anterior (FIG 4).6

The anterior horn is attached firmly to the tibia anterior to the intercondylar eminence and to the anterior cruciate ligament (ACL).

Most of the weight is borne on the posterior portion of the meniscus.

The posterior horn is anchored immediately in front of the attachments of the posterior cruciate ligament posterior to the intercondylar eminence.
Its entire peripheral border is firmly attached to the medial capsule and through the coronary ligament to the upper border of the tibia.

The lateral meniscus is more circular in form, covering up to two thirds of the articular surface of the underlying tibial plateau.

The anterior horn is attached to the tibia medially in front of the intercondylar eminence.

The posterior horn inserts into the posterior aspect of the intercondylar eminence and in front of the posterior attachment of the medial meniscus.

The posterior horn often receives anchorage also to the femur via the ligament of Wrisberg and the ligament of Humphrey and from fascia covering the popliteus muscle and the arcuate complex at the posterolateral corner of the knee.

The inner border, like that of the medial meniscus, is thin, concave, and free.

The tendon of the popliteus muscle separates the posterolateral periphery of the lateral meniscus from the joint capsule and the lateral collateral ligament. This tendon is enveloped in a synovial membrane and forms an oblique groove on the lateral border of the meniscus.

The lateral meniscus is smaller in diameter, thicker in periphery, wider in body, and more mobile than the medial meniscus.

The menisci follow the tibial condyles during flexion and extension, but during rotation they follow the femur and move on the tibia (FIG 5).

Consequently, the medial meniscus becomes distorted.

Its anterior and posterior attachments follow the tibia, but its intervening part follows the femur; thus, it is likely to be injured during rotation.

However, the lateral meniscus, because it is firmly attached to the popliteus muscle and to the ligament of Wrisberg or of Humphrey, follows the lateral femoral condyle during rotation and therefore is less likely to be injured.

In addition, when the tibia is rotated internally and the knee flexed, the popliteus muscle, by way of the arcuate ligament complex, draws the posterior segment of the lateral meniscus backward, thereby preventing the meniscus from being caught between the condyle of the femur and the plateau of the tibia.

The vascular supply to the medial and lateral menisci originates predominately from the lateral and medial geniculate vessels (both inferior and superior).

Branches from these vessels give rise to a perimeniscal capillary plexus within the synovial and capsular tissue, which supplies the peripheral border of the meniscus throughout its attachment to the joint capsule.

These vessels are oriented in a predominantly circumferential pattern, with radial branches directed toward the center of the joint.

Arnoczky and Warren\(^3,4\) used microinjection techniques to show that the depth of peripheral vascular penetration is 10% to 30% of the width of the medial meniscus and 10% to 25% of the width of the lateral meniscus.

The medial geniculate artery, along with a few terminal branches of the medial and lateral geniculate artery, also supplies vessels to the menisci through the vascular synovial covering.

The menisci have several proposed functions in the knee joint.

They act as a joint filler, compensating for gross incongruity between the femoral and tibial articulating surfaces.

They are believed to have a joint lubrication function, distributing synovial fluid and aiding the nutrition of the articular cartilage.

![FIG 4 • Superior view of tibial condyles. Lateral meniscus is smaller in diameter, thicker about its periphery, wider in body, and more mobile than the medial meniscus; posteriorly it is attached to the medial femoral condyle by either the anterior or posterior meniscofemoral ligament, depending on which is present, and to the popliteus muscle.](image)

![FIG 5 • Kinematics of the menisci with knee flexion, extension, and rotation. Although the lateral meniscus and lateral tibial plateau have a smaller AP width, the lateral meniscus moves more than the medial meniscus through each range of motion. (Adapted from Tria AJ Jr, Klein KS. An Illustrated Guide to the Knee. New York: Churchill Livingstone, 1992.)](image)
The menisci are also at increased risk in the presence of joint incongruities, ligamentous instability, profound muscle weakness, or congenitally relaxed joints.

As the knee is internally rotated during flexion, the medial meniscus is forced posteriorly. If the peripheral attachment stretches or tears, the posterior part of the meniscus is forced centrally, caught between the femur and tibia, and torn longitudinally as the knee extends.

If this longitudinal tear extends anteriorly beyond the medial collateral ligament, the inner segment of the meniscus is caught in the intercondylar notch and cannot return to its former position; thus, a classic bucket-handle tear with locking of the joint is produced (FIG 6).

The menisci are also at increased risk in the presence of joint incongruities, ligamentous instability, profound muscle weakness, or congenitally relaxed joints.

As the knee is internally rotated during flexion, the medial meniscus is forced posteriorly. If the peripheral attachment stretches or tears, the posterior part of the meniscus is forced centrally, caught between the femur and tibia, and torn longitudinally as the knee extends.

If this longitudinal tear extends anteriorly beyond the medial collateral ligament, the inner segment of the meniscus is caught in the intercondylar notch and cannot return to its former position; thus, a classic bucket-handle tear with locking of the joint is produced (FIG 6).

The same mechanism can produce a posterior peripheral or a longitudinal tear of the lateral meniscus.

Because of its mobility and structure, the lateral meniscus is not as susceptible to bucket-handle tears, but incomplete transverse tears are more common here than in the medial meniscus.

NATURAL HISTORY

The effects of meniscectomy on joint laxity have been studied for anteroposterior and varus-valgus motions and rotation.

These studies indicated that the effect on joint laxity depends on whether the ligaments of the knee are intact and whether the joint is bearing weight.

In the presence of intact ligamentous structures, excision of the menisci produces small increases in joint laxity.

When combined with ligamentous insufficiency, these increased instabilities caused by meniscectomy are greatly exaggerated.

In an ACL-deficient knee, medial meniscectomy has been shown to increase tibial translation by 58% at 90 degrees, whereas primary anterior and posterior translations were not affected by lateral meniscectomy.

Anatomically, the capsular components that attach the lateral meniscus to the tibia do not affix the lateral meniscus as firmly as they do the medial meniscus.

These results indicate that in contrast to the medial meniscus, the lateral meniscus does not act as an efficient posterior wedge to resist anterior translation of the tibia on the femur.

Therefore, in knees that lack an ACL, the lateral meniscus is subjected to different forces than those that occur on the medial side.

Allen et al,2 in a biomechanical study, determined that force in the medial meniscus increased significantly in response to an anterior tibial load after ACL transection, which may
account for some of the differences in injury patterns between the medial and lateral menisci in the anterior cruciate-deficient knee.

- Walker and Erkman noted that under loads of up to 150 kg, the lateral meniscus appeared to carry 70% of the load on that side of the joint, whereas on the medial side the load was shared about equally by the meniscus and the exposed articular cartilage.
- Medial meniscectomy decreases contact area by 50% to 70% and increases contact stress by 100%.
- Lateral meniscectomy decreases contact area by 40% to 50% but dramatically increases contact stress by 200% to 300% because of the relative convex surface of the lateral tibial plateau.
- Presumably the menisci provide mediolateral stability where the load is supported by the entire width of the tibial articular surface. Without the menisci the load is supported centrally on each plateau, diminishing the lever arm of load support.
- Radiographic changes apparent after meniscectomy include narrowing of the joint space, flattening of the femoral condyle, and formation of osteophytes.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Mechanical symptoms, such as catching, popping, and locking, usually occur only with longitudinal tears and are much more common with bucket-handle tears, usually of the medial meniscus.
- Locking of the knee is not pathognomonic of a bucket-handle tear of a meniscus: other conditions such as loose body, patellar maltracking, and intra-articular tumor can cause similar findings.
- The following clues can be important in the differential diagnosis:
  - Sensation of giving way
  - Effusion
  - Atrophy of the quadriceps
  - Tenderness over the joint line (or the meniscus)
  - Reproduction of a click by manipulative maneuvers during the physical examination
  - Probably the most important physical finding is localized tenderness along the posteromedial or posterolateral joint line, which is most commonly caused by reactive synovitis.
- A history of specific injury may not be obtained, especially when tears of abnormal or degenerative menisci have occurred.
- A patient without locking typically gives a history of several episodes of trouble referable to the knee, often resulting in effusion and a brief period of disability but no definite locking.
- A sensation of giving way or snaps, clicks, catches, or jerks in the knee may be described, or the history may be even more indefinite, with recurrent episodes of pain and mild effusion in the knee and tenderness in the anterior joint space after excessive activity.
- The injured knee should be compared with the opposite knee, which can exhibit 5 to 10 degrees of physiologic recurvatum. In this case, the injured knee can be locked and still extend to neutral position.
- Regardless of its cause, locking that is unrelieved after aspiration of the hemarthrosis and a period of conservative treatment may require surgical treatment.

- A serious error would be failure to distinguish locking from false locking.
- False locking occurs most often soon after an injury in which hemorrhage about the posterior part of the capsule or a collateral ligament with associated hamstring spasm prevents complete extension of the knee.
- Aspiration and a short period of rest until the reaction has partially subsided usually will differentiate locking from false locking of the joint, and magnetic resonance imaging (MRI) can confirm the diagnosis.
- A sensation of giving way is often present but is not specific to meniscal tear.
- Effusion indicates that something is irritating the synovium; therefore, it has limited specific diagnostic value.
- The sudden onset of effusion after an injury usually denotes a hemarthrosis, and it can occur when the vascularized periphery of a meniscus is torn.
- Tears occurring within the body of a meniscus or in degenerative areas may not produce a hemarthrosis.
- Repeated displacement of a pedunculated or torn portion of a meniscus can produce sufficient synovial irritation to produce a chronic synovitis with an effusion of a nonbloody nature.
- The absence of an effusion or hemarthrosis does not rule out a tear of the meniscus.
- Atrophy of the musculature about the knee suggests a recurring disability of the knee but does not indicate its cause.
- Clicks, snaps, or catches, either audible or detected by palpation during flexion, extension, and rotary motions of the joint, can be valuable diagnostically, and efforts should be made to reproduce and accurately locate them.
- Numerous manipulative tests have been described, but the McMurray test is most commonly used. Although other tests cannot be considered diagnostic, they are useful enough to be included in the routine examination of the knee.
- For the McMurray test, with the knee completely flexed, the examiner palpates the joint line with one hand and uses the other hand to rotate the foot internally while extending the knee. The maneuver is repeated with the foot externally rotated. If a meniscal tear is present, a click may be heard or felt in the joint line of the affected side during this maneuver.
- The grinding test, as described by Apley, is another test for isolating meniscal pathology. With the patient prone, the knee is flexed to 90 degrees and the anterior thigh is fixed against the examining table. Traction on the foot is used to distract the joint and the foot is rotated. Next, with the knee in the same position, the foot and leg are pressed downward and rotated as the joint is slowly flexed and extended.
- Another useful test, the squat test, consists of several repetitions of a full squat with the feet and legs alternately fully internally and externally rotated as the squat is performed. Reproduction of pain on the medial or lateral side of the knee is suggestive although not diagnostic of meniscal tear.
- The diagnosis of internal derangement of the knee caused by a meniscal tear can be difficult to make even for an experienced orthopedic surgeon, but a careful history and physical examination combined with appropriate imaging studies help to limit errors in diagnosis and unnecessary arthroscopy.
During an injury, damage to other structures of the knee such as the ligaments and articular cartilage is common. For simplicity, tears of the menisci are discussed here as though they were isolated injuries, but evidence of other injuries always must be sought.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Imaging includes standing anteroposterior, 45-degree posterior, and patellofemoral views to exclude other causes of knee pain such as joint degeneration, loose bodies, and osteochondritis dissecans.
- Other noninvasive diagnostic studies, such as ultrasonography, scintigraphy, computed tomography (CT), and MRI, have been shown to improve diagnostic accuracy in many knee disorders.
- Compared with arthroscopy, MRI has been shown to have 98% accuracy for medial meniscal tears and 90% for lateral meniscal tears.
- Others have reported that MRI had a positive predictive value of 73%, a negative predictive value of 90%, a sensitivity of 83%, and a specificity of 84% for pathologic changes in the menisci.
- MR arthrography may be useful in evaluating knees with prior meniscectomy or meniscal repair.
- High-resolution CT has been reported to have a sensitivity of 96.5%, specificity of 81.3%, and accuracy of 91%, but we usually use this study to evaluate the patellofemoral joint.

**DIFFERENTIAL DIAGNOSIS**
- Ligament injury
- Chondral injury
- Osteochondral loose body
- Pathologic plica
- Patellar maltracking
- Intra-articular tumor

**NONOPERATIVE MANAGEMENT**
- An incomplete meniscal tear or a small (5-mm) stable peripheral tear with no other pathologic condition, such as a torn ACL, can be treated nonoperatively with predictably good results. Many incomplete tears will not progress to complete tears if the knee is stable.
- Small stable peripheral tears have been observed to heal after 6 to 8 weeks of protection.
- Stable vertical longitudinal tears, which tend to occur in the peripheral vascular portions of the menisci, have been reported to heal with nonoperative treatment.
- Meniscal tears that cause infrequent and minimal symptoms can be treated with rehabilitation and restricted activity.
- Tears associated with ligamentous instabilities can be treated nonoperatively if the patient defers ligament reconstruction or if reconstruction is contraindicated.
- Nonsurgical management consists of activity modification, nonsteroidal anti-inflammatory, and physical therapy.
- If symptoms recur after a period of nonoperative treatment, surgical repair or removal of the damaged meniscus may be necessary.
- The most important aspect of nonoperative treatment, once the acute pain and effusion have subsided, is restoration of the normal knee range of motion and muscle strength. This can be accomplished through a regular program of progressive exercises to include the quadriceps, hamstrings, hip flexors, and hip abductors.

**SURGICAL MANAGEMENT**
- Indications for surgical treatment of meniscal tears include:
  - Symptoms that affect sports participation or activities of daily living or work (locking, giving way, frequent effusions)
  - Failure of nonoperative treatment
  - Absence of other causes of knee pain (based on complete clinical and imaging evaluations)
- Meniscectomy is categorized into three types depending on the amount of meniscus removed:
  - Partial meniscectomy, in which only loose, unstable meniscal fragments are excised and a stable and balanced peripheral rim of healthy meniscal tissue is preserved (FIG 7)
  - Subtotal meniscectomy, in which the type and extent of the tear require excision of a portion of the peripheral rim, usually leaving most of the anterior horn and a portion of the middle third intact
  - Total meniscectomy
- Historically, the indications and surgical techniques for excision of torn menisci have been controversial.
  - Some have advocated total excision of torn menisci, whereas others have proposed subtotal excision.
  - Justification for total excision often was based on short-term, functional recovery criteria; however, longer follow-up showed associated degenerative changes.
  - Removal of even one third of the meniscus has been shown to increase joint contact forces by up to 350%.
  - The amount of degenerative change in the articular cartilage appears to be directly proportional to the amount of meniscus removed.
- If meniscal pathology produces almost daily symptoms, frequent locking, or repeated or chronic effusions, the pathologic portion of the meniscus should be removed because the problems caused by the present disability far outweigh the probability or significance of future degenerative arthritis.
  - If a significant portion of the peripheral rim can be retained by subtotal meniscal excision, the long-term result is improved.
  - Partial meniscectomy by arthroscopic technique has sufficient support and clinical results to indicate its routine use.
  - Subtotal meniscectomy is justified only when it is irreparably torn, and the meniscal rim should be preserved if at all possible.
  - Total meniscectomy is no longer considered the treatment of choice in young athletes or other people whose daily activities require vigorous use of the knee.

**FIG 7** Partial meniscectomy: loose unstable fragments are excised and a stable and balanced peripheral rim of healthy meniscal tissue is preserved.
Preoperative Planning
- A discussion regarding meniscal repair versus removal should be conducted preoperatively. The patient should understand the risks, benefits, alternatives, and potential complications of both, as well as the variations in postoperative recovery time and rehabilitation.
- The patient also should understand the potential for recurrent meniscal tear and long-term consequences of meniscectomy.
- A discussion also should be held about the treatment of additional pathology, such as chondral lesions, that may be a source of continued symptoms postoperatively.
- The necessary equipment should be present to treat whatever meniscal or chondral pathology might be encountered.

Positioning
- The patient is placed supine with the nonoperative leg in a leg holder that brings the extremity into flexion at the hip and knee (FIG 8A).
- The use of a proximal leg holder for the operative knee places the patient’s foot on the surgeon’s iliac crest, eliminating the need for an assistant to hold the leg.

Approach
- After an examination under anesthesia, joint lines and soft tissue and bony landmarks are drawn on the skin before joint distention (FIG 8B).
- Typically, these are the outlines of the patella and patellar tendon, the medial and lateral joint lines, and the posterior contours of the medial and lateral femoral condyles.
- Standard and optional arthroscopic portals are marked (see Chap. SM-31).
- A small outflow, needle-type cannula can be placed superomedially or superolaterally, with inflow through the arthroscope, but this often is not needed for meniscectomy.
- A two-portal or three-portal technique can be used (see Chap. SM-31).
- The anterolateral and anteromedial portals are most commonly used with the two-portal technique.
- Occasionally, a posteromedial, accessory medial, or central portal is used to assist in removal of displaced meniscal fragments.
- Thorough, systematic arthroscopic examination of the knee joint must be done before the decision is made for partial or subtotal meniscectomy (see Chap. SM-31).
- An arthroscopic probe should be used to examine the meniscal tear to determine its anterior and posterior extents (FIG 8C). The probe should be used to palpate the superior and inferior extents of the meniscus.
- When an irreparable meniscal tear is identified, all mobile fragments that can be pulled past the inner margin of the meniscus into the joint should be removed and the remaining meniscus contoured to reduce the risk of leaving a defect that can propagate into a larger tear.
- The meniscal rim does not need to be perfectly smooth, and the amount of meniscus removed and contouring of the rim must be weighed against the risk of degenerative changes (the risk of degenerative changes is directly proportional to the amount of meniscus removed).
- The goal is to remove the tear entirely while removing as little meniscus as possible.

ARThROSCOPIC PARTIAL MENISCETOMY FOR CONVENTIONAL TEARS
- The goals of surgery are to remove the mobile segment at the meniscal base and to contour the remaining meniscus to leave as wide a rim as possible.
- Any tags or pieces of meniscus that may catch in the joint or can be displaced into the center of the joint are resected with meniscal forceps, baskets, scissors, or graspers (TECH FIG 1).
- Full-radius resectors and motorized suction shavers are used to remove damaged cartilage, smooth the meniscal rim, and remove loose pieces of meniscus and cartilage.
- Various ablation devices can be used to contour tears; however, care must be taken not to damage adjacent articular cartilage.
- For horizontal cleavage tears, one or both “leaves” can be resected, depending on surgeon preference. No definitive study has shown that preserving either the superior or inferior leaf improves results.
ARTHROSCOPIC PARTIAL MENISCECTOMY FOR BUCKET-HANDLE TEARS

- A probe or blunt trocar is used to reduce the fragment to its normal position (TECH FIG 2A).
- Partial division of the posterior attachment of the meniscal fragment is done with basket forceps, scissors, or an arthroscopic knife. The cut should go almost completely through the posterior attachment of the mobile fragment at its junction with the remaining normal meniscal rim (TECH FIG 2B).
- To avoid damage to the normal meniscus or articular cartilage, this cut should not be made blindly. Exposure can be aided by passing the arthroscope through the intercondylar notch to view the posterior horn of the meniscus while cutting. Alternatively, a posteromedial portal can be made for direct observation.
- A small tag of meniscal tissue is left intact posteriorly to prevent the meniscus from becoming a loose body in the joint after anterior release.
- The anterior horn attachment is divided with angled scissors, basket forceps, or an arthroscopic knife. The release should be made flush with the intact anterior rim so that no stump or dog-ear remains (TECH FIG 2C).
- If access to the anterior horn attachment is difficult through the ipsilateral portal, changing portal sites and approaching from the contralateral portal with the
instrument often makes this easier. Rarely, a midpatellar portal is necessary so that both anterior portals can be used for instruments.

- A hemostat is used to enlarge the capsular incision before attempting meniscal removal.
- A grasping clamp is inserted through the ipsilateral portal to grasp the meniscal fragment as close to its remaining posterior attachment as possible. With the fragment in view, the grasping forceps are twisted and rotated while applying traction to avulse the few remaining strands of meniscus, and the fragment is removed from the joint (TECH FIG 2D).
- Occasionally, the meniscal fragment cannot be detached with the grasping forceps alone. With a grasper through the lateral portal for traction on the meniscus, an arthroscopic scissor can be passed through the same portal to complete the resection. If necessary, an accessory portal can be made for the scope so that the two anterior portals can be used for instruments.
- A motorized meniscal shaver is used to smooth the remaining rim.

### ARTHROSCOPIC PARTIAL MENISCECTOMY AND MENISCAL CYST DECOMPRESSION

- The meniscus is carefully probed to identify the extent of the meniscal tear. Radial tears are trimmed to a stable peripheral rim. For stable horizontal tears, only the inferior leaf is resected and the superior leaf is gently trimmed.
- The cyst is palpated externally, which may push the cyst material into the joint and decompress the cyst, allowing identification of the cyst communication.
- If this is not successful, a spinal needle can be inserted percutaneously through the cystic mass to help locate the track between the cyst and the meniscus. Punch forceps passed through the tear and tracked into the cyst may widen the track enough for the contents of the cyst to be evacuated into the joint.
- If necessary, a small, motorized shaver is inserted into the cyst to break up loculations, assist in cyst decompression, and stimulate inflammation and scarring of the cyst.

### ARTHROSCOPIC PARTIAL EXCISION OF DISCOID LATERAL MENISCUS

- The following principles can be applied to all three types of discoid lateral menisci, including incomplete, complete, and Wrisberg types.
- In young patients with small knees, a 2.7-mm arthroscope and small-joint instruments should be used.
- In older individuals, the standard 4-mm arthroscope is used. In addition to standard technique, anteromedial and lateral portals can be used for instrumentation while viewing through a medial midpatellar portal.
- With the knee in a figure 4 position, basket forceps are used to begin the central resection of the discoid tissue (TECH FIG 3A).
- With the discoid meniscus under direct observation, resection is planned so that a healthy peripheral meniscus about 8 mm wide remains.
- When the desired amount of meniscal tissue has been removed and the rim is balanced, the thickness of the inner edge is much greater than that after routine partial meniscectomy (TECH FIG 3B).
- For a Wrisberg-type discoid meniscus, a repair with saucerization is recommended; however, if an inadequate posterior tibial attachment is present, total meniscectomy may be indicated.

**TECH FIG 3 • A.** Knee is placed in figure 4 position for resection of discoid meniscus. B. Discoid meniscus with radial tear.
PEARLS AND PITFALLS

The number of portals should be minimized. ■ With multiple portals, the surgeon must watch for fluid extravasation.

The knife blade is directed medially or laterally away from the patellar tendon for horizontal portals and superiority away from the anterior of the menisci for vertical portals.

The leg holder or post is placed about 10 cm above the superior pole of the patella. ■ If too proximal or distal, the surgeon cannot obtain sufficient valgus stress to open the medial joint for inspection.

A systematic approach is used so that any pathology present can be identified.

1. The surgeon inspects the following:
   a. Anterior compartment (suprapatellar region, patellofemoral joint [including tracking], lower trochlea).
   b. Medial and lateral gutters
   c. Medial and lateral compartments
   d. Posterior compartment (by directing arthroscope medial to posterior cruciate ligament)

2. The surgeon probes the menisci superiorly and inferiorly: can have up to 5 mm physiologic excursion of posterior horn of medial meniscus; can have up to 10 mm physiologic excursion posterior horn of lateral meniscus.

3. The surgeon inspects for pathologic plicae that may mimic meniscal tear.

4. The surgeon inspects and probes for displaced meniscal fragments, which may be submeniscal or in the posterior compartment (FIG 9).

POSTOPERATIVE CARE

■ No brace or range-of-motion restrictions
■ Immediate full weight bearing with crutches as needed
■ Cold therapy
■ Nonsteroidal anti-inflammatories at 2 weeks if not contraindicated
■ Active, passive, and active-assisted range of motion immediately postoperatively
■ Straight-leg-raise exercises immediately
■ Return to sports when full range of motion is regained, no effusion is present, and strength is 80% of uninjured side (usually 4 to 6 weeks minimum)

OUTCOMES

■ The knee can function well without the meniscus, sometimes for the rest of a patient’s life, but late degenerative changes within the joint sometimes occur, and the loss of the meniscus undoubtedly plays some part in producing these changes.
■ In addition to the condition of the meniscus, numerous other factors can influence long-term function, such as joint alignment, laxity of the capsular or ligamentous structures, and incomplete rehabilitation of the musculature about the knee.

■ Fairbank10 described three changes he had observed in the knee, alone or in combination, in patients who had had a meniscectomy, at intervals ranging from 3 months to 14 years after the surgery:
   a. The development of an anteroposterior ridge that projected distally from the margin of the femoral condyle
   b. Flattening of the peripheral half of the articular surface of the condyle
   c. Narrowing of the joint space

   These changes have been reported in 40% to 90% of patients with meniscectomy in ACL-deficient knees.

Considerable evidence indicates that meniscectomy often is followed by degenerative changes within the joint, but whether the injury, the damaged meniscus itself, or its excision led to the degenerative changes cannot be determined with certainty in most of these studies. Probably all these factors, and others as well, have an influence.

■ Partial meniscectomy has been proven to have significantly better outcomes than total meniscectomy (90% and 68% good results, respectively, reported in comparison study).
- Generally, outcomes after medial partial meniscectomy (80% to 100% good to excellent results) have been better than after lateral partial meniscectomy (54% to 92% good to excellent results). A recent review of the literature, however, reported that there were consistently no significant differences in radiographic or functional outcome between medial and lateral meniscal injury in the studies included in their analysis.

- Reported results of partial meniscectomy for discoid meniscus in children are generally good (87% to 100% good to excellent results).

- Results tend to deteriorate with time because of degenerative changes in the knee joint; however, continued good to excellent results have been reported with follow-up as long as 20 years.

- Two primary factors associated with worse results of partial meniscectomy are preexisting osteoarthritis and ACL deficiency. Other factors suggested to predispose to poor outcomes are age more than 35 years, female gender, presence of medial cartilage degeneration, resection of the posterior third of the meniscus, and meniscal rim resection.

- Preoperative participation in sports has been shown to be a predictor of a better outcome.

COMPLICATIONS

- Possible complications after partial or total meniscectomy are the same as those after any arthroscopic procedure on the knee (see Chap. SM-31).

- Patients should be informed of the risks of infection, deep vein thrombosis (with or without pulmonary embolism), recurrent effusions, incomplete tear removal, synovial-cutaneous fistula, arteriovenous fistula, popliteal pseudoaneurysm, and compartment syndrome.

REFERENCES


13. Herrlin S, Hallander M, Wange P, et al. Arthroscopic or conserva-


16. Lee SJ, Aadaljen KJ, Malaviya P, et al. Tibiofemoral contact mechan-


18. Meredith DS, Losian E, Mahomed NN, et al. Factors predicting func-
tional and radiographic outcomes after arthroscopic partial menis-


23. Scheller G, Sobau C, Bulow JU. Arthroscopic partial lateral menis-
cectomy in an otherwise normal knee: clinical, functional, and radi-

24. Shellbourne KD, Carr DR. Meniscal repair compared with menis-


DEFINITION
- A meniscus tear results in mechanical disruption of the gross structure of the medial or lateral meniscus or both.
- The goals of meniscus repair are to preserve and optimize meniscus function and to restore joint biomechanics.

ANATOMY
- The medial meniscus and the lateral meniscus are crescent-shaped and triangular in cross section.
- The medial meniscus is C-shaped. It covers about 64% of the tibial plateau. Its width varies from anterior to posterior, with an average of 10 mm (FIG 1).
- The lateral meniscus is more circular. It covers about 84% of the tibial plateau, with an average width of 12 to 13 mm.
- The menisci are fibrocartilaginous structures made up of collagen (90% type I and the remainder made up of types II, III, V, and VI), fibrochondrocytes, and water.
- The collagen fibers are arranged in a circumferential pattern in the peripheral third, whereas the inner two thirds is organized with a combination of radial and circumferential fibers (see Fig 3A in Chap. SM-33).
- The menisci function to deepen the articular surface of the tibial plateau, providing shock absorption and compensating for gross incongruity between the articulating surfaces, acting as joint stabilizers. They provide joint lubrication and maintenance of synovial fluid and assist in providing nutrition of articular cartilage.16
- The vascular supply comes from the perimeniscal capillary plexus supplied by the medial and lateral inferior and superior geniculate arteries. The plexus penetrates the meniscus peripherally and its abundance decreases as it crosses centrally.
- This difference in vascularity creates the red-red, red-white, and white-white zones.2
- The meniscus contains free nerve endings and corpuscular mechanoreceptors, providing pain and proprioception in the knee joint.16

PATHOGENESIS
- Acute tears typically occur in younger patients from compression and rotational injury of the knee joint as it moves from a flexed to an extended position.
- Degenerative tears are typically chronic in nature, are found in older patients, are complex, and are usually irreparable.
- Medial meniscus tears most often occur in the stable knee or chronic anterior cruciate ligament (ACL)-deficient knee, whereas lateral tears occur more often in younger patients with acute ACL tears.
- Associated injuries are often found. The “terrible triad” consists of tears of the lateral meniscus, ACL, and medial collateral ligament. It is often sustained from a hyperextension with a valgus stress, such as during a “clipping” injury in football.
- Tears may be classified according to anatomic zone (as described by Cooper et al7), vascularity (red-red, red-white, white-white), or by tear pattern.
- Tear patterns are described as horizontal, radial, longitudinal, bucket-handle, oblique, or complex (see Fig 2 in Chap. SM-33).7

NATURAL HISTORY
- Walker and Erkman24 in 1975 found that with loads up to 150 kg, the lateral meniscus bore most of the weight bearing in that compartment, whereas the medial meniscus shared about 50% of the load with the articulating surfaces of the tibiofemoral joint.
- Partial and total meniscectomy has been shown to increase the contact stresses exerted on the articular cartilage, resulting in its degeneration and ultimately osteoarthritis.
- After partial meniscectomy, femoral–tibial contact areas decrease by about 10%, with peak local contact stresses (PLCS) increasing by about 65%. After total meniscectomy, contact areas decrease about 75% and PLCS increases about 235%.3
- PLCSs and contact areas were found to be the same with meniscus repair.3
- Partial meniscectomy has been shown to improve prognosis and decrease chondral wear compared to total meniscectomy.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The history should include location of pain (joint line tenderness), recent traumas, prior injuries and surgery, as well as evidence of effusions, locking, catching, or instability (which may indicate associated ligamentous pathology).
- In addition, questions should be asked about the patient’s age, function, activity level, occupation, goals, expectations, and other pertinent medical problems. These will help the surgeon decide on nonsurgical versus surgical treatment and resection versus repair.
A complete examination of the knee should be performed, including evaluation for:
- Anterior and posterior ligament injury: Lachman, anterior and posterior drawer, pivot shift, along with a history of hearing a “pop” with injury and acute swelling
- Posterolateral corner injury: injury of the popliteus tendon, iliotibial band, popliteofibular ligament, biceps, and posterior capsule. Asymmetry on the dial (external rotation) test is the most sensitive examination.
- Medial and lateral collateral ligament injuries may be assessed by palpation and widening with varus–valgus stresses at 30 degrees and at full extension.

The examiner should also:
- Inspect for effusion. The presence of diffuse joint effusion is not specific enough. A localized swelling at the joint line may indicate a parameniscal cyst.
- Palpate all ligament and tendon insertions, as well as the patellofemoral joint; this may indicate associated pathology.
- Evaluate range of motion. Loss of extension or locking may relate to a displaced or bucket-handle tear. Pain with squatting may indicate a posterior horn tear.
- Perform the Apley test to look for a meniscus tear. Relief on distraction is found if a meniscus tear is the only pathology, but no relief will be found if a concomitant collateral ligament injury is present.
- Perform the Childress test, which is positive if the patient has pain or mechanical blocking; this may indicate a meniscus tear.

While assessing for the Merkel sign, pain with internal rotation of tibia is consistent with a medial meniscus tear; pain with external rotation is consistent with a lateral meniscus tear.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs should be taken to evaluate for bony pathology, extremity alignment, arthritis, chondrocalcinosis, or findings consistent with associated injuries such as a Segond sign (ACL injury), osteochondritis dissecans lesion, or osteochondral fracture.
  - Typically four views are obtained: a 30- or 45-degree posterioranterior flexion weight-bearing view, a true lateral view, a notch view, and a patella skyline view.
- Magnetic resonance imaging (MRI) is not always indicated to evaluate for meniscal pathology, but it is typically used and helpful in evaluation of associated injuries when a meniscus tear is suspected. The sensitivity of MRI for meniscus tears is reported as high as 96%, with a specificity of 97%.
- MRI classification is as follows:
  - Grade 1: small focal area of increased signal, not extending to the joint surface
  - Grade 2: linear area of increased signal, not extending to the joint surface
  - Grade 3: linear area of increased signal extending to the joint surface
- A linear abnormality is identified as extension to the articular surface on two consecutive images and is considered to have a high likelihood of being a true tear (FIG 2A).
- A bucket-handle tear may be identified by the “double PCL” (posterior cruciate ligament) sign (FIG 2B,C).

FIG 2 • A,B. Lateral and PA MRIs of meniscus tears. C. MRI of medial bucket-handle meniscus tear and double PCL sign. D,E. Sagittal and coronal MRIs of discoid lateral meniscus tears.
Evaluation of the meniscus postoperatively presents a challenge because the repair site becomes filled with fibrous scar and may continue to produce abnormal MR signal on postoperative imaging. Currently the best method of evaluation is with a gadolinium-enhanced MRI.

A discoid meniscus may be evident on MRI as a rectangular meniscus on all slices as opposed to the wedge shape typically seen. It is more commonly found in the lateral meniscus (FIG 2D,E).

DIFFERENTIAL DIAGNOSIS

- ACL or PCL tear
- Medial or lateral collateral ligament tear
- Osteochondritis dissecans lesion
- Patellofemoral syndrome
- Osteoarthritis
- Chondrocalcinosis

NONOPERATIVE MANAGEMENT

- Conservative treatment options include physical therapy, nonsteroidal anti-inflammatory medications, steroid injections, and activity modification.
- Typically, a stable longitudinal tear in the periphery less than 10 mm is likely to heal on its own.
- Bracing usually is not indicated in the treatment of meniscus tears.
- The expected result of nonoperative treatment is improved symptoms in 6 weeks, with return to full activities by 3 months.

SURGICAL MANAGEMENT

- Intervention may proceed after failure of conservative treatment or more urgently if the patient shows mechanical symptoms such as locking or catching. These may represent loose bodies or an unstable torn meniscus (ie, bucket-handle tear), which can cause significant articular damage if left untreated.
- With all meniscus pathology, the goal is to preserve as much meniscus as possible.
- Repair versus resection
  - The potential long-term benefit of repairing the meniscus is chondroprotection.
  - The surgeon should consider tear location, pattern, vascularity, and associated pathology when determining whether to repair or resect the meniscus.
  - The surgeon should consider the patient’s age, activity level, overall health, and compliance with a limited postoperative activity regimen.
  - When resection is performed, all efforts should be made to preserve as much viable meniscus as possible. Mobile, unstable meniscus fragments should be resected, leaving a smooth contour.
  - The meniscosynovial junction should be preserved because this is where the circumferential collagen fibers form the predominant amount of “hoop stresses.”
  - The surgeon should consider leaving a stable tear alone. An unstable tear will be easily mobilized, displaced at least 7 mm, and/or will have the ability to “roll” (FIG 3).

Preoperative Planning

- Before the surgery, all radiologic studies should be reviewed.
- The knee should be examined under anesthesia before beginning the surgery in an attempt to detect associated pathology.

The healing potential for a meniscus repair in conjunction with an anterior cruciate ligament reconstruction is far superior to that of a repair alone.

The surgeon should discuss with the patient the risks and benefits of the surgery as well as the principle of informed consent.

All patients should be apprised of the possibility of meniscus resection versus repair.

They should understand the implications of each in terms of short- and long-term consequences and postoperative rehabilitation protocols.

The surgeon may discuss the potential for associated pathology and may obtain a better understanding of the patient’s treatment preferences before entering the operating room.

This may be a particularly crucial conversation with an elite athlete who would prefer to undergo a resection in an attempt to return to competitive sport faster.

The anesthesia used is typically decided on by the anesthesiologist and orthopedist before entering the operating room. General anesthesia or a laryngeal mask airway (LMA) may be used.

We prefer to have the anesthesiologist provide sedation in conjunction with a local anesthetic administered by the surgeon.

We typically use a mixture of 0.5% bupivacaine and 1% lidocaine with epinephrine in equal proportions. About 30 to 40 cc is injected intra-articularly, and about 5 cc is injected into each portal site.

Positioning

- Typically the patient is lying supine.
- The two most popular methods of leg support are a knee holder (thigh immobilizer) and a lateral post.
- The knee holder should be placed perpendicular to the position of the femur at a level above the patella and portals that allows for a valgus force on the knee. The end of the table is dropped down below 90 degrees from horizontal to allow both legs to hang freely from the knees.
- The lateral post should be placed above the patella and angled outwardly to allow for a valgus force on the operative knee. This technique is performed without dropping the end of the table. The surgeon should check that the knee may be taken through a range of motion by abducting the leg against the lateral post with flexion of the knee off the side of the table.
• A tourniquet may be placed on the upper thigh if bleeding is suspected, such as in debridement of a hypertrophic fat pad.
• Padding of the contralateral leg is used to prevent pressure-related injury to the bony prominences or superficial nerves.

Approach
• The typical portal sites are a superomedial, anteromedial, and anterolateral portal (FIG 4).
  • The superomedial portal is typically made proximal to the superior pole of the patella in line with the medial border of the patella (medial to the quadriceps) and is directed in an oblique manner into the joint. This portal is typically used for outflow or inflow.
  • The anterolateral portal is created by making a small (about 6 mm) stab incision 1 cm proximal to the joint line and 1 cm lateral to the patella tendon. This area can be identified as the “soft spot.” This portal is used for insertion of the arthroscope.
  • The anteromedial portal is considered the working portal for insertion of instruments. It is typically made under direct visualization by inserting a spinal needle into the medial “soft spot” 1 cm medial to the patella tendon and 1 cm proximal to the joint line.
  • Accessory portals may include superolateral, posteromedial, posterolateral, midpatella, central, far medial, or lateral (Fig 4).
• The tears may be stimulated to heal with either rasping or trephination.
  • Rasping may be performed with either an arthroscopic shaver or a meniscal rasp that lightly abrades both the tibial and femoral edges of the tear site, as well as the meniscosynovial junction, to stimulate vascularity.
  • Trephination is performed by inserting a long 18-gauge needle either percutaneously or through the arthroscopic portals across the meniscus tear to create vascular channels. The surgeon should avoid perforation of the meniscus surface, causing further injury.

INSIDE-OUT TECHNIQUE
• This technique requires passage of double-loaded 2-0 or 0 nonabsorbable sutures with long flexible needles passed arthroscopically through thin cannulas (TECH FIG 1).
• It is best used for posterior horn, middle third, peripheral capsule, and bucket-handle tears.
• Before passage of the sutures, an incision is made posteromedial or posterolaterally to capture the needles as they exit through the capsule. In this manner, all neurovascular structures are protected.
• For passage of a needle through the medial compartment, the knee is placed in 20 to 30 degrees of flexion to avoid tethering the capsule.
  • A 4- to 6-cm posteromedial incision is made just posterior to the lateral collateral ligament, anterior to the biceps femoris tendon, extending one-third above and two-thirds below the joint line.
  • Dissection is continued anterior to the sartorius and semimembranosus musculature, deep to the medial head of the gastrocnemius.
  • The posterolateral incision is made with the knee in 90 degrees of flexion to allow the peroneal nerve, popliteus, and lateral inferior geniculate artery to fall posteriorly.
• A 4- to 6-cm incision is made just posterior to the lateral collateral ligament, anterior to the biceps femoris tendon, extending one-third above and two-thirds below the joint line.
• Dissection is continued between the iliotibial band and the biceps tendon and then proceeds deep and anterior to the lateral head of the gastrocnemius. On exposure of the capsule, a “spoon” or popliteal retractor is placed against the capsule to visualize the exiting needles.
• A single- or double-lumen cannula is passed through the arthroscopic portals to the site of the tear.
• Long flexible needles are then passed through the cannula, piercing the meniscus above and below the tear site and creating vertical mattress sutures.
• The needles are captured one at a time by an assistant who is retracting on the capsule. Care is taken not to pull either suture all the way through until both needles are passed.
• The sutures are then tensioned and tied to the capsule while viewing the repair arthroscopically.
OUTSIDE-IN TECHNIQUE

- This technique is performed by passing multiple long 18-gauge spinal needles percutaneously from outside of the knee to inside the knee joint (TECH FIG 2).
- This technique is best performed on tears of the anterior and middle third, as well as radial tears.
- Needles should be spaced about 3 to 5 mm apart.
- The needle should enter the joint through the periphery to achieve a vertical or horizontal mattress suture configuration.
- An absorbable monofilament suture is passed into the joint.
- A second needle with a wire retriever trocar is passed through the tear to retrieve the suture.
- After tensioning of the mattress suture, a 3- to 5-mm skin incision is made near the suture strands and blunt dissection carried down to the capsule with a hemostat.
- A probe may be used to retrieve the sutures and tie them down to the capsule under direct visualization, taking care to avoid incarceration of any neurovascular structures.

TECH FIG 1 • Inside-out repair technique. A. Diagram of technique. B. Skin incision on medial side. C. Skin incision on lateral side. D. Intraoperative image and popliteal retractor in place. E. The cannulas used to pass the needles.

ALL-INSIDE FIXATION TECHNIQUE

- Multiple proprietary fixation devices are available with variations on the popular reverse-barbed fishhook design (eg, Meniscus Arrow, Bionx, Blue Bell, PA; Biostinger, and ConMed Linvatec, Largo, FL; Dart, Arthrex, Naples, FL) (TECH FIG 3).
  - They are also referred to as first-generation fixators.
  - These devices are best used in vertical longitudinal tears in the red-white zone of the posterior horn.
  - They are typically made of bioabsorbable copolymers such as poly-L-lactic acid and poly-D-lactic acid.
- After identification of the tear site, accurate measurement of the size of the meniscus is performed with an arthroscopic measuring device.
- Insertion of the fixator must be performed perpendicular to the tear and parallel to the tibial surface.
- Fixators can be placed at 3- to 5-mm intervals.
- Care must be taken to implant the fixator so that it is seated flush or countersunk to the meniscus surface while spanning the tear equally on both sides to appropriately compress the tear.

TECH FIG 3 • Use of arthroscopic fixator. A. Meniscal fixators. B. Placement of meniscal arrow.
ALL-INSIDE SUTURE FIXATION TECHNIQUE

- Multiple proprietary designs are available (eg, FasT-Fix, Smith and Nephew, Andover, MA; RapidLoc, Mitek, Westwood, MA) (TECH FIG 4).
  - They are also referred to as second-generation fixators.
- The suture fixators are designed to allow repair of the meniscus with mattress sutures without creating an incision through the skin.
- The devices deploy two absorbable or nonabsorbable suture anchors with attached nonabsorbable sutures between them.
- The sutures can then be arthroscopically tied or they may come pretied, depending on proprietary design.
- After preparing the tear in the standard manner, the fixator should be inserted from the contralateral portal.
- Use of a curved needle provides the surgeon with more options compared to the straight needle with regard to position and reduction and insertion angles.
- Insertion of the needle through a sheath or insertion cannula prevents the delivery system from getting caught on loose tissue.
- The surgeon starts the repair from the center and works outward. This avoids gapping, ruffling, and dog-ears.
- The use of an outside-in stay suture may aid in holding the reduction until the mattress sutures can be placed.
- The devices are placed perpendicular to the tear.
- The first anchor should be placed superiorly and posteriorly and the second should be placed inferiorly and anteriorly across the tear to create a vertical mattress.
- The knot pusher is used to slide and manually assist in cinching down the knot; however, the surgeon should avoid overtightening and puckering the repair.
- The devices are placed about 4 to 5 mm apart.

REPAIR BIOLOGIC AUGMENTATION METHODS

- These techniques are indicated in cases of isolated meniscus repair (no concomitant ACL reconstruction) in which there is concern for healing.
- It is generally accepted that results of meniscus repair are improved when performed in conjunction with ACL reconstruction. The reason for the success is theoretically secondary to the release of intraosseous growth factors and cytokines when bone tunnels are drilled.
- Several methods have been used in an attempt to recreate that biologic advantage.
- Trephination or rasping may be performed in an attempt to increase vascularity delivered to the tear site.
- The use of fibrin clot or platelet-rich fibrin matrix attempts to deliver biologically active factors directly to the repair site.
- The fibrin clot technique introduces a concentrated autologous platelet-rich matrix to the repair site. The platelet-rich matrix technique is a refinement of the fibrin clot technique designed to deliver a more concentrated and volume-stable matrix to the repair site.
- The fibrin clot is performed by first obtaining 30 to 50 mL of blood from the patient intraoperatively and transferring it to a glass container. The blood is stirred with a sintered glass rod. A clot will form, which is blotted dry and then inserted using an arthroscopic grasper to the repair site. The clot is best placed with the fluid flow turned down and is best placed on the tibial site of the repair (TECH FIG 5A,B).
The platelet-rich fibrin matrix technique is performed by obtaining a smaller sample of autologous blood intraoperatively (about 10 mL) and placing it in a centrifuge for about 20 minutes. After centrifugation is completed, the fibrin matrix is retrieved and placed arthroscopically into the repair site in similar fashion to the fibrin clot. Proprietary technology is available (Cascade Autologous Platelet System, MTF, Edison, NJ) to perform this method (TECH FIG 5C,D).

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Repair of red-white and red-red tears only optimally.</td>
</tr>
<tr>
<td>• If concurrent pathology is present, meniscus tears should always be repaired in conjunction with anterior cruciate ligament reconstruction.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tear site management</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The tear should be approached from the contralateral portal.</td>
</tr>
<tr>
<td>• Preparation of the tear site with abrasion, débridement, or trephination is essential.</td>
</tr>
<tr>
<td>• The tear should be reduced accurately and reduction should be maintained during fixator placement.</td>
</tr>
<tr>
<td>• Tears should be bisected with reduction to avoid a dog-ear result.</td>
</tr>
<tr>
<td>• An anchoring stitch may assist with tear reduction.</td>
</tr>
<tr>
<td>• Hybrid techniques are very effective.</td>
</tr>
<tr>
<td>• Accessory portals improve access and fixation configuration.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fixation placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Implants should be separated by about 5 mm.</td>
</tr>
<tr>
<td>• Implants should be placed perpendicular to the tibia.</td>
</tr>
<tr>
<td>• Implants should not be left proud.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Suture techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Vertical mattress sutures are used when possible.</td>
</tr>
<tr>
<td>• Skin incisions are made in 90 degrees of flexion for posteromedial and posterolateral approaches.</td>
</tr>
<tr>
<td>• Sutures are passed in 20 degrees of flexion for medial tears and 90 degrees of flexion for lateral tears.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rehabilitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Programs should be individualized for each patient in terms of protection, weight bearing, range of motion, and return to activities.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

• Postoperative care must be individualized based on tear geometry, repair construct strength, associated surgical procedures, and surgeon preference.
• In the operating room, our patients are placed in a knee immobilizer or hinged brace locked in extension.
• A patient with an isolated meniscus repair will remain partially weight bearing with crutches for about 1 month.
• Early range of motion is performed passively from postoperative day 1.
• Typically, range of motion is limited to 90 degrees for the first 3 weeks for nondisplaced meniscus tears and 4 to 6 weeks for displaced bucket-handle tears.
• Crutches are discontinued when the patient shows good quadriceps function and no antalgia.
Return to pivoting sports ranges from 4 to 6 months, or when the patient has no point tenderness or effusion and can show full extension and painless terminal flexion.

OUTCOMES

The success rate of meniscus repair has been estimated at 50% to 90%, with a higher likelihood of success when repair is performed in conjunction with an ACL reconstruction.

- Early studies by Cannon and Vittori reported on inside-out repairs of 90 knees. Overall clinical success was found to be 82%. Those repaired in conjunction with ACL reconstruction had a 93% success rate while isolated repairs were successful in only 50% of cases.
- Henning et al. reported on 260 repairs in 240 patients with follow-up of about 2 years. On arthroscopic second-look or arthrogram evaluation, inside-out repairs had a 62% success rate, with 17% incompletely healed and 21% not healed. Ninety-two percent of the knees were stable and ACL reconstruction was performed on 80% of them.
- Rodeo et al. found an overall success rate of 87% with use of the outside-in technique in 90 patients. He noted failure in 38% of the unstable knees, 15% in stable knees, and 5% in ACL-reconstructed knees.
- Studies have shown inside-out vertical mattress suture placement to be the strongest fixation technique, whereas the all-inside suture fixators provide excellent repair strength. The all-inside first-generation fixators have shown inferior results compared to the newer fixators.

Biomechanical testing of longitudinal tears in adult porcine meniscus showed mean load to failure of inside-out vertical mattress sutures to be 80.4 N, FasT-Fix 70.9 to 72.1 N (vertical and horizontal configuration), the Dart 61.7 N, horizontal sutures 55.9 N, Rapidloc 43.3 N, and Meniscus Screw (Arthrotek, Biomet, Warsaw, IN) 28.1 N.4

- Two recent studies showed early and intermediate success of Rapidloc.
  - One study found a 90.7% success rate with the use of Rapidloc to repair 54 menisci in 49 patients with an average follow-up of 34.8 months.15
  - Another prospective analysis of 32 meniscus repairs performed with Rapidloc, at an average of 32 months of follow-up, found clinical success in 87.5% of patients.2
  - A recent study of 61 menisci repaired with the FasT-Fix found, at an average follow-up of 18 months, a 90% success rate. ACL reconstruction was performed in 62% of them. Excellent or good clinical results were found on Lysholm knee scoring in 88%.10
- Spindler et al. compared 47 inside-out suture repairs to 98 all-inside meniscal arrow repairs, with clinical failure as defined as reoperation. They found seven failures in each group, but the mean time to follow-up was 68 months for the inside-out repairs and only 27 months for the all-inside group.
- One study of 60 meniscus repairs using the meniscal arrow showed a failure rate of 28% on MRI and repeat arthroscopy at a mean follow-up of 54 months. They found an increasing rate of significant complications in addition to meniscus repair failure, including chondral scoring, fixator breakage, and joint-line irritation.11
- Lee and Diduch also showed deteriorating results with first-generation fixators. They studied 32 meniscus repairs, all performed exclusively with arrows in conjunction with an ACL reconstruction. They reported a success rate of 90.6% at a mean follow-up of 2.3 years; subsequent reports of those same patients found a 71.4% success rate at a mean follow-up of 6.6 years.

COMPLICATIONS

- The overall incidence of complications from arthroscopic meniscus surgery is 0.56% to 8.2%.21
- Meniscus repair surgery has a higher complication rate than meniscus resection, with reports as high as 18%.20
- Commonly discussed complications include infection, deep vein thrombosis, vascular injury, and neurologic complications.
- The rate of infection is 0.23% to 0.42%, with an increasing incidence associated with extended operating time, extended tourniquet time, performance of multiple concurrent procedures, and a history of prior surgeries.1
- There is no clear consensus on the use of prophylactic perioperative antibiotics.
- There are published reports of an increased incidence of infection associated with intra-articular corticosteroid injections given intraoperatively.14
- When an infection has been diagnosed after a repair, it is appropriate to leave the implant or sutures in place; however, there is a higher failure rate associated with it.
- The incidence of deep vein thrombosis ranges from 1.2% to 4.9% after arthroscopic knee surgery.8 No clear consensus exists with regard to perioperative anticoagulation.
- The overall incidence of vascular complications is 0.54% to 1.0%, with complications including popliteal artery injury, pseudoaneurysm, and arteriovenous fistulas.9
- Neurologic complications include direct or indirect nerve injury or complex regional pain syndrome. The overall incidence is 0.06% to 2.0%.18
- Medial meniscus repairs using an inside-out or outside-in technique can result in saphenous neuropathy or neuropraxia, with reports of up to 43% of cases.23
- More recent reports of neuropraxia with all-inside techniques have yet to be published.
- The most common complications associated with the inside-out and outside-in techniques are traumatic neuropathy to the saphenous or peroneal nerves.
- The all-arthroscopic implant fixators can be associated with complications such as retained fragments that fail to resorb, broken implants, fixator migration, and inflammatory responses to the implant. A retained implant may cause further chondral damage secondary to implant abrasion.11

REFERENCES

DEFINITION
- An estimated 850,000 meniscal procedures are performed yearly in the United States.
- Although meniscus preservation is always preferable, large irreparable tears often require partial or subtotal meniscal excision.
- Many patients will become symptomatic in the meniscal-deficient compartment as the result of increased articular cartilage contact stresses and progressive cartilage deterioration.
- Meniscal allograft transplantation is an option in the carefully selected patient with symptomatic meniscal deficiency.

ANATOMY
- The menisci are semilunar fibrocartilaginous discs made of predominantly type I collagen. Water, which accounts for 70% of meniscal composition, is trapped within the matrix by negatively charged glycosaminoglycans (FIG 1).
- Only the peripheral third of the meniscus is vascularized (10% adjacent to popliteal hiatus). Blood is supplied via the perimeniscal capillary plexus with contributions from the superior and inferior medial and lateral geniculate arteries.
- Medial meniscus
  - The medial meniscus covers a smaller percentage of medial compartment surface than the lateral meniscus.
  - A portion of the anterior cruciate ligament (ACL) tibial insertion footprint lies between the anterior and posterior horn attachment sites.
- Lateral meniscus
  - The lateral meniscus covers a relatively larger percentage of the articular surface in its respective compartment than the medial meniscus.
  - The anterior horn attaches adjacent to the ACL and the posterior horn attachment is behind the intercondylar eminence.
  - The anterior and posterior horn attachments are closer to each other than the medial meniscus without a ligament insertion footprint interposed between the two sites. This makes the lateral meniscus more amenable to a bone bridge transplantation technique.
  - A discoid variant is found in 3.5% to 5% of patients.

PATHOGENESIS
- Meniscal pathology is generally of two types:
  - Acute traumatic tears
    - These injuries typically occur in a previously relatively “healthy” meniscus in patients younger than 35.
    - They may also occur in older individuals, but typically in the setting of an acute ACL tear.
    - Traumatic tears often include unstable longitudinal tears in the vascular zone, which are optimal candidates for meniscal repair.
    - They often occur in association with combined knee injuries (ACL, medial collateral ligament).
  - Degenerative tears
    - This is a more complex tear pattern that typically occurs in patients older than 35.
    - Often a relatively minor trauma or event “breaks the camel’s back” and a tear propagates through degenerative meniscal tissue.
    - These are not repairable.
  - Risk factors for meniscal tears include sports participation (especially jumping and cutting sports at risk for concurrent ACL injury), age, higher body mass index, occupational kneeling and squatting (associated with degenerative rather than acute traumatic meniscal lesions), level of activity, and ACL instability.
  - The association of meniscal tears with ACL tears is well documented. Lateral meniscal injuries occur more frequently with acute ACL disruption, while medial meniscal injuries occur more often in the setting of chronic ACL insufficiency.
  - Irreparable tear patterns or failed previous meniscal repairs often necessitate arthroscopic meniscal excision of the tear component. The degree of tear propagation typically dictates the resection required.

NATURAL HISTORY
- Meniscectomy can decrease contact area by 75% and increase joint contact stresses by over 200%.1
- Contact stresses increase as a function of the amount of meniscus resected.
- These increases in joint contact stress often lead to premature cartilage deterioration and the development of osteoarthritis. Although patients often remain relatively asymptomatic until they have advanced degenerative changes, many patients (who tend to be younger and more active) develop pain earlier in the degenerative process.
- Lateral meniscectomy is considered to have a poorer prognosis than medial meniscectomy.
- The medial meniscus is the secondary stabilizer to anterior tibial translation. Medial meniscectomy (posterior horn) in the ACL-deficient knee often increases tibial translation and instability.

The views expressed in this article are those of the authors and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the United States Government.

Dr. Kent and Kurtz are military service members (or employees of the U.S. Government). This work was prepared as part of their official duties. Title 17 U.S.C. 105 provides that ‘Copyright protection under this title is not available for any work of the United States Government.’ Title 17 U.S.C. 101 defines a United States Government work as a work prepared by a military service member or employee of the United States Government as part of that person’s official duties.
Meniscus implantation decreases peak stresses and improves contact mechanics but does not restore perfect knee mechanics.\textsuperscript{5,9}

PATIENT HISTORY AND PHYSICAL FINDINGS

Potential transplant patients are typically younger than 40 years of age, with an absent or nonfunctioning meniscus, who are symptomatic from their meniscal insufficiency. The upper limit is generally age 50 (not absolute) for highly active patients who are not good candidates for arthroplasty.

- A detailed history includes specific symptoms, prior injuries, and subsequent surgery. Arthroscopy pictures are helpful in determining the degree of meniscal resection and the condition of the articular cartilage.
- Symptomatic postmeniscectomy patients typically present with joint line pain (sometimes subtle), swelling, and pain associated with barometric pressure changes. Symptoms are usually activity-related.
- The physical examination should focus on determining pain location, ligament stability, and alignment, assessing the cartilage, and ruling out elements of the differential diagnosis.
- Palpating the joint line for tenderness will localize the source of pain.
- Sharp pain on the McMurray test may indicate recurrent meniscal injury or chondral lesion versus meniscal insufficiency (dull ache).
- The Lachman test assesses for concomitant ACL pathology, which should be addressed at the time of surgery.
- Concerns about malalignment and gait problems necessitate long-leg alignment films.
- Symmetric range of motion is needed before the transplant.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs
  - Anteroposterior (AP) view of both knees in full extension (FIG 2A): Look for subtle joint space narrowing.

![Meniscal anatomy](image1)

![Meniscal anatomy](image2)

![Meniscal anatomy](image3)

![Meniscal anatomy](image4)

![Meniscal anatomy](image5)

![Meniscal anatomy](image6)

![Meniscal anatomy](image7)

![Meniscal anatomy](image8)

![Meniscal anatomy](image9)

![Meniscal anatomy](image10)

![Meniscal anatomy](image11)

![Meniscal anatomy](image12)

![Meniscal anatomy](image13)

![Meniscal anatomy](image14)

![Meniscal anatomy](image15)

![Meniscal anatomy](image16)

![Meniscal anatomy](image17)

![Meniscal anatomy](image18)

![Meniscal anatomy](image19)

![Meniscal anatomy](image20)

![Meniscal anatomy](image21)

![Meniscal anatomy](image22)

![Meniscal anatomy](image23)

![Meniscal anatomy](image24)

![Meniscal anatomy](image25)

![Meniscal anatomy](image26)

![Meniscal anatomy](image27)

![Meniscal anatomy](image28)

![Meniscal anatomy](image29)

![Meniscal anatomy](image30)

![Meniscal anatomy](image31)

![Meniscal anatomy](image32)

![Meniscal anatomy](image33)

![Meniscal anatomy](image34)

![Meniscal anatomy](image35)

![Meniscal anatomy](image36)

![Meniscal anatomy](image37)

![Meniscal anatomy](image38)

![Meniscal anatomy](image39)

![Meniscal anatomy](image40)

![Meniscal anatomy](image41)

![Meniscal anatomy](image42)

![Meniscal anatomy](image43)

![Meniscal anatomy](image44)

![Meniscal anatomy](image45)

![Meniscal anatomy](image46)

![Meniscal anatomy](image47)

![Meniscal anatomy](image48)

![Meniscal anatomy](image49)

![Meniscal anatomy](image50)

![Meniscal anatomy](image51)

![Meniscal anatomy](image52)

![Meniscal anatomy](image53)

![Meniscal anatomy](image54)

![Meniscal anatomy](image55)

![Meniscal anatomy](image56)

![Meniscal anatomy](image57)

![Meniscal anatomy](image58)

![Meniscal anatomy](image59)

![Meniscal anatomy](image60)

![Meniscal anatomy](image61)

![Meniscal anatomy](image62)

![Meniscal anatomy](image63)

![Meniscal anatomy](image64)

![Meniscal anatomy](image65)

![Meniscal anatomy](image66)

![Meniscal anatomy](image67)

![Meniscal anatomy](image68)

![Meniscal anatomy](image69)

![Meniscal anatomy](image70)

![Meniscal anatomy](image71)

![Meniscal anatomy](image72)

![Meniscal anatomy](image73)

![Meniscal anatomy](image74)

![Meniscal anatomy](image75)

![Meniscal anatomy](image76)

![Meniscal anatomy](image77)

![Meniscal anatomy](image78)

![Meniscal anatomy](image79)

![Meniscal anatomy](image80)

![Meniscal anatomy](image81)

![Meniscal anatomy](image82)

![Meniscal anatomy](image83)

![Meniscal anatomy](image84)

FIG 2 • A. AP weight-bearing bilateral knee views showing subtle medial compartment joint space narrowing of the right knee (arrow). B. MRI showing deficient medial meniscus. C. Arthroscopic image of right knee showing deficient medial meniscus.
Meniscal Allograft Sizing Methods

<table>
<thead>
<tr>
<th>Sizing Method</th>
<th>Strengths and Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct measurement</td>
<td>Contralateral knee may be used for sizing, though some variability exists in menisci of opposite knees.</td>
</tr>
<tr>
<td>Plain radiographs</td>
<td>The consistent relationship between meniscal size and landmarks in plain radiographs is often used by tissue banks for allograft sizing. By using measurements of the length and width of the medial and lateral tibial plateaus, McDermott et al determined that meniscal size can be predicted with a mean error rate of 5%. Although compared to plain radiographs MRI is historically considered to be slightly more accurate at sizing allografts, Shaffer et al found that only 35% of menisci measured with MRI were found to be within 2 mm of the actual size needed. Carpenter et al reported that MRI consistently underestimated the anteroposterior and mediolateral sizes of both the medial and lateral meniscus but was more accurate in estimating meniscal height. They concluded that CT and plain radiographs were more useful in allograft sizing.</td>
</tr>
<tr>
<td>MRI</td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td></td>
</tr>
</tbody>
</table>

- Weight-bearing 45-degree flexion posteroanterior view: Look for subtle joint space narrowing.
- Merchant view
- Non-weight-bearing lateral views
- Long-leg alignment films (if malalignment is suspected)
- MRI: to assess menisci, articular cartilage, and subchondral bone (FIG 2B).
- Bone scan can be considered and may reveal increased activity in the involved compartment. However, it is not typically used and its sensitivity in this setting is unknown.
- Diagnostic arthroscopy is often recommended.
  - It will accurately define the extent of meniscectomy and the degree of arthrosis if previous arthroscopic images are unavailable or unclear, or if more than 1 year has elapsed since the last arthroscopy (FIG 2C).
- Outerbridge grade III or less articular cartilage damage is acceptable (grade I or II is preferable) unless a focal grade IV lesion is addressed concurrently with a cartilage resurfacing procedure.

**DIFFERENTIAL DIAGNOSIS**

- Recurrent meniscal tear
- Chondral or osteochondral lesion (may be the primary cause of pain but may require chondroprotection of meniscus transplant)
- Advanced bipolar degenerative arthritis
- Synovitis
- Patellofemoral pain (radiating medial)
- Extra-articular sources (ie, hamstring or pes tendinitis)

**NONOPERATIVE MANAGEMENT**

- Activity modification (nonimpact activities and exercises)
- Appropriate pharmacologic therapy
- Injection therapy (may be helpful for diagnostic purposes as well)
- Unloader braces
- A potential exception to nonsurgical management may be in the setting of the chronically ACL-insufficient knee or failed ACL-reconstructed knee with medial meniscal deficiency.
- A concomitant reconstruction of the ACL with meniscal allograft replacement may improve joint stability, ACL graft survival, and eventual clinical outcome.
- This is a new relative indication.

**SURGICAL MANAGEMENT**

- Indications are patient younger than 40 years with an absent or nonfunctioning meniscus and with pain due to meniscal insufficiency or progressive joint space narrowing.
- Upper limit is generally age 50 for highly active patients who are not good candidates for arthroplasty.
- Contraindications to surgery include immunodeficiency, inflammatory arthritis, prior deep knee injection, osteophytes indicating bony architectural changes, marked obesity, Outerbridge grade IV articular changes (focal chondral defects can be addressed concurrently), knee instability, or marked malalignment (unless these issues are corrected).

**Preoperative Planning**

- Graft sizing: Although size matching of meniscal allografts to recipient knees is thought to be critical, the tolerance of size mismatch is unknown. While various sizing methods have been proposed, measurements based on plain radiographs and MRI are most commonly used (Table 1).
- Meniscal allografts are procured under strict aseptic conditions within 12 hours of cold ischemic time in accordance with standards established by the American Association of Tissue Banks for donor suitability and testing (Table 2).
■ All equipment should be ordered and readily available (ie, commercially available meniscal workstations).
■ An experienced assistant is very valuable for this procedure.

### Positioning
■ The patient is placed in the supine position with the knee at the table break (FIG 3).
■ For a lateral meniscal transplant, there is the option of a figure 4 position versus the leg over the table break for femoral distractor application (see Approach).

### Approach
■ For the lateral meniscus, a lateral parapatellar arthrotomy with posterolateral meniscus repair approach is used.
■ For the medial meniscus, a medial parapatellar arthrotomy with posteromedial meniscus repair approach is used.

![FIG 3 • Patient positioned with the knee at the table break. Femoral distractor optimizes compartment distraction with the knee flexed.](image)

### LATERAL MENISCUS GRAFT PREPARATION
■ A previously size-matched lateral meniscus with the attached tibial plateau is thawed in a saline and antibiotic solution.
■ Remove soft tissue from the meniscus (capsular tissue) (TECH FIG 1A).
■ Always use the bone bridge-in-slot technique; it maintains the bridge of bone between the anterior and posterior insertion sites.
■ Commercially available meniscus workstations can facilitate bone bridge preparation into various shapes that will match tibial recipient sites (Arthrex, Naples, FL) (TECH FIG 1B,C).
■ The most common bone preparation techniques include keyhole, dovetail, and slot configurations (TECH FIG 1D).
■ Prepare the bone bridge shape between the meniscus insertion sites using the appropriate workstation (TECH FIG 1E).
■ During bone preparation, be careful not to injure the meniscus insertion sites.
■ Mark the superior surface of the meniscus and the popliteal hiatus with a surgical marker.
■ Using 10-inch flexible meniscus repair needles (Ethibond, Somerville, NJ), place one or two vertical mattress sutures (may place up to four if desired) through the posterior horn of the meniscus (TECH FIG 1F,G). Do not cut off the needles. These will serve as passage sutures and are used for fixation as well.

![TECH FIG 1 • Lateral meniscus graft preparation. A. Prepreparation lateral meniscus graft (after capsular soft tissue has been removed). B. Preparing a keyhole graft with the workstation. C. Dovetail workstation. (continued)](image)
LATERAL MENISCUS APPROACH AND TIBIAL PREPARATION

- A combined arthroscopic and lateral parapatellar arthrotomy approach is performed.
- Perform an arthroscopic débridement and excoriation to the far peripheral meniscal rim or joint capsule with a shaver or meniscal rasp.
- A no. 15 blade may be used to excise the anterior horn and any remnant of the body.
- Use an arthroscopic burr to create a small trough in line with the anterior and posterior horn attachments (guide for recipient site) (TECH FIG 2A).
- Expose the proximal tibia through a small lateral parapatellar arthrotomy in line with the trough (TECH FIG 2B).
- Commercially available instrumentation will facilitate creation of the tibial recipient site in line with the anterior and posterior horn attachments (Arthrex, Naples, FL) (TECH FIG 2C–E).
- Take care to avoid penetration through the posterior cortex.
- Perform posterolateral exposure to receive inside-out sutures (meniscus repair approach) (TECH FIG 2F).
DELIVERY AND FIXATION OF LATERAL MENISCUS

- Before delivery of the graft into the recipient site, place the 10-inch needles from the passage sutures through the miniarthrotomy and posterolateral capsule to assist in delivery of the graft (TECH FIG 3A).
- Exposure, retraction, and needle retrieval are identical to an inside-out repair technique.
- Plan optimal placement of sutures through the capsule relative to their position in the meniscus (TECH FIG 3B). Use the popliteus tendon and the popliteal hiatus in the graft as a guide for suture placement.
- By simultaneously inserting the shape-matched donor graft into the tibial recipient site and pulling on the posterior inside-out passage suture, the graft is delivered to re-establish the normal insertion site (TECH FIG 3C).
- A varus stress to the knee, combined with pulling on the posterior passage sutures, will help reduce the posterior horn under the femoral condyle (TECH FIG 3D).
- Matching the anterior cortices (graft and recipient) and bringing the knee through a range of motion will assist in final anteroposterior positioning.
- Place additional inside-out meniscus sutures with the suture cannula placed in the medial portal. The scope is placed into the miniarthrotomy.

Tech Fig 2 (continued) D. Preparation of dovetail recipient site. E. Completed keyhole recipient site. F. Posterolateral exposure.

Tech Fig 3 Delivery of lateral meniscus. A. Ten-inch needles from the passage suture are placed through the posterolateral capsule and retrieved by the assistant. B. Inside-out vertical sutures are placed through the appropriate location within the posterolateral capsule. (continued)
TECH FIG 3 • (continued) C,D. The dovetail graft is delivered into the recipient site. E. Posterior horn is reduced by pulling on the posterior passage suture combined with varus stress to the knee. F. Completed lateral meniscus transplant.

- Additional anterior sutures can be placed through the anterior arthrotomy using standard open suturing techniques.
- Tie sutures with the knee in flexion (TECH FIG 3E,F).
- An interference screw or transosseous suture fixation may be placed with the slot technique, but this is typically unnecessary with the dovetail and keyhole technique.

MEDIAL MENISCUS GRAFT PREPARATION

- A previously size-matched medial meniscus with the attached tibial plateau is thawed in a saline and antibiotic solution. Remove soft tissue as described for the lateral meniscus.
- Medial meniscal allografts may be fashioned with or without bone plugs at the anterior and posterior horn insertion sites (TECH FIG 4A,B).
- For preparation without bone plugs, detach the anterior and posterior horns from the bone block and whipstitch each horn with heavy nonabsorbable suture. We do not typically use this technique unless a plug fractures.
- For preparation with bone plugs (recommended), place a 2.4-mm Beath guide pin through the bone block into the posterior insertion site at about a 60-degree angle. Place
MEDIAL MENISCUS APPROACH AND TIBIAL PREPARATION

- The case is performed via arthroscopic, medial parapatellar, and posteromedial meniscal repair approaches (TECH FIG 5A).
- The remaining meniscus is débrided, leaving 1 mm of meniscal rim. The surrounding capsule and meniscal bed is abraded with the shaver and rasps.
- To visualize and access the posterior horn insertion site, perform a small notchplasty of the medial wall of the notch inferior to the posterior cruciate ligament (PCL) insertion. Likewise, débride back the medial tibial spine until easy access is obtained (TECH FIG 5B).
- Place a vertical passing stitch of nonabsorbable suture up the guide pin hole, through the meniscal tissue, then back down the guide pin hole for each bone plug.
- Perform a medial parapatellar incision, extending distally to allow access to the anteromedial proximal tibia. Do not perform the arthrotomy portion until the posterior tunnel is complete.
- Repeat these steps for the anterior horn insertion, but angle the guide pin approximately 20 degrees and create a bone plug 10 mm in diameter. Place a heavy nonabsorbable suture (no. 2 FiberWire) up the guide pin hole, through the meniscal tissue, then back down the guide pin hole for each bone plug.

a commercially available collared pin into the 2.4-mm hole. Ream over the collared pin using an 7- or 8-mm coring reamer (creates a plug 6 or 7 mm in diameter) (TECH FIG 4C). Trim and taper the end to create a 10-mm-long plug.

- Repeat these steps for the anterior horn insertion, but angle the guide pin approximately 20 degrees and create a bone plug 10 mm in diameter. Place a heavy nonabsorbable suture (no. 2 FiberWire) up the guide pin hole, through the meniscal tissue, then back down the guide pin hole for each bone plug.

- Place a vertical passing stitch of nonabsorbable suture at the junction of the posterior and middle thirds of the meniscus.
- Mark the anterior and posterior horns on the superior meniscal surface.
Under direct visualization, position a variable-angle ACL-PCL tibial drill guide such that the guide pin will exit in the center of the native posterior horn insertion site footprint (TECH FIG 5C,D).

Drill a 9-mm tibial tunnel. Débride and chamfer the intra-articular portion of the tunnel. Pass a shuttle suture up the tunnel and out the medial portal (TECH FIG 5E).

Complete the medial parapatellar arthrotomy, incorporating the medial portal (do not cut the shuttle suture) (TECH FIG 5F).

Perform posteromedial exposure to receive inside-out sutures (meniscus repair approach).

**DELIVERY AND FIXATION OF MEDIAL MENISCUS**

Shuttle-exchange the shuttle sutures with the posterior bone plug suture and allograft passing suture. Via the parapatellar arthrotomy, deliver the meniscal allograft into the knee and fully seat the posterior bone plug into the posterior tunnel (TECH FIG 6A,B). Apply a valgus stress to the knee while pulling on the posterior bone plug sutures and the posterior passing sutures.

Using zone-specific cannulas (Linvatec, Largo, FL), suture the allograft to the periphery approximately two thirds of the way posterior to anterior with multiple vertical mattress sutures.

Through the parapatellar arthrotomy, determine the anterior horn insertion site and place a Beath guide pin in its center.

Drill a blind 10-mm tunnel vertically to a depth sufficient to accept the anterior allograft bone plug (TECH FIG 6C).

Drill a 2-mm hole perpendicular to the tunnel from the anterior tibial cortex entering the tunnel base.

**TECH FIG 6 • A,B.** Meniscus delivery. Shuttle suture and delivery of the posterior bone plug and meniscus. C. Anterior recipient tunnel created by reaming over guide pin. D. Anterior bone plug seated into tunnel. E. Bone plug sutures tied over anterior bone bridge. *(continued)*
POSTOPERATIVE CARE
- Postoperative rehabilitation may need to be altered based on concomitant procedures.
- A hinged knee brace locked in extension is used for 6 weeks.
- Weight bearing as tolerated is typically permitted with the knee braced in full extension (this may be limited by other procedures).
- Range of motion is limited between 0 and 90 degrees for the first 6 weeks. Flexion is increased between 6 and 12 weeks.
- Closed-chain exercises, cycling, and swimming are started at 6 weeks.
- Running may begin at 4 to 6 months.
- Squatting and pivoting sports are not allowed for 6 to 9 months.

OUTCOMES
- With appropriate indications, current success rates for allograft meniscus transplantation are about 75% to 85%. 3,4,6,10
- Bone plug fixation may improve outcomes, although this is controversial.
- Poor results are typically associated with more advanced articular cartilage degeneration.
Meniscus transplants that are combined with articular cartilage resurfacing or realignment procedures can yield favorable outcomes.

One study reported that 86% of patients with a combined ACL reconstruction and meniscus transplant had normal or near-normal International Knee Documentation Committee (IKDC) scores, with an average maximum KT arthrometer side-to-side difference of 1.5 mm.¹²

**COMPLICATIONS**

- Nonhealing or incomplete healing
- Infection
- Neurovascular injury
- Loss of motion
- Meniscus tear or extrusion (late)
- Persistent or progressive symptoms (typically related to articular cartilage)

**REFERENCES**

DEFINITION
- Chondral defects in the knee are common.
- The lesions may be partial- or full-thickness (FIG 1), through all layers of the articular cartilage down to the level of the subchondral bone.
- Chondral defects may be acute or chronic.
- These articular cartilage lesions may present in a variety of clinical settings and at different ages.5–10

ANATOMY
- The articular cartilage of the knee is 2 to 4 mm thick, depending on the location within the joint.
- The articular cartilage is avascular tissue that is devoid of nerves and lymphatics.
- Relatively few cells (chondrocytes) are present in the abundant extracellular matrix.
- These factors are critical in the lack of a spontaneous or naturally occurring repair response after injury to articular cartilage.

PATHOGENESIS
- The shearing forces of the femur on the tibia as a single event may result in trauma to the articular cartilage (FIG 2), causing the cartilage to fracture, lacerate, and separate from the underlying subchondral bone or separate with a piece of the subchondral bone.
- Chronic repetitive loading in excess of normal physiologic levels also may result in fatigue and failure of the chondral surface.
- Single events usually occur in younger patients, whereas chronic degenerative lesions are seen more commonly in persons of middle age and older.5–10
- Repetitive impacts can cause cartilage swelling, an increase in collagen fiber diameter, and an alteration in the relation between collagen and proteoglycans.

NATURAL HISTORY
- Articular cartilage defects that extend for the full thickness to subchondral bone rarely heal without intervention.5–10
- Some patients may not develop clinically significant problems from acute full-thickness chondral defects, but most eventually suffer from degenerative changes that can be debilitating.

FIG 1 • A. A full-thickness chondral defect through all layers of the articular cartilage is outlined (arrows). B. A full-thickness chondral lesion.

FIG 2 • A shearing injury has resulted in a full-thickness chondral defect, as seen on this MRI scan. The dark arrow denotes the cartilage defect, and the light arrows show the limits of the subchondral bone edema secondary to the shearing injury. (Courtesy of Dr. Charles Ho, Vail, CO.)
Acute events may not result in full-thickness cartilage loss but, rather, may start a degenerative cascade that can lead to chronic full-thickness loss.

The degenerative cascade typically includes early softening and fibrillation (grade I); fissures and cracks in the surface of the cartilage (grade II); severe fissures and cracks with a “crab meat” appearance (grade III); and, finally, exposure of the subchondral bone (grade IV).

PATIENT HISTORY AND PHYSICAL FINDINGS

The physical diagnosis can be difficult to establish, especially if the chondral defect is isolated.

Chondral lesions can be located on the joint surfaces of the femur, tibia, or patella.

Point tenderness over a femoral condyle or tibial plateau is a useful finding, but is not diagnostic.

If compression of the patella elicits pain, a patellar or trochlear lesion may be indicated.

Joint effusion may be present, but it is not a consistent finding.

Catching or clicking may be present, especially if there is an elevated flap of cartilage.

Restricted range of motion (ROM) can be associated with many pathologic conditions of the knee, but the ROM should be documented as a baseline prior to any treatment.

Physical examinations should be performed, as follows:

- The patella is palpated in superior-inferior and medial-lateral directions for evidence of effusion. About 50% of patients with chondral defects have an effusion.
- The Lachman test is used to rule out ligamentous instability by applying anterior force to the tibia with the knee in 20 to 30 degrees of flexion.
- The thumb and index finger are used to place digital pressure over all geographic areas of the knee to detect point tenderness; this finding is useful but is not in itself diagnostic.
- A palpable or audible pop in combination with pain is considered a positive result to the McMurray’s test, indicating a meniscus lesion rather than a chondral lesion.

IMAGING AND OTHER DIAGNOSTIC STUDIES

For diagnostic imaging, angular deformity and joint space narrowing are assessed using long standing radiographs.

Two methods for radiographic measurement of the biomechanical alignment of the weight-bearing axis of the knee are used in our facility:

- The angle between the femur and tibia on anteroposterior (AP) views obtained with the patient standing.
- The weight-bearing mechanical axis drawn from the center of the femoral head to the center of the tibiotarsal joint on long (~51 inches/130 cm) standing radiographs (FIG 3A).

If the angle drawn between the tibia and femur shows more than 5 degrees of varus or valgus compared with the normal knee, this amount of axial malalignment would be a relative contraindication for microfracture.

We rely most often on the mechanical axis. It is preferable for the mechanical axis weight-bearing line to be in the central quarter of the tibial plateau of either the medial or lateral compartment.

If the mechanical axis weight-bearing line falls outside the quarter of the plateaus closest to the center (FIG 3B), either medial or lateral, this weight-bearing shift also would be a relative contraindication if left uncorrected. In such cases, a realignment procedure should be included as a part of the overall treatment regimen.
Standard AP, lateral, and weight-bearing radiographic views with knees flexed to 30 to 45 degrees also are obtained. MRI that uses newer diagnostic sequences specific for articular cartilage is crucial to our diagnostic workup of patients with suspected chondral lesions (FIG 3C).

DIFFERENTIAL DIAGNOSIS
- Meniscus tear
- Loose bodies
- Attached chondral flap
- Symptomatic plica
- Synovitis
- Chondral bruising, with or without subchondral edema

NONOPERATIVE MANAGEMENT
- Patients with acute chondral injuries are treated as soon as practical after the diagnosis is made, especially if the knee is being treated concurrently for meniscus or anterior cruciate ligament pathology.
- Patients with chronic or degenerative chondral lesions often are treated nonoperatively (conservatively) for at least 12 weeks after a suspected chondral lesion is diagnosed clinically.
- This treatment regimen includes activity modification, physical therapy, nonsteroidal anti-inflammatory drugs, viscosupplement injections, and possibly dietary supplements that may have cartilage-stimulating properties.
- If nonoperative treatment is not successful, then surgical treatment is considered.

SURGICAL MANAGEMENT
- Microfracture initially was designed for patients with post-traumatic articular cartilage lesions of the knee that had progressed to full-thickness chondral defects.
- The microfracture technique still is most commonly indicated for full-thickness loss of articular cartilage in either a weight-bearing area between the femur and tibia or an area of contact between the patella and the trochlear groove.
- Unstable cartilage that overlies the subchondral bone also is an indication for microfracture (FIG 4).
- If a partial-thickness lesion is probed and the cartilage simply scrapes off down to bone, we consider this a full-thickness lesion.

Degenerative joint disease in a knee that has proper axial alignment is another common indication for microfracture.
- These lesions all involve loss of articular cartilage at the bone–cartilage interface.

Preoperative Planning
- All imaging studies are reviewed.
- MRI scans are re-reviewed for presence of concomitant pathology.
- Radiographs are carefully studied for fractures, loose bodies, axial alignment, and joint space narrowing.
- The surgical plan should include addressing concomitant pathology concurrently, as appropriate.
- Examination under anesthesia should be accomplished before skin preparation and draping.

Positioning
- The patient is positioned supine.
- Initially, for the diagnostic portion of the arthroscopy, the foot is on the table.
- For the definitive procedure, the distal portion of the table is lowered so that the foot is off the table and the knee is flexed 90 degrees (FIG 5).
- A lateral post is raised so that a varus force can be placed on the joint to increase visualization as necessary.

Approach
- Our primary approach to chondral lesions is arthroscopic microfracture chondroplasty (Table 1).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Indications and Contraindications for Microfracture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Indications</strong></td>
<td></td>
</tr>
<tr>
<td>Full-thickness defect (grade IV), acute or chronic</td>
<td>Partial-thickness defects</td>
</tr>
<tr>
<td>Unstable full-thickness lesion</td>
<td>Uncorrected axial malalignment</td>
</tr>
<tr>
<td>Degenerative joint disease lesion (requires proper knee alignment)</td>
<td>Inability to commit to rehabilitation protocol</td>
</tr>
<tr>
<td>Patient capable of rehabilitation protocol</td>
<td>Global degenerative osteoarthritis</td>
</tr>
</tbody>
</table>

FIG 4 • The probe (red arrow) shows that this chondral defect has areas of unstable cartilage (black arrows) that are fissured fully to subchondral bone. These unstable cartilage segments must be removed until a stable margin is achieved.

FIG 5 • For the definitive procedure, the distal portion of the table is lowered so that the foot is off the table and the knee is flexed 90 degrees.
DIAGNOSTIC ARTHROSCOPY

- Three portals routinely are made about the knee for use of the inflow cannula, the arthroscope, and the working instruments (TECH FIG 1).
- Typically, a tourniquet is not used during the microfracture procedure; rather, the arthroscopic fluid pump pressure is varied to control bleeding.
- An initial, thorough diagnostic examination of the knee should be done.
- All geographic areas of the knee must be inspected carefully, including the suprapatellar pouch, the medial and lateral gutters, the patellofemoral joint, the intercondylar notch and its contents, and the medial and lateral compartments, including the posterior horns of both menisci.
- All other intra-articular procedures are done before microfracture.
  ▪ This technique helps prevent loss of visualization when fat droplets and blood enter the knee from the microfracture holes.
  ▪ Importantly, particular attention must be paid to soft tissues such as plicae and the lateral retinaculum that potentially could produce increased compression between cartilage surfaces.

INITIAL PREPARATION

- After careful assessment of the full-thickness articular cartilage lesion, the exposed bone is débrided of all remaining unstable cartilage.
- A hand-held curved curette (TECH FIG 2A) and a full radius resector (TECH FIG 2B) are used to débride the cartilage.
  ▪ It is critical to débride all loose or marginally attached cartilage from the surrounding rim of the lesion.
  ▪ The calcified cartilage layer that remains as a cap to many lesions must be removed, preferably with a curette (TECH FIG 2C).
- Thorough and complete removal of the calcified cartilage layer is extremely important, based on animal studies we have completed.\(^2\)
- Care should be taken to maintain the integrity of the subchondral plate by not débriding too deeply.
- This prepared lesion, with a stable perpendicular edge of healthy, well-attached viable cartilage surrounding the defect (TECH FIG 2D), provides a pool that helps hold the marrow clot—“super clot”—as it forms.
After preparation of the lesion, an arthroscopic awl is used to make multiple holes, or “microfractures,” in the exposed subchondral bone plate.

An awl with an angle that permits the tip to be perpendicular to the bone as it is advanced, typically 30 or 45 degrees, is used.

A 90-degree awl is available that should be used only on the patella or other soft bone. The 90-degree awl should be advanced only manually, not with a mallet.

The holes are made as close together as possible but not so close that one breaks into another, thus damaging the subchondral plate between them.

This technique usually results in microfracture holes that are approximately 3 to 4 mm apart.

When fat droplets can be seen coming from the marrow cavity, the appropriate depth (approximately 2–4 mm) has been reached.

Arthroscopic awls produce essentially no thermal necrosis of the bone compared with hand-driven or motorized drills.

Microfracture holes around the periphery of the defect should be made first, immediately adjacent to the healthy stable cartilage rim (TECH FIG 3A,B).

The process is completed by making the microfracture holes toward the center of the defect (TECH FIG 3C).

The treated lesion is assessed at the conclusion of the microfracture to ensure a sufficient number of holes have been made before reducing the arthroscopic irrigation fluid flow.

After the arthroscopic irrigation fluid pump pressure is reduced, the release of marrow fat droplets and blood from the microfracture holes into the subchondral bone is observed under direct visualization (TECH FIG 4).

The quantity of marrow contents flowing into the joint is judged to be adequate when marrow is observed emanating from all microfracture holes.

Finally, all instruments are removed from the knee and the joint is cleared of fluid.
POSTOPERATIVE CARE

- We prescribe cold therapy for all patients postoperatively, and it is continued for 1 to 7 days.5–10
- The specific post-microfracture rehabilitation protocol recommended depends on both the anatomic location and the size of the defect.3,4
- If other intra-articular procedures are done concurrently with microfracture, such as anterior cruciate ligament reconstruction, we do not hesitate to alter the rehabilitation program as necessary.3
- After microfracture of lesions on the weight-bearing surfaces of the femoral condyles or tibial plateaus, we initiate immediate motion with a continuous passive motion (CPM) machine in the recovery room.5–10
- The initial ROM typically is 30 to 70 degrees, which is increased as tolerated in 10- to 20-degree increments until full passive ROM is achieved.
- The machine usually is set at 1 cycle per minute, but the rate can be varied based on patient preference and comfort.
- The goal is to have the patient in the CPM machine for 6 to 8 hours every 24 hours.
- If the patient is unable to use the CPM machine, instructions are given for passive flexion and extension of the knee with 500 repetitions three times per day and encouragement to gain full passive ROM of the injured knee as soon as possible after surgery.
- Crutch-assisted touchdown weight-bearing ambulation (10% of body weight) is prescribed for 6 to 8 weeks, depending on the size of the lesion.
- Patients with lesions on the femoral condyles or tibial plateaus rarely use a brace during the initial postoperative period.
- Patients begin therapy immediately after surgery with an emphasis on patellar mobility and ROM, with instructions to perform medial to lateral and superior to inferior movement.

TECH FIG 5 • Chronic degenerative chondral lesions commonly have extensive eburnated bone and bony sclerosis with thickening of the subchondral plate, making it difficult to do an adequate microfracture procedure. The black arrow points to a single microfracture hole that has been made to help assess the depth of eburnated or sclerotic bone that must be removed before performing the microfracture procedure.
of the patella as well as medial to lateral movement of the quadriceps and patellar tendons (FIG 6).

- This mobilization is crucial in preventing patellar tendon adhesions and associated increases in patellofemoral joint reaction forces.
- ROM exercises (without ROM limitations), quadriceps sets, straight leg raises, hamstring stretching, and ankle pumps also are initiated the day of surgery.
- Stationary biking without resistance and a deep water exercise program are initiated at 1 to 2 weeks postoperatively.
- After 8 weeks of touchdown weight bearing, the patient is progressed to weight bearing as tolerated, typically weaning off crutches within 1 week.
- Restoration of normal muscular function through the use of low-impact exercises is emphasized during weeks 9 through 16.
- Depending on the clinical examination, the patient’s size, the sport, and the size of the lesion, we usually recommend that patients not return to sports that involve pivoting, cutting, and jumping until at least 4 to 9 months after microfracture.
- All patients treated by microfracture for patellofemoral lesions must use a brace set at 0 to 20 degrees for the first 8 weeks postoperatively to limit compression of the regenerating surfaces of the trochlea or patella, or both.

- We allow passive motion with the brace removed, but otherwise the brace must be worn at all times.
- Patients with patellofemoral lesions are placed into a continuous passive motion machine set at 0 to 50 degrees immediately postoperatively.
- Apart from the ROM setting, parameters for the CPM are the same as for tibiofemoral lesions.
- With this regimen, patients typically obtain a pain-free and full passive ROM soon after surgery.
- Patients with lesions of the patellofemoral joint treated by microfracture are allowed to bear weight as tolerated in their brace 2 weeks after surgery.
- After 8 weeks, we open the knee brace gradually before it is discontinued, and then patients are allowed to advance their training progressively.
- Stationary biking without resistance is allowed 2 weeks postoperatively; resistance is added at 8 weeks after microfracture.
- Starting 12 weeks after microfracture, the exercise program is the same as that used for femorotibial lesions.

OUTCOMES

- With appropriate indications, surgical technique, and especially use of our prescribed rehabilitation program, the success rate of microfracture chondroplasty is approximately 90%.3–10
- In a study that followed 72 patients (95% follow-up rate) for an average of 11 years (range, 7–17 years) following microfracture, results showed improvement in symptoms and function in all patients.5
- Patient-reported pain and swelling decreased at postoperative year 1 and continued to decrease at year 2, and clinical improvements were maintained over the study period.
- Age was the only independent predictor of functional (Lysholm) improvement, with patients over 35 years of age improving less than patients under 35; however, both groups showed improvement.
- In National Football League (NFL) players treated with microfracture (FIG 7) between 1986 and 1997, 76% of players returned to play in the NFL the next football season.6

![FIG 6](image1.png)

**FIG 6** • We place great emphasis on patellar mobility and range of motion with instructions to perform medial to lateral and superior to inferior movement of the patella as well as medial to lateral movement of the quadriceps and patellar tendons as shown here.

![FIG 7](image2.png)

**FIG 7** • **A.** A National Football League player presented with a severe defect of the femoral condyle that measured about 5 × 9 cm. This lesion was treated with the microfracture procedure as described here, and the patient was fully compliant with the rehabilitation protocol. **B.** Four months after the microfracture procedure a relook arthroscopy was carried out. The blue arrows show the margins of the lesion, which has been completely filled with repair tissue. **C.** Illustration of how new “repair” cartilage formed over the damaged area.
Those players played an average of 4.6 additional seasons in the NFL.
All players showed decreased symptoms and improvement in function.
Of those players who did not return to play, most had preexisting degenerative changes of the knee.

**COMPLICATIONS**

- Mild transient pain, most often after microfracture in the patellofemoral joint
- A grating or “gritty” sensation of the joint, especially when a patient discontinues use of the knee brace and begins normal weight bearing through a full ROM
- “Catching” or “locking” as the apex of the patella rides over this lesion during joint motion
- Recurrent effusion between 6 and 8 weeks after microfracture, most commonly when beginning to bear weight on the injured leg after microfracture of a defect on the femoral condyle
- Decreased ROM due to secondary scarring

**REFERENCES**

DEFINITION
- Osteochondral autograft “plug” transfer is a technique for treating full-thickness, localized articular cartilage lesions with or without subchondral bone loss in a nonarthritic joint.
- Cylinders or “plugs” of healthy cartilage, with their associated tidemark and subchondral bone, are harvested from one location in the joint and press-fit into same-length recipient holes prepared in the lesion to restore bone contour and the articular surface.
- Multiple plugs may be transferred to the same region, depending on the defect size.

ANATOMY
- Articular cartilage has a complex structure and plays a vital role in normal and athletic activity. It transmits loads uniformly across the joint and provides a smooth, low-friction, gliding surface.
- Articular cartilage is a smooth, viscoelastic, hypocellular structure with a low coefficient of friction (estimated to be 20% of the friction seen with ice on ice) and the ability to withstand significant recurring compressive loads.
- The articular surfaces of diarthroidal joints are covered with hyaline cartilage.
  - Hyaline cartilage is composed of sparsely distributed chondrocytes in a large extracellular matrix made of about 80% water and 20% collagen.
  - Collagen fibers provide form and tensile strength; water gives it substance.
  - Type II collagen accounts for 95% of the total collagen present. The cellular component (chondrocytes) synthesizes and degrades proteoglycans and is the metabolically active portion of this structure.
- Articular cartilage has four distinct zones: a superficial (tangential) zone; a middle (transitional) zone; a deep (radial) zone; and the calcified zone (FIG 1).
  - The superficial zone collagen fibers are oriented parallel to the joint surface and resist both compressive and shear forces. This zone is the thinnest and sometimes is called the gliding zone.
  - The surface layer, known as the lamina splendens, is cell free, and consists mainly of randomly oriented flat bundles of fine collagen fibrils.
  - Under that layer are more densely packed collagen fibers interspersed with elongated, oval chondrocytes oriented parallel to the articular surface.
  - This superficial zone acts as a barrier, limiting the penetration of large molecules into the deeper zone and preventing the loss of molecules from the cartilage into the synovial fluid.
  - The middle (transitional) zone collagen fibers are parallel to the plane of joint motion and resist compressive forces.
- This zone has more proteoglycans and less water and collagen than the superficial zone.
- The chondrocytes are more spherical with more cellular structures, suggesting a matrix synthesis function.
- The deep (radial) zone fibers are perpendicular to the surface and resist both compressive and shear forces.
- The collagen bundles are arranged in a formation known as the arcades of Benninghoff, in which the round chondrocytes are arranged in columns perpendicular to the joint surface.
- The tidemark is located at the base of the deep zone and resists shear stress. It represents a zone of transition from the deep zone to the zone of calcified cartilage.
- The calcified zone acts as an anchor between the articular cartilage and the subchondral bone.
  - It is the deepest zone and is a thin layer of calcified cartilage creating a boundary with the underlying subchondral bone.
  - The cells in this zone usually are smaller and are surrounded by a cartilaginous matrix.

PATHOGENESIS
- Chondral damage can result from a variety of mechanisms, including a pivoting twisting fall, significant direct impacts on the knee, anterior cruciate ligament (ACL) tears, or a patellar dislocation (FIG 2).
ACL injuries cause direct contusions to the articular surfaces and may lead to instability and localized, full-thickness articular cartilage defects.

- Osteochondritis dissecans involves the separation of subchondral bone and cartilage from surrounding healthy tissues.
- It most commonly occurs in the lateral aspect of the medial femoral condyle.
- Traumatic osteochondral lesions include acute bone and cartilage loss due to fracture, crush, or shear injuries.
- Sometimes, even without a clearly remembered traumatic event, the patient develops pain with weight bearing.

NATURAL HISTORY

- Cartilage biopsy samples overlying bone bruises have shown degeneration, necrosis of the chondrocytes, and a loss of proteoglycan.
- An experimental model suggests that a severe bone bruise and its associated chondral necrosis are precursors to degenerative changes.
- Instability secondary to ACL loss has been shown to contribute to the onset of osteoarthritis after ACL tears.
- Articular cartilage has limited regeneration potential.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Various mechanisms of injury are associated with full-thickness articular cartilage lesions, including pivoting twisting falls, direct impacts, and patellar instability.
- Full-thickness chondral lesions often are clinically silent and should be suspected in the setting of any traumatic hemarthrosis, especially with a ligament disruption.
- Reports of pain localized to one compartment, a persistent dull aching pain worsening after activity, and pain most noticeable when falling asleep are common.
- Running, stair climbing, rising from a chair, and squatting may aggravate the symptoms, as does sitting for a prolonged period.
- Physical findings include joint line tenderness, effusion, crepitus, grinding, or catching.
- Effusion is nonspecific but suggests intra-articular pathology.
- Pain on direct palpation of the femoral condyles may indicate cartilage damage.
- Decreased range of motion is nonspecific but often indicates pathology.
- The Lachman test detects ACL instability that may lead to cartilage injury.
- Malalignment of the tibia to the femur when standing may lead to abnormal chondral wear.
- A positive patellar apprehension test signals damage to the medial patellofemoral ligament.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- A standard radiographic knee evaluation should be performed.
- This includes standing anteroposterior (AP) views in full extension to identify angular changes and to compare joint space height.
- A 45-degree flexion posteroanterior (PA) weight-bearing view may identify subtle joint space narrowing.
- A non–weight-bearing lateral view obtained in 45-degree flexion in which the posterior femoral condyles overlap, an axial view of both patellae to help evaluate the patellar alignment, and an AP knee flexion view to outline the femoral intercondylar notch also should be obtained.
- Osteochondritis dissecans lesions most commonly are found in the lateral aspect of the medial femoral condyle (FIG 3A) and are best demonstrated on an AP knee flexion view.
- Long-leg hip-to-ankle films accurately determine varus or valgus alignment.
- Proper MRI protocols have high sensitivity and specificity.
- MRI has evolved into a proven tool to evaluate chondral surfaces and detect full- and partial-thickness lesions that may be clinically silent (FIG 3B,C).
Clinical proven cartilage-sensitive sequences include T1-weighted gradient echo with fat suppression and fast spin-echo sequences with and without fat suppression.

Many newer sequences offer promise but have not yet been validated.²²

**DIFFERENTIAL DIAGNOSIS**

- Partial- or full-thickness cartilage lesion
- Osteonecrosis
- Osteochondritis dissecans
- Meniscal tear
- Ligament injuries

**NONOPERATIVE MANAGEMENT**

- Nonoperative treatment for full-thickness, discrete chondral lesions consists of physical therapy, anti-inflammatory medication, and activity modification to avoid high-impact or patella-destabilizing activities.
- Bracing options include patellar stabilizing braces for patellofemoral instability and load-shifting braces that unload the injured compartment.
- Unloading the compartment also can be accomplished by shoe inserts that provide an appropriate heel and sole wedge.
- These efforts are more effective for medial femoral condyle lesions than lateral ones.
- It is important to ensure that the patient understands that full-thickness lesions have little spontaneous healing capacity and that further degeneration is likely.

**SURGICAL MANAGEMENT**

- The indications for osteochondral autograft transplantation include discrete, isolated, full-thickness articular cartilage lesions between 1.0 and 2.5 cm in diameter (FIG 4).
- Acceptable results with larger defects have been reported, but not consistently.
- If the depth of subchondral bone loss exceeds 6 mm, it will be necessary to adjust the harvested graft accordingly.
- Contraindications include opposing full-thickness articular cartilage damage (“kissing” lesions), multiple-compartment full-thickness lesions, significant angular changes, history of joint infection, intra-articular fracture, and rheumatoid arthritis.
- This technique is most commonly performed on the femoral condyle; however, osteochondral autograft transplantation of the trochlea, patella, tibial plateau, humerus, and talus has been reported.
- The COR osteochondral repair system (Depuy Mitek, Raynham, MA) allows for the harvesting of a precisely sized osteochondral plug and transplantation into a precisely drilled defect. The technique illustrated here uses this system.
- Other systems have been developed, including the osteochondral autologous transfer system (OATS; Arthrex, Naples, FL), and MosaicPlasty (Smith & Nephew Endoscopy, Andover, MA).

**Preoperative Planning**

- The success of this procedure depends upon maintaining viable chondrocytes. Confocal microscopy studies demonstrate that greater pressure on the articular cartilage cells leads to cell death. Several technical issues are related to greater transplanted cell death. These include high impact pressure during insertion, proud grafts which are not advanced to the level of the adjacent native articular cartilage, and sunken grafts depressed 2 mm or more compared to the adjacent articular cartilage.
- The ideal technique optimizes graft position and stability, provides for consistent graft length harvesting, and minimizes the forces required to insert the grafts.
- Multiple procedures can be performed at the same time, including meniscal repair and ligament reconstruction.
- Improved results occur with concomitant ACL reconstruction.¹⁸
- Any ligament instability or malalignment should be corrected at the time of autografting to avoid increased failure rates.
- All radiographs and MRI images should be reviewed before surgery to confirm whether the lesion can be treated arthroscopically or whether an arthrotomy is needed.
- Perpendicular placement of the harvester and drill to the articular surface is required.
- The COR transfer system has a unique “perpendicularity” guide which enhances the perpendicular harvest of the donor graft as well as the perpendicular orientation of the drilled recipient site.
- Any allograft or synthetic materials that may be needed should be available in the operating room.
- Although allograft tissue avoids concerns about harvest site morbidity, it is offset by the risks of transmitted disease and decreased chondrocyte viability¹⁷ as well as significant costs.

**Positioning**

- Osteochondral autograft transfer in the knee is performed with the patient supine and the operative knee in an arthroscopic leg holder flexed off the table.
- It is crucial to confirm that the knee can be flexed adequately to access the lesion before operative preparation and draping.
- The contralateral leg should be well padded and positioned out of the operative field.
- It may be necessary to drape the operative leg free of a leg holder to obtain enough knee flexion to access the lesion.

**Approach**

- Arthroscopic osteochondral autograft transplantation can be technically difficult, because of the need to achieve perpendicular access to the articular cartilage and adequate knee flexion.

---

**FIG 4** - The indications for osteochondral autograft transplantation include discrete, isolated, full-thickness articular cartilage lesions between 1.0 and 2.5 cm in diameter.
The use of the intercondylar notch as a donor site allows for ready arthroscopic access and avoids the need for an arthrotomy such as is required when obtaining grafts from either the superior medial or lateral femoral condyles above the linea terminalis.

A thorough arthroscopic diagnostic knee evaluation should be performed first.

An arthrotomy can be performed for lesions that cannot be addressed adequately arthroscopically. A spinal needle can be used to determine the best angle for portal creation, ensuring a perpendicular approach to the harvest and defect sites.

Arthroscopic osteochondral autografting includes five steps: lesion evaluation and preparation, determination of the number of grafts needed, defect preparation, graft harvest, and graft delivery.

An adequate synovectomy, especially of the fat pad, is needed to facilitate complete visualization of both the defect and harvest sites.

A spinal needle should be used to identify the correct portal placement for a perpendicular approach.

### Diagnostic Arthroscopy

- During the diagnostic evaluation, a complete examination must be performed to rule out other pathology and confirm that no contraindications to the procedure exist.
- It is necessary to look in the posterior recesses and underneath the menisci for chondral pieces.
- Concomitant ligament surgery should be addressed after the transplantation.

### Lesion Evaluation and Preparation

- A 16-gauge needle can be used to plan the best (perpendicular) approach to both the defect and donor sites.
- The defect is prepared by removing loose debris and freshening the edges with a curette or an arthroscopic knife to create perpendicular chondral walls (TECH FIG 1).
- The subchondral bone should be cleared of any residual articular cartilage, but generalized bone bleeding should be avoided.

**TECH FIG 1** - The defect is prepared by removing loose debris and freshening the edges with a curette or an arthroscopic knife to create perpendicular chondral walls.

### Determining Number of Grafts

- The number of grafts required is planned using the probe to obtain a preliminary measurement of the defect's shape and dimensions (TECH FIG 2A).
- When using more than 1 graft, a 2–3-mm bone bridge should be maintained between the recipient sites to ensure a good press fit.
- The depth of the lesion should be estimated using the 2-mm marks on the harvester.
  - A series of grafts 6 mm in diameter fills the defect best.
  - Larger-plug harvesters are available but may require an arthrotomy and are more likely to encroach on weight-bearing areas at harvest sites.
- Specifically, given that a 10-mm diameter lesion is an indication for grafting, harvesting a 10-mm graft defeats the purpose of using this grafting technique.
- The plan should be to place the grafts starting at the periphery of the defect so that the articular cartilage matches the adjacent chondral edge after transplantation (TECH FIG 2B).
- The depth of the defect also should be analyzed.
- In most cases, the standard 10½–12-mm harvester depth is sufficient to fill the defect.
- Osteochondritis dissecans lesions or those with significant bone loss may require the use of the variable depth harvester and placement of grafts that have cancellous sections standing above the crater base.
DEFECT PREPARATION

- Any residual articular cartilage is removed from the subchondral bone, but generalized bone bleeding should be avoided.
- Drilling the recipient site before harvesting the donor autograft plugs allows the selection of the best match on the femoral surface between the donor grafts and the articular cartilage adjacent to the recipient sites.
- Using the COR perpendicularity system reproducibly identifies the best orientation for drilling the recipient site and makes it feasible to drill the recipient site before harvesting the grafts.
- Insert the drill guide with the perpendicularity rod through the portal and into position at the recipient site. With the drill guide positioned in a perpendicular orientation, turn the perpendicularity rod counterclockwise until it disengages and remove the rod.
- The recipient sites in the defect are drilled with the corresponding size COR drill bit under direct arthroscopic visualization, keeping the drill perpendicular to the articular surface.
  - The projecting tooth at the drill tip keeps the drill from “walking” and allows for precise recipient site placement by creating a starter hole (TECH FIG 3).
- The drill is advanced to the appropriate depth using the markings of 5 mm, 8 mm, 10 mm, 12 mm, 15 mm, and 20 mm found on the side of the drill. This line is compared to the adjacent articular cartilage. The fluted drill’s concave sides remove bone during drilling and reduce both friction and heat.
- In cases of subchondral bone loss, the depth should be used and the depth underdrilled to restore the contour and height of the articular surface.
  - This is accomplished by aligning the laser mark with the desired articular cartilage height.
  - The recipient holes can be drilled at the same time or sequentially after autograft insertion.
  - Care should be taken to maintain a bone bridge between recipient sites of 2 to 3 mm and to avoid recipient site convergence.

GRAFT HARVEST

- Potential harvest sites include the lateral and medial trochlea above the linea terminalis and the intercondylar notch.
  - In general, contact pressures are lower in the intercondylar notch and medial trochlea, but available harvest material is limited.¹
  - Higher contact pressures are found in the lateral trochlea, but these decrease more posteriorly.
- Harvesting 5-mm plugs from the lateral trochlea did not result in significant increases in stress concentration and loading in one study.⁷
- We prefer to harvest from the superior and lateral intercondylar notch, because it commonly is obliterated in ACL reconstruction without subsequent morbidity and allows for an entirely arthroscopic procedure (TECH FIG 4A).
Once the number of plugs to be obtained is determined and the sites prepared, the harvester is inserted into the disposable cutter.

The retropatellar fat pad is completely débrided to improve visualization and avoid soft tissue entrapment.

The COR Harvester Delivery Guide comes with the cutting tool pre-assembled as a single unit. The perpendicularity rod should be inserted into this Harvester/Cutter assembly before insertion into the joint. The perpendicularity rod will function as an obturator and minimize both soft tissue capture and fluid loss as the assembly is inserted into the knee.

The Harvester Delivery Guide/Cutter/perpendicularity rod assembly is positioned on the donor site in preparation for the graft harvest. The perpendicularity rod is used to confirm the perpendicular position of the cutter and then removed.

The arthroscope is rotated to confirm this alignment from several angles.

- Perpendicular grafts can be obtained readily with both arthroscopic and open approaches.4

Using a mallet and continuing to hold the harvester perpendicular to the articular cartilage in all planes, use a mallet to tap the Harvester Delivery Guide/Cutter to the desired depth based upon the 5-mm, 8-mm, 10-mm, 12-mm, 15-mm, and 20-mm markings on the side of the harvester (TECH FIG 4B).

A unique feature of the COR system is the cutter tooth on the harvester which underscores the cancellous bone at the distal end of the harvester tube allowing for a precise and consistent depth cut (TECH FIG 4C).

The T-handle of the harvester is rotated clockwise at least two full rotations, undercutting the distal bone and creating a precise harvest depth.

The plug is removed by gently twisting the T-handle while withdrawing the plug. Care should be taken to avoid toggling the donor hole.

On a firm surface, insert the Harvester Delivery Guide/Cutter into the graft loader and push down firmly until it makes contact with the bottom of the loader. The harvested graft will be pushed from the cancellous bone side through the graft loader (TECH FIG 4D).

**TECH FIG 4** • **A.** Harvest sites include the superior and lateral intercondylar notch, an area that is commonly removed in anterior cruciate ligament reconstruction notchplasty. **B.** Position the Harvester/Delivery Guide/Cutter with the perpendicularity guide on the selected donor site. After verifying the perpendicularity, remove the guide and then tap the harvester until the desired laser line depth has been reached. **C.** A unique feature of the COR system is the cutting tooth which underscores the cancellous bone at the distal end of the harvester tube and allows for a precise depth cut. (B,C: Courtesy of Depuy Mitek, Inc, Raynham, MA.)
of the graft plug upwards into the Harvester/Delivery Guide and out of the cutter section (TECH FIG 5). A loud noise usually accompanies this transfer.

- The harvester is removed from the cutter. The graft plug remains inside the harvester until it is transplanted.
- This transfer system eliminates any loads to the articular surface of the graft and eliminates the danger of chondrocyte damage in this step.

TECH FIG 5 • On a firm surface, insert the Harvester Delivery Guide/Cutter into the graft loader and push down firmly until it makes contact with the bottom of the loader. The harvested graft will be pushed from the cancellous bone side of the graft plug upwards into the Harvester/Delivery Guide and out of the cutter section.

TECH FIG 6 • The loaded harvester–clear plastic delivery guide system is held perpendicular to the articular cartilage and implanted with gentle tapping.

GRAFT INSERTION

- Once the harvester tube is disassembled from the cutter, it is placed in the clear plastic insertion tube with depth markings.
- The plastic plunger is placed in the harvester delivery system before insertion of the delivery system into the joint.
- The loaded harvester–clear plastic delivery guide system is then inserted into the knee. It may be necessary to enlarge the portal slightly to permit this passage.
- The clear end of the delivery system, with the graft tip slightly projecting, is held perpendicularly at the recipient site outlet, and, aligning the articular cartilage of the autograft with the adjacent articular cartilage, implanted with gentle tapping until it is flush with the articular cartilage (TECH FIG 6).
- The Universal tamp may be used to fine-tune the graft placement.
- The 8 mm side is recommended for 4 mm and 6 mm grafts and the 12 mm side is recommended for 8 mm and 10 mm grafts.

MULTIPLE GRAFT REPAIR

If more than one graft is needed to repair an articular cartilage defect, the Harvester/Delivery Guide and Cutter is re-assembled and the process repeated until the defect is completely filled. A 2-mm to 3-mm bone bridge should be maintained between the drilled holes to allow for a secure graft press fit.
POSTOPERATIVE CARE

- Immediate range-of-motion exercises without a brace are begun.
- Non-weight bearing is observed for 3 weeks, followed by progressive weight bearing during weeks 3 to 6 after surgery and then full weight bearing beginning at 6 weeks after surgery.
- A progressive quadriceps strengthening program is then started.
- Full athletic activity is permitted at 4 months.

OUTCOMES

- Condylar lesions typically have excellent clinical results.
- Multiple authors report excellent and good results ranging from 78% to 96% at a minimum of 2 years follow-up.\(^2,6,8,18,19\)
- Patellar or patellar and trochlear mosaicplasties have been reported to have good to excellent results in 79% of patients.\(^9,23\)
- Allograft has been shown to be an effective treatment for patellofemoral disease.\(^14,23\)
- Comparisons of osteochondral transplantation with microfracture, Pridie drilling, and abrasion arthroplasty have shown better results with osteochondral transplantation.\(^5,10\)
- Osteochondral transplantation consistently results in restoration of hyaline cartilage versus “hyaline-like” or fibrocartilage.\(^2,3,6,12\)
- Patients younger than 40 years of age have better results.\(^6,11,18\)

COMPLICATIONS

- Infection
- Loose body if graft loosens
- Graft reabsorption
- Cartilage degeneration due to excessive pressure when seating the graft
- Proud graft leading to excessive contact pressures, graft destruction, and possible “catching” sensation.

REFERENCES

DEFINITION

- Articular cartilage of joints such as the knee is essential to the joint’s normal function, in which it acts as a load-bearing structure and provides a nearly friction-free surface. Unfortunately, articular cartilage is particularly susceptible to traumatic injury or pathologic conditions such as osteochondritis dissecans, which can, over time, be significantly disabling in the young athlete and have the potential of degenerating over time.
- The natural history of articular cartilage injuries is poorly understood.
- The treatment of focal chondral lesions remains a significant challenge for the sports medicine orthopedic surgeon.
- A retrospective review of 31,516 knee arthroscopies examined the prevalence of chondral injuries. This review reported 41% Outerbridge III chondral injuries and 19.2% Outerbridge IV chondral injuries, with an estimated 3% to 4% isolated chondral lesions that were larger than 2 cm².¹³
- The orthopedic surgeon is armed with a variety of surgical treatments for pathologic problems in articular cartilage. Numerous surgical techniques have been proposed to address this difficult and often disabling condition in a young patient population.
- Current articular cartilage resurfacing procedures can be divided into three categories:
  - Bone marrow stimulation
  - Implantation of autologous articular cartilage
  - Transplantation of osteochondral allograft
- The clinical results of all of these surgical procedures have generally good short- and long-term clinical results.²⁻⁵,¹⁴,¹⁹ All have specific drawbacks: for example, marrow stimulation produces fibrocartilage; the autogenous osteochondral autograft transfer system (OATS) has an issue with donor site morbidity; and allograft OATS has a significant risk of disease transmission along with a possible immune response to the allograft tissue.
- In 1994, Brittberg et al⁷ proposed an innovative surgical treatment for articular cartilage injuries, autologous cartilage implantation (ACI).
- ACI is performed in two stages.
  - The initial procedure is a comprehensive arthroscopic evaluation of the articular cartilage defect covering size, location, and depth of lesion (FIG 1).
  - At the same time, if the surgical indications are favorable, the orthopedic surgeon can harvest autologous articular cartilage cells. These articular cartilage cells are then digested enzymatically, with the ultimate isolation of mature chondrocytes.
  - The second stage involves implantation of these autologous chondrocyte cells into the defect through a small knee arthrotomy with a periosteal graft sutured over the defect. The cultured chondrocytes are then injected into the defect beneath the periosteal graft.
- This once-experimental procedure, initially directed toward articular cartilage and used for broad-based indications, has become an important procedure for a specific subset of patients. More than 5000 ACI procedures have been performed in the United States by more than 600 orthopedic surgeons.
- Second-look arthroscopy and biopsy of surgically implanted chondrocytes have documented a reconstitution of the articular surface with similar mechanical properties to the surrounding “hyaline-like articular cartilage,” with documented durability of clinical results.

ANATOMY

- Articular cartilage consists of four distinct histologic zones: superficial, middle, deep, and calcified (FIG 2A).
- The chondrocyte is the cell responsible for the growth of cartilage.
- The metabolic balance of the protein macromolecular complex of articular cartilage is maintained by chondrocytes, which constitute about 5% of the weight of cartilage.
- Water makes up about 75% of the weight of articular cartilage. Water’s role as a cation makes it one of the most important elements.
- Glycosaminoglycans provide the compressive strength of articular cartilage and account for about 10% of cartilage weight. These function to trap and hold water with the articular cartilage.
- Collagen, predominantly type II, provides the form and tensile strength of articular cartilage. It makes up about 10% of the weight of cartilage.

![FIG 1 • Overview of the autogenous cartilage implantation (ACI) technique. Step 1: articular cells are harvested. Step 2: cells are grown in culture for 4 to 6 weeks. Step 3: the lesion is débrided. Step 4: harvested periosteum is sutured onto the defect. Step 5: cultured chondrocyte cells are implanted.]

Sean M. Jones-Quaidoo and Eric W. Carson

Chapter 38
The chondrocyte is the major producer of collagen, proteoglycans, and noncollagenous proteoglycans, as well as enzymes (FIG 2B).

Articular cartilage receives its nutritional supply from the synovial fluid in which it is bathed; it does not have a true blood supply.9

PATHOGENESIS

Injuries of the articular cartilage can result from either trauma, as in the case of a partial- or full-thickness chondral or osteochondral injury, or a pathologic process such as osteochondritis dissecans or local osteonecrosis.

Shallow or partial articular cartilage lesions have limited ability to heal, related primarily to the lack of a blood supply.

An inflammatory response cannot occur, leading to a defect within the articular cartilage.13

In full-thickness chondral lesions, in contrast, there is penetration of the subchondral plate, leading to the migration of progenitor cells from the vasculature in the subchondral bone marrow mesenchymal cells to the surface, an inflammatory response, and an attempted healing response.

The mesenchymal progenitor cells differentiate into fibrocartilage.

This tissue is a weak substitute for hyaline articular cartilage and lacks its resilient mechanical properties.11,20

NATURAL HISTORY

The natural history of articular cartilage injury is poorly understood. It is well recognized, however, that the human body has a limited capacity—or no capacity—to repair articular cartilage injuries.11,20

Limited studies have demonstrated progressive and variable degenerative changes equivalent to those of osteoarthritis.

The repair tissue often succumbs to mechanical stresses with premature degeneration, delamination, interarticular osteophyte formation, and eventual breakdown and joint destruction over time.

Some limited studies have been published with long-term follow-up of untreated osteochondritis dissecans that progressed on to osteoarthritis in adulthood.13

PATIENT HISTORY AND PHYSICAL FINDINGS

Articular cartilage injury can present after a trauma sustained during an athletic event or as a slow progression of symptoms, as in osteochondritis dissecans.

Patients may present with what initially is believed to be meniscal pathology, with swelling, pain, palpable tenderness, and locking of the knee.

Articular cartilage chondral flap or more significant osteochondral injury must be part of the differential diagnosis in evaluating the young patient with knee pain.

Those patients with a more insidious onset and no trauma tend to fit more into the category of osteochondritis dissecans. The findings are more consistent with chronic or recurrent effusion, pain, and mechanical symptoms similar to those of meniscus pathology.

IMAGING AND OTHER DIAGNOSTIC STUDIES

The following plain radiographs are obtained in weight-bearing knee flexion: anteroposterior view; notch view; sunrise view of the patella and trochlea; and lateral views (FIG 3A,B).

Although the articular cartilage itself cannot be appreciated, joint space narrowing and other bony defects will be apparent.

Full-length lower-extremity radiographs are indicated for most patients to assess overall alignment and in consideration of the possibility of performing a realignment procedure concomitantly at the time of the ACI procedure in those patients with malalignment problems.

MRI can more clearly demonstrate articular lesions. As the technology advances, better imaging quality is becoming available.

MRI can assess the size of the lesion, location, involvement of subchondral bone, and number of lesions (FIG 3C).

After ACI, MRI also is being used to assess the degree of defect fill, the integration of the repair cartilage to the subchondral bone plate, and the status of the subchondral bone plate and bone marrow.

Recently, the development of MRI cartilage sequencing has better defined articular cartilage injuries and postoperative osteochondral fill.

T2-weighted MRI mapping techniques give remarkable detail at the proteoglycan level (FIG 3D,E).

Optical coherence tomography (OCT)12 involves cross-sectional imaging technology using near-infrared light technology. The high-resolution images provide a noninvasive look at the microstructural level of articular cartilage.

DIFFERENTIAL DIAGNOSIS

Osteoarthritis

Osteochondritis dissecans
Osteonecrosis
Meniscus injury
Loose body
Chondral flap
Osteochondral injury

NONOPERATIVE MANAGEMENT
- Nonoperative treatment is controversial. Patients without symptoms can be treated nonoperatively, with modification of activity level. This may be effective for a period of time; however, with age there is the potential of developing degenerative arthritis, particularly in those younger patients with large lesions. The true natural history of articular cartilage injuries is not known.
- Some surgeons have proposed aggressive surgical treatment in the hope of preventing degenerative arthritis. Few clinical data are available to support such a treatment algorithm, however.

SURGICAL MANAGEMENT
- Patients who fail conservative treatment for chondral injury must be evaluated for surgical treatment.
- The patient must have a full understanding of the surgical procedure and the extensive rehabilitation it requires.
- The indications for ACI are as follows:
  - Symptomatic weight bearing, unipolar, focal full-thickness chondral injury
  - Cartilage lesions of grade III or IV in the Outerbridge classification
  - Unstable osteochondritis dissecans fragment
  - There is no size restriction on the lesion treated, although lesions typically are larger than 1.5 to 2.0 cm².
  - Physiologic young, active patients who will be compliant with the rehabilitation protocol

- Contraindications
  - Osteoarthritis or bipolar lesions with characteristic radiographic Fairbanks changes:
    - Joint space narrowing
    - Osteophyte formation
    - Subchondral bony sclerosis or cyst formation
  - Comorbidities such as ligamentous instability or meniscal pathology, unless they are addressed either concomitantly with the ACI or in a staged fashion
  - Coexisting inflammatory arthritis or active infections

Preoperative Planning
- The size of the lesion and the availability of adequate cartilage cells for ACI are assessed.
- Any bony deficit is assessed for possible bone grafting at the same time as the ACI. This is especially important for those patients with traumatic osteochondral fractures and large osteochondritis dissecans lesions. These lesions are best evaluated with MRI or at the time of the initial knee arthroscopy and direct examination of the lesion.
- Staged bone grafting can be done at the time of arthroscopic evaluation. In general, 6 months are required between bone grafting and ACI, to allow time for the bone graft to consolidate and recreate a new subchondral plate.
- Alignment of the entire extremity and the status of ligaments and meniscus must be taken into consideration. Biomechanical malalignment, maltracking of the patella, lack of meniscus, and ligament insufficiency are examples of an altered intra-articular environment that can lead to shear stresses, excessive friction, and abnormal compressive loads across the autogenous chondrocyte implantation and thence potentially to failure.
Chapter 38  AUTOGENOUS CARTILAGE IMPLANTATION

- Improvement in ACI results is directly related to recognizing coexisting knee pathology and addressing it, either in a staged procedure or concomitantly at the time of the ACI.
  - For patients with limb malalignment, the surgeon must consider either proximal tibia osteotomies (opening or closing) for varus alignment or, for those with valgus alignment, a distal femoral osteotomy.
  - Most lesions of the patellofemoral joint require distal patella realignment procedures.
  - Ligamentous insufficiency, whether of the ACL, which is most common, or medial or lateral collateral laxity, even the most subtle, may produce excessive shear forces in the knee, which may irreversibly damage the maturing repair tissue produced by ACI. These ligament injuries must be addressed at the time of the ACI.
  - Patients with significant loss of meniscus tissue, through either subtotal or total meniscectomy, must be considered candidates for allograft meniscus transplantation.

Positioning
- The patient is placed on the operating table in the supine position, and the entire lower extremity is steriley prepared and draped so that the knee may be placed in extreme flexion if necessary.
  - A tourniquet is applied to the upper thigh.

Approach
- The first stage of a standard arthroscopy is performed for the harvest of articular cartilage followed by implantation of cells into the chondral defect.
  - A midline incision usually is recommended, followed by a medial or lateral parapatellar arthrotomy to expose the corresponding site of the chondral defect.
  - A separate incision is made or the proximal incision is continued along its distal extent to harvest the periosteal patch on the proximal medial tibia.

ARTHROSCOPIC ASSESSMENT
- Prior to the arthroscopic evaluation, a comprehensive knee examination is performed, with close detail to the ligament stability of the knee and overall alignment.
  - Any ligament instability or malalignment must be addressed either concomitantly or in a staged procedure.
- Taking into account all factors, including the preoperative evaluation, the arthroscopic evaluation of the osteochondral lesion or defect provides the ultimate determination as to whether a patient is a candidate for ACI. Strict attention is paid to the condition of the intra-articular structures, such as integrity of the ligaments and meniscus.
  - Undiagnosed pathology may be critical to the outcome of ACI surgery.

- Complete arthroscopic evaluation of the articular surfaces, both visual and probing (TECH FIG 1), is undertaken.
  - Accurate assessment of the osteochondral lesion, including size (anteroposterior and medial–lateral dimensions), is best obtained with a graduated probe. The estimation of size is of utmost importance with regard to the number of chondrocytes that must be grown in culture to provide optimal fill for the defects.
  - The cartilage injury area is probed for depth, size, number, and location of lesions. Additional assessment determines whether the lesion is a contained or uncontained defect, referring to the borders of the lesion.
  - The Outerbridge system (Table 1) is a practical working approach to arthroscopic grading of articular cartilage defects.
  - A newer, more functional classification has been proposed by the International Cartilage Repair Society (Table 2).

Table 1  Outerbridge Classification of Cartilage Lesions

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Articular surface is swollen and soft and may be blistered.</td>
</tr>
<tr>
<td>II</td>
<td>Characterized by the presence of fissures and clefts measuring &lt;1 cm in diameter</td>
</tr>
<tr>
<td>III</td>
<td>Characterized by the presence of deep fissures extending to the subchondral bone, measuring &gt;1 cm in diameter; loose flaps and joint debris also may be noted.</td>
</tr>
<tr>
<td>IV</td>
<td>Subchondral bone exposed</td>
</tr>
</tbody>
</table>

TECH FIG 1  Arthroscopic view of a full-thickness medial femoral condyle lesion.
CARTILAGE BIOPSY FOR AUTOLOGOUS CARTILAGE IMPLANTATION

- A biopsy specimen of cartilage can be obtained at the time of the diagnostic arthroscopy.
- Articular cartilage biopsy sites include the superior medial and lateral femoral condyle, as well as the intercondylar notch.
- The best instrument for harvesting is either a ring curette or a curved notchplasty gauge (TECH FIG 2A).
- The two biopsies should be full-thickness cartilage measuring 5 × 8 mm, with a total weight of 200 to 300 mg (TECH FIG 2B).
- The biopsy specimens are placed in a vial of media in the prepackaged biopsy transport kit from Carticel. This articular cartilage biopsy contains about 200,000 to 300,000 cells, which will be enzymatically digested and grown to approximately 12 million cells per 0.4 mL of culture medium per implanted vial after 4 to 6 weeks, to be used for the implantation procedure.

DEFECT PREPARATION

- After the diagnostic arthroscopy, a medial or lateral parapatellar mini-arthrotomy is performed to provide adequate exposure to the osteochondral defect. If a lesion of the patella or trochlea is present, a formal medial parapatellar arthrotomy with eversion of the patella is done for complete exposure.
- Defect preparation is crucial to the outcome of ACI. All of the unhealthy cartilage surrounding and remaining in the lesion must be débrided completely using a curette and a no. 15 scalpel blade.
- Healthy vertical cartilage borders are necessary for optimal suturing of the periosteum graft (TECH FIG 3A–E).
- The bed of the defect is débrided of fibrous tissue and calcified cartilage, but the subchondral plate must not be violated in the débridement process.
Chapter 38  AUTÓGENOUS CARTILAGE IMPLANTATION

PERIOSTEAL GRAFT HARVEST

- The osteochondral defect is measured with a disposable ruler at its widest mediolateral and superoinferior dimensions.
- An alternative method is to create a template of the lesion with sterile paper, as just described above. The lesion is traced on the paper.
- The proximal medial tibia provides the best site for harvesting periosteum. An alternative site for periosteal tissue is the distal femur.
- The incision is placed 2.5 cm below the pes anserinus (TECH FIG 4A).
- The dissection is carried out down to the periosteum with complete removal of the subcutaneous tissue and fascia. A sharp dissection is recommended to remove this fascia layer.

PERIOSTEUM GRAFT FIXATION

- If a tourniquet has been used, it is deflated at this point, and meticulous hemostasis of the defect bed is undertaken with the techniques described earlier.

- Bleeding at the cartilage defect must be controlled.
  - Three means of controlling bleeding from the subchondral plate are available:
    - Application of sponges soaked in a 1:1000 solution of epinephrine and saline
    - Application of fibrin glue on sites of bleeding on the subchondral bone
    - Use of a needle-point electrocautery with a needle-tip Bovie set on low.
  - Defect dimensions can be measured with a sterile ruler to determine the size of the periosteal patch.
  - The longest anterior to posterior and medial to lateral dimensions should be measured, after which 2 to 3 mm are added to each dimension to obtain the appropriate dimensions for the periosteal graft (TECH FIG 3F).
  - Another method is to make a template from sterile paper from the surgical gloves. A template is placed on the lesion and the defect is outlined with a permanent marking pen, oversizing by 1 to 2 mm. This template is then placed on the proximal tibia as a guide for the periosteal graft.

- With a permanent marker, the template of the lesion is used to outline the periosteum with 2 to 3 mm added to the measured dimensions of the defect to take into account shrinkage of the periosteal graft after removal from the bone.
- The cambium layer is marked to avoid confusion when suturing the periosteum onto the graft with the cambium layer closest to the defect.
- With a no. 15 knife blade cutting sharply down to bone circumferentially, a sharp periosteal elevator is used to elevate the periosteum from the proximal tibia (TECH FIG 4B). It is lifted off the proximal tibia with a smooth pair of pick-ups so as to not damage the cells of the periosteum.
- The periosteum is kept moist with saline.
The orientation of moist periosteal graft on the defect is determined, with the cambium layer closest to the defect. Keeping the periosteum moist is of the utmost importance to preserve the viability of the cambium layer.

Any excess periosteum overlying the borders of the defect must be trimmed to provide an exact fit of the defect.

Once the appropriate orientation and size of the graft are established, the periosteum graft is secured in place with a 6.0 Vicryl suture on a P1 cutting needle using simple interrupted suture technique.

To facilitate easy passage of the suture through the cartilage and thin periosteum, mineral oil or glycerin is applied to the suture.

The four corners of the periosteal graft are first secured and tensioned, followed by sequential sutures about 3 to 4 mm apart from each other (TECH FIG 5A).

This will ensure a watertight seal for the implanted chondrocytes beneath the periosteal graft.

It is critical for the knots of the suture to be placed on the periosteum side to prevent shearing off of the knot and failure of the periosteal graft as the graft is maturing during early rehabilitation.

The suture needle should be passed through the periosteum from outside to inside, approximately 2 mm from the edge of the periosteum.

The needle then is passed through the cartilage using the curvature of the needle, from inside to the outside of the cartilage with the needle entering the cartilage perpendicular to the inside wall of the defect and exiting the articular surface 2 to 3 mm from the débrided defect (TECH FIG 5B,C).

The sutures are placed alternately around the defect, spaced about 3 mm apart, leaving a 5- to 6-mm opening to accommodate an angiocatheter for injection of the chondrocyte cells.

A watertight integrity test is performed with the placement of the 18-gauge catheter into the superior aspect, and saline is slowly infused to assess the graft suturing (TECH FIG 5D).

Areas with saline leakage are reinforced with additional sutures. The area then is retested until the graft is watertight.

Once a watertight seal is obtained, the excess saline is aspirated from the defect.

Commercially prepared fibrin glue, available in most operating rooms, is then passed circumferentially over the periosteum graft—cartilage interface suture line as an additional sealant to prevent leakage of the injected chondrocytes (TECH FIG 5E,F).

**SPECIAL SITUATIONS**

Uncontained defects without vertical cartilage borders on the periphery or encroaching on the intercondylar notch require the use of mini-anchors or suturing into the synovial layer to secure the periosteal graft.

Those osteochondral defects may require bone grafts. Bone graft can be obtained from the proximal tibia or iliac crest in the standard fashion.

This can be done either in a staged fashion or concomitantly at the time of the ACI. Those procedures that are staged can have the bone graft packed into the defect with the plan of returning in 3 months after consolidation. If done concomitantly with ACI, the “periosteal graft sandwich” technique is used. Bone graft is placed in the defect, followed by a periosteal patch. Another periosteal graft is then sutured into place as described previously. The chondrocyte cells are then slowly injected between the two periosteum layers.
Chapter 38  AUTGENOUS CARTILAGE IMPLANTATION

IMPLANTATION OF AUTOGENOUS CHONDROCYTES

- The chondrocyte cells are delivered into the culture medium inside a Carticel vial (Genzyme Biosurgery, Cambridge, MA; TECH FIG 6A).
  - The cells require resuspension in the medium.
  - A sterile 18-gauge catheter is then inserted into the Carticel vial to mix and resuspend the chondrocytes, which settle to the bottom during shipping. This is repeated until the cells are completely resuspended in the medium.
- The cells then are slowly injected under the periosteal patch into the defect.

- After injection of the cells is completed, the needle is withdrawn, and the small opening for the angiocatheter is then sutured with 6.0 Vicryl and sealed with fibrin glue (TECH FIG 6B,C).
- The arthrotomy wound is copiously irrigated, and the retractors are removed slowly. The arthrotomy is then closed in the standard, layered fashion.
- A sterile dressing is applied. No drain is placed in the joint, because the ACI graft may be damaged by the suction of the drain.

PEARLS AND PITFALLS

PEARLS
- Leaving unhealthy cartilage: not excising enough cartilage to define true size of lesion
- Sharp dissection and the taking of bone when harvesting the periosteum
- Not removing the fascia layer off of the periosteum
- Injecting cells before obtaining adequate hemostasis or watertight seal in defect bed
- Attaching the periosteum too low into the lesion
- Tying knots too loosely or on the cartilage rim, or cutting too close to the knot
- Violating the subchondral bone, causing bleeding and potential lysis of implanted chondrocyte cells
- Leaving fibrocartilage in the base of the defect from a previous failed marrow-stimulating procedure
- Not allowing the fibrin glue to congeal before applying it in a drop fashion
- Not harvesting a large enough amount of periosteum. Needs to be oversized by 2 to 3 mm to accommodate for shrinkage

PITFALLS WITH ACI
- Leaving unhealthy cartilage: not excising enough cartilage to define true size of lesion
- Sharp dissection and the taking of bone when harvesting the periosteum
- Not removing the fascia layer off of the periosteum
- Injecting cells before obtaining adequate hemostasis or watertight seal in defect bed
- Attaching the periosteum too low into the lesion
- Tying knots too loosely or on the cartilage rim, or cutting too close to the knot
- Violating the subchondral bone, causing bleeding and potential lysis of implanted chondrocyte cells
- Leaving fibrocartilage in the base of the defect from a previous failed marrow-stimulating procedure
- Not allowing the fibrin glue to congeal before applying it in a drop fashion
- Not harvesting a large enough amount of periosteum. Needs to be oversized by 2 to 3 mm to accommodate for shrinkage

TECH FIG 6 • A. Vial of chondrocyte for injection. B. Injection of cells. C. Periosteum graft post injection of cells. (B: Courtesy of Genzyme, Inc.)
Table 2

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>1</td>
<td>Nearly normal superficial lesions</td>
</tr>
<tr>
<td>1A</td>
<td>Soft indentation</td>
</tr>
<tr>
<td>1B</td>
<td>Superficial cracks or fissions</td>
</tr>
<tr>
<td>2</td>
<td>Abnormal lesion extending down to &lt;50% of cartilage depth</td>
</tr>
<tr>
<td>3</td>
<td>Severely abnormal cartilage defects &gt;50% of cartilage depth</td>
</tr>
<tr>
<td>3A</td>
<td>Down to calcified layer</td>
</tr>
<tr>
<td>3B</td>
<td>Down to but not through subchondral layer</td>
</tr>
<tr>
<td>3C</td>
<td>Blistering</td>
</tr>
<tr>
<td>4</td>
<td>Exposed subchondral bone</td>
</tr>
</tbody>
</table>


POSTOPERATIVE CARE

- The concept of a slow, gradual time course for healing is critical to understand in post-ACI rehabilitation. The foundation principles of a successful ACI rehabilitation program center on protection of the graft, mobility and motion exercises, muscle strengthening, progressive weight bearing, and patient education.
- Protection of the repaired tissue from excessive intraarticular joint forces is critical during the early postoperative period, although early motion aids in cell orientation of the repaired tissue and prevents arthrofibrosis.
  - If the graft is overloaded with friction and delamination of the ACI tissue, or potential hypertrophy of the ACI tissue occurs, potential complications must be understood.
  - The intraarticular microenvironment must be protective of this complicated interaction of the implanted chondrocytes and the stimulatory aspects of the rehabilitation, such as early motion to allow for the remodeling and maturation of these chondrocytes into a hyaline-like cartilage phenotype.
- During the early phase (day 1 through week 12), the patient is permitted non-weight bearing during weeks 0 to 2, toe-touch weight bearing until weeks 8 to 9, and full weight bearing at 9 weeks.
  - The patient begins continuous passive motion (CPM) 6 to 24 hours after surgery.
  - CPM is performed 6 to 8 hours a day for 6 weeks.
  - The patient should obtain full range of motion.
  - The patient gradually returns to activities of daily living.
- The transition phase is from week 13 through month 6.
  - The patient has increased activities of daily living and increased standing and walking.
  - The patient should have quadricep and hamstring strength greater than 80%.
- The mid-phase is from month 7 through month 9.
  - The patient advances to strength training involving non-pivoting activities.
  - The final phase is month 10 through month 18.
  - The patient can perform low-impact activities, such as skating and cycling, during months 9 through 12; repetitive impact activities such as jogging and aerobic classes during months 13 through 15; and high-level pivoting activities such as tennis and basketball during months 16 through 18.
- Rehabilitation of patellar and trochlear lesions requires special consideration. The contact pressure of the patellofemoral articulation is maximal between 40 and 70 degree of knee flexion; therefore, flexion of this magnitude should be avoided during active knee flexion until the graft is mature and can withstand these shear stresses.
  - Early, gentle patella mobility exercises also are important to prevent adhesions and decreased patella mobility.
  - Avoidance of active knee extension during the first 10 to 12 weeks and the use of continuous passive motion is encouraged to give the best clinical results.
  - The gradual progression of active extension exercises also depends on the size and location of the patellar or trochlear lesion as observed in the operating room.

OUTCOMES

- Brittberg et al7 published their initial results with ACI in The New England Journal of Medicine, a study that revealed impressive initial results. Fourteen of 16 patients (87%) with isolated femoral condyle lesions treated with ACI had good to excellent results with 2-year follow-up. Subsequent follow-up of these patients at 11 years revealed the durability of patient satisfaction with the ACI procedure.6,17,18
- A more recent multicenter study assessed the clinical outcome of lesions of the distal femur treated with ACI in 100 patients.3 Eighty-seven percent of the patients completed a 5-year follow-up assessment. Patients were, on average, 37 years of age and had a mean total defect size of 4.9 cm²; and 70% of the patients had undergone at least one previous articular cartilage procedure. Seventy-three percent showed significant improvement, with an increase of 4.1 points on the Cincinnati knee rating system, substantiating ACI as a viable option for the treatment of chondral injuries.
- Even though ACI is highly successful, new treatment modalities continue to be developed, including an arthroscopic approach and possibly a one-stage procedure.
  - Matrix-induced autologous chondrocyte transplantation (MACI) is one such treatment modality that is conducted arthroscopically (FIG 4).
  - Similar to ACI, autologous chondrocytes are used but are placed into a collagen scaffold for implantation. This construct can be used instead of a periosteal graft, with stabilization still provided with fibrin glue.
  - The scaffold has a porous surface that can embody the repairing tissue. Different scaffolds are under development. Each scaffold must fulfill specific requirements in regard to biocompatibility, endurance, and structural stability. The scaffold should induce maturation and differentiation of the cellular structures that it supports.
  - About 3200 surgical procedures using this technique have been performed in Europe, with excellent early clinical results.1
Chapter 38  AUTOGENOUS CARTILAGE IMPLANTATION

COMPLICATIONS

- Hypertrophy or overgrowth of the periosteum graft
- Delamination of the periosteum graft
- Postoperative stiffness, arthrofibrosis
- Infection
- Donor site morbidity
- Partial or full graft detachment

REFERENCES


FIG 4 • Overview of the matrix-induced autologous chondrocyte transplantation (MACI) technique. Step 1: the defect is assessed and damaged cartilage débrided. Step 2: MACI membrane is cut according to the template, matching defect size and shape. Step 3: proper membrane orientation, in which cells face the bone bed. Step 4: fibrin sealant is applied to the defect and to the bone bed. Step 5: MACI is held in place with light pressure and fixed by fibrin glue, with no suturing required.
DEFINITION

- Articular cartilage lesions are focal, usually isolated, cartilage defects that may be either symptomatic or incidentally found.
- Osteochondritis dissecans is an osteochondral lesion that occurs in adolescents and, therefore, may have different management ramifications from lesions in adults.
- Lesions can be partial- or full-thickness, down to subchondral bone.
- Lesions can be secondary to trauma or atraumatic, as is the case for osteochondritis dissecans.
- Cases with a traumatic etiology may have associated ligamentous or meniscal injury.
- Small full-thickness chondral defects may heal adequately with mechanically inferior fibrocartilage (primarily type I collagen), but larger defects often require cartilage transplant surgery to replace the damaged chondral surface.

ANATOMY

- Articular cartilage is composed primarily of type II collagen.
- Chondrocytes that produce the extracellular matrix are of mesenchymal stem cell origin.
- Osteochondral lesions may occur in all three compartments of the knee.
- Chondral defects after a patellar dislocation may be found on the medial patellar facet or lateral trochlea.
- Classically, osteochondritis dissecans occurs at the lateral aspect of the medial femoral condyle.

PATHOGENESIS

- Osteochondral lesions may be traumatic or may have no known history of trauma.
- Traumatic lesions may be caused by compaction, as with an anterior cruciate ligament tear and lateral-based osteochondral injury, or by a shearing mechanism, as seen with patellar dislocations.
- Articular lesions may be found in young persons, as is the case with osteochondritis dissecans, or in elderly persons, as seen with degenerative lesions.
- The etiology of osteochondritis dissecans is uncertain. Traumatic, inflammatory, developmental, and ischemic causes have all been proposed but not proven.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with focal osteochondral lesions typically are active and young, ranging in age from adolescence to middle age.
- Often, the history does not include a specific traumatic episode. History and physical findings can be subtle.
- Presentation is variable; it may mimic meniscal pathology, with intermittent pain and swelling.
- Condylar defects may present with high-impact loading complaints, whereas patellofemoral defects may produce anterior knee pain–type complaints, with stairs and prolonged sitting causing symptoms.
- Patients with large cartilage lesions who are candidates for osteochondral allograft transplant surgery may have a history of previous knee surgery and previous attempts at cartilage regeneration by other methods (eg, microfracture, autologous chondrocyte implantation, osteochondral autograft transplant).
- Physical findings can be nonspecific and may include joint effusion and painful range of motion.
- Tenderness at the defect, on either the condyle, patellar facets, or trochlea, may be elicited.
- In the case of patellofemoral defects, patellar mobility and apprehension must be assessed.
- Ligament integrity must be determined.
- Mechanical alignment must be assessed, and appropriate imaging studies obtained.
- Failure to identify and address ligamentous deficiency or mechanical malalignment will lead to compromise of restorative cartilage procedures.
- Physical examination of the knee should note the following:
  - Chronic or recurrent effusion associated with, although not predictive of, a chondral lesion
  - Pain at extremes of range of motion (ie, forced flexion or forced extension) may indicate meniscal pathology. An extension block may indicate a displaced meniscus tear.
  - Osteochondral defects may cause decreased flexion via effusion, or may have normal range of motion.
  - An isolated lesion may have point tenderness, although it often is difficult to palpate.
  - Increased patellar mobility may indicate generalized ligamentous laxity, increasing suspicion for patellar instability.
  - Mechanical axis views are obtained if there is any hint of malalignment based on gait and stance analysis.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Anteroposterior, lateral, and sunrise views are mandatory to determine overall knee condition, rule out diffuse degenerative arthritis, and assess patellar position within the trochlea.
Large chondral defects may not be visible on plain radiographs, or may have a small radiodense bone fragment attached.

“Notch views” may better define more central lesions.

Long-leg mechanical axis views are mandatory in patients with malalignment on physical examination, and should be considered in all candidates for osteochondral autograft transfer.

MRI is the best modality to determine the presence, size, and location of cartilage lesions, as well as to determine the integrity of menisci and ligaments (FIG 1A–C).

Arthroscopy remains the gold standard for evaluation of articular cartilage lesions (FIG 1D).

**DIFFERENTIAL DIAGNOSIS**

- Meniscal tear
- Degenerative arthritis
- Patellar instability
- Bone contusion
- Avascular necrosis
- Undiagnosed ligamentous injury

**NONOPERATIVE MANAGEMENT**

- Patients with asymptomatic osteochondral lesions (often found incidentally on standard knee arthroscopy) may be candidates for nonoperative treatment.
- Long-term studies may indicate an increased risk for degenerative arthritis with conservative management, but no randomized controlled studies exist.
- Nonoperative treatment should consist of physical therapy to obtain or maintain painless, full range of motion.
- Aggravating impact activities should be avoided.

- Patients may participate in sports as tolerated.
- Unloader braces or shoe wedges may help alleviate mild symptoms.

**SURGICAL MANAGEMENT**

- Osteochondral allograft transplantation often is a two-stage procedure.
- The magnitude of the lesion and occasionally the diagnosis itself often are not appreciated until first-look arthroscopy (FIG 2).
- Size and location of the cartilage lesion is determined.
- Lesions 1 cm in diameter or larger are considered for allograft transplant. Smaller lesions may be amenable to microfracture or autograft cartilage transplant with single or multiple plugs.
Donors are screened with a multifactorial process promoted by the American Association of Tissue Banks to minimize the risk of disease transmission.

**Positioning**
- We prefer to have the patient supine, keeping the foot of the table up.
- A lateral post and sliding footrest or taped sandbag allow for 90-degree flexion positioning of the knee.
- The surgeon should be able to flex the knee to 120 degrees if needed.
- A tourniquet is placed but is inflated only if visualization is compromised by intra-articular bleeding.

**Approach**
- The approach depends on the location of the defect.
- The defect typically is on the medial or lateral femoral condyle, requiring a longitudinal parapatellar tendon arthrotomy.
- Large trochlear or patellar defects amenable to osteochondral allograft transplantation (rare) may require a larger parapatellar incision and eversion of the patella.

**Preoperative Planning**
- Mechanical alignment must be assessed and, if necessary, osteotomy planned for.
- Templated radiographs are obtained for appropriate allograft sizing, based on the medial-lateral dimension of the lesion.
- The patient must be informed that there is no way to predict when an appropriate-sized donor will become available, and that a moderate waiting period (weeks to months) may be required before surgery can be done.
- Fresh osteochondral allografts are used. Frozen chondral grafts are unacceptable.
- Allografts are harvested within 24 hours of donor death and can be preserved for up to 4 days at 4°C.
- Chondrocyte viability likely declines after 5 days, but prolonged storage—up to 21 days—currently is acceptable. After 28 days, chondrocyte viability is unacceptably diminished.
- Tissue matching and immunologic suppression are unnecessary with osteochondral grafts.

**FEMORAL CONDYLE OSTEOCHONDRAL ALLOGRAFT TRANSPLANT**

**Diagnostic Arthroscopy**
- A brief diagnostic arthroscopy is performed to fully assess or reassess the condylar defect (TECH FIG 1A) as well as to examine for additional knee pathology and any changes from the original arthroscopy.

**Sizing**
- The size of the defect is determined using a cannulated cylindrical sizing device.
- A circumferential mark is placed around the sizer to outline the margins of the defect to be grafted (TECH FIG 2A).
- Occasionally, a chondral defect is large or irregularly shaped, and requires more than one allograft. The resultant graft may be in the form of a “snowman,” with two or even three differently sized circular grafts stacked on top of one another.
- A central guide pin is placed through the sizer into bone to a depth of 2 to 3 cm. The sizer is then removed (TECH FIG 2B).
- A reference mark is placed at the superior (12 o’clock) position of the recipient site.

**Recipient Site Preparation**
- The recipient site is prepared by first scoring the periphery of the lesion (TECH FIG 3A).
- Next, a counterbore or reamer is used to drill the defect to a depth of 8 to 10 mm circumferentially, to bleeding subchondral bone (TECH FIG 3B).
- Following that, the recipient bed should be drilled with a small (1.6 to 2.0 mm) drill bit to stimulate additional vascular response (TECH FIG 3C).
- The recipient site depth is then measured in four positions, as on the face of a clock: 12 o’clock, 3 o’clock, 6 o’clock, and 9 o’clock.
Chapter 39 ALLOGRAFT CARTILAGE TRANSPLANTATION

Donor Preparation

- The same sizer used for defect sizing is used to template the allograft hemicondyle on the back table. Careful comparison of defect location (e.g., relative to femoral notch) and donor position is imperative to ensure optimal donor-recipient fit (TECH FIG 4A,B).
- We use the Arthrex Osteochondral Allograft Transfer System (OATS) Workstation (Naples, FL) to help secure the donor graft. This instrument allows for multiple degrees of freedom while positioning and contouring the graft (TECH FIG 4C).
- The angle of harvest of the donor tissue must match the angle at which the recipient site was reamed (TECH FIG 4D).
- Next, the donor osteochondral plug(s) is harvested. The Arthrex system makes it possible to completely drill through the donor condyle, which is held in place with the OATS Workstation. The relevant donor graft tissue is then carefully removed from the harvester drill (TECH FIG 4E,F).

Graft Harvest

- The graft depth is now measured and marked to the precise degree that the recipient bed was measured, in the same four quadrants.
- The graft is held using allograft holding forceps, similar to the manner in which the patella is prepared during total knee arthroplasty. The graft cut is made using a power saw, with care taken to match the cut to the previously made depth measurements. The osteochondral portion of the graft should be held within the forceps, so as not to drop the relevant portion of the graft once the cut is completed (TECH FIG 5A-C).

#### TECH FIG 2 • A. Sizing of osteochondral defect. B. Placement of a central pin through the center of the sizer into the center of the defect after circumferential marking of the sizer on the condyle.

- The depth of the recipient site may not be precisely consistent throughout its circumference. Donor modification will allow for fine tuning.

6 o’clock, and 9 o’clock. This may be done using a standard paper ruler, or by a measuring device supplied by the equipment company (TECH FIG 3D).

#### TECH FIG 3 • A. Scoring of peripheral cartilage. Note placement of the 12 o’clock reference mark. B. Counterbore reaming of a defect, over the central pin, to a depth of 8 to 10 mm. C. Recipient site reamed to subchondral bone and drilled with 2.0-mm drill bit to enhance subchondral bleeding. D. Measuring of defect depth.

TECH FIG 5 • A. Donor plug. B. Sawing of excess subchondral bone to exact depth of four quadrants of recipient site. C. Diagram of sawing excess bone at precise quadrant levels. (continued)
The bony end of the graft’s edges should be slightly rounded, or “bulletized,” to ease insertion of the graft into the recipient socket (TECH FIG 5D,E).

**Delivery**

- Before graft insertion, the recipient bed may be further prepared by using a dilator to widen the socket by 0.5 mm and to smooth the socket surfaces. (This step is optional.)
- The graft is then inserted manually, after lining up the 12 o’clock recipient and donor reference marks (TECH FIG 6A). If the press-fit method is inadequate, an appropriately sized tamp is used to gently tap the graft into position (TECH FIG 6B).
- Additional fixation usually is unnecessary (TECH FIG 6C–E).

**TECH FIG 5** (continued) D. Contouring of osteochondral plug. E. Fully contoured and “bulletized” osteochondral plug.

**TECH FIG 6** A. Manual graft insertion. B. Diagram of insertion using graft delivery tube. C. Final graft, open. D. Final graft, as seen through the arthroscope. E. Three month follow-up, with a second-look arthroscopy.
**POSTOPERATIVE CARE**

- Patients typically are discharged home from same-day surgery.
- An ice cuff about the knee helps alleviate postoperative pain and swelling.
- Bracing is not indicated for isolated OATS.
- Continuous passive motion is begun on day 1 and progressed to full as tolerated; typically 0 to 60 degrees on postoperative day 1, then increased by 5 degrees per day; however, there are no passive range-of-motion restrictions.
- Patients are given strict non-weight-bearing instructions.
- Our preference is strict non-weight bearing for 8 weeks, followed by partial weight bearing for another 4 weeks.
- Patients may be expected to return to full activities by 6 to 8 months.

**OUTCOMES**

- Gross et al² reported on 60 fresh femoral osteochondral allografts at an average of 10 years and 65 fresh tibial plateau osteochondral allografts at 11.8 years (average) with 84% good/excellent results and 86% good/excellent results, respectively, for posttraumatic defects.
- Kaplan-Meier survivorship analysis determined 95% survival at 5 years, 85% at 10 years, and 74% at 15 years for femoral grafts.
- Tibial allografts were reported to have 95% survivorship at 5 years, 80% at 10 years, and 65% at 15 years.
- We determined no negative outcome with meniscal transplant or limb realignment surgery.
- Shasha et al⁷ reported the results of 60 fresh femoral allografts for varying etiologies (ie, posttraumatic, osteoarthritis, osteonecrosis, osteochondritis dissecans) with an average follow-up of 10 years.
- Survivorship data revealed 95% survivorship at 5 years, 85% at 10 years, and 74% at 15 years, with 84% good/excellent results and 12 graft failures.

**COMPLICATIONS**

- Infection
- Stiffness
- Thromboembolic events
- Reflex sympathetic dystrophy
- Graft dislodgment/failure

**REFERENCES**

DEFINITION

- Osteochondritis dissecans (OCD), avascular necrosis (AVN), spontaneous osteonecrosis of the knee, and chondral and osteochondral lesions all occur at or beneath the articular surface of a weight-bearing joint and are easily confused (FIG 1).
- OCD lesions occur when a segment of subchondral bone becomes avascular. The wafer of bone plus the overlying articular cartilage may become separated from the underlying bone.
- Chondral lesions on the articular surface do not penetrate subchondral bone; damage is to chondrocytes and extracellular matrix, and there is no inflammatory healing response.
- Osteochondral lesions not only damage articular cartilage but also penetrate subchondral bone, and, therefore, cause an inflammatory healing response.
- AVN occurs when a larger wedge segment of bone loses its blood supply. If the necrosis extends to the subchondral bone, this can lead to subchondral fracture and bone surface collapse.
- In OCD, the avascular fragment separates from a normal, vascular bony bed beneath a sclerotic rim. In AVN the avascular osteochondral surface breaks into multiple fragments and separates from an avascular bed.

Osteochondritis Dissecans

- OCD lesions most often are found in the knee. They also occur commonly in the capitellum and talus.
- In the knee, OCD lesions involve the medial femoral condyle 80% to 85% of the time, the lateral femoral condyle 10% to 15% of the time, and the trochlea less than 1% of the time. Patellar lesions are uncommon, seen in only 5% to 10% of cases, and typically occur in the inferomedial area.4,7,8
- Classic lesions occur in the lateral aspect of the medial femoral condyle. Lateral lesions most often are located in the inferocentral region and involve a significant portion of the weight-bearing surface (FIG 2).

Avascular Necrosis

- AVN most commonly is seen in the hip. The knee is the second most common location, but accounts for only about 10% as many cases as the hip. AVN can affect the femur, tibia, or both; is bilateral in over 80% of cases; and usually involves multiple condyles (FIG 3A).
- AVN involves a larger area of subchondral bone, with extension into the epiphysis and even the metaphysis or diaphysis.

Spontaneous Osteonecrosis of the Knee

- Spontaneous osteonecrosis of the knee is different from AVN. Spontaneous osteonecrosis of the knee occurs in patients older than 55 years, involves only one condyle (most commonly medial), and is unilateral in 99% of cases (FIG 3B,C).
- The pathologic lesion in spontaneous osteonecrosis of the knee is a stress fracture of subchondral bone with collapse of the articular surface and secondary joint incongruity and pain.

PATHOGENESIS

Osteochondritis Dissecans

- The definitive cause of OCD lesions remains elusive. Several theories exist, including trauma, ischemia, abnormal ossification involving the physis, genetic predisposition, and combinations of these. Prominent theories are further discussed in the following paragraphs, with most authors suspecting that repetitive stress plays a central role.
- Repetitive microtrauma may create a stress fracture within subchondral bone. If the microtrauma continues and overwhelms the ability of the subchondral bone to heal, necrosis may occur, leading to separation and nonunion of the segment.4
- The epiphyseal artery supplies the epiphysis and secondary centers of ossification.
- Repetitive microtrauma or a trauma in a growing child to one of these small end arteries with a tenuous blood supply
Classical (70%)

Extended classical (5%)

Inferocentral (10%)

Medial Femoral Condyle Osteochondritis Dissecans Lesions (80%-85%)

Inferocentral (10%)

Lateral Femoral Condyle Osteochondritis Dissecans Lesions (10%-15%)

Anterior (2%)


FIG 3 • A. MRI scan of AVN involving multiple condyles with extension into the metaphysis. B,C. MRI scans of spontaneous osteonecrosis of the knee involving the medial condyle only. Note the edema adjacent to the involved area.

FIG 4 • Osteochondritis lesions can occur from an interruption of the epiphyseal blood supply to a specific area. (Adapted from Williams JS Jr, Bush-Joseph CA, Bach BR. Osteochondritis dissecans of the knee: a review. Am J Knee Surg 1998;11:221–232.)
can result in disruption of the vascular supply to the segment, with resultant development of an OCD lesion (FIG 4).

- The alteration of subchondral vascularity is precipitated by insult at a vulnerable point.
  - In juvenile cases, revascularization can occur.
  - In most situations, however, healing is inadequate, and persistent avascularity of the fragment, along with mechanical forces at the subchondral region, leads to articular surface fracture.
- Synovial fluid pumped into the bone around the fragment via knee motion limits healing by preventing fibrin clot formation. The pressurized fluid can even erode bone and create a cystic defect. Loss of fragment stability results in loose body formation.
- Shear stress may be created by the medial tibial spine abutting the medial femoral condyle, possibly coupled with traction from the posterior cruciate ligament origin. However, this theory does not account for the presence of lesions at other locations and the fact that tibial eminence impingement does not occur in connection with normal walking or running.

Avascular Necrosis

- AVN of the knee has been called ischemic, idiopathic, or corticosteroid-associated necrosis.
  - As with AVN of the hip, necrotic bone leads to subchondral fracture and subsequent joint collapse.
- Similar to OCD lesions, AVN occurs from interruption of blood supply to a segment of bone, but in AVN the interruption is nontraumatic and may involve the epiphysis and also extend into the metaphysis.

NATURAL HISTORY

Osteochondritis Dissecans

- OCD lesions occur in between 15 and 21 per 100,000 population, with a peak between the ages of 10 and 15 years.
- They are more common in males, by a 5:3 ratio.
- A history of previous knee trauma is seen in 40% to 60% of patients.
- Lesions are bilateral in 15% to 30% of patients, usually prompting evaluation of both knees after making the diagnosis.
  - If lesions are bilateral, they typically are in different phases of development.
- Patient maturity aids in prediction of treatment outcome.
  - Juvenile cases with open physes have a high (65% to 75%) potential to heal.
  - Results in adolescent cases are less predictable. About 50% do go on to heal, but the remainder have a progressive, nonhealing course similar to that of adult (ie, patients with closed physes) patients.
  - In skeletally mature patients, healing potential is essentially nonexistent.
- Factors affecting prognosis include size and site of the lesion, fragment stability, joint fluid behind the fragment, status of the articular surface, and duration of the disorder.

Avascular Necrosis

- AVN of the knee occurs most often in patients younger than 55 years of age, involves multiple condyles, and is bilateral more than 80% of the time.
- Patients have AVN in other large joints in 60% to 90% of cases, are predominantly women, and often have a history of systemic lupus erythematosus, sickle cell disease, alcoholism, or systemic corticosteroid use.
  - In general, only AVN involving the epiphysis is clinically important. Here, loss of structural support can lead to collapse and fragmentation of the overlying joint surface, resulting in a painful arthritic joint (FIG 5).

PATIENT HISTORY AND PHYSICAL FINDINGS

Osteochondritis Dissecans

- Vague, poorly localized complaints of knee pain often are the initial presentation for OCD lesions.
- Swelling is important to note, because an effusion strongly suggests that the fragment is loose to at least some degree.
- Loose or detached lesions may have mechanical symptoms such as crepitus, catching, or locking. These symptoms can mimic meniscal pathology.
- Symptoms tend to progress with time as continued activity causes a stable lesion to become unstable.
■ Quadriceps atrophy may be present as a late finding with chronic lesions.
■ Loss of range of motion is uncommon. Pain with range of motion, crepitus, or mechanical symptoms may represent an unstable lesion.
■ Wilson’s sign is specific for medial femoral condyle lesions and is tested for by flexing the knee to 90 degrees, then internally rotating and slowly extending it.
■ Patients develop pain (positive Wilson’s sign) at approximately 30 degrees as the tibial spine abuts against the medial femoral condyle; pain is relieved with external rotation.
■ According to recent studies, this sign may lack sensitivity.8
■ Patients may walk with an antalgic gait, externally rotating the affected leg to avoid contact of the tibial spine against the medial femoral condyle in the classic lesion.
■ Tenderness to direct palpation of the lesion (Axhausen’s sign) is found in patients with subchondral instability and is a helpful indicator of progressive healing as the sign abates.

Avascular Necrosis
■ Patients with AVN have insidious onset of knee pain.
■ The pain may be medial, lateral, or diffuse.
■ Mild effusions and joint line tenderness may be present.
■ The physical examination often is unremarkable.

IMAGING AND OTHER DIAGNOSTIC STUDIES
Osteochondritis Dissecans
■ In OCD, plain films help to localize and characterize the lesion while also providing valuable information regarding skeletal maturity and age of the lesion, and ruling out other bony injuries.
■ Radiographic evaluation should include anteroposterior (AP), lateral, tunnel, and sunrise views (FIG 6A,B).
■ Tunnel views provide visualization of the femoral condyles in greater profile than can be obtained with AP views (FIG 6C,D). The tunnel view often is the most revealing view.
because OCD lesions commonly are located on the lateral aspect of the medial femoral condyle.

- Comparison views of the opposite knee should be considered, because 15% to 30% of cases are bilateral.
- Children younger than 7 years of age may have irregularities of the distal femoral ossification centers that simulate OCD lesions. These represent anatomic variants of normal ossification and are asymptomatic.
- MRI is an essential part of the diagnostic evaluation of OCD.
- It provides critical information regarding the status of cartilage and subchondral bone, size of the lesion, presence of fluid beneath the lesion, extent of bony edema, as well as loose bodies or other knee injuries (FIG 6E,F).
- DeSmet et al found four MRI criteria that are negatively correlated with the ability of OCD lesions to heal after nonoperative treatment: a line of high signal intensity beneath the lesion, indicating synovial fluid, that (1) is at least 5 mm long; (2) is at least 5 mm thick; or (3) communicates with the joint surface; and (4) a focal defect of 5 mm or more in the articular surface.
- The high-signal line was found in 72% of unstable lesions and was the most common sign in patients who failed nonoperative treatment.
- Historically, Cahill and Berg advocated the use of serial technetium 99m bone scans for evaluation of healing. This recommendation was based on the relation between blood flow and osteoblastic activity with scintigraphic activity.
- Unfortunately, the isotropic tracer remains in the affected area well after healing, making interpretation difficult.
- The use of serial bone scans for the management of OCD lesions has not been universally accepted, in large part because of the need for intravenous access, time required for the study, and, more importantly, the emergence of MRI.

Avascular Necrosis

- For patients with AVN, plain radiographs and MRI scans should be obtained.
- Once the diagnosis of AVN is established, screening MRI of both hips should be considered.

DIFFERENTIAL DIAGNOSIS

- Normal accessory ossification centers
- Loose bodies
- Meniscus pathology
- Acute osteochondral fracture
- Avascular necrosis
- Epiphyseal dysplasia

NONOPERATIVE MANAGEMENT

Osteochondritis Dissecans

- Initial nonoperative treatment is indicated in children with open physis because of the favorable natural history in this patient population.
- Cahill reported that 50% of juvenile OCD lesions will heal within 10 to 18 months if the physis remains open and patient compliance is maintained.
- Most authors agree that 6 weeks of protected weight bearing followed by 6 weeks of activity modification and re-evaluation with radiographs plus MRI at 3 months constitutes an adequate trial of nonoperative treatment.

Children present unique challenges with regard to compliance.

- Some authors advocate use of a knee immobilizer as part of the nonoperative regimen, believing that the combination of a stable lesion, non-weight bearing, knee immobilization, and daily range-of-motion exercises followed by activity modification will result in successful healing by 3 to 6 months in over 90% of cases.
- Although no randomized prospective data have been released to support use of a knee immobilizer, a brace may be useful to increase compliance with the nonoperative regimen in this difficult patient population.
- Nonoperative management rarely is indicated in the symptomatic adult population because of the unremitting course of the disease.

- After closure of the physis, healing capacity is greatly reduced, and the possibility of instability, loosening, and subsequent detachment of the lesion is high.
- Careful evaluation of adolescent patients nearing skeletal maturity is necessary, because their healing ability also is decreased compared to that of younger patients.
- Aggressive and early operative intervention usually is indicated to preserve the integrity of the joint.

Avascular Necrosis

- In AVN, initial treatment with analgesics, nonsteroidal anti-inflammatory medications, and protected weight bearing for 3 months represents an adequate trial of nonoperative management.
- If symptoms persist, surgical intervention should be considered.

SURGICAL MANAGEMENT

Osteochondritis Dissecans

- In OCD, operative treatment goals are to maintain joint congruity, rigidly fix unstable fragments, and repair osteochondral defects, thereby reducing symptoms and preventing additional cartilage deterioration (FIG 7).
- Operative treatment should be performed in skeletally immature patients with unstable or detached lesions, and also in patients who are approaching physeal closure whose lesions have failed nonoperative intervention.
- Surgical intervention in OCD begins with arthroscopy. The stability of the lesion and the integrity of the overlying cartilage can be assessed directly.
- Arthroscopic drilling of juvenile OCD lesions is appropriate in patients who have failed nonoperative management in lesions that remain stable with intact articular surfaces. Drilling aims to create channels for possible revascularization and healing.
- Retrograde drilling across the epiphysis avoids penetration of the articular surface but is technically demanding in terms of drill depth and placement accuracy.
- Antegrade transarticular drilling is straightforward and creates channels that heal with fibrocartilage on the joint surface.
- Arthroscopic drilling and fixation in situ can be performed for stable or minimally unstable lesions without evidence of articular cartilage disruption or fluid behind the fragment on MRI.
Fixation can be accomplished by a variety of open or arthroscopic methods, including Kirschner wires, cannulated screws, headless variable pitch compression screws, bone pegs, and bioabsorbable implants. Nonabsorbable fixation requires an additional surgery for hardware removal.

- Unstable lesions have fibrous tissue and a sclerotic bony rim behind them that is best removed to allow healing to occur (FIG 8). Furthermore, any joint fluid beneath a fragment will prevent formation of a fibrin clot, thereby preventing the first step necessary for bony healing.
- Unstable lesions with subchondral bone loss should be grafted with autogenous bone graft packed into the defect before fragment reduction and subsequent fixation.
- Bone grafting fills any voids that would prevent the fragment from sitting flush with the surrounding articular cartilage. Local autogenous bone graft sources include the distal femur and proximal tibia.
- Patients with completely unstable lesions (loose bodies) that have subchondral bone attached can be trimmed to match the defect, bone grafted, and fixed primarily.
- Several salvage options are available for lesions that cannot be repaired primarily.
- Débridement and lavage are used for incidentally discovered lesions or those not involving a major weight-bearing area in patients with mostly mechanical symptoms. No attempt is made to repair or replace the damaged articular surface.

Marrow-stimulating techniques (eg, drilling, abrasion arthroplasty, or microfracture) promote a healing response in the form of fibrocartilage in the area of the lesion.

Restorative techniques replace damaged areas with new articular cartilage. These include osteochondral autografting, osteochondral allografting, and autologous chondrocyte implantation.

**Avascular Necrosis**

- Surgical treatment of AVN can include arthroscopic débride-ment, arthroscopic drilling, core decompression, or high tibial osteotomy.
- Core decompression has been shown to be relatively successful for symptomatic subchondral lesions prior to collapse.
- Resurfacing with osteoarticular allografts or autografts is not generally favored because the bony bed is dead.
- For patients with collapse and secondary arthrosis, unicompartmental arthroplasty and total knee arthroplasty are additional options.

**Preoperative Planning**

**Osteochondritis Dissecans**

- Plain radiographs should be reviewed for growth plate status, localization of lesion in both AP and lateral planes, presence or absence of sclerosis, and possible loose bodies.
- MRI scans should be reviewed for accurate estimate of lesion size, status of cartilage and subchondral bone, high-signal zone beneath the fragment, bony edema, presence of loose bodies, or concomitant intra-articular pathology. In particular, the presence of joint fluid or cystic erosions behind the fragment determines the need for bone grafting.

**AVASCULAR NECROSIS**

In AVN, plain films evaluate for evidence of collapse and secondary arthrosis (FIG 9). Once present, core decompression is not indicated.

MRI aids in determining the location and extent of subchondral bone involvement. Only lesions extending to subchondral
bone are at risk for collapse and, therefore, appropriate for core decompression.

**Positioning**
- Patients are positioned supine.
- Retrograde drilling of femoral lesions is aided by placing an image intensifier on the opposite side of a radiolucent table to facilitate intraoperative imaging.
- A tourniquet is placed on the operative thigh, and a lateral post is used to stabilize the extremity for valgus stress. The post also facilitates hip rotation in the figure 4 position, allowing lateral knee access and ease in obtaining lateral imaging.
- The extremity is then prepared and draped, the tourniquet is inflated, and diagnostic arthroscopy is performed.

**Approach**
- Lesions may be approached using standard arthroscopic techniques.
- The surgeon should have a low threshold for making a limited medial or lateral arthrotomy for direct access to the lesion. It is crucial to be perpendicular to the lesion for placement of hardware or osteochondral grafting.

**TRANSCHONDRAL DRILLING OF INTACT OCD LESIONS WITH OR WITHOUT FIXATION**
- Drilling can be accomplished using either an antegrade or retrograde technique (TECH FIG 1A).
- Antegrade techniques are technically easier but violate the articular cartilage.
- Retrograde techniques avoid violation of the articular surface but involve the technical challenges of maintaining drill depth and placement accuracy, and also require the use of fluoroscopy. A cannulated anterior cruciate ligament (ACL) guide is useful for guiding Kirschner wire placement.
- First, a thorough diagnostic arthroscopy is completed.
- Careful inspection of the affected condyle is accomplished by varying the degree of knee flexion. Subtle irregularity at the borders of the lesion is looked for; the remaining articular cartilage will appear smooth.
- The lesion is probed along its borders to ensure that there are no discontinuities in the articular cartilage overlying the subchondral bone (TECH FIG 1B). Once the presence of an intact lesion has been verified, several drill holes are made in the lesion using a 0.062-inch Kirschner wire (TECH FIG 1C,D).
TECHNIQUES

The wire must be positioned perpendicular to the surface.
- A soft tissue protector or drill sleeve is used over the wire.
- Surgeons should use whichever portal provides perpendicular access to the lesion, whether anteromedial or anterolateral. Large lesions may require use of both portals to access the entire lesion.
- Drilling to a depth of 1.5 to 2 cm is done to encourage vascular access to the lesion. In skeletally immature patients, careful limitation of depth is essential to avoid penetration of the physis.
- If any motion can be created by pressing against the fragment, or if the patient is approaching skeletal maturity, fixation of the fragment also should be performed.
- Absorbable fixation options include “headed” nails with barbs at the tip to provide compression, our preferred technique (TECH FIG 1E,F); screws, which have more potential to cause joint surface damage; or smooth pins, which require varied angles of insertion to hold the fragment.
- Metal fixation options include lag screws, variable pitch fully threaded screws, or Kirschner wires (less compression).

PRIMAR Y FIXATION AND BONE GRAFTING OF OSTEOCHONDROSIS DISSECSAN S LESIONS

- Primary fixation of OCD lesions of the knee should be attempted whenever possible.
- The presence of subchondral bone on the undersurface of the lesion is a prerequisite for success of primary fixation. A lesion made of cartilage alone will not heal (TECH FIG 2A).
- First, a diagnostic arthroscopy is performed. Once the lesion is identified it is probed and examined for any fibrous tissue in the bed of the lesion.
- The surgeon should have a low threshold for making a mini-arthrotomy for direct access and visualization of the lesion. This facilitates fixation perpendicular to the fragment, thereby maximizing stability and the compression obtained.
- Mini-arthrotomies can be made by extension of the anteromedial or anterolateral portal, depending on the location of the lesion. Care must be taken to avoid injury to the anterior horn of the meniscus during distal extension of the arthrotomy.
- A limited fat pad excision is helpful to improve visualization.
- Anterior and posterior lesions can be visualized by varying extention or flexion of the knee.
- A curette is used to remove fibrous tissue from both the bed and the undersurface of the lesion until exposed bleeding bone is seen. The arthroscopic burr can help penetrate the dense sclerotic rim.
- Reduction of the fragment is then performed either manually or with Kirschner wires.
- It is imperative that the reduction sit flush with the articular surface.
- Any stepoff will result in increased contact stress and shear forces secondary to surface irregularity, with resultant edge loading.
Bone grafting is essential, therefore, to avoid malreduction of the fragment.

Cancellous autograft can be harvested from local sources such as Gerdy’s tubercle on the tibia, or the outer aspect of the distal femur below the physis.

In both cases the periosteum is incised, and then a small cortical window is made with an osteotome. A curette is used to harvest the cancellous bone.

The cortical window is then replaced, and the periosteum is repaired over the defect.

The bone graft is impacted into the bed, followed by repeat reduction and assessment of the chondral surface.

Fixation is achieved by placing the device perpendicular to the surface.

Screw heads should be countersunk beneath the chondral surface to avoid hardware problems.

Multiple fixation points may be necessary, depending on the size of the lesion.

Combining types or techniques of fixation is acceptable. For instance, a compression screw may be placed centrally in a lesion surrounded by absorbable pins at the periphery of the lesion to enhance fixation. Also, if only a portion of the lesion has subchondral bone attached, it is acceptable to fix that portion of the lesion and use osteochondral plug autografts to fill the remainder of the defect (TECH FIG 2B).

Overtightening of screws used for fixation must be avoided. Overly aggressive compression can fracture the fragment.

Final inspection should demonstrate a congruent reduction with secure fixation of the lesion.

Either an antegrade or a retrograde technique can be used in the femur.

Retrograde Drilling of the Femur

Retrograde techniques are preferred because they permit creation of a larger channel for a more effective core decompression.

Retrograde drilling of femoral lesions requires fluoroscopy plus arthroscopy.

A 2.4-mm guidewire is used to pierce from skin down to bone.

The starting point is verified with fluoroscopy in both the AP and lateral planes.

The guidewire is advanced to within 1–2 mm of the articular surface (TECH FIG 3A).

Position of the wire is confirmed on the lateral projection by placing a probe against the target condyle’s distal articular surface. This technique helps avoid confusion created by overlapping shadows when identifying the target condyle (TECH FIG 3B).
Arthroscopic visualization is then used to advance the guidewire to barely pierce the articular surface.

Drilling decompression is performed with a 4.5-mm cannulated drill bit (Endobutton drill bit, Smith & Nephew, Andover, MA) placed over the guidewire.

As it approaches the articular surface, the drill bit should be advanced by hand for better control.
- The drill bit is stopped 2 mm short of the articular surface (TECH FIG 3C,D).
- Two or three passes with the guidewire and cannulated drill bit are required for each lesion.

Antegrade Drilling of the Femur
- Antegrade drilling of femoral lesions involves drilling from the articular surface into the lesion.
- It does not require fluoroscopy.
- Lesions are localized by correlation of arthroscopic findings with MRI images.
- Multiple drill holes are made directly into the lesion using a smooth, 1- to 2-mm guidewire to a depth that penetrates through the lesion and into healthy bone.
- The drilled tract is then aspirated for bleeding using the shaver with suction.
- This bleeding indicates decompression and is evidence that the guidewire passed completely through the necrotic subchondral bone (TECH FIG 4).

Retrograde Drilling of the Tibia
- Tibial lesions are drilled using a retrograde technique.
- Fluoroscopy is optional.
- An ACL guide is used to target the lesion (TECH FIG 5A).
- Lesions are localized by correlation of arthroscopic findings with MRI images.
- A 2.4-mm guidewire is placed through the ACL guide and allowed to just pierce the articular surface (TECH FIG 5B).
- A 4.5-mm drill bit is then used for drilling decompression, stopping the drill bit just beneath the articular surface.

Motorized shaver with suction can be used to aspirate the drill tract for bleeding using the antegrade technique. (Reprinted with permission from Diduch DR, Hampton BJ. Avascular necrosis drilling in the knee. In: Miller MD, Cole BJ, eds. Textbook of arthroscopy. Philadelphia: Elsevier, 2004:593–599.)
**PEARLS AND PITFALLS**

### Mistakes to avoid when treating OCD
- Underestimating instability of the lesion and drilling in situ when fixation of the fragment is necessary for healing to occur.
- Underestimating fluid behind the fragment and pinning in situ when fixation and bone grafting are necessary for healing.
- Excision alone of a fragment with subchondral bone on its undersurface when reduction and fixation are necessary.
- Attempting fixation of a fragment that consists of cartilage only. Without subchondral bone, healing will not occur.
- If in doubt, a mini-arthrotomy should be made for direct access and visualization of the lesion. This facilitates perpendicular fixation, which maximizes healing potential.

### Mistakes to avoid when treating AVN
- Overtreatment of MRI findings. AVN is not always the source of the patient’s pain. Look for other pathology in the knee that may account for the patient’s symptoms. Only lesions with involvement of subchondral bone with potential for subsequent collapse are clinically relevant.
- Drilling of AVN lesions should not be abandoned if initial attempts fail. Repeat drilling is effective in 60% of cases.\(^5\)

---

### POSTOPERATIVE CARE

**Osteochondritis Dissecans**
- After transchondral drilling, with or without fixation of intact OCD lesions, full range-of-motion and closed chain resistance exercises are encouraged.
- Daily range-of-motion exercises are encouraged, because motion is important to provide articular cartilage nutrition via synovial fluid diffusion.
  - Touch-down weight bearing is done for 6 weeks.
  - Advanced weight-bearing and resistance exercises are done from 6 to 12 weeks.
  - Sports or running is avoided until 3 months or radiographic union.
  - Patient compliance is an issue owing to the minimally invasive nature of the surgery.
- After primary fixation and bone grafting of OCD lesions, patients may be placed in a hinged knee brace that is unlocked for self-guided exercises.
  - A continuous passive motion machine may be used for 2 to 3 weeks to help achieve motion.
  - Physical therapy is focused on range of motion for the first 2 weeks, after which gentle, progressive strengthening is initiated.
  - Touch-down weight bearing is permitted during the first 6 weeks, followed by progressive weight bearing.
  - Radiographs are taken 1 to 2 weeks after surgery and on successive visits every 4 weeks thereafter.
  - Once healing is verified radiographically, the patient may be taken back to surgery for hardware removal if necessary. The chondral surface can be inspected and the stability of the lesion can be evaluated at that time.
  - Most authors recommend removal of any metal hardware on the joint surface to minimize secondary wear or possible corrosion from synovial fluid.
  - Return to sports or running usually is not permitted until 6 months after surgery, unless radiographic union is demonstrated before that point.

**Avascular Necrosis**
- After drilling of AVN, patients are limited to 50% weight bearing for 2 weeks, until repeat radiographs are taken to rule out collapse.
- Once collapse is ruled out, weight bearing can be advanced as tolerated.
- Patients may benefit from physical therapy three times a week for 4 weeks. Therapy should focus on quadriceps strengthening and both active and passive range of motion.

### OUTCOMES

**Osteochondritis Dissecans**
- Many authors have found transchondral drilling to be effective in treating OCD lesions in skeletally immature patients. Results are less effective in patients with closed physes.
  - Anderson et al used transchondral drilling to treat 17 patients (20 knees) with open physes and 4 patients with closed physes. The open physes group had a 90% healing rate, whereas the skeletally mature group had a healing rate of 50%.
  - At Children’s Hospital of Philadelphia, 51 patients up to 18 years of age were treated with transchondral drilling. Skeletally immature patients had an 83% success rate, as opposed to 75% success in patients with closed physes. Failure to heal was associated with lesions in nonclassic locations, multiple lesions, and other underlying medical conditions.
  - Aglietti et al noted radiographic healing in 16 knees, and all patients were asymptomatic at follow-up of 4 years.
  - Kocher et al reported on 23 patients (30 knees) treated with transchondral drilling with a follow-up of 3.9 years. Radiographic healing was seen in all patients at an average of 4.4 months. Patients also had significant improvement in Lysholm scores.
  - Primary fixation of OCD lesions has had positive results.
  - Johnson et al treated 35 patients with an arthroscopically assisted technique that employed cannulated screw fixation of the fragment. Results were good or excellent in 90% of cases.
  - Zuniga et al treated 11 patients with symptomatic OCD lesions of the medial femoral condyle with a combination of Herbert screws and absorbable pins. Radiographic signs of healing correlated with the clinical outcome, which was good or excellent in 81.8% of patients.
  - Cugat et al used cannulated screws for fixation of OCD lesions in 14 patients. All patients returned to their previous sporting activity 3 to 11 months after surgery.
Avascular Necrosis

- Treatment of symptomatic AVN with nonoperative methods such as restricted weight bearing, analgesics, and observation has a clinical failure rate higher than 80%.
  - Core decompression of stage I, II, or III knees (Table 1) provides symptomatic relief, with 79% of patients having good or excellent Knee Society scores at 7 years.
  - For patients who fail initial core decompression, repeat decompression and arthroscopic débridement provides some benefit, with results comparable to those of the initial decompression.
  - Core decompression will not improve symptoms once collapse has occurred, because the joint surface then is irregular and essentially arthritic.

COMPLICATIONS

- Nonunion with loose body formation
- Persistent symptomatic lesions
- Inability to localize the lesion
- Drill bit penetration of the articular surface
- Synovitis or foreign body reactions with absorbable implants
- Postoperative knee stiffness
- Hardware migration or failure
- Damage to adjacent articular surfaces

REFERENCES

DEFINITION

Anterior cruciate ligament (ACL) injuries result in a disruption of the fibers of this ligament and an ACL-deficient knee. Although most injuries are complete, partial injuries have been described. In our practice, partial injuries—defined as an asymmetrical Lachman test (or 3 to 4 mm of asymmetry on KT-1000 testing) with a negative pivot shift test during examination under anesthesia, or a one-bundle ACL disruption seen arthroscopically—are rare. The key point in determining how to treat partial injuries is to determine whether functional stability of the ACL has been maintained.

ANATOMY

- The ACL is about 33 mm long and 11 mm in diameter. It is composed of two “bundles”—a more important posterolateral portion, which is tight in extension, and a less critical anteromedial portion, which is tight in flexion.
- It is composed of 90% type I collagen; the remaining collagen is predominantly type III.
- The main blood supply for the ACL is the middle geniculate artery. Mechanoreceptor nerve endings have been identified within the ACL and are thought to have a proprioceptive role.

PATHOGENESIS

ACL injuries usually result from a noncontact pivoting injury, typically involving a change of direction or deceleration maneuver. Patients often describe hearing or feeling a “pop” and will develop an acute or subacute effusion (ie, “swells up like a balloon”). In most cases, the athlete will not be able to return to play and may need assistance to leave the field or slope (we have termed the latter a “positive ski patrol sign”). Combined ACL, medial collateral ligament (MCL), and meniscal injuries have been referred to as the “unhappy triad.”

- Lateral meniscal tears are more common in acute ACL injuries.

NATURAL HISTORY

Researchers from Kaiser Permanente in Southern California, including Donald Fithian and the late Dale Daniel, have done much to contribute to our knowledge of the natural history of the ACL-injured knee.
- From their work, we recognize that patients with a high level of participation in jumping or cutting sports and significant side-to-side differences (>5 mm) on KT-1000 arthrometer measurements are at high risk for recurrent injury without ACL reconstruction.
- Unfortunately, these same researchers have shown an increased incidence of arthritis in the surgically reconstructed ACL group.
- The difficulty with these and other studies is that multiple variables are involved, making comparisons difficult and possibly inaccurate.
- It is clear from the literature that the incidence of meniscal tears and chondral injury can be reduced with ACL reconstruction. Advocates of double-bundle ACL reconstruction propose that the incidence of arthritis may be reduced with this technique, but that theory has yet to be proved clinically.

PHYSICAL FINDINGS

Physical examination methods include the following:

- Effusion: about 70% of acute hemarthrosis cases represent ACL. Range of motion (ROM): loss of extension may be a result of a displaced bucket handle meniscal tear or arthrofibrosis (stiff knee). Loss of flexion may be related to a knee effusion.
- The Lachman test is highly sensitive for ACL deficiency. The patient must relax for this examination, and effusion or a displaced meniscal tear may give a false endpoint.
- The anterior drawer test is poorly sensitive and outdated, but is helpful to rule out a posterior cruciate ligament (PCL) injury.
- The pivot shift test is difficult to perform in the clinic setting, but is an especially helpful and sensitive test during examination under anesthesia.

A complete examination of the knee also should include evaluation of associated injuries and ruling out differential diagnoses, including (but not limited to) the following:

- Meniscal tears: joint line tenderness, pain or popping with provocative maneuvers (eg, McMurray, Apley compression, duck walk), and loss of full extension may be present.
- PCL injury: a “pseudo-Lachman” may be appreciated if the PCL is present, and the unwary examiner may falsely attribute this to an ACL injury. The key is the starting point on the drawer examination. The tibial stepoff in PCL-injured knees will be absent, or the tibia may actually be displaced (or be displaceable) posteriorly, signifying a PCL injury.
- Posterolateral corner (PLC) injury: Injury to the popliteus, popliteofibular ligament, biceps, iliobibial band, or posterior capsule will result in external rotation asymmetry (dial test), a positive posterolateral drawer test, and external rotation recurvatum.
Collateral ligament injury: MCL injuries are recognized as opening with valgus force, and lateral collateral ligament (LCL) injuries open with varus stress. These examinations are tested in both 30 and 0 degrees of knee flexion. Opening to valgus or varus stress in 0 degrees (ie, full extension) signifies a more severe injury, usually involving one or both cruciate ligaments.

Patellar instability: localized tenderness or instability with apprehension testing is essential to rule out a patellar dislocation that reduced spontaneously. This type of injury also can cause an acute knee effusion and can be easily confused with an acute ACL injury.

IMAGING AND DIAGNOSTIC STUDIES

Plain radiographs, including anteroposterior, lateral, and patellar views, should be obtained to rule out bony avulsion fractures or associated injuries.

A small avulsion fracture off the lateral tibial plateau (FIG 1A) represents a lateral capsular avulsion (Segond sign) and is highly associated with an ACL injury. It is very specific, but not sensitive.

Flexion weight-bearing radiographs are important in older or posttraumatic patients to rule out associated osteoarthritis.

Long-leg hip-to-ankle radiographs must be obtained in patients with varus or valgus malalignment.

An osteotomy should be performed before ACL reconstruction in select cases.

MRI is highly sensitive and specific in diagnosing ACL tears as well as associated injuries.

Bone contusions, or bruises, also may be detected in the mid-lateral portion of the lateral femoral condyle (near the sulcus terminalis) and the posterior tibial plateau (FIG 1B).

DIFFERENTIAL DIAGNOSIS

- Meniscal tear
- Osteochondral injury
- Contusion
- Patellar dislocation
- Other ligament/capsular injury (eg, MCL, LCL, PLC, multiple ligament injury)

NONOPERATIVE MANAGEMENT

Although nonoperative management is controversial, patients with less laxity and those who are less involved with high-level pivoting sports may be treated nonoperatively.

Nonoperative treatment is done in three phases over a period of about 3 months.

- In the initial phase, emphasis is placed on regaining full motion, controlling effusion, and maintaining quadriceps tone. (This is appropriate for patients who are surgical candidates as well.)
- In the second phase, quadriceps and hamstring strengthening is emphasized.
- In the third and final phase, sport-specific rehabilitation is accomplished.

Patients may attempt to return to sports after their effusion has completely resolved, they have full ROM, their quadriceps tone and strength have been restored (isokinetic testing is
Patellar tendon grafts (TECH FIG 1) are harvested through a 5- to 7-cm paramedian incision.

- Saphenous nerve branches are protected if identified.
- The paratenon is incised vertically and reflected off the underlying tendon.
- The central third of the tendon (typically 10 mm) is harvested, with care taken not to cut across the longitudinal fibers of the tendon.
- Bone blocks (approximately 25 mm long) are obtained using a micro oscillating saw.
- Care is taken to saw no deeper than 10 mm, particularly on the patellar side, to avoid an iatrogenic fracture.

The tibial bone block can be either more rectangular or more trapezoidal in cross section.

- The patellar bone block should be more triangular in cross section, to avoid injury to the patella.
- The bone blocks are removed using a curved osteotome (again, being careful on the tibial side) and taken to the back table for preparation.
- A rongeur or burr is used to fashion the bone blocks so that they will fit through an appropriately sized tunnel.
- With retraction, the lower portion of the incision can be used to prepare the tibial tunnel.
- If the tendon is harvested at the beginning of the procedure, arthroscopic portals can be made through the incision.

### Table 1  ACL Graft Choice Indications

<table>
<thead>
<tr>
<th>Patellar tendon</th>
<th>Football players</th>
<th>Gymnasts</th>
<th>Sprinters</th>
<th>Ballet dancers</th>
<th>Martial arts participants</th>
<th>Patients with systemic laxity</th>
<th>Revision of prior hamstring grafts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamstring</td>
<td>Jumping sport athletes</td>
<td>Clergy, carpenters</td>
<td>Older patients</td>
<td>Those with prior anterior knee pain</td>
<td>Those with patellar chondrosis</td>
<td>Those with narrow patellar tendons</td>
<td>Revision of prior patellar tendon grafts</td>
</tr>
</tbody>
</table>

(hamstring) autograft. We use both patellar tendon and hamstring grafts and have found that certain parameters are helpful in determining graft choice (Table 1).

- Other graft choices include quadriceps tendon autograft and a variety of allografts. Although these grafts may be useful in certain cases, they are not popular choices for most surgeons.

- After the graft is selected, the procedure involves arthroscopic diagnosis and repair of pathology, tibial and femoral tunnel placement, graft passage and fixation, and wound closure.

**TECH FIG 1 -** Patellar tendon graft harvesting. A. Exposure of the patellar tendon and paratenon. B. The middle third (~10 mm) of the patellar tendon is measured. (continued)
Hamstring grafts (TECH FIG 2) are harvested through a 2- to 3-cm paramedian incision centered at the level of the tibial tubercle, approximately 6 cm below the medial joint line.

- The sartorial fascia is exposed, and the tendons are palpated.
- The tendons insert in an oblique fashion and are more horizontal than vertical.
- The gracilis tendon insertion is superior to the semitendinosus tendon insertion, but both tendons converge at the pes anserine.
- It is necessary to reflect the overlying sartorial fascia that covers both tendons.
- Alternatively, the tendons can be exposed from their deep side if their insertions are sharply reflected off the tibia.
- Once the tendons are identified, a whipstitch is placed in them near their insertions so that they can be reflected off their insertions and mobilized.

- Blunt dissection and palpation are essential in mobilizing the tendons.
- Both tendons must be mobilized and all tendinous slips freed.
- The semitendinosus will have one or more large bands that attach to the medial head of the gastrocnemius. These must be incised before a tendon stripper is used, or the tendon will be inadvertently cut at this location.
- After harvesting, the tendons are prepared on the back table.
- Muscle fibers are removed from the tendons using a curette or elevator, a whipstitch is placed in the free end, and the tendons are tensioned using a commercially available graft board.
- The grafts are folded in half and the diameter of the four-strand graft measured before tensioning.
- The harvest incision can easily be used for tibial tunnel placement.
- Standard arthroscopic portals are made through the skin at the level of the joint.
ARTHROSCOPY

- Diagnostic arthroscopy is completed, and all pathology is identified.
- Meniscal tears are repaired if possible.
- Articular cartilage lesions are addressed.
- Loose bodies that are identified are removed.
- The ACL is visualized and, if torn, it is débrided with baskets and a shaver.
- The tibial footprint of the ACL and the “over-the-top” position in the back of the notch are cleared of all soft tissue (TECH FIG 3).
- Although most surgeons no longer perform an aggressive notchplasty, it is important to clear enough soft tissue and bone to identify all landmarks and to ensure that the graft will not be impinged upon.
- It also is important to ensure that the roof of the notch will not impinge on the graft. (This is more important in hamstring reconstructions because the anterior portion of the graft may be more easily impinged.)

TECH FIG 3 • A. Remnant ACL tissue is débrided with a combination of arthroscopic shaver, scissors, osteotome, and electrocautery. B. Notchplasty is performed with a combination of a 1/4-inch curved osteotome, mallet, and grasper, or with a spherical motorized burr. Some patients may require minimal or even no notchplasty. The goal is to have enough space for graft placement and visualization purposes. Notchplasty should not extend cephalad to the intercondylar apex. A 3- to 5-mm notchplasty usually is performed, depending on the width of the intercondylar notch. C. The torn ACL. D. Notchplasty is performed. E. Careful débridement of the notch is done before drilling tunnels. F. Notchplasty/débridement of the ACL stump.
TIBIAL TUNNEL PLACEMENT

- A commercially available guide is used to place a guidewire for the tibial tunnel.
- The intra-articular landmarks for the tibial tunnel are as follows (TECH FIG 4):
  - Posteromedial aspect of the ACL footprint
  - Adjacent to the slope of the medial eminence
  - Along a line extended from the posterior border of the anterior horn of the lateral meniscus
  - 7 mm in front of the PCL
- The extra-articular portion of the guide should be positioned midway between the tibial tubercle and the posteromedial aspect of the tibia.\(^5\)
- For patellar tendon reconstructions, the angle of the guide should be set based on the “N + 7 rule”\(^9\) and checked based on the “N + 2 rule.”\(^12\)
  That is, the guide is provisionally set at an angle that is 7 degrees more that the tendon length (in mm) between the bone blocks, and the distance is checked on the plunger for the guide—it should be 2 mm longer than the tendon length. The guide is set between 45 and 50 degrees for hamstring grafts.
- Once the guidewire is placed and checked, a cannulated drill is used to complete the tibial tunnel.
- We use a fully threaded drill bit and save the bone graft that collects in the flutes of the drill to fill the patellar defect (it usually is discarded for hamstring graft reconstructions).
- The PCL is protected with a curette during final tunnel drilling.
- The back edge of the tibial tunnel is rasped to keep the graft from being abraded.

TECH FIG 4 • A. Tibial targeting guide set at N + 7. B. Arthroscopic view of ACL tibial tunnel guide pin placement. C. Fluted reamer showing collected bone graft following tibial tunnel drilling. D. Tibial pin placement usually is performed at an angle 10 degrees greater than the graft–soft tissue construct. For example, a 45-mm soft tissue construct usually is drilled at 55 degrees. This illustration demonstrates that if a steeper angle is selected, it may be more difficult to place the femoral tunnel anatomically.

FEMORAL TUNNEL PLACEMENT

- An endoscopic offset guide is placed through the tibial tunnel and off the back of the posterolateral notch (TECH FIG 5). Some surgeons prefer to place this guide through the medial portal with the knee hyperflexed.
- The guide pin should be placed in the 10:30 (right knee) or 1:30 (left knee) position. (While looking arthroscopically, the top of the notch is the 12:00 position.)
- The offset guide should be chosen to retain a 1-mm posterior wall following drilling. A 10-mm tunnel should be
GRAFT PASSAGE AND FIXATION

- A Beath needle is placed through both tunnels and pierces the quadriceps muscles and skin.
- Sutures from the graft or fixation device are pulled through the tunnels and outside the thigh.
- The graft is pulled into both tunnels and fixed with an interference screw or a fixation device of the surgeon’s choice.
- Once the femoral side is fixed, the knee is cycled through the complete ROM, and the graft is tensioned.
- The tibial side is then fixed with an interference screw or secured to the tibia with a screw and washer or staple (TECH FIG 6).
- The graft is probed and inspected before wound closure is performed.

made with a 6-mm offset guide, because the guide is used to place a guidewire for the center of the tunnel and the radius of a 10-mm drill is 5 mm.
- The femoral tunnel is drilled to a depth of approximately 30 mm for a patellar tendon graft and to within 5 to 8 mm of the far cortex for a hamstring graft.
- Depending on the surgeon’s choice for femoral graft fixation, additional tunnel preparation may be necessary.
- For Endobutton (Smith & Nephew Arthroscopy, Andover, MA) fixation, a 4.5-mm tunnel is drilled through the far cortex.
- For TransFix (Arthrex, Naples, FL), Bone Mulch (Arthrotek, Warsaw, IN), Rigid Fix (DePuy Mitek, Norwood, MA), and other similar fixation systems, transverse pilot holes are created from lateral to medial.
**WOUND CLOSURE**

- The wounds are closed in layers.
- Bone graft from the drill bit or bone block preparation is packed into the patellar defect, and the paratenon is closed for patellar tendon graft cases.
- The sartorial fascia is closed for hamstring graft cases.
- Subcutaneous tissue and skin are closed in standard fashion.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Indications</th>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A complete history and physical examination should be performed.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Care must be taken to address associated pathology.</td>
<td></td>
</tr>
<tr>
<td>Graft management</td>
<td>Extreme care should be taken when harvesting and preparing grafts.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patellar bone blocks should be carefully harvested to avoid fracture.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The hamstring must be completely freed prior to harvesting.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The graft should be secured at all times and handled carefully.</td>
<td></td>
</tr>
<tr>
<td>Tunnel placement</td>
<td>Anterior tunnel placement is responsible for most ACL reconstruction failures.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Careful tunnel placement should be routine.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intraoperative radiographs can be obtained to check tunnel locations before drilling.</td>
<td></td>
</tr>
</tbody>
</table>
**POSTOPERATIVE CARE**

- Radiographs are evaluated to ensure that graft placement and fixation are appropriate (FIG 3).
- Some surgeons place the patient in a knee immobilizer or a hinged brace, but we have found that this may restrict their motion and does not provide any benefit.
- Early range of motion (especially extension) is emphasized.
- It is important that a pillow be placed under the heel (not under the knee, which is more comfortable), beginning in the recovery room.
- Closed-chain rehabilitation (beginning with a stationary cycle) is emphasized in the early postoperative course.
- Running typically is delayed until 3 or 4 months postoperatively, and most athletes can return to their sport by 6 months.

**OUTCOMES**

- With appropriate indications and surgical technique, success rates for ACL reconstruction are on the order of 90% to 95%.
- In one study, 96% of patients had KT-1000 side-to-side differences of less than 5 mm. ²
- Comparisons between patellar tendon and hamstring reconstruction have yielded equivalent results.
- Some studies suggest that hamstring grafts may have slightly increased laxity (1 to 2 mm) compared with patellar grafts.
- Other studies have cited an increased incidence of anterior knee pain following ACL reconstruction with patellar tendon grafts.

**COMPLICATIONS**

- Intraoperative graft mishandling ⁴
- Knee flexion must not change following guide pin placement.
- A few degrees of flexion may result in the guidewire bending and shearing by the drill.

- Fixation problems
  - Interference screws must be inserted along the path of the tunnel to avoid divergence.
  - For the femoral tunnel, the surgeon should hyperflex the knee and drop his or her hand toward the tibia while inserting the screw.
  - Intraoperative radiographs should be taken so that problems may be recognized and fixed before leaving the operating room.

**REFERENCES**

DEFINITION
- Anterior cruciate ligament (ACL) tears have been described in detail in Chapter SM-41.
- Any patient with functional instability or pivoting of the knee is considered to have an ACL insufficiency.

ANATOMY
- To fully understand the principles of ACL reconstruction, it is important to understand the complex anatomy of the ACL, which is composed of two major bundles.
  - These bundles are named relative to their relation to the tibial footprint: the posterolateral (PL) bundle is posterior and lateral on the tibial footprint, whereas the anteromedial (AM) bundle is anterior and medial on the tibial footprint.
  - The PL bundle originates more distally and anteriorly relative to the AM bundle on the wall of the intercondylar notch.
  - The femoral insertion site of ACL changes based on flexion angle (FIG 1).
    - With the knee in full extension, the alignment of the AM and PL bundle insertion sites on the femur is vertical.
    - With the knee in 90 degrees of flexion, the insertion sites are horizontal, with the PL bundle insertion site anterior to that of the AM bundle.
  - Measurements of individual bundles have found the AM bundle to be, on average, 38.5 mm long and 7.0 mm wide, whereas the PL bundle is 19.7 mm long and 6.4 mm wide.4,5,8
  - When the knee is extended, the PL bundle is under tension and the AM bundle is moderately lax.
  - With knee flexion, the AM bundle tightens and the PL bundle becomes lax.
  - With internal and external rotation of the tibia at 90 degrees of flexion, the PL bundle tightens.

BIOMECHANICAL STUDIES
- ACL single-bundle reconstruction using either patellar tendon or quadrupled hamstring autograft successfully limits anterior tibial translation but provides insufficient control of the combined rotatory load of internal and valgus torque.9
- In a single-bundle ACL reconstruction, rotatory stability was improved with the use of the 2 o’clock or 10 o’clock femoral tunnel position compared with the 1 o’clock or 11 o’clock position. Neither the 10 o’clock nor the 11 o’clock tunnel position could restore the kinematics and the in situ forces of the intact knee, however.6

PATIENT HISTORY AND PHYSICAL FINDINGS
- The history of a noncontact valgus pivoting injury followed by an effusion of the knee is highly suspicious for an ACL tear.
- The physical examination and methods for examination of the ACL are covered in Chapter SM-41.

- Patients with a partial or single-bundle tear may have either a positive pivot shift or positive Lachman test. For example, an intact AM bundle and torn PL bundle may have a normal Lachman and positive pivot shift, whereas an intact PL bundle and a torn AM bundle may have a normal pivot shift and an increased Lachman test.

IMAGING AND DIAGNOSTIC STUDIES
- Radiographs should include the following views:
  - 30-degree flexion weight-bearing posteroanterior view
  - Lateral
  - Sunrise view of the patella
  - Long-leg alignment view in the case of coronal angular deformity

FIG 1 • Anatomy of the anterior cruciate ligament (ACL). The femoral insertion of the anteromedial (AM) and posterolateral (PL) bundles varies based on degree of flexion. At 0 degrees, the femoral insertion is vertical, with the AM bundle superior to the PL bundle (A), whereas at 90 degrees, the femoral insertion is horizontal, with the PL bundle anterior to the AM bundle (B).
■ MRI should be used to confirm the suspicion of an ACL tear and look for associated injuries of the chondral surfaces (including bone bruises), meniscus, patella, and other ligamentous structures.
■ A KT-1000 arthrometer test is performed to determine absolute translation and side-to-side translation difference.

DIFFERENTIAL DIAGNOSIS
■ Meniscal tear
■ Osteochondral injury
■ Contusion
■ Patellar dislocation
■ Other ligament/capsular injury (eg, medial collateral ligament, lateral collateral ligament, posterolateral corner, multiple ligament injury)
■ It is important to remember that patella dislocation may mimic the initial presentation of ACL tear.

NONOPERATIVE TREATMENT
■ Potential nonoperative candidates and rehabilitation protocol are detailed in Chapter SM-41.

SURGICAL TREATMENT
Indications
■ The indications for anatomic double-bundle ACL reconstruction are similar to those for traditional single-bundle reconstruction.
■ Patients with recurrent instability or episodes of giving way or those who are unable to return to activities of daily living or sports are appropriate for surgical reconstruction.
■ Patients with complaints of instability and a single-bundle or “partial” tear may benefit from single-bundle augmentation, or double-bundle reconstruction in the event the remaining bundle is incompetent.
■ Double-bundle reconstruction has been useful in the revision setting, particularly when the previous femoral tunnel placement was in the traditional “over the top” position, which is too high in the femoral notch. This allows anatomic placement of the two femoral tunnels without interfering with the previous tunnel.

Contraindications
■ We have not found any contraindication to this procedure in the skeletally mature patient.
■ Neither the height of the patient nor the size of the knee has been a factor when performing the surgery.

Evaluation Under Anesthesia
■ Range of motion in comparison to the contralateral knee
■ Ligamentous examination
  ▪ Lachman
  ▪ Pivot shift
  ▪ Varus and valgus stress
  ▪ Anterior and posterior drawer

Positioning
■ The patient is positioned supine on the operating table, and the nonoperative leg is placed in a well-leg holder in the abducted lithotomy position.

A pneumatic tourniquet is applied around the upper thigh of the operative leg, the operative limb is exsanguinated by elevation for 3 minutes, and the tourniquet is insufflated to 300 to 350 mm Hg, depending on patient size.
■ The operative leg is positioned in an arthroscopic leg holder and prepared and draped.

Approach
■ The portals used for this procedure are slightly different from standard arthroscopy portals (FIG 2).
■ The anterolateral portal is placed more superior, at the level of the inferior pole of the patella, just lateral to the patella tendon.
■ A central anteromedial portal is placed just below the inferior pole of the patella, approximately 1 cm lateral to the medial edge of the patella tendon (intratendinous central portal).
■ An accessory anteromedial portal is established using direct visualization with an 18-gauge spinal needle, which is inserted medially and distally to the inferomedial portal, just above the anterior medial meniscus.
■ The accessory medial portal is used for better access to the lateral wall of the intercondylar notch when placing the femoral PL tunnel and femoral AM tunnel if transtibial tunnel location placement is unacceptable.
■ The arthroscope is placed in the central anteromedial portal during femoral tunnel placement for better visualization of the intercondylar notch.
■ The arthroscope is placed in the anterolateral portal for tibial tunnel placement.

![FIG 2 • Portal placement for anatomic double-bundle ACL reconstruction.](image-url)
DIAGNOSTIC ARTHROSCOPY

- Thorough inspection of the joint, including:
  - Patellofemoral joint compartment
  - Lateral compartment and meniscus
  - Medial compartment and meniscus
  - Posterior cruciate ligament
  - ACL
- Any associated meniscal or chondral lesions are addressed before the ACL reconstruction.
- The torn ACL is dissected carefully using a thermal device to determine the injury pattern and with special attention to the anatomic footprints of the two ACL bundles, on the lateral wall of the intercondylar notch and on the tibial insertion (TECH FIG 1).
- Injury patterns may include the following:
  - Tear or stretch of one or both bundles
  - Injury from femoral insertion, tibial insertion, and midsubstance

There are 25 different injury patterns.
- Anatomic insertion sites of the AM and PL bundles on the tibia and femur are marked.
- The tibial footprints are left intact because of their proprioceptive and vascular contributions.

POSTEROLATERAL FEMORAL TUNNEL

- The PL femoral tunnel is the first tunnel to be drilled.
- A 3/32 Steinmann pin is inserted through the accessory anteromedial portal.
- The tip of the guidewire is placed on the femoral footprint of the PL bundle on the lateral wall of the intercondylar notch adjacent to the articular surface (TECH FIG 2A).
- Once the tip of the guidewire is placed in the correct anatomic position (8 mm from anterior and 5 mm from distal articular cartilage), the knee is flexed to 120 degrees and the guidewire is manually tapped into the femur.
- Hyperflexion is performed while placing the PL femoral tunnel to avoid injury to the peroneal nerve when passing a Beath pin.

The guidewire is over-drilled with a 7-mm acorn drill, taking care to avoid injury to the medial femoral condyle articular cartilage.
- The PL tunnel is drilled to a depth of 25 to 30 mm (TECH FIG 2B).
- The far cortex is then breached with a 4.5-mm EndoButton drill (Smith & Nephew, Andover, MA), and the depth gauge is used to measure the distance to the far cortex.

**TECH FIG 1** • Dissection and marking of the femoral insertion of the ACL with a thermal device.

**TECH FIG 2** • A. Insertion of a guide pin in the femoral insertion of the PL bundle through the accessory anteromedial portal. B. PL femoral tunnel drilled to 7 mm diameter.
TIBIAL TUNNELS

- To establish the two tibial tunnels, a 4-cm skin incision is made over the anteromedial surface of the tibia at the level of the tibial tubercle.
- First the PL tunnel is drilled.
- An Accufex (Smith & Nephew, Andover, MA) ACL tibial tunnel tip drill guide set to 55 degrees is placed through the accessory medial portal intra-articularly on the tibial footprint of the PL bundle, which was previously marked using a thermal device (TECH FIG 3A).
- On the tibial cortex, the tibial drill starts just anterior to the superficial medial collateral ligament fibers.
- A 3.2-mm guidewire is then passed into the stump of the PL tibial footprint.

- The AM tibial tunnel is drilled with the tibial drill guide set at 45 degrees and placed through the anteromedial portal, and the tip of the drill guide is placed on the tibial footprint of the AM tunnel (TECH FIG 3B).
- The starting point of the AM tunnel on the tibial cortex is more anterior, central, and proximal than the starting point of the PL tunnel.
- The 3.2-mm guidewire is passed into the stump of the AM tibial footprint, and placement of both guidewires is assessed for satisfactory position (TECH FIG 3C).
- The tibial tunnels are then overdrilled with 7- and 8-mm compaction drill reamers for the PL and AM tunnels, respectively.

ANTEROMEDIAL FEMORAL TUNNEL

- The femoral AM tunnel is the last tunnel to be drilled.
- A transtibial technique is used most commonly, in a similar fashion to that of a femoral tunnel for ACL single-bundle reconstruction (TECH FIG 4A).
- A guidewire is passed through the AM tibial tunnel, and the tip of the guidewire is placed on the femoral footprint of the AM bundle, which was marked previously with a thermal device.
  - At 90 degrees, the location is directly posterior to the PL femoral tunnel.
- If the location of the guidewire tip is unacceptable, the accessory medial portal is used to insert the guidewire in the proper location.
- After the guidewire is inserted in the desired position, an 8-mm acorn drill is inserted over the guidewire, and the AM femoral tunnel is drilled to a depth of 35 mm to 40 mm (TECH FIG 4B).
- The far cortex of the AM femoral tunnel is breached with a 4.5-mm EndoButton drill, and the depth gauge is used to measure the distance to the far cortex.
GRAFT CHOICE

- During the arthroscopic procedure, the ACL grafts are prepared on the back table.
- We prefer to use two separate tibialis anterior or tibialis posterior tendon allografts.
- These grafts usually are 24 cm to 30 cm in length, and we fold each tendon graft to obtain 12- to 15-cm double-stranded grafts (TECH FIG 5).
- The AM tendon double-stranded graft typically is 8 mm, and the PL double-stranded graft is 7 mm.
- Alternatively, autogenous semitendinosus and gracilus grafts can be harvested (see Chap. SM-41) and used for the reconstruction.
- The ends of the tendon grafts are sutured using a whip-stitch with no. 2 Ticron sutures (Tyco, Waltham, MA).

GRAFT PASSAGE

- The PL bundle graft is passed first. A Beath pin with a long looped suture attached to the eyelet is passed through the accessory anteromedial portal and out the PL femoral tunnel and lateral aspect of the thigh.
- Hyperflexion of the knee is performed to protect the peroneal nerve.
- The looped suture is visualized within the joint and retrieved with an arthroscopic suture grasper through the PL tibial tunnel.
- The graft is passed, and the EndoButton is flipped in standard fashion to establish femoral fixation of the PL bundle graft (TECH FIG 6A).
- Next, the AM bundle graft is passed using the transtibial technique and out the anterolateral thigh with a Beath pin loaded with a looped suture (TECH FIG 6B).
- If the transtibial technique is not used for the AM femoral tunnel, then the graft is passed in a similar fashion to the PL bundle graft.
- The EndoButton is flipped in standard fashion to establish femoral fixation of the AM bundle graft.
- Preconditioning of the grafts is performed by flexing and extending the knee through a range of motion (ROM) from 0 to 120 degrees approximately 20 to 30 times.

TECH FIG 6 • A. Arthroscopic view from the anterolateral portal of the passage of the PL bundle graft. The PL graft is passed first, followed by the AM graft. B. Arthroscopic view from the central anteromedial portal following passage of the AM and PL grafts, completing the anatomic double-bundle ACL reconstruction.

FIXATION

- Each graft is looped around an EndoButton.
- The length of the EndoButton loop is chosen according to the measured length of the femoral tunnels.
- On the tibial side, we prefer the use of a bioabsorbable interference screw fixation combined with Richards staple fixation (Smith & Nephew Richards, Memphis, TN) for each graft (TECH FIG 7).
- The PL bundle graft is tensioned and fixed at full extension, and the AM bundle graft is tensioned and fixed at 60 degrees of flexion.
- After the fixation is complete, the knee is tested for stability and full ROM. The wounds are closed in standard fashion, and the leg locked in full extension in a hinged knee brace with a Cryocuff (Aircast, Summit, NJ) placed under the brace.
TECH FIG 7 • Postoperative AP radiograph after anatomic double-bundle ACL reconstruction. The femoral fixation uses an EndoButton for each graft, and tibial fixation is obtained using a bioabsorbable interference screw and Richards staple for each graft.

PEARLS AND PITFALLS

Grafts
- We prefer soft tissue grafts (and prefer allograft over autograft).
- AM graft: 7 to 8 mm
- PL graft: 6 to 7 mm

Examination of injury pattern
- Inspection for tear or stretch of either or both bundles

Portals
- Three portals are used.
- The lateral wall is visualized through the central portal.

Tunnel placement
- Marking anatomic insertion sites
- PL femoral tunnel placed first
- AM femoral tunnel based on PL tunnel

Fixation
- For femur: EndoButton
- For tibia: biointerference screw plus staple

Postoperatively
- Early ROM

POSTOPERATIVE CARE
- The authors’ postoperative rehabilitation follows the same standard protocol used for patients undergoing ACL single-bundle reconstruction using soft tissue grafts.
- Patients wear a hinged knee brace for 6 weeks.
- For the first week, the brace is locked in extension.
- Continuous passive motion is started immediately after surgery, from 0 to 45 degrees of flexion, and is increased by 10 degrees per day.
- Patients use crutches for 4 weeks postoperatively.
- From the first postoperative day, patients are allowed full weight bearing as tolerated.
- Non-cutting and non-twisting sports such as swimming, biking, and running in a straight line are allowed at 12 weeks after surgery.
- Return to full activity level usually is allowed at 6 months postoperatively.

OUTCOMES
- No current long-term studies on the results of anatomic double-bundle ACL reconstruction have been performed.
- Several short-term studies and multiple prospective studies currently are ongoing in Japan, France, Italy, and the United States.
- Muneta et al\textsuperscript{7} reported on 54 patients 2 years after double-bundle ACL reconstruction using autogenous hamstring and found a trend toward improved anterior stability compared with the single-bundle technique.
- Zaricznyj\textsuperscript{11} found 86% good or excellent results at 3.6 years follow-up in 14 patients after using doubled hamstring autograft for ACL reconstruction with one femoral and two tibial tunnels. Rotational stability was achieved in each patient, as demonstrated by a negative pivot shift.
- In a case series with 57 consecutive patients, Yasuda et al\textsuperscript{10} demonstrated that anatomic ACL double-bundle reconstruction
appears to be a safe technique with satisfactory outcomes. They evaluated functional outcomes at 24 to 36 months follow-up and compared their results with historic data on ACL single-bundle reconstruction. Patients undergoing anatomic ACL double-bundle reconstruction trended toward better AP knee stability, as measured by the KT-2000, compared with the single-bundle group.

- In a prospective, randomized clinical trial including 108 patients, Adachi et al compared the outcomes of anatomic ACL double-bundle reconstruction with the ACL single-bundle technique at an average follow up of 32 months. Their outcome measures included AP knee stability, as measured by the KT-2000, and the joint position sense of the knee. These authors did not find any difference between the ACL double-bundle and the ACL single-bundle group.

COMPlications

- Traditional complications for single-bundle reconstruction include graft failure, hardware complications, and infection.
- In our series, we have had three graft failures, all occurring after returning to sports.
  - Two failures were sustained during contact injuries while playing collegiate football. The third occurred in a noncompliant patient 3 months after reconstruction when she returned to playing high school basketball without a brace.
  - Four patients have undergone staple removal for symptomatic hardware.
- Specific complications for double-bundle reconstruction include:
  - Risk of femoral condyle fracture
  - Graft impingement
  - Incorrect tunnel placement
  - Tunnel enlargement
  - Difficulty with revision surgery
- We have performed 186 double-bundle ACL reconstructions and have had no fractures and no radiographic signs of femoral condylar avascular necrosis or tunnel widening.
- Bell et al performed biomechanical and computer modeling studies comparing single and double femoral tunnels and the risk of femoral condyle fracture.
- Results of these studies have shown that fracture risk increased significantly for the single tunnel versus the native condyle procedure, but no significant increase in fracture risk was found for one versus two tunnels.

- ROM studies are in progress. Preliminary results have shown earlier return to full extension and symmetric flexion to the contralateral knee by 3 months after surgery.
- Proper tunnel location is achieved by marking the anatomic sites for each bundle prior to ACL debridement.
- Prospective studies measuring for radiographic tunnel enlargement are ongoing. Thus far, no significant tunnel enlargement has been found; however, follow-up has been short-term only.
- Revision surgery has not been compromised in the two patients in our cohort who have undergone repeat ACL surgery following traumatic re-tear after double-bundle reconstruction.

REFERENCES

DEFINITION

- The anterior cruciate ligament (ACL) is the primary stabilizer preventing anterior displacement of the tibia. The ligament is made up of an anteromedial and a posterolateral bundle.
- The ACL also plays a role in assisting the capsular structures, collateral ligaments, joint surface, and meniscal geometry in preventing rotational instability.
- Failure of a primary ACL reconstruction may be due to traumatic re-rupture, stretch-out of the graft, failure to diagnose concomitant injuries (ie, posterolateral corner injury), or technical issues encountered during primary ACL reconstruction (ie, tunnel malposition, fixation failure etc. See Chap. SM-41).

PATHOGENESIS

- Poor outcomes following ACL reconstruction can be due to a multitude of factors and commonly are grouped into one of four areas: recurrent instability; motion loss; persistent pain; or extensor mechanism dysfunction. This chapter focuses on recurrent instability.
- The incidence of recurrent instability after primary ACL reconstruction is 3% to 10%.9
- Graft failure has been reported as the primary cause of recurrent instability. Three different categories of graft failure have been described: failure of graft incorporation; suboptimal surgical technique (eg, tunnel malposition, loss of fixation); and traumatic re-rupture. Although these categories may occur together, a critical step in the successful outcome of treatment for a failed ACL reconstruction is to define the primary cause of failure.

NATURAL HISTORY

- The natural history of the ACL-deficient knee is not well understood.
- It is commonly thought that patients who continue to experience episodes of instability place the knee at risk of further damage to the articular cartilage and menisci.
- While it may be possible for some patients to avoid activities that result in instability, others may continue to participate in sports, and still others may experience episodes of instability with activities of daily living.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A detailed history of the primary injury and reconstruction, postoperative course, ability to return to activity, and current symptoms is helpful to determine the optimal treatment.
- It also is helpful to know the time from the initial injury to the index reconstruction.
- An explanation of the postoperative therapy program and progress should be obtained, and any traumatic episodes after surgery should be noted.
- A copy of the operative report from the previous repair should be obtained from the primary surgeon to note graft type, tunnel placement, fixation methods and materials, and condition of the articular surfaces and menisci at the time of that procedure.
- An antalgic gait may suggest persistent pain after surgery, or a recent second traumatic event.
- A varus thrust during gait is highly suggestive of incompetence of the lateral or posterolateral structures and requires further evaluation with long-film standing anteroposterior radiographs for mechanical alignment.
- Buckling of the knee, especially in the initial phase of gait, may suggest quadriceps weakness, and may give the patient the subjective sensation of knee instability.
- Sensory status and palpation of pulses must be noted in all cases. Any decreases may suggest an initial dislocation of the knee and require appropriate workup to rule out a vascular injury.
- Common examinations to determine instability patterns of the knee include:
  - Anterior drawer test. When compared to the contralateral knee, increased anterior laxity may indicate an ACL-deficient knee.
  - Posterior drawer test. When compared to the contralateral knee, increased posterior laxity may be indicative of a posterior cruciate ligament (PCL)-deficient knee.
- **Lachman’s test.** Sensitive test for ACL deficiency, especially when the contralateral knee has intact native ACL.
- **Varus/valgus stress testing.** Opening in 30 degrees of flexion is consistent with injury to collateral ligaments alone. If opening in both 0 and 30 degrees, injury to collateral ligaments and other structures, such as the cruciate ligaments or capsule, is suggested.
- **Pivot shift.** Highly sensitive test for the ACL-deficient knee. It often is difficult for the patient to relax in the setting of a painful knee, however.
- **Posterolateral drawer test.** Increased posterolateral translation compared with the intact, contralateral knee may suggest posterolateral rotatory instability.
- **Dial test.** Difference of more than 10 degrees at 30 degrees flexion is consistent with injury to the posterolateral corner (PLC). Difference of more than 10 degrees at 90 degrees flexion is consistent with injury to both PLC and PCL.
- **The varus recurvatum test reveals varus angulation, hyperextension, and external rotation of the tibia.** It suggests posterolateral rotatory instability of the knee.
- **Testing for concurrent intra-articular injuries should be performed to detect possible meniscal, articular cartilage, or patellofemoral pathology.**
- **Large effusions are common in the setting of a ruptured native ACL.** In the revision setting, rupture of the graft may not lead to a large hemarthrosis, because of decreased vascularity of the graft material compared to the native ACL. Effusions in the setting of a failed ACL reconstruction may be small or even nonexistent.

### IMAGING AND OTHER DIAGNOSTIC STUDIES
- **Routine radiographs,** including weight-bearing anteroposterior and lateral views as well as patellar views, should be performed. In the revision setting, these images allow for critical assessment of previous tunnel placement and assessment for possible bone loss at previous tunnels, which may require further evaluation and treatment.
- **Metallic fixation devices make previous tunnel placement easy to identify, but bioabsorbable screws and other types of fixation also can be evaluated for tunnel placement on these images (FIG 1).**
- **These images also allow evaluation for possible evidence of osteoarthritis.**
- **If concern regarding a significant amount of bone loss is present after initial radiographic evaluation, CT imaging allows more precise evaluation of possible tunnel enlargement.** MRI also may allow evaluation of tunnel size, along with further evaluation of possible intra-articular pathology.
- **Metallic fixation devices may create significant artifacts on both of these imaging techniques, at times limiting their usefulness.**

**FIG 1 • A,B.** Anterior cruciate ligament (ACL) reconstruction performed with an EndoButton (Smith & Nephew, Andover, MA) on the femur and staple fixation of the graft on the tibia. **C,D.** Anterior placement of the femoral tunnel in this primary ACL reconstruction performed with a two-incision technique.
For varus alignment, or chronic posterolateral rotatory instability, radiographs that allow full evaluation of mechanical alignment may be necessary. These will help the surgeon to determine whether there is a significant varus alignment of the knee.

- In ACL-deficient knees with varus bony alignment, any reconstruction may be doomed to failure if the alignment is not first addressed with an osteotomy procedure.
- Bone scan and serologic tests, including complete blood count, erythrocyte sedimentation rate, C-reactive protein, and bacterial cultures of knee aspirates, should be performed in any setting suggestive of infection, including those cases with significant osteolysis of previous tunnels.

DIFFERENTIAL DIAGNOSIS

- Meniscal injury
- Osteochondral injury
- Subjective weakness or anterior knee pain secondary to quadriceps weakness
- Patella subluxation or dislocation
- Multiligamentous injury (eg, PCL, PLC, medial collateral ligament, lateral collateral ligament)

NONOPERATIVE MANAGEMENT

- Patients with painful ACL-deficient knees after attempted reconstruction must understand that reconstruction of the ACL will not address their pain symptoms and that nonoperative management might be a better approach to address their complaints.
- The basis of any nonoperative treatment for an ACL-deficient knee is to avoid those activities that put the knee at risk, such as cutting sports.
- Strengthening the dynamic stabilizers of the knee, such as the hamstrings (an antagonist to anterior translation of the tibia) may increase stability of the knee for routine activities.
- Bracing

SURGICAL MANAGEMENT

- The primary indication for revision ACL surgery is a patient whose chief complaint is symptomatic instability with his or her activities.
  - ACL reconstruction does not address the pain symptoms of an ACL-deficient knee, and other intra-articular pathology should be investigated as the cause of the subjective pain complaints.
  - ACL reconstruction may decrease the progression of intra-articular pathology, but will not, in itself, treat other lesions that may be present.

Preoperative Planning

- A common cause of failure related to surgical technique is anterior placement of a femoral tunnel, which often is detected on the lateral radiograph ([FIG 1D]). This may lead to tightening of the graft with knee flexion resulting in graft stretch-out or failure.
- A preoperative plan should include evaluation of the knee based on history, examination, and imaging for possible other intra-articular pathology, such as meniscal tears or cartilage lesions. The surgeon should be prepared to address these comorbidities at the time of revision surgery.
- Even if the surgeon does not expect to discover such findings, the possibility of their existence, and their treatment options, must be covered in all preoperative discussions with the patient.

- In the setting of possible posterolateral rotational instability, varus malignment, or significant bone loss requiring bone grafting, the patient must be aware of the possible need for staged procedures, and the necessary postoperative course should this become the case.
- The possibility of hardware removal requires knowledge of any previous implants used, and extraction tools, such as a commercially available ACL revision tray. These should be available in the operating room at the time of surgery.
- Once anesthesia has been induced, a thorough examination of the knee as compared to the contralateral extremity is critical. Concerns regarding posterolateral or varus and valgus instability will not be answered during arthroscopic evaluation and are best assessed prior to prepping and draping.

Positioning

- Our preferred positioning for ACL reconstructive surgery is with the patient in the supine position using a lateral post.
- The lateral post should be placed proximal enough to allow for the surgeon’s hand to drill the tibial tunnel without hitting the table when the patient’s knee is flexed over the edge of the table ([FIG 2]).

Approach

- A standard superolateral outflow and anteromedial and anterolateral portals are used for diagnostic arthroscopy.
  - If the previous incisions were adequately positioned, they may be used, but the placement of portal incisions should not be compromised for the sole purpose of reusing the previous incisions.
  - A complete diagnostic arthroscopic evaluation of the knee should be performed.
  - Treatment of other comorbid conditions should be performed before the ACL reconstruction is done. These include repair or débridement of meniscal tears, removal of loose bodies, débridement with possible microfracture of osteochondral lesions, and hardware removal, if necessary.

![FIG 2 - The lateral post is placed high against the lateral femur to allow adequate room on the medial aspect of the tibia to drill a tibial tunnel without interference from the operative table.](image-url)
The ACL-deficient knee is diagnosed at the time of examination under anesthesia.

After completion of the arthroscopic inspection of the knee and treatment of any other intra-articular pathology, the tourniquet is inflated.

The knee is flexed 90 degrees over a bump under the distal thigh, with the popliteal space free, allowing the neurovascular structures to fall posterior to the posterior capsule of the knee and thus remain out of harm’s way.

The previous graft is removed with a 5.5-mm shaver down to the footprint of the native ACL.

The shaver also is used to remove any fat pad obstructing the view, periosteum off the lateral wall of the notch, and any scar tissue present in the notch.

In revision ACL reconstruction, the notch often is overgrown and narrow, likely as a result of the previous ACL reconstruction (TECH FIG 1A).

A notchplasty is completed with use of a 5.5-mm burr, starting at the anterior opening of the notch if necessary.

The location of the previous femoral tunnel is noted.

Notchplasty is carried back to the posterior wall as needed. A small, curved curette may be used to inspect the back of the notch. A thin white strip of periosteum usually identifies the posterior wall (TECH FIG 1B). Careful attention to localizing the posterior wall is critical, especially because the sides and roof of the notch often are irregular owing to the previous surgery.

Anterior placement of the femoral tunnel is the primary cause of recurrent laxity for ACL reconstructions, so in many cases there is enough room to place a second femoral tunnel in the appropriate position without interference or compromise from the previous tunnel. If this is the case, the previous interference screw can be left in place or removed (TECH FIG 1C,D).

A curved curette is used to remove a small area of bone to localize the desired position of the new femoral tunnel.

A more difficult scenario is the situation where the femoral tunnel was well placed. In this case, it can be difficult to create a new tunnel that does not overlap with the old tunnel.

We have found that transtibially placed femoral tunnels often can be revised by drilling the revision tunnel through the anteromedial portal. In this way, the tunnels diverge, with only the intra-articular outlets overlapping (TECH FIG 1E).

Likewise, if a previously well-placed femoral tunnel was placed via the anteromedial portal, it often can be revised by drilling transtibially.

**TECH FIG 1** - A. Significant overgrowth of the notch noted at the time of revision anterior cruciate ligament (ACL) reconstruction. B. A thin layer of periosteum is easily visualized at the posterior wall of the notch. C. Note the anterior placement of the femoral tunnel interference screw used during the primary ACL reconstruction. The femoral tunnel for the revision can be placed at the appropriate location without removing the interference screw used in the primary procedure. D. The new femoral tunnel and interference screw are placed in the appropriate location without compromise from the screw used in the index procedure. E. View of femoral notch after placement of femoral tunnel and interference screw via anteromedial portal. This allows divergence of the old and new femoral tunnels.
**GRAFT PREPARATION**

- We usually wait to prepare the graft until the tunnels are drilled. This way the bone plugs on the graft can be oversized, in the unlikely event that the new tunnel and old tunnel substantially overlap and create a bony defect that is considerably larger than the standard tunnel size.
- The graft of choice can be used.
  - We do not reharvest previously harvested tendons.
  - Graft options include both autogenous and allogenic grafts.
  - We commonly use bone–patellar tendon–bone allograft.
- Both bone plugs are cut to a length of 25 mm, with a height of 10 mm and width of 10 mm using a micro oscillating saw.
- A small rongeur is used to contour the bone plugs to fit through a 10-mm tunnel.
- A 2-mm drill is used to drill one hole between the proximal two thirds and the distal one third of the bone plug from the patella.
- Two similar holes are drilled in the tibial bone plug at one- and two-thirds the length of the plug, at a 90-degree angle to each other.
- No. 5 Ethibond (Ethicon, Inc.) sutures, loaded on Keith needles, are then passed through each hole.
- The graft is then passed through a 10-mm sizer. The graft should slide easily while still having contact with the sides of the sizer.
- The length of the tendon part of the graft is then measured from bone plug to bone plug.
- The graft is wrapped in saline-soaked gauze and protected on the back table.

**TUNNEL PLACEMENT**

- Neither tibial nor femoral tunnel placement should be compromised based on the location of the previous tunnels.
- The tibial tunnel guidewire is placed the same as for a primary ACL reconstruction, using a commercially available tibial guide.
  - We set the tibial guide at \( n + 7 \), with \( n \) being the length of the graft between the two bone plugs (\( n + 7 \) rule).\(^8\)
  - The tip of the guide is placed in the posteromedial aspect of the native ACL footprint. The difficulty is that the native ACL footprint is no longer visible. Therefore, we place the guidewire so that it penetrates the joint 6 to 7 mm anterior to the PCL and in a line that intersects the posterior aspect of the anterior horn insertion of the lateral meniscus (TECH FIG 2A).
- The guide is placed in the joint through the anteromedial portal, and a 1.5-cm skin incision is placed just medial to the tibial tubercle, in line with the anteromedial portal for placement of the guidewire.
- If a metallic tibial interference screw was used in the previous reconstruction, it usually is in a location that necessitates its removal.
  - At this point the leg is brought back onto the table, and the interference screw is localized.
  - All overgrown soft tissue and bone is carefully removed, and then the appropriate driver (based on the operative note from the previous procedure) is placed into the head of the screw and it is removed.
  - Next, the guide is rechecked, with the sliding bullet placed down to bone. The measurement on the bullet should be just longer than the tendinous portion of the graft (\( n + 2 \) rule).\(^11\)

**TECH FIG 2** • A. Placement of the tibial tunnel guidewire just anterior to the native posterior cruciate ligament (PCL). B. Appearance of the revision tibial tunnel using the arthroscope to inspect for compromise from the index procedure. C. After reaming the femoral tunnel to a depth of 10 mm, the tunnel is inspected to ensure the posterior wall is intact.
The guidewire is then advanced, and, if correctly placed, the tibial tunnel is made with a 10-mm drill.

The tunnel is inspected with the arthroscope for wall compromise from the previous tunnel (TECH FIG 2B). This can be performed by placing the arthroscope up the tibial tunnel.

If there is concern for fixation strength with the interference screw, the tibial bone plug can be reinforced by tying the suture previously placed through the bone plug over a post just distal to the tibial tunnel.

Attention is then directed to the femoral notch.

A point is marked with a curette in the femoral notch 6 mm (for a 10-mm graft) anterior to the posterior wall in the 1:00 to 1:30 position (left knee) or the 10:30 to 11:00 position (right knee).

A Beath pin is advanced across the joint to the previously marked site on the femur. This usually can be done transtibially.

In some cases, it is not possible to get the pin to the desired location. In such a case, the knee is flexed to 120 degrees and the Beath pin is passed through the anteromedial portal.

As previously mentioned, this technique also can be used when the previous femoral tunnel was placed in an acceptable position transtibially.

This allows for divergence of the new tunnel with respect to the old without compromising the entry point into the femoral notch.

A 10-mm acorn reamer is then advanced by hand through the joint, using care not to damage the PCL.

The reamer is advanced to a depth of 10 mm.

It is then brought back into the notch so that the back wall can be inspected (TECH FIG 2C).

At this time, the tunnel also is inspected to ensure that the previous femoral tunnel does not compromise the new tunnel.

If there is compromise, one of the other techniques mentioned in the following sections is performed.

If the back wall is intact, the reamer is advanced to a depth of 30 mm.

GRAFT PASSAGE AND TENSIONING

Once appropriate tunnels have been drilled, the single suture from the bone plug from one end of the graft is passed through the Beath pin and then advanced into place.

The bone plug is advanced into the femoral tunnel under careful visualization to ensure the graft does not rotate and the bone plug is in the anterior aspect of the tunnel.

The knee is flexed to 120 degrees, and the interference screw is placed while gentle tension is maintained on the graft.

Again, careful visualization is used to ensure the graft is not cut by the threads of the advancing screw.

The screw is advanced so that it is recessed 1 to 2 mm from the tunnel opening (TECH FIG 3).

After checking for appropriate isometry of the graft by palpating the tibial bone plug through an arc of motion, the graft is manually tensioned.

While maintaining tension, the knee is flexed to about 10 to 20 degrees, and the tibial interference screw is placed.

TECH FIG 3 • The femoral interference screw is seated approximately 1 to 2 mm beyond the opening into the notch.

A final range-of-motion check is performed, and a gentle Lachman test is performed to ensure that stability has been restored.

TWO-INCISION TECHNIQUE

In cases in which the previous femoral tunnel was placed in the location that would have been preferred for the current one, or osteolysis around the previous tunnel makes placement of the new tunnel difficult, the two-incision technique may be used to create the femoral tunnel.

This technique uses the same tunnel aperture, but at a different angle.

This allows for fixation of the femoral bone plug at the lateral cortex of the distal femur, a location typically not affected by previous ACL reconstruction.

In cases in which the primary ACL reconstruction was performed with a two-incision technique, our standard endoscopic technique usually works without difficulty for placement of the femoral tunnel.

After drilling the tibial tunnel, and assessment that the femoral tunnel location necessitates two-incision technique, a commercially available, rear-entry, drill guide is used.

A lateral incision is performed over the distal metaphyseal region.
The tip of the guide is placed at the posterior aspect of the lateral wall of the notch in the 1:30 position (left knee) or 10:30 position (right knee).

- The sliding bullet is advanced to bone, and the guidewire is advanced.
- While protecting the PCL with a large curette, the femoral tunnel is reamed with a 10-mm reamer.
- After graft passage using suture material in the bone plugs of the graft, an interference screw is placed at the lateral cortex and advanced until it is adjacent with the bone plug (TECH FIG 4).
- The remainder of the procedure is performed as previously described.

TECH FIG 4 • The femoral interference screw is placed into the femoral tunnel through the lateral cortex.

BONE GRAFTING OF TIBIAL TUNNELS

- If significant bone loss has occurred around the previous tibial tunnel, bone grafting may be necessary, followed by staged revision ACL reconstruction. This is common with synthetic grafts, which can cause an immune reaction to the graft material, and also has been proposed to occur more frequently with hamstring grafts owing to the theoretical “windshield wiper” effect of the graft with fixation at the distal end of the tunnel.3,13
- After removal of the fixation devices, the previous tunnels are fully débrided of soft tissue using a shaver, curette, and rasp.
- If sclerotic bone is encountered, a 2-mm drill can be used to drill the wall of the tunnel.
- The old tunnels and regions of bony deficiency can be filled with autograft bone (taken in dowels from the iliac crest13), or allograft dowels (commonly available from tissue banks3).
- Allograft dowels, when used, should be about 1 mm larger than the diameter of the tunnel and placed using a press-fit technique.
- Reconstruction must be staged to allow time for incorporation of the bone graft.
- Incorporation of the bone graft can be monitored on CT imaging; it usually takes 4 to 6 months.13

PEARLS AND PITFALLS

| Indications | It is critical to determine whether the patient’s chief complaint is instability or pain.
|             | For patients 25 years of age and younger, a good reason is needed not to perform revision reconstruction of an ACL-deficient knee.
|             | For patients 45 years of age and older, a good reason is needed to consider revision reconstruction in an ACL-deficient knee.
|             | Subjective and objective findings of instability should be present to support consideration of revision surgery. Some patients with objective instability are able to participate at a high level of competition in cutting sports without symptomatic instability.
| Interference screws | In our experience, metallic screws allow easy identification of tunnel placement. We currently do not use “bioabsorbable” screws because we have found that they commonly do not absorb and can be difficult to drill across and difficult to remove during revision surgery.
| Synthetic grafts | Careful débridement of all synthetic material must be performed to prevent further immune reaction around the new graft.

POSTOPERATIVE CARE

- In the operating room the knee is placed in a hinged knee brace locked in extension, and the patient is permitted to bear weight as tolerated with the brace.
- At all other times, the brace can be removed and immediate postoperative range of motion is begun.
- Once adequate quadriceps control has been regained, the hinged knee brace is discontinued.
OUTCOMES

The critical factor in successful revision ACL reconstruction is to determine why the initial ACL reconstruction failed before planning the revision surgery. The ultimate clinical outcome likely is based on a combination of factors, including laxity, chondral injury, and meniscal status.

Grossman et al., in a study that focused on failure of revision ACL reconstruction based on patholaxity, found fairly similar outcomes for subjective and objective measures when compared with primary ACL reconstruction studies.

However, only 68% of these patients were able to return to the level of activity and sport they had before the initial injury, significantly lower than the commonly reported 75% to 85% return to pre-injury level sports with primary ACL reconstruction.

A prospective study by Noyes and Barber-Westin looking at revision ACL reconstructions using autogenous bone-patellar tendon–bone grafts resulted in an improvement in subjective scores in 88% of patients, with 62% of these patients able to return to athletics without symptoms.

The authors did report an overall graft failure rate of 24%, a threefold increase compared to a previous study by the same authors looking at primary ACL reconstruction.

In both of the studies by Noyes and Barber-Westin, the condition of the articular cartilage had a significant effect on the subjective scores.

In their later study, Noyes and Barber-Westin reported that 93% of patients had compounding problems such as articular cartilage damage, meniscal pathology, loss of secondary ligament restraints, and varus malalignment.

While reconstruction of the ACL may provide stability to the knee, these compounding problems play a significant role in patient satisfaction and in patients’ ability to return to their level of activity before the primary surgery.

COMPLICATIONS

- Loss of motion
- Graft failure
- Anterior knee pain secondary to damage to the patellofemoral cartilage or quadriceps weakness
- Unrealistic expectations in those patients with articular cartilage damage regarding their ability to return to strenuous sports
- Complex regional pain syndrome

REFERENCES

DEFINITION

- The posterior cruciate ligament (PCL) serves as the primary restraint to posterior translation of the tibia relative to the femur.
- PCL injuries are uncommon, may be partial or complete, and rarely occur in isolation.
- Our understanding of the PCL with respect to its natural history, surgical indications and technique, and postoperative rehabilitation is improving rapidly.

ANATOMY

- The PCL has a broad femoral origin in a semicircular pattern on the medial femoral condyle.
  - It inserts on the posterior aspect of the tibia, in a depression between the medial and lateral tibial plateaus, 1.0 to 1.5 cm below the joint line.
  - Its width, on average, is 13 mm, which is variable along its course; the average length is 38 mm.
- Anatomic studies have delineated separate characteristics of the anterolateral (AL) and posteromedial (PM) bundles within the PCL.
  - The AL bundle origin is more anterior on the intercondylar surface of the medial femoral condyle, and the insertion is more lateral on the tibia, relative to the PM bundle.
  - The larger AL bundle has increased tension in flexion, whereas the PM bundle becomes more taut in extension.
- The meniscofemoral ligaments, which arise from the posterior horn of the lateral meniscus and insert on the posterolateral aspect of the medial femoral condyle, also contribute to the overall strength of the PCL.

PATHOGENESIS

- Acutely, there usually is a history of a direct blow to the anterior lower leg. Common mechanisms include high-energy trauma and athletic injuries.
  - In motor vehicle trauma, the “dashboard injury” occurs when the proximal tibia strikes the dashboard, causing a posteriorly directed force to the proximal tibia.
  - Athletic injuries usually involve a direct blow to the anterior tibia or a fall onto a flexed knee with the foot in plantar flexion.
- Hyperextension injuries, which often are combined with varus or valgus forces, often result in combined ligamentous injuries.

NATURAL HISTORY

- There is little conclusive clinical information regarding the natural history of patients with PCL tears treated nonoperatively.
  - Most studies suggest that patients with isolated grade I–II PCL injuries usually have good subjective results, but few achieve good functional results.\(^{11,13,14}\)
- A high incidence of degeneration, primarily involving the medial femoral condyle and patellofemoral joint, has been noted in patients treated nonoperatively. This finding is especially prevalent in those patients with grade III injuries or combined ligamentous injuries.
- Consequently, pain rather than instability may be the patient’s primary symptom following a PCL injury treated nonoperatively.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The initial history should focus on the mechanism of injury, its severity, and associated injuries.
- With acute injuries, the patient often does not report feeling a “pop” or “tear,” as often is described with ACL injuries.
- The history also should focus on assessing the chronicity of the injury and the instability and pain experienced by the patient.
- A complete knee examination, including inspection, palpation, range of motion (ROM) testing, neurovascular examination, and special tests, should be performed.
- Posterior drawer test: the most accurate clinical test for PCL injury
  - Posterior sag (Godfrey) test: A positive result is an abnormal posterior sag of the tibia relative to the femur from the force of gravity. This result suggests PCL insufficiency if it is abnormal compared to the contralateral side.
  - Quadriceps active test: useful in patients with combined instability. A posteriorly subluxed tibia that reduces anteriorly is a positive result.
  - Reverse pivot shift test: A palpable reduction of the tibia occurring at 20 to 30 degrees indicates a positive result. The contralateral knee must be examined, because a positive test may be a normal finding in some patients.
- Dial test: A positive test is indicated by asymmetry in external rotation. Asymmetry of more than 10 degrees at 30 degrees rotation indicates an isolated posterolateral corner (PLC) injury, while asymmetry at 30 and 90 degrees suggests a combined PCL and PLC injury.
- Posterolateral external rotation test: Increased external rotation of the tibia is a positive result. Increased posterior translation and external rotation at 90 degrees indicate a PLC or PCL injury, while subluxation at 30 degrees is consistent with an isolated PLC injury.
- It is important to assess the neurovascular status of the injured limb, especially if there is a history of a knee dislocation.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiographs of the knee should be performed following an acute injury to assess for a fracture. An avulsion of the tibial insertion of the PCL may be identified on a lateral radiograph (FIG 1A).
In the chronic setting, radiographs may identify posterior tibial subluxation (FIG 1B) or medial and patellofemoral compartmental arthrosis. Stress radiographs may be used to confirm and quantify dynamic posterior tibial subluxation. Long-cassette films should be obtained if coronal malalignment is suspected. MRI is important to confirm a PCL injury, determine its location and completeness, and assess for concomitant injury, including meniscal and PLC pathology.

**DIFFERENTIAL DIAGNOSIS**
- Combined ligament injury
- PLC injury
- ACL tear
- Tibial plateau fracture
- Articular cartilage injury
- Medial or lateral collateral ligament tear
- Meniscal tear
- Patellar or quadriceps tendon rupture
- Patellofemoral dislocation

**NONOPERATIVE MANAGEMENT**
- Most experts advocate nonoperative management of isolated, partial PCL injuries (grades I and II).
  - In these cases, we recommend immobilization in full extension with protected weight bearing for 2 weeks. The goal is to protect the healing PCL/PLC.
  - ROM exercises are advanced as tolerated, and strengthening is focused on the quadriceps muscles.
  - Closed chain exercises (foot on the ground) are recommended.
  - Applying an axial load across the knee causes anterior translation of the tibia because of the sagittal slope. This important biomechanical principle allows early ROM exercises and protects PCL/PLC healing.

  - The patient usually can return to athletic activities after isolated grade I and II PCL injuries in 4 to 6 weeks. It is important to protect the knee from injury during this time to prevent progression to a grade III injury.
  - Functional bracing is of little benefit after return to sports activities.
  - Isolated grade III injuries are more controversial, and nonoperative management may be appropriate in certain patients.
    - We recommend immobilization in full extension for 2 weeks to prevent posterior tibial subluxation. Weight bearing is protected during these 2 weeks, then slowly advanced.
    - Quadriceps strengthening such as quadriceps sets and straight leg raises is encouraged; hamstring loading is prohibited until later in the rehabilitation course.
    - After 1 month, ROM, full weight-bearing, and progression to functional activities are instituted.
    - Return to sports usually is delayed for 2 to 4 months in patients with grade III injuries.

**SURGICAL MANAGEMENT**
- Surgical indications include those patients with displaced bony avulsions, acute grade III injuries with concomitant ligamentous injuries, and chronic grade II–III injuries with symptoms of instability or pain.
  - With any PCL injury, it is imperative to assess the PLC to rule out injury, because surgery is indicated for combined injuries.
  - In higher-level athletes, surgical treatment may be considered for acute isolated grade III PCL injuries.
  - The timing of PCL reconstruction depends on the severity of the injury and the associated, concomitant ligamentous injuries.
  - Displaced bony avulsions and knees with multiligamentous injuries should be addressed within the first 3 weeks to provide the best opportunity for anatomic repair.
  - A number of graft options are available for PCL reconstruction.
    - Autologous tissue options include bone–patellar tendon–bone, hamstring tendons, and quadriceps tendons.
    - Advantages of allograft tissue include decreased surgical time and no harvest site morbidity. Disadvantages include the possibility of disease transmission. The operating surgeon should discuss these issues with the patient preoperatively.
    - Currently, allograft tibialis anterior tendon is our graft of choice for single- and double-bundle PCL reconstructions (FIG 2).

**Preoperative Planning**
- In the office setting, the surgeon should have a variety of options available and explain that the final surgical plan will depend on the examination under anesthesia (EUA) and the diagnostic arthroscopy.
In the preoperative holding area, sciatic and femoral nerve block catheters may be placed by the anesthesiology staff.

- No anesthetic is introduced, however, until neurologic assessment has been completed.
- After anesthesia induction in the operating room, an EUA is performed on both the nonoperative and the operative knees.
- A detailed examination is performed to determine the direction and degree of laxity.
- Data from the contralateral knee may be particularly helpful with combined injuries.
- Fluoroscopy may be used after the EUA to assess posterior tibial displacement.

Positioning

- The patient is positioned supine on the operating room table.
- We do not use a tourniquet.
- Depending on the anticipated length of the planned procedure, a Foley catheter may be used.
- A padded bump is taped to the operating room table to hold the knee flexed to 90 degrees. A side post is placed on the operative side just distal to the greater trochanter to support the proximal leg with the knee in flexion (FIG 3A). Padded cushions are placed under the nonoperative leg.
- For the inlay technique, a gel pad bump is placed under the contralateral hip to facilitate later exposure to the posteromedial knee of the operative extremity in the figure 4 position.
- After prepping and draping the operative site, a hole is cut in the stockinette for access to the dorsalis pedis pulse throughout the case (FIG 3B).

Approach

- Several techniques have been described for PCL reconstruction. We have developed the following treatment algorithm:
  - For acute injuries, we employ the single-bundle technique.
  - If some component of the native PCL remains, we spare this tissue and use the augmentation technique.
  - This technique can be time-consuming and difficult, but preservation of PCL tissue may provide enhanced posterior stability of the knee and may promote graft healing.
  - We most commonly perform the double-bundle technique in the chronic setting, when any remaining structures are significantly incompetent.
  - Some authors advocate the tibial inlay technique for all settings. We typically do not use this technique, but have included a description of an open double-bundle technique here as part of a comprehensive overview. All arthroscopic tibial inlay techniques also have recently been described.6,9
  - In cases of displaced tibial avulsion, we use the technique described in the Techniques box.

SINGLE-BUNDLE TECHNIQUE

Diagnostic Arthroscopy

- A bump is placed between the post and the leg to stabilize the knee in a flexed position while the foot rests on the pre-positioned sandbag.
- The knee is flexed to 90 degrees, and the vertical arthroscopy portals are delineated.
- The anterolateral portal is placed just lateral to the lateral border of the patellar tendon and adjacent to the inferior pole of the patella.
- The anteromedial portal is positioned 1 cm medial to the medial border of the superior aspect of the patellar tendon.
- Diagnostic arthroscopy is conducted to determine the extent of injury and evaluate for other cartilage or meniscal derangements.
- The notch is examined for any remaining intact PCL fibers. If augmentation is to be performed, care should be taken to preserve these fibers (see Single-Bundle Augmentation Technique).
First the 70-degree arthroscope is placed into the anterolateral portal, and a commercially available PCL curette is introduced through the anteromedial portal. A lateral fluoroscopic image can be obtained to confirm its position. The 30-degree arthroscope is then introduced through the posteromedial portal. The soft tissue on the posterior aspect of the tibia is carefully elevated centrally and slightly laterally. A shaver can be placed through the anterolateral portal to débride some of the surrounding synovium. The 70-degree arthroscope is returned to the anterolateral portal and the shaver placed in the posteromedial portal to complete the exposure.

Creating the Tibial Tunnel

A commercially available PCL tibial drill guide set to 55 degrees is advanced through the anteromedial portal and placed just distal and lateral to the PCL insertion site, 1.5 cm distal to the articular edge of the posterior plateau along the sloped face of the posterior tibial fossa (TECH FIG 2A). The position is checked fluoroscopically using a lateral view and arthroscopically via the posteromedial portal. An incision and dissection through periosteum to bone is made on the anteromedial aspect of the tibia in line with the guide. The PCL guide is set, and its position is confirmed with fluoroscopy and arthroscopy (TECH FIG 2B). A guidewire is drilled to but not through the posterior cortex. Fluoroscopy is used to confirm the path of the guidewire (TECH FIG 2C,D). With the 30-degree arthroscope in the posteromedial portal, the PCL curette is introduced through the anteromedial portal and is used to protect the posterior knee.

Preparation and Exposure of the Tibia

Correct preparation and exposure of the tibia is essential for drilling the tunnel safely in the appropriate position.
structures as the guidewire is carefully advanced through the posterior cortex under arthroscopic visualization.

- A parallel pin guide can be used to make small pin placement corrections if necessary.
- A cannulated compaction reamer is used to drill the tibial tunnel.
- The tibial cortex is cautiously perforated by hand reaming under arthroscopic visualization.
- The tunnel is irrigated, and increasing serial dilators are used under arthroscopic visualization up to the graft size.

Creating the Femoral Tunnel

- An angled awl, via the anterolateral portal, is used to create a starting hole at the 1:00 (right knee) or 11:00 (left knee) position.
- The anteroposterior position depends on the size of the graft, but the hole should be positioned so the tunnel edge is located at the junction with the articular cartilage (TECH FIG 3).
- A guidewire is impacted into the starting hole via the anterolateral portal.
- An appropriately sized cannulated acorn reamer is carefully passed over the guidewire, taking into consideration the close proximity of the patellar articular surface.
- The tunnel is drilled to a depth of approximately 30 mm, taking care to avoid penetrating the outer cortex of the medial femoral condyle.
- Increasing serial dilators are passed to match the size of the graft.
- A smaller EndoButton drill (Smith & Nephew, Andover, MA) is used to perforate the outer cortex of the medial femoral condyle, and a guidewire is inserted through the anterolateral portal into the femoral tunnel.
- An incision is made parallel to Langer’s lines over the anteromedial aspect of the distal medial femoral condyle, at the estimated exit of the guidewire from the bone.
- The vastus medialis obliquus fascia and muscle is split in line with their fibers, and the muscle and periosteum are elevated off the anteromedial distal femur.
- The drill hole is exposed and guidewire is removed.

Graft Passage

- Passage of the graft may require enlarging the anterolateral portal.
- The 30-degree arthroscope is placed in the posteromedial portal, and a long 18-gauge bent wire loop is passed with the loop bent upward from anterior and distal to posterior and proximal through the tibial tunnel.
- A tonsil is introduced through the anterolateral portal and through the notch to retrieve the bent wire loop (TECH FIG 4).
- Leading sutures from the free ends (tibial side) of the graft are placed through the wire loop.
- The wire and sutures are pulled back through the tibial tunnel in an anterograde fashion.
- A small scooped malleable retractor is introduced through the anterolateral portal and placed just posterior to the femoral tunnel to retract the fat pad and provide an unobstructed path for a Beath pin.
- A Beath pin is then passed through the anterolateral portal and through the femoral tunnel.
- The lead suture limbs from the EndoLoop (Ethicon, Inc.) side of the graft are threaded through the eye of the Beath pin.
- The pin, with the suture limbs, is pulled proximally.
- Traction on the suture limbs pulls the graft into the femoral tunnel to the marked line, while traction of the tibial suture limbs pulls the graft into the femoral tunnel.
- The position of the graft is confirmed arthroscopically.

Graft Fixation

- Graft fixation is achieved by placing the EndoLoop along the medial femur with a tonsil to estimate its most proximal extent.
- A 3.2-mm drill bit is used to make a unicortical hole at the most proximal extent of the EndoLoop.
- After the hole is measured and tapped, a 6.5-mm cancellous screw and washer are placed through the EndoLoop into the femur.
- The screw is tightened as the graft is pulled tight distally.
- The fixation is palpated to ensure the EndoLoop limbs are tight distal to the screw and washer.
**Wound Closure**
- The incisions are irrigated, and the fascia in the anterolateral femoral incision is closed with size 0 Vicryl suture.
- The subcutaneous layer is approximated with interrupted, inverted 3-0 Vicryl suture, and the skin is closed with a running 4-0 absorbable suture.
- The portals are closed with 3-0 nylon suture.
- The dorsalis pedis and posterior tibialis pulses are assessed by palpation and a Doppler ultrasound examination if necessary.
- The incisions are covered with adaptic gauze and sterile gauze, then wrapped in cast padding and bias wrap.

**SINGLE-BUNDLE AUGMENTATION**
- For single-bundle augmentation, much of the technique is identical to the single-bundle technique already described. Often, the AL bundle is ruptured and the PM bundle remains intact. Consequently, for the purposes of this chapter, AL bundle augmentation will be described.
- The diagnostic arthroscopy is performed.
- If the AL bundle is found to be intact, special care is taken to preserve this bundle while the overlying synovium and ruptured PCL fibers are débrided (TECH FIG 5A).
- When preparing the posterior aspect of the tibia, preservation of the PCL origin is essential.
- Tibial tunnel preparation is performed similarly to the single-bundle technique.
  - The exit point for the guide pin along the sloped face of the posterior tibial fossa is just distal and lateral to the intact PCL insertion site (TECH FIG 5B).

**DOUBLE-BUNDLE RECONSTRUCTION**
- For double-bundle PCL reconstruction, the initial aspects of the technique are identical to those of single-bundle reconstruction, including portal placement, arthroscopy, and preparation for drilling.

**Tibial Tunnel Creation**
- Throughout this process, care must be taken to avoid tunnel convergence and ensure an adequate bony bridge between the two tibial tunnels.
- First, the guide pin for the AL tunnel is positioned using the same technique as with single-bundle reconstruction.
  - It exits the tibia just distal and lateral to the PCL insertion site, 1.5 cm distal to the articular edge of the posterior plateau.
  - The PCL guide is reintroduced into the joint.
- When preparing the medial femoral condyle for tunnel drilling, care again is taken to preserve the intact PCL bundle.
  - The starting hole is placed at the 1:00 (right knee) or 11:00 (left knee) position.
  - The hole should be positioned in the anteroposterior plane so the tunnel edge is located at the junction with the articular cartilage.
  - This location depends on the size of the graft and the distance from the intact PM bundle.
  - The graft is passed around the intact bundle, which is the final augmentation consideration.
  - Fixation and closure are then performed.

**TECH FIG 5**
- **A.** An intact AL bundle is preserved and the overlying synovium and ruptured PCL fibers are débrided. **B.** The exit point for the tibial tunnel along the sloped face of the posterior tibial fossa is just distal and lateral to the intact PCL insertion, as demonstrated by a long 18-gauge bent wire loop.

The same steps and precautions are repeated for placement of the PM tibial guidewire.
- The PM tibial guidewire enters the tibia on the anteromedial aspect of the tibia, slightly more proximal and medial than the AL guidewire.
- Conversely, the PM guidewire can be introduced through the anterolateral tibia, crossing the AL guidewire on the coronal view, but remaining proximal to the AL guidewire throughout its course on the sagittal view. It exits the tibia in the footprint more medial and slightly proximal to the AL tibial guidewire (TECH FIG 6A).
- It is important to ensure adequate separation between the two guide pins to accommodate both tunnels with a bony bridge separation.
Once the guidewire positions are satisfactory, a cannulated compaction reamer is used to first drill the AL tibial tunnel.
- The drill is advanced under fluoroscopic guidance.
- The posterior tibial cortex is cautiously perforated by hand reaming under arthroscopic visualization.
- The tunnel is irrigated, and increasing serial dilators are used under arthroscopic visualization.
- The steps are repeated for drilling the PM tibial tunnel with a 7-mm cannulated compaction reamer (TECH FIG 6B).

**Femoral Tunnel Creation**

- An angled awl is used to create the starting holes.
- For the AL bundle, the starting hole is placed at the 1:00 (right knee) or 11:00 (left knee) position.
- The hole should be positioned in the anteroposterior plane so the tunnel edge is located at the junction with the articular cartilage.
- The guidewire is passed via the anterolateral portal and impacted into the starting hole.
- The appropriately sized cannulated acorn reamer is passed over the guidewire.
- The reamer should be passed carefully, given the close proximity of the patellar articular surface.
- The tunnel is drilled to a depth of about 30 mm, with care taken to avoid penetration of the outer cortex of the medial femoral condyle.
- Increasing serial dilators are passed to match the size of the graft.
- A smaller EndoButton drill (Smith & Nephew, Andover, MA) is used to perforate the outer cortex of the medial femoral condyle.
- This inside-out femoral tunnel preparation technique is then repeated for the PM tunnel.
- The angled awl is used to create the starting hole at the 3:00 (right knee) or 9:00 (left knee) position.
- The PM tunnel is placed parallel or slightly posterior to the AL tunnel.
- The guide pin is then placed via the anterolateral portal and impacted into the starting hole.
- A 7-mm acorn reamer is passed over the guidewire and drilled to a depth of approximately 30 mm (TECH FIG 7).
- The medial femoral condylar cortex is perforated with the EndoButton drill.

**Graft Placement and Fixation**

- The AL graft is passed first, using the same technique as with single-bundle reconstruction.
- This process is then repeated for the PM graft (TECH FIG 8).
- It is helpful to keep tension on the AL graft suture ends when passing the PM graft to ensure that the AL graft does not get pulled into the joint.
- Graft fixation is performed first on the femoral side.
- The AL bundle is secured as previously described.
- This process is repeated for the PM bundle, ensuring that adequate separation exists between the two screws and washers to prevent overlap.
- An anterior tibial force is applied to reduce the tibia before and during final tibial fixation.
- Two 4.5-mm cortical screws and washers are placed from anteromedial to posterolateral within the proximal tibia, just distal to the respective tunnels.
- As with the single-bundle technique, before the screw advances to the second cortex, the suture limbs from the tibial side of the graft are tied with tension over the post, and then the screw is tightened.
- The AL graft is secured first at 90 degrees flexion, and the PM bundle then is secured at 15 degrees of flexion.
- The arthroscope is inserted to confirm adequate position, tension, and fixation of the grafts.
Tibial Inlay

For the double-bundle tibial inlay PCL reconstruction, the initial aspects of the technique are similar to those for single-bundle reconstruction, including portal placement, arthroscopy, and débridement.

A whole, nonirradiated, frozen patellar tendon allograft is prepared with two bundles attached to a common tibial bone block and distinct femoral bone blocks.

- The tibial bone block is fashioned from the tibial side of the graft and should measure 20 mm long, 13 mm wide, and 12 mm thick.
  - A single 4.5-mm gliding hole is placed in the center of the block for later fixation.
- The tendon bundles stemming from the tibial bone block should measure 11 mm (AL bundle) and 9 mm (PM bundle).
- The femoral bone plugs from the patellar side of the graft are shaped to 20 mm in length and 11 mm (AL bundle) and 9 mm (PM bundle) in diameter.
  - The femoral bone plugs are each drilled with two separate 2.0-mm holes, through which Fiberwire (Arthrex, Naples, FL) passing sutures are placed.
- The leg is brought into a figure 4 position, with the knee flexed to 90 degrees and the bump repositioned under the lateral ankle.
  - A 6-cm incision is made over the posterior border of the tibia from the crease of the popliteal fossa and curving distally along the posteromedial border of the tibia.

The dissection is continued through the subcutaneous fat to the sartorius fascia and the fascia overlying the medial head of the gastrocneumius.

- The fascia is incised along the palpable posteromedial tibial border.
- The semimembranosus and pes anserinus tendons are retracted anteriorly and proximally.
- The medial head of the gastrocneumius is elevated from the tibial cortex and retracted posteriorly.
- The medial border of the gastrocneumius is followed distally along the posterior tibia, and the proximal border of the popliteus muscle is identified. The popliteus muscle is elevated subperiosteally off the posteromedial surface of the tibia and mobilized laterally and distally.

Attention is then turned to drilling an 11-mm AL and a 9-mm PM femoral tunnel, performed as described for the double-bundle technique.

The leg is returned to the figure 4 position, and the tibial trough is prepared by creating a vertical arthrotomy between the palpable prominences of the medial and lateral tibial plateaus at the native PCL tibial insertion.

The remaining PCL is identified and débrided, and a ⅛-inch curved osteotome is used to create a trough measuring 13 mm wide, 12 mm deep, and 20 mm long.

A 3.2-mm transtibial drill hole is placed in the trough that corresponds to the 4.5-mm gliding hole in the tibial bone block.

TECH FIG 9 • A. The tibial inlay graft. B. The approach for the tibial inlay begins with a 6-cm incision over the posterior border of the tibia from the crease of the popliteal fossa, which curves distally along the posteromedial border of the tibia. C. The posterior aspect of the tibia after the popliteus muscle has been elevated subperiosteally off the posteromedial surface of the tibia and mobilized laterally and distally. D. The posterior aspect of the tibia after the inlay trough has been created. E. The double-bundle tibial inlay graft after being positioned in the tunnels. F. Lateral radiograph demonstrating the tibial inlay fixation with a 4.5-mm fully threaded cortical screw on the tibial side, and interference screws on the femoral side.
The graft is passed through the joint via an enlarged anteromedial portal into the tibial trough.
- A 4.5-mm fully-threaded cortical screw is used to lag the bone block into the trough.
- Fluoroscopy is used to verify the position of the graft.
- A 4-cm incision is made along the posterior border of the vastus medialis at the center of the medial femoral condyle, and the femoral tunnels are identified.
- The AL and PM bundle grafts are then passed through their respective femoral tunnels using a suture passer.
- Several cycles of flexion and extension are performed to pretension the graft.
- The bundles are secured with metal interference screws placed outside-to-in (TECH FIG 9E,F).
- The AL graft is secured first at 90 degrees flexion, and the PM bundle then is secured at 15 degrees of flexion.
- A gentle anterior drawer is applied during screw insertion to recreate the natural tibial step-off.

Any remaining bone plug protruding from the femoral tunnels is removed with a rongeur, and sutures are tied together over the tunnel bone bridge.

**Tibial Avulsion**
- The PCL tibial avulsion is approached similarly to tibial inlay reconstruction.
- The patient is positioned supine, as in the tibial inlay technique, to facilitate arthroscopic examination.
- The skin incision and the dissection are performed as described for the tibial inlay technique.
- A vertical arthrotomy is made, and the avulsed fragment of the tibia with the attached PCL is identified.
- The bone fragment and PCL are reduced and secured with a 4.0-mm cortical or a 6.5-mm cancellous screw and spiked washer, depending on the size of the fragment.
- The reduction is confirmed with fluoroscopy or a radiograph (TECH FIG 10).

**PEARLS AND PITFALLS**

**Indications**
- Assess for concomitant PLC injury on the EUA and following PCL reconstruction, because deficiency of these structures may lead to PCL graft failure.
- Employ the appropriate technique based on the chronicity of the injury and remaining native PCL.

**Arthroscopy**
- Exposure of the posterior tibia may be tedious but is essential for appropriate, safe tunnel placement.
- When working in the posterior knee joint, be certain the shaver or electrocautery device always faces anteriorly, away from the popliteal vessels.
- Fluid extravasation and lower extremity compartments must be monitored throughout the procedure.

**Tunnel placement**
- A parallel pin guide can be used to make small corrections in tunnel placement.
- Perforate the posterior tibial cortex by hand with the guide pins or reamers in a controlled fashion under direct arthroscopic visualization to avoid neurovascular injury.
- If the patella causes resistance to the acorn reamer when drilling the femoral tunnels, use a smaller reamer to make a starting hole, then hand-dilate the tunnel to the appropriate size with larger reamers.

**Graft management**
- An arthroscopic switching rod, placed via the posteromedial portal between the graft and the posterior tibial cortex, can facilitate graft passage by decreasing friction.
- Avoid penetrating soft tissue with the Beath pin while passing through the anterolateral portal to prevent the graft from getting caught in the soft tissue.

**Fixation**
- An anterior tibial force should be applied during fixation to prevent posterior subluxation.

**Rehabilitation**
- Closed-chain exercises that apply an axial load across the knee protect the PCL reconstruction owing to the sagittal slope of the tibial plateau.
POSTOPERATIVE CARE
- A hinged knee brace is applied and locked in extension. The patient is awakened and taken to the recovery room, where pain and neurovascular status are reevaluated.
- Patients may be kept overnight for pain management and to monitor their neurovascular status.
- Patients are given instructions for exercises (quadriceps sets, straight-leg raises, and calf pumps) and crutch use.
- All dressing changes are performed while an anterior tibial force is applied.
- Patients are instructed to maintain touch-down weight-bearing for 1 week.
- Partial weight bearing is initiated after the first postoperative visit.
- The brace is unlocked after 4 to 6 weeks, and usually is discontinued after 8 weeks.
- Symmetric full hyperextension is achieved, and passive prone knee flexion, quadriceps sets, and patellar mobilization exercises are performed with the assistance of a physical therapist for the first month.
- Mini-squats are performed from 0 to 60 degrees after the first week and from 0 to 90 degrees after the third week.
- Once full, pain-free ROM is achieved, strengthening is addressed.
- The goals for achievement of flexion are 90 degrees at 4 weeks and 120 degrees at 8 weeks.

OUTCOMES
- Choice of graft (autograft vs allograft) has not been shown to affect overall outcome.1
- Acute single-bundle reconstructions have been demonstrated to have significantly better outcomes than chronic reconstructions.6,7
- The clinical outcomes after single-bundle and tibial inlay reconstructions have produced a satisfactory return of function and improvement in symptoms.8,9
- Neither transtibial or tibial inlay has been shown to be superior with regard to overall outcome.7
- No studies have specifically addressed the long-term clinical outcomes of double-bundle reconstructions and PCL augmentation reconstructions.

COMPLICATIONS
- Failure to carefully position the extremity with adequate padding may result in neuropraxia.
- Loss of motion (usually decreased flexion) can result from errors in graft positioning or excessive tensioning during graft fixation. Inadequate rehabilitation also may lead to loss of motion.
- Residual laxity also can occur as a result of graft positioning or failure to address concomitant ligamentous injury.
- Injury to the popliteal vessels is rare, but may be a very serious complication. Care must be taken to prevent overpenetration of the posterior tibial cortex.
- The thigh and calf should be routinely palpated to ensure no compartment syndrome develops from fluid extravasation into the soft tissues.

REFERENCES
DEFINITION

- A medial collateral ligament (MCL) injury usually is the result of a valgus stress on the knee.
- Forced external rotation injuries with a valgus component also have been described as a mechanism that can disrupt the MCL.
- While the direct valgus force is more likely to injure the superficial MCL, external rotation and valgus stress often causes additional injuries to the deep MCL, the anterior cruciate ligament (ACL), the posteromedial corner, or the posterior oblique ligament.
- The most common combined injury is an ACL and MCL injury, followed by meniscus injuries.

ANATOMY

- The medial side of the knee can be divided into three layers: superficial (I); intermediate (II); and deep (III).
- Layer I: the crural fascia extending from the quadriceps fascia into the tibial periosteum
- Layer II: the superficial medial collateral ligament (SMCL) and the medial patellofemoral ligament (MPFL)
- Layer III: the deep MCL (ie, the meniscotibial and meniscofemoral ligaments) and the posteromedial corner (ie, semimembranosus and posterior oblique ligament [POL])
- The superficial MCL originates from the medial femoral epicondyle. It inserts approximately 4 to 6 cm distal to the medial joint line and can be divided into an anterior and a posterior portion. The anterior portion tightens in flexion; the posterior portion tightens in extension.
- The deep MCL tightens in knee flexion and is lax in full knee extension.
- The posteromedial corner provides rotational stability to the medial side of the knee. Injuries to these structures cause anteromedial rotatory instability.
- The semimembranosus has five main attachments to the posterior capsule of the knee:
  - Pars reflexa, attaching directly to the proximal medial tibia
  - Direct arm, attaching to the posteromedial tibia
  - Insertion to the proximal medial capsule
  - Attachment to the POL
  - Attachment to the popliteus aponeurosis

PATHOGENESIS

- The typical mechanism for an MCL injury is a valgus stress acting on the knee joint with the foot planted. This mechanism often leads to a disruption of the deep and superficial MCL.
- If an external rotational component is added, a disruption of additional restraints such as the ACL and the posteromedial corner is likely. In particular, an injury to the POL indicates a significant capsular injury that leads to a higher grade of medial and rotatory instability.5
- MCL injuries can be partial or complete. A complete MCL injury involves disruption of the superficial and deep MCL and usually results initially in inability to ambulate.
- MCL injuries can be on either the femoral or tibial side. It is important for the treatment algorithm to differentiate whether the tear involves the femoral origin of the MCL or the tibial insertion.

NATURAL HISTORY

- Acute isolated MCL injuries usually are treated nonoperatively with protective weight bearing and bracing for 2 to 6 weeks.
  - In particular, partial tears of the MCL (grade I or II) heal well with conservative treatment.
  - Complete MCL injuries (grade III injuries) initially can be treated conservatively if they are femoral-based ligament ruptures.3
- A complete tibial-sided MCL avulsion with POL extension is less likely to tighten up with nonoperative management and may require repair or reconstruction.
- Grade 3 MCL injuries in combination with other ligament injuries of the knee may require acute surgical repair in case of a complete tibial avulsion with POL extension.5

PATIENT HISTORY AND PHYSICAL FINDINGS

- A description of the mechanism of injury (eg, valgus mechanism, valgus rotation mechanism) must be elicited.
- The examination includes inspection for peripheral hematoma along the medial side of the knee, palpation of hamstrings, joint line (meniscal injury) and the femoral origin and tibial insertion of the MCL stability testing.
- Valgus stress at 0 and 30 degrees: grade 1 (0- to 4-mm opening) and 2 (5- to 9-mm opening) injuries usually can be treated nonoperatively; grade 3 (10- to 15-mm opening) injuries are associated with other ligament tears (ie, ACL, POL) in over 75% of cases.
- Slocum’s modified anterior drawer test: disruption of the deep MCL allows the meniscus to move freely and allows the medial tibial plateau to rotate anteriorly, leading to an increased prominence of the medial tibial condyle.
- Anterior drawer test in external rotation: disruption of the MCL alone should not lead to an increased anteromedial translation. An increased anteromedial translation indicates an anteromedial rotatory instability that involves an injury of the posteromedial capsule (eg, POL, semimembranosus attachments, as well as deep MCL).
- A thorough examination of the knee should always include the following assessments:
  - Meniscus: tenderness directly at the joint line is a sensitive sign for a meniscus injury. The McMurray test or a flexion–rotation–compression maneuver may accentuate medial
joint line pain, suggesting a medial meniscus tear. (This test may not be helpful in an acute setting.)
- ACL: An immediate (within 24 hours) intra-articular effusion after the injury indicates a high likelihood of ACL injury. Positive Lachman test (acute) and pivot shift test (chronic) indicate an associated ACL tear. In the acute or subacute setting, these tests may be difficult to perform. Instrumented laxity testing (KT-1000) may be helpful in these situations. An increased valgus laxity in full extension almost always indicates something more than an MCL injury.
- PCL: A positive posterior drawer test indicates a PCL injury. The endpoint is important to assess the grade of the PCL injury.
- Patella: The apprehension sign and localized tenderness on the lateral or medial aspect of the patella or the lateral trochlea indicates a possible patella dislocation, which can go hand-in-hand with an intra-articular effusion. Tenderness at the medial femoral epicondyle also can be caused by an avulsion of the MPFL.

IMAGE AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs help to assess the bony integrity of the knee joint. They may show indirect signs of ligament injury (eg, Segond fracture), but they usually are not helpful for the diagnosis of an acute MCL injury.
- In the case of chronic MCL instability, a Pellegrini-Stieda lesion (bony spur originating at the femoral origin of the MCL, usually visualized on the flexion weight-bearing posteroanterior radiograph) may be present (FIG 1A).
- MRI with or without contrast is helpful to identify medial collateral ligament damage.
- Edema or MCL disruption can be visualized.
- The location and extent of the disruption (femoral vs tibial) can be determined.
- The amount of bone bruising can be assessed, and associated pathology (eg, meniscal tears, ACL tears, posteromedial corner injuries) can be visualized.
- Arthroscopic examination is a formidable tool to assess the true nature of the MCL injury.
- An ipsilateral “drive-through” sign (ie, opening of the medial compartment of more than 10 mm, allowing for complete insertion of the arthroscope into the medial compartment [FIG 1B]) should arouse suspicion for a significant MCL injury that may require repair or reconstruction.
- The location of the acute or chronic injury —femoral or tibial—also can be evaluated. Separate injuries of the POL also can be visualized (FIG 1C).

DIFFERENTIAL DIAGNOSIS
- Medial meniscus tear
- ACL tear
- Posteromedial corner injury
- Patella dislocation
- Pes-anserine bursitis

NONOPERATIVE MANAGEMENT
Grade 1 and 2 Medial Collateral Ligament Sprains
- Rest, ice compression, elevation (RICE) for 24 hours or until swelling is controlled
- Once swelling is controlled, partial weight bearing, range-of-motion (ROM) exercises, and electrical stimulation can be started. A simple hinged brace is applied.
- Full weight bearing can be allowed once ROM over 90 degrees of flexion as well as motor control of the thigh muscle has been demonstrated.\(^2,4\)
- Once full ROM and 80% strength of the opposite side have been achieved, closed kinetic chain exercises, jogging, and treadmill exercise may begin.
- In athletes, a return to sport-specific training is safe once 80% of the maximum running speed is achieved.\(^2,4\)
- Return to play depends on the grade of the sprain:
  - Grade 1: 10 to 14 days
  - Grade 2: 3 to 4 weeks

Grade 3 Medial Collateral Ligament Sprains
- MCL sprains without associated ACL or meniscus tear account for less than 20% of all grade 3 sprains.
- The knee is re-evaluated frequently (every 7 to 10 days) to assess whether the MCL “tightens up.” Tibial-sided complete avulsions of the MCL may not heal and require acute surgical repair if they do not tighten up within the first 4 weeks.
- It is important to check for combined ACL/MCL tears. Grade 3 MCL tears with POL extension in combination with
an acute ACL tear often require surgical repair or even augmentation because of the rotational laxity that results from the POL injury.

- **RICE** is maintained until the swelling is controlled.
  - 0 to 4 weeks: restoration of ROM, quadriceps/hamstring strengths, normal gait pattern, full weight bearing with hinged knee brace
  - 4 to 6 weeks: full ROM, full quadriceps/hamstring strengths, closed kinetic chain exercises, stair-stepper exercise, proprioceptive exercises
  - 6 to 10 weeks: full squatting, jogging, light agility drills, slow return to competition, brace discontinued for non-contact sports

**SURGICAL MANAGEMENT**

**Preoperative Planning**

- All radiographs and MRIs are reviewed before surgery.
- Associated injuries must be addressed at the same time and often determine the sequence of the surgery (PCL before ACL before MCL)

**TECHNIQUES**

**INCISION AND DISSECTION FOR MID-MEDIAL APPROACH**

- The incision should be centered over the joint line and can be extended proximally or distally, as necessary.
- In case of a proximal extension, the incision should be slightly curved posteriorly over the medial femoral epicondyle.
- Retraction of the skin exposes the sartorius fascia, which must be split in a longitudinal or T fashion. Underneath the sartorius fascia (layer I), the superficial MCL is exposed.
- The posterior border of the superficial MCL and the anterior border of the POL are identified, and a vertical incision is made along this interval, exposing the deep MCL.
- This incision can be carried down through the capsule to expose the meniscal attachments. An avulsion of the POL from the posterior capsule may be identified in select cases.
- A plane can be developed between the superficial and the deep MCL.
- This plane allows for a separate repair of the deep MCL against the POL to tension the POL.
- It also exposes the medial tibial plateau and allows for easy placement of a suture anchor for a repair of the deep MCL at the level of the joint line, which is critical.

**ACUTE REPAIR OF TIBIAL-SIDED ISOLATED GRADE 3 MCL TEARS**

- Tibial avulsion is documented arthroscopically by a positive "drive-through" sign (>10 mm of medial opening).
  - The medial meniscus lifts off from the tibial plateau during this maneuver, revealing the tibial-sided tear of the deep MCL.
  - A limited direct medial approach is performed through a 5- to 6-cm incision along the posterior aspect of the MCL.
  - The sartorius fascia is divided, which usually exposes acute avulsion of the deep MCL from the tibia. The superficial MCL also usually is torn but can be sharply divided from the deep MCL.
  - Three or four double-loaded suture anchors are then placed along the medial border of the tibial plateau about 5 mm below the joint line.
  - The meniscotibial ligament can be secured to the suture anchors, allowing for an excellent repair of the deep MCL along with the coronary ligament and medial meniscus.
  - The sutures can be left long after the initial knots are tied and also can be used to tie down the superficial MCL (**TECH FIG 1**).
AUTOGRAFT RECONSTRUCTION OF ISOLATED CHRONIC MCL TEARS

- Reconstruction of the superficial MCL requires stabilization of the central pivot of the knee. Any associated ACL or PCL injury must be addressed simultaneously with or before the MCL reconstruction.
- The reconstruction includes repair and tightening of the deep MCL/POL complex, which should be tightened at 0 degrees. The superficial MCL reconstruction should be tightened at 30 degrees of flexion.
- The deep MCL and POL can be identified through the midmedial incision and can be retightened using suture anchors, as with the primary repair of the MCL (TECH FIG 2A,B).
- Chronic MCL injuries should be augmented with a superficial MCL reconstruction.
- Autograft MCL reconstruction can be done using a Bosworth reconstruction.
- In the Bosworth reconstruction, a semitendinosus tendon is harvested using the open or closed tendon stripper. The femoral origin of the MCL is identified. A K-wire is inserted into the insertion site, and isometry is tested to avoid a flexion contracture after the superficial MCL repair.
- Once the isometric site is identified, the semitendinosus can be routed around a screw and washer femorally and can be attached distally using a staple or bone tunnels. This allows for reconstruction of the posterior and anterior bundles of the superficial MCL (TECH FIG 2C,D).

ALLOGRAFT RECONSTRUCTION OF ISOLATED CHRONIC MCL TEARS

- Borden et al\(^1\) have described an allograft reconstruction of the MCL.
- A double anterior tibialis tendon or a split Achilles or patella tendon can be used for this technique.
- The surgical approach is the same as that described for autograft reconstruction.
- The origin of the MCL on the medial epicondyle must be identified. The femoral fixation is positioned at the anatomic insertion of the MCL.
- Fixation can be achieved in various ways—bone tunnel using a soft tissue screw fixation, bone block using an interference screw fixation, bone trough, or screw and washer fixation.
Chapter 45  REPAIR OF ACUTE AND CHRONIC KNEE MEDIAL COLLABORAL LIGAMENT INJURIES 379

- The distal tibial fixation has to reconstruct the anterior and posterior aspect of the native MCL (TECH FIG 3).
- The allograft can be anchored anteriorly and posteriorly along the anatomic attachment sites using an interference screw (as depicted), a screw and washer, or a staple.

**Distal Fixation in Chronic Injuries**

- In chronic MCL injuries, it often is the distal end of the MCL that has failed to heal.

- Using the standard medial approach, the distal end of the MCL often can be identified (TECH FIG 4A).
- This attachment can be used in the reconstruction if the length is adequate; if not, it can be sutured to the reconstruction.
- The allograft is then fixed femorally (as described earlier) and routed along the course of the superficial MCL (TECH FIG 4B).
- The posterior and anterior portions of the superficial MCL can then be individually attached to the tibia.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Grade 3 MCL tear</th>
<th>Obtain MRI and check for tibial-sided avulsions, which may require surgical repair.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Be sure to follow patients closely if conservative management is chosen. The MCL should tighten up after 4 to 6 weeks. If it fails to tighten in valgus stress, reconstruction may be necessary.</td>
</tr>
<tr>
<td></td>
<td>Diagnose associated injuries with clinical examination and MRI.</td>
</tr>
<tr>
<td></td>
<td>When doing multiple ligament surgery, make sure that the ACL and PCL tunnels have been drilled before positioning of the MCL tunnels.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- The postoperative course is as follows:
  - 0 to 3 weeks: touch-down weight bearing, hinged brace locked in 30 to 90 degrees of flexion, hamstring/quadriceps strengthening in brace
  - 3 to 6 weeks: progress to full weight bearing, ROM free in brace, quadriceps/hamstring strengthening, closed kinetic chain exercises. The repair must be protected.
  - 6 to 12 weeks: the brace is discontinued. Light jogging and stair-stepper exercise are begun.
  - 12 to 18 weeks: progressive return to sports with sport-specific drills and return to play once 90% of quadriceps and hamstring strength and 75% of maximum running speed have been regained.

**OUTCOMES**

- Grade 1 and 2 MCL sprains should be treated nonoperatively. The average time to return to athletic activities is between 19 and 23 days, on average, for grade 1 and 2 injuries, respectively.
Grade 3 MCL sprains can be treated nonoperatively with good success if several pitfalls are avoided:

- Conservative treatment of an isolated Grade 3 MCL injury allows most athletes to return to play after an average of 34 days.\(^2\)
- Tibial-side avulsions of the deep and superficial MCL with POL extension tend to progress toward chronic MCL laxity. Either early surgical treatment or repetitive clinical examination to assess the gradual return of valgus stability over the course of 4 weeks is advisable. If valgus laxity is still present after 4 weeks, surgical treatment is advised.
- Concomitant ACL injuries are common and often will result in residual chronic MCL laxity if treated nonoperatively.

COMPLICATIONS

- Failure to diagnose associated ligament, meniscal, and articular cartilage injuries
- Deep venous thrombosis
- Infection

REFERENCES

DEFINITION
The posterolateral corner (PLC) of the knee is a complex area, both anatomically and functionally, that has the potential to cause great disability when injured.
- Injuries to the structures of the PLC are uncommon, accounting for only 2% of all acute ligamentous knee injuries.
- Because of the high incidence of combined ligament injuries associated with PLC injuries, other ligament injuries in the knee always should be suspected when treating the PLC.
- Conversely, cruciate ligament reconstructions have a tendency to fail if PLC injuries are left untreated, so one must always have a high index of suspicion for PLC injuries when treating other injuries in the knee.
- The significance of a PLC knee injury can be great.
- Chronic instability due to the untreated PLC injury can be debilitating.
- The complex biomechanical relationships among the structures of the PLC are important in resisting varus and external rotation forces.
- Insufficiency in the posterolateral structures of the knee can lead to a varus-thrust gait and the sensation of instability, especially when the knee is in extension during the toe-off phase of walking.
  - The convexity of the lateral tibial plateau and lateral femoral condyle may contribute to this instability.
  - This instability may hinder stair-climbing or cutting activities, and patients may complain of lateral knee pain.
  - Chronic PLC insufficiency also may lead to tricompartmental degenerative joint disease.
  - An increase in patellofemoral joint contact pressure has been found to occur with PLC and posterior cruciate ligament (PCL) sectioning in cadaveric studies.

ANATOMY
Before treating a patient with a PLC injury, one must be familiar with the complex anatomy of the area.
- The PLC is made up of both dynamic and static stabilizers.
- Seebacher et al organized the posterolateral structures into three layers.
  - The superficial layer is made up of the iliotibial tract anteriorly and the biceps femoris posteriorly.
  - The common peroneal nerve lies deep and posterior to the biceps femoris in this layer at the level of the distal femur.
  - The iliotibial (IT) tract or band, which inserts on Gerdy’s tubercle on the tibia, is tight and moves posteriorly in knee flexion. It actually places an external rotational force on the tibia during knee flexion. During knee extension, the IT band moves anteriorly and becomes less taut. Because of its relaxed state in knee extension, this structure rarely is injured in PLC injuries, so it is a good reference point for the location of other structures in surgery.
- The biceps femoris inserts on the fibular head, but also has attachments to the IT band, Gerdy’s tubercle, the lateral collateral ligament (LCL), and the posterolateral capsule. It adds dynamic stability to the PLC.
- The middle layer of the PLC consists of the quadriceps retinaculum anteriorly, the patellofemoral ligaments posteriorly, and the patellomeniscal ligament.
  - These structures add accessory static stability to the PLC.
- The deep layer, which is the most important, consists of the lateral part of the joint capsule and the coronary ligament, which inserts on the lateral meniscus; the popliteus tendon and the popliteofibular ligament; the arcuate ligament; the LCL; and the fabellofibular ligament.
  - The popliteus originates on the posterior tibia, passes through the hiatus of the coronary ligament, and inserts on the lateral femoral condyle. It also has attachments to the lateral meniscus.
  - The popliteofibular ligament exists as a direct static attachment of the popliteus tendon from the posterior tibial head to the lateral femoral epicondyle.
  - The arcuate ligament is a Y-shaped ligament that reinforces the posterolateral capsule of the knee and runs from the fibular styloid to the lateral femoral condyle. In radiographs, the arcuate fracture shows an avulsion of this ligament off of the fibular styloid.
  - The LCL originates on the lateral epicondyle of the femur and inserts on the fibular head. This ligament is the primary static restraint to varus stress from 0 to 30 degrees of knee flexion. The LCL becomes progressively more lax in greater degrees of flexion, however. Aponeurotic layers of the biceps femoris provide tension to the LCL to assist in dynamic resistance to varus stress. The LCL also provides resistance to external rotation stress.
- Much anatomic variation has been noted in the structures of the deep layer, especially the arcuate and fabellofibular ligaments.
- Hughston et al described the importance of an arcuate ligament complex consisting of the LCL, arcuate ligament, popliteus, and the lateral head of the gastrocnemius. This complex acts as a “sling” of static and dynamic restraint to rotation of the lateral tibiofemoral articulation.

PATHOGENESIS
PLC knee injuries most commonly are caused by sports injuries (40%), motor vehicle accidents, and falls.
- Any mechanism that can cause a knee dislocation theoretically can cause an injury to the PLC.
- The most common mechanism for an isolated PLC injury is hyperextension of the knee with a varus moment. This mechanism can be caused by blunt posterolaterally forced trauma to the medial proximal tibia, such as a helmet to the knee in football.
Other mechanisms of injury include hyperextension alone, hyperextension with an external rotation force, a severe varus force alone, or a severe external rotation torque to the tibia.

As mentioned earlier, an isolated PLC knee injury is rare. A flexed knee with tibial external rotation and posterior translation can cause a PCL/PLC combined injury.

**NATURAL HISTORY**

Posterolateral knee injuries rarely occur as isolated ligament disruptions. They most often are associated with injury to the PCL, the ACL, or both. Therefore, the true natural history of these injuries is unknown.

If left untreated, they will contribute to failure of other ligament reconstruction.

Repair, and often supplementation with exogenous grafts, is recommended in all cases of combined PLC injury.

**HISTORY AND PHYSICAL FINDINGS**

Methods for examining the PLC include the following:

- **Dial test.** More than 10 degrees difference between limbs is consistent with ligamentous PLC injury. Increased rotation at 30 degrees but not at 90 degrees indicates isolated PLC injury. Increased rotation at both 30 degrees and 90 degrees indicates PLC and PCL injuries.
- **Posterolateral external rotation test.** Increased posterior translation and external rotation at 90 degrees are suspicious for PLC or PCL injury. Subluxation at 30 degrees is consistent with isolated PLC injury.
- **Posterior drawer test (PCL testing).** More than 10 mm translation is highly suggestive of multiligamentous knee injury.
- **Varus stress test (LCL testing).** An isolated tear of the LCL causes maximal varus angulation at 30 degrees.
- **Quadriceps active test.** Forward translation of the tibia after attempted knee extension is positive for PCL insufficiency (reduction of posterior tibial sag).
- **Gait.** The patient may walk with a slightly flexed knee to avoid pain and instability with hyperextension of the knee. Varus thrust also may be present.
- **Reverse pivot-shift test.** Palpable shift of the lateral tibial plateau is positive, but not specific for PLC injury. This test is difficult to perform on the awake patient.
- **External rotation recurvatum test.** Hyperextension and increased varus of the knee and external rotation of the tibia are positive for PLC injury.
- **Range of motion (ROM).** The normal range is 0 to 135 degrees of motion. Loss of extension may be due to a displaced meniscus tear. Loss of flexion may be due to effusion.
- **Effusion.** A large effusion suggests other intra-articular pathology, such as an ACL or PCL tear or a peripheral meniscus tear. Effusion may be diminished if the capsule is torn.
- **Neurovascular examination (serial).** The incidence of popliteal artery injury is increased in knee dislocations. An arteriogram should be obtained if the vascular examination is different from that in the contralateral leg. The incidence of peroneal nerve injury is increased by 10% to 33% with PLC injuries.
- **It is important to obtain a good history from the patient with an acute PLC injury.**
Pain and swelling of the posterolateral knee are common.

A rapid knee effusion suggests the possibility of intra-articular pathology, such as a cruciate ligament injury or peripheral meniscus tear.

It also is important to obtain history about the presence or absence of a true tibiofemoral dislocation, because there is an association between PLC injuries and knee dislocations.

Neurologic changes also must be investigated because of the increased incidence of peroneal nerve injuries in the patient with an injured PLC.

Patients with chronic posterolateral instability commonly present with the sensation of instability with the knee in extension and lateral or posterolateral aching pain in the knee.

PLC injuries can be graded as 1, 2, or 3.

Grade 1 injuries involve minimal tearing of the ligaments and are not associated with abnormal joint motion.

Grade 2 injuries have partial tearing, but still have no abnormal joint motion.

Grade 3 injuries have complete tearing of the ligaments and abnormal joint motion.

Hughston et al graded PLC injuries based on ligamentous instability. Cases of mild, moderate, and severe instability are graded as 1+, 2+, and 3+, respectively.

Because PLC knee injuries have such a high association with combined ligament injuries, a careful examination for other knee pathology is necessary.

PCL injury can be recognized by a positive posterior drawer test, tibial sag or recurvatum, and hemarthrosis.

A positive Lachman test is the most sensitive test for an ACL tear. The examiner should not be fooled by a false endpoint caused by a tight effusion or a displaced meniscal tear. A positive pivot shift also is a sensitive test for an ACL tear, although it is difficult to perform on an acute patient because of discomfort.

Meniscal tears can also be associated with PLC injuries. Joint line tenderness is the most sensitive test for meniscal tears. A lateral meniscus tear may give lateral-sided knee pain, which could be confused with a posterolateral knee injury. Mechanical symptoms also raise concern for meniscal tears. Loss of full extension of the knee hints at the possibility of a locked bucket handle meniscus tear.

Although it is rare to have LCL and medial collateral ligament (MCL) tears in the same injury, one must examine all ligaments of the knee in a traumatic injury. The MCL is tested by valgus stress at 0 and 30 degrees of knee flexion.

Laprade and Wentorf recommend obtaining not only the standard coronal, sagittal, and axial cuts of the knee but also coronal oblique 2-mm thin cuts to include the entire fibular head and styloid, to better evaluate the popliteus tendon and the LCL.

Laprade and Wentorf also recommend using a magnet with a signal of at least 1.5 T.

MRI is useful in evaluating the soft tissues of the knee and for evaluating the bone for contusions or edema.

A bony contusion of the anteromedial femoral condyle is concerning for a PLC injury.

Arthroscopy can be useful in diagnosing posterolateral ligament pathology.

An avulsion of the popliteus off of the femur can be visualized directly, as can injuries to the coronary ligament of the posterior horn of the lateral meniscus.

The “drive-through” sign is another arthroscopic finding in the patient with a PLC injury. This is defined as more than 1 cm of the lateral joint line opening to varus stress during arthroscopic evaluation of a posterolaterally insufficient knee.

**IMAGING AND DIAGNOSTIC STUDIES**

The initial diagnostic imaging examination should begin with standard anteroposterior (AP) and lateral radiographs of the knee.

Laprade and Wentorf recommend obtaining full-length standing AP radiographs to evaluate for varus malalignment in chronic patients.

Plain radiographs may show increased joint space laterally or a frank knee dislocation.

Plain radiographs also can be obtained to evaluate associated fractures, such as an arcuate avulsion fracture of the fibular head, a Gerdy’s tubercle avulsion, and a Segond fracture, which is an avulsion of the lateral capsule off of the tibia.

Segond fractures typically are thought to be associated with ACL injuries, but they also can be associated with posterolateral ligament injuries.

Patellofemoral or tricompartmental arthritis may be associated with chronic instability. Typically, the lateral compartment is more involved than the medial compartment.

An effusion in the suprapatellar pouch also can be visualized on plain radiographs and hints at the presence of an intra-articular pathology, such as an ACL or PCL tear.

Varus stress films may be used to evaluate the integrity of the LCL as well.

MRI also is helpful in evaluating a PLC injury.

Laprade et al recommend obtaining not only the standard coronal, sagittal, and axial cuts of the knee but also coronal oblique 2-mm thin cuts to include the entire fibular head and styloid, to better evaluate the popliteus tendon and the LCL.

Laprade and Wentorf also recommend using a magnet with a signal of at least 1.5 T.

MRI is useful in evaluating the soft tissues of the knee and for evaluating the bone for contusions or edema.

A bony contusion of the anteromedial femoral condyle is concerning for a PLC injury.

Arthroscopy can be useful in diagnosing posterolateral ligament pathology.

An avulsion of the popliteus off of the femur can be visualized directly, as can injuries to the coronary ligament of the posterior horn of the lateral meniscus.

The “drive-through” sign is another arthroscopic finding in the patient with a PLC injury. This is defined as more than 1 cm of the lateral joint line opening to varus stress during arthroscopic evaluation of a posterolaterally insufficient knee.

**FIG 2** Lateral compartment. Arthroscopic views demonstrating popliteal tendon injury (A) and excessive opening, or “drive-through” sign (B).
DIFFERENTIAL DIAGNOSIS

- Lateral meniscus tear
- Other ligamentous injury (e.g., PCL, ACL)
- Tibial plateau fracture
- Supracondylar femur fracture
- Contusion
- Degenerative joint disease with varus malalignment

NONOPERATIVE MANAGEMENT

- Grade 1 and most grade 2 posterolateral ligament injuries of the knee usually are treated successfully without surgery.2 These patients typically do well without significant lingering symptoms or instability.
- For grade 1 and 2 injuries, patients are immobilized for 2 to 4 weeks in either an immobilizer or cast.
- Quadriceps sets and straight leg raises are allowed in the immobilizer only.17
- Weight bearing also is restricted during this period.17
- After 3 or 4 weeks in an immobilizer, protected ROM exercises are initiated in a hinged knee brace.
- The patient is allowed to bear weight as tolerated, and closed-chain quadriceps strengthening is begun.
- Hamstring strengthening is avoided for 6 to 10 weeks after injury.17
- Because of altered gait mechanics, formal gait instruction also should be initiated once the patient begins weight bearing.
- Although patients with grade 1 or 2 injuries typically do well with nonoperative treatment, residual laxity and instability may require surgical intervention.

SURGICAL MANAGEMENT

- Grade 3 PLC injuries tend to do poorly with nonoperative management.11
  - Indications for operative treatment of PLC injuries consist of 5 to 10 mm of opening to varus stress at 30 degrees of knee flexion and a positive dial test or posterolateral external rotation test.2 These findings are consistent with a grade 3 PLC injury.
- Ideally, PLC injuries should be treated between 10 days and 3 weeks after injury.2,4,12,23
  - Before 10 days, the knee usually is significantly swollen and still is in the acute inflammatory stage of the injury.
  - It also is possible to regain some quadriceps tone and ROM if surgery is postponed more than 10 days. Theoretically, the risk of arthrofibrosis would, therefore, be diminished.2,3
  - Waiting more than 3 weeks to operate results in increased scarring and difficulty in repairing the posterolateral structures primarily.23

  - Identifying and protecting the peroneal nerve becomes more difficult with increased scarring.17
  - Results of chronic repair are inferior to those of acute repair.2

Preoperative Planning

- In treating posterolateral ligament injuries, one must decide whether to repair the torn structures primarily, augment the repair, do an advancement, or perform a reconstruction of the posterolateral corner using allograft or autograft.
- Much of the preoperative planning is contingent on whether the PLC injury is isolated or combined with other ligamentous injuries.
- Preoperative radiographs are important to evaluate for fractures or other bony abnormalities.
- Hip-to-ankle films may be helpful in chronic cases to evaluate for varus malalignment.
- MRI helps evaluate for other associated ligamentous or meniscal injuries and should be used in preoperative planning if possible.
- If cruciate ligamentous injuries exist, they should be reconstructed prior to or concurrently with the PLC repair and reconstruction; otherwise, there is an increased risk that the PLC reconstruction will fail.2

Positioning

- Positioning for posterolateral surgery is contingent on the presence of other ligamentous injuries.
- Placing the patient in a lazy lateral position with a beanbag allows the surgeon to rotate the hip and leg externally for arthroscopic and cruciate ligament work as well as to internally rotate the leg into the lateral decubitus position for the lateral knee work.
- We have found a foot holder to be helpful for arthroscopic work.
- A well-padded tourniquet is placed high on the patient’s thigh to avoid interference with the operative field.

Approach

- Arthroscopic visualization of the lateral compartment may demonstrate injuries or excessive opening (the “drive-through” sign).
- After arthroscopy and additional procedures, as indicated, the surgical approach is carried out as described in Techniques.
Chapter 46  MANAGEMENT OF POSTEROLATERAL CORNER INJURIES

TECH FIG 1 • Exposure begins with an incision along the posterior border of the iliobial band.

DIRECT PRIMARY REPAIR

- For best results, primary repair should be done within 2 to 3 weeks of injury.17
- The structures should be repaired with the knee in 60 degrees of flexion and neutral tibial rotation.23
- A tibial avulsion of the popliteus can be repaired directly to the posterolateral tibia using suture anchors, sutures, or a cancellous screw with soft tissue washer (TECH FIG 2).
- A femoral avulsion of the popliteus typically occurs with an avulsion of the LCL.
  - Both of these structures can be sutured back to the lateral femoral condyle using transosseous drill holes.
- Laprade and Wentorf17 described the use of a recess procedure for treatment of a femoral avulsion of the popliteus or LCL.
  - In this procedure, a whipstitch is placed in the proximal popliteus, a small bone tunnel is made at the original femoral insertion of the popliteus, a stylette pin is used to pass the sutures from the whipstitch to the medial side of the knee, and the popliteus is pulled into the tunnel with the sutures.
  - The sutures are then tied over a button medially.
- A popliteofibular ligament avulsion off the fibula can be treated with tenodesis of the popliteus tendon to the posterior fibular head using suture anchors.2
  - The tenodesis can be reinforced with the fabellofibular ligament.
  - An avulsion of the LCL and arcuate ligament off of the fibular head can be reattached with transosseous sutures into the fibular head.2

TECH FIG 2 • Direct primary repair of the popliteus tendon using a transosseous suture and button.

AUGMENTATION

- If the repair of the structures of the PLC is tenuous or the tissue is poor, the surgeon should consider augmentation of the repair.
  - The tibial attachment of the popliteus can be augmented with a strip of IT band left attached distally to Gerdy’s tubercle (TECH FIG 3A).
  - The strip is passed through a drill hole in the proximal tibia from anterior to posterior and sutured to the popliteus.2
- Terry and Laprade27 described three fascial incisions for exposure of the PLC:
  - The first incision bisects the IT band.
  - The second incision is made between the posterior border of the IT band and the short head of the biceps femoris.
  - The third incision is made along the posterior border of the long head of the biceps.
- A capsular incision can be made along the anterior border of the LCL.
  - The popliteofibular ligament can be augmented using a central slip of the biceps femoris.29
  - The biceps distal attachment is left intact, and the slip is sutured to the posterior fibula, passed under the remaining biceps posteriorly, and attached to the lateral femur with suture anchors or screw and soft tissue washer (TECH FIG 3B).
**ADVANCEMENT**

- In the patient in whom the posterolateral structures are insufficient for primary repair or in chronic cases, an arcuate complex advancement can be performed.\(^{10}\)
- The LCL must be of normal integrity, and the popliteofibular ligament must be intact.
- The LCL, popliteus, lateral gastrocnemius, arcuate ligament, and posterolateral capsule are advanced en bloc in line with the LCL, tensioned with the knee at 30 degrees of flexion and neutral tibial rotation, and inserted into a trough in the distal lateral femur (TECH FIG 4).
- The disadvantage of this procedure is that the advancement does not restore isometry, thus leading to stretching of the reconstruction over time.\(^{20}\)

**TECH FIG 4** • Proximal arcuate complex advancement. The lateral collateral ligament (LCL), popliteus, lateral head of the gastrocnemius, arcuate ligament, and posterolateral capsule are advanced and inserted en bloc to the distal lateral femur.

**RECONSTRUCTION**

- Reconstruction of the posterolateral corner is used in acute injuries when the tissue is poor or irreparable and in chronic cases in which the tissues are scarred and attenuated.
- The lateral collateral ligament, the popliteofibular ligament, and the popliteus are the three most important structures to be reconstructed in the PLC.\(^{20}\)
- Reconstruction of the lateral collateral ligament using local tissue, allograft, and autograft has been described.
**BICEPS TENODESIS TECHNIQUE**

- Clancy et al. reconstructed the lateral collateral ligament using a biceps tenodesis technique (TECH FIG 5).
- In this technique, the entire biceps is transferred to the lateral femoral condyle 1 cm anterior to the LCL origin.
- The distal biceps is left attached to the fibular head.
- Disadvantages of this technique are that it does not reconstruct the popliteus or popliteofibular ligament, and it sacrifices the dynamic stabilizing effect of the biceps femoris.

**Collateral Ligament Reconstruction**

- Isolated LCL reconstruction also can be performed using Achilles tendon allograft, patellar tendon auto- or allograft, or a central tubularized slip of the biceps tendon (TECH FIG 6).
  - Fluoroscopy can be used to ensure proper placement of the proximal end of the graft to the lateral femoral epicondyle.
  - Plication of the remaining posterolateral structures can be performed.

**Two-Graft Technique**

- Laprade et al. have described an anatomic posterolateral knee reconstruction (TECH FIG 7) using a two-graft technique (ie, Achilles tendon allograft split in half).
- The first graft is used to reconstruct the popliteus.
  - The bone plug is secured in the anatomic location of the popliteus insertion on the femur, and the graft is passed from posterior to anterior through an anatomically placed tibial tunnel.
- The second graft is used to reconstruct both the LCL and the popliteofibular ligament.
  - The bone plug is secured in the femoral tunnel at the anatomic location of the LCL origin.
The graft is then passed through a tunnel from lateral to posteromedial and then pulled through the same tibial tunnel from posterior to anterior.

Interference screws are used to secure the grafts in their tunnels, and soft tissue staples are used for secondary fixation.

**Split Patellar Tendon Technique**

Veltri and Warren\(^2^9\) have described a technique of reconstructing the PLC using a split patellar tendon allograft or autograft (TECH FIG 8).

- The patellar bone plug is fixed in a tunnel in the lateral femoral condyle using a suture button on the medial femoral cortex.
- The graft is then split. The anterior limb is brought from posterior to anterior through a tunnel in the fibular head reproducing the popliteofibular ligament. The posterior limb is brought through a tibial tunnel from posterior to anterior. Both limbs are secured with suture buttons.
- A central slip of biceps can be used to reconstruct the LCL, as described earlier.
**Popliteus Bypass Technique**

- Muller\(^2\) described a popliteus bypass technique (TECH FIG 9) in which a free graft is passed through a tibial tunnel from anterior to the posterolateral proximal tibia and secured to the anterior aspect of the lateral femoral condyle.
- This technique does not reproduce either the LCL or the popliteofibular ligament.

**Figure 8 Technique**

- Semitendinosus and gracilis autograft have been used to reconstruct the popliteofibular ligament and LCL concurrently.
- Larson\(^18\) described a figure 8 technique in which he used hamstring autograft passed through a fibular tunnel, crossed in a figure 8 pattern, and wrapped around a screw and soft tissue washer at an isometric point on the lateral femoral condyle (TECH FIG 10).

**Lateral Collateral Ligament Reconstruction Using Bone–Patellar Tendon–Bone Allograft**

- Lattimer et al\(^19\) described using a bone–patellar tendon–bone allograft fixed distally to the fibular head with an interference screw and proximally to the lateral femoral condyle 5 mm anterior to the femoral origin of the LCL.
- The graft is tensioned with a valgus force placed on the 30-degree flexed knee.
- The large cross-sectional area of the graft theoretically restores LCL and arcuate and popliteofibular ligament function.
- This reconstruction neglects the popliteus, however.

**Authors’ Preferred Technique**

- We have found at our institution that a combination of the Larson and Muller techniques is the most effective approach to reconstructing the LCL, popliteofibular ligament, and popliteus.
PEARLS AND PITFALLS

- Monitor for fluid extravasation and increased compartment pressures during the arthroscopic portion of the procedure, because the capsule usually is disrupted in PLC injuries.
- Do not miss PLC injury when treating cruciate ligament injuries, to avoid failed cruciate ligament reconstruction.
- Reconstruct the cruciate ligaments before or concurrently with PLC reconstruction.
- Repair structures of the PLC beginning from deep to superficial.
- Varus malalignment may lead to failed PLC reconstruction; therefore, valgus osteotomy may be needed in chronic PLC insufficiency.
- Determine safe ROM of the knee before leaving the operating room, to guide postoperative rehabilitation.

POSTOPERATIVE CARE

- A hinged knee brace locked in extension should be used, and protected weight bearing should be followed for 3 weeks following a reconstruction and 6 weeks following a direct primary repair.2,17
  - Weight bearing theoretically places tension on the repair because of the normal mechanical axis of the leg.
  - Straight leg raises may be allowed in the knee brace initially.
  - Active knee extension and closed chain kinetic quadriiceps strengthening may be initiated at 4 to 8 weeks postoperatively.
  - Gentle leg presses, proprioceptive training, and squats may be initiated at 3 months.
  - Hamstring exercises should be strictly avoided until 12 to 16 weeks postoperatively.2,17
  - A fairly intensive rehabilitation protocol should be followed for 9 to 12 months.
  - The goal of rehabilitation is to achieve symmetrical quadriiceps strength, knee stability, and full knee ROM.

OUTCOMES

- Hughston and Jacobsen10 reported good functional results at 4 years in 12 of 19 patients treated with arcuate complex advancement combined with distal primary repair.
- DeLee et al8 also reported that 8 of 11 patients treated with advancement surgery had good results, with no arthritis or revisions at 7.5 years.
- Noyes and Barber-Westin22 reported on 42 months of follow-up in 21 patients treated with Achilles tendon allograft reconstruction of the LCL with plication or advancement of attenuated posterolateral structures.
- Failure occurred in 2 patients, and good to excellent functional results were reported in 16 (76%) patients.
- Lattimer et al19 reported on 10 patients treated with bone–patellar tendon–bone reconstruction of the LCL as well as cruciate ligament reconstruction at 28 months of follow-up.
  - All 10 patients had a reduction in their sensation of instability.
  - The patients all had less than 5 mm of lateral opening to varus stress and less than 5 degrees of external rotation.
  - Nine of the 10 patients returned to within one level of their preinjury level of activity.
- The long-term incidence of degenerative arthritis following PLC injuries treated with surgery remains unknown.
- No long-term prospective studies exist that evaluate the different ways to ligamentously reconstruct the knee with a PLC injury. Because this injury is uncommon, large study populations are difficult to obtain.

- Consequently, it is difficult to determine the clinically best method of treating this injury.

COMPLICATIONS

- Because of the extensive trauma usually incurred by the PLC-injured knee, arthrofibrosis is one of the most common complications associated with this injury.
- Residual knee instability also can occur, especially in grade 3 PLC injuries treated nonoperatively.
- These two conflicting complications make postoperative management as important as the surgical treatment itself for a good result.
- Neurovascular complications are more often associated with the initial trauma rather than the surgical management. Delayed surgical treatment increases the incidence of iatrogenic peroneal nerve injury, however.
- The incidence of wound complications can be decreased by delaying surgery until the skin has recovered from the acute phase of the injury, which usually is 10 days or more after the initial injury.
  - Bulky compressive dressings and elevation of the leg also may help decrease swelling before surgery.
  - Skin incisions should be planned to avoid skin bridges less than 7 cm wide.
  - The incidence of degenerative joint disease is increased in patients with PLC injuries due to abnormal joint motion.2,17
- The goal of surgical intervention is to reconstruct knee motion and stability to be as normal as possible.
- The lateral compartment and patellofemoral compartments are most commonly affected by PLC injuries.
- Because of long surgical times and use of graft material, infection is a possible complication of PLC surgery.
- Infection is a devastating complication, because to clear the infecting organism, it is often necessary to débride the grafts that were used to reconstruct the knee.

REFERENCES


DEFINITION

- Multiligament knee injuries result from both high-energy (eg, motor vehicle collisions) and low-energy (eg, athletic injuries, falls) events. Dislocation of the tibiofemoral joint is common, with or without spontaneous reduction.

ANATOMY

- Put very simply, knee dislocations can be viewed as injuries to one or both cruciate ligaments (ie, anterior cruciate ligament [ACL] or posterior cruciate ligament [PCL]), with variable involvement of the collateral ligaments (ie, the medial collateral ligament [MCL] and the fibular collateral ligament [FCL]) with important musculotendinous stabilizers—the biceps femoris and popliteus posterolaterally, and the pes anserine complex medially, all of which must be considered in restoring knee function. Palpable bony landmarks about the knee are crucial to aid in orientation for examination and when planning subsequent surgical approaches.

- The lateral femoral epicondyle and the fibular head are critical to identify the placement of lateral incisions, as are anatomic structures such as the FCL and peroneal nerve. Medially, the femoral epicondyle, tibial tubercle, pes insertion site, and posteromedial tibial edge are crucial landmarks for medial surgical exposures for inlay and MCL reconstruction.

- The intrinsic structure of the vascular system of the knee consists of an anastomotic ring of five geniculates: the superficial, superolateral, inferomedial, inferolateral, and middle geniculates, as well as muscular and articular branches.

- The extrinsic system plays a crucial role when parallel medial or lateral incisions are made about the knee in the sagittal plane.

- Proper planning should allow 7 to 10 cm between superficial parallel incisions to greatly lessen the risk of skin bridge loss, but it has been our experience that such incisions should be avoided if possible. This network alone cannot support vascularity distal to the knee with popliteal vessel occlusion.

- The surgical anatomy of the knee usually is described in layers, going from the superficial structures to the deep structures.

- Layer I is commonly described as consisting of Marshall’s layer (arciform) anteriorly, the sartorius medially, and the iliotibial band and biceps femoris fascia laterally.

- Layer II includes the FCL, patellar tendon, and superficial MCL.

- Layer III includes the posterior oblique, arcuate ligament, and deep portion of the MCL. Layer III is thin anteriorly and has distinct, structurally important thickenings posteromedially (posterior oblique ligament) and posterolaterally (arcuate ligament). A Segond fracture is caused by avulsion of the thickened middle third of the lateral knee capsule in this layer.

- Posterolateral reconstructions are complex because of this anatomy and variability and require restoration of both the FCL and popliteofibular (PFL) ligaments.

- The surgeon should understand the important anatomic relationships of the posterior structures of the knee, especially in regard to the popliteal neurovascular bundle.

- The medial and lateral heads of the gastrocnemius are the borders of the popliteal fossa distally, the pes anserinus tendons medially, and the biceps femoris tendon laterally. The popliteus, posterior joint capsule, oblique popliteal ligament, and posterior femoral cortex form the floor of the fossa. Through this fossa run the plantaris muscle and the neurovascular structures. The popliteal artery enters through the adductor magnus superiorly as it leaves Hunter’s canal, courses through the fossa, and exits through the soleal arch. The popliteal vein enters superficial to the artery and continues superficial to the artery, but is located deep to the tibial and common peroneal nerves, leaving the fossa medial to the popliteal artery.

- The vascular structures are located directly behind the posterior horns of the medial and lateral menisci. The vascular structures are protected during posteromedial and posterolateral approaches if the surgeon remains anterior to the medial and lateral heads of the gastrocnemius during dissection and careful retraction; of course, further dissection towards the midline can injure the bundle with either approach.

- With the advent of posterior procedures to the tibial side of the PCL, it is critical to understand the posterior neurovascular anatomy. The posteromedial approach also is useful to gain access to the tibial insertion of the PCL.

- Deep dissection along the posterior tibial surface and femoral condyles provides additional safety for this approach. Use of a tourniquet during dissection provides improved visualization of the surgical planes.

- Unlike the vascular surgeon, who uses a posteromedial approach for the neurovascular (popliteal) bundle, the orthopedic surgeon dissecting posteromedially should avoid the neurovascular bundle. Staying anterior to the medial gastrocnemius and hugging the posterior aspect of the knee joint protects the bundle in the orthopedic approach.

- It is important to stop the dissection at the PCL, because further dissection laterally with this approach eventually will reach and potentially injure the bundle.

NATURAL HISTORY

- Before the development of modern surgical techniques for management of multiligament injuries, scores of patients were left with stiff, unstable, or even amputated limbs. Today, even with aggressive evaluation and treatment, patients ultimately may have residual instability with a lower level of activity, decreased range of motion (ROM), and even amputation. The use of allografts in multiligament-injured knees is a recent advance, although occasionally it is complicated by deep infection.
PATIENT HISTORY AND PHYSICAL FINDINGS

- During the initial evaluation of a patient with a suspected multiligament knee injury, the clinician should be cognizant of the potential for concomitant injuries. High- or low-energy knee trauma can have potentially life- or limb-threatening injuries, which must be identified acutely.
- Once any life-threatening injuries have been treated, careful examination of the injured limb focuses both above and below the knee to evaluate for fracture as well as continuity of the extensor mechanism.
- A careful injury history should be obtained if possible, including pre-hospital neurovascular status of the limb, time of injury, and mechanism. Patients often relate a history of hyperextension of the knee in sporting events or a flexed knee that struck the dashboard during a motor vehicle accident.
- Any evidence of current dislocation of the tibiofemoral joint should be addressed emergently, with attempted reduction under sedation, splinting, careful neurovascular examination pre- and post-reduction, and high-quality radiographic evaluation following reduction.
- The radiographic evaluation should include an anteroposterior and lateral radiographs of the knee with the limb in a long-leg splint to demonstrate that a successful reduction has been achieved.
- Any asymmetry in the vascular examination from the uninjured extremity, even pre-hospital, necessitates further evaluation, with the specifics often dictated by vascular surgery protocols and regional preference.
- Many clinicians routinely obtain angiograms regardless of the vascular examination findings with multiligament injured knees. Nonetheless, the current trend toward using sequential clinical examinations in the reduced dislocation with normal pulses is becoming more popular and is considered safe.
- Use of Doppler or other noninvasive vascular laboratory studies in conjunction with an ankle brachial index is very useful, because these studies can provide objective information (rather than the subjective findings of pulses), and also avoids the invasiveness of angiography.
- The surgeon must be aggressive in the management of any abnormal vascular findings, with immediate vascular consultation and immediate surgical exploration of ischemia in the reduced knee dislocation. Ischemia in the dislocated knee requires reduction and pulse or vascularity reevaluation. Continued ischemia for more than 6 to 8 hours results in amputation rates of up to 80%.
- Medial puckering of the soft tissues of the knee usually suggests a posterolateral dislocation with buttonholing of the medial femoral condyle through the joint capsule, MCL incarceration into the joint, and irreducibility with closed methods of reduction.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- An integral part of evaluation of the multiligamentously injured knee is plain radiographs before and after reduction to confirm congruity of the joint, evaluate for associated fractures, and detect ligament avulsion injuries that may aid in timing of the treatment plan.
- MRI is an excellent adjunct to delineation of the extent of injury and pattern of ligament injury and musculotendinous and osteoarticular injuries. These studies are combined with a careful examination of the ligamentous structures with and without anesthesia, which are compared to the uninjured extremity.
- MRI cannot replace a careful clinical examination under anesthesia, which can determine ligament function and the need for ligament reconstruction.

CLASSIFICATION

- Multiple classification systems have been used to describe dislocations of the knee.
- Historically, the most commonly used system has been based on a positional description of the relationship of the femur on the tibia when the knee is dislocated. However, this system is not without problems.
- First, most knee dislocations present spontaneously reduced, making classification based on position at the time of injury difficult, if not impossible.
- Second, this system does not provide information regarding the energy of the injury, the ligaments injured, or associated neurovascular injuries, all of which play a part in the overall treatment plan.
- Classifying dislocations based on the anatomic injury pattern (ie, ligaments torn and associated neurovascular injuries) allows for adequate physician communication (especially for future reconstructions) and preoperative planning. The anatomic classification is shown in Table 1.

DIFFERENTIAL DIAGNOSIS

- Knee dislocations can be difficult to assess in the presence of gross knee swelling or with the presentation of multi-trauma.
- Accurate detection of associated neurovascular injuries is critical.
- Identification of the ligaments injured is based on the initial examination, imaging studies, and examination under anesthesia.

NONOPERATIVE MANAGEMENT

- Many patients today are treated with surgical management of some type; however, depending on their injury pattern,
there are still subsets that are treated nonoperatively. These include patients with severe comorbidities that increase the risks of surgery or those with open dislocations or greatly damaged soft tissue envelopes, where the focus is on restoring the envelope and treating infection.

**Cast Immobilization**
- Although cast immobilization technique was used for many years to treat multiligament injuries to the knee before modern reconstructive procedures were available, closed treatment as definitive management rarely is indicated.
- Immobilization in extension for 6 weeks, as described by Taylor,26 can result in a stable knee, but in our experience should be used only in circumstances where the preferred technique of ligamentous reconstruction is not applicable or feasible.

**External Fixation**
- External fixation may be used to span the knee joint with fixation in the tibia and femur, and is useful in patients who have poor rehabilitation potential. It also may be used as a temporary stabilizing measure in open knee dislocations, severe soft tissue injuries, and vascular reconstructions while awaiting optimal conditions for operative ligamentous reconstructions.
- Advantages include adequate maintenance of reduction, access to soft tissue wounds, and protection of maturing reverse saphenous vein grafts.
- However, the potentials for loss of knee motion and exuberant scar formation (arthrofibrosis) exist, and these often require later manipulation under anesthesia and lysis of adhesions.

**Hinged Knee Brace**
- The patient is placed in a hinged knee brace, and supervised ROM exercises are initiated in the first few weeks following the injury.
- This treatment method is ineffective in creating a stable knee but is an extremely important step in the process to a successful multiligamentous reconstruction.
- Gaining extension, a more normal gait pattern, full flexion, and decreased swelling (resolution of inflammation) add to an easier postoperative course, with avoidance of postoperative stiffness and heterotopic ossification with multiligamentous reconstruction. In our experience, early multiligamentous reconstruction has tremendous risks for stiffness and a poor result.
- The work of Shelbourne21 and others with ACL/MCL injuries with preoperative rehabilitation is even more applicable to multiligament knee injuries. Obtaining preoperative ROM before PCL, ACL, and collateral ligament reconstruction is extremely useful in obtaining a stable, pain-free knee after dislocation.

**SURGICAL MANAGEMENT**

**Indications**
- Operative reconstruction is recommended to most patients with multiligament knee injuries. In some cases, an external fixator is used temporarily followed by surgical reconstruction; in most cases, early braced knee motion is instituted with delay of reconstruction of ligament injuries undertaken only once motion is restored and inflammation is resolved.
- Ligamentous repair (ie, suture repair) is less and less commonly used, because the results are variable, and the use of early postoperative ROM, in our experience, results in failure of the suture repair.
- Crucial to the immediate care of these injuries is a meticulous neurovascular examination. Any vascular deficit necessitates emergent vascular surgery consultation and consideration for an open popliteal artery exploration and reverse saphenous vein graft reconstruction.
- Patients with open injuries, popliteal artery reconstructions, severe soft tissue injuries, or complex injury patterns (concomitant fractures) should be considered for external fixation for 2 to 4 weeks to allow healing of the soft tissue envelope and maturation of the arterial repair or reconstruction. Once conditions have been optimized and wounds are healed without infection, reconstruction can be performed.
- The optimal timing for surgical intervention is not clearly defined, although many investigators recommend waiting for several weeks after the injury before performing surgical repair or reconstruction of these multiligamentous injuries. The operating surgeon must have a good working knowledge of ligamentous reconstructions and should proceed according to his or her level of experience and preference.
- In our experiences, it is best to wait for preoperative motion, gait, and swelling to improve. Over 15 years of experience with knee dislocations has led to the following guidelines:
  - Delayed reconstruction is better than immediate surgery.
  - Preoperative rehabilitation is useful to regain motion, and resolution of swelling and inflammation is critical to surgical success.
  - Reconstruction is done with allo- and autografts, avoiding surgical repairs.
  - Both cruciates and involved collateral(s) are reconstructed simultaneously.

**Graft**

**Graft Choice**
- Many graft choices are available for ACL reconstruction in the multiligament-injured knee. We prefer a bone–patellar tendon–bone (BTB) allograft.
- While a BTB autograft is the gold standard in an isolated ACL reconstruction, the comorbidities of ipsilateral graft harvest in combined ACL-PCL injuries can result in stiffness, especially in simultaneous cruciate reconstruction.
- The ipsilateral hamstring autograft should not be considered in a type III knee dislocation (KDIII) injury, because the hamstrings provide a secondary restraint to valgus load and may be required for MCL reconstruction.
- Allografts are ideal for the multiligamentous knee injury.

**Posterior Cruciate Ligament Reconstruction**
- A number of approaches to modern PCL reconstruction are available, including (1) transtibial and femoral tunnels (with or without dual femoral socket) and (2) tibial inlay using a single or dual femoral tunnel in which tibial fixation is achieved by securing a bone plug into a trough positioned at the anatomic insertion of the PCL.
- The inlay technique places the bone–tendon junction of the graft at the joint line of the proximal tibia and may avoid the risk of the “killer curve” graft impingement seen experimentally with the transtibial tunnel technique.
- One of the senior authors prefers a dual femoral socket (ie, double-bundle femoral) and tibial inlay PCL reconstruction through a posteromedial approach.
BONE–PATELLAR TENDON GRAFT FOR BONE–ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

- The patient is positioned supine with a lateral post or leg holder in place.
- Standard arthroscopy portals are used, and a systematic examination of the knee is performed.
- Tibial and femoral tunnels 10 to 11 mm in diameter are drilled using standard methods.
- The allograft BTB bone plugs for the ACL are fashioned to match the tunnel diameter, and the femoral plug is fashioned to a length of 25 mm.
- A small drill is used to place a hole in the femoral bone plug of the graft and a no. 2 braided composite suture (Fiberwire, Arthrex, Naples, FL) is passed through the hole for graft passage.
- Two holes are drilled in the tibial bone plug and a no. 2 suture is passed to aid in graft passage, and even potential post or staple fixation in case of graft length mismatch.
- A critical step in planning the depth of the femoral tunnel is factoring in the length of the allograft.
  - The femoral tunnel should be drilled to a length of 30 to 35 mm.
  - Most patients require an intra-articular graft length of 25 mm.
  - Sixty millimeters (35 mm for the femoral tunnel plus 25 mm for the intra-articular portion) should be subtracted from the length of the entire graft to yield the ideal tibial tunnel length.
  - This method ensures that optimal fixation of the bone plug in the tibial tunnel will be possible.
  - A guide pin is placed endoscopically through the tibial tunnel into the femoral ACL origin and drilled out the anterolateral cortex of the femur and through the skin.
- A no. 2 braided composite suture from the femoral bone plug is placed through the eyelet of the guide pin.
- The guide pin and suture are pulled up into the femoral ACL socket, passing into the femoral tunnel.
- Fixation on the femoral side is performed using an interference screw through the inferomedial portal with a protective sleeve.
- Fixation and tensioning of the tibial side of the ACL graft are delayed until after PCL reconstruction.
- At this point, the PCL dual femoral socket sites are selected and drilled (discussed later in this section).
- Sutures are placed in the PCL femoral tunnels to allow graft passage.
- Once the PCL graft is securely fixed, then, and only then, is the ACL allograft tensioned in full extension and secured to the tibial tunnel using a metal interference screw.
- If graft tunnel mismatch occurs and the ACL tibial bone plug is not completely within the tibial tunnel, tibial interference fixation can be performed with an oversized soft tissue biodesgradable interference screw, or staple–post fixation can be performed externally on the tibial surface.
- In our experience, simultaneous bicruciate reconstruction, although complex, can be simplified by the following steps, performed in this order:
  - ACL femoral and tibial tunnel preparation; dual femoral PCL tunnel preparation; ACL graft passage with fixation of the femoral side only; tibial inlay via the posteromedial approach; PCL graft passage and fixation; ACL tibial fixation; and, lastly, collateral reconstruction as indicated.
  - Such steps allow for the most time-efficient process for simultaneous cruciate reconstruction.
DOUBLE-BUNDLE POSTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

Positioning and Preparation
- The patient is positioned supine on the operating table with the use of a lateral post. A careful examination under anesthesia is performed to confirm the ligament injury and diagnosis.
- Standard inferomedial and inferolateral arthroscopy portals are used.
- A 30-degree arthroscope is inserted and diagnostic arthroscopy performed to confirm the PCL tear.
- The PCL remnant is removed and the anatomic origin identified.

Double-Bundle Tunnel Preparation
- A long drill-tip guidewire is placed through the inferolateral portal with the knee positioned at 90 degrees, viewing the pin placement from an inferomedial portal. This allows sequential femoral bundle pin placement and reaming for the anterolateral bundle of the PCL (8-mm tunnel) followed by posteros medial tunnel creation (6 mm).
- The guidewire is inserted in the anatomic site of the anterolateral bundle (usually high in the notch, near the articular surface), drilled into the condyle and exiting out of the skin overlying the distal medial thigh.
- The slotted end of the guidewire is used to pass a suture into the tunnel, with the loop remaining in the tunnel.
- At our institution, both tunnels are reamed endoscopically through the medial cortex to allow for adequate graft tensioning.
- At this point, both femoral sockets have been reamed, passing sutures are in place (exiting the inferomedial portal), and the posteros medial approach is performed.

Posteromedial Approach and Tibial Inlay Site Preparation
- All arthroscopic instruments are removed from the knee, and the leg is placed in the figure 4 position.
- The primary surgeon is positioned on the contralateral side of the operating table with the assistant on the ipsilateral side of the injured knee.
- The leg is exsanguinated, and the tourniquet is inflated with the knee hyperflexed.
- A posteromedial approach to the knee is utilized, with a 6- to 10-cm incision centered over the posterior joint line. The incision should follow the posterior cortex of the proximal tibia and the medial femoral epicondyle.
- The sartorius fascia is exposed and incised in line with the skin incision. The gracilis and semitendinosus tendons are retracted posteriorly and distally. The fascia between the medial head of the gastrocnemius muscle and the posterior border of the semimembranosus muscle is divided in line with the incision. The semimembranosus muscle is then dissected off of its tibial insertion and tagged with a nonabsorbable suture for later repair.
- The remainder of the exposure is performed by blunt dissection following the posterior border of the joint line and remaining anterior to the medial head of the gastrocnemius muscle at all times to protect the popliteal neurovascular structures.

Graft Preparation
- As noted earlier, our preferred graft for PCL reconstruction is an Achilles tendon allograft.
- This graft allows for either a single- or double-bundle femoral technique, depending on surgeon preference and experience.
- The graft can easily be fashioned into a double-bundle graft.
- The ends are prepared by placing a traction stitch with a no. 2 Fiberwire suture to facilitate graft tubulization and eventual passage.
- The calcaneal bone plug is fashioned to maintain the double-bundle tendons and can vary in size (often, it is 15 mm wide × 15 mm deep × 35 mm long). Hence, graft preparation must be performed before tibial trough creation.

Tibial Graft Passage and Fixation
- The tibial inlay graft is positioned into the tibial trough with care taken to ensure that the bone–tendon junction is positioned at the joint line.
- The tibial side of the graft is fixed first to ensure that the bone–tendon junction is positioned at the joint line to avoid graft abrasion.
The key components of the deep posterolateral corner are the popliteus, the PFL, and the FCL. The modified two-tailed reconstruction\(^\text{16}\) addresses each of these components.

### SINGLE-LOOP POSTEROMEDIAL COMPLEX RECONSTRUCTION

- An incision is made from the medial femoral epicondyle to the posterior aspect of the insertion of the pes anserinus tendon on the tibia. The sartorius fascia is incised in line with the semitendinosus tendon from distal to proximal, and graft harvest is performed, leaving the tibial attachment in place.
- The proximal end of the semitendinosus is cleared of remaining muscle, and a Krackow suture is placed in its free end.
- A subretinacular tunnel is made from distal to proximal, and the graft is passed using this approach.
- Using a high-speed burr, a U-shaped trough is made around the isometric point of the medial epicondyle.
- The graft is laid into this trough and stapled in place.
- The graft is passed back through the fascial tunnel, and the knee is cycled through a ROM.
- The graft is then stapled to the tibia at the insertion of the MCL.
- After wound closure, the limb is placed in a sterile bulky dressing with medial and lateral plaster slabs for 7 to 10 days.
- We monitor these patients carefully and progress them slowly through ROM.

### MODIFIED TWO-TAILED RECONSTRUCTION OF THE POSTEROLATERAL CORNER

- The patient is positioned supine on the operating table, with the injured extremity draped free. The leg is carefully positioned on the operative table, with the foot resting in the seated surgeon’s lap.
The knee is flexed to 90 degrees to relax the peroneal nerve, and a skin incision is made beginning at the lateral epicondyle of the femur toward the fibular head.

The iliotibial band is incised in line with the fibers from Gerdy’s tubercle, extending proximally to the supracondylar process of the femur.

At this point, the peroneal nerve is identified as it courses from the biceps femoris through the perineural fat to the fibular neck.

In our experience, the nerve is identified most easily at the level of the joint line, where it can be palpated. However, depending on the specific injury and the presence of inflammation, the nerve may be identified along the fibular neck or even as it crosses the lateral gastrocnemius head.

It is critical to identify the nerve first before any ligamentous exploration or reconstruction is performed.

Neurolysis is performed distally through the length of the incision. The nerve is protected with a small vessel loop.

Once the nerve is exposed and protected, the FCL and the posterolateral structures are identified through blunt dissection. The surgeon should not dissect posterior to the lateral gastrocnemius muscle, because this places the popliteal neurovascular structures at risk.

Once the exposure is complete, a 5-mm tunnel is drilled from anterior to posterior on the lateral tibia, exiting where the popliteus tendon traverses the back of the tibia.

A retractor is placed posteriorly during the drilling to protect the neurovascular structures.

The tibial tunnel is tapped with a 7-mm tap to allow fixation with a bioabsorbable interference screw.

A tibialis tendon allograft is fashioned to approximately 5 mm and passed into the tunnel from posterior to anterior.

The allograft tendon must be at least 24 cm long to allow reconstruction of all three components.

The graft is secured in the tibial tunnel with a 7-mm bioabsorbable interference screw from anterior to posterior.

A second 5-mm tunnel is made in the fibular head from anterolateral to posteromedial, but is not tapped.

The isometric point on the lateral femoral condyle is located by finding the intersection of the FCL and the popliteus tendon.

Using a 3.2-mm drill bit, a hole is made in the lateral femoral condyle at the isometric point from lateral to medial to allow placement of a 4.5-mm bicortical screw.

If a concomitant ACL reconstruction is performed, this hole must be drilled from posterior to anterior to avoid interfering with the femoral tunnel of the ACL graft.

An osteotome is used to decorticate the bone around the screw to allow healing of the allograft to bone. A spiked soft tissue washer is used with the screw.

The graft is then passed from the posterior aspect of the tibia to the anterior portion of the screw and then posteriorly around to the fibular tunnel.

The popliteofibular portion of the graft should lie deep to the popliteus portion of the graft.

The graft is then passed from posterior to anterior through the fibular tunnel and back to the screw and washer.

The graft is tensioned with the foot internally rotated and the knee flexed 40 to 60 degrees.

The screw and washer are then secured to the lateral femoral condyle and graft.

This completes the reconstruction of all three posterolateral components described earlier. If there is an injury to the PLC, early repair should be considered.

We prefer allografts for cruciate reconstructions performed simultaneously, but the decision is based on surgeon experience, patient preference, and risk tolerance.

Our graft of choice for bicruciate injuries is BTB allograft for the ACL and an Achilles tendon allograft for the PCL (dual-bundle femoral with inlay tibial bone plug).

The patient is positioned supine with the injured extremity draped free. A post is used to assist with arthroscopy.

Diagnostic arthroscopy is performed through standard portals, and associated injuries are treated as required.

The remnants of the cruciate ligaments are debrided, and a notchplasty is performed to allow for adequate visualization of ACL femoral tunnel placement and graft passage.

The detailed technique for ACL and PCL reconstructions is described earlier in this chapter.

The ACL tibial and femoral tunnels are prepared first, and the guide pin advanced into the femoral tunnel to be used later for graft passage. The femoral tunnel may be drilled under dry visualization.

The PCL femoral tunnel(s), either double-socket (preferred) or single, are prepared next under dry visualization. The guide pin is advanced into the femoral tunnel and the attached suture brought through the inferomedial portal for later graft passage.

Knee Dislocation Type II: Anterior and Posterior Cruciate Ligaments Torn

The integrity of the collateral ligaments allows for early ROM and a delayed reconstruction of the cruciate ligaments.

Knee Dislocation Type I: Anterior Cruciate and Collateral Ligaments Torn

The integrity of the ACL determines the timing of reconstruction for a type I knee dislocation.

ACL reconstruction is best delayed until ROM is restored, for two reasons:

- Collateral ligament healing usually occurs nonoperatively.
- Postoperative stiffness often is avoided.

We prefer to regain complete ROM and delay reconstruction for this type of injury. Patients usually regain knee motion within 6 weeks of the injury.

Graft choice is based on surgeon experience and patient preference and usually involves an ipsilateral bone–tendon–bone autograft.

Collateral ligament injury associated with only one torn cruciate ligament usually can be treated nonoperatively.

MULTILIGAMENT RECONSTRUCTIONS
PEARLS AND PITFALLS

### Neurovascular status
- Carefully evaluate pulses and the neurologic examination. Use noninvasive studies to objectively document the findings of a normal vascular examination. Aggressively (emergently) evaluate asymmetry or ischemia on vascular examination with vascular consultation and intraoperative arteriography/exploration.

### Planning
- Determine the impact of ligamentous reconstructions on the patient as a whole. Delay reconstructions for multi-trauma, and consider external fixation for such patients to assist in transfers and mobilization.
- Obtain preoperative ROM with normalized gait prior to reconstruction. This will maximize the final result. The PCL often will heal to a grade I or II, thereby making it possible to perform only an ACL/collateral reconstruction.
- Use allografts over autografts, depending on patient preference and religious beliefs.

### Diagnosis
- Clearly diagnose the ligaments involved. Examination under anesthesia combined with MRI can give an accurate picture of the needed reconstructions. Remember, MRI may overdiagnose ligamentous injuries, which will be found on EUA not to need reconstruction.

### Surgery
- Use reconstructions over repairs. If using repairs, delay postoperative ROM.
- Perform bicruciate and collateral reconstructions at the same sitting (simultaneously), if possible.

---

**Knee Dislocation Type III: Torn Anterior and Posterior Cruciate Ligaments and Lateral Complex**
- As for the Type III reconstruction, the reconstruction of a Type III injury proceeds through double-bundle passage into the dual femoral sockets.
- After the PCL is tensioned, the lateral approach to the knee is performed, and the FCL and posterolateral corner reconstructed using the technique described earlier.
- The ACL graft is then tensioned in extension and secured to the tibia.

**Knee Dislocation Type IV: Torn ACL, PCL, MCL, and Lateral Complex**
- This pattern most often is associated with a high-energy injury and represents a complex reconstruction.
- Careful attention to knee position during tensioning of the grafts is required to achieve a stable and concentric reconstruction in which the tibiofemoral joint is not subluxed.
- The initial reconstruction follows bicruciate ligament reconstruction through double-bundle passage into the dual femoral sockets, including exposure of the MCL.
- A lateral approach is used to expose the posterolateral corner, as described earlier.
- The MCL and PLC are prepared.
- The MCL graft is tensioned and fixed.
- The posterolateral graft is tensioned and fixed.
- The ACL graft is tensioned in extension and fixed to the tibia.
POSTOPERATIVE MANAGEMENT

- A thorough understanding of the reconstruction and tailoring the treatment plan to each individual patient are crucial to all rehabilitation protocols.
- Patients who undergo early repair or reconstruction of multiligament knee injuries should begin supervised knee motion exercises within the first 3 days after surgery to decrease the risk of arthrofibrosis.
- A hinged knee brace is used after bicruciate reconstructions, with non-weight bearing of the extremity recommended for 3 to 4 weeks.
- Weight bearing is progressed to full, usually at 6 weeks, with a brace and crutches.
- With medial or lateral procedures consideration is given for a slower return to full weight bearing owing to poor quadriceps tone and potential unfavorable mechanics.
- Early postoperative therapy focuses on control of edema and pain to facilitate return of quadriceps function.
- Following PCL reconstruction, early return of full extension is paramount.
- Supervised passive extension exercises are performed with a simultaneous, anteriorly directed force on the proximal tibia twice daily.
- The knee is kept in a postoperative brace from 0 to 90 degrees for the first 6 weeks.
- Closed kinetic chain active exercises are allowed in this arc of motion.
- The goal is to regain full ROM by 3 months.
- If 90 degrees of flexion is not achieved by 6 to 12 weeks, manipulation under anesthesia (MUA) is strongly recommended.
- Straight-line jogging usually is begun at 5 to 6 months, depending on quadriceps function.
- Patients may return to full activity in 9 to 12 months.

OUTCOMES

- The trend in recent years of increased surgical management of ligamentous injuries, coupled with earlier motion and a more aggressive approach to the management of stiffness (eg, MUA, arthroscopic lysis of adhesions), has yielded more favorable results than those previously reported regarding function, pain, and the incidence of debilitating instability.
- Studies using Lysholm scores for outcomes favor surgical treatment of these injuries over nonoperative treatment, with an average increase of 20 points reported with operative intervention.
- Generally speaking, 93% of patients are able to return to some type of occupation, but may not be able to work at a highly demanding job. In seven studies, approximately 70% of patients returned to their previous occupation.
- With surgical intervention, many patients ultimately have knees that function well for activities of daily living, and some are able to participate in recreational sports, but only 40% are able to return to their previous level of activity.

COMPLICATIONS

- One of the most devastating problems encountered in multiligament knee injuries is failure to identify and appropriately manage vascular injuries in the acute phase.
- Another common problem is failure to recognize the full extent of the ligamentous injury, including capsular disruption at the time of surgical management.
- There also is potential for nerve injury, with peroneal nerve involvement more common than tibial nerve injury.
- Complete nerve dysfunction carries a much worse prognosis than a partial injury, especially regarding the tibial nerve. Fewer than half of these patients have complete functional recovery of the nerve.
- The necessity of creating multiple femoral and tibial tunnels brings with it the potential risk of tibial plateau fracture, medial femoral condyle avascular necrosis, and subchondral fracture.
- The potential also exists for intraoperative neurovascular injury, especially with lateral side reconstructions (peroneal nerve) and PCL reconstructions (popliteal neurovascular bundle).
- Postoperatively, the risks include infection (especially with open injuries), wound healing problems with multiple incisions, and arthrofibrosis (with or without heterotopic ossification).
- On average, 38% of multiligament knee injuries require at least one surgical intervention to regain motion.
- There also is concern for posttraumatic arthritis (especially of the patellofemoral joint), potential loss of graft or repair fixation, and deep venous thrombosis with pulmonary embolus.

REFERENCES

Chapter 47 MANAGEMENT OF THE MULTIPLE LIGAMENT-INJURED KNEE

DEFINITION
- Complete tears of the patella tendon are best classified into acute versus chronic.
- Partial tears often can be managed nonoperatively. The functional integrity of the extensor mechanism is the key to determining the need for surgical repair.
- This chapter focuses on the surgical treatment of complete tendon disruption.

ANATOMY
- The patella tendon is approximately 30 mm wide × 50 mm long, with a thickness of 5 to 7 mm.¹
- The origin on the inferior pole of the patella is juxtaposed to the articular cartilage on the deep side and becomes confluent with the periosteum of the patella anteriorly.²
- The tibial insertion is narrower and invests the entirety of the tibial tubercle.
- The overlying peritenon is thought to be the cellular source for healing of tendon injuries.

PATHOGENESIS
- Tendon rupture usually is the result of underlying tendinosis.⁶
- There is some evidence of genetic predisposition to tendon rupture.
- Certain conditions predispose individuals to tendon rupture, including renal dialysis, chronic corticosteroid use, fluoroquinolone antibiotics, and corticosteroid use.

NATURAL HISTORY
- The natural history of an untreated patella tendon is complete extensor mechanism dysfunction.
- Untreated acute ruptures result in chronic lesions that are more difficult to manage surgically. These often require reconstructive procedures and have inferior functional results.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients with acute tendon tears may report an audible “pop” or the sensation of their knee giving way.
- Patients with chronic injuries may report ambulatory difficulty and pain. These injuries often are treated with bracing before definitive evaluation.
- The loss of active knee extension is the key physical examination finding when evaluating for patella tendon rupture.
- Loss of tension in the patella tendon with the knee at 90 degrees of flexion and patella alta are indirect signs of rupture.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs may reveal patella alta, avulsion fractures, Osgood-Schlatter lesions, or other concomitant knee injuries.
- MRI scans may be helpful in determining the exact location of the rupture and evaluating concomitant intraarticular knee lesions.

DIFFERENTIAL DIAGNOSIS
- Quadriceps tendon rupture
- Patella fracture
- Tibial tubercle avulsion fracture

NONOPERATIVE MANAGEMENT
- Nonoperative management should be considered only for patients who are not surgical candidates because of medical comorbidities.

SURGICAL MANAGEMENT
- Although not considered to be a surgical emergency, prompt surgical management of acute patella tendon ruptures is recommended.

Preoperative Planning
- Repairs of chronic injuries often require allograft tissue availability and careful surgical planning.
- Significant patella alta may require proximal release in conjunction with the repair.

Positioning
- Supine positioning is recommended.
- Use of a tourniquet may preclude proper repair tensioning in chronic injuries.
- Prepping and draping of both lower extremities allows use of contralateral limb as a template for patella positioning.

Approach
- An anterior approach is used, regardless of the repair technique.
- A midline longitudinal incision is made over the patella tendon.
- The peritenon is incised longitudinally and dissected away from the underlying tendon.
ACUTE REPAIR

Midsubstance
- Grossly pathologic tendon tissue is aggressively débrided.
- The full length of the patella tendon is exposed.
- Two Krackow locking stitches are placed in each tendon stump with no. 2 or no. 5 Fiberwire (Arthrex, Inc., Naples FL; TECH FIG 1).
- Any required retinacular repair stitches are placed with absorbable suture before the tendon repair.
- The four proximal core sutures are tied to the four distal core sutures with the knee in full extension.
- Integrity of the repair is evaluated by checking the maximal flexion possible prior to gap formation.
- The peritenon is closed with absorbable suture.

Proximal Avulsion
- Grossly pathologic tendon or bone is removed.
- Exposure of the inferior pole of the patella is performed.
- If the transosseous drill hole technique is preferred, superficial exposure of the superior pole of the patella is required.
  - A smaller exposure is required for suture anchor technique.
- Three suture anchors are placed in the inferior pole of the patella, equally spaced along the anatomic tendon footprint.
  - We prefer the 5.0 Bio-Corkscrew FT Suture Anchor (Arthrex, Inc., Naples, FL) loaded with no. 2 Fiberwire (Arthrex, Inc., Naples, FL).

Distal Avulsion
- Grossly pathologic tendon or bone is removed.
- The tibial tubercle is exposed.
- Two suture anchors are placed in the tibial tubercle.
  - We prefer the 5.0 Biocorkscrew FT Anchor loaded with no. 2 Fiberwire (Arthrex, Inc., Naples, FL).
- The suture is pulled through the anchor eyelet to produce long and short suture arms. The long suture arm is passed down and back up the tendon stump in a locking Krackow fashion (TECH FIG 2).
- The tendon is manually reduced to the inferior pole of the patella, and the slack is taken out by the short arm of suture pulled through the eyelet.
- Each suture pair is tied securely to complete the repair.
- Repair integrity is evaluated by checking the maximal flexion possible before gap formation.
- The peritenon is closed with absorbable suture.

The suture is pulled through the anchor eyelet to produce long and short suture arms.
- The long suture arm is passed down and back up the tendon stump in a locking Krackow fashion (TECH FIG 2).
- The tendon is manually reduced to the inferior pole of the patella, and the slack is taken out by the short arm of suture pulled through the eyelet.
- Each suture pair is tied securely to complete the repair.
- Repair integrity is evaluated by checking maximal flexion possible before gap formation.
- The peritenon is closed with absorbable suture.
**TECH FIG 3** • Repair of acute distal avulsion.

- The block is secured to the tubercle with 2-mm × 3.5-mm cortical screws (TECH FIG 4A).
- Suture anchors are placed into the distal pole of the patella and onto the anterior cortex of the patella to secure allograft tendon to the patella (TECH FIG 4B).
- The allograft tendon is draped over the quadriceps tendon and muscle fascia and secured with nonabsorbable suture.

**RECONSTRUCTION OF CHRONIC TEARS**

- Reconstruction of a chronic tear begins with aggressive débridement of dysplastic tissue.
- Remaining tendon tissue is assessed for possible repair.
- The tibial tubercle is exposed.
- The Achilles allograft is prepared with 15-mm × 25-mm bone block.
- A rectangular box is cut out of the tubercle with an oscillating microsurgical saw and osteotomes to receive the bone block.
- The block is secured to the tubercle with 2-mm × 3.5-mm cortical screws (TECH FIG 4A).
- Suture anchors are placed into the distal pole of the patella and onto the anterior cortex of the patella to secure allograft tendon to the patella (TECH FIG 4B).
- The allograft tendon is draped over the quadriceps tendon and muscle fascia and secured with nonabsorbable suture.

**TECH FIG 4** • Chronic reconstruction with Achilles tendon allograft. The bone block is inlayed into the tibial tubercle and fixed with screws or staples. The soft tissue end of the graft is sutured into the patella with suture anchors and into the quadriceps with heavy nonabsorbable sutures. **A.** Lateral view. **B.** AP view.
AUGMENTATION PROCEDURES

- After the repair has been completed, it is assessed for any need for augmentation.
- The following materials can be used for augmentation. They are placed in a box-stitch fashion through drill holes in the patella and tubercle (TECH FIG 5A):
  - Mersilene tape
  - No. 5 Fiberwire
  - No. 5 Ethibond
  - Steel wire
  - Cerclage cables
  - Tibialis tendon allograft
  - A semitendinosus autograft also may be harvested proximally (while leaving its distal insertion intact) and passed through a drill hole in the patella and either through a drill hole in the tubercle or potted into the proximal tibia if the length is insufficient (TECH FIG 5B).

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Preoperative planning</th>
<th>Failure to recognize significant patella alta may lead to abnormal knee kinematics and weakness of extension.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical technique</td>
<td>Reattachment of the patella tendon into its anatomic footprint on the patella is essential for re-establishing normal patellofemoral kinematics.</td>
</tr>
<tr>
<td>Intraoperative assessment</td>
<td>Maximum allowed knee flexion angle without repair gap formation is determined immediately after repair.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Weight bearing is allowed with the knee braced in extension.
- Early flexion allowances are determined intraoperatively by the quality of the tendon tissue and repair.
- Active-assisted range of motion is advanced as tolerated with the goal of 90 degrees of flexion by 4 to 6 weeks and full motion by 10 to 12 weeks after repair.
- Strengthening is initiated immediately with isometric quadriceps contractions and progressed to straight-leg raises at 6 weeks.
- Return to unrestricted activities is delayed until 6 months.

OUTCOMES

- Marder and Timmerman\(^9\) reported excellent results in 12 of 14 patients treated with acute repair without augmentation.
- Larson and Simonian\(^7\) reported excellent results (mean Lysholm score, 97.5) in four cases of acute repair augmented with autologous semitendinosus graft placed in a looped fashion.
- Lindy et al\(^8\) reported excellent results in 24 patients repaired acutely and augmented with Mersilene tape placed in a looped configuration.
- Fujikawa\(^5\) reported good results with a patella tendon repair augmented with a synthetic figure-8 weave performed on six
patella tendon ruptures. They noted that the augmentation device allowed for early mobilization and good functional outcome.

- Two recent biomechanical studies show that an augmented repair is stronger than an unaugmented repair and that suture anchor repair is at least as strong as repair through drill holes.
- Two cases of successful treatment of chronic patella tendon ruptures with Achilles allograft reconstruction have been reported.

COMPLICATIONS

- Rerupture is the most worrisome complication.
- Infection is uncommon but devastating.
- Residual quadriceps weakness and extensor lag are more common with repairs of chronic injuries.

REFERENCES

DEFINITION

- Quadriceps tendon ruptures result in disruption of the fibers of this tendon, thereby disrupting the extensor mechanism of the knee.
- Injury is prevalent in patients more than 40 years old and is more common in men.
- Ruptures usually occur transversely through the tendon at a pathologic area approximately 2 cm proximal to the superior pole of the patella, and then progress obliquely into the medial and lateral retinacula based on the amount and duration of force.
- Ruptures can occur at the bone–tendon interface (older patients), or at the midtendinous or musculotendinous area (younger patients).9
- Unilateral ruptures are more common; bilateral ruptures may occur because of a predisposition from an underlying systemic condition.
- Acute repair of the tendon provides a higher rate of return of function.

ANATOMY

- The quadriceps tendon consists of the coalescence of the rectus femoris, vastus medialis, vastus lateralis, and vastus intermedius, about 3 to 5 cm proximal to the patella, and inserts into the superior pole of the patella.
- The quadriceps tendon averages 8 mm in thickness and 35 mm in width.11
- Normal quadriceps tendon layers include three layers:
  - Superficial layer, which originates from the posterior fascia of the rectus femoris
  - Deep layer, which originates from the anterior fascia of the vastus intermedius
  - Middle layer, which originates from the deep fascia separating the vastus medialis and lateralis from the vastus intermedius.11
- The tendon receives its blood supply from multiple contributions: branches of the lateral circumflex femoral artery, the descending geniculate artery, and the medial and lateral superior geniculate arteries.8
- The distribution of the blood supply in the tendon is asymmetric8:
  - The superficial tendon vascular supply is complete from the musculotendinous junction to the patella.
  - The deep portion of the tendon has an oval avascular area.

PATHOGENESIS

- Quadriceps tendon rupture typically occurs through a site of pathologic degeneration in the tendon caused by repetitive microtrauma.4,5
- Rupture is the result of eccentric contraction of the extensor mechanism against a sudden load of body weight with the foot planted and the knee flexed.7
- Rupture can be due to trauma, use of corticosteroids, and systemic diseases (eg, gout, pseudogout, systemic lupus erythematosus, renal failure, hyperparathyroidism, diabetes mellitus).2
- Fluoroquinolone antibiotics (eg, ciprofloxacin) also have contributed to tendon weakness.
- Bilateral ruptures typically are the result of systemic medical conditions.

NATURAL HISTORY

- Unrepaired quadriceps tendon rupture can lead to chronic extensor lag and weakness.
- Long-term rupture may lead to quadriceps fibrosis as well as patella baja.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Immediate pain, occasional swelling, subcutaneous hematoma
- Occasionally hears or feels a “pop”
- Inability to bear weight
- Pre-existing pain and symptoms related to quadriceps tendon (tendinitis) prior to injury
- Effusion can be indicative of hemarthrosis.
- Loss of extension (straight leg raise) indicates lack of continuity of the extensor mechanism (note: ability to extend may be due to intact retinacula).
- Suprapatella gap (ie, soft tissue defect proximal to the superior pole of the patella) is indicated by loss of continuity of the extensor mechanism at the quadriceps tendon attachment.
- Patella baja (ie, patella of the injured knee more inferior than the contralateral knee) is indicated by loss of proximal extensor mechanism.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs (especially lateral view) may demonstrate bony avulsion fractures at the superior patella or soft tissue calcific deposits in chronic tendinosis.
- Tooth sign$: on Merchant’s view, vertical ridging of osteophytes at the quadriceps tendon attachment site
- Ultrasound, while operator dependent and not as specific, may demonstrate a discrete break in the tendon with abnormal overlying soft tissue.
- Arthrography is invasive; however, it is positive with extravasation of contrast dye from the suprapatellar pouch and along the tendon sheath of the tendon.1
- MRI remains the gold standard in diagnosing partial and complete quadriceps tendon ruptures, in addition to associated soft tissue injuries.
- Notable findings include focal tendon discontinuity, increased signal in the tendon, wavy patella tendon, as well as possible pre-existing pathology.
DIFFERENTIAL DIAGNOSIS
- Patella tendon rupture
- Quadriceps tendon rupture
- Patella femoral contusion
- Cartilage contusion
- Neural injury

NONOPERATIVE MANAGEMENT
- Patients with partial quadriceps tear may be treated non-operatively.
- For the first 6 weeks, the knee is immobilized in extension to assist with tendon healing and maintenance of tendon length.
  - This can be done with a long-leg brace locked in extension or with a long-leg cylinder cast.
  - Patients should be non-weight bearing with crutches.
- In the first 6 weeks, the patient may begin isometric straight leg raises.
- In the next phase, regaining flexion is emphasized and the brace is unlocked to allow restoration of normal gait.
  - The patient is advanced to full weight bearing.
- In the last phase, strengthening is emphasized.
- Patients can return to activity once full range of motion and strength are restored, usually in 4 months.

SURGICAL MANAGEMENT
- All complete tendon ruptures should be repaired acutely to restore extensor function.
- Any partial rupture that has progressed to a complete rupture should also be repaired as soon as diagnosed.

PREOPERATIVE PLANNING
- Review all imaging studies.

ACUTE TENDON REPAIR AT THE TENDON–BONE INTERFACE

Tendon Preparation
- A straight 10-cm midline incision is made, centered over the bone–tendon interface.
- The superficial layers are retracted to examine the deep tissue layers (TECH FIG 1A).
- Hematoma is irrigated.
- The medial and lateral retinaculae are evaluated (TECH FIG 1B).
- The tendon edge of necrotic and degenerative tissue is débrided to normal-appearing healthy tendon tissue (TECH FIG 1C,D).
- Ability to reapproximate tendon ends without undue tension (TECH FIG 1E,F) is confirmed.

Suturing
- Using no. 2 or no. 5 nonabsorbable suture, beginning near the lateral free edge of the tendon, a continuous running-type stitch (eg, Krackow stitch, Mason-Allen stitch) is placed, exiting back at the free end of the tendon (TECH FIG 2A).
- This is repeated for the medial aspect of the tendon.
- When completed, there should be four equal strands of sutures exiting the free tendon edge (TECH FIG 2B,C).
- A trough is made at the superior pole of the patella to assist with tendon reattachment. The trough should not be placed too anteriorly, to avoid patellar tilt.
- Three longitudinal drill holes, 1 to 1.5 cm apart, are placed, exiting out of the inferior pole of the patella.
- Using a suture passer, beginning at the inferior pole of the patella, each of the four strands of suture is brought longitudinally through the patella (TECH FIG 2D,E).
- Holding the sutures provisionally, knee flexion is evaluated with patellar tracking and rotation.
- The tendon is reduced to the superior pole of the patella, and the sutures are tied with the knee in full extension (TECH FIG 2F).
- Knots are buried behind the patellar tendon at the inferior pole.
- To complete the repair, no. 0 nonabsorbable sutures are used in interrupted fashion to repair the medial and lateral retinacula (TECH FIG 2G).
- Patellar positioning, tracking, and tensioning of the repaired tendon are evaluated.
- The position of knee flexion at which tension begins on the repair should be noted, because this will determine the amount of maximum knee flexion allowed in postoperative rehabilitation.
Chapter 49  REPAIR OF ACUTE AND CHRONIC QUADRICEPS TENDON RUPTURES

TECH FIG 1 • Evaluating the deep tissue layers (A) and the medial and lateral retinacula (B). C. Patella retracted inferiorly, demonstrating tear. D. Alice clamps on quadriceps tendon demonstrating mobility of soft tissue. E. Reapproximating the quadriceps tendon to the patella. F. Confirmation that there is no excess tension on reapproximation for tendon repair.

TECH FIG 2 • A. Placement of a continuous running stitch, beginning laterally and exiting back at the free edge of the tendon. B. Four sutures exiting the free edge of the quadriceps tendon. C. Close-up of the four exiting sutures. D. Four sutures from the free edge of the quadriceps tendon brought inferiorly through three longitudinal drill holes in the patella. (continued)
A straight 10-cm midline incision is made centered over the bone–tendon interface. 
- Hematoma is irrigated.
- The tendon edge of necrotic and degenerative tissue is débrided down to normal-appearing healthy tendon tissue.
- Ability to reapproximate tendon ends without undue tension (see Tech Fig 1E,F) is confirmed.
- No. 2 or no. 5 nonabsorbable sutures are used for a continuous running stitch to reapproximate both proximal and distal free lateral edges of the tendon (TECH FIG 3A).
- Procedure is repeated for the proximal and distal medial edges of the tendon.

Tendon edges are reapproximated by provisionally tensioning sutures together and evaluating knee flexion with patellar tracking and rotation.
- The sutures are tied together with the knee in full extension, making sure not to overtension or overlap the reattachment (TECH FIG 3B).
- No. 0 nonabsorbable suture is used, if necessary, to reinforce repair with interrupted figure 8 stitches.
- To complete the repair, no. 0 nonabsorbable suture is used in interrupted fashion to repair the medial and lateral retinacula.
- Patellar positioning, tracking, and tensioning of the repaired tendon are evaluated.
- The position of knee flexion at which tension on the repair begins should be noted, because this will determine the amount of maximum knee flexion allowed in postoperative rehabilitation.

ACUTE TENDON REPAIR AT MUSCULOTENDINOUS AND MIDTENDINOUS AREAS

- A straight 10-cm midline incision is made centered over the bone–tendon interface.
- Hematoma is irrigated.
- The tendon edge of necrotic and degenerative tissue is débrided down to normal-appearing healthy tendon tissue.
- Ability to reapproximate tendon ends without undue tension (see Tech Fig 1E,F) is confirmed.
- No. 2 or no. 5 nonabsorbable sutures are used for a continuous running stitch to reapproximate both proximal and distal free lateral edges of the tendon (TECH FIG 3A).
- Procedure is repeated for the proximal and distal medial edges of the tendon.

TECH FIG 2 • (continued)  
E. The center two sutures exit through a central drill hole. F. Sutures are secured with their continuous loop mate—first the lateral set, followed by the medial set. G. Repair of lateral and medial retinacula.

TECH FIG 3 • A. Placement of two sets of continuous running stitches laterally and medially in both the proximal and distal stumps. B. Alignment of four exiting proximal and distal sutures that makes it possible to secure them to each other as tension is applied on the untied suture sets.
**CHRONIC TENDON REPAIR**

- Chronic ruptures have scar tissue present in addition to shortening.
- A longitudinal midline incision is used.
- The tendon is mobilized by releasing adhesions to the surrounding soft tissues, skin, and underlying femur.
- The tendon edges are débrided down to healthy tissue, and scar tissue is removed from the tendon gap.
- If the tendon can be reaproximated, it is repaired similarly to an acute repair.
- If the tendon cannot be apposed without undue tension, a reinforcement (Scuderi technique) or lengthening (Codivilla technique) procedure is indicated.

**Scuderi Technique**

- The tendon edges are débrided to healthy tissue, and scar tissue is removed from the tendon gap (TECH FIG 4A).
- The quadriceps edges are reapproximated and repaired together with interrupted no. 0 nonabsorbable sutures (TECH FIG 4B).
- An inverted V is incised through the full thickness of the proximal quadriceps tendon, with the base of the V ending approximately 1 cm proximal to the rupture (TECH FIG 4C).
- The apex of the V is folded distally and sutured in place (TECH FIG 4D).

This technique also can be used for acute repairs.10

**Codivilla Technique**

- The tendon edges are débrided to healthy tissue, and scar tissue is removed from the tendon gap (TECH FIG 5A).
- The quadriceps edges are apposed and repaired together with interrupted no. 0 nonabsorbable sutures (TECH FIG 5B).
- An inverted V is incised through the full thickness of the proximal quadriceps tendon, with the base of the V ending approximately 1 cm proximal to the rupture (TECH FIG 5C).
- The apex of the V is folded distally and sutured in place (TECH FIG 5D).
- The proximal length of the V is closed longitudinally with interrupted no. 0 nonabsorbable sutures.
- If further augmentation is required, autograft or allograft of fascia lata, semitendinosus and gracilis tendons, or Mersilene tape can be used.

![TECH FIG 4](image1)

**TECH FIG 4** • A. Proximal tendon edge following débridement of scar tissue. B. Apposition and repair of quadriceps tendon to distal quadriceps stump. C. Incision of inverted V through full thickness of proximal quadriceps tendon. D. Apex of V folded distally and secure in place.

![TECH FIG 5](image2)

**TECH FIG 5** • A. Following débridement of tendon to healthy tissue, excess tension is placed on the tendon for reapproximation. B. Reapproximate the quadriceps edges and secure with sutures. C. Incision of inverted V through full thickness of quadriceps tendon for the purpose of lengthening the tendon as it is reapproximated. D. Apex of V folded distally and secured, as proximal tendon is closed to each other to allow for lengthening and repair of tendon without excess tension.
POSTOPERATIVE CARE

- A long-leg hinged brace with the knee locked in full extension is used for 6 weeks (a long-leg cast may be used for unreliable patients).
- The patient is instructed to observe toe-touch weight bearing for the first 1 to 2 weeks, followed by weight bearing as tolerated with crutches during the remainder of the 6-week period.
- Compliant patients can begin range-of-motion (ROM) exercises within the parameters of the hinged brace, which usually is set from 0 to 90 degrees.
  - This flexion amount is the value attained inter-operatively following complete repair to determine when tension begins stressing the repair.
- At 6 weeks, the long-leg hinged brace is unlocked gradually to full flexion.
- Once 90 degrees of knee flexion is achieved and quadriceps strength is sufficient, use of the brace can be discontinued.
- The patient may advance bearing weight without crutches as function returns.
- Therapy is continued to achieve full ROM and quadriceps strength.

OUTCOMES

- Following acute quadriceps tendon repair and rehabilitation, most patients achieve normal gait, regain full quadriceps strength, and regain satisfactory flexion (some knee flexion may be lost owing to tendon shortening during débridement of necrotic tissue for repair).2,9
- Chronic repairs are associated with persistent quadriceps weakness and extensor lag.
- Older patients often have pre-existing patellofemoral chondromalacia and degeneration, often causing exacerbation of anterior knee pain.5
- Recurrence of tendon rupture is rare.

PEAKS AND PITFALLS

| Proper diagnosis | Complete history and physical examination
| Medial or lateral patellar tilt | Anatomic and balanced repair of medial and lateral retinacula
| Excessive patellofemoral contact stress | Avoid excessive shortening of the extensor mechanism
| Patella baja | Avoid overtightening of the tendon repair.
| Superior patellar tilt | Avoid anterior reattachment of tendon to the superior pole of the patella

COMPICATIONS

- Loss of full knee flexion
- Residual weakness of quadriceps
- Infection
- Wound complications
- Patella tilt
- Excessive patellofemoral contact stress
- Patella baja
- Residual extensor lag

REFERENCES

**DEFINITION**
- **Loss of motion** is a generic term that can refer to a loss of flexion, extension, or both. It does not specifically imply a particular etiology.
- **Flexion contracture** implies a loss of extension secondary to contracture or relative shortening of the posterior soft tissues (capsular or muscular).
- **Arthrofibrosis** describes knee loss of motion (ie, flexion, extension, or both) caused by diffuse adhesions or fibrosis within a joint.
- **Ankylosis** describes immobility of a joint, usually secondary to fibrous, cartilaginous, or bony overgrowth.
- Knee loss of motion is a common and serious complication of knee ligament injury or reconstruction. Surgeon understanding of the pathogenesis, preventive measures, and surgical management of this condition is vital for optimum patient care.

**ANATOMY**
- The knee has been described as a ginglymus (simple hinge-type) articulation.
- In actuality, knee motion is complex and requires at least six degrees of freedom (ie, translation in the anteroposterior, mediolateral, and tibial axial planes with rotational moments corresponding to abduction-adduction, flexion-extension, and internal-external rotation).
- The knee joint consists of three independent articulations: the patellofemoral, medial tibiofemoral, and lateral tibiofemoral articulations.
- Constraint of the knee joint is complex and dynamic. It depends on the position of the knee, the direction and nature of a given load, and the integrity of its bony and soft tissue restraints.
- The knee joint is the largest in the body. Its capsular attachments extend from the suprapatellar pouch proximally to posteromedially and from the posterolateral recesses distally.
- Fibrosis can occur anywhere within these confines and ultimately may lead to loss of motion.
- Normal knee motion varies from person to person.
- Most people achieve some degree of recurvatum in full extension, with men averaging 3 degrees and women averaging 6 degrees of hyperextension.
- Normal knee flexion ranges from 140 degrees in men to 143 degrees in women.
- Slight losses of flexion are much better tolerated than slight losses of extension. Full extension is required to allow quadriceps relaxation during the stance phase of gait. Small deficits in terminal flexion may go unnoticed by all but the elite athlete.

**PATHOGENESIS**
- Loss of motion after a knee injury can vary, depending on patient predisposition, the extent and nature of the injury, the timing and technique of surgery, and postoperative management (Table 1).
- Motion loss in an injured or reconstructed knee can be associated with any of a wide variety of conditions.
- A complete understanding of the terminology associated with knee loss of motion is essential to diagnose and communicate the patient’s condition appropriately (Table 2).
- Each area has its own pathoanatomy and relevant physical findings.

**NATURAL HISTORY**
- Loss of knee motion, particularly extension, can have a tremendous effect on clinical outcomes and overall patient satisfaction.
- Pressures across the patellofemoral joint during stance increase from 0 to 30% of body weight when comparing full extension to a 15-degree flexed position.
- These altered mechanics can lead to pain, apprehension regarding motion, and, ultimately, worsening stiffness. Aggressive intercession via a carefully directed physical therapy protocol or appropriate surgical intervention is essential.

**PHYSICAL FINDINGS**
- Knee motion after ligament reconstruction must be monitored vigilantly.
- Motion should be compared with the contralateral extremity.
- Any loss of motion in the flexion or extension plane should be considered abnormal.

**Table 1**  
<table>
<thead>
<tr>
<th>Pathogenesis of Knee Loss of Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patient factors</strong></td>
</tr>
<tr>
<td><strong>Injury pattern</strong></td>
</tr>
<tr>
<td><strong>Timing of surgery</strong></td>
</tr>
<tr>
<td><strong>Technical factors</strong></td>
</tr>
<tr>
<td><strong>Postoperative factors</strong></td>
</tr>
</tbody>
</table>
A complete examination of the knee is essential and can help determine the etiology.

- Inspection
- Swelling or erythema may indicate infection, reflex sympathetic dystrophy, or reinjury.
- Palpation
- Effusion may indicate infection or reinjury.
- Allodynia may indicate reflex sympathetic dystrophy.
- Crepitus may indicate fibrosis, soft tissue calcification, or an anterior cruciate ligament (ACL) nodule.
- A “clunk” may indicate an ACL nodule.
- Range of motion (ROM)
- Extension loss may indicate posterior capsular contracture, infrapatellar contracture syndrome, medial collateral ligament (MCL) calcification, hamstring contracture, notch impingement, ACL nodule, or graft malposition or tension.
- Loss of flexion may indicate quadriceps contracture, infrapatellar contracture syndrome, graft malposition or tension, patellar entrapment, or suprapatellar adhesions.
- Loss of flexion and extension may indicate arthrofibrosis, infection, soft tissue calcification, infrapatellar contracture syndrome, or graft malposition or tension.

**IMAGING AND DIAGNOSTIC STUDIES**

- Plain radiographs—including anteroposterior, lateral, sunrise, and tunnel views—are the essential first step in imaging.
- Hardware failure, osteochondral defects, MCL calcifications, patellar height, patellofemoral alignment, and tunnel placement can be assessed with these images.
- MRI can be obtained to more clearly evaluate the soft tissues.
- The extent and nature of adhesions, graft position, graft failure, and the presence of an ACL nodule can be clarified by MRI.

**DIFFERENTIAL DIAGNOSIS**

- Arthrofibrosis
- ACL nodule
- Graft malposition
- Infection
- Infrapatellar contracture syndrome
- Muscle contracture
- Reflex sympathetic dystrophy

**NONOPERATIVE MANAGEMENT**

- Rest, ice and anti-inflammatory medications should be the first-line intervention for any knee with an acute process as found on physical examination: ie, an inflamed, warm, swollen knee with motion loss.
- Controlled, guided physical therapy is an excellent tool to help regain motion.
- Quadriceps strengthening, active ROM exercises, use of continuous passive motion machines, hanging weights, and extension bracing or casting may all have a role. Each intervention depends on the clinical picture and pathogenesis.
- Our rehabilitation protocol for a multiple ligament knee reconstruction typically involves four phases (Table 3).
- Manipulation under anesthesia has been used by some to improve postoperative motion.4
  - Manipulation should be done with caution, because the procedure itself can cause an inflammatory reaction and lead to further fibrosis.

**SURGICAL MANAGEMENT**

- Failure to progress with nonoperative treatment is a general indication for operative management.
- Identification of the primary cause of the knee stiffness is essential to maximize outcomes.
- Indications for surgical intervention include:
  - Loss of flexion of 10 degrees or more
  - Extension deficits of 10 degrees or more
  - Failure to improve despite 2 months of intense therapy
- The primary goal of operative treatment is restoration of normal knee motion without causing iatrogenic damage to the joint.
- In both acute and chronic knee stiffness, resolution of the inflammatory phase of the condition is mandatory before proceeding with surgical intervention.
- Epidural or regional anesthesia can be used to assist with postoperative pain control to allow more intensive physical therapy in the immediate postoperative period.
- Millett et al10,13 have outlined a systematic nine-step evaluation of potential causes for knee loss of motion, all of which must be addressed whether surgical intervention is performed in an open fashion or arthroscopically.

**Open Surgical Treatment**

- In severe cases of loss of motion of the knee, open releases may be indicated.
- Indications for open débridement and soft tissue release typically include patients with severe arthrofibrosis or patients who have failed previously attempted arthroscopic releases.
- Our general approach is to restore flexion by releasing capsular contractures, by lysing intra-articular fibrosis, and by mobilizing the extensor mechanism.

### Table 2 Terms Associated with Knee Loss of Motion

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arthrofibrosis</td>
<td>Diffuse fibrosis or adhesions</td>
</tr>
<tr>
<td>ACL nodule</td>
<td>Described as a “cyclops lesion,” this is a dense fibrous scar that can form after bone–patellar tendon–bone autograft for ACL reconstruction. It typically is located anterior-lateral to the tibial tunnel and can lead to impingement on the intercondylar notch, preventing full extension.</td>
</tr>
<tr>
<td>Infrapatellar contracture syndrome</td>
<td>Pathologic fibrous hyperplasia of the anterior fat pad leads to adherence of the patellar tendon to the tibia. This leads, in turn, to limited patellar excursion and can be a cause of patella infera.</td>
</tr>
<tr>
<td>Soft tissue calcifications</td>
<td>Calcification and contracture of the capsuloligamentous structures about the knee are a less common, but well-described, cause of motion limitation.</td>
</tr>
<tr>
<td>Muscle contracture</td>
<td>Prolonged immobilization, in either flexion or extension, may lead to deficits in motion due to muscle contracture.</td>
</tr>
</tbody>
</table>
### Chapter 50  KNEE LOSS OF MOTION

#### Table 3  Rehabilitation of Knee Loss of Motion

<table>
<thead>
<tr>
<th>Goals</th>
<th>Program</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase I: 0 to 6 weeks</strong></td>
<td>Full-leg hinged knee brace locked in extension for 3 weeks; may begin passive ROM exercises in neutral weeks 4 through 6 and beyond</td>
</tr>
<tr>
<td>Maximum protection of grafts during early healing phase</td>
<td>Patellar mobilization exercises</td>
</tr>
<tr>
<td>Maintain patellar mobility</td>
<td>Straight leg raises in brace</td>
</tr>
<tr>
<td>Maintain quadriceps tone</td>
<td>Cryotherapy</td>
</tr>
<tr>
<td>Control pain and swelling</td>
<td>Non-weight bearing with crutches</td>
</tr>
<tr>
<td>Maintain full passive extension</td>
<td></td>
</tr>
<tr>
<td><strong>Phase II: 6 to 12 weeks</strong></td>
<td>Begin full flexion in brace</td>
</tr>
<tr>
<td>Increase flexion ROM</td>
<td>Partial weight bearing, slowly progress to full weight bearing by postoperative week 10</td>
</tr>
<tr>
<td>Initiate weight bearing</td>
<td>Stationary bike, patella mobilization, prone hangs</td>
</tr>
<tr>
<td>Quadriceps strengthening</td>
<td>Closed chain strengthening after full weight bearing</td>
</tr>
<tr>
<td>Proprioceptive training</td>
<td></td>
</tr>
<tr>
<td><strong>Phase III: 3 to 6 months</strong></td>
<td>Aggressive ROM exercises</td>
</tr>
<tr>
<td>Increase knee flexion to within 10 degrees of uninvolved side by end of 6th month</td>
<td>Advance proprioceptive training</td>
</tr>
<tr>
<td>Improve strength and proprioception</td>
<td>Agility drills/sport-specific practice sessions without contact at 6th month</td>
</tr>
<tr>
<td>Incorporate functional drills</td>
<td></td>
</tr>
<tr>
<td><strong>Phase IV: 6 to 12 months</strong></td>
<td></td>
</tr>
<tr>
<td>Return to sport if minimal pain and swelling, functional strength within 10% of uninvolved side, successful participation in practice drills</td>
<td></td>
</tr>
<tr>
<td>Multidirectional functional brace recommended for sports up to 18 months</td>
<td></td>
</tr>
</tbody>
</table>

- Extension is restored by addressing notch pathology, posterior capsular contractures, and anterior fibrosis.
- **Positioning**
  - The patient is placed supine on the operating table.
  - A pneumatic tourniquet is placed high on the thigh over a cotton wrap. It is not routinely inflated.
- **Preoperative Planning**
  - Examination under anesthesia is performed.
  - Flexion, extension, and patellar mobility should all be assessed preoperatively.
- With the patient fully anesthetized, the hip should be flexed to 90 degrees.
- Gravity should then be allowed to flex the knee. This reveals the true flexion limit.
- With the hip extended, the heel should be supported; the extension limit is then measured.
- Patellar mobility should then be documented with regard to superior–inferior glide, mediolateral glide, and patellar tilt.
- Comparison to the normal, uninvolved knee is extremely useful.

#### ARTHROSCOPIC EVALUATION

- The affected limb is then prepped and draped in standard fashion.
- A side post is utilized under the drapes along the lateral thigh.
- All surgical landmarks and proposed incisions are then drawn on the skin with a surgical marker.
- A surgical timeout is then performed, confirming the patient, the procedure, and the operative limb.
- Perioperative antibiotics are administered within 30 minutes of the surgical incision.
- In severely fibrotic knees, capsular distention using 120 to 180 mL of saline may be necessary to gain safe access to the knee joint without causing iatrogenic damage to the articular cartilage.
- A standard superolateral inflow portal is then created, followed by an inferolateral viewing portal, and, lastly, by an inferomedial working portal.
- Portals are interchanged as necessary, and additional arthroscopic surgical portals are established when necessary (TECH FIG 1).

#### Suprapatellar Pouch

- In a normal knee, a view of the suprapatellar pouch should reveal the vastus intermedius rising off of the femoral shaft.
- The suprapatellar pouch should extend 3 to 4 cm proximal to the superior pole of the patella.
Scarring in the suprapatellar pouch is the most common cause of loss of flexion and, in certain cases, may preclude safe passage of instruments between the femur and patella (TECH FIG 2).

- Lateral or medial retinacular release, or both, may be necessary before suprapatellar pouch débridement can be done.
- Dense fibrous tissue may make it difficult to visualize normal articular cartilage.
- Using a combination of electrocautery, motorized shavers, arthroscopic knives, or heavy scissors, the suprapatellar pouch is reconstituted by performing aggressive releases.
- Care must be employed to avoid damage to the overlying quadriceps tendon or surrounding articular cartilage.

**Medial and Lateral Gutters**

- Adhesions in the gutters also are common causes of flexion loss.
- Dense bands of fibrous tissue course between the femoral condyles and the medial and lateral retinaculi.
- The surgeon should then clear all abnormal tissue, moving proximally to distally from the femur to the retinaculum.
- The gutters should be débrided to the level of the tibial plateau, both medially and laterally.
- Ninety degrees of knee flexion should be attainable at this point of the procedure.
- Failure to reach 90 degrees of knee flexion at this point mandates further débridement of the suprapatellar pouch or medial–lateral gutters.

**Anterior Interval**

- Débridement of the infrapatellar fat pad and pretibial recess is then performed (TECH FIG 3).
- Care must be undertaken to avoid the intermeniscal ligament.
- The release should proceed 1 cm distal to the level of the meniscus along the anterior tibial cortex.
- Hemostasis is essential in the pretibial recess to avoid recurrent scarring of the infrapatellar fat pad.
- Visualization in the anterior interval often can be difficult. A small, medial parapatellar tendon arthrotomy often is used to initiate débridement in the anteroinferior aspect of the knee.

**Lateral and Medial Retinaculum**

- Using electrocautery, selective lateral and medial retinacular releases are performed.
- This improves patellar mobility and increases the effective joint space in the knee.
- Adequate release is achieved when the patella can be everted at least 45 degrees.

**Intercondylar Notch**

- Scarring over the anterior aspect of the ACL, “cyclops” lesions, or graft impingement within the notch can all be addressed.
- A notchplasty is performed if there is evidence of graft impingement as the knee nears maximal extension.
- Cyclops lesions should be débrided and excised.
- In severe cases, malpositioned cruciate grafts may require débridement or release to achieve full extension.
Menisci
- Normal menisci have significant anteroposterior excursion with knee motion.
- In cases of knee stiffness, the menisci can become scarred in a posterior position during knee flexion, which will limit full extension.
- A probe can be used to assess for meniscal mobility.
- If anterior meniscal excursion is poor, a gutter should be created along the periphery of the meniscus from the midbody, working anteriorly until normal mobility is restored.
- This should help achieve full extension, but a posterior capsular release may be necessary in severe cases.

Posterior Capsule
- If full extension cannot be achieved after release of all the tissues just discussed, open posterior capsular release may be indicated.
- Posteromedial and posterolateral approaches commonly are used.
- The posteromedial approach uses an interval between the superficial MCL anteriorly and the pes anserine tendons posteriorly, revealing the underlying medial head of the gastrocnemius and the posterior oblique ligament.
- The posterior oblique ligament is then released from its femoral attachment, and extension is reassessed.
- If extension is still limited, a posterolateral release is necessary.
- The lateral approach courses over the anterior aspect of the biceps tendon distally to the fibular head.
- The short head of the biceps is reflected posteriorly, revealing the lateral head of the gastrocnemius, which often is intimately attached to the lateral capsule.
- The capsule is then incised anterior to the gastrocnemius tendon, releasing the posterolateral capsule.
- Care is taken to avoid the lateral collateral ligament, the popliteus tendon, and the popliteofibular ligament.

OPEN SURGICAL TREATMENT

Open Anterior Release
- Positioning and examination under anesthesia are performed just as described in the arthroscopic section.
- An anterior extensile approach to the knee is used. Previous vertical incisions can be used, or arthroscopic portal incisions may be extended (TECH FIG 4A).
- The subcutaneous tissues are dissected sharply, and full-thickness flaps are raised medially over the extensor mechanism.
- A medial parapatellar arthrotomy is then employed to gain access to the joint.
  - Care must be taken to protect the medial meniscus and the intermeniscal ligament (TECH FIG 4B).
- A medial release is performed by subperiosteally dissecting the soft tissues off of the medial proximal tibia.
- The release is extended posteriorly, and the deep MCL and semimembranosus are elevated to assist in mobilizing the tibia. The insertion of the superficial MCL must be protected.
- Débridement of the medial and lateral gutters is then performed using a combination of finger dissection along with sharp excision of dense adhesions and fibrosis (TECH FIG 4C,D).

TECH FIG 4 • A. Anterior extensile exposure of the knee is used in the open surgical treatment of arthrofibrosis. B. Medial parapatellar arthrotomy is used to gain access to the knee joint. Note the severity of the intra-articular fibrous adhesions. C. Débridement of the medial and lateral gutters using a combination of sharp and blunt dissection. D. A large quantity of pathologic fibrous tissue was excised during the débridement.
POSTOPERATIVE CARE

- If epidural anesthesia or regional blocks were used during the operative procedure, patients may benefit by continuing their use in the postoperative period. Additionally, intra-articular injections of bupivacaine combined with morphine given in the operating room can assist with postoperative pain control.
- Adequate pain relief is essential for the patient to tolerate the immediate postoperative rehabilitation.
- Continuous passive motion (CPM) is used in the immediate postoperative period to assist with knee ROM.
- When patients are not using the CPM machine, they are placed in a hinged knee brace locked in extension.
- Home CPM usually is needed for 2 to 3 weeks.
- Outpatient physical therapy also is implemented early in the postoperative period.
- Gentle ROM exercises are encouraged initially, so as not to exacerbate the inflammatory process that originally created

Extensor Mechanism Release

- The patellar tendon is dissected free from encasing fibrosis on all sides.
- The infrapatellar fat pad is excised in its entirety. The insertion of the patellar tendon on the tibial tubercle must be protected (TECH FIG 5).
- Adhesions between the quadriceps tendon and the distal femur must be released prior to patellar mobilization.
- An inside-out lateral release is then employed, and the patella is then everted or translated laterally to assist with notch visualization.
- Patellar tracking is then assessed throughout the entire ROM.

Notch Débridement

- If full extension is still unattainable at this point of the procedure, graft impingement and malposition must be addressed.
- Residual cyclops lesions are débrided.
- It may be necessary to excise anteriorly positioned ACL grafts, with removal of involved hardware (TECH FIG 6A).
- Posterior capsular contractures can be released by peeling the capsule off the posterior aspect of the femoral condyles.
- The PCL is then evaluated for impingement and is released if found to be a block to extension.
- Finally, a posterior capsular release from the proximal tibia may be needed if full extension has not yet been achieved (TECH FIG 6B,C).

Closure

- Meticulous hemostasis is achieved using electrocautery following deflation of the tourniquet.
- A medium Hemovac drain is placed intra-articularly to reduce postoperative hematoma formation and is left in place for 1 to 2 days.
- The medial parapatellar arthrotomy is closed with absorbable suture if it can be performed without significant tension on the extensor mechanism.
- The subcutaneous tissues and skin are then closed in standard fashion, and compressive dressings are applied.
- The knee is placed in a hinged knee brace and locked if necessary.
the knee loss of motion. Additionally, articular cartilage may be prone to injury by forced motion or excessive activity.

- Prone hangs, knee sags, patellar mobilization, and active quadriceps contraction are emphasized to maintain full extension.
- More aggressive strengthening exercises are begun as the patient continues to progress and improve.
- Multiple modalities are implemented to minimize postoperative swelling and pain.
  - A cryotherapy device is applied in the recovery room and used in both the inpatient and outpatient settings.
  - Nonsteroidal anti-inflammatory medications (NSAIDs) or short courses of oral corticosteroids can be given to reduce inflammation.
  - Compressive dressings are used.
  - Knee aspiration may be necessary for effusions that are large enough to cause pain, inhibit quadriceps activity, or limit ROM.
  - In severe cases, it may be necessary to restrict weight-bearing postoperatively to protect compromised articular cartilage.
  - Initiation of weight-bearing activities is at the surgeon’s discretion.
  - Extension bracing often can be discontinued once patients have full return of quadriceps function.

OUTCOMES

Nonsurgical Results

- Few studies have been written regarding nonoperative management of knee loss of motion.
- Noyes and associates\(^{11}\) reported on 18 patients who did not regain full motion following ACL reconstruction despite implementation of an early active and passive motion protocol.
- Six knees were treated with serial extension casts, nine had early gentle manipulation under anesthesia, and three required arthroscopic lysis of adhesions.
- Thirteen of the 15 patients treated nonsurgically regained full ROM of the knee.
  - In a separate study, Noyes et al\(^{15}\) prospectively evaluated 443 knees and reported that 23 developed arthrofibrosis following ACL reconstruction.
    - Twenty knees (87%) were treated successfully using manipulation under anesthesia, extension casting, and continuous epidural anesthesia.
    - The authors stated that nonsurgical management often can be successful if initiated early.
    - Loss of knee motion that is present more than 3 months following ligament reconstruction surgery is less likely to respond to nonsurgical means.
  - Dodds et al\(^{9}\) evaluated the results of knee manipulations performed for loss of motion in 42 knees that previously had undergone intra-articular ACL reconstruction.
    - The average time from reconstruction to manipulation was 7 months.
    - Ten knees had concomitant arthroscopic débridement.
    - Average flexion increased from 95 to 136 degrees, and extension improved from 11 to 3 degrees.
    - No complications were reported.

Arthroscopic Results

- Most studies in the literature pertaining to knee loss of motion contain a mixed group of patients with varying degrees of severity, chronicity, and etiology. Results should be interpreted based on the specific variant of motion loss.
  - ACL nodule
    - The term “cyclops syndrome” was coined by Jackson and Schaefer\(^{9}\) after reviewing 13 patients with loss of knee extension after ACL reconstruction.
      - All patients were treated with arthroscopic débridement and manipulation. Patients gained an additional 10 degrees of extension and 27 degrees of flexion immediately postoperatively.
      - Motion continued to improve with longer follow-up.
      - Six of the patients required more than one procedure to achieve these results.
      - Marzo et al\(^{11}\) reported on 21 patients with restricted knee extension following ACL reconstruction.
      - All patients had a cyclops lesion at surgery and were treated with arthroscopic débridement, with 10 patients requiring an additional notchplasty for graft impingement.
      - All patients had good results, with an average extension gain of 8 degrees leaving them with an average final extension deficit of 3 degrees.
      - Fisher and Shelbourne\(^{6}\) reported on 42 patients who required arthroscopic débridement for symptomatic extension loss following ACL reconstruction.
      - Both pain relief and ROM improved postoperatively.
      - No complications were reported.
  - Diffuse arthrofibrosis
    - Multiple studies have documented successful treatment of diffuse intra-articular arthrofibrosis with arthroscopic débridement and release.\(^{1,3,17,24–26}\)
    - Shelbourne and Johnson\(^{22}\) reported on nine consecutive patients with symptomatic knee loss of motion following ACL surgery.
      - Eight of the nine patients underwent ACL reconstruction within 2 weeks of the initial injury and were immobilized in flexion postoperatively.
      - The patients underwent arthroscopic débridement of adhesions in the superior patellar pouch, medial and lateral gutters, and in the anterior interval. Notchplasties also were performed followed by manipulations to regain flexion. Extension casting and physical therapy were used postoperatively.
      - At an average of 31 months follow-up, patients had gained 23 degrees of extension and 18 degrees of flexion. Eight of the nine patients returned to sports.
    - Hasan and associates\(^{8}\) reviewed 17 knees with symptomatic extension deficits following ACL reconstruction.
      - All knees were treated with arthroscopic débridement of intra-articular adhesions with excision of cyclops lesions and revision notchplasties.
      - Postoperative ROM yielded 7- and 8-degree improvements in extension and flexion, respectively.
    - Harner and colleagues\(^{7}\) reviewed 21 of 27 patients who developed motion deficits following ACL reconstruction.
      - Fourteen of the patients were successfully treated arthroscopically, although three of those required a second procedure.
      - Six of the knees underwent formal open débridement for more severe intra- and extra-articular adhesions.
      - Sixty-seven percent of the patients had a good or excellent result at final follow-up.
Open Results

- Open débridement and lysis of adhesions are indicated in cases of severe knee loss of motion, infrapatellar contracture syndrome, and failed arthroscopic intervention.

**Infrapatellar Contracture Syndrome**

- Paulos et al. described infrapatellar contracture syndrome (IPCS) as an exaggerated pathologic fibrous hyperplasia of the anterior soft tissues of the knee.
- Patients with this condition presented with loss of knee flexion and extension, patellar entrapment, and patella infera. The authors recommended open débridement in cases with extra-articular involvement.
- Aggressive rehabilitation was done postoperatively.
- Patients gained an average of 12 degrees of extension and 35 degrees of flexion at final follow-up.
- Eighty percent of patients had signs and symptoms of patellofemoral arthritis, however, with 16% of patients demonstrating patella baja.
- A long-term follow-up study of IPCS reported on 75 patients who had undergone previous surgical intervention.
- Depending on the severity of patellar involvement, arthroscopic and open releases were performed. In cases of patella infera, DeLee tibial tubercle osteotomies were performed.
- Significant gains in ROM were achieved, but numerous patients required revision lysis of adhesions and manipulations.
- The authors concluded that the longer the knee was without acceptable motion, the more likely the patient was to have a poor final outcome.
- Richmond and Al Assal reported on arthroscopic treatment of IPCS. Their results revealed a total increase in knee ROM of 45 degrees in 12 patients with that condition.

**Severe and revision cases**

- Millett et al. retrospectively reviewed eight patients who had undergone an open débridement and soft tissue release for severe knee loss of motion.
  - All patients had failed previous arthroscopic intervention. The average arc of motion preoperatively was 62.5 degrees.
  - At final follow-up, the average motion had increased to 124 degrees.
  - Patient satisfaction scores were high, but there was a significant incidence of patellofemoral arthritis.
  - The authors concluded that an aggressive open release is a reasonable option for stiff knees that are recalcitrant to less invasive procedures.
- A recent study detailed a mini-invasive extra-articular quadricepsplasty followed by an intra-articular arthroscopic lysis of adhesions for severe cases of knee arthrofibrosis. Twenty-two patients were treated with the aforementioned technique, in which a five-stage quadricepsplasty is performed to regain knee flexion. Knee arthroscopy was then performed to remove any intra-articular adhesions and to address pathology within the notch and the anterior interval.
- At 44 months of follow-up, the average maximum degree of flexion had increased from 27 to 115 degrees.
- Complications were rare: one superficial wound infection and one persistent 15-degree extension lag were reported.

**COMPLICATIONS**

- The primary complication of surgical intervention for knee loss of motion is recurrence of knee stiffness.
- Rates of reoperation following arthroscopic débridement range from 6% to 43%. Failure of surgical treatment is directly proportional to the severity of the preoperative stiffness.
- The more invasive the procedure necessary to regain full knee motion, the higher is the risk of potential complications.
- Other complications related to arthroscopic or open débridement and release include the following:
  - Skin tearing or necrosis
  - Wound dehiscence
  - Postoperative infection
  - Septic arthritis
  - Neurovascular injury
  - Extensor mechanism disruption
  - Hemarthrosis
  - Patellofemoral pain syndrome

**REFERENCES**

DEFINITION
- Patellofemoral pain is a common symptom in active adolescents and adults.
- The diagnosis of patellofemoral pain is nonspecific. It may be caused by trauma, instability, or overuse. It also may be caused by lateral compression of the patella on the femur.
- The patella is guided through its normal course in the trochlea of the femur by the static soft tissue as well as the dynamic muscular stabilizers.11
- The lateral retinaculum and patellofemoral ligament make up the lateral static soft tissue stabilizers and can lead to painful compression between the patella and femur if excessively tight.
- This scenario has been described as excessive lateral pressure syndrome (ELPS),7 patellar compression syndrome,14 and patellofemoral stress syndrome.14
- This chapter describes the surgical treatment of ELPS.

ANATOMY
- The patella acts as a fulcrum and provides a smooth surface on which the extensor mechanism can function.3
- The thickest articular cartilage in the body is located in the patellofemoral joint.
- Forces across the patellofemoral joint are about three times body weight during ascending and descending stairs and can reach up to 20 times body weight during activities such as jumping.3
- As the knee flexes from a fully extended position, the patella is drawn into the trochlear groove at approximately 20 degrees.
- In extension, the medial patellofemoral ligament is the primary restraint to excessive lateral translation.
- In early flexion, the lateral trochlear ridge is the primary restraint.
- A tight lateral retinaculum and patellofemoral ligament are responsible for constricting the patella in ELPS.

PATHOGENESIS
- An abnormally tight lateral retinaculum can cause pressure and subsequent pain and degeneration of articular cartilage on the lateral aspect of the patella as it encounters the femoral condyle.
- Some conditions, such as a weak vastus medialis obliquus, malalignment (abnormal Q angle), internal tibial torsion, and femoral anteversion predispose to lateral tracking.
- Other conditions, such as direct trauma (eg, dashboard injury) and dislocation, can result in degeneration of the lateral patellofemoral articular cartilage.

NATURAL HISTORY
- No good long-term natural history studies of ELPS have been reported to date.
- It is well known, however, that disruption of articular cartilage results in progressive degenerative changes.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients typically report insidious onset of anterior knee pain that is activity-related, although some may have experienced trauma in the past.
- Pain typically is exacerbated by prolonged sitting and stair climbing.
- Symptoms and clinical findings of instability do not play a part in ELPS.
- A thorough physical examination should include the following:
  - Examination for effusion. Effusion may indicate traumatic or degenerative disruption of the articular surface.
  - Observation of patellar tracking (J-sign)
  - Patellar tilt test. If the lateral facet cannot be tilted to neutral, the lateral retinaculum is abnormally tight.
  - Patellar glide test. A lateral glide of up to two quadrants is normal. More than this may indicate excessive lateral translation. Comparison should be made to the normal extremity.
  - Patellar apprehension test. Apprehension suggests an unstable patella.
  - Examination for quadriceps tightness, which often is associated with patellofemoral pain.
  - Patellar grind test. Pain may indicate patellofemoral arthritis but also may be found in normal articular surfaces.
  - Inspection for bony knee malalignment (Q angle)

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographs of the knee should include anteroposterior, tunnel, Merchant (sunrise), and 30-degree lateral views. If arthritis is suspected, a posteroanterior flexed 45-degree view should be obtained.
- Lateral subluxation can be measured on the Merchant radiograph. If the line through the patellar apex is lateral to a line bisecting the trochlear sulcus angle, then the patella is subluxed laterally (FIG 1A).
- A CT scan is the best way to evaluate patellar tilt radiographically. Using an axial image, a line is drawn parallel to the posterior femoral condyles and is compared to a line along the lateral patellar facet. If these lines converge laterally, then the patella has excessive lateral tilt (FIG 1B).
- An MRI may be beneficial in evaluating the integrity of articular cartilage and also may show concomitant meniscal and ligamentous pathology (FIG 1C).

DIFFERENTIAL DIAGNOSIS
- Patellofemoral pain (without excessive lateral pressure syndrome)
- Patellar instability
- Lateral meniscal tear
- Patellar fracture
■ Iliotibial band syndrome
■ Prepatellar bursitis
■ Neuroma
■ Osteochondritis dissecans of the patella or trochlea

NONOPERATIVE MANAGEMENT
■ The mainstay of treatment is nonoperative, with most patients benefiting from quadriceps stretching and selective strengthening exercises.
■ Oral analgesics and bracing also can be beneficial.
■ Corticosteroid injection or viscosupplementation may be helpful in patients with concomitant arthritis.

SURGICAL MANAGEMENT
■ The indication for lateral retinacular release is failure of an adequate trial of rehabilitation in a patient with symptomatic patellofemoral pain, excessive lateral retinacular tightness, and lateral tilt.8
■ Lateral release usually is not a successful treatment for lateral patellar instability and, in some cases, can result in iatrogenic medial patellar instability.
■ Successful lateral retinacular release can be performed using either arthroscopic or open techniques.

Preoperative Planning
■ Range of motion, patellar tilt and subluxation, and ligamentous stability should be examined while the patient is under anesthesia.
■ Particular attention should be paid to patellar tracking as the knee is taken through a range of motion (ROM).
■ The operative knee should be compared to the contralateral side.

Positioning
■ The patient is placed in the supine position with the operative leg supported according to the surgeon’s preference for standard knee arthroscopy (FIG 2).
■ A nonsterile tourniquet is placed around the thigh.

Approach
■ A superolateral inflow portal is established just lateral to the vastus lateralis obliquus.
■ Standard inferomedial and inferolateral portals are used.

FIG 2 • Patient positioning for standard knee arthroscopy using a leg holder and superolateral portal.
ARTHROSCOPIC LATERAL RELEASE

- Diagnostic arthroscopy is performed with the 30-degree arthroscope placed in the anterolateral portal.
- The entire knee is examined to rule out concomitant intra-articular pathology.
- The posteromedial and posterolateral compartments are visualized using the Gillquist technique.
- Meniscal tears, articular cartilage lesions, and loose bodies are identified and addressed surgically when indicated.
- Patellofemoral tracking is visualized as the knee is put through its ROM.
- Once the diagnostic arthroscopy is completed, an Esmarch bandage is used to exsanguinate the leg, and the tourniquet is inflated.
- The camera is placed in the inferomedial portal and a hooked coagulation device in the inferolateral portal.
- Under direct arthroscopic visualization, the release is started just distal to the inflow cannula (TECH FIG 1A).
- First the synovium is cut, exposing the underlying retinaculum.

The retinaculum, which has a distinct firm feel, is then cut using multiple passes with the electrocaudery device (TECH FIG 1B).
- The release should extend down to the level of the inferolateral portal.
- Great care should be taken to not cut the vastus lateralis muscle or tendon.
- If the superior lateral geniculate vessels are seen, they should be aggressively coagulated.
- Patellar tilt is assessed after release. The surgeon should be able to tilt the patella 30 to 45 degrees with the knee fully extended.
- Excessive lateral release may result in medial instability.
- After the release is completed, the tourniquet is gradually deflated to assess for excessive bleeding.
- The portal sites are closed, and a sterile compression dressing and cryotherapy device are applied.
- Use of a drain may be considered on a case-by-case basis.

PEARLS AND PITFALLS

| Indications | The indication for isolated lateral release is retropatellar pain from the lateral patellofemoral joint secondary to soft tissue tightness. Lateral retinacular release should not be performed as an isolated procedure if patellar instability is the primary problem.⁸,¹⁷ |
| Instability | It is important to not transect the vastus lateralis obliquus muscle and tendon during release, because that can predispose to medial instability. |
| Hemostasis | The superior lateral geniculate vessels are at risk during lateral release. Deflating the tourniquet before closing can help identify excessive bleeding. Use of a cryotherapy device and a compression dressing will also decrease the risk of hemarthrosis. |
| Landmarks guiding length of release | The superolateral inflow cannula is an excellent guide for the most proximal starting point of the release. The release should extend distally to the inferolateral portal. |

POSTOPERATIVE CARE

- A compression dressing and a cryotherapy device are used to decrease risk of hemarthrosis.
- Patients are allowed to progress to weight bearing as tolerated and discard crutches when they are ambulating safely.
- Patients are initially seen 1 week after surgery to assess knee motion and quadriceps function and to remove sutures.
- Some patients benefit from formal physical therapy for ROM and quadriceps strengthening to facilitate return to normal function.

OUTCOMES

- Arthroscopic isolated lateral retinacular release has a success rate ranging from 70% to 93%.¹²,¹³,¹⁵
One prospective, randomized study found that 93% of patients returned to presymptomatic activity level.

The same study found quadriceps strength deficits in 40% of patients, but in almost all cases the strength was within 10% of the normal leg.

Arthroscopic and open techniques have similar success rates. Arthroscopic and open techniques have similar success rates.

Success rates of lateral release are lower when performed for instability alone or when advanced patellofemoral arthritis is present.

COMPLICATIONS

Hemarthrosis is the most common complication, followed by infection. Medial instability from overaggressive release can be especially difficult to manage. The diagnosis of medial instability can be difficult to make. Patients may report a sensation of lateral instability if the patella sits in a medially subluxed position during early flexion, then snaps laterally during continued flexion. This is important because if the clinician incorrectly treats the presumed lateral instability with a medial stabilization procedure, the symptoms could worsen.

Other potential complications include quadriceps tendon rupture, patella baja, thermal injury, and arthrofibrosis.

REFERENCES

DEFINITION

- In most cases, patellar dislocation results in injury to the medial retinacular ligaments, including the medial patellofemoral ligament (MPFL), leading to increased lateral patellar mobility.
- The MPFL is the primary ligamentous restraint against lateral patellar displacement.
- Competency of the MPFL is both necessary and sufficient to restore lateral patellar mobility to a normal range; consequently, surgical treatment should aim for restoration of a functional MPFL.

ANATOMY

- The main stabilizer of the patella in normal knees is the bony congruence between the patella and trochlear groove.
  - When the trochlear groove is dysplastic, as it is in many patients with patellar instability, the medial retinacular ligaments (ie, the MPFL) take on a greater role.
  - Even in the presence of a normal trochlea, MPFL deficiency can result in symptomatic lateral patellofemoral instability.
- The patellotibial and patellomeniscal ligament complex play a secondary role in restraining lateral patellar displacement, whereas the medial patellofemoral retinaculum contributes little to patellofemoral stability.
- The MPFL is an extra-articular ligament that lies in layer 2, between the medial retinaculum superficially and the joint capsule on its deep surface. The vastus medialis obliquus (VMO) tendon lies superficially anteriorly and inserts onto the anterior third of the MPFL.
- In a recent cadaveric study, the MPFL was moderately or well developed in 17 of 20 (85%) specimens, and poorly developed in 3 of 20 (15%).
- The MPFL is about 58 mm long, with a width and thickness of 12 mm and 0.44 mm, respectively, at its midpoint.
- The MPFL fans out anteriorly, inserting on the proximal two thirds of the patella.
- The femoral attachment of the MPFL is posterosuperior to the medial femoral epicondylye and just distal to the adductor tubercle when the knee is fully extended. The center of the anterior edge of the femoral attachment is located 9.5 mm proximal and 5.0 mm posterior to the center of the medial femoral epicondylye (FIG 1).

PATHOGENESIS

- Patellar dislocations usually occur when the foot is planted, the knee is partially flexed, and the body pivots abruptly, resulting in internal rotation of the femur. Patients may or may not have sustained a direct blow.
- Patients may report that something “popped out” medially, as the uncovered medial femoral condyle becomes prominent.
- The knee usually gives way secondary to pain inhibition of the quadriceps and disruption of the mechanical advantage of the extensor mechanism, and the patient falls down.
- If the knee remains flexed, the patella may remain dislocated over the lateral femoral condyle.
- The history of injury may be unclear, especially if the patella rapidly and spontaneously reduced.
- In one cohort of 189 patients, 61% of first-time dislocations occurred during sports activity.

NATURAL HISTORY

- Fithian et al reported a 17% incidence of redislocation in a cohort of first-time dislocators followed over 2 to 5 years.
- On the other hand, patients presenting with recurrent patellar instability are much more likely to continue experiencing additional dislocations than patients who present with their first dislocation.
  - The risk of a repeat dislocation in patients presenting with a history of prior patellar dislocation is about 50% over a 2- to 5-year period.
  - The strongest risk factor for recurrent patellar instability is a history of prior patellar subluxation or dislocation.
  - Other risk factors include female gender and younger age (less than 18 years old).
  - In one study, girls with open tibial apophyses had the worst prognosis for instability.
- It is unclear whether patellar dislocation leads to premature arthritis.
  - Crosby and Insall reported that degenerative changes were uncommon after patellar dislocation.
  - In a more recent study, however, the incidence of degenerative changes was significantly higher at 6- to 26-year follow-up in first-time dislocators treated nonoperatively.

FIG 1 • Schematic diagram of the medial knee. The medial patellofemoral ligament (MPFL) arises between the adductor tubercle and medial epicondylye, then runs forward just deep to the distal vastus medialis obliquus (VMO) to attach to the superior two thirds of the medial patellar margin.
PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient should be asked about mechanical complaints of locking or catching, because osteochondral loose bodies off the medial patellar facet or lateral trochlea (kissing lesion), impaction fracture of the lateral femoral condyle, or avulsion fragments off the medial patella may result from a patellar dislocation.
- Physical examination should include:
  - Lateral-medial patellar translation. Increased laxity is signified by more than two quadrants of translation; 10 mm or more of lateral translation; or the absence of an endpoint.
  - Apprehension sign. Inability to fully translate the patella laterally because of patient guarding may lead to a false-negative result.
  - J-sign. The patella abruptly translates laterally as the knee is fully extended, moving in an upside-down “J” pattern.
  - Check-rein sign. A positive test (no endpoint) signifies MPFL laxity (analogous to a Lachman test).
  - Patellar facet palpation. Tenderness may indicate an osteochondral or avulsion injury.
  - Medial retinacular palpation. Tenderness may indicate retinacular injury. A palpable defect may be felt in the retinaculum or even the VMO.
  - Effusion. A tense effusion or hemarthrosis (on aspiration) after an acute dislocation raises suspicion for an osteochondral fracture. MRI or arthroscopy should be considered.
- The examination also should evaluate associated injuries and rule out differential diagnoses:
  - Anterior cruciate ligament (ACL) injury results from a similar noncontact pivoting mechanism and also leads to an acute effusion. The Lachman test is highly sensitive for an ACL disruption. Pivot shift also may be attempted, but may be difficult to perform on an acutely injured knee. To rule out ACL injury definitively, ligament arthrometry or stress radiography is recommended for all patients presenting with knee injury.
  - If posterior cruciate ligament (PCL) injury is suspected, the patient is checked for normal tibial stepoff with the knee flexed to 90 degrees. A posterior drawer and quadriceps active test also may be done.
  - Medial collateral ligament (MCL) and lateral collateral ligament (LCL) injuries result in joint space opening with valgus or varus stresses, respectively. These tests are performed in both full extension and 30 degrees of flexion. Comparison stress radiographs can be useful to control for individual variation.
  - A posterolateral corner (PLC) injury results in 10 degrees or more of external rotation asymmetry (dial test) and a positive posterolateral drawer test.
  - Medial patellar instability can occur following prior lateral retinacular release. Medial patellar instability can be distinguished from lateral instability by the DeLee sign. The patient is placed in the lateral decubitus position with the injured side up. With medial patellar instability, gravity subluxates the patella medially. As the knee is flexed, the patella reduces in the trochlea with pain. The DeLee sign is positive if the application of a laterally directed force on the patella (which reduces the patella from its subluxated position) eliminates the pain caused by flexion of the knee.
  - Meniscal tears are indicated by joint line tenderness and also possibly by positive McMurray and Appley’s grind tests.
  - Diagnosis of extensor mechanism disruption should be obvious based on an inability to straight-leg raise and actively extend the knee.
  - Patellofemoral osteoarthritis may be obvious on plain radiographs, but early stages require MR arthrography or arthroscopy for diagnosis.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Recommended plain radiographs include a standing anteroposterior view, a true lateral view with the knee flexed 30 degrees, and a standard axial patellar view at 30 or 45 degrees flexion.
- On the lateral radiograph, patellar height is measured according to the method of Caton and Deschamps (ie, the ratio of the floor of the trochlea crosses the anterior border of both femoral condyles (crossing sign)\(^4\) (FIG 2A). Alternatively, the positive trochlear prominence (ie, the sagittal distance between the trochlear groove and the anterior femoral cortex) on the lateral view has been shown to correlate well with trochlear dysplasia\(^4,5\) (FIG 2B). A trochlear groove prominence of 3 mm indicates trochlear dysplasia (FIG 2C).
- The axial patellar view may demonstrate lateral patellar subluxation or even frank dislocation. It may demonstrate medial patellar avulsion fractures, although these may be missed on plain radiographs.
- Stress radiography has been advocated to demonstrate abnormal patellar mobility.
  - With the knee flexed to 30 degrees, an axial patellar view is taken with a laterally directed force applied to the medial side of the patella.
  - Measurements are made on both the symptomatic and asymptomatic knees.
  - A side-to-side increase of 3.7 mm of lateral translation on the symptomatic side compared to the asymptomatic side is considered abnormal.\(^24\)
  - MRI identifies osteochondral injuries on the patella and femur, as well as loose bodies, that may be missed on plain radiographs.
  - A tense effusion should be aspirated.
  - Presence of gross hemorrhrosis on joint aspiration is an indication for MRI to assess for osteochondral fracture and loose body.
  - The TT–TG offset is the transverse distance between the anterior tibial tuberosity (TT) and the center of the trochlear groove (TG).\(^4\)
  - It can be measured on axial CT or MRI (FIG 2D).
  - Lateral offsets of 20 mm or more should be corrected with medialization of the tibial tubercle.
FIG 2 • A. On a true lateral radiograph, trochlear dysplasia is evident when the floor of the trochlea crosses the anterior borders of both femoral condyles (ie, the “crossing” sign). B. Measurement of the trochlear prominence on the lateral view according to Dejour et al. X and Y are lines tangential to the anterior and posterior cortices of the distal femoral metaphysis, respectively. Line Z crosses the most prominent point of the line of the trochlear groove (point B) and the upper aspect of the posterior border of the condyle. Line Z crosses the anterior aspect of the lateral condyle (point A) and line X (point C). The distance BC (in mm) is the trochlear prominence. C. Lateral radiograph demonstrating a knee with positive trochlear prominence. Note that the floor of the trochlea lies anterior to the line tangential to the anterior cortex of the distal femur. D. Measurement of the tibial tuberosity–trochlear groove (TT-TG) offset, the transverse distance between the apex of the anterior tibial tuberosity and the center of the trochlear groove. Measurements are made on superimposed axial CT or MRI images. E,F. MPFL injury appearance on MRI. E. Transverse gradient-echo image of the knee obtained at the level of the insertion of the adductor magnus tendon 3 weeks after lateral patellar dislocation demonstrates a complete tear of the femoral origin of the MPFL, with MPFL fibers retracted anteriorly (solid arrow). Partial injury, with surrounding edema, to the midsubstance of the patellar retinaculum (open arrow) also is seen. F. Transverse gradient-echo image of the knee in a different patient 2 days after lateral patellar dislocation showing partial injury to the femoral origin of the MPFL. The MPFL fibers (solid white arrow) are wavy and show longitudinal split, and there is extensive surrounding edema. A complete tear (open arrow) is seen in the patellar insertion of the medial patellar retinaculum. A large joint effusion with layering (black arrows) is present, consistent with hemarthrosis. Note also the inferior fibers of the VMO (arrowheads).

- MRI also is useful in identifying the location and degree of medial soft tissue injury preoperatively.
- MPFL injuries occur commonly in the form of tears near the femoral attachment or avulsions off the femur, but also may occur as midsubstance tears or avulsions off the patella (FIG 2E,F). Injuries to multiple sites in the medial ligamentous stabilizers may occur.5

DIFFERENTIAL DIAGNOSIS
- Ligament/capsular injury (ACL, PCL, MCL, LCL, PLC)
- Osteochondral injury
- Medial patellar dislocation
- Extensor mechanism disruption
- Meniscal tear
Chapter 52  PROXIMAL REALIGNMENT OF THE MEDIAL PATELLOFEMORAL LIGAMENT

- Patellofemoral osteoarthritis
- Contusion

**NONOPERATIVE MANAGEMENT**
- Nonoperative treatment usually is indicated for acute, first-time dislocators without associated osteochondral fracture and loose bodies.
- Randomized prospective studies comparing operative and nonoperative treatment of initial patellar dislocation found no benefit from immediate medial retinacular repair.
- Although there is evidence suggesting that immobilization following patellar dislocation may lower the risk of redislocation, patients often do not accept prolonged cast or splint immobilization. As a result, nonoperative management relies on brace protection during early progressive mobilization and functional rehabilitation.
- After an acute dislocation, patients initially are placed in knee immobilizers for comfort and weight bearing as tolerated.
- As soon as comfort allows, passive ROM exercises and resisted closed-chain exercises in a patella-stabilizing brace are begun.
- Patients are allowed to return to stressful activities, including sports, on resolution of the effusion, attainment of a full ROM, and return to at least 80% of their quadriceps strength compared to the noninjured limb.
- Patients are encouraged to continue wearing the patella-stabilizing brace during participation in pivoting activities and sports.

**SURGICAL MANAGEMENT**
- An associated osteochondral fracture and loose body occurs in 3% to 4% of first-time dislocators and is an indication for acute surgical treatment.
- In this case, primary MPFL repair should be performed after fixation of the osteochondral fracture. Preoperative MRI can help in localizing the site of MPFL injury.
- Surgical management usually is indicated for any patient with at least two documented patellar dislocations and a physical examination demonstrating excessive lateral patellar laxity.
- For these recurrent dislocators, MPFL reconstruction should be done.

**Preoperative Planning**
- Appropriate imaging studies should be reviewed.
- Plain radiographs should be reviewed for the presence of trochlear dysplasia (ie, a cross sign and trochlear prominence of 3 mm or more), avulsion fractures, and loose bodies.
- If signs of trochlear dysplasia are present, an axial CT or MRI scan should be obtained to measure the TT-TG offset. Offset of 20 mm or more should be treated with medialization of the tibial tubercle.
- If patella alta is present (ie, Caton-Deschamps ratio of 1.2 or greater), then distalization of the tibial tubercle should be considered.
- MRI scans should be reviewed for the presence of avulsion fractures, osteochondral fractures, and loose bodies.
- If MPFL repair is to be performed, MRI should be reviewed to identify all locations of MPFL disruption. Failure to identify and treat each location of MPFL disruption may jeopardize the repair.
- Examination under anesthesia should confirm excessive lateral patellar mobility.
- The patella should displace more than 10 mm laterally from the centered position with the knee flexed 30 degrees, and there should be a soft endpoint or no endpoint with the knee extended.

**Positioning**
- The patient is positioned supine.
- If an osteochondral fracture and loose body amenable to reduction and fixation are present, surgery may proceed with an open approach (see Primary MPFL Repair at the Patellar Insertion, in the Techniques section).
- If a diagnostic arthroscopy is performed before MPFL reconstruction, then the limb is placed in an adjustable leg holder to adjust knee flexion during the procedure.

**Approach**
- The surgical approach depends on whether a primary MPFL repair or reconstruction is to be performed.
- During MPFL repair, the surgical approach is determined by the location of MPFL and retinacular injury. MPFL injury may be seen as a proximal or distal avulsion, or as a tear near the femoral origin, the midsubstance, or the patellar insertion. Multiple sites of injury may coexist.

**DIAGNOSTIC ARTHROSCOPY**
- Standard anterolateral and anteromedial portals are used.
- A superolateral portal is used to facilitate viewing of the patellar articular surface and passive patellar tracking and mobility.
- Articular cartilage lesions are addressed.
- Specifically, the patellofemoral compartment is assessed for the severity of articular cartilage injury and the presence of degenerative changes.
- Unstable cartilage flaps are débrided.
- Loose bodies are removed.

**PRIMARY MPFL REPAIR AT THE PATELLAR INSERTION**
- A midline skin incision is made extending from the superior pole of the patella to the midaspect of the patellar tendon.
- After dissection through the subcutaneous tissue, the superficial medial patellar retinaculum (layer 1) is identified. It is incised and reflected medially, exposing the underlying MPFL.
- The MPFL is inspected both visually and digitally along its entire length to identify all sites of injury.
- The deep synovial layer (layer 3) can be dissected off the deep surface of the ligament to aid in inspection.
- The knee is then flexed to 30 degrees with the patella manually reduced in the trochlear groove.
TECHNIQUES

- Avulsions are repaired with suture anchors.
- Tears of the substance of the MPFL are repaired with no. 2 Fiberwire (Arthrex, Naples, FL) in a modified Kessler fashion (TECH FIG 1).
- After the repair, proper tensioning is assessed.
  - The knee is taken through a full passive ROM to evaluate patellar tracking, looking for abrupt or gradual deflection of the patella that might indicate either excessive or insufficient medial tightening.
- The femoral origin of the MPFL may be accessed through an extensile midline skin incision.
  - Alternatively, the origin may be approached through a separate posterior incision centered between the medial epicondyle and the adductor tubercle.
  - The dissection is carried down through the subcutaneous tissue, and the injured medial retinacular tissue is identified.
  - MPFL avulsions off the femur are repaired with suture anchors placed at a point 9 mm proximal and 5 mm posterior to the medial epicondyle, just distal to the adductor tubercle.
  - To augment the repair, a 10-mm × 60-mm strip of medial retinacular tissue (layer 1) is dissected off the femur, leaving the patellar attachment intact (TECH FIG 2).
  - This medial retinaculum strip may be placed over the repaired MPFL and anchored into the adductor tubercle using a cancellous screw and either a spiked washer or suture anchor.

AUGMENTED MEDIAL PATELLOFEMORAL LIGAMENT REPAIR AT ITS FEMORAL ORIGIN

- With the knee extended, a laterally directed force should reproduce a firm endpoint ("check rein" sign).
- Patellar mobility is assessed by applying medial and lateral forces of about 5 pounds with the knee flexed to 30 degrees. This should produce 5 to 10 mm of medial and lateral translation, respectively. If lateral displacement is less than 5 mm or more than 10 mm, then the medial repair is retensioned.
- The wound is closed in layers.

TECH FIG 1 • A. Disruption of the medial patellofemoral ligament (MPFL) near its femoral origin. B. For repair at this site, the superficial medial patellar retinaculum (layer 1) is reflected medially, exposing the torn MPFL. With the knee flexed 30 degrees, midsubstance MPFL tears are repaired primarily while avulsions are repaired using suture anchors.

MEDIAL PATELLOFEMORAL LIGAMENT RECONSTRUCTION

Semitendinosus Tendon Graft Harvest and Preparation

- The sartorial fascia is exposed through a 2- to 3-cm skin incision made 2 cm medial and distal to the medial border of the tibial tubercle (TECH FIG 3).
- The sartorial fascia is incised in line with the palpable gracilis tendon.
  - Avoid making this incision too deep, to avoid injury to the underlying superficial MCL.
- Identify and isolate both the gracilis (proximal) and semitendinosus (distal) tendons from their deep aspect, ie, from within the bursal layer.
- Apply tension to the semitendinosus while freeing it from the crural fascia at the posteromedial corner with tissue scissors.
- Place stay sutures of no. 0 or 1 absorbable on a tapered needle, and then divide the tendon from the tibial insertion.
- Once all tendinous slips have been freed, harvest the semitendinosus tendon using a closed (preferred) or open tendon stripper.
- Baseball stitches are placed on both free ends for later graft passage through the two patellar tunnels. The remaining free ends are discarded after graft fixation.
- The graft is prepared on the back table by first sizing the graft to 240 mm, then folding it in half, leaving a doubled graft of 120 mm. The excess is removed.
- A pullout suture of no. 5 polyester is placed through the loop to be used for pulling the doubled graft into the blind femoral tunnel.
- A baseball stitch 25 mm in length is placed in the looped end of the graft.

Patellar Tunnel Placement

- A longitudinal incision the length of the patella is made at the junction of the medial and middle thirds of the patella (in line with the medial border of the patellar tendon at the distal patellar pole).
- The medial 8 to 10 mm of the patella is exposed by subperiosteal dissection with a no. 15 scalpel.
- The dissection extends medially and dorsally around the patella through layers 1 (longitudinal retinaculum) and 2 (native MPFL), stopping after the transverse fibers of the native MPFL have been cut. The capsule (layer 3) is left intact (TECH FIG 4A).
- A 4.5-mm drill hole is placed on the medial side of the upper pole of the patella adjacent to the articular margin (TECH FIG 4B).
- A corresponding drill hole is placed on the anterior surface of the patella approximately 8 mm from the
medial border (this point corresponds to the lateral edge of the original retinacular dissection).
- The two drill holes are connected with a curved curette.
- A second 4.5-mm drill hole is placed on the medial side of the patella at a point two thirds down the length of the patella.
- Again, a corresponding drill hole is placed on the anterior surface of the patella about 8 mm from the medial border, and the two holes are connected with a curved curette.
- If the semitendinosus graft is more than 4.5 mm in diameter, the drill holes are enlarged slightly to facilitate graft passage.
- It is important to avoid placing the distal patellar tunnel distal to the native insertion of the MPFL to avoid constraining the distal pole of the patella.

**Femoral Tunnel Placement and Checking Isometry**
- A skin incision is made just anterior to the palpable ridge connecting the medial femoral epicondyle and the adductor tubercle (see Tech Figs 3 and 4).
- The knee is flexed slightly to facilitate palpation of this landmark (flexion moves the hamstrings posteriorly away from the medial epicondyle).
- If the patient is obese and the landmarks are difficult to palpate, a small skin incision is made and palpation is done through the wound to identify the ridge.
- The graft may be placed between layers 1 and 2 or between layers 2 and 3 (joint capsule) (ie, it may lie superficial or deep to the native MPFL).
- Placing the graft between layers 2 and 3 is preferred, because blind dissection superficial to the native MPFL may disrupt the insertion of the VMO into the anterior portion of the MPFL; in addition, by placing the graft deep to the native MPFL, the latter may be repaired to the graft during wound closure.
- The graft should not be placed deep to the capsule, because it should remain extra-articular to avoid graft abrasion and facilitate complete healing.
- Using a long, curved clamp, the selected interval is developed (again, preferably between layers 2 and 3) from the patellar incision anteriorly to the medial femoral epicondyle posteriorly.
- With the tip of the clamp overlying the ridge between the medial epicondyle and adductor tubercle, layers 1 and 2 are incised using a no. 15 blade.

**Graft Passage and Fixation**
- No. 5 suture is passed through the Beath pin on the looped end of the graft, and the pin then is advanced out the lateral femoral cortex to pass the graft into the femoral tunnel.
- Fixation to the femur may be achieved reliably with a 20-mm absorbable interference screw.
- The looped isometry suture, if left in place in the retinacular tunnel, may be used to pass the free ends of the graft through the retinacular interval created previously (TECH FIG 5A, B).
- The free graft arms are passed individually through their respective patellar tunnels using double 22-gauge stainless steel wire or a curved suture passer.
- The graft arms enter the medial border of the patella and exit anteriorly (TECH FIG 5C).
- The free graft arms are then doubled back and sutured on themselves just medial to the patella using two figure 8 mattress sutures of no. 2 nonabsorbable suture on a tapered needle.

**TECH FIG 5 • A.** The synthetic isometry suture is in place. After correct placement of the femoral attachment site is confirmed using the isometry suture, the semitendinosus graft has been fixed to the femur using an interference screw. **B.** The isometry suture is used to shuttle the graft anteriorly out the medial patellar incision. The graft will then be fixed to the two patellar tunnels. (continued)
Graft arms are passed through the 2 patellar tunnels and sutured back onto themselves.

Interference screw in blind femoral tunnel

MPFL graft tunneled between layers 2 and 3 of the medial retinaculum

TECH FIG 5 * (continued) C. Schematic diagram demonstrating fixation of the graft posteriorly into a blind femoral tunnel, and anteriorly to two patellar tunnels. At the patella, each limb of the graft enters into respective medial drill hole, exits the anterior drill hole, then is sutured back to itself medial to the patella.

- Patellar mobility is checked after the first suture is placed. There should be a good endpoint, or checkrein, with the knee in full extension and at 30 degrees of flexion, full knee ROM, and 7 to 9 mm of lateral patellar displacement from the centered position at 30 degrees of flexion.

- Excess graft is sharply removed.

- The native MPFL is sutured to the graft, and then the retinaculum is closed over the graft.

- The wounds are closed in standard fashion.

**PEARLS AND PITFALLS**

**Indications**
- Perform examination under anesthesia to confirm excessive lateral patellar mobility.
- Perform arthroscopy to stage articular cartilage lesions and rule out preexisting arthritis, a contraindication to MPFL reconstruction.

**Femoral tunnel placement**
- This is one of the most critical steps in the operation.
- Adjust the tunnel placement to ensure appropriate graft behavior during flexion and extension, recreating isometry.

**MPFL graft tensioning**
- Center the patella in the patellar groove and ensure that the MPFL graft is lax throughout a range of motion, becoming tight only when the patella is displaced laterally from its centered position.
- The patella should enter the trochlea from the lateral side as the knee is flexed.

**Overtightened graft resulting in excessive medial constraint**
- If the patella enters the trochlea from the medial side as the knee is flexed or if there is less than 5 mm of lateral patellar glide with gentle manual force at 30 degrees of knee flexion, then the graft is overtensioned. The sutures should be removed and the graft retensioned.

**Breakage of patellar bone bridge**
- May occur during preparation of the two patellar tunnels or during passage of an oversized graft through a tight patellar tunnel.
- If this occurs, then drill a second exit hole more laterally on the anterior patellar surface or drill the tunnel transversely across the patella, exiting at the lateral patellar margin.
- The graft can be secured by tying the sutures over a button or suturing the end of the graft to the soft tissues on the lateral patellar border.
POSTOPERATIVE CARE

- Weight bearing as tolerated is allowed immediately postoperatively in a drop-lock or knee extension brace.
- Bracing may be continued for up to 6 weeks during ambulation to prevent falls until quadriceps control is restored.
- After the soft tissue procedure, passive ROM exercises and resisted closed-chain exercises are begun as soon as possible to restore ROM and quadriceps control.
- If a tibial tubercle osteotomy is performed, passive ROM using heel slides is begun postoperatively. No active extension is allowed for 6 postoperative weeks. At that time, full active ROM is begun, followed by closed-chain resistance exercises at 3 postoperative months.
- Patients are allowed to return to stressful activities, including sports, when they attain full ROM and have regained at least 80% of their quadriceps strength compared to the noninjured limb.
- If at least 90 degrees of flexion is not achieved by 6 postoperative weeks, then the intensity of the therapy program must be increased; manipulation under anesthesia (MUA) may be needed between 9 and 12 postoperative weeks if stiffness does not resolve with therapy alone.

OUTCOMES

- In a series of 92 knees treated with MPFL reconstruction, Fithian et al17 reported only 7 failures or reoperations (7.6%) and only one case of frank patellar redislocation (1.1%). Most of the reoperations were for stiffness and were treated successfully with MUA.
- Schottle et al22 reported 86% good and excellent results at 47 months after MPFL reconstruction using semitendinosus autograft. In their series of 15 MPFL reconstructions, there was one case of bilateral recurrent instability.
- Steiner et al,23 in a series of 34 patients treated with MPFL reconstruction using a variety of graft sources, reported 91.1% good and excellent results at 66 months and no recurrent dislocations.
- In series by both Schottle et al22 and Steiner et al,23 the presence of trochlear dysplasia did not affect the outcome of MPFL reconstruction.
- Nomura and Inoue18 reported on 12 knees after hybrid MPFL reconstruction using semitendinosus graft at a minimum of 3 years follow-up. There were 83% good and excellent results, and no cases of recurrent patellar subluxation or dislocation.

COMPLICATIONS

- Stiffness
- Redislocation
- Excessive medial patellar constraint resulting in a painful, overconstrained patella6,12,16,17
- Patellar fracture

REFERENCES

DEFINITION
- Tibial tubercle transfer is a versatile surgical alternative in the treatment of difficult and resistant patellofemoral disorders ranging from patellofemoral instability to patellofemoral arthritis.
- Patients with combined instability and arthritis often benefit from tibial tubercle transfer.
- Tibial tubercle transfer may be best regarded as “compensatory.” In other words, if a multiplicity of structure and alignment factors leads to patellar instability or arthritis, carefully planned repositioning of the tibial tubercle can compensate for these deficiencies, providing permanent relief of pain and instability.

ANATOMY
- The patella articulates within the femoral trochlea in such a way that the distal aspect of the patella enters the trochlea from a slightly lateralized position upon initiation of knee flexion. Normally the patella enters the trochlea promptly within the first 10 degrees of flexion, first making contact with the distal aspect of the patella.
- As the knee flexes further, load is transferred more proximally on the patella such that in full flexion, contact is on the proximal aspect of the patella. The intervening flexion transfers load more gradually along the patella, moving proximally with each degree of flexion load.¹¹
- As the patella enters the trochlea with further knee flexion, the trochlea becomes deeper, so that containment of the patella is improved. Therefore, in most people, the point of greatest instability is early flexion of the knee, when the trochlea is at its shallowest and containment of the patella is most limited.

PATHOGENESIS
- The pathogenesis of problems around the patellofemoral joint relates to dysplasia of anterior knee anatomy, malalignment, and trauma.
- Most patients with significant dysplasia have a congenital underlying imbalance of the extensor mechanism, which leads to improper morphologic development.

The position of the tibial tuberosity relative to the femoral trochlea further complicates the process of patella entry into the trochlea.⁴
- This relationship has been referred to as the tibial tuberosity to trochlea groove (TT-TG) index, measured in millimeters using superimposed tomographic images of the position of the central trochlea and the tibial tubercle (FIG 1).
- The patella is contained within a soft tissue investing layer of tendon and retinacular structure.
- The lateral retinaculum extends to the iliotibial band but also proximally to the lateral femur and to the tibia (the patellofemoral and patellotibial components, respectively, of the lateral retinaculum).
- On the medial side is the medial patellofemoral ligament (MPFL), which extends from the proximal half of the patella to the adductor tubercle region.¹
- The patellar tendon is located distally, with the quadriceps tendon proximally connecting the patella to the quadriceps muscle. The quadriceps tendon is a massive tendon, including a major vastus lateralis tendon component on the proximal lateral aspect of the patella.
- The superolateral corner of the patella is supported dynamically by the vastus lateralis obliquus, which interdigitates with the lateral intermuscular septum.¹⁴

FIG 1 • The relation of the tibial tubercle (TT) to the central trochlear groove (TG)—the TT-TG relationship—pertains to patella instability. A. Normal TT-TG relationship, in which the tibial tubercle and trochlear groove are lined up. B. Lateralized tibial tubercle.
A chronically lateralized extensor mechanism is likely to cause abnormally high lateral pressure on the femoral trochlea, thereby leading to developmental flattening of the lateral trochlea and also flattening of the patella (FIG 2). Although it is not always the case, this pattern of development most likely explains the poor development of the lateral trochlea and persistent instability in patients with abnormal extensor mechanism alignment. Such patients stretch the medial patella support structure over time, leading to subluxation and tilt of the patella in many cases.

This stretching can lead to chronic instability, chronic overload of the lateral patellofemoral joint, dislocation (which often causes medial patella articular damage), breakdown of the lateral patellofemoral joint, and pain related to overload of the joint and peripatellar retinacula.13

Some patients have anterior knee pain as the result of blunt trauma, usually with the knee flexed.

An impact to the flexed knee and resulting trauma to the patellofemoral joint usually leads to proximal patella injury.

This is important, because anteriorization of the tibial tubercle shifts contact on the patella proximally and can, therefore, exacerbate a lesion on the proximal patella related to blunt injury.

Because movement of the tibial tubercle was not involved in the injury in many patients who have had blunt trauma, the problem usually is not one of abnormal extensor mechanism alignment requiring correction.

NATURAL HISTORY

The natural history of patellofemoral pain, instability, or arthrosis often relates to the imbalance noted earlier. With chronic lateral tracking of the patella in the trochlea, overload occurs with increased point loading on the patella and trochlea, particularly the patella.

Eventually this can lead to breakdown of articular cartilage and what Ficat7 has called excessive lateral pressure syndrome (FIG 3).

Schutzer21 demonstrated a high incidence of patellofemoral tilt and subluxation in patients with patellofemoral pain, compared with controls.

With dislocation of the patella, the medial patellofemoral ligament is torn and, even after healing, elongated. This further exacerbates any tendency toward lateral displacement of the patella out of the trochlea.

With blunt trauma, pain is related to impact and subchondral bone injury, generally on the proximal patella. This pain, then, originates from injured subchondral bone, because there are no nerves in cartilage.

PATIENT HISTORY AND PHYSICAL FINDINGS

With the patient who may be a candidate for tibial tubercle transfer, it is important to establish that this definitive surgery truly is indicated because of a structural alignment imbalance or articular overload condition leading to instability or pain.

The physical examination should emphasize a very critical look at patella tracking within the femoral trochlea, the condition of the medial patellofemoral ligament, evidence of articular breakdown of the patellofemoral joint, evidence of retinacular or soft tissue pain, and a search for other possible causes of pain such as medial or lateral compartment disease or referred pain from the hip or back.

Careful palpation of the retinacular structure around the patella will indicate whether there is soft tissue or retinacular overload contributing to pain.18

In some cases, simple release of the painful retinacular structure may be all that is needed.

When examining the medial patellofemoral ligament, holding the patella laterally in extension is recommended, then slowly...
flexing the knee to see whether the medial patellofemoral ligament delivers the patella into the central trochlea by 20 to 30 degrees of knee flexion. A distinct pressure, pushing the examining finger back as the patella enters the trochlea, should be encountered using this technique.

- If the patella remains lateralized with the examining finger holding it lateral as the knee is flexed to 20 to 30 degrees of flexion, the medial patellofemoral ligament is incompetent.10

- Similarly, in a patient who has had previous extensor mechanism surgery, the examiner should hold the patella medially in extension and flex the knee abruptly to 30 to 40 degrees of flexion (FIG 4).

- If the patella enters the trochlea very suddenly and reproduces the patient’s symptom, he or she actually may have a medial instability problem (ie, medial subluxation) that requires repair or reconstruction of the lateral support structure or even lateralization of the tibial tubercle if it previously was over-medialized.

- The patella is held in the central trochlea, and the knee is flexed with compression of the patella to see if this elicits crepitus or pain. The degree of flexion at which this crepitus or pain occurs is important in localizing the location of the lesion, bearing in mind that the articulation surface of the patella moves proximally as the knee is flexed. This compression of the patella in the trochlea should be repeated as the patient extends the knee actively against resistance of the other examining hand from full flexion up to full extension, taking note of where pain or crepitus occurs with active extension against resistance.

- Every patient should be examined prone so that the hip can be rotated internally and externally to see if there is a source of pain within the hip. With the patient prone, the pelvis is flat, and, therefore, flexion of the knee may be completed to compare with the contralateral side to establish whether the quadriceps and extensor mechanism are overly tight. The patient should be taught at this time how to stretch the extensor mechanism.

- Nonoperative treatment should be exhausted before considering surgical intervention.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- In diagnosis of the anterior knee, a standardized office radiograph with the knee flexed 45 degrees and standardized axial radiograph of the patellofemoral joint with the knee flexed exactly to 30 degrees is very important.15

- By 45 degrees of knee flexion, the patella normally is centralized in the femoral trochlea. This is a good screening test in the office to determine whether there is significant imbalance of the extensor mechanisms.

- Radiographs taken in more than 45 degrees knee flexion are not particularly useful in most patients.

- Our practice has not found 30-60-90-degree radiographs useful.

- Many patients present for evaluation with axial radiographs taken only at 90 degrees of flexion. This probably is easier for radiology technicians, because they can simply hang the patient’s legs over the side of an examining table and take the axial radiograph in this fashion. It is very important to standardize flexion to 45 degrees, using a support frame as needed.

- The other important office radiograph is the true lateral view16 (FIG 5), which is taken with the knee at 30 degrees of flexion and standing. The posterior femoral condyle should be overlapped.

- This view is technically demanding, but most radiology technicians with reasonable experience can palpate the posterior condyles, and with one or sometimes two tries, obtain a good lateral view with overlap (or near-complete overlap) of the posterior condyles.

- This study shows the femoral trochlea completely, so that the central sulcus can be identified as well as both medial and lateral aspects of the trochlea from proximal to distal.

- Other imaging studies include CT, MRI, and radionuclide scan. Relatively few patients require these studies.

- If CT is done, it is best performed at 0, 15, 30, and 45 degrees of knee flexion, obtaining mid-patella transverse images to see how the patella enters the trochlea. This should be done with reproduction of normal standing alignment on the tomographic table.

- MRI is less useful in many patients but can be helpful in evaluating articular cartilage and soft tissue structure, as well as gaining insight into subchondral bone reaction.
Radionuclide scanning is not often used but can be extremely helpful in determining subchondral bone reaction to overload. It may be most applicable in patients with trauma to the anterior knee, unexplained anterior knee pain, or chronic patella overload, and in cases involving workers’ compensation litigation where objective findings beyond the normal studies needed to determine appropriate treatment are particularly important.

In some cases, a single photon emission computed tomographic (SPECT) scan also can help in accurately locating a source of subchondral bone overload. SPECT may play a role, selectively, in patients who require a patella unloading or resurfacing procedure.

Nonoperative Management

Before tibial tubercle transfer is considered, all patients must exhaust nonoperative management, including complete lower extremity core stability therapy, patellofemoral taping and bracing (I prefer the Tru-Pull brace that I helped design, DJ ORTHO, Vista, CA), and modification of activity.

Viscosupplementation may be helpful in some patients with patellofemoral arthritis but has not been very helpful in most cases.

Surgical Management

In patients with more severe extensor mechanism malalignment, instability, pain, and eventual articular cartilage breakdown are fairly common. When specific factors such as disruption of the MPFL cause instability, reconstruction of the deficient structure should be considered first.

In many patients with patella instability, restoration of medial support, either by imbrication (open or arthroscopic) or reconstruction of the medial patellofemoral ligament and release of tight lateral retinaculum, may be the procedure of choice. In general, this is the first line of surgical treatment after failed nonoperative measures in a patient with patella instability related to deficiency of medial support structure.

In patients with more severe dysplasia, a high TT-TG index (see Fig 1B), and degenerative change in the patella or trochlea, tibial tubercle transfer offers an opportunity to improve balance permanently and provide long-term relief of instability.

Tibial tubercle transfer in the treatment of patella instability is best used when the TT-TG index is high (>20 in most cases), the Q angle is high (usually >20 degrees) or the lateral trochlea is dysplastic, such that soft tissue reconstruction alone will either be less likely to succeed or require excessive tension resulting in overload of the medial patellofemoral joint.

Anteriorization alone is best reserved for patients with patella arthritis alone without malalignment.

The primary concern with MPFL reconstruction in the face of more serious malalignment and patella instability is the need to “pull” the patella in a posteromedial direction to gain stability, thereby adding load to the patella that eventually might lead to patellofemoral joint degeneration. For this reason, the wise surgeon will recognize the inherent benefit of tibial tubercle transfer in selected patients with more severe patella instability to compensate for the malalignment problems leading to the instability in a way that limits or avoids point articular loading on the patella.

Tibial tubercle transfer also provides immediate fixation and stability, making early ROM possible, further reducing the risk of stiffness, tightness, and chronic pain in the anterior knee following reconstructive surgery for instability.

In the treatment of patellofemoral arthritis, tibial tubercle transfer plays an important role in joint preservation.

Many patients have patellofemoral arthritis as a result of excessive lateral pressure, as originally described by Ficat. This excessive lateral pressure eventually causes erosion of the lateral patellofemoral joint, sometimes to bone, because of the constant lateralization of the patella related to lateral subluxation and high lateral pressure on the lateral patella facet. Lateral release has been used to reduce some of this pressure and is helpful in the early stages when patella tilt is prominent.

Tibial tubercle transfer is a powerful procedure for unloading and rebalancing the extensor mechanism, however, placing the patella into the center trochlea and maintaining it there through a range of motion.

By adding some anteriorization to a medial tibial tubercle transfer (ie, anteromedial tibial tubercle transfer) the distal articular surface of the patella also may be unloaded. This is important, because many patients with patellofemoral chondrosis or arthrosis have distal patella articular breakdown or pain. Anteriorization of the tibial tubercle unloads the distal articular surface of the patella permanently, and the medialization component of this procedure rebalances the patella in the central trochlea, unloading the lateral facet.

Most patients with chronic lateralization of the extensor mechanism develop lateral facet breakdown and distal patella degeneration over time because of the abnormal shear stress and lateral overload. Anteromedial tibial tubercle transfer compensates for this and is, therefore, the procedure of choice for treating articular degeneration and pain emanating from the distal or lateral patella articular surface.

Anterolateral tibial tubercle transfer may be best regarded as a salvage procedure in patients who have had previous overmedialization of the tibial tubercle. It has been helpful in relieving pain related to chronic medial patellofemoral arthritis resulting from a previous Hauser procedure in which the tibial tubercle was moved posteriorly, medially, and distally to stabilize the extensor mechanism at an earlier time.

Medial Tibial Tubercle Transfer

Incision and Dissection

Medial tibial tubercle transfer is best approached through a midline incision from the mid patella to a region approximately 5 to 7 cm distal to the tibial tubercle.

The medial and lateral borders of the patella tendon are identified, the anterior tibialis muscle is reflected posteriorly and retracted, the skin edges are retracted, and a cut is made deep to the tibial tubercle.

Osteotomy

A flat incision is made posterior to the tibial tubercle, tapered anteriorly at its distal extent such that only about 1 mm of bone is left at the distal tip of the osteotomy and the proximal cut is made about 2 mm above the patellar tendon insertion.

This cut should be made perpendicular to the anterior surface of the tibia such that a flat ledge is left to add
additional stability to the transferred tibial tubercle. This proximal cut must be made in such a way that the tibial tubercle may be freely moved medially, i.e., so that the medial side of the proximal cut is more proximal than the lateral side of the proximal cut, open medially.

- The thickness of the cut deep to the tibial tubercle will vary depending on the individual patient’s need for medialization.
- In patients with a severe dysplasia requiring more than 1 cm of medialization, a deeper cut will be required.
- In patients requiring 1 cm of medialization, a proximal tibial tubercle thickness of 1 to 1.5 cm is ample in most cases.
- Care must be taken to taper this osteotomy anteriorly at the distal extent of the cut to allow for easy green-stick fracturing of the tip of the osteotomy to move the tubercle medially.

Completion of the Transfer

- After the osteotomy has been completed with an oscillating saw, the proximal cut usually is made with a ½-inch osteotome.
- The osteotomized fragment is elevated and then displaced medially. If there is an overhang of bone medially, it can be removed with the saw or a rongeur.
- The fragment is then stabilized securely with two cortical lag screws (TECH FIG 1), carefully measuring the depth of the drill hole, overdrilling the proximal fragment, and lagging the fragment down using the posterior cortex to hold the cortical screw.
- Care must be taken not to allow the cortical screw tip to protrude any more than necessary beyond the posterior cortex.

ANTEROMEDIAL TIBIAL TUBERCLE TRANSFER

Incision and Dissection

- To unload both the distal and lateral aspects of the patella, an oblique osteotomy must be created deep to the tibial tubercle, and the tibial tubercle transferred in both anterior and medial directions.8,12
- To perform anteromedial tibial tubercle transfer, a longitudinal incision close to midline, extending from a region about halfway between the patella and the tibial tubercle to about 7 cm distal to the tibial tubercle usually is sufficient.
- After isolating the patellar tendon, the anterior tibialis muscle is released and reflected posteriorly.
- Because an oblique osteotomy will be made from medial to lateral, a large retractor must be placed to retract the anterior tibialis muscle laterally to view the saw making the osteotomy cut as it exits on the posterolateral aspect of the tibia. The entire lateral side of the tibia must be under direct view11 (TECH FIG 2).

Osteotomy

- At this point, it usually is best to use a guide, such as the Tracker guide (Mitek, Norwood, MA), to ensure an accurate osteotomy cut. With experience, some surgeons can
TECH FIG 3 • A. Displacement of the tibial tubercle transfer showing planes for cuts. B. For anteromedial tibial tubercle transfer, the cut proceeds obliquely from medial to lateral, tapering toward the anterior crest distally. After transferring the tibial tubercle along the osteotomy (C), both anteriorization and medialization of the tibial tubercle are achieved (D).

- make this cut without a guide, but only a surgeon who is doing this type of surgery on a regular basis will feel comfortable without guide control.
- An external fixator block also may be used to create an appropriate orientation for the osteotomy (TECH FIG 3A). A drill bit is left at the top and bottom of the osteotomy.
- The osteotomy usually extends from the level of the tibial tubercle to a level of about 7 to 9 cm distally on the tibia and again must exit at the level of the anterior cortex of the tibia to avoid a large fragment distally.
  - Making a deep cut distally increases the risk of tibia fracture; this should be avoided.
- After the guide is placed at the desired angle to create an oblique osteotomy from medial to lateral, a cut is made from the region immediately adjacent to the patellar tendon insertion medially and angled posterolaterally so that the saw blade will exit on the lateral cortex (TECH FIG 3B).
  - This strategy avoids injury to the anterior tibial artery and deep peroneal nerve, which are around the posterolateral corner of the tibia posteriorly.
  - The cut should start distally first where it is most visible, and as the oblique cut proceeds proximally, it will become more posterior.
  - Once the proximal extent of the cut has reached the level of the mid to posterior portion of the lateral tibia cortex, it should be stopped at the lateral side. An osteotome or saw then is used to make a back cut from the corner of the proximal lateral corner of the osteotomy up to a point proximal to the patellar tendon laterally.
  - This allows for release of the lateral cortex when the osteotomy has been completed, and the osteotomized fragment will be displaced anteromedially.
- The third cut for anteromedial tibial tubercle transfer is directly proximal to the patellar tendon insertion on the tibia, about 2 mm above the patellar tendon insertion.
  - This cut usually is made with a ¼- or ½-inch osteotome under direct vision using an Army-Navy retractor to hold the patellar tendon anteriorly.
  - It is best made from medial to lateral and connects the proximal extent of the medial osteotomy cut to the oblique back cut on the lateral side so that the osteotomy is now free to displace anteromedially.
  - It is moved anteromedially by greenstick fracturing the anterior cortex distally, which should be no more than 1 to 2 mm thick at its distal extent.
  - The osteotomized fragment is moved about 1 cm but may be moved slightly more, as needed, to achieve more anteriorization or medialization.
PEARLS AND PITFALLS

**Avoiding complications**

- Patients should stay on crutches for at least 6 weeks, because fracture is a risk with weight bearing that is too aggressive.
- Smoking should be stopped before surgery and not resumed for at least 2 months because of its adverse effect on bone healing.
- Surgery should be accurate and fixation secure.
- Patients should start ROM very soon after surgery to avoid stiffness.
- All patients should receive some form of postoperative anticoagulation, and should have prophylactic antibiotics at the time of surgery.
- Hemostasis should be meticulous, and proper drainage of hematoma implemented as needed.

POSTOPERATIVE CARE

- Following tibial tubercle transfer, immediate ROM is important.
  - If stability is secure, patients are started immediately on ROM exercises.
  - These may start with a single cycle of flexion a day if proximal reconstruction has been done and there is concern about stretching out a proximal repair.
  - In such cases, a short period of immobilization in extension may be appropriate for soft tissue healing, but a single cycle of knee flexion daily after the first 10 to 12 days is important to ensure full ROM later and maximal ROM ultimately.
- Patients are kept on crutches for 6 to 8 weeks and resume weight bearing as tolerated after 6 weeks.
- During the initial 6 weeks, we recommend toe-touch or light weight bearing on the affected side.
- We recommend anticoagulation with aspirin for at least 4 to 6 weeks for most patients.
- Most of our patients go home from same-day surgery and are seen in 1 to 3 days as needed and then for suture removal and radiographs at 10 to 12 days.
- Steri-strips are applied and kept in place for 4 to 6 weeks to minimize wound spread.

COMPLICATIONS

- The primary concerns following tibial tubercle transfer are fracture of the tibia,22 stiffness, thrombophlebitis, nonunion, infection, and hematoma.
- These complications usually can be avoided with proper care.
- Gross obesity increases the risk of complications.

OUTCOMES

- Buuck2 reviewed the results of anteromedial tibial tubercle transfer in patients 4 to 12 years following the procedure and demonstrated that good results are maintained over time.
- Our follow-up studies have consistently revealed a satisfactory outcome in 85% to 90% of patients. Pidorianet al17
demonstrated that results are closely related to the location of articular lesions. Patients with lateral and distal patellar lesions are more likely to experience relief than patients with proximal (dashboard) or medial (s/p dislocation) lesions.

REFERENCES
DEFINITION
- Compartment syndrome can be either acute or chronic.
- Acute compartment syndrome usually is due to trauma to, or reperfusion of, the extremity. Chronic exertional compartment syndrome (CECS) often is associated with the repetitive loading or microtrauma of endurance activities.
- Both acute and chronic compartment syndromes are due to increased interstitial pressure within a compartment, resulting in decreased perfusion and ischemia of soft tissues.
- In contrast to the reversible nature of CECS, acute compartment syndromes progress rapidly and require urgent fasciotomy to avoid irreversible soft tissue necrosis in the affected compartment.
- Wilson first described the concept of CECS in 1912, but Mavor\textsuperscript{12} was the first to successfully treat a patient with anterior compartment syndrome of the leg using a fasciotomy.
- Clinical manifestations of exercise-induced pain relieved by rest, swelling, numbness, and weakness of the extremity have long been attributed to elevated intracompartmental pressures.\textsuperscript{5,17}

ANATOMY
- The leg contains four compartments: anterior, lateral, superficial posterior, and deep posterior (FIG 1).
- The anterior compartment contains the anterior tibial artery, the deep peroneal nerve, and four muscles (tibialis anterior, extensor digitorum longus, extensor hallucis longus, and peroneus tertius). Its borders are the tibia, fibula, interosseous membrane, anterior intermuscular septum, and deep fascia of the leg.
The lateral compartment contains the superficial peroneal nerve and two muscles (peroneus longus and peroneus brevis).

The common peroneal nerve branches into the superficial and deep peroneal nerves within the substance of the peroneus longus after passing along the neck of the fibula.

The superficial peroneal nerve continues within the lateral compartment, while the deep peroneal nerve wraps around the fibula deep to the extensor digitorum longus until reaching the anterior surface of the interosseous membrane.

The lateral compartment does not contain a large artery; the peroneal muscles receive their blood supply via several branches of the peroneal artery.

The lateral compartment is bordered by the anterior intermuscular septum, the fibula, the posterior intermuscular septum, and the deep fascia.

The superficial posterior compartment contains the sural nerve and three muscles (gastrocnemius, soleus, and plantaris) and is surrounded by the deep fascia of the leg.

The deep posterior compartment contains the posterior tibial and peroneal arteries, tibial nerve, and four muscles (flexor digitorum longus, flexor hallucis longus, popliteus, and tibialis posterior).

It is bordered anteriorly by the tibia, fibula, and interosseous membrane, and posteriorly by the deep transverse fascia.

A fifth compartment that encloses the tibialis posterior muscle has been described, but its existence is controversial. It has been suggested that the presence of an extensive fibular origin of the flexor digitorum longus muscle may create a sub-compartment within the deep posterior compartment that may develop elevated pressures.

**PATHOGENESIS**

The etiology of CECS is not entirely understood. It is thought to be due to an abnormal increase in intramuscular pressure during exercise resulting in impaired local perfusion, tissue ischemia, and pain.

Contributing factors may include exertion-induced swelling of the muscle fibers, increased perfusion volume, and increased interstitial fluid volume within a constrictive compartment.

The elevated intramuscular pressure decreases arteriolar blood flow and diminishes venous return.

This, in turn, results in tissue ischemia and accumulation of metabolites.

Elevated lactate levels and water content have been documented in muscle biopsies from compartments with elevated pressures following exercise.

Muscle hypertrophy and increased perfusion volume with exertion do not explain the elevated resting pressure seen in patients with CECS, however. The mechanical damage theory hypothesizes that heavy exertion results in myofibril damage, release of protein-bound ions, increased osmotic pressure in the interstitial space, and, therefore, decreased arteriolar flow in the compartment.

Additionally, in some cases focal fascial defects may be a contributing factor.

Anterolateral fascial hernias are present in 39% to 46% of patients with CECS, as compared to less than 5% of asymptomatic individuals.

**NATURAL HISTORY**

CECS of the leg is a common injury in people involved in running and endurance sport activities, such as young athletes and military personnel.

Pain, as well as occasional numbness and weakness, develops at a predictable interval after initiation of a repetitive, endurance type activity and resolves with rest.

The symptoms are longstanding and recurrent, because patients tend to self-limit but then subsequently attempt to resume activities.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

The following symptoms may be present upon exertion and resolve with rest:

- A sensation of cramping, burning, aching, or tightness in the region of the affected compartment(s)
- Numbness or weakness in the extremity
- A transient footdrop may develop if the deep peroneal nerve is affected.
• A temporary loss of eversion strength may occur if the superficial peroneal nerve is affected.
• Physical examination of the resting lower extremity often is unremarkable.
• Examination following exercise may reveal:
  • Increased tightness of the involved compartments
  • If a fascial defect is present, a focal area of tenderness and swelling may develop as the underlying muscle bulges through the defect.
  • A positive Tinel’s sign over the defect if the superficial peroneal nerve is compressed
• When the history and physical examination findings are consistent with CECS, the diagnosis should be confirmed with pre- and postexercise compartment pressure measurements.
• Most clinicians follow the diagnostic criteria of Pedowitz et al, in which a resting pressure greater than or equal to 15 mm Hg or a 1-minute postexercise measurement greater than or equal to 30 mm Hg or a 5-minute postexercise measurement greater than or equal to 20 mm Hg is considered abnormal and diagnostic of CECS.
• The exercise performed at the time of testing must be intense enough to reproduce the patient’s symptoms; otherwise, the postexercise pressure measurements may be falsely low.
• Several methods for measuring compartment pressures have been described in the literature.
  • These include the slit catheter, wick catheter, needle manometry, digital pressure monitor, microcapillary infusion, and solid-state transducer intracompartmental catheter methods.
  • The Stryker intracompartmental pressure monitor (Kalamazoo, MI) is a handheld digital monitor that can be used to check multiple compartments. It can be used with a side port needle or with an indwelling slit catheter to obtain serial measurements in a single compartment.
  • A new handheld digital device recently developed by Synthes (Paoli, PA) also allows placement of indwelling catheters and may be useful for obtaining serial measurements.
• Near-infrared spectroscopy has been used to determine tissue oxygen saturation. This may be a noninvasive, painless alternative to intracompartmental pressures in the diagnosis of CECS, but is not currently standardized or readily available.
• The vibration test consists of placing a vibrating tuning fork over bone at the area of suspected stress; an elicitation of pain is consistent with a stress fracture.
• Pain when performing resisted ankle dorsiflexion and inversion is consistent with tibialis posterior tendinitis or posteromedial periostitis.

IMAGING AND OTHER DIAGNOSTIC STUDIES
• When pressure measurements are not consistent with CECS, further diagnostic studies may be necessary to explore the differential diagnosis.
• Plain radiographs may demonstrate a periosteal reaction in patients with tibial stress fractures or posteromedial tibial periostitis.
• Bone scan will show increased uptake, and MRI may show edema or a black line at the site of a stress fracture.
• Tingling, numbness, or a positive Tinel’s sign at a specific location may warrant an EMG and nerve conduction study to evaluate for peripheral nerve entrapment.

DIFFERENTIAL DIAGNOSIS
• Tibial stress fractures
• Posteromedial tibial periostitis
• Tenosynovitis of posterior tibialis or ankle dorsiflexors
• Peripheral nerve entrapment
• Radiculopathy secondary to lumbar pathology
• Complex regional pain syndrome
• Peripheral vascular disease
• Popliteal artery entrapment syndrome
• Deep venous thrombosis

NONOPERATIVE MANAGEMENT
• Nonoperative management usually requires activity limitation.
• Symptoms usually return with resumption of prior activity level. Surgery, therefore is indicated in patients who cannot tolerate activity restriction.

SURGICAL MANAGEMENT
• Surgical treatment involves fasciotomy of the affected compartments, sometimes with partial fasciectomy.
• Patients who are unable to maintain their desired activity level owing to symptoms of CECS are appropriate operative candidates.

Preoperative Planning
• It is critical to identify which compartments are affected.
  • All symptomatic compartments should be addressed at the time of surgery. It is common for a failed index procedure to be due to a failure to release an affected compartment.
  • The appropriate approach should be selected based on the compartments that need to be released.

Positioning
• The patient is placed in the supine position for each technique.

Approach
• A single- or dual-incision technique can be used to release the lateral and anterior compartments.
• The perifibular approach can be used to access all four compartments.
• A second posteromedial approach offers easier access to the superficial and deep posterior compartments.
• Endoscopically assisted fasciotomies allow access to the entire length of the compartment, allow visualization of fascial hernias, and may minimize surgical complications such as postsurgical fibrosis and injury to the superficial peroneal nerve.
• The safety and effectiveness of endoscopically assisted compartment release has been demonstrated in cadavers.
• A technique using balloon dissectors and carbon dioxide insufflation is described in the Technique section.
SINGLE-INCISION LATERAL APPROACH FOR ANTERIOR AND LATERAL COMPARTMENT FASCIOTOMY

- The patient is placed in the supine position on the operating table.
- A 5-cm vertical incision is made halfway between the fibular shaft and the tibial crest at the midportion of the leg. The incision should lie over the anterolateral intermuscular septum (TECH FIG 1A).
  - If a focal fascial defect is present, the incision should be adjusted so that the defect can be incorporated.
- A small transverse incision is made just through the fascia, and the septum and the superficial peroneal nerve, which lie near the septum in the lateral compartment and exit the fascia near the distal aspect of the incision, are identified (TECH FIG 1B).
- Longitudinal releases of the anterior and lateral compartments are performed using long Metzenbaum scissors in a proximal and distal direction from the transverse incision in the fascia that crosses over the anterolateral intermuscular septum (TECH FIG 1C).
- A partial fasciectomy may be performed, particularly in cases of recurrence following a prior fasciotomy.
- The fascia is left open.
- The subcutaneous tissue is approximated using 2-0 absorbable suture material.
- The skin is closed with a running subcuticular 4-0 nonabsorbable suture material and Steri-strips.

DUAL INCISION LATERAL APPROACH FOR ANTERIOR AND LATERAL COMPARTMENT FASCIOTOMY

- The patient is placed in a supine position.
- The leg is divided into thirds, and two 3-cm incisions are placed at the junction of the thirds over the anterolateral intermuscular septum (TECH FIG 2A,B).
- The superficial peroneal nerve is identified as it exits the fascia near the distal incision (TECH FIG 2C).
- Fasciotomies of the anterior and lateral compartments are performed on each side of the intermuscular septum (TECH FIG 2D).
- The incisions in the fascia are connected using Metzenbaum scissors to divide the fascia from the proximal incision toward the knee (TECH FIG 2E), then from
TECH FIG 2 • Dual-incision approach. **A.** The leg is visually split into thirds, and two 3-cm incisions are placed at the junction of the thirds over the anterolateral intermuscular septum. **B.** The superficial peroneal nerve is located 10 to 12 cm proximal to the tip of the lateral malleolus. The inferior incision is centered over this area. **C.** Dissection of the superficial peroneal nerve. **D.** A fascial defect often is present in this area, and compartment releases should be centered over these areas if possible. **E.** The incisions in the fascia are connected using Metzenbaum scissors to divide the fascia. **F.** Long scissors are used and are opened only slightly at the tips. (B–D, F: Courtesy of Mark D. Miller, MD.)

the proximal incision toward the distal incision, and finally from the distal incision toward the ankle (TECH FIG 2F).

- Distally, the fasciotomy should extend to 4 to 6 cm proximal to the ankle.
- At the distal aspect of the anterior compartment, the release should be directed more toward the midline to minimize risk of injuring cutaneous sensory nerves at the lateral aspect of the compartment.

- The distal aspect of the lateral compartment fasciotomy should be directed more laterally.
- The subcutaneous tissue is closed with 2-0 absorbable suture material.
- The skin is closed with running subcuticular 4-0 sutures and Steri-strips.

PERIFIBULAR APPROACH FOR FOUR-COMPARTMENT FASCIOTOMY

- The patient is placed in the supine position.
- A 10-cm incision is made directly over the midportion of the fibula (TECH FIG 3A).
- The skin is retracted anteriorly and the fascia of the anterior and lateral compartments is released longitudinally in a proximal and distal direction (TECH FIG 3B).
- The skin is retracted posteriorly.
- The fascia overlying the lateral head of the gastrocnemius is released.
- The fascia over the superficial posterior compartment is incised for a distance of about 15 cm.
The anterior and lateral compartments are retracted anteriorly and the superficial posterior compartment posteriorly. The soleal bridge must be released from the fibula (TECH FIG 3C).

The fascia over the flexor hallucis longus is identified and incised.

The gastrocnemius is retracted posteriorly and the flexor hallucis longus laterally to expose the posterior tibial artery, tibial nerve, and peroneal artery overlying the tibialis posterior.

The fascia is incised around the tibialis posterior and the interval between the muscle and the origins of the flexor hallucis longus is widened if it is constrictive.

The subcutaneous tissue is approximated with 2-0 absorbable suture.

The skin is closed with running subcuticular nonabsorbable 4-0 suture.

---

**POSTEROMEDIAL INCISION FOR FASCIOTOMY OF THE POSTERIOR COMPARTMENTS**

A vertical incision 8 to 10 cm in length is made over the midportion of the leg approximately 1 cm posterior to the posteromedial edge of the tibia (TECH FIG 4A).

The saphenous vein and nerve are identified in the subcutaneous tissue and retracted anteriorly.

The fascia over the superficial posterior compartment is incised for a distance of about 15 cm (TECH FIG 4B, C).

To fully access the deep posterior compartment, the origin of the soleus from the proximal tibia and fibula must be detached (TECH FIG 4D).

The deep fascia can then be sharply divided with Metzenbaum scissors (TECH FIG 4E–G).

The fasciotomy should extend distally to 8 to 10 cm above the ankle.

The opening between the origins of the flexor hallucis longus and the tibialis posterior is enlarged if constrictive.

The subcutaneous tissue is closed with 2-0 absorbable suture.

The skin is closed with running subcuticular nonabsorbable 4-0 suture.
ENDOSCOPICALLY ASSISTED COMPARTMENT RELEASE

- The patient is placed in a supine position.
- Balloon dissectors can be used to create an optical cavity at the fascial cleft, which is the potential space between the superficial fascia (the deepest layer of the skin and subcutaneous tissue) and the deep fascia (the fascia overlying a muscle compartment; TECH FIG 5).
- To insert the balloon dissector, a 2-cm transverse incision is made either at the anterolateral aspect of the knee between the fibular head and Gerdy’s tubercle or at the posteromedial aspect of the knee at the level of the tibial crest.
- Dissection is carried down through the subcutaneous fat and superficial fascia until the deep fascia overlying the muscle is visualized.
- The balloon dissector with a sheath around it is inserted between the superficial and deep fascial layers under direct observation and manual palpation to the level of the ankle.
- The sheath is removed and the balloon is inflated to create a cavity within the fascial cleft.
- The balloon is then deflated and removed.
- A one-way cone-shaped cannula is inserted in the skin at the site of balloon insertion.
- The optical cavity between the superficial and deep fascial layers can be maintained subsequently with 15 mm Hg of carbon dioxide insufflation to allow adequate visualization of the fascia to be released and to allow adequate space to perform soft tissue dissection with the endoscopic equipment.
Alternatively, the cavity is not insufflated, but is maintained with towel clips externally.

Next, the fascia is released with endoscopic scissors down to the level of the ankle under direct vision.

If necessary, a distal instrument portal with a pneumatic lock can be placed, but the fasciotomies usually are carried out proximal to distal through the initial portal.

After the release, the cannula is removed and the cavity is deflated.

The wound is closed in a two-layer fashion with 2-0 Vicryl for the deep layer and a running subcuticular stitch for the skin over a medium Hemovac drain.

---

**PEARLS AND PITFALLS**

| Superficial peroneal nerve injury | Identify the nerve as it exits the fascia at the junction of the distal and middle thirds of the leg; direct the anterior fasciotomy medially and the lateral fasciotomy posteriorly at the distal extent. |
| Saphenous vein and nerve injury | Identify the structures in the subcutaneous tissue at the medial aspect of the leg. Avoid excessive traction on the saphenous nerve, which results in a traction paresthesia. |
| Incomplete fascial release | Muscle herniates at the bottom of the “V” of the fasciotomy, resulting in pain. Extend lateral and anterior fasciotomies to 4 to 6 cm above the ankle and posterior fasciotomies to 8 to 10 cm above the ankle. |

**POSTOPERATIVE CARE**

- Active range of motion at the ankle and knee should begin immediately.
- Crutches can be used as needed in the initial postoperative period, but patients are encouraged to bear weight as tolerated and perform light activities.
- Elevation of the legs while at rest may help to decrease pain and swelling.
- Full activity usually can be resumed 4 to 6 weeks after surgery.

**OUTCOMES**

- Various techniques of compartment release have reports of success rates ranging from 81% to 100%.
  - These techniques include open fasciotomies, one- or two-incision minimally invasive subcutaneous fasciotomies, and fasciotomies with partial fasciectomy.
  - Adequate long-term follow-up is lacking in the literature.
  - Slimmon et al reported on long-term follow-up of patients treated with fasciotomy with partial fasciectomy and noted a good or excellent outcome in 60% at a mean follow-up of 51 months. Thirteen of 62 had reduced activity levels due to recurrence of symptoms or development of a different lower extremity compartment syndrome.
  - Fasciotomy appears to be less effective in alleviating pain in the deep posterior compartment than in other compartments.
  - Some authors have postulated that failure of the fasciotomy may be due to an incomplete fasciotomy or not identifying and releasing the fascia around the tibialis posterior.
- Recurrence rates of 3% to 17% have been reported after fasciotomy.
  - Recurrence may be due to a number of factors, including inadequate fascial releases, failure to decompress a compartment that was believed to be asymptomatic, nerve compression by an unrecognized fascial hernia, and the development of proliferative scar tissue.
  - Other reported complications of fasciotomies with some degree of subcutaneous or blind dissection include arterial injury, hematoma or seroma formation, superficial wound infections, peripheral cutaneous nerve injuries, and deep venous thromboses.
  - The superficial peroneal nerve is particularly vulnerable as it exits the fascia over the lateral aspect of the leg at the junction of the middle and distal thirds.

**REFERENCES**

BACKGROUND

- Care of peripheral nerve problems requires knowledge and understanding of nerve pathology, anatomic nerve variations, patterns of nerve damage and entrapment that follow trauma and common operative procedures, and specialized surgical techniques for manipulation of the damaged peripheral nerve.
- Unlike other surgical disciplines, a large proportion of peripheral nerve surgery attempts to correct neuropathy in the postoperative patient and, therefore, is reoperative in nature.
- Lateral femoral cutaneous nerve (LFCN) neuropathy can be encountered in the orthopedic patient after injuries or procedures in proximity to the anterior superior iliac spine (ASIS), the inguinal region, or the anterior thigh.
  - The symptoms are limited to pain or paresthesias in the distribution shown in FIGURE 1, because this nerve carries only sensory signals.
  - Surgical procedures and trauma to the lateral knee both represent potential for common peroneal nerve (CPN) injury.
  - The nerve can become entrapped in postoperative scar tissue, stretched with knee or ankle dislocations, or inadvertently directly damaged, resulting in neuropathy.

ANATOMY

Lateral Femoral Cutaneous Nerve

- The LFCN arises from the lumbar plexus through contributions from the dorsal divisions of the L2 and L3 spinal roots. In most people, the nerve courses medial to the ASIS and traverses the groin crease under the inguinal ligament as it descends to innervate the thigh.
- The nerve is prone to iatrogenic injury when its anatomy is aberrant; the surgeon should be aware that the LFCN can run through the inguinal ligament and against the ASIS or over the most medial portion of ASIS rather than in its usual course.
- The surface anatomy and the most common site of impingement can be seen in FIGURE 2.

Common Peroneal Nerve

- The CPN is a branch of the sciatic nerve, formed from contributions from the sacral plexus from L4 to S2.
- Pathology of the CPN classically is seen as it wraps around the neck of the fibula, deep to the peroneus longus muscle just before it splits into its deep and superficial branches (FIG 3).
- The CPN innervates the muscles for foot dorsiflexion and eversion and provides sensory innervation to the anterolateral lower leg and the majority of the dorsum of foot and toes.

General Nerve Anatomy

- The peripheral nerve has a significant intrinsic blood supply that permits the surgeon to lift the nerve from its anatomic bed, open the epineurium, and operate between the fascicles.¹
- The endoneurial and perineurial microvessels maintain excellent vascularity to the peripheral nerve. Segmental blood vessels enter the peripheral nerve through the mesoneurium. In addition, an extensive number of longitudinal vessels in the epineurium, perineurium, and endoneurium supply the nerve.²
- Maki et al³ have demonstrated that the “safe” length a nerve can be elevated from its bed (its segmental vascular supply) is a distance of about 60 times the diameter of the nerve. Therefore, the surgeon should consider primarily the need to move the nerve into an area that is free from forces that might externally compress it and, thus, cause symptomatic neuropathy but also should acknowledge internal
Peripheral nerve surgery encompasses repair of two common pathophysiologic entities:

- Accidental nerve transection or direct crush injury leads to nerve dysfunction and possible painful neuroma formation.
- Scar formation from any surgery or trauma can engulf a peripheral nerve and compress it; symptomatic relief can then be accomplished through surgical decompression of the peripheral nerve.

Peripheral nerve injury becomes symptomatic either when a critical function is lost or when paresthesia and pain replace normal sensory signaling.

- Partial or complete nerve transection causes loss of sensory or motor function because of loss of nerve continuity or disruption of the nerve’s blood supply. The nerve’s regenerative capacity then either re-establishes neuronal continuity or forms a disorganized scar within a mature end-bulb neuroma.
- Similarly, compression on a peripheral nerve causes ischemia and neuroma formation.1
- A neuroma contains bundled, disorganized nerve endings within a collagenous mass, and is an anatomic source of the localized pain and paresthesia following peripheral nerve damage.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- History and physical examination, particularly a thorough neurologic examination, often suggest the diagnosis by demonstrating a dermatomal distribution of pain or paresthesia. Further imaging and electrodiagnostic testing may be necessary, mainly to evaluate other causes for the symptoms.2,4
- Central nervous system disease, particularly spinal root impingement, shares many of the same symptoms and must be excluded.
- Diagnostic workup must evaluate and exclude other etiologies for postoperative pain, particularly infection, loosened hardware, mechanical misalignment, spinal involvement, and neoplasm.
- The timing of the sensory or motor symptoms needs to be considered when taking the history and performing the physical examination, because that can aid in understanding the cause of neuropathy.
- When encountering potential neuropathies in the knee or lower leg, the clinician must consider that, although the common peroneal nerve is the major peripheral nerve affected following knee surgery, neuromas of sensory nerves supplying the knee and its surroundings may develop when they are severed or encased in scar tissue.
- These smaller peripheral nerves can be the source of chronic postoperative knee pain and can be mistaken for CPN neuropathy or mask the CPN involvement.
- Therefore, the examining physician should be aware of the different possible causes of pain in this anatomic area and should be able to distinguish deep and superficial paresthesias and pains in the knee area.
- The most commonly affected sensory nerves involved in deep knee pain are the lateral retinacular nerve, the medial retinacular nerves, and the articular branch of the common peroneal nerve, whereas superficial knee pain is caused mainly by involvement of the infrapatellar branch of the saphenous nerve and the medial and anterior cutaneous nerves of the thigh.

**FIG 3** Anatomy of the common peroneal nerve. Note the proximity of the nerve to the fibula as it wraps anteriorly on the lower leg.
If any of these smaller nerves is suspected as the cause of a patient’s symptoms, referral to a peripheral nerve surgeon is suggested.

**IMAGING AND DIAGNOSTIC STUDIES**

- Current imaging techniques—including CT, MRI, and radiolabeled bone scans—have limited, if any, value confirming the diagnosis of a malfunctioning nerve.
- Electrodiagnostic studies also can have a false-negative rate as high as 33%, whereas nerve blocks, because of anatomic variations, can give a false-negative result.
- For these reasons, it cannot be overstated that a diagnostic workup must be interpreted cautiously.

**NONOPERATIVE MANAGEMENT**

- Medical management of paresthesias and pain from injured peripheral nerves centers on symptom management:
  - Activity and lifestyle modification
  - Narcotic and nonnarcotic analgesics
  - Centrally acting agents such as gabapentin and pregabalin
  - Nerve blocks
  - Physical and occupational therapy
- Although medical management offers temporary relief in most patients, it can be complicated by increasing dosage requirements and narcotic dependence, as an acute insult develops into a chronic pain syndrome.
- Among the first steps to focus on are eliminating possible causes of neuropathy and optimizing the patient’s medical condition if comorbidities are present.
- Nonoperative management is considered a failure when patients with neuropathy do not achieve a reasonable recovery by approximately 12 weeks.
  - At that point, additional evaluation by a peripheral nerve surgeon or electrodiagnostic workup is appropriate to determine whether surgical intervention or continued observation is indicated.

**LATERAL FEMORAL CUTANEOUS NERVE**

- The patient is placed in the supine position, and an incision of about 6 cm is made anterior to the anterior superior iliac spine, extending toward the thigh.
- Careful dissection is then carried to deep fascia and toward the inguinal ligament (**TECH FIG 1A**).
- The use of loupe magnification as well as proper microsurgical instruments and bipolar electrocautery is essential when identifying the LFCN because of the variability in its anatomy (**TECH FIG 1B**).
- The LFCN could be encountered at any point in the dissection of the inguinal ligament and must not be damaged.
- Once identified, the nerve is first decompressed distally approximately 4 to 6 cm and then proximally at the inguinal ligament and internal oblique and transversalis deep muscle fascia, where most compression typically occurs (**TECH FIG 1C**).
  - After this release, retroperitoneal decompression is performed by retraction of the muscle and excision of the deep fascia sitting on the top of the nerve (**TECH FIG 1D,E**).
  - Great caution must be exercised dissecting in this area because of the proximity of the deep circumflex iliac artery that crosses the nerve in the retroperitoneum.

**TECH FIG 1**

A. Exposure for dissection of the lateral femoral cutaneous nerve (LFCN). B. Identification of LFCN. C. Internal oblique muscle elevated off LFCN at compression site. D,E. LFCN proximally and distally decompressed. Note the cuff of internal oblique that has been removed around the LFCN proximally.
COMMON PERONEAL NERVE

- With the patient in a supine position, a thigh tourniquet is placed—as long as the patient does not have previous vascular bypasses in this area—and an incision is made 1 to 2 fingerbreadths below the fibular head (TECH FIG 2A).
- Dissection is carried to the deep fascia under loupe magnification, because proper identification of the nerve is critical (TECH FIG 2B).
  - The nerve can easily be mistaken for yellow fat, particularly if it runs abnormally superficially or was displaced with trauma.
- Proximal decompression is performed first by release of the gastrocnemius fascia and its attachment to hamstring and iliotibial fascial tissues (TECH FIG 2C).
- Distal dissection is performed by incising the peroneus longus fascia and retracting this muscle laterally.
- A fascial band that causes both a kink in the nerve as well as compression against the fibula can then be visualized and addressed (TECH FIG 2D).
- Closure is then performed in anatomic layers, sparing the deep fascia, which is not closed, to avoid recreating the nerve compression.
- Great caution should be exercised in patients with a history of previous knee trauma or dislocation, because the anatomy of the nerve may be aberrant, which could lead to iatrogenic nerve injury during surgical approach and manipulation.

TECH FIG 2 • A. Schematic for skin incision to access the common peroneal nerve. B. Exposure of CPN through surgical incision. C. Identification of CPN. D. Identification of compressive band of peroneus longus muscle fascia over CPN.
**POSTOPERATIVE CARE**

- Wound healing concepts should be applied to the peripheral nerve.
  - During the first week after surgery, the nerve will lie in an environment that is predominantly inflammatory. Collagen is not deposited into the wound until the second week, and cross-linking of the collagen does not occur until after the third week.
  - If the nerve is kept immobile during the second and third postoperative weeks, it will become adherent to the surrounding tissues.
  - Conversely, for the nerve to be loose and able to slide through its surrounding tissues, it is necessary to allow the nerve to move with respect to its bed following the first week of splinting.
  - The fact that a nerve will not adhere to a bed of cut muscle and fibrous tissue if it is allowed to glide early in the postoperative period was demonstrated for the ulnar nerve at the elbow in a baboon model.\(^7\)
  - Therefore, in operation on the peripheral nerve, it is essential that the postoperative regimen include some movement of the joints during the first week and splinting be reserved mainly for cases involving nerve grafting.

**REFERENCES**

Chapter 1
External Fixation of the Pelvis 462

Chapter 2
Open Reduction and Internal Fixation of the Symphysis 476

Chapter 3
Open Reduction and Internal Fixation of the Sacroiliac Joint and Sacrum 487

Chapter 4
Open Reduction and Internal Fixation of the Posterior Wall of the Acetabulum 503

Chapter 5
Open Reduction and Internal Fixation of Femoral Head Fractures 514

Chapter 6
Open Reduction and Internal Fixation and Closed Reduction and Percutaneous Fixation of Femoral Neck Fractures 521

Chapter 7
Cephalomedullary Nailing of the Proximal Femur 533

Chapter 8
Open Reduction and Internal Fixation of Peritrochanteric Hip Fractures 547

Chapter 9
Retrograde Intramedullary Nailing of the Femur 558
Chapter 10
Anterograde Intramedullary Nailing of the Femur 569

Chapter 11
Open Reduction and Internal Fixation of the Distal Femur 582

Chapter 12
Open Reduction and Internal Fixation of the Patella 604

Chapter 13
Open Reduction and Internal Fixation of the Bicondylar Plateau 613

Chapter 14
Lateral Tibial Plateau Fractures 622

Chapter 15
External Fixation of the Tibia 629

Chapter 16
Intramedullary Nailing of the Tibia 642

Chapter 17
Fasciotomy of the Leg for Acute Compartment Syndrome 660

Chapter 18
Open Reduction and Internal Fixation of the Pilon 671
Chapter 19
Open Reduction and Internal Fixation of the Ankle 687

Chapter 20
Open Reduction and Internal Fixation of the Talus 697

Chapter 21
Surgical Treatment of Calcaneal Fractures 712

Chapter 22
Open Reduction and Internal Fixation of Lisfranc Injury 724

Chapter 23
Open Reduction and Internal Fixation of Jones Fracture 734
DEFINITION
- Pelvic instability is defined as inability of the pelvis to assume physiologic loads without displacement and functional compromise.
- Pelvic external fixation can serve several different purposes depending on hemodynamic and pelvic structural instability.
- Early external fixator application during resuscitative acute phase management can serve to control intrapelvic hemorrhage.
- External fixation of the pelvis may confer sufficient provisional stability to some injury patterns to facilitate patient mobilization. It may, however, prove inadequate in achieving long-term goals in the absence of additional surgical stabilizing efforts.
- With certain rotationally unstable yet vertically stable patterns, external fixation of the pelvis may serve as definitive management.

ANATOMY
- The pelvis provides structural continuity between the axial skeleton and lower extremities.
- The pelvis affords protection and passage for genitourinary, gastrointestinal, and neurovascular structures.
- Life-threatening massive hemorrhage, a complication of pelvic injury, can be of arterial (branches of the iliac system), venous plexus, or fracture surface origins.
- Additional concerns when treating pelvic ring trauma include injury to the lumbosacral and coccygeal nerves and male urethra.
- The anterior portion of the pelvic ring assumes minimal weight-bearing function and affords little pelvic ring stability.
- The pelvic ring is made up of the sacrum and paired innominate bones. Ligamentous, rather than osseous, support is the sole source of stability to the pelvis.
- Stability of the pelvis is particularly dependent on the tension band of the posterior weight-bearing sacroiliac complex (comprising the anterior sacroiliac ligaments, the interosseous ligaments, and the posterior sacroiliac ligaments) in addition to the iliosacral ligaments within the pelvic floor (sacrospinous and sacrotuberous). The iliolumbar ligaments confer additional stability between the axial skeleton (L5 transverse process) and the hemipelvis (ilium).

PATHOGENESIS
- Pelvic injury patterns (osseous or ligamentous) are determined by the direction, point of application, and magnitude of applied forces.
- Applied forces can be simplified into anteroposterior compression, lateral compression, and vertical shear. Actual forces and accordingly mechanism of injury are likely more complex.
- Resultant instability patterns are categorized as (1) vertically and rotationally stable, (2) rotationally unstable and vertically stable; and (3) rotationally and vertically unstable.
- Anteroposterior compression and hemipelvic rotational forces tend to result in injury to the “anterior ligamentous” complex (severity order: symphysis pubis, ischiosacral ligaments, anterior sacroiliac ligament). The integrity of the posterior tension band is preserved and vertical stability accordingly maintained (FIG 1A). Depending on the severity of injury to the anterior ligamentous complex, rotational instability may ensue.
- Lateral compression injuries, depending on severity, may result in internal collapse of the pelvis. Ligaments both anteriorly and posteriorly generally remain intact. Osseous injuries both anteriorly and posteriorly are typically stable impaction variants. Occasionally internal rotatory instability is sufficient to warrant surgical stabilization (external or internal fixation).
- Vertical instability implies disruption of the posterior tension band of the pelvic ring. This may be of osseous, ligamentous, or combined origin. Division of the sacrospinous and sacrotuberous ligaments in the presence of intact posterior ligaments will render a pelvis rotationally unstable. Further division of the posterior ligaments of the sacroiliac complex will result in both rotational and vertical instability. The involved hemipelvis is unstable in the axial, sagittal, and coronal planes (FIG 1B).
- Any injury mechanism (anteroposterior compression, lateral compression, vertical shear) may result in complete (vertical and rotational) instability if the magnitude of force is sufficient.

NATURAL HISTORY
- Life-threatening hemorrhage associated with pelvic fractures may be intrapelvic or extrapelvic. Identifying the source of bleeding may be challenging. In the absence of extrapelvic and intraperitoneal sources, external fixation of the pelvis may prevent life-threatening exsanguination.
- Early sheeting (circumferential external compression) may offer an initial beneficial hemodynamic response. Suspected sustained hemorrhage of indeterminate source may be intrapelvic arterial in origin. This may respond favorably to angiographic transcatheter embolization.
- Exploratory laparotomy, from the standpoints of role and timing, remains controversial.
- Imaging findings, results of diagnostic peritoneal lavage (if indicated), and response to fluid resuscitation must be considered before exposing the unstable trauma victim to the potential negative effects of abdominal exploration (decompression of intrapelvic tamponade, among others).
- Pelvic fractures associated with violation of the perineal, rectal, or vaginal regions must be identified immediately, and early measures directed toward preventing regional and systemic sepsis must be implemented. Appropriate soft tissue management requires early aggressive débridement and restoration of pelvic stability to facilitate wound care. External fixation is of paramount importance in many such cases, as is diverting colostomy.
Lumbosacral plexopathy may present in combination with sacral spinal canal or foraminal fractures. Pelvic reduction with restoration of stability and occasionally neurologic decompression may afford a more favorable prognosis if properly indicated and executed. Insufficient restoration of pelvic stability may result in complications associated with prolonged recumbency. Additional concerns include malunioin and nonunion. Lower extremity limb-length inequality and rotational deformity may result in functional deficits. Anterior ring injuries with significant displacement (tilt fragments) can result in sexual dysfunction, particularly in females.

PATIENT HISTORY AND PHYSICAL FINDINGS

The history, in terms of the mechanism of injury, offers insight into the energy of injury imparted. Force application and magnitude in turn determine pelvic injury and instability patterns as well as the type and frequency of associated injuries. The patient’s age may affect both physiologic reserve and bone quality. This dictates, respectively, the hemodynamic response and the energy of injury required to generate certain pelvic ring injuries. Preexisting medical comorbidities must be ascertained, as they may have considerable impact on survivability and complications associated with both operative and nonoperative management of pelvic injuries. Pelvic ring disruption is often accompanied by potentially life-threatening injuries to organs, vessels, and nerves within the pelvis, as well as other extrapelvic and closed cavity lesions of the abdomen, thorax, and head. Adequate adherence and response to principles of resuscitation must be assessed and primary and secondary surveys completed. Clinical evaluation includes inspection for abrasions, contusions, limb-length discrepancy, or abnormal rotation of the lower extremities. Palpation and manual testing for instability patterns may be pursued with caution. Stability is suggested (not confirmed) both radiographically and clinically. Identification of any open fracture variants and those with rectal or vaginal continuity is mandatory, as mortality rates in the presence of such lesions are considerable. Physical examination should include:

- Pelvic inspection to identify threatened or compromised soft tissues
- Inspection of lower extremities for limb-length inequality, rotational deformity, associated limb fractures or dislocations
  - Significant asymmetry in limb length or rotation implies rotational or vertical pelvic instability.
  - Further clinical examination or imaging of the limb is warranted if asymmetry is of other than pelvic origin.
- Assessment of pelvic instability
  - Lateral compression injury is implied by internal rotation and shortening.
  - Vertical shear injury is implied by external rotation and shortening.
- The genitourinary area is observed for regional hemorrhage. If present, it implies a urethral tear in a male and a vaginal tear in a female.
- Neurologic assessment to identify deficits in voluntary sphincter control or perianal sensation. Lumbosacral plexopathy implies pelvic instability.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Imaging studies offer a static view of the pelvis. These accordingly may imply but do not confirm stability (or instability) of the pelvis. Conventional radiography is initiated with performance of an anteroposterior (AP) radiograph of the pelvis. In the hemodynamically unstable patient, this image alone is sufficient to allow implementation of treatment. The pelvic inlet and outlet views in combination with the AP radiograph constitute the pelvic trauma radiographic triad (FIG 2A). The inlet view (FIG 2B) best depicts axial (most

### FIG 1 • A. An external rotation injury (AP compression) resulting in “anterior ligamentous complex injury.” Instability is rotational in character and demonstrated in the axial plane. The posterior tension band is intact and vertical stability is preserved. B. A vertical shear injury. In addition to compromise to the “anterior ligamentous complex,” the integrity of the posterior tension band is disrupted. The involved hemipelvis is unstable in all planes. (Modified from Buckle R, Browner B, Morandi M. Emergency reduction for pelvic ring disruptions and control of associated hemorrhage using the pelvic stabilizer. Tech Orthop 1995;9:258–266.)
often posterior) and rotational displacement. In contrast, the outlet view (FIG 2C) best demonstrates vertical displacement.

- Posterior pelvic displacement of more than 1 cm suggests posterior pelvic disruption. Symphyseal diastasis of more than 2.5 cm denotes disruption of the anterior ligament complex.
- Other radiographic clues implying vertical or rotational instability include the following:
  - Sacrospinous ligament avulsions (ischial spine or sacral border fractures)
  - Iliolumbar ligament avulsion (L5 transverse process fracture)
  - Sacral fractures or sacroiliac joint displacement
  - Stress radiographs (“push–pull” studies) may offer a dynamic interpretation of pelvic instability (FIG 3). Longitudinal load and traction are sequentially imparted to the lower extremity of the involved hemipelvis with manual stabilization of the contralateral extremity.
  - This is performed with the patient anesthetized and under AP radiographic control.
  - Such maneuvers are contraindicated in the presence of lumbosacral plexopathy, hemodynamic instability, or ipsilateral lower extremity fractures.
  - Computed tomography (CT) serves as a valuable adjunctive study. Cross-sectional axial images characterize posterior lesions best. Sacral foraminal and central spinal canal involvement is confirmed, as is integrity of the posterior tension band. Sacral impaction as opposed to gap displacement may suggest (but does not confirm) inherent stability.
  - The role of diagnostic and therapeutic angiography remains controversial with regard to management pathways.\(^4,9,16\) External fixation of the pelvis may effectively arrest venous and osseous hemorrhage (the source of 90% of intrapelvic hemorrhage). Sustained hemodynamic instability may suggest extrapelvic or intrapelvic arterial blood loss. In such cases exploratory angiography may be considered and therapeutic arterial angiographic embolization performed as necessary.
  - Diagnostic peritoneal tap and lavage (first described in 1965) has a poorly defined contemporary role.\(^{15}\) Procedure performance, indications, and assay result criteria (cell count) remain ambiguous. The presence of a pelvic fracture may contribute to a false-positive result.
  - Current imaging technology (contrast-enhanced CT, focused abdominal ultrasound) may prove a more reliable tool to determine the likelihood of abdominal injury and the need for laparotomy.

DIFFERENTIAL DIAGNOSIS

- Low-energy pelvic fractures in senescent bone
- High-energy pelvic fractures in younger patients with better-quality bone
Similar fracture patterns in the two groups above suggest a high magnitude of force in the younger population. This in turn is more commonly associated with additional injuries of concerning severity.
- “Non-ring” fractures: iliac crest, ischial tuberosity
- Ring fractures of increasing severity and instability
  - Rotationally and vertically stable
  - Rotationally unstable and vertically stable
  - Rotationally and vertically unstable

NONOPERATIVE MANAGEMENT
- Circumferential pelvic antishock sheeting may offer comfort and enhance ring stability. This noninvasive method employs readily available and inexpensive materials.
- Nonsurgical management is appropriate for lesions accurately deemed stable (confirmed on follow-up both clinically and radiographically).
- The goals for nonsurgical and surgical management are identical. These include avoidance or correction of deformity, maintenance of stability, and pain-free function.

SURGICAL MANAGEMENT
- The role of the external fixator must be defined before application. By decreasing pelvic volume, it offers intrapelvic tamponade. This, in addition to diminishing fracture motion, encourages hemostasis. In this capacity it serves as acute phase management.
- It may offer provisional stabilization of some injury patterns to facilitate patient mobilization. Attempts to stabilize vertically unstable lesions with external fixation alone are inadequate; these injuries require staged supplemental posterior fixation. Used for this purpose, it serves as provisional stabilization.
- Rotationally unstable yet vertically stable patterns may be amenable to external fixation as a source of definitive stabilization. Lesions with considerable symphyseal comminution unreceptive to anterior plating may be managed to union with external fixation, provided the posterior tension band remains functionally intact.

Preoperative Planning
- The surgeon must identify associated intrapelvic, vascular, urologic, and gynecologic comorbidities.
- The surgeon must confirm the patient’s neurologic status and document deficits. Soft tissues are inspected thoroughly and circumferentially.
- The surgeon characterizes, if applicable, the presence and type of pelvic instability, assigning the injury pattern to a classification scheme.
- The intended purpose of external fixator must be defined (resuscitation or provisional versus definitive stabilization).
If for purposes of provisional stabilization, the surgeon should determine the anticipated timing, sequence, and method of subsequent definitive stabilization.

- Frame design and pin location are selected (anterior iliac crest, supra-acetabular, posterior C-clamp) based on the pelvic injury pattern, the patient’s hemodynamic status, the available imaging, and surgeon familiarity.
- An immediate presurgical pelvic radiograph is obtained to assess the impact of retained bowel gas or contrast on imaging capability (if required).

### Positioning

- The patient is placed supine on a radiolucent table.
- Adequacy of imaging and efficacy of closed reduction maneuvers are confirmed.
- Preparation is done from the umbilicus to the anterior thighs, including both iliac crests.
- One or both lower extremities are included circumferentially as required to effect rehearsed closed reduction maneuvers.

### Approach

- Adequate fixation and accordingly proper pin placement are the principal requirements for restoring pelvic stability when applying an external fixator.
- Pins for purposes of anterior pelvic external fixation may be placed either in the anterior iliac crest or in the supra-acetabular region (FIG 5).
- Ease of insertion is an important attribute when applying a resuscitation frame.
- Pin placement within the iliac crest is more expeditiously performed and lacks significant regional anatomic hazards.
- On occasion, this area may be compromised by soft tissue concerns or proximity to fracture planes.
- In such cases, pin placement within the supra-acetabular region is an option.

- Pins and frames in this lower position may offer improved access to the abdomen and unlike pins placed within the iliac crest are less irritating to anterolateral abdominal soft tissues.¹⁸
- In an obese patient, these pins (supra-acetabular) may be better tolerated and less prone to loosening and infection.
- The dense bone of the supra-acetabular region offers stability of fixation as good as or better than the iliac crest.
- Some authors investigating the biomechanical performance of these pins (supra-acetabular) demonstrated superior purchase within bone and diminished displacement of posterior portions of the pelvic ring.¹¹
- Because supra-acetabular pin insertion is more time-consuming and instrumentation and fluoroscopy dependent, its role as a resuscitative measure is limited.
- The pelvic antishock clamp (C-clamp) is a posteriorly (or trochanteric) applied device that may offer greater stability to vertically unstable fractures than anteriorly applied frames (FIG 6).¹,¹⁰ It is designed for the emergent treatment of unstable pelvic ring injuries.

  - The device is indicated in both rotationally and vertically unstable pelvic ring injuries.
  - It is contraindicated in lateral compression injuries and fractures involving comminution of the iliac wing or sacrum. If the device is used in lateral compression-type injuries, it may accentuate the deformity. Use of the pelvic antishock clamp with iliac wing fractures may lead to the pins traversing the fracture sites, subsequently causing internal injury.

---

**FIG 5** • The anterior hemipelvis offers two sites for pin insertion: the iliac crest (superiorly) and the supra-acetabular region (more inferiorly). **A.** Profile view. **B.** Frontal view.

CIRCUMFERENTIAL PELVIC ANTISHOCK SHEETING

- Several techniques of noninvasive external pelvic ring stabilization have been described. Among them are the use of inflatable antishock trousers and spica casts. These do not permit abdominal access, they require skill and familiarity, and they conceal the abdomen.

- The simple application of a circumferential bed sheet may be considered during the resuscitation of the hemodynamically unstable patient. Unlike methods described above, this technique requires materials that are inexpensive, easy to apply, and readily available. No incisions that may jeopardize subsequent operative procedures are required. The sheet may be positioned to allow assessment of abdominal and lower extremity regions.

- The patient’s clothing should be removed before application. The sheet ends are crossed and overlapped anteriorly.

- The position of sheet application is directed more at the level of the greater trochanters of the hips than more proximally at the injured pelvis. Clamps secure the snugged sheets (TECH FIG 1).

- Long-term pelvic sheeting is discouraged as soft tissue compromise is a concern. It is contraindicated in the presence of unstable lateral compression injuries. Its use in such situations may aggravate deformity, resulting in internal visceral injury and posterior neurologic compression.

- Pelvic circumferential compression devices may offer the simplicity and effectiveness of sheeting with the benefit of feedback controlled force. This may prevent inadequate or excessive compression.

ANTERIOR ILIAC CRESCENT: OPEN TECHNIQUE

- A manual trial reduction is recommended before establishing a site for a skin incision.

- An 8- to 10-cm oblique wound adjacent and parallel to the iliac crest anteriorly is established.

- This incision is made in the anticipated site of the reduced hemipelvis to minimize tension on soft tissues (TECH FIG 2A).

- Dissection continues through skin and subjacent soft tissues, allowing palpation of the underlying iliac crest.

- Subperiosteal elevation of the external oblique exposes the inner table (TECH FIG 2B,C).

- Subperiosteal elevation of the hip abductors exposes the outer table (TECH FIG 2D).

- Exposure of the inner and outer tables continues within the confines of the surgical wound.

- The thick anterior pillar is identified (TECH FIG 2E).

- The surgeon’s index digit is introduced, confirming inner table inclination.

- The surgeon’s thumb and index fingers palpate the outer and inner tables respectively to aid in establishing proper pin orientation within the two tables (TECH FIG 2F).

- The first pin is placed anteriorly within the anterior pillar, about 1 to 2 cm posterior to the anterior superior iliac spine.

- The iliac crest anteriorly is asymmetric with regard to cross-sectional anatomy.

- The ideal starting point is thus along the medial third of the crest at the junction of the inner and middle thirds (“rule of thirds”) (TECH FIG 2G).

- Pins placed centrally or laterally are likely to be misdirected, exiting the desired intercortical path (TECH FIG 2H).

- A unicortical drill hole, no more than 1 to 2 cm deep, initiates access within the crest.

- Pin direction is judged by manually grasping the crest within the surgeon’s digits as described. This is typically 25 to 45 degrees medially and 10 to 15 degrees caudad.
The pin may be introduced through the established surgical wound or adjacent (medial) percutaneous ones (TECH FIG 2J).

- The pin is advanced 5 cm (50-mm threaded 5.0-mm-diameter pin), directed within the pillar between the osseous tables of the ileum.
- The second pin and the third if applicable are inserted one fingerbreadth posterior to the previous pin.
- The narrow and curved profile of the crest does not allow parallel pin insertion and on occasion accommodates no more than two pins.
- Subsequent pins should appear to converge toward each other and the common target of the supra-acetabular region within the anterior pillar (TECH FIG 2J).

- In an effort to retain intrapelvic tamponade, pins may be introduced through a similar approach without elevation of periosseous muscular attachments.
- Small Kirschner wires or spinal needles are directed along the iliac fossa to orient proper pin placement.
- Inner and outer table soft tissue attachments are preserved. Hematoma is not accessed and intrapelvic tamponade is preserved.
- A fluoroscopic obturator oblique outlet view of the pelvis can aid in identification of misdirected pins exiting the desired intercortical path (TECH FIG 2K).

**TECHNIQUES**

**TECH FIG 2 • Anterior iliac crest pin insertion, open technique.**

A. The skin incision is made at the anticipated site of the reduced iliac crest. B,C. The internal oblique is elevated from the inner table. D. The hip abductors are elevated from the outer pelvic table. E. The thick osseous pillar (*) is the desired site of pin insertion. (continued)
F. Palpation of the inner and outer tables confirms proper pin trajectory. G. The “rule of thirds” (cross-sectional junction of inner third and outer two thirds of the crest) aids in establishing the preferential pin entry point. H. This facilitates pin insertion, preventing misdirection and premature exit. I. Alternatively, pins may be placed through percutaneous wounds subjacent to the open surgical incision. J. Pins should converge on the supra-acetabular region while remaining within the anterior pillar. K. Fluoroscopic guidance facilitates proper pin placement within the inner and outer tables. (A: Modified from Yang AP, Iannacone WM. External fixation for pelvic ring disruptions. Orthop Clin North Am 1997;28:331–344. J: Modified from Poka A, Libby EP. Indications and techniques for external fixation of the pelvis. Clin Orthop Relat Res 1996;329:54–59.)
ANTERIOR ILIAC CREST: PERCUTANEOUS TECHNIQUE

- Stab wounds 1 to 2 cm long are directed perpendicular from the anterior iliac crest toward the umbilicus (TECH FIG 3).
- This orientation diminishes undesirable soft tissue tension around the pin on pelvic reduction and greatly enables pin tract release in the event of impending pin tract infection.
- After completing the skin incision, dissection continues by spreading a surgical clamp, clearing away subcutaneous fat.
- Through these small wounds, Kirschner wires or spinal needles can be introduced along both sides of the iliac wing.
- This provides a targeting method to accurately position the pins within the two tables of the ilium.
- Guided by the spinal needles, a soft tissue trocar assembly is introduced and situated medial of the midline to account for lateral overhang ("rule of thirds").
- Sagittal plane orientation of the pin must be considered as well.
- This requires that the drill be held more cephalad (directed caudad) than expected to allow proper position within the desired supra-acetabular bone (superior and cephalad to the acetabulum), rather than the thin bone of the ilium. Triple cannulated drill sleeves are used to protect soft tissues.
- The fixation pin is inserted, allowing the cortical walls of the ilium to establish direction. An image intensifier may aid in elective nonemergent fixator application.

SUPRA-ACETABULAR TECHNIQUE

- The patient is positioned supine on a radiolucent table.
- Safe introduction and proper positioning of the pin require the assistance of fluoroscopic guidance.
- The open approach for pin placement begins with a vertically oriented 5- to 10-cm incision, depending on patient body habitus and prereduction pelvic deformity. A smaller transverse incision has been described in addition to entirely percutaneous techniques of pin insertion.
- This vertical approach begins along the lateral border of the anterior superior iliac spine, extending distally and lateral to the anterior inferior iliac spine.
- The interval between the sartorius and tensor fascia lata is identified (TECH FIG 4A).
- Tissue planes are developed with blunt dissection and the anterior inferior spine is palpated.
- The lateral femoral cutaneous nerve is most commonly identified medial to the anterior iliac spine.
- Anatomic studies have demonstrated the lateral femoral cutaneous nerve to have a variable course, often within 10 mm of inserted pins.\(^6\)
- With blunt dissection and the use of protective drill sleeves, the lateral femoral cutaneous nerve may be adequately protected.
- Supra-acetabular pins should be inserted no less than 2 cm proximal to the joint to avoid intra-articular penetration. Capsular extension of the hip may be up to 16 mm superiorly.
- An obturator oblique view with slight cephalad angulation (obturator outlet view) is first obtained. A metallic marker is positioned 2 cm proximal to the hip joint under fluoroscopic control (TECH FIG 4B).
- The trocar assembly is positioned under fluoroscopic control superior to the hip joint.
- Only the outer cortex is drilled. A triple cannulated guide facilitates atraumatic drill and pin insertion.
- The drill, followed by the pin, is directed within the pelvis, avoiding intra-articular penetration of the hip joint.
- Pin angulation is typically 20 degrees medial from the vertical axis and slightly cephalad.
- The drill is directed toward and superior to the sciatic notch (30 to 45 degrees in the sagittal plane). Fluoroscopic guidance (iliac oblique view with slight cephalad angulation) ensures proper pin trajectory and depth of insertion (TECH FIG 4C,D).
- Intercortical pin orientation within the tables of the pelvis is monitored on an obturator oblique inlet view ("rollover view") (TECH FIG 4E,F).
- A 5-mm-diameter 50-mm thread length pin is inserted to the depth of the threads.
- A second pin may be inserted proximal to the first, if desired.
No frame, regardless of complexity, restores sufficient definitive fixation to vertically unstable lesions. Accordingly, simple constructs are preferred to permit patient mobilization, abdominal access, and performance of subsequent diagnostic and therapeutic procedures. Accurate pin placement within the curved iliac crest mandates a nonparallel converging pin pattern. Pin clamps with a straight configuration require that pins be prestressed to conform and accommodate such clamps (TECH FIG 5A). Those with an independent ball joint design offer an attractive alternative (TECH FIG 5B).

Applied pin clamps should remain three fingerbreadths above the skin surface. This is less threatening to subjacent soft tissues and permits adequate pin tract care. The frame is fabricated with inclusion of universal ball joints and reduction is performed. Anteroposterior compression injuries are reduced with midline-directed compression and lateral compression injuries with distraction. Adjunctive lower extremity skeletal traction may be considered for vertically displaced patterns. Bar-to-bar connectors are next secured and operative incisions are closed and dressed.
TECH FIG 5 • Pin clamps: straight (A) and multiplanar (B).

PELVIC ANTISHOCK CLAMP: C-CLAMP

- The surgeon can choose between two coronally oriented pin placement positions (anterior or posterior) (TECH FIG 6A). Anterior pins are placed in the dense column of bone of the gluteal ridge. Anterior pin placement will allow for compression of the anterior and, to some degree, the posterior pelvic ring. Posterior pin placement allows for compression of the posterior pelvic ring.
- Landmarks for anterior pin placement include the anterior superior iliac spine, the tip of the greater trochanter, and the axis of the femur.
- The surgeon should ensure that the patient’s legs are not externally rotated, as this will place pins too far posterior.
- The surgeon finds the gluteal ridge, which is three fingerbreadths posterior to the anterior superior iliac spine on the iliac wing.
- Next, the surgeon locates the tip of the greater trochanter and the axis of the femur with legs in neutral rotation.
- The center of the line connecting the gluteal ridge and the greater trochanter corresponds to the pin site.

TECH FIG 6 • Pelvic antishock clamp. A. Anterior and posterior sites of application. B. Pin site. (continued)

- Landmarks for posterior pin placement include the anterior superior iliac spine, posterior superior iliac spine, and dorsal axis of the femur. A line is drawn between the anterior and posterior superior iliac spines. The intersection of this line and the dorsal axis of the femur corresponds to the pin site. The pin site should be about 4 to 5 cm anterior to the posterior iliac spine (TECH FIG 6F). The surgeon must avoid the greater sciatic notch and the soft bone of the iliac fossa.

- The pin site is infiltrated with local anesthetic and an incision is made. Blunt dissection is carried down to bone. The pins are adjusted to be in a single axis. This orientation allows rotation of the C-clamp, permitting abdominal access. Reduction of any vertical displacement is now completed with traction.

- Alternatively, the C-clamp may be directly applied to the trochanteric region of the femur. The anatomic hazards of the previous method of application are thus avoided. In this manner, it serves a role similar to circumferential sheeting.
PEARLS AND PITFALLS

Enhancing pin fixation
- The pin–bone interface has maximal stress concentration and represents the weakest component of the external frame assembly.
- Bone quality, frame rigidity, pin number, and pin placement and diameter can all affect the strength of the pin–bone interface.
- The insertion length, also referred to as the intercortical distance, greatly influences pullout forces.
- As a general rule, pins should be maintained within the two cortices as long as possible. Distal cortical penetration is technically undesirable and should be avoided.
- Pins of adequate intercortical distance consistently appear to outperform those with transcortical purchase (undesired extracortical exit).

Avoiding conflicting surgical exposures
- Surgical wounds and pin location in the supra-acetabular region are less likely to compromise future anticipated surgical wounds. This is particularly important if anterior access to the sacroiliac joint is anticipated and pursued later.

Anterior iliac crest wound
- The surgical wound anteriorly should be placed in the anticipated region of the hemipelvis after reduction. This minimizes tension on soft tissues.
- Percutaneous wounds may be made adjacent to the open exposure to allow pin introduction.
- The wound is closed before frame application.

Anticipating pin trajectory in the unreduced pelvis
- Pin inclination in the unreduced pelvis does not reflect normal parameters.
- Depending on deformity, pin inclination may be more vertical (lateral compression) or horizontal (externally rotated, AP compression).

Avoiding extrapelvic misguided pins
- “Preferential errors” do exist!
- For AP compression injuries, an internal exit is preferred. For lateral compression injuries, an external exit is preferred. This maintains three-point fixation in a mechanically advantageous manner.

Overcompression is possible
- Depending on the method of application, reduction, and fracture pattern, compression with an anteriorly applied frame may accentuate posterior displacement.

POSTOPERATIVE CARE
- After satisfactory application of the frame, individual pin sites are scrutinized and soft tissues are released to prevent tension-induced necrosis and subsequent infection.
- Post-application imaging confirms pelvic stability, symmetry, and indications for additional anterior or posterior (open or percutaneous) stabilization techniques.
- Pin sites are debrided of organized blood and cleansed once or twice daily with peroxide solution. Dressings may be applied (if inspected regularly) or the wounds may be left open. Peripheral pin site tension should be released with sharp dissection under local anesthesia. Regional necrosis and subsequent pin tract sepsis are thereby avoided.
- Mobilization and weight bearing are dictated by the injury pattern and designated stability classification.

OUTCOMES
- Severe hemodynamic instability on arrival is a useful predictor of mortality and transfusion demands. Death within the first 24 hours is often due to acute blood loss; after this time it is usually secondary to multisystem organ failure.
- Reported mortality rates of open pelvic fractures range from 10% to 45%. These injuries are often associated with injuries of prognostic significance. Life-saving strategies to address this problem continue to evolve. The degree of pelvic instability clearly parallels rates of morbidity and mortality.
- Vertically unstable fractures, despite adequate contemporary management, have significant neurologic and associated injuries that remain of long-term consequence and disability. Those with rotational instability alone have a considerably more favorable prognosis.17,26
- The transient use of external fixation is efficacious if its role and indication are clearly defined. Use for definitive treatment is associated with a high rate of infection and aseptic pin loosening. Unstable posterior lesions are adequately managed with external fixation alone.

COMPLICATIONS
- Sheeting: overcompression (lateral compression injuries)
- General: pin tract sepsis, loss of pin fixation, malreduction, loss of reduction14
- Anterior external pelvic fixation: inadequate or aggravated posterior alignment
- Supra-acetabular pin placement: lateral femoral cutaneous nerve injury, intra-articular hip penetration, sciatic notch neurovascular injury
- C-clamp: intrapelvic pin penetration

REFERENCES
DEFINITION
- The pubic symphysis comprises a fibrocartilaginous disc between the bodies of the two pubic bones.
- A diastasis of the pubic symphysis indicates a disruption of the pelvic ring and an unstable pelvis.
- The symphysis is disrupted in anterior–posterior compression (APC) injuries as classified by Young and Burgess and occasionally in lateral compression fractures.

ANATOMY
- The symphysis is an amphiarthrodial joint, consisting of a fibrocartilaginous disc, and stabilized by the superior and inferior arcuate ligaments (FIG 1A).
- The corona mortis is a vessel that represents the anastomosis between the obturator artery and the external iliac artery. It is located about 6 cm laterally on either side of the symphysis (FIG 1B).14
- Lateral to the symphysis on the superior rami is the pubic tubercle, a prominence representing the attachment of the inguinal ligament.
  - This bony landmark must be accounted for when contouring a plate that is going to span the symphysis.
  - Anatomic variation exists between the sexes, with females having a wider and more rounded pelvis, making their anterior pelvic ring more concave than males (FIG 2).
  - The pelvic arch formed by the convergence of the inferior rami tends to be more rounded in females because their pubic bodies are shallower than males.
  - The arcuate ligaments are the main soft tissue stabilizers of the anterior pelvis.
  - These ligaments are both superiorly and inferiorly and are firmly attached to the pubic rami.
  - The sacrospinous and sacrotuberous ligaments play an important role in the stability of pelvic fractures. These ligaments connect the sacrum to the ilium via the ischial spine and the ischial tuberosity. The sacrospinous ligament resists the rotational forces of the hemipelvis, and the sacrotuberous ligament prevents rotation as well as translation of the hemipelvis.13
  - If these ligaments and the pelvic floor are torn in conjunction with a pelvic fracture, symphyseal widening is more significant (see Chap. TR-1).4

PATHOGENESIS
- The Young and Burgess classification describes the injury by the type of force acting on the pelvis. Symphyseal diastasis is most commonly seen in APC injuries or open book pelvis injuries.
- In APC injuries minor widening of the symphysis may not involve disruption of the pelvic floor, including the sacrospinous ligaments.
- In cadaver pelvis, where the symphysis and sacrospinous ligaments were sectioned, more than 2.5 cm of symphyseal widening was observed, thus defining a rotationally unstable pelvis.12
- If the pelvic floor and the sacrospinous ligaments are torn, the involved hemipelvis can externally rotate down and out,
rotating on the intact posterior sacroiliac ligaments and creating an unstable pelvis (FIG 3). \(^4\)
- Occasionally, lateral compression (LC) injuries involve fractures of the pubic rami and a symphyseal disruption. This occurs when the compressed hemipelvis causes the contralateral rami to fracture and the contralateral symphyseal body to tilt inferiorly. Because one side of the symphysis is off and can compress the bladder or uterus, altering the pelvic ring, it should be reduced to the other pubic body, which remains intact.
- These are referred to as tilt fractures, and open reduction and internal fixation should be considered to prevent impingement of the birth canal and bladder. \(^13\)
- A diastasis of the pubic symphysis can also occur in pregnancy and during childbirth because of hormonally induced ligamentous laxity. This can lead to chronic instability, and stabilization of the symphysis has been shown to relieve painful symptoms. \(^16\)

**NATURAL HISTORY**
- Persistent low back pain, anterior pain, sitting imbalance, and an impaired, painful gait are common sequelae after pelvic fractures.
- Early studies looking at pelvic fractures without surgical treatment demonstrated that almost a third of these patients had disabling pain and impaired gait. Only a third had no symptoms if the posterior ring was involved. \(^16\)
- APC type I injuries are Tile type A stable pelvic injuries, which do well with nonoperative treatment. These injuries tend to occur in younger patients involved in motor vehicle trauma or in elderly patients as a result of a direct injury such as a fall.
- APC type II and III injuries are unstable injuries. Nonoperative treatment has resulted in late pain in these injuries. In a retrospective study by Tile, APC type II injuries treated nonoperatively had a 13% incidence of late pain, with the majority of patients reporting persistent moderate pain. The patients with APC type III injuries reported a 16% incidence of late pain, with most pain being reported as moderate or severe. \(^13\)
- Patients with pelvic trauma tend to have other organ systems involved, and these associated injuries contribute to long-term disability. The more severe injuries associated with pelvic fractures are urologic and neurologic injuries. \(^16\)
- Whitbeck et al demonstrated higher morbidity and mortality rates as well as an increased incidence of arterial injuries in APC type III injuries compared to other pelvic fractures. \(^18\)
Disruption of the pubic symphysis is associated with urologic injuries. Bladder ruptures and urethral tears occur about 15% of the time in association with pelvic trauma and can lead to late complications such as strictures and incontinence. These associated injuries potentially lead to a higher infection rate when open reduction and internal fixation is performed. An increased incidence of incontinence has also been seen in women with APC injuries.

Neurologic injuries associated with pelvic fractures occur when there is posterior pathology and are more common with sacral fractures and vertically unstable fracture patterns.

Dyspareunia and sexual dysfunction are also described as complications after pelvic fractures. They can occur directly from the injury or as a result of ectopic bone formation during healing.

Symphyseal pelvic dysfunction, a relatively common condition, presents as anterior pelvic pain secondary to the laxity in the symphysis. This condition typically resolves spontaneously and can take some time but needs to be differentiated from traumatic symphyseal diastasis as a result of childbirth. Traumatic diastasis occurs in about 1 in 2000 births to 1 in 30,000 births, and the diastases from pregnancy can be as great as 12 cm.

Most patients with postpartum displacement recover with no residual pain or instability after treatment with pelvic binders, girdles, and the recommendation to lie in the lateral decubitus position.

There are a limited number of studies looking at symphyseal disruption secondary to pregnancy. The exact incidence of persistent long-term pain is unknown, but chronic pelvic instability can occur if it is unrecognized.

In the few series reporting operative treatment, the indication was persistent pain for at least 4 to 6 months postpartum.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

Pelvic injuries usually occur as a result of any high-energy trauma, such as high-speed motor vehicle accidents, motorcycle accidents, or falls from heights.

Patients with pelvic fractures may become hemodynamically unstable, and close monitoring of blood pressure and fluid requirements is needed.

Typically, if a patient requires more than 4 units of blood to maintain hemodynamic stability, an angiogram should be obtained to diagnose and embolize any arterial injuries. Clotting factors and platelets should also be administered.

Patients may have tenderness to palpation in the area of the symphysis. If motion of the pelvis is detected, manipulation of the pelvis should cease, as unnecessary manipulation may disturb any clot formation (see Exam Table for Pelvis and Lower Extremity Trauma, pages 1 and 2).

If there is no radiographic demonstration of displacement, the iliac wings can be compressed to test for stability of the pelvic ring and each hemipelvis.

A careful examination of the skin to identify areas of ecchymosis and hematoma formation, particularly in the flanks, groin, and abdominal regions, also needs to be performed.

The presence of a Morel-Lavalle lesion indicates that high-energy trauma has occurred in the pelvic region (FIG 4). Recognition of this lesion is important to prevent infection.

A good pelvic examination and evaluation of the perineum are essential. Swelling or open wounds in the perineal area may indicate a high-energy mechanism of injury. Open injuries require emergent management.

Evaluation of other organ systems, looking for associated injuries, is essential.

In males, a high-riding prostate on the rectal examination or blood at the meatus may indicate injury to the urethra or bladder, and placement of a Foley catheter should be delayed until a retrograde urethrogram is performed, unless the patient is in extremis.

Urethral injuries are less common in females because the urethra is shorter.

A thorough neurologic examination of the lower extremities also needs to be performed, as injuries to the L4 and L5 nerve roots can occur in pelvic fractures. It is essential to test the sensation and motor functions of specific roots, identifying any neurologic injury that can differentiate between a nerve root lesion or a more central lesion.

A limb-length discrepancy or a rotational deformity of the lower extremities should prompt radiographic evaluation of the pelvis.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

Radiographic evaluation of the pelvis consists of anteroposterior (AP), inlet, outlet, and Judet views (FIG 5).

A retrograde urethrogram and sometimes a CT cystogram should be performed to rule out an injury to the genitourinary system in men. A CT cystogram is sufficient for females.

A CT scan of the pelvis is also indicated to help evaluate intra-articular injuries to the sacroiliac joints and further delineate the fracture pattern.

A CT angiogram can also be used at the time of the trauma scan to help predict if an arterial bleed is present and requires further treatment with angiography and embolization.

Angiography may be used to treat patients who are hemodynamically unstable and do not respond to standard resuscitation, particularly if a CT angiogram indicates arterial bleeding.

A stress examination in the operating room can be performed under fluoroscopy to assess stability if there is a question of an unstable pelvis.

Single-leg stance views can also be performed if it is not clear whether an injury is unstable. This is a good examination for evaluating patients who may have chronic instability, such as a female patient with ligamentous laxity secondary to pregnancy or unrecognized pelvic injury.

**DIFFERENTIAL DIAGNOSIS**

- Rami fractures
- Symphyseal strain
- Hip fracture

![FIG 4 • Morel-Lavalle lesion.](image-url)
Muscle strain or avulsion
- Lumbar fracture

**ACUTE MANAGEMENT**
- The patients should be hemodynamically stabilized.
- The pelvis can be stabilized by placing ankles together with Ace wraps. Heels and ankles should be padded to prevent skin breakdown and ulcer formation.
- Placing a sheet across the pelvis at the level of the greater trochanters can be used to reduce the symphysis and temporarily stabilize the pelvis. The sheet can be affixed with towel clips to hold it with tension rather than tying a knot across the abdomen (see Chap. TR-1).

**NONOPERATIVE MANAGEMENT**
- If minimal separation of the symphysis is present, the patient can be made non-weight bearing on the affected side and can be allowed to ambulate.
- Close radiographic monitoring should ensue, with weekly radiographs. Single-leg stance views can be used to help identify late instability.

**SURGICAL MANAGEMENT**
- A diastasis larger than 2.5 mm indicates a disruption of the sacrospinous ligaments and thus an unstable pelvis. Open fixation of the symphysis stabilizes the anterior pelvis.\(^2\)
- Open injuries can be stabilized with external fixation, using iliac wing pins or Hanover pins placed at the level of the anterior inferior iliac spine. Refer to Chapter TR-1 for more details.
- In APC type II injuries with an intact hemipelvis, no posterior fixation is needed, and the symphysis is reduced and stabilized first.
- For type III injuries, if the innominate bone is broken, the anterior pelvic ring is reduced and fixed after the posterior ring is reduced and fixed. The anterior pelvic ring is reduced and fixed as a first step if the innominate bone remains intact.
- Indications for anterior stabilization for vertically unstable pelvic fractures include improving anterior stability to the pelvic ring, stabilizing a pelvic injury that is associated with an injury requiring a laparotomy, treatment of bone protruding into the perineum (ie, a tilt fracture), or in association with an acetabular fracture requiring open reduction.\(^3\)

**Preoperative Planning**
- The surgeon should review appropriate radiographic studies (AP, inlet, and outlet views and CT scan).
- Identifying all rami fractures and the presence of any pubic body fractures is essential, as this will help determine how to obtain a reduction as well as dictate the type of fixation necessary.
- The surgeon should plan to obtain stress views in the operating room to determine the stability of the pelvis if there is any question of stability.
- The surgeon should rule out the presence of a bladder rupture or urethral tear. If one is present, repair should be performed at the same time as internal fixation of the symphysis if possible to avoid a more complex late reconstruction.
- Any history of previous abdominal surgery or the presence of prior incisions should be identified before going to the operating room.
- The proper equipment must be available, such as C-arm, radiolucent table, large bone clamps, external fixation equipment, and a C-clamp.

**Positioning**
- The patient is placed on a radiolucent flat-top table with legs together to facilitate reduction of the symphysis.
- Fluoroscopic radiographs confirming the ability to obtain a good inlet and outlet views with the C-arm are obtained before preparing and draping the patient.
Right-handed surgeons may prefer to have the C-arm on the patient’s right side and the drill and instruments on the patient’s left for easier access to the symphysis with the drill. Placement of a Foley catheter is needed to decompress the bladder; it can also be felt intraoperatively to help identify the bladder. Venodyne boots are placed on both legs if possible for deep vein thrombosis prophylaxis during the case.

Approach

Open reduction of the symphysis is performed with an anterior Pfannenstiel approach.

**PFANNENSTIEL APPROACH**

- The entire lower abdomen is prepared, including both anterior superior iliac spines, the symphysis, and the umbilicus.
- Access to the anterior superior iliac spines is important if an external fixator is to be placed to assist in reduction or for additional fixation.
- A transverse incision is made 2 cm above the symphysis (TECH FIG 1A).
- Once through the skin, a large rake is placed to help create a plane above the rectus fascia.
- A longitudinal incision is then made along the fascia of the linea alba. The rectus muscle insertion is not taken down, although it is common to see an avulsion of one of the rectus muscles off the rami from the initial injury (TECH FIG 1B).
- Blunt dissection is continued longitudinally to spread the rectus muscle and protect the underlying peritoneum and bladder.
- Electric cautery can be used to divide the remaining fibers of the rectus while protecting the underlying structures.
- The bladder and bladder neck are evaluated for the presence of any injury.
- At this point, a blunt malleable retractor can be placed into the space of Retzius to protect the bladder (TECH FIG 1C).
- Care should be taken laterally, as the vessels known as the corona mortis tend to be about 6 cm lateral to the symphysis.
- The corona mortis is an anastomosis of the obturator and external iliac arteries (see Fig 1B).¹⁴
- Hohmann retractors are placed through the periosteum superiorly over the superior pubic rami one side at a time to retract the rectus muscle laterally and expose the superior body of the symphysis.
- These retractors are placed close to the external iliac vessels, so they need to be placed with care directly onto bone.
- The periosteum on the superior aspect of the rami can now be stripped off with an electric cautery and osteotomes.
- Some surgeons remove the symphyseal cartilage to promote fusion, and we agree with this approach.

**WEBER CLAMP REDUCTION**

- Once the superior aspect of the symphyseal bodies is exposed, the Weber clamp is placed anteriorly to avoid removing the insertion of the rectus (TECH FIG 2A).
- The goal in using this technique is to have the tips of the Weber clamp at the same level on each symphyseal body.
- If anterior displacement is present on either side, the tip of the clamp is placed slightly anterior on that side so at the time of reduction the tips are at the same level.⁴
- The clamp is tilted distally to engage the tines (TECH FIG 2B).
- The clamp is placed anterior to the rectus insertions.
USE OF A C-CLAMP TO AID IN REDUCTION

- The C-clamp has been described for use in unstable APC pelvic fractures in patients requiring an exploratory laparotomy or as temporary pelvic fixation if the patient cannot go to the operating room. It can also be used to assist in the open reduction of the symphysis if conventional clamps cannot hold the reduction.
- This is a similar concept to the one described by Wright et al for assisting in the reduction of the posterior pelvic ring.17
- To apply the C-clamp, the pins are placed two fingerbreadths directly posterior to the anterior superior iliac spine. This places the pins in the gluteus pillar, a thickened portion of the lateral ilium above the acetabulum (TECH FIG 3A).

Once the pins are in place, the clamp can be fitted onto the pins. The clamp is then used to compress the pelvis and reduce the rotationally unstable hemipelvis (TECH FIG 3B,C). Once reduced, the clamp is tightened and locked down. Fluoroscopy is used to confirm reduction of the symphysis as well as any posterior pathology. (See Chap. TR-1 for further description of the C-clamp.)
- Care should be taken not to overreduce rami fractures if they are present.
- The goal of this technique is to obtain most of the reduction and then fine-tune the reduction once the symphysis is exposed in the usual manner with the Weber clamp.
JUNGABLUTH CLAMP REDUCTION (TECHNIQUE OF MATTA)

- Jungabluth clamp reduction is used when the innominate bone is intact and the posterior ring is unstable.
- The innominate bone tends to be externally rotated, posteriorly displaced, and superiorly translated. If this is the case or vertical instability exists, the entire innominate bone needs to be manipulated to obtain a reduction.
- In these cases, the use of the Jungabluth clamp may be necessary to achieve reduction.
- Drill holes are made in an anterior-to-posterior direction for the placement for 4.5-mm screws.
- For the screw being placed on the unstable side (with posterior displacement), a 4.5-mm gliding hole is drilled and the screw is secured to the bone through a small plate on the posterior side of the pubis using a nut (TECH FIG 4A,B).
- The plate will act as a washer and provides a larger surface area of force to be exerted on the hemipelvis so one does not have to rely on the pullout strength of a single screw.
- The Jungabluth clamp is then placed anteriorly and secured to the 4.5-mm screws and can then be used to achieve the reduction (TECH FIG 4C,D).5

TECH FIG 4 • The Jungabluth clamp can be used to reduce the symphysis if there is posterior translation of the hemipelvis and intact innominate bone. A,B. On the side of the displacement, a screw is placed with a small plate attached with a nut so the plate acts a washer. C,D. The clamp is then attached to the head of the screw and is used to pull the hemipelvis forward to reduce the symphysis. A gliding hole must be used so the clamp pulls through the plate and does not rely on the pullout strength of a single screw. (Adapted from Matta JM, Tornetta P. Internal fixation of pelvic fractures. Clin Orthop Relat Res 1996;329:129–140.)
PLATE PLACEMENT

- Before fixation placement, the reduction should be confirmed on the AP, inlet, and outlet views with the C-arm.
- With the symphysis reduced, a six-hole, curved 3.5 reconstruction plate or precontoured plate is placed across the symphysis.
- A Kirschner wire can be placed into the fibrocartilaginous disc space to aid in centering the plate.
- Before the plate is placed, it is contoured to fit the curve of the superior surface of the symphysis and rami. The ends are contoured if a six-hole plate is used to allow for anatomic contact to the ramus (TECH FIG 5A). Alternatively, precontoured plates can be used.
- In a six-hole plate, the two medial screws on each side go into the symphyseal body and the most lateral screw goes into the rami.
- Careful planning of screw placement must be considered if the Jungabluth clamp is used so that the screws are placed into the plate without loosing the reduction.
- The first screws placed are adjacent to the symphysis on either side (TECH FIG 5B).
- The drill hole should be placed eccentrically, laterally in the hole to generate compression. The drill should be oriented parallel to the posterior aspect of the symphyseal body.
- The proper angle can be determined by using a finger to feel the inner surface of the pubic body, using it as a guide for the drill (TECH FIG 5C).
- These initial screws should be angled slightly anteriorly and laterally in the pubic body so that they stay in bone and achieve the best bite.
- These screws can be placed to go down to the ischium if necessary.

**TECH FIG 5** • **A.** Example of how the plate needs to be contoured to accommodate the pubic tubercle on either side of the symphysis. The concavity of the plate also has to be contoured, and this can vary between genders (see Fig 2).  **B.** Clinical photograph of plate after all screws are placed. Numbering indicates the order of screw placement, with the screws closest to the symphysis being placed first. After screws 1 and 2 are placed, any order may follow for the remaining screws.  **C.** Drilling the proper angle is imperative to ensure the screw will stay in bone. To gauge the angle, one may place a finger on the posterior aspect of the pubic body and then drill parallel to that finger to ensure the drill is held at the proper angle.  **D–F.** Postoperative AP, inlet, and outlet view radiographs of a pre-contoured plate and a reduced symphysis.
The two most medial screws on each side of the symphysis can be placed either parallel to each other or in a crossing pattern within the symphyseal body (TECH FIG 5D–F).

The lateral screws in the plate are placed last and will be shorter than the other screws, as they will be at the level of the obturator foramen.

When drilling for these screws, care should be taken as the obturator vessels are at risk.

### DOUBLE PLATING TECHNIQUE

- Tile described placing a second plate anteriorly if there is no posterior fixation to be placed in vertically unstable patterns (TECH FIG 6).13
- This technique can also be used if insufficient purchase is achieved with initial plate placement.

- In placing the anterior plate, care must be taken in placing screws around the screws of the other plate.
- The same sequence of screw placement should be followed, with the medial screws placed first and subsequent screws placed laterally.

### TECH FIG 6 • Example of double plating described by Tile.

### WOUND CLOSURE

- Once the symphysis is reduced and the plate is in place, a Hemovac is placed in the space of Retzius, between the bladder and the symphysis, and is brought through the rectus fascia.
- After drain placement, the wound is pulse lavaged and the rectus fascia is closed with running heavy absorbable sutures. Care should be taken not to include too many muscle fibers to avoid muscle necrosis.
- Interrupted sutures are used at the distal end to provide a side-to-side closure of the avulsed side.
- The skin is then closed with subcutaneous sutures and staples.

### PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Setup</th>
<th>It is important to make sure that adequate fluoroscopic AP, inlet, and outlet views can be obtained in the operating room before draping.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction</td>
<td>Reduction is confirmed under direct vision as well as on inlet and outlet views of the pelvis. The C-clamp can also be used to maintain reduction before plating if conventional clamps cannot hold the reduction.</td>
</tr>
<tr>
<td>Reduction aids</td>
<td>A second clamp or a ball-spike can be used to assist in reduction if there is difficulty obtaining reduction or holding the symphysis reduced. For instance, in tilt fractures a ball-spike can be used to push against the intact rami while pulling up the pubic body on the fractured side. Again, the C-clamp or an external fixator can be placed to help approximate the pubic bodies to facilitate reduction with a Weber clamp.</td>
</tr>
<tr>
<td>Backup</td>
<td>If fixation is tenuous or if the patient becomes too sick to continue with plating, an external fixator can always be added.</td>
</tr>
<tr>
<td>Screw placement</td>
<td>C-arm is used to confirm placement of screws and confirm that they are not too prominent</td>
</tr>
<tr>
<td>Poor fixation with one plate</td>
<td>Double plating can be used to improve fixation by creating a 90-90 construct.</td>
</tr>
<tr>
<td>Two-hole plate</td>
<td>A two-hole plate should not be used: it allows for rotational instability and has a high failure rate.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- Deep vein thrombosis prophylaxis is imperative, as 35% to 60% of patients with a pelvic fracture are at risk. Of these, proximal thrombosis can occur 2% to 10% of the time, and they are at higher risk of developing a pulmonary embolism.  
- With such a high risk of deep venous thrombosis, prophylaxis should consist of a combination of mechanical and chemical means. Venodyne boots or serial compression devices are essential.
- Chemical modalities consist of unfractionated heparin, low-molecular-weight heparin, vitamin K antagonists, and factor Xa indirect inhibitors.
- If patients have a contraindication for chemical prophylaxis secondary to another injury such as a head bleed, an inferior vena cava filter should be considered.
- Our protocol consists of serial compression devices and subcutaneous heparin three times a day preoperatively. Postoperatively patients are started on low-dose Coumadin. Patients remain on Coumadin for at least 6 weeks, depending on their mobility.
- Early mobilization is imperative to prevent comorbid conditions from arising.
  - Once stable fixation is in place, patients should be out of bed to a chair within 24 hours of surgery if their overall condition allows.
  - The patient’s weight-bearing status is highly dependent on the operative surgeon understanding the overall injury pattern of the pelvis.
  - If anterior fixation is used alone, such as for an APC type II injury, patients are made partial weight bearing for about 8 weeks on the operative side.
  - If there is more extensive injury to the posterior pelvis and fixation is required, partial weight bearing should be continued for up to 12 weeks.
  - Patients should be followed routinely with radiographs. On postoperative day 1, before the patient gets upright, AP, inlet, and outlet radiographs should be obtained to assess the reduction and more importantly to be used for comparison for future follow-up radiographs taken at 6 and 12 weeks.

OUTCOMES

- Stabilizing the anterior pelvis improves outcomes, and anatomic alignment allows for ligamentous healing.
- Kellam\(^1\) defined an adequate reduction of anterior symphysis widening as less than 2 cm and reported that when this was obtained in rotationally unstable fractures, 100% of patients returned to normal function. Patients with posterior pathology had poor outcomes, with only 31% reporting normal function.
- Pohlemann et al\(^7\) reported no residual posterior displacement in 95 patients with type B fractures treated with anterior plating. This was associated with an 11% incidence of late pain that occurred after exercise. No patients had pelvic pain at rest.
- Tornetta et al\(^{15,16}\) also reported that APC type II injuries, when treated with anatomic open reduction and internal fixation, have a 96% rate of good to excellent outcomes.
- Pohlemann et al\(^7\) also demonstrated type C injuries radiographically had more residual posterior displacement than type B injuries. Only 33% of these type C patients were pain-free after combined anterior and posterior fixation.
- In general, functional outcomes correlate with the initial displacement of the injury.
- Associated injuries will also dictate outcome. Patients with associated urologic injuries are at risk for urethral strictures, urinary tract infections, and even late infections.
- There is a greater than 90% chance of a good outcome in patients with near-anatomic fixation of the symphysis in APC type II pelvic fractures, and about 96% will be able to return to work within a year of injury.\(^{15}\)

COMPLICATIONS

- Proximal deep vein thrombosis occurs in 25% to 35% of pelvic fractures, so it is imperative to provide proper prophylaxis both mechanically and chemically.\(^6\)
- Plates and screws can fracture or loosen secondary to fatigue due to the physiologic motion that is maintained between the two pubic bodies. This tends to occur after 8 weeks and generally does not affect healing.
- If it occurs earlier and a loss of reduction occurs, then revision osteosynthesis should be considered.\(^4,5,16\)
- Loss of reduction can also occur with widening of the symphysis with and without the plate breaking. Although no data exist, the quality of the initial reduction appears to be the best predictor. Therefore, if a perfect reduction cannot be maintained, additional fixation should be added or activity modification should be implemented postoperatively.\(^5,15\)
- In most series of pelvic fractures reporting on the use of anterior fixation there is a low incidence of anterior wounds developing deep infections.
  - Most resolve with irrigation and débridement and go on to union.\(^2,4,5\)
- Urologic injuries occur in about 15% of pelvic fractures. Urologic complications include late urethral strictures, incontinence, and erectile dysfunction.
  - Early repair of bladder or urethral injuries at the same time of fixation avoids more complex reconstructions, but the rate of late urologic complications is still relatively high.\(^8\)

REFERENCES

DEFINITION

- Pelvic fractures are serious injuries associated with a diverse assortment of morbidities and mortality rates ranging from 0% to 50%.
- Fractures and dislocations of the pelvis involve, in broad terms, injuries to the anterior and posterior structures of the pelvic ring.
  - Injuries to the anterior pelvic ring include symphyseal disruption and pubic body or rami fractures.
  - Injuries to the posterior pelvic ring involve iliac wing fractures, sacroiliac (SI) joint dislocations and fracture-dislocations, and sacral fractures.
- The implications and treatment of damage to these structures vary widely with the broad spectrum of injury patterns, combinations of injuries, and degree of displacement.
- This chapter will focus on treatment of displaced sacral fractures and type 3 SI joint dislocations.

ANATOMY

- The pelvis is a ring structure composed of the two hemipelvises, or innominate bones, and the sacrum. Each innominate bone is formed as the result of fusion of the three embryonic bony elements: the ilium, the pubis, and the ischium (FIG 1A).
- The two innominate bones are joined anteriorly at the pubic symphysis, a symphyseal joint. Posteriorly, the two innominate bones articulate with the wings, or alae, of the sacrum via the strong SI joints to complete the ring (FIG 1B).
- The sacrum represents the terminal structural segment of the spinal column that connects the pelvis and extremities to the trunk and spine.
- As the sacrum is essentially a spinal element, it is subject to segmentation abnormalities and dysmorphisms.
  - Most commonly, segmentation anomalies such as a lumbarized S1 and a sacralized L5 will be present (FIG 2).
  - The only true way to be sure which defect, if any, is present, is to count down from the first thoracic vertebrae, which is the first vertebra to have transverse processes that are inclined cephalad.
  - As a general rule of thumb, however, the top of the iliac crest is usually at the same level as the L4/5 disc space. This rule can be used to judge the presence of dysmorphism (see Fig 2A).
- These issues are pertinent to interpretation of the radiographic landmarks required to safely place iliosacral screws (see later).
- Being wedge-shaped, the sacrum forms a keystone articulation with the innominate bones.
- By virtue of this shape and their orientation, the SI joints are inherently unstable and the maintenance of posterior pelvic ring integrity is wholly dependent on the support provided by the ligamentous structures for stability (see Fig 1B and FIG 3).
- With axial loading, the natural tendency is for each hemipelvis to externally rotate and translate in a cephalad and posterior direction. The pelvic ligaments are structured and positioned to re-
The symphyseal ligaments (themselves contributing no more than 15% to pelvic ring stability), the sacrotuberous ligaments, and the sacrospinous ligaments resist external rotation.13,32

The bladder is immediately posterior to the pubic bodies and symphysis, separated only by a thin layer of fat and the potential space of Retzius.

The intimate relationship of the L5 nerve root to the superior aspect of the sacral ala as it courses to join the lumbosacral plexus is a key anatomic feature that must be kept in mind during reduction and stabilization of posterior pelvic ring injuries (FIG 4).

The superior gluteal artery is immediately lateral to the inferior aspect of the SI joint as it arises from the internal iliac artery to exit the greater sciatic notch with the superior gluteal nerve. The obturator nerve and artery course along the quadrilateral plate (medial wall) of the acetabulum as they exit the superior and lateral quadrant of the obturator foramen (see Fig 4).
PATHOGENESIS
■ Because the SI ligaments are the most resilient in the human body, SI dislocations occur purely as a result of high-energy traumatic injuries.
■ Anteroposterior compression of the pelvic ring causing external rotation of the innominate (which may or may not be coupled with a vertical shearing force) is the most common cause of SI joint dislocation.
■ Sacral fractures, however, can occur in three distinctly different situations.
  ● Insufficiency fractures of the sacrum arise secondary to failure through excessively osteoporotic or osteopenic bone.
  ● Stress fractures of the sacrum result from fatigue and cyclic failure of normal bone in high-level athletes or military recruits.
  ● Traumatic disruptions result from high-energy lateral or anteroposterior compression or vertical shear injuries such as (in order of decreasing frequency) motorcycle crashes, auto–pedestrian collisions, falls from height, motor vehicle accidents, or crush injuries.5,32

NATURAL HISTORY
■ Pelvic fractures occur in at least 20% of blunt trauma admissions, most frequently in young males.
■ They can result in small insignificant fractures of the pubic rami with no compromise of pelvic ring stability, or major injuries and disruptions that can be associated with life-threatening bleeding or visceral injury.
■ The pelvic ring encloses the true pelvis (organs contained below the pelvic brim, extraperitoneal) and the false pelvis (organs contained above the pelvic brim, both peritoneal and retroperitoneal).
■ The most commonly associated injuries to structures contained within the true pelvis are the internal iliac arterial and venous systems and branches, the bladder (20%) and urethra (14%), the lumbosacral plexus, and the rectum and vaginal vault (open pelvic fractures).
■ Injuries to structures within the false pelvis as a direct result of the pelvic fracture are uncommon, but severe iliac wing fractures with abdominal wall disruption can result in intestinal injury and even entrapment.
■ Morbidity and mortality from pelvic fractures can be high and are most commonly secondary to pelvic hemorrhage.
  ● The mortality rate associated with pelvic fracture with an associated bladder rupture approaches 35% in some series, and the mortality rate of open pelvic fractures involving the perineum used to be as high as 50%.
  ● Fortunately, this has decreased to about 2% to 10% with the liberal use of diverting colostomies and more advanced stabilization techniques.
  ● Neurologic injury to the lumbosacral plexus can lead to significant sensorimotor dysfunction involving the extremities, bowel, bladder, and sexual functions.
  ● Because of these associated neurovascular and visceral injuries, pelvic fractures often result in prolonged recovery periods, significant chronic pain, permanent disability, and loss of psychological and socioeconomic structure.5,9,21–29

PATIENT HISTORY AND PHYSICAL FINDINGS
■ Any patient presenting with a history of trauma or satisfying criteria for a Trauma Alert in the emergency department should be suspected of having a pelvic fracture until otherwise ruled out by radiologic and physical examination.
■ The physical examination should follow the primary and secondary survey of the Advanced Trauma Life Support protocol.1
■ Examination of a patient suspected of having a pelvic fracture should be divided into the examination of the abdomen, pelvic ring, perineum, rectum, vagina, and lower extremities.
■ The abdominal examination should elucidate:
  ● Tenderness, fullness, or rigidity
  ● Abdominal wall disruptions, defects, or open wounds
  ● Flank ecchymosis
  ● Presence of internal degloving or a Morel-Lavalle lesion (separation of the subcutaneous tissues from the underlying fascia). This can be recognized by subcutaneous fluctuance or a fluid wave and, later, extensive ecchymosis.
■ The rectal and vaginal examination should consider:
  ● The position of the prostate (a high-riding prostate may be a sign of urethral injury)
  ● Palpable bony fragments perforating the rectal or vaginal mucosa
  ● Defects or tears in the wall of the rectum or vagina indicating possible bony penetration
  ● Rectal or vaginal bleeding indicating possible tears or bony penetration
  ● Urethral bleeding at the meatus indicating possible urethral or bladder disruption
  ● Scrotal or labial swelling and ecchymosis indicating pelvic hemorrhage (FIG 5)
  ● Rectal tone, perianal sensation, voluntary sphincter control, and bulbocavernosus reflex to assess for the presence of cauda equina syndrome or lower sacral nerve root injury
■ Examination of the pelvic ring and extremities should focus on the following key factors:
  ● Palpable internal or external rotation instability of the pelvic ring with manually applied anteroposterior and lateral compressive forces on the iliac wings and crests
  ● Leg-length discrepancy with asymmetrical internal or external rotation
  ● Neurologic status in patients able to comply can be assessed as follows:
    ● L1/2: iliopsoas (hip flexors) and upper anterior thigh sensation
    ● L3/4: quadriceps (knee extensors) and lower anterior thigh and medial calf sensation
    ● L5: extensor hallucis longus, digitorum longus (toe dorsiflexion), peroneal eversion (although this can have a
strong L4 component) and lateral calf and dorsum of foot sensation

- S1: gastrocnemius complex (ankle plantarflexion) and posterior calf sensation
- S2/3: flexor hallucis and digitorum longus (toe plantarflexion) and sole of foot sensation

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

**Plain Radiographs**

- The standard anteroposterior (AP pelvis) view should be part of the initial trauma series screening. With enough experience, many of the injuries to the posterior pelvic ring can be diagnosed with this single projection (FIG 6A,B).
- A good AP radiograph should have the pubic symphysis co-linear with the sacral spinous processes.
  - This allows side-to-side comparison of bony landmarks to aid in diagnosis of subtle displacements of the sacrum or SI joint.
- The cortical density of the pelvic brim and iliopectineal line should be traced back to its intersection with the lateral margin of the sacral ala.
  - This intersection should be at the same level (usually the inferior margin of the S2 foramen) bilaterally.
- Asymmetry in the SI joint space and the appearance of the sacral foramina should alert the surgeon to the presence of an SI joint dislocation or sacral fracture.
- Fractures of the L5 transverse process may be a clue to a vertical shear injury that has avulsed the transverse process via the iliolumbar ligament.
- Symphyseal diastasis or displaced rami fractures should alert the examiner to additional injuries in the posterior ring, even though they may not be readily apparent on first glance.

- The inlet projection is taken with the x-ray beam directed caudally about 45 degrees to the radiographic film.
- A true inlet view of the pelvis, however, may require variations on this degree of angulation because of the normal variations in sagittal plane pelvic obliquity.
- This view simulates a direct view into the pelvis from above along its longitudinal axis (FIG 6C,D).
- The inlet view is helpful in imaging:
  - External or internal rotation of the hemipelvis
  - Opening of the SI joint or an impaction fracture of the sacrum
  - “AP” displacement or translation of the hemipelvis (see below)
- The outlet projection of the pelvis is obtained by directing the x-ray beam about 45 degrees cephalad to the radiographic film.
- This view simulates looking at the sacrum and SI joints directly en face (FIG 6E,F).
- The outlet view is helpful in imaging:
  - Cephalad or “vertical” shift of the hemipelvis
  - Sacral fractures relative to the foramina
  - Flexion–extension deformity of the hemipelvis
- These radiographs are taken at about 45 degrees to the long axis of the patient’s body.
- Therefore, a given amount of translation or displacement seen on the inlet or outlet view is in fact the sum of displacement vectors in both the coronal and axial planes. For example, “posterior” shift seen on the inlet projection is in fact a combination of both posterior and cephalad translation.
- Another important point to bear in mind is the appearance of the sacrum on the AP projection.
- If one sees a paradoxical inlet view of the upper sacrum and outlet view of the distal sacrum, a lateral radiograph and CT scan with sagittal reconstruction must be performed to rule out an occult sacral fracture-dislocation (a U-shaped
sacral fracture otherwise known as spinal-pelvic dissociation; FIG 7).

Computed Tomography

CT is imperative in any suspected pelvic ring injury.
- As the pelvis is a ring structure, any disruption in one location (no matter how seemingly insignificant) must (by virtue of ring structure mechanics) be accompanied by disruption in another location.
- Three-millimeter axial sections (or 3 mm of vertical travel per 360-degree rotation of the gantry in a spiral CT) are recommended to disclose the majority of significant injuries and to allow for good-quality three-dimensional reconstructions (FIG 8).

Retrograde Urethrography and Cystography

- Retrograde urethrography and cystography are mandatory in pelvic fractures with ring disruption to rule out urethral and bladder injury.
- The Foley catheter is partially inserted into the urethra, and the balloon is inflated with 2 to 3 mL of sterile saline to occlude the urethra. Ten to 15 mL of water-soluble contrast is then injected into the urethra and the outlet view of the pelvis is repeated.
- If no extravasation is seen, the catheter is advanced into the bladder with injection of a further 300 mL of water-soluble contrast to rule out a bladder rupture. If no contrast extravasation is noted, the bladder is drained with the Foley, and any residual dye is noted.
- If passage of the catheter is not possible or there is a tear of the urethra or bladder neck, suprapubic catheterization should be performed well above the umbilicus if possible (to avoid contamination of potential future anterior pelvic operations).

Pelvic Angiography

- Angiography is indicated in patients with persistent hemodynamic instability despite:
  - Adequate volume resuscitation
  - Other sources of hemorrhage being ruled out (abdomen, thorax, and long bone fractures)
  - Attempts to “close” the pelvic ring (see below) have failed to stop pelvic hemorrhage
- Most cases of pelvic hemorrhage (85%) arise from venous bleeding, which is not amenable to angiographic embolization.
- Arterial bleeding is usually from branches of the internal iliac system (median sacral, superior gluteal, pudendal, or obturator arteries; FIG 9).
If diagnostic peritoneal lavage is being performed to rule out abdominal hemorrhage, then it must be performed above the umbilicus and arcuate line to avoid false-positive results from pelvic hemorrhage.

NONOPERATIVE MANAGEMENT

- As a general rule, traumatic type 3 SI dislocations should not be managed nonoperatively.
- Progressive cephalad displacement of the hemipelvis will result in pelvic malunion. Leg-length inequality, chronic mechanical low back and buttock pain, pelvic obliquity with sitting imbalance, and dyspareunia are common complaints when the hemipelvis and ischial tuberosities are positioned medially or cephalad.
- For patients in extremis or those with sepsis or critical medical comorbidity, nonoperative therapy may be the only option.
- In these cases, the pattern of deformity dictates the maneuvers to be used to minimize the malunion.
- Patients with any evidence of vertical instability should be placed into balanced longitudinal skeletal traction in an attempt to reduce or prevent further cephalad displacement.
- Distal femoral traction is preferable.
- Patients with external rotation deformity of the pelvic ring (ie, “open book” pelvis) should be initially treated with some form of temporizing pelvic binder (ie, the T-POD pelvic binder, Bio-Cybernetics, LaVerne, CA) or an external fixation clamp.
- This helps to reduce the external rotation deformity, stabilize the pelvic hemorrhage and clot, and improve patient comfort in the acute resuscitative period.²
- Ideally, circumferential devices such as pelvic binders (FIG 10) should be applied over the greater trochanters, and frequent skin checks are mandatory to prevent full-thickness pressure ulceration. As such, they are rarely if ever indicated for definitive treatment. Anterior pelvic external fixators can be applied either in the iliac crest or the anterior inferior iliac spine and supra-acetabular bone.
- Anterior external fixators are good for controlling external and internal rotation of the anterior pelvic ring. Thus, the surgeon may elect to use them definitively if the SI joint is disrupted only through the anterior SI ligaments (a type 2 injury with no vertical or sagittal plane instability) or with certain lateral compression injuries where the sacral fracture is stable by virtue of its impaction.
- By themselves, however, anterior external fixators are not effective in controlling the posterior pelvic ring, and if applied incorrectly they can make some pelvic deformities worse.¹⁶,³⁰
- For external fixation control of the posterior ring, external C-clamps and pelvic clamps are used on occasion, but expertise is required in their use to prevent serious complications from misplacement.⁸,¹⁸
- In contrast to SI joint dislocations, most traumatic sacral fractures can be treated successfully with nonoperative care.
- Although vertical shear sacral fractures represent the far end of the spectrum of unstable sacral fractures needing operative stabilization, impacted sacral fractures resulting from lateral compression mechanisms can be relatively stable injuries (FIG 11A,B).
- If the radiographic and CT scanning evaluation reveals an impacted sacral alar fracture without significant displacement in other planes, a trial of nonoperative therapy is warranted. The patient must comply with the weight-bearing restrictions and close radiographic follow-up to prevent gradual shift that will result in a pelvic malunion and leg-length inequality with sitting imbalance (FIG 11C).
- Often, the presentation of the patient in bed can help to predict success with nonoperative treatment of impacted sacral fractures.
- Patients able to roll in bed on their own and help with hygienic care with only minimal or moderate discomfort often have a relatively stable pelvis and will be able to mobilize with physical therapy.
- Some patients, however, will not be able to tolerate even log-rolling in the bed with nursing care.
- They may be found on examination under anesthesia to have an unstable pelvis despite innocuous-appearing imaging studies.
If a patient with an impacted sacral fracture is deemed to be a candidate for nonoperative treatment, he or she is mobilized with physical therapy in 3 to 5 days so long as all other injuries permit.

- The patient is instructed in touch-down weight bearing on the affected extremity.
- If the patient can successfully mobilize, then AP, inlet, and outlet radiographs are repeated within a week to assess for any further displacement and increasing leg-length inequality.
- If no further displacement occurs, the patient is instructed to continue touch-down weight bearing for another 8 to 10 weeks, with repeat radiographs every 4 weeks.

**SURGICAL MANAGEMENT**

**Treatment Options**

**Iliosacral Screws**

- In general, all complete SI joint dislocations and unstable displaced nonimpacted sacral fractures should be treated with operative stabilization.
- The choice of fixation in most instances for both SI joint dislocations and sacral fractures will be with iliosacral screws (SI screws).
- Biomechanical studies have validated the strength of this technique in comparison to more traditional anterior SI plating and transsacral bars and plates.\(^{11,26}\)

- Also, SI screws can be applied with the patient in either the prone or supine position, and in either an open or closed percutaneous fashion.
- SI screw placement, however, does require an exacting knowledge of the radiographic correlates of anatomic landmarks to prevent neurologic and vascular injury.\(^{3,6,13,22,31,33}\)
- Transforaminal sacral fractures with comminution and vertical instability treated with standard SI screw fixation alone may be suboptimal and have a high reported failure rate.
- In these instances, the surgeon may elect to place alternate forms of fixation to augment the SI screw (such as with transsacral screws or with some form of spinal pelvic construct to better resist the tendency for vertical displacement).\(^{12,24,27}\)

**Spinal Pelvic Fixation**

- Also known as *lumbopelvic fixation* and *triangular osteosynthesis*, spinal pelvic fixation is done to augment an SI screw for a very unstable posterior ring injury that has been reduced and temporarily stabilized but remains at risk for failure of fixation and subsequent redisplacement.
- This usually arises in the case of extensively comminuted transforaminal sacral fractures.

**Sacral Nerve Decompression**

- Sacral nerve decompression is indicated in either of two situations:
  - The patient has a neurologic deficit attributable to sacral radiculopathy and preoperative imaging shows fracture fragments within the sacral foramen.
  - The patient is neurologically intact, but preoperative imaging studies disclose a large bone fragment within the foramen that during reduction will further compress the nerve root and stenose the foramen, resulting in iatrogenic nerve root injury (**FIG 12**).

**Zone 3 Sacral Fractures**

- Vertically oriented zone 3 sacral fractures are usually the result of wide anteroposterior compression forces and are associated with anterior ring disruption.
- Generally, they can be treated with internal rotation and anterior ring fixation alone.
- If residual sacral gapping persists, however, an SI screw with short threads can be placed into the contralateral S1 body to close the residual gap.

**U-Shaped Sacral Fractures**

- Otherwise known as spinal-pelvic dissociation, this fracture is essentially a sacral fracture-dislocation.
- It tends to occur through the vestigial disc space and result in kyphosis.

---

**FIG 11 • A,B.** Impacted sacral fracture from lateral compression mechanism with internal rotation. **C.** Nonoperative treatment of vertical shear sacral fracture with resultant malunion and leg-length inequality.

**FIG 12 •** Axial CT scan of a sacral fracture showing large intraforaminal bony fragment.
These fractures can be easily missed on the standard AP pelvis view (FIG 13A) and even axial CT scans, but they are quite evident on the sagittal CT reconstruction (FIG 13B).

These injuries generally do not result in pelvic ring instability, as the SI joints and distal surrounding sacrum are intact; they are more commonly associated with spinal instability. They can be associated with cauda equina syndrome and significant spinal instability and should be treated by an experienced spinal surgeon.

Although some trauma surgeons have advocated bilateral SI screw fixation alone for these injuries, they more commonly require reduction, decompression, and some form of posterior lumbopelvic fixation to control kyphotic deformity.

Preoperative Planning

Proper preparation and preoperative planning for any major pelvic surgery are mandatory.

These operations can be associated with prolonged anesthetics, lengthy prone positioning, extensive blood loss, and complex reduction maneuvers that can pose serious risk to the patient with other medical or traumatic comorbidities.

Having a detailed understanding of the deformity and the reduction and fixation strategy can help to significantly decrease operative time and blood loss.

All patients should have had anticoagulation started within 24 hours of admission.

If there are contraindications to anticoagulation, inferior vena caval filter placement should be requested.

If an open reduction is predicted to be necessary, waiting for 3 to 5 days is prudent to allow the pelvic clot to stabilize and diminish intraoperative bleeding.

Patients should have at least three units of typed and cross-matched blood on hold.

The surgery should be booked semielectively if possible, with a surgical team that is familiar with complex pelvic surgery.

Positioning

Patients should be positioned on a radiolucent table that allows traction to be applied in some fashion.

Regarding the standard OSI (Orthopaedic Systems Inc., Union City, CA) fracture table with the perineal post, adequate caudal translation cannot be obtained as long as the perineal post is in place because the ischial tuberosity and pubis tend to abut the post, preventing further caudal translation of the hemipelvis.

This problem can be overcome by stabilizing the contralateral extremity in a traction boot without applying traction to provide some vertical support for the contralateral side while traction is applied to the affected extremity.

Another alternative in cases with severe vertical displacement is to rigidly fix the contralateral pelvis to the OR table with Schanz pins and an external fixator with a frame supplied by OSI.

Patient positioning will be in either the prone or supine position, depending on the surgeon’s assessment of the ability to achieve reduction using closed (supine) or open (prone) means.

In some cases, initial reduction of the anterior pelvic ring will facilitate reduction of the posterior ring, allowing the entire procedure to be performed in the supine position.

However, an imperfect reduction of the anterior pelvic ring and subsequent rigid stabilization may actually impair reduction of the more important posterior ring. In this case, anterior fixation would have to be removed to allow for an exact reduction of the posterior ring.

For the patient positioned in the prone position (FIG 14), the surgeon must ensure proper padding and support for the chest to allow adequate ventilation.

FIG 13 • U-shaped sacral fractures can be difficult to detect on standard AP pelvis views (A) but are more evident on sagittal CT reconstruction (B).

FIG 14 • Positioning and setup of patient for posterior approach and reduction of sacral fracture or sacroiliac joint dislocation. Note the pelvis hanging freely, traction setup, and rigid stabilization frame on contralateral stable hemipelvis.
It is preferable to use longitudinal chest rolls that come short of the pelvis, allowing the lower trunk to hang freely and not rest on the anterior superior iliac spine. If the pelvis is permitted to rest on the anterior superior iliac spine, posterior translation of the unstable hemipelvis may result or reduction may be impaired. The extremity ipsilateral to the unstable hemipelvis should be draped free to allow longitudinal traction and internal–external rotation. It should be placed in either boot or skeletal (distal femoral or proximal tibial) traction that allows for rotation and abduction–adduction. Extension of the hip and extremity will help to indirectly reduce the hemipelvis as well, since some degree of flexion deformity exists in vertically displaced pelvic fractures. Draping of the operative field should include the entire flank on the affected side. The field should continue to include the buttoc and upper thigh, with free draping of the affected extremity. The natal cleft and contralateral buttock are excluded from the field. For the patient positioned in the supine position, a small folded sheet or pad should be placed under the sacrum or buttock on the affected side to lift the pelvis away from the table. Again, the affected extremity should be placed into traction to aid in reduction, as detailed above. If there is posterior displacement of the hemipelvis, placing the bump under the buttock will help to anteriorly translate the pelvis when traction is applied. If there is anterior translation of the hemipelvis, placing the bump directly midline will help to lift the pelvis away from the table and also let the affected hemipelvis hang freely to allow posterior translation during reduction maneuvers.

**Approach**

Approach to the SI joint can be either anterior or posterior. If significant displacement exists and a difficult open reduction is predicted, the posterior approach should be chosen. The anterior approach does not afford good visualization of the entire SI joint, only the superior aspect at the top of the ala. Also, placement of reduction clamps anteriorly across the SI joint, while possible, is cumbersome and places the L5 nerve root at risk. The anterior approach to the SI joint is advocated only in situations in which:
- The soft tissues do not permit the posterior approach.
- The patient will not tolerate prone positioning because of poor pulmonary status.
- A close-to-anatomic closed reduction of the SI joint can be obtained with traction and manipulation and only minor adjustments need to be made.

**POSTERIOR APPROACH**

For the posterior approach to the SI joint dislocation and sacral fracture, the incision is vertical and paramedian, centered directly over the involved SI joint. The incision is not carried directly over the bony prominence of the posterior superior iliac spine; rather, it is placed just medial to the posterior superior iliac spine (TECH FIG 1A). The tissues that bridge the SI joint posteriorly in the intact state include the lumbodorsal fascia, the transverse fibers of the gluteus maximus (TGM), the paraspinal...
erector spiniae muscles, the iliolumbar ligament, and the posterior SI ligaments (TECH FIG 1B).

- With SI joint dislocations, some or all of these fascial, muscular, and ligamentous layers may be completely disrupted, and no further dissection is needed.
- Often, however, to visualize the inferior aspect of the SI joint posteriorly, the TGM needs to be mobilized. The TGM attachment to the sacral spinous processes and thoracolumbar fascia is released and the TGM is reflected laterally and inferiorly to expose the inferior aspect of the SI joint. To prevent wound complications, the attachment and origin of the gluteus maximus must be preserved.

- Occasionally some of the lumbodorsal fascia will need to be released from the posterior iliac crest.
- This allows dissection up over the superior aspect of the SI joint and sacral ala to permit digital palpation to assess reduction of the anterior SI joint.
- Once exposure is complete, it is usually necessary to evacuate a significant amount of blood clot and hematoma from the joint.
- On occasion, loose fragments of denuded articular cartilage will require removal.
- Routine removal of articular surfaces for a primary SI joint fusion is not performed, however, unless there is significant cartilaginous destruction to begin with.
- During removal of blood clot and debris, specific attention must be paid to the superior gluteal vessels and the internal iliac vascular system.
- Removal of clot may restart arterial bleeding that was initially controlled by tamponade and spasm, or direct iatrogenic injury may occur with dissection through the fracture hematoma and clot.
- All sacral fractures that necessitate an open reduction require a posterior approach.
- Anterior approaches are not recommended as it is not possible to dissect onto the anterior aspect of the sacrum without posing excessive risk to the lumbar-sacral nerve roots and iliac vessels.
- The posterior approach for sacral fracture reduction varies depending on the fracture location and the need for sacral nerve root decompression.
- In general, however, most sacral fractures and foraminal decompressions can be performed through the same paramedian approach as described above for SI joint dislocations. The only alterations in technique would be as follows:
  - Subperiosteal elevation of the paraspinal muscles from the dorsal aspect of the sacrum to the spinal processes is required to expose the whole posterior surface of the sacrum (TECH FIG 1C).
  - Proximal extension in the intermuscular plane of the paraspinal muscles exposes the L4–L5 facet joint in the manner described by Wiltse, if a spinal pelvic construct is to be applied.

Open Reduction of the SI Joint and Sacrum via the Posterior Approach

- Reduction of the dislocated SI joint is complex and requires a good knowledge of the three-dimensional anatomy of the sacrum, ilium, and SI joint.
- Although some anteroposterior translation and lateral–medial translation may be necessary to reduce the SI joint, longitudinal traction is the single most important indirect maneuver to perform.
- Adequate longitudinal traction can be assessed intraoperatively with direct visualization, digital palpation, and the image intensifier.
- Reduction of the superior aspect of the SI joint can be assessed with digital palpation, ensuring that the superior–anterior aspect of the SI joint is flush.
- Final confirmation with inlet, outlet, and AP radiographs will help disclose subtle rotational deformities not appreciated by direct visualization or palpation.
- Only once adequate length has been restored can the need for additional anteroposterior or medial-to-lateral translation be assessed.
- Fine-tuning of the SI joint reduction will require the placement of one or two reduction clamps to medially translate and internally rotate the hemipelvis. Large pointed reduction clamps (eg, Weber clamp or offset Matta clamps) are used.
- Posteriorly, a clamp can be placed over the sacral spinous process or into the posterior cortex of the sacrum inferiorly and into the cortical bone of the medial aspect of the greater sciatic notch. This can help close the inferior aspect of the SI joint (TECH FIG 2A).
Chapter 3  ORIF OF THE SACROILIAC JOINT AND SACRUM 497

• The anterior approach to the SI joint uses the upper limb of the Smith-Peterson approach, taking the external oblique fibers off the iliac crest and elevating the iliacus muscle subperiosteally from the inner table of the ilium.

• When the SI joint is encountered, careful mobilization of the tissue on the sacral ala using a blunt periosteal elevator and finger dissection helps to move the L5 nerve root medially out of harm’s way.

• A second clamp can be used superiorly, with one tine placed carefully over the top of the joint onto the sacral ala anteriorly and the second tine placed just lateral to the posterior superior iliac spine (TECH FIG 2B,C).

• Alternatively, this second clamp can be placed through the greater notch, with one tine on the sacral ala and the other on the posterior cortex of the ilium (TECH FIG 2D,E).

• Once this tissue is mobilized and the sacral ala is seen under direct vision, a sharp Hohmann retractor is driven into the alar cortex and used to protect the L5 nerve root, which lies medial (TECH FIG 3).

Open Reduction of the SI Joint via the Anterior Approach

• Once the SI joint and sacral alae have been exposed, reduction can be carried out.

• Similar to the posterior approach, longitudinal traction is applied with internal rotation of the extremity.

• If there is wide diastasis of the SI joint and symphysis, the surgeon may elect at this stage to expose the symphysis and temporarily reduce it with a clamp to aid in internal rotation and reduction.

• However, permanent fixation of the symphysis at this time is not indicated, as it may impede anatomic reduction of the SI joint by limiting motion of the unstable hemipelvis.

• If open reduction of the symphysis is performed, it is held temporarily with a clamp so that it can be removed or adjusted if the SI joint does not reduce satisfactorily.

• Should persistent diastasis of the SI joint exist despite these indirect maneuvers, a Verbrugge or Farabeuf reduction clamp can be used to complete the reduction.

• A single cortical screw is placed on either side of the SI joint into the ilium and sacral ala, respectively.

• The heads of the screws are left proud off the cortex, allowing the reduction clamp to engage the screw heads.

• The clamps can be rotated and twisted in any direction while closing the gap to achieve reduction of the joint (TECH FIG 4).

• Alternatively, an offset reduction clamp or King Tong reduction clamp can be placed on the ala and external iliac wing, as in Techniques Figure 2B, but from the front.
**TECH FIG 4** • Farabeuf pelvic reduction clamp reducing the sacroiliac joint from the anterior approach using the two-screw technique.

**PLACEMENT OF ILIOSACRAL SCREWS**

**Entry Points**
- Large cannulated partially threaded screws are used (7.3 or 8.0 mm).
- The entry point externally is typically 10 to 20 mm anterior to the crista glutea two thirds of the way from the iliac crest (posterior superior iliac spine) to the greater sciatic notch, or 2 cm up and 2 cm posterior to the notch (TECH FIG 5A).
- Percutaneously, the external landmark for choosing the correct entry site is the point of intersection between a line extending proximally from the greater trochanter and a horizontal line extending laterally from the posterior superior iliac spine (TECH FIG 5B).
- In percutaneous procedures, the surgeon must be wary of injury to the superior gluteal neurovascular bundle since the entry point is close to the neurovascular bundle as it exits the greater sciatic notch.4,23
- “Safe” placement is maximized by careful attention to radiographic bony landmarks.6,33

**Safe Placement and Trajectory**
- The three critical projections for placing an SI screw are:
  - The lateral projection to center the guidewire on the sacrum anterior to the canal and to ensure that the guidewire is below the iliac cortical density and sacral alar slope to prevent injury to the L5 nerve root (TECH FIG 6A).
  - The outlet projection to ensure that the guidewire passes above the S1 sacral foramen (TECH FIG 6B).
  - The inlet view to ensure that the guidewire is at the proper trajectory and coming to rest in the anterior aspect of the sacral body–promontory for maximal purchase (TECH FIG 6C).
  - The surgeon should be attentive to sacral dysmorphism and segmentation defects that give rise to altered anatomy, such as lumbarized S1 or sacralized L5 vertebral bodies.
  - The case shown in TECHNIQUES FIGURE 7A,B demonstrates a unilateral sacralized L5 on the right. The left side is normal. The iliac crest is in line with the L4–5 disc space.
  - The safe corridor for the SI screw is between the valley of the ala anteriorly (L5 nerve root), the sacral canal posteriorly (cauda equina), and the sacral foramen inferiorly (S1 nerve root).
  - In the normal situation (no segmentation abnormality), the corridor is well defined (TECH FIG 7C), but in the case of a sacralized L5, the safe corridor is either exceedingly narrow or nonexistent (TECH FIG 7D,E).
  - If this abnormality is not recognized and an SI screw is placed into L5 assuming it is S1, the L5 nerve root is likely to be injured.
  - If the surgeon is unsure, the lateral projection with the iliac cortical densities is key in determining the correct level to place the screw, since they are constant with their relationship to S1 even in segmentation abnormalities (TECH FIG 7F).
  - TECHNIQUES FIGURE 7G shows a reduced SI joint dislocation with a safely placed SI screw.

For SI joint dislocations, the screw trajectory should be from inferior to superior on the outlet view, and from
posterior to anterior on the inlet view (perpendicular to the plane of the SI joint).

- For sacral fractures, the screw trajectory should be straight across from lateral to medial on the inlet view (perpendicular to the fracture plane).
- The tip of the SI screw should come to rest in the contralateral side of the S1 body and promontory.
- Carrying the screw into the ala provides weaker purchase secondary to poor bone quality and increased risk to the contralateral L5 nerve root.

- In situations of comminuted transforaminal sacral fractures, the theoretical risk of overcompression and iatrogenic sacral nerve root injury exists. To gain stability with the construct and avoid a nonunion, some compression is necessary, however.
- If this risk exists, sacral nerve root decompression should be performed before placing the SI screw, or an alternative form of fixation such as spinal pelvic fixation or a transsacral screw should be placed.

**TECH FIG 6**

A. Lateral projection of pelvis showing the iliac cortical density (ICD) or sacral alar slope line. The tip of the sacroiliac screw and guidewire must be below this line when the screw is at the level of the foramen on the outlet projection. Outlet (B) and inlet (C) projection showing path of iliosacral screw for sacroiliac joint dislocation.

**TECH FIG 7**

Outlet projection (A) and three-dimensional reconstruction (B) showing the segmentation anomaly (in this case a unilateral sacralized L5). C. Safe corridor for placement of an S1 iliosacral screw into the ala of S1. D,E. Lack of safe corridor into “S1” demonstrated on this axial CT of the patient with the unilateral sacralized L5. On some cuts and the lateral projection this may appear as S1 when it is in fact L5. There is no safe corridor at this level. F. Safe placement of an iliosacral screw into S1 under the iliac cortical densities (red arrow). G. AP projection demonstrating a reduced sacroiliac joint with a well-placed sacroiliac screw.
SPINAL PELVIC FIXATION

- Through a posterior approach as described above, the L4–5 facet joint is exposed, taking care not to disrupt the capsule.
- A 6.2-mm titanium Schanz screw is placed into the L5 pedicle, with the entry point at the junction of the transverse process and the lateral border of the facet joint.
- A second Schanz screw is placed into the ilium at the posterior superior or inferior iliac spine, and then directed between the inner and outer tables of the ilium.
- The trajectory should be aiming for the ipsilateral greater trochanter as an external landmark. The screw should be directed to pass through the region of the sciatic buttress as seen on the iliac oblique view.
- Placement out of the SI joint and within the confines of the inner and outer tables can be confirmed on the obturator and iliac oblique views (TECH FIG 8A,B).
- These two screws are then connected with fixed-angle clamps and a 5.0-mm rod, supplementing the SI screw to resist vertical displacement (TECH FIG 8C).
- Sacral fracture reduction and fixation with clamps and an SI screw as described above should be performed before placing any spinal pelvic construct.
- This avoids rigid fixation with residual sacral gap and subsequent nonunion or delayed union.

SACRAL NERVE ROOT DECOMPRESSION

- In most transforminal fractures, the incriminating fragment of bone can be found and removed by working directly through the fracture in the sacrum.
- A laminar spreader can be placed into the fracture to spread the respective portions of the fracture.
- After the clot is removed, careful dissection along the exposed surface of the medial sacral fragment will disclose some portion of the foramen.
- Tracing the nerve root anteriorly will usually lead to the bone fragment.
- Occasionally, a Kerrison and pituitary rongeur will be needed to remove some portion of the sacral lamina to find the nerve root, so these instruments should always be readily available.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Poor SI screw purchase</th>
<th>Placement of a second SI screw into S2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The surgeon should ensure appropriate length into the anterior aspect of the sacral vertebral body and promontory. Alar purchase is poor secondary to low bone density here.</td>
</tr>
<tr>
<td></td>
<td>Placement of a transsacral SI screw into contralateral SI joint</td>
</tr>
<tr>
<td></td>
<td>Placement of transiliac bars or plates</td>
</tr>
<tr>
<td>Fixation of sacral fracture with residual gap</td>
<td>Clamps and SI screws are used to close the fracture gap under fluoroscopic control, without overcompressing.</td>
</tr>
<tr>
<td></td>
<td>The spinal pelvic fixation construct should not be used before manipulative reduction and SI screws, as it will lock down the fracture, preventing reduction and gap closure.</td>
</tr>
</tbody>
</table>
### POSTOPERATIVE CARE

- Provided that all other injuries permit, the patient is mobilized the first postoperative day.
  - The patient is instructed to be touch-down weight bearing on the ipsilateral extremity for 10 to 12 weeks for SI dislocations and sacral alar fractures stabilized with SI screws.
  - Patients with spinal pelvic fixation can be allowed to bear full weight within 4 to 6 weeks.
  - All patients are given a regimen of pelvic, core trunk, hip, and knee range-of-motion exercises.
  - Common early postoperative problems in patients with severe pelvic fractures include ileus and urinary retention; these need to be addressed early.
    - The Foley catheter is usually not removed until the patient can mobilize well with physical therapy.
    - Diet is not advanced until flatus and normal bowel sounds have returned.
    - Anticoagulation is administered in all patients for 6 weeks, with low-molecular-weight heparin or Coumadin for deep venous thrombosis and pulmonary embolism prophylaxis.

### OUTCOMES

- Outcome studies after fixation of pelvic fracture-dislocations are difficult to interpret because of poor follow-up, heterogeneity of the injury pattern, associated visceral and neurologic injury, and the lack of reliable outcome measures for pelvic ring injuries.
- Improved short-term patient outcomes with early stabilization and mobilization as well as numerous reports citing improved outcomes with anatomic reduction of the posterior ring continued to provide the impetus to develop more rigid and stable posterior fixation constructs.
- Earlier outcome studies support the position that the long-term functional results are improved if reduction with less than 1 cm of combined displacement of the posterior ring is obtained, especially with pure dislocations of the SI complex.
  - Fractures of the posterior ring, as opposed to pure SI dislocations, tend to display superior outcomes, presumably because bony healing can restore initial strength and stability.
  - In contrast, SI dislocations rely purely on ligamentous healing and scar formation; as a result, these patients tend to have worse functional outcomes in the short term and long term with pain and ambulation compared to patients with other injury patterns.
- More recent detailed clinical outcome studies have shown that with current fixation techniques, many patients continue to have poor outcomes with chronic posterior pelvic pain despite seemingly anatomic reductions and healing, with less than 50% returning to previous level of function and work status.
- This disparity in results is likely related to multiple confounding factors, such as:
  - Poor financial and psychosocial and emotional status of trauma patients
  - Extensive soft tissue damage and associated long bone and extremity fractures
  - Associated neurologic, visceral, and urogenital injuries, resulting in dyspareunia, sexual dysfunction, and incontinence
  - Prolonged recovery and rehabilitation time, with loss of job, home, and family roles
COMPLICATIONS

- Blood loss and the need for transfusion is common with any open procedure on the posterior pelvic ring, particularly with open reduction of the SI joint and sacral fracture, where injury to the superior gluteal artery is always a danger.
- Wound infection occurs surprisingly infrequently given the medical condition of these patients, prolonged ICU and hospital admission, and associated soft tissue injury.
- Infection and wound complications occur in about 3% of all patients.
- Patients with internal degloving injuries (a Morel-Lavallée lesion), where the skin and subcutaneous fatty layer are sheared and separated from the underlying musculofascial layers, are particularly prone to severe wound complications, with dehiscence, necrosis, and slough.
- Patients who have been identified as having an internal degloving lesion in the area of operative approach should first have drainage and débridement of the lesion, and the reduction and placement of fixation should be performed through an alternate approach.
- Neurologic injury from manipulation of fracture fragments or placement of SI screws is also a possibility.
- Careful attention to the radiologic landmarks and clear appropriate imaging should allow the surgeon to avoid these iatrogenic complications, although even smooth, gentle reductions of widely displaced fractures and dislocations can result in neuropraxic injury to the nerve roots and postoperative deficits.
- Patients need to be informed of this risk preoperatively.
- The risk of misplaced SI screws varies widely with surgeon and individual experience.
- Loss of reduction and failure of fixation can occur in very comminuted and unstable fracture-dislocations, particularly in patients with poor bone quality.
- These situations should be recognized preoperatively and intraoperatively, and the appropriate supplemental fixation (additional SI screws or spinal pelvic fixation constructs) should be applied.
- Nonunion of sacral fractures and SI dislocations is rare and not reported specifically in the literature.
- Rigidly stabilizing a sacral fracture with a residual gap predisposes to malunion and nonunion.
- Some patients with SI dislocations continue to have chronic SI joint pain, requiring SI joint fusion.

REFERENCES

DEFINITION

A posterior wall fracture is one of the elementary fracture types as described by Letournel.\(^6\) It is a fracture of the posterior rim of the socket portion of the ball-and-socket joint of the hip (FIG 1).

The disruption separates a segment of articular surface that involves varying amounts of the bony posterior wall of the acetabulum. It can exist as one single fragment or as several comminuted pieces.

The wall fracture can exist alone or as part of an associated acetabular fracture.

By definition, the posterior column, and therefore the iliosischial line, remains intact, despite varying amounts of retroacetabular surface disruption.

ANATOMY

The hip is a constrained ball-and-socket joint composed of the femoral head as the ball and the acetabulum as the socket.

The capsule surrounding the joint extends from the bony acetabular rim to the intertrochanteric line anteriorly and to the femoral neck posteriorly. It is thickened in specific areas, creating ligaments.

Anteriorly, the iliofemoral Y ligament exists as two bands. The inferior capsule is supported by the pubofemoral ligament and the posterior capsule is strengthened by the ischiofemoral ligament.

The acetabular labrum is a fibrocartilaginous structure attached to the bony rim, deepening the socket and making the joint more stable. It adds an additional 10% of coverage to the femoral head.

FIG 1 • AP (A) and Judet (B,C) radiographs of a posterior wall fracture. The posterior wall fracture fragment is outlined.
The acetabulum is composed of two columns, two walls, and the roof within the pelvis. The anterior and posterior columns form an inverted Y and are attached to the sacrum via the sacral buttress. The articular surface of the joint sits on the anterior and posterior walls and the roof, which is located within the arms of the Y.

- The anatomic roof is located between the anterior inferior iliac spine and the ilio-ischial notch of the acetabular margin.
- The weight-bearing dome, as determined by 45-degree roof arc measurements on anteroposterior (AP) and Judet radiographs, is the most important articular portion of the acetabulum. This functional aspect of the acetabulum includes the excursions of all resultant force vectors during normal daily activities.
- Two additional segments should also be considered separately.
  - The posterosuperior segment is the bridge between the roof and the posterior wall.
  - The posteroinferior segment is the lower part of the posterior wall and the posterior horn of the cartilage.
- Due to the large area of muscular attachments, the blood supply to the acetabulum is vast. Small arteries start peripherally and flow centrally, parallel to each other.
  - The largest nutrient foramina on the internal aspect of the ilium is reliably located 1 cm lateral to the sacroiliac joint and 1 cm above the iliopectineal line. It is fed by a branch of the iliolumbar artery.
  - A branch of the superior gluteal artery feeds the largest nutrient foramina on the external surface in the center of the iliac wing, just anterior to the anterior gluteal line.
  - The obturator artery supplies foramina in front of the sciatic notch just below the iliopectineal line and in the roof of the obturator canal. The body of the pubis is also supplied by the obturator artery. A branch of this artery, the acetabular branch, feeds the cotyloid fossa via a number of small perforators.
  - A complete vascular circle supplies multiple nutrient vessels around the periphery of the acetabulum. The artery of the roof of the acetabulum (from the superior gluteal artery), the obturator artery, and the inferior gluteal artery are main contributors.
  - The iliac crest, from the anterior inferior iliac spine posteriorly to the auricular articular surface of the sacroiliac joint, is supplied by branches of the external anterior iliac artery, branches of the fourth lumbar artery, and branches of the iliolumbar artery.
  - The sciatic buttress receives its blood supply from multiple branches of the superior gluteal artery.

**PATHOGENESIS**

- Acetabular fractures occur when a force is transmitted from the femur, through the femoral head, to the acetabulum. The specific pattern of the fracture is determined by the position of the hip at the time of injury and the magnitude of the force of the trauma.
- A common mechanism of injury of posterior wall fractures and fracture-dislocations is a motor vehicle crash in which the unrestrained patient is sitting with a flexed knee and the knee strikes the dashboard, creating an axial load along the length of the femur, loading the posterior aspect of the acetabulum.
- With a posterior wall fracture or fracture-dislocation, one of two possibilities exists for the capsule.
  - The capsule can rupture and allow the head to dislocate. In this scenario, varying sizes of wall fragments and labral injury can exist.
  - Alternatively, the capsule can remain intact to the wall fragment and to the femur, with all of the displacement (or even the dislocation) occurring through the fracture site.
- The size of the posterior wall fragment and the integrity of the capsule and the labrum play a role in hip stability. Despite attempts to quantitate fragment size to define operative indications, stress examination remains the only method to predict instability.
- When the capsule remains intact and the head dislocates, the fracture edges often fragment. This creates osteochondral fragments, which can lead to impaction or incarceration of the pieces upon reduction of the femoral head.
NATURAL HISTORY
- The goal of the treatment of acetabular fractures is to achieve a stable, congruent hip joint with an anatomically reduced articular surface. Anatomic reduction and stabilization will decrease the incidence of posttraumatic arthritis.8
- Although fractures of the posterior wall are common, representing 24% of Letournel’s initial series, they are frequently reported as having poor results, with 10% to 30% of patients developing post-traumatic arthritis within 1 year.
- Nonoperative treatment is unsuccessful, and Epstein3 has documented that 88% of patients treated with closed reduction alone had unsatisfactory long-term results.
- Roof arc and subchondral arc measurements do not apply to typical posterior wall fractures; however, the size of the posterior wall fragment may play a role.
- Multiple authors have attempted to define the size of the fragment that will predict instability.
  - In cadaveric studies, fragments that include greater than 50% of the wall were always unstable, while those less than 20% were stable.5,16
  - A clinical study revealed that acetabuli with less than 34% of the posterior wall intact were unstable and those with greater than 55% intact were stable.2
  - Dynamic stress examination that uses fluoroscopy to assist with the detection of suble subluxation can define a stable or unstable joint without depending on fragment size measurements.14

PATIENT HISTORY AND PHYSICAL FINDINGS
- Acetabular fractures are often the result of high-energy trauma, and therefore other associated injuries must be sought.
- Hemorrhage and hemodynamic instability are rarely associated with isolated fractures of the posterior wall; however, the superior gluteal artery and vein may be lacerated when fractures extend to the greater sciatic notch.
- Patients will frequently present with hip or groin pain and a shortened lower extremity due to the posterior, superior dislocation of the femoral head.
- Soft tissue injuries around the pelvis are uncommon because the mechanism of injury is indirect. Nonetheless, the skin overlying the hip and pelvis of any pelvic or acetabular fracture should be carefully evaluated for any subcutaneous fluctuance, ecchymosis, or cutaneous anesthesia.
  - The Morel-Lavallée lesion, a subcutaneous degloving injury, although a closed injury, is culture positive in up to 40% of cases.4 Initial débridement of these lesions as well as a delay in internal fixation is recommended by some authors.
  - Soft tissue injuries at the knee are more common and often missed. Ligamentous or chondral injuries are often discovered on secondary survey, but only if they are considered and a careful and thorough examination is performed.
  - The incidence of damage to the femoral head is unknown as the head is not routinely dislocated during fixation of the acetabular fracture for complete evaluation. However, it is not surprising when associated femoral head fractures or chondral lesions are noted, as the large amount of force needed to cause the acetabular fracture is transmitted via the femoral head.
  - Careful neurologic examination at the time of injury reveals deficits in up to 30% of cases. The peroneal division of the sciatic nerve is the most commonly seen nerve injury, especially when the femoral head is dislocated posteriorly.
  - Other ipsilateral extremity injuries often discovered include fractures of the femur, tibia, and foot.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- The diagnosis and classification of an acetabular fracture is made from the initial trauma AP radiograph.
  - Two 45-degree oblique radiographs (Judet views) must be obtained also to aid in classification and treatment planning.
  - Completing the five views of the pelvis series with pelvic inlet and outlet views allows potential injuries to the pelvic ring to be evaluated.
  - A CT scan of the pelvis will assist in defining displacement, intra-articular fragments, marginal articular impaction, and associated femoral head injuries.
  - The size of the posterior wall fragment can also be determined more accurately using a CT scan, which is optimally obtained after the initial reduction.
  - The size and number of incarcerated fragments can be more precisely determined with a CT scan. Preoperative planning allows determination of the size and number of free fragments that must be removed from the joint, as well as the location of any impaction that must be elevated.

DIFFERENTIAL DIAGNOSIS
- Posterior hip dislocation
- Associated acetabular fracture
  - Associated transverse and posterior wall fracture
  - Associated posterior column and posterior wall fracture
  - Associated T-shaped fracture
  - Associated both-column fracture
  - Pelvic fracture
  - Femoral head fracture
  - Proximal femur fracture

NONOPERATIVE MANAGEMENT
- Nondisplaced, stable fractures with a congruent joint can be treated with protected, footflat weight-bearing restrictions if no instability is evident on fluoroscopic-assisted stress examination.14
- Posterior wall fractures that present dislocated should be considered a surgical emergency.
  - A prompt closed reduction with satisfactory general anesthesia is recommended.
  - The surgeon should check the femoral neck before reduction.
  - Once reduced, the joint should be evaluated fluoroscopically in both the AP and obturator oblique views for stability: the joint should be axially loaded with the hip in flexion and in flexion plus adduction.14 Only if the joint is stable (nonsubluxated) is nonoperative management sufficient.

SURGICAL MANAGEMENT
- Surgical management of acetabular fractures is technically demanding. The goal of surgery is to obtain an anatomic reduction of the joint surface and to create a congruent and stable hip joint while avoiding complications.
Other factors that play a role in surgical management include surgeon experience and the timing of operative intervention.

Letournel described his learning curve in 4-year intervals. He also reported reduced ability to achieve anatomic reduction when fractures are operated on more than 21 days after injury.

Unlike most conditions in orthopedic surgery, all displaced fractures of the acetabulum, which include marginal impaction, are indicated for surgery unless specific criteria for nonoperative management are met. These include:

A congruent hip joint on AP and Judet radiographs and on CT scan
An intact weight-bearing surface, as defined by roof arc measurements and subchondral arc measurements on CT scan
At least 50% of the posterior wall intact on CT scan
A stable joint, including on a dynamic stress examination
Patient factors must also be considered.

Age, bone quality, comorbidities, preinjury functional status, type of employment, and personal expectations all must factor into the decision-making process.

Preoperative Planning

Open reduction and internal fixation of a posterior wall fracture is based upon evaluation of the AP pelvic and Judet view radiographs and the CT scan.

The surgeon should closely evaluate the films for a transverse component, which may be overlooked on initial viewing.

The identification of marginal impaction necessitates elevating the articular cartilage and packing behind it with some form of bone graft or bone void filler to reconstruct the joint surface successfully (see Fig 2).

Careful review of the CT scan will allow identification and quantification of the number of intra-articular fragments that exist to ensure that all foreign bodies are removed from the joint upon exploration.

Positioning

Most acetabular surgeons position the patient prone on a fracture table (Fig 3).

The affected side is suspended using a distal femoral traction pin.

The peroneal post must be appropriately padded to prevent pudendal nerve palsy.

The affected leg is placed in traction, with the hip in extension and the knee flexed to at least 80 degrees; the foot is well padded and secured in a fracture table boot in the resting position. Sequential compression devices are applied to both lower extremities.

Traction is positioned to pull in line, neutral abduction–adduction, neutral internal/external rotation, with the table’s arm holding the foot free enough to allow internal and external rotation intraoperatively.

The contralateral leg is in extension in a fracture table boot with the foot well padded and in neutral position.

Pads are placed to support both thighs.

Chest pads are positioned to allow adequate room for the abdomen and breasts, and for chest excursion.

Arms are abducted to 90 degrees at the shoulders and 90 degrees at the elbows.

Once positioning is completed, PA and oblique views are obtained with the C-arm before draping or preparation to ensure that the hip is reduced and that the necessary images can be obtained.

The obturator oblique view can be obtained by rotating the C-arm 45 degrees toward a lateral view.

Pushing upward on the anterior superior iliac spine can assist with the last 15 degrees of rotation to obtain an iliac oblique view, an image that most C-arms cannot otherwise obtain.

Approach

The posterior wall of the acetabulum is accessed via the Kocher-Langenbeck approach.

KOCHER-LANGENBECK APPROACH

Incision and Dissection

The incision is based on two limbs (Tech Fig 1A).

One starts at the posterior tip of the greater trochanter and extends distally along the posterior aspect of the femoral shaft, distal to the trochanter and the gluteal crease, which serves as an external landmark for the gluteus maximus tendon.

The proximal limb extends about 45 degrees toward a spot 1 cm cephalad to the posterior superior iliac spine. The length of this limb depends on the amount of posterior column that must be accessed.

The skin and subcutaneous tissue are divided down to the fascia lata and the gluteal aponeurotic fascia.

Once identified, the tensor fascia lata and iliobibial band are sharply divided longitudinally in line with the underlying femoral shaft (Tech Fig 1B).

To open the proximal limb, the surgeon sharply divides the gluteal aponeurosis and then gently splits the gluteus maximus muscle via finger dissection.
The surgeon must watch for crossing vessels and cauterize them before they are torn.

The nerves that innervate the proximal third of the gluteus maximus will cross in this area, about halfway between the greater trochanter and the posterior superior iliac spine. The surgeon should stop splitting at the first nerve trunk to prevent postoperative palsy.

The Charnley retractor is helpful for holding the fascia away from the operative field. The surgeon must take care not to insert too deeply to prevent iatrogenic injury to the sciatic nerve.

The bursa over the trochanter is often hemorrhagic from the injury and can be resected at this time if it is large and hindering visualization (TECH FIG 1C).

Protecting the Sciatic Nerve

The sciatic nerve is identified. This can be difficult owing to the conditions of the traumatized tissues; often it will be easiest to identify the nerve in an area of healthy tissue, such as at the level of the quadratus femoris.

If overall visualization is inadequate at this point, the gluteus maximus tendon can be divided at its insertion on the femur. A cuff of tissue is left on the femur so an adequate repair can later be performed.

With the posterior aspect of the gluteus medius tendon retracted anteriorly, the piriformis tendon can be identified (TECH FIG 2A).

It can be helpful to internally rotate the leg to put the short external rotators and the piriformis on stretch to assist with identification.

In some cases the short external rotators have been avulsed by the dislocation.

It is easier to palpate the edges of the piriformis tendon with a finger and then pass a finger behind the tendon to better isolate it.

The surgeon confirms that the correct muscle has been identified by following its path backward and toward the greater sciatic notch.

Once isolated, the tendon is tagged and divided at its attachment to the femur (TECH FIG 2B). This tag suture is used to retract the muscle posteriorly (TECH FIG 2C).

With the piriformis retracted, the sciatic nerve should now be easily visible, lying over the short external rotators. The surgeon visually examines the sciatic nerve for any contusion or laceration.

Next, the surgeon identifies the tendon composed of the superior and inferior gemelli and the obturator internus.

Another tag suture is passed through this tendon, and it is released from the femur.

Since the piriformis lies superficial to the sciatic nerve, it will not retract or protect the nerve.

In contrast, the gemelli and the obturator internus can be used to effectively protect and retract the sciatic nerve posteriorly (TECH FIG 2D).

By pulling upward on this tag stitch–tendon, the surgeon can pass a finger into both the greater and lesser sciatic notches, beneath the muscle, and therefore the nerve, making a path.

A sciatic nerve retractor can then be placed along this path, into either notch. (Care should be exercised if a retractor must be placed into the greater sciatic notch due to the presence of the superior gluteal neurovascular bundle.)

By continuously checking that the external rotators are above the retractor, the surgeon can ensure that the sciatic nerve is protected. In addition to protecting the nerve, this helps to retract the soft tissues and provides excellent visualization of the retroacetabular surface.

The posterior hip capsule, the fracture line, and the posterior wall fragment are now within the surgical field (TECH FIG 2E).
With the retroacetabular surface now exposed, the fracture site and the joint must be débrided and prepared.

- By removing any residual hematoma from the field, the posterior wall fragment and the posterior column will become easily visible.
- The posterior column is inspected carefully for any nondisplaced transverse fracture line. It is better to recognize this early than to displace it later.
- The surgeon “books open” the fracture site by flipping the wall piece out into the wound.
- The posterior wall piece will typically remain attached by the capsule and some periosteum. The surgeon strips away from the wall any periosteum that may be preventing its mobilization, taking care not to injure the labral attachments. The surgeon must be sure to peel all the periosteum off the fracture edges. Direct visualization of interdigitation at the fracture site is vital in judging anatomic reduction, and the rate of nonunion is low after reduction and fixation of acetabular fractures.\(^8\)
- It is often necessary to sharply dissect the overlying gluteus minimus muscle from the posterior wall to allow mobilization.
- The femoral head will be easily visualized once the wall is mobilized and the interior of the hip joint is inspected.
- Any damage to the femoral head is noted.
- Intra-articular fragments can be removed and the joint can be irrigated to remove any other debris.
- With the fracture table used to pull traction, the joint can be distracted, which will assist with joint débridement. If the fracture table allows such movement, the hip can be flexed to assist with fragment removal.
- The intact segment must be prepared in a similar fashion.
The surgeon strips any additional periosteum and soft tissue that remains attached to the intact retroacetabular surface at the fracture edge. Again, this area will later be inspected for fracture line interdigitation.

- Any soft tissue is elevated from the top of the ischium. This will prepare the ischium to receive the reconstruction plate.
- The soft tissues superolateral to the acetabulum, on the outer table of the ilium, must be elevated in preparation to receive the proximal aspect of the plate. In this area, it is often necessary to elevate the overlying gluteus minimus muscle.

- It is safe to pass an elevator under the abductor muscles, staying on bone, down toward the iliac crest at the level of the anterior superior iliac spine. A spiked Hohmann retractor inserted in this path can also assist with retraction and visualization.

- With the fracture bed, the joint, the wall fragment, and the intact segment débrided, fracture reduction is the next step.

### FRACTURE REDUCTION

#### Reduction of Marginal Impaction

- Careful dissection of the posterior wall fragments and the intact portion of the pelvis is necessary for an accurate reduction.
- Preoperative review of all the radiographic images will normally identify any marginal impaction, which must be reduced.
- When the femoral head is sitting in the acetabulum, the areas of impaction can be reduced to the head.
- An osteotome is placed deep to the depressed subchondral bone. Gentle malting allows the osteotome beneath the impacted bone. By manipulating the bone and its overlying cartilage, the articular surface is reduced to the femoral head with its intact cartilage.
- Once reduced, there will be an empty space deep to the subchondral bone where the osteotome entered and the original bone collapsed. This area is packed with an osteoconductive bone void filler that can provide structure and prevent recollapse. Options include autogenous cancellous bone, allograft cancellous bone chips, and calcium sulfate bone graft substitute.
- As in other areas of the body, overreduction is better than underreduction, as often there is settling.
- Once the fracture bed has been meticulously débrided of fracture hematoma and soft tissue, interdigitation of the posterior wall to the remaining intact retroacetabular surface can be visualized.

#### Reducing the Posterior Wall Fragment

- With the marginal impaction reduced, attention is turned to reducing the posterior wall fragment into its bed in the intact acetabulum.

### INTERNAL FIXATION

#### Provisional Fixation

- Once the posterior wall pieces are reduced, provisional fixation to hold the fragment in place can make the overall procedure easier.
- Options for provisional fixation include either interfragmentary lag screws (2.7 or 3.5 mm) or Kirschner wires.
- By using a ball spike pusher, the fracture fragment is stabilized within its bed, and a Kirschner wire or a lag screw can be placed to hold the reduction.

- We prefer to use 2.7-mm lag screws. With these screws, the heads sit flush with the bony cortex and do not interfere with the subsequent placement of the definitive fixation.
- An alternative to a lag screw is the use of one or multiple Kirschner wires. If Kirschner wires are used, the reconstruction plate can be placed around the wires without difficulty, and subsequent removal is easy.
- Occasionally, when the posterior wall piece is small or comminuted, lag screws and Kirschner wires may not be
possible. A spring plate can be used (similar to when preventing medial wall “kick-up”).

- The end hole of a one-third tubular plate is cut into a V, creating tines. The plate is bent so the tines can effect a reduction. This plate can be used as provisional fixation to hold a small wall fragment in place or as a spring plate to prevent the medial aspect of a large wall fragment from “kicking up.”
- The tines and a portion of the plate are placed over the wall fragment. The fracture edge is spanned with the remaining plate. Either of the remaining holes of the plate can be used for screw placement, depending on the size of the wall being stabilized.
- The plate is positioned so it is possible to drill outside of the joint. Once secured, this spring plate will prevent the wall piece (if small) or the medial fracture edge (if the wall piece is large) from “kicking up” or displacing.

Reconstruction Plate Stabilization

- Now that the wall piece is reduced, it is definitively stabilized with a 3.5-mm pelvic reconstruction plate (TECH FIG 3).
- Most commonly, a slightly underbent, contoured eight-hole plate is used. It is fashioned to sit at the edge of the posterior wall, from the top of the ischial tuberosity to the bone posterior to the anterior inferior iliac spine.
- By using a finger or a Kirschner wire to feel the edge of the wall and the labrum, the surgeon can ensure that there is no portion of the plate resting on the labrum or in the joint. Placement in this location provides the greatest biomechanical advantage in buttressing the wall.
- It is not unusual for the reconstruction plate to sit on top of the heads of the lag screws or rest over the tines of the spring plate.
- With the plate adequately contoured and positioned, it is initially fixed to the pelvis at the level of the ischial tuberosity.

The surgeon drills into screw hole no. 2 from the distal aspect of the plate, which should be resting within the recess at the top of the ischial tuberosity. The surgeon aims distally and medially, into the proximal portion of the ischium. There will be good bone in this location.

Next, the plate position is checked again, at the edge of the wall but not impinging on the labrum, and then a ball spike pusher is placed into screw hole no. 8.

Since the plate is underbent, use of a ball spike pusher and the first proximal screw, placed in screw hole no. 7, will compress the plate to the posterior wall, further enhancing reduction, fixation, and stability of the posterior wall fragment.

The surgeon must take care not to violate the joint or the femoral head while drilling. In most patients, screw holes no. 7 and no. 8 are proximal to the joint even when drilling “straight” across.

The plate will now be holding the reduction, so if any Kirschner wires were used they can be removed.

The surgeon should note whether the medial aspect of the fracture fragment springs up with removal of the Kirschner wire. If it does, further fixation will be required in addition to the primary reconstruction plate.

This is an excellent time to obtain C-arm images to evaluate the reduction and to ensure that the screws have been placed extra-articularly.

One or two additional screws should be placed in the proximal end of the plate, and at least one more screw needs to be inserted into the distal part of the plate, at the most distal hole.

The most distal screw can be placed into the ischium, toward the tuberosity, where one should find great bony purchase.

Checking the Fixation

Once the final screws are placed, the surgeon evaluates the retroacetabular surface, ensuring that the medial aspect of the fracture piece has not “kicked up.”

If the medial wall kicks up, it must be further stabilized.

- A lag screw can be used in the same way as previously described.
- A three-hole one-third tubular plate spring plate is another option, as described.
- Once the medial aspect of the wall is reduced and stabilized, the smooth convexity of the retroacetabular surface should once again be restored.
- Any traction that has been applied to the extremity is removed.
- Final C-arm images are obtained to be sure that the joint is reduced and congruent and that all screws are out of the joint.
- The proximal screws are best seen with an obturator oblique view.
- The distal screws are best confirmed as extra-articular with the iliac oblique view.

TECH FIG 3 • The surgeon reduces the posterior wall piece in the fracture bed and fixes it with a buttress plate placed along the edge of the wall.
WOUND CLOSURE

- The wound is copiously irrigated.
- The surgeon checks the integrity and condition of the sciatic nerve one final time.
- A Hemovac drain is placed on the bone, along the posterior aspect of the posterior wall. A long path will help prevent inadvertent pullout of the drain and will allow hematoma to drain over a long distance.
- The first stage of closure is to reattach the piriformis and the external rotators. This can be accomplished in several different ways, including drill holes into the greater trochanter or suturing to the gluteus medius tendon. The author prefers to suture to the tendon, a site shorter than the original insertion site, to decrease the risk of pullout or failure of the repair.
- If the gluteus maximus tendon was released, it is repaired next. Typically, the tendon edges are easily visualized and sutured to each other.
- Any injured or devitalized muscle should be further débrided to decrease the risk of heterotopic ossification.
- Next, the fascia lata is identified and closed watertight.
- Routine soft tissue closure is performed. We prefer to decrease dead space, and therefore areas for hematoma to collect, with a layered closure, when possible, between the fascia lata and the skin.
- We prefer to obtain an AP pelvis radiograph with the patient supine on the regular hospital bed to inspect the reduction, the fixation, and the joint before extubation (TECH FIG 4).

PEARLS AND PITFALLS

Table and positioning
- Using a fracture table, prone positioning, and distal femoral skeletal traction reduces the risk of injuring the sciatic nerve. The hip is extended and the knee flexed to at least 80 degrees in the prone position on the table at all times, allowing the surgeon to concentrate on the procedure. Freedom is allowed in the internal–external rotation plane during the procedure to aid in soft tissue identification and manipulation and to allow differentiation between the femoral head and the edge of the posterior wall.

Internal fixation
- The reconstruction plate is placed at the lateral edge of the posterior wall to gain maximum buttressing capability. A Kirschner wire is used to feel the edge of the wall and the beginning of the labrum to clearly define location if unable to visualize with certainty. The plate is underbent to assist with the reduction.

Superior posterior wall fractures
- These fractures should be stabilized with a superior antiglide plate in addition to the traditional buttress plate.

Imaging
- Intraoperative C-arms often rotate to only 30 degrees “over the top.” To obtain an adequate iliac oblique image, the surgeon can push up on the anterior superior iliac spine, which will further rotate the pelvis and provide a more familiar radiographic image. The surgeon must be certain that all screws are out of the joint! With a convex joint, if the screw is completely out on one image, it is located outside of the joint.

Transverse fracture
- The surgeon must look for it!

Medial wall kick-up
- Often the medial aspect of the posterior wall piece will “kick up” when the plate along the edge of the wall is secured. To prevent this, the surgeon must first look for it and recognize it. Then, a three-hole one-third tubular plate, with one distal hole cut into a V to act as a hook (or a tubular 2.7 minifragment plate), can be placed along this medial aspect of the fracture. One or two screws can secure this plate, which will function as a spring plate and prevent the medial wall from kicking up. This will help restore the smooth convexity of the retroacetabular surface.
POSTOPERATIVE CARE

- A drain is maintained until drainage measures less than 30 cc in a 24-hour period.
- Antibiotics are prophylactically used until 24 hours after the drain is discontinued or until the wound is completely free of any drainage.
- Often hip wounds will have serous drainage for several days postoperatively. It is the author’s opinion that this signifies that the wound is not sealed and therefore the patient should continue to receive prophylactic antibiotics.
- Indomethacin 25 mg is given orally three times a day to prevent heterotopic ossification.
- Chemical deep venous thrombosis prophylaxis is given at the surgeon’s discretion, plus sequential compression boots for mechanical prophylaxis.
- Physical therapy restrictions
  - No active range of motion at the hip
  - Passive range of motion only; this is easily accomplished with use of a continuous passive motion (CPM) machine.
  - Any necessary flexion limit will be determined by intraoperative evaluation.
- Footflat weight bearing for 3 months is instituted immediately and patients are allowed to get out of bed the next day, once they understand their limitations.
- This weight-bearing restriction (about 30 pounds) unloads the weight of the extremity from the hip joint.
- By choosing footflat weight bearing and no active muscle contraction, the joint reaction forces of the hip joint are decreased to attempt to further protect the internal fixation and cartilage during the reparative and healing process.
- At the 3-month mark, with evidence of callus on the radiographs, weight bearing will be advanced to partial weight bearing, with the patient and the physical therapist advancing further as tolerated.
- Strengthening and gait training will begin at this time, with special concentration on the hip abductors.

OUTCOMES

- The outcome of an acetabular fracture after surgical intervention correlates with the quality of reduction and avoidance of complications.
- Although regarded as the simplest type of acetabular fracture, most posterior wall fractures are either comminuted or have marginal impaction, making anatomic reduction difficult and clinical outcomes worse than for most more complex, associated types of acetabular fractures.\textsuperscript{1,13}
- Letournel reported only a 93.7% perfect reduction rate for posterior wall fractures and an 82% good to excellent clinical outcome.\textsuperscript{6}
- Matta reported 100% anatomic reduction of posterior wall fractures in his series but only 68% good to excellent clinical outcome.\textsuperscript{8} Similarly, Moed et al had 97% perfect reductions and 89% good to excellent clinical outcomes for their series.\textsuperscript{12}

COMPLICATIONS

- Posttraumatic osteoarthritis was reported in 17% (97 of 569) of Letournel and Judet’s patients operated on within 3 weeks of injury with at least 1 year of follow-up.\textsuperscript{6} It occurred in 10.2% (43 of 418) of hips after perfect reductions and in 35.7% (54 of 151) of hips after imperfect reductions. The incidence of osteoarthritis for posterior wall fractures was 22.7% (22 of 97). It occurred in 16% (19 of 119) patients with perfect reductions. The rate after perfect reductions is higher compared to perfect reductions for all types of acetabular fractures (16% versus 10.2% respectively).
- Matta reported a 32% (7 of 22) clinical failure rate despite perfect reduction of posterior wall fractures, which was higher than for any other fracture pattern in his series.\textsuperscript{8}
- Infection after acetabular surgery is reported in about 2% to 5% of patients.\textsuperscript{6,8,9} It can be intra-articular or extra-articular, depending on the approach used. The presence of a soft tissue injury, such as a Morel-Lavallée, can increase the risk of infection.\textsuperscript{4,6}
- Heterotopic ossification occurs after use of the extended iliofemoral approach, the Kocher-Langenbeck approach, or the ilioinguinal approach when it is combined with elevation of the external fossa. Letournel and Judet reported it in 20% (41 of 208) of operatively treated posterior wall fractures.\textsuperscript{6} They also reported a decrease from 24.6% (123 of 499) in all cases via all approaches before treatment to prevent formation to 10.2% (5 of 49) in patients receiving indomethacin for prophylaxis to 0% (0 of 29) in patients receiving both indomethacin and radiation therapy.
- Indomethacin is generally considered safe and effective, although a randomized trial has questioned its utility in prevention.\textsuperscript{10}
- The unknown long-term complications associated with radiation therapy, however, make it generally not recommended for isolated posterior wall fractures in young, healthy patients.
- Avascular necrosis of the femoral head must not be confused with rapid mechanical wear or deterioration due to osteochondral injury. Epstein reported a rate of 5.3% in operatively treated posterior wall fractures.\textsuperscript{3} Letournel and Judet reported a 7.5% incidence after posterior dislocation (17 of 227) and a total of 22 of 569 (3.1%) fractures operated on within the first 3 weeks after injury.\textsuperscript{6}
- The rate of iatrogenic nerve injury, typically the sciatic nerve, is reported to be about 2% (range 2% to 18%) in the hands of experienced surgeons.\textsuperscript{6,9,11}

REFERENCES

DEFINITION
- Fractures of the femoral head are rare, and occur almost exclusively with associated high-energy hip dislocations, where they may be seen in 5% to 15% of cases.
- Associated injuries to the femur, acetabulum, or acetabular labrum can affect treatment options.

ANATOMY
- The spherical femoral head is almost completely covered by articular cartilage, which often is damaged during the hip dislocation.
- Blood is primarily supplied to the superior dome of the femoral head by the medial femoral circumflex artery, which travels around the posterior aspect of the proximal femur, traveling deep to the quadratus femoris and penetrating the joint capsule just inferior to the piriformis tendon (FIG 1).
  - Additional vascular support is supplied by the lateral femoral circumflex artery and the foveal artery within the ligamentum teres.
  - The anterior half of the femoral neck is devoid of vascular structures. Therefore, anterior surgical approaches to the hip joint do not compromise the vascular supply of the femoral head.
- The acetabular labrum increases the coverage of the femoral head, but may be damaged during hip dislocation.

PATHOGENESIS
- Both the position of the leg at the time of impact and the patient’s hip anatomy have been shown to play a role in the etiology of hip fracture-dislocations.
- Posterior dislocations, the most common type, occur when the hip is in a flexed, adducted, and internally rotated position. Decreased femoral anteverision leads to reduced femoral head coverage by the acetabulum and increases the risk of hip dislocation.
- The fracture is a shearing injury. Injury to the articular cartilage of the femoral head is common with femoral head fractures, and posterior wall fractures also can occur with this injury.
- Anterior dislocations are less common. They occur when the hip is in an abducted and externally rotated position, which results in an impaction injury to the anterolateral femoral head (FIG 2).

NATURAL HISTORY
- In an intermediate-term follow-up study by Jacob et al.,4 despite open or closed treatment, only 40% of patients had satisfactory results after hip dislocation at an average of 4.5 years after injury. More than half of the patients had posttraumatic arthrosis.
- Osteonecrosis of the femoral head may develop in 20% of patients with femoral head fractures despite anatomic reduction.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Because of the high energy required to induce a fracture-dislocation of the hip, all patients should undergo a thorough trauma evaluation for associated injuries.
  - Airway, cardiovascular, head, and spine injuries should be stabilized emergently.
  - Narcotic pain medication usually is required.
  - Careful evaluation of the affected extremity is essential.
  - The leg often appears shortened and internally rotated or flexed and abducted after a posterior hip dislocation.
  - Suspicion for associated injuries, particularly around the knee, should remain high; such injuries can be recognized on physical examination.
  - Injury to the knee ligaments or extensor mechanism is associated with traumatic hip dislocations and should be assessed with a stability examination.
- Because sciatic nerve injuries are common, motor and sensory examination of the affected extremity is critical, with particular attention paid to strength grades (1–5) and sensation in the peroneal and tibial nerve distribution.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- The hip fracture-dislocation is first evaluated on the trauma anteroposterior (AP) pelvis radiograph (FIG 3A). The goal should be to emergently reduce the hip, and further imaging should not delay such treatment excessively.
- Associated injuries such as femoral neck fractures, acetabular fractures, or pelvis fractures may require additional dedicated hip, Judet view, or pelvic inlet and outlet radiographs.

FIG 1 • The blood supply to the superior dome of the femoral head is primarily supplied by the medial femoral circumflex artery. It travels around the posterior aspect of the proximal femur, traveling deep to the quadratus femoris and penetrating the joint capsule just inferior to the piriformis tendon.
A fine-cut CT scan of the pelvis and femoral neck with coronal and sagittal reconstructions will further define the anatomy of the femoral head fracture and associated injuries (FIG 3B,C).

This should be obtained after reduction of the hip. A pre-reduction CT scan of the hip is not typically indicated.

Although MRI can be used to evaluate femoral head osteonecrosis in follow-up care, acute imaging has not been demonstrated to be prognostic of this complication.

DIFFERENTIAL DIAGNOSIS

Femoral head fractures typically are classified according to Pipkin (Table 1).

An isolated posterior wall fragment may be confused with a femoral head fracture.

NONOPERATIVE MANAGEMENT

Surgical management to reconstruct the articular surface usually is indicated.

Nonoperative management is used only in Pipkin type I fractures with small articular fragments with an associated concentric reduction of the hip.

No quality clinical studies are available to define the amount of displacement of the fragment that can be tolerated. The accepted guideline is that the fragment should be congruent with the intact femoral head.

Small impaction injuries associated with anterior dislocation also may be treated nonoperatively in many cases.

Patients managed nonoperatively should remain toe-touch weight bearing for 8 to 12 weeks. For posterior dislocations, hip flexion beyond 70 degrees should be avoided for 6 weeks to protect the posterior capsule. Pool therapy can be initiated between 6 and 8 weeks.

SURGICAL MANAGEMENT

Most patients with femoral head fractures require surgery to provide an anatomic reduction of the femoral head, remove osteochondral loose bodies, or obtain a concentric reduction of the hip joint. Loose body removal can delay the onset of arthrosis.
Large, displaced fragments should be anatomically fixed. Smaller fragments inferior to the fovea can be excised if a quality, stable reduction of the fracture fragment cannot be obtained. Hip arthroplasty is another good treatment option in elderly patients, especially with large head fragments. Femoral head fractures in this age group tend to have a large amount of associated articular cartilage damage and impaction of the bone at the fracture line, which compromises the patient’s outcome.

Although their significance is unknown, labral tears often can be evaluated and treated surgically.

Algorithm for surgical management:
- Nondisplaced fracture or small impaction injury
  - Nonoperative treatment
- Displaced fracture
  - Small: surgical excision
  - Large: surgical fixation
- Elderly patient
  - Small fragment with evidence of associated femoral head impaction: surgical excision
  - Large fragment or significant femoral head impaction: hip arthroplasty

Preoperative Planning
- If the hip is dislocated, it should be emergently reduced under general anesthesia with skeletal relaxation.
- Inadequate anesthesia during this reduction can lead to further damage to the articular surfaces of the femoral head and acetabulum as the hip is relocated.
- If the hip is reduced, the patient should be placed in 30 pounds of longitudinal skeletal traction until formal open reduction and internal fixation of the femoral head occurs. Traction will unload the femoral head and prevent ongoing third-body wear within the hip joint.
- Repeat radiographs and a post-reduction CT scan should be obtained to evaluate the hip joint.
- It is reasonable at this point to delay definitive surgery until the appropriate surgeon, anesthesiologist, and equipment are available.
- If the hip is irreducible, or there is an associated femoral neck fracture, emergent open reduction and internal fixation are required.

Positioning
- For an anterior Smith-Peterson approach, the patient is positioned supine on a radiolucent table with a hip bump and the affected leg draped free.

For a posterior Kocher-Langenbeck approach, the patient is placed prone on a radiolucent fracture table with a distal femoral traction pin and the knee flexed to 90 degrees to relieve sciatic nerve tension.

For a Ganz surgical dislocation, the patient is placed on a radiolucent table with a beanbag in the lateral decubitus position and the affected leg draped free.

Approach
- The most difficult decision is determination of the best operative approach.
- Epstein originally argued that all femoral head fractures should be approached posteriorly, because the posterior blood supply to the femoral head had already been damaged during hip dislocation. This left the anterior capsular blood supply intact.
- However, the anterior capsule and anterior femoral neck provide very little vascular supply to the femoral head. In addition, visualization of the anteriorly located femoral head fracture often is inadequate.
- This approach is best used when large femoral head fragments remain dislocated posteriorly after reduction of the hip or with an associated posterior column or posterior wall fracture.
- However, visualization of the anterior head fragment is difficult through a posterior approach, and such a fracture may be better treated with a surgical dislocation (see Techniques section).

Swiontkowski effectively demonstrated that better visualization of the femoral head was obtained for most Pipkin I and II femoral head fractures by using the distal limb of an anterior Smith-Peterson approach.

No increased incidence of osteonecrosis was seen, although a slightly higher risk of heterotopic ossification was observed.

A Smith-Peterson approach is currently the most commonly used method for fixation, and is the preferred approach for excision of the fragment.

The best visualization of the femoral head can be obtained through a surgical hip dislocation, as described by Ganz et al.

This approach safely preserves the medial circumflex arterial supply to the femoral head.

It also allows the best access to associated injuries such as posterior acetabular fractures, labral tears, osteochondral debris, or posteriorly dislocated femoral head fragments.

Surgical dislocation also provides improved access to anulate lag screw fixation perpendicular to the femoral head fracture line.

SMITH-PETERSON ANTERIOR APPROACH

Incision and Dissection
- This is the preferred approach for fragment excision.
- The patient is positioned supine on a radiolucent table with the leg draped free.
- A vertical incision is made from the anterosuperior iliac spine extending distally toward the lateral border of the patella (TECH FIG 1A).
- The sartorius and tensor fascia lata are identified (TECH FIG 1B). The fascia is incised over the medial aspect of the tensor muscle, and the medial border of the tensor muscle is followed to develop the interval between the tensor and sartorius muscles (TECH FIG 1C).
- The tensor muscle is retracted laterally and the sartorius muscle medially.
- The direct and indirect heads of the rectus femoris muscle are identified and are retracted medially (TECH FIG 1D). There is an overlying fascial layer that must be divided to be able to see this muscle. The lateral femoral circumflex vessel traverses the inferior part of the wound and marks the distal aspect of the incision.
TECH FIG 1 • A. Incision starts from the anterosuperior iliac spine extending distally toward the lateral border of the patella. B. The fascia is incised over the medial border of the tensor muscle. C. The medial border of the tensor muscle is followed to develop the interval between the tensor muscle and the sartorius muscle. D. The direct and indirect heads of the rectus femoris muscle are identified and retracted medially. E. The iliocapsularis muscle lies deep to the rectus muscle. This muscle is swept medially to expose the joint capsule.
In most patients, a residual muscle belly, the ilio-capsularis muscle, is deep to the rectus muscle (TECH FIG 1E). This muscle is swept medially, exposing the capsule.

**Capsulotomy**
- A longitudinal incision is made from the articular rim to the base of the femoral neck along the axis of the femoral neck. Anteriorly, a capsular incision is made along both the acetabular rim and the base of the femoral neck (TECH FIG 2A). Posteriorly, only a capsular incision along the articular rim is made.
- Incising the capsule posteriorly along the base of the femoral neck places the medial femoral circumflex artery at risk. The medial femoral circumflex vessel, which rests in a synovial fold on the posterolateral femoral neck, and the acetabular labrum must be protected. The anterior aspect of the femoral neck is devoid of vascular structures.
- If additional exposure is necessary, a portion of the direct head of the rectus muscle may be released.
- Blunt retractors are placed within the joint capsule to obtain good exposure of the head fracture (TECH FIG 2B).

**Fracture Reduction and Fixation**
- Reduction of fragment is facilitated by cutting the ligamentum teres.
- The fragment is excised if it is too small for internal fixation.
- A pointed reduction clamp is used to reduce the displaced fragment.
  - Many fractures have a component of impaction injury on the femoral head, so the fracture may not key in circumferentially. Circumferential visualization of the fracture is necessary to confirm that adequate reduction has been obtained.
- In some cases, anterior dislocation of the femoral head will facilitate both fracture reduction and insertion of definitive fixation.
- The fracture is fixed with recessed 3.5- or 2.7-mm lag screws or headless self-compressing screws (eg, Acutrack [Acumed LLC] or Herbert-Whipple screws [Zimmer Inc.]).
  - It is important to ascertain that the screw heads are recessed within the bone.

**Ganz Surgical Dislocation**
- The patient is in the lateral position.
- Either a direct lateral incision or a traditional posterolateral approach is used.
- The gluteus maximus is retracted posteriorly and the tensor fascia lata anteriorly.
- The interval between the gluteus minimus and the piriformis is identified, and the gluteus minimus is sharply elevated anteriorly.
- The trochanter is osteotomized, leaving a portion of the tip of the trochanter intact to protect the medial femoral circumflex vessel. The osteotomy is oriented parallel to the shaft of the femur (TECH FIG 3A).
- The gluteus minimus and medius, the trochanteric fragment, and the vastus lateralis and intermedius muscles are sharply elevated anteriorly.
- The dissection is kept superior to the piriformis muscle, because the medial femoral circumflex vessel penetrates the hip capsule at the inferior margin of the piriformis.

**TECH FIG 2**
- **A.** A capsulotomy is performed by making a longitudinal incision from the articular rim to the base of the femoral neck along the axis of the femoral neck. Anteriorly, a capsular incision is made along both the acetabular rim and the base of the femoral neck. Posteriorly, only a capsular incision is made along the articular rim. **B.** After the capsulotomy is performed, blunt retractors are placed around the femoral neck to expose the femoral head and neck.
Chapter 5 ORIF OF FEMORAL HEAD FRACTURES

TECH FIG 3 • A. The trochanteric osteotomy is made parallel to the shaft of the femur. B. Z-shaped capsulotomy. C–E. Intraoperative views following surgical dislocation of the hip. The ligamentum teres was transected to improve exposure, but the medial retinaculum was left intact. The fragment is fixed with three headless screws. Note the area of femoral head bone loss due to impaction. F,G. Posterosuperior labral tear is demonstrated. The labrum is reduced and secured with suture anchors. Surgical dislocation provides the best exposure of the acetabulum and is our preferred exposure for this fracture pattern. H. Postoperative radiograph. The trochanteric fragment is stabilized with two or three 3.5-mm cortical screws directed in a cephalad to caudad direction.

- Placing the leg in the figure 4 position with the operative-side foot on the table improves exposure of the anterior capsule.
- A Z-shaped capsulotomy is performed with the cephalad limb posterior and the caudad limb anterior (TECH FIG 3B).
- The femoral head is dislocated anteriorly.
- The femoral head fragment is reduced or excised. The labrum is assessed, and is fixed with suture anchors if it is torn (TECH FIG 3C–H).
- If an associated posterior wall fragment is present, the hip is reduced and the wall fragment repaired.
- The capsule is loosely repaired, and the trochanter is reattached with two or three 3.5-mm cortical screws.
PELVIS AND LOWER EXTREMITY TRAUMA • Section I PELVIS AND HIP

POSTOPERATIVE CARE

- Patients are given 24 hours of appropriate antibiotic prophylaxis.
- Deep venous thrombosis prophylaxis is started 24 hours postoperatively, and is used before surgery if it has been delayed more than 24 hours after injury.
- Heterotopic ossification prophylaxis using either 700 cGy of radiation or indomethacin 25 mg three times daily is considered in patients with significant damage to the gluteus minimus muscle.
- Patients are allowed 30 to 40 pounds weight bearing for 8 to 12 weeks, then progressed to full weight bearing as tolerated.
- Hip flexion is limited to 70 degrees for 6 weeks.
- Pool therapy is started once the incision is dry and the sutures are removed.
- Once weight bearing is initiated at 12 weeks, more aggressive physical therapy focusing on gait training and quadriceps and hip abductor strengthening is started.

OUTCOMES

- Because of the rarity of femoral head fracture-dislocations, no large prospective trials have compared surgical versus nonsurgical treatment methods.
- Most retrospective reviews, including those by both Epstein and Jacob, report less than 50% good or excellent results at 5 to 10 years of follow-up.
- Posttraumatic arthrosis is common following a femoral head fracture, and patients should be warned early of the poor prognosis.

COMPLICATIONS

- Posttraumatic arthrosis: >50%
- Femoral head osteonecrosis: 20%
- Neurologic injury: 10% (60% of these recover some function)
- Heterotopic ossification: 25% to 65%; higher risk with anterior approach
- Hip instability
- Deep venous thrombosis

REFERENCES

DEFINITION
- Femoral neck fractures occur in two patient populations.
  - Most commonly, they happen in older, osteopenic patients after low-energy trauma, such as falls.
  - When they occur in younger patients with normal bone, they are usually the result of high-energy trauma, such as a motor vehicle collision.
- Femoral neck fractures can be classified by several characteristics. The most important distinguishing feature in regard to treatment decisions is the degree of displacement.
  - Fractures that are nondisplaced or impacted into valgus can usually be treated with fixation in situ using percutaneous methods.
  - Displaced fractures usually require reduction and fixation or replacement.
- The location of the fracture in the femoral neck can be described as subcapital, transcervical, or basicervical (FIG 1).
  - Transcervical femoral neck fractures can be further characterized by the angle of the fracture line with respect to the perpendicular of the femoral shaft axis. This is the Pauwels classification (Table 1).
  - The importance of this feature is to recognize high-angle fractures (more vertical), which have the greater risk of displacement when treated with screws along the neck axis.

ANATOMY
- The femoral neck axis forms an angle of about 140 degrees to the femoral shaft axis. In addition, it is anteverted about 15 degrees with reference to the plane of the posterior condyles of the distal femur.

PATHOGENESIS
- Low-energy femoral neck fractures generally are a result of a fall from standing height in an osteoporotic individual.
  - This is an increasing public health problem, with projections of 512,000 total hip fractures in the United States by the year 2040.1
  - High-energy (comminuted) femoral neck fractures generally result from high-speed motor vehicle collision or falls from greater than 10 feet.
  - These patients frequently have multiple injuries, which can complicate treatment.

NATURAL HISTORY
- Nondisplaced or minimally displaced fractures that are not surgically stabilized are likely to suffer worsened displacement owing to the high mechanical forces associated with hip motion and the instability that comes from comminution of the cortical bone.
  - The intra-articular location of the femoral neck means that there is not a well-vascularized soft tissue envelope, and the fracture is exposed to synovial fluid, which contains enzymes that lyse blood clot, the required first stage in bone healing. As a result, femoral neck fracture healing is slowed.
  - In addition, the blood supply comes from tenuous retrograde blood flow.
  - Nonunion rate for untreated displaced fractures approaches 100%.
  - Nonunion of the femoral neck leads to a shortened limb, variable restriction in motion, and pain with weight bearing.
  - Fracture of the femoral neck can lead to interruption of the blood supply to the femoral head due to kinking or disruption of vessels or tamponade from hemarthrosis.
  - This results in avascular necrosis in about 15% of cases.2
  - Many surgeons believe that time to treatment is an important factor, with delay increasing the incidence. This is difficult to prove, and the time imperative probably varies from patient to patient.
  - Femoral neck fractures in the elderly are associated with about 20% 1-year mortality.4
  - About 50% of patients return to their previous level of function after surgery.3
PATIENT HISTORY AND PHYSICAL FINDINGS

- In most patients with femoral neck fracture, the history will contain a distinct traumatic episode, after which the patient could not ambulate.
- Physical findings reveal limb shortening, external rotation, and pain on attempted hip motion.
- In some patients, the onset of pain is more insidious.
  - It is usually associated with weight bearing, and it is located in the groin rather than in the buttock or trochanteric area.
  - In the case of a stress fracture, the history of increased activity over a short period of time is suggestive.
  - Night or rest pain suggests pathologic fracture or impending fracture.
- In highly osteoporotic patients with minor trauma, a history of groin pain with weight bearing may be a symptom of occult femoral neck fracture, which is a nondisplaced fracture not visible on plain radiographs.
- Physical examination should include:
  - Observation of the lower extremities with comparison of foot position in the supine patient. A shortened, externally rotated limb indicates fracture.
  - Gait observation. Groin pain on attempted weight bearing or an antalgic gait suggests occult femoral neck fracture.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Standard plain radiographs consist of an AP view of the pelvis and AP and frog-leg lateral films of the hip.
- An AP traction film with internal rotation can be helpful if initial films are difficult to interpret in terms of the location of injury or fracture pattern.
- If clinical suspicion is high (eg, an elderly patient who cannot ambulate because of groin pain) but plain radiographs are negative, a bone scan or MRI may be obtained for low-energy injuries.
  - The bone scan will not turn positive for 24 to 72 hours, but the MRI should be diagnostic within hours of injury.
- Some studies have suggested that any multiply injured patient with a high-energy femur fracture should have imaging of the femoral neck with a CT scan in addition to plain films to identify minimally displaced femoral neck fractures. However, the CT scan may be false negative as well, and the routine use of this modality is controversial.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Fracture Plane Angle*</th>
<th>Example</th>
<th>Effect of Vertical Forces on Fracture Site</th>
<th>Fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pauwels 1</td>
<td>Low, ≈30 degrees</td>
<td><img src="image1.png" alt="Image" /></td>
<td>Compression, stable</td>
<td>Lag screws in axis of femoral neck</td>
</tr>
<tr>
<td>Pauwels 2</td>
<td>30 to 50 degrees</td>
<td><img src="image2.png" alt="Image" /></td>
<td>Variable</td>
<td>Lag screws in axis of femoral neck</td>
</tr>
<tr>
<td>Pauwels 3</td>
<td>High, ≧50 degrees</td>
<td><img src="image3.png" alt="Image" /></td>
<td>Shear, unstable; tends to displace into shortened, varus position</td>
<td>At least one lag screw perpendicular to fracture plane</td>
</tr>
</tbody>
</table>

*Fracture plane angle is relative to a line perpendicular to the femoral axis on AP radiograph.
DIFFERENTIAL DIAGNOSIS
- Intertrochanteric, pertrochanteric, or subtrochanteric fracture
- Anterior pelvic ring (ramus) fracture
- Hip dislocation
- Femoral head fracture
- Pathologic lesion, including neoplasm or infection
- Arthritis
- Avascular necrosis
- Contusion
- Muscle strain

NONOPERATIVE MANAGEMENT
- Nonoperative treatment may be appropriate in patients who are nonambulators, neurologically impaired, moribund, or in extremis.
- Nonoperative treatment should initially consist of bed rest, appropriate analgesia, protection against decubitus ulcers, and appropriate medical supportive treatment.
- Buck’s traction or pillow splints may be helpful in reducing pain.
- As soon as pain control is adequate, patients should be mobilized out of bed to a chair to help prevent the complications of bed rest, such as pneumonia, aspiration, skin breakdown, and urinary tract infection.
- Some valgus impacted fractures may be treated nonoperatively, particularly if discovered after several weeks, but there is a risk of displacement of up to 46%.
- Nonoperative treatment for these patients should consist of mobilization on crutches or a walker.
- Stress fractures may be treated nonoperatively if they are caught early and are nondisplaced and if the fracture line does not extend to the tension side or superior neck.

SURGICAL MANAGEMENT
- Most patients with femoral neck fracture should be considered for surgical treatment.
- Displaced femoral neck fractures in some patient populations may be better served by hemiarthroplasty or

FIG 2 • A,B. AP and lateral model showing gentle S curve of the outline of the head and neck. This smooth contour should be present and symmetrical on superior, inferior, anterior, and posterior surfaces. C,D. Vascular supply to the femoral head. The medial and lateral femoral circumflex arteries arise from the profunda femoris and form a ring around the base of the femoral neck, which is predominantly extracapsular. From this ring, the arteries of the retinaculum of Weitbrecht ascend along the femoral neck to provide retrograde flow to the femoral head. The foveal artery arises from the obturator artery and supplies a variable but usually minor portion of the femoral head.
total hip arthroplasty, which is beyond the scope of this chapter.

- This includes elderly patients, osteoporotic patients, those with neurologic disease, patients with preexisting hip arthritis, and those with medical illnesses impairing bone healing or longevity (eg, renal failure, diabetes, malignancy, or anticonvulsant treatment).

- Nondisplaced fractures, valgus-impacted femoral neck fractures in the elderly, or stress fractures in athletes can be treated with fixation in situ through percutaneous techniques.

- Open reduction and internal fixation is the standard for high-energy injuries in younger healthy patients with good bone.

- Closed reduction of a displaced femoral neck fracture in the young patient is difficult, and one should not accept a less-than-perfect reduction to avoid an open procedure.

- The quality of the reduction is the most important surgeon-controlled factor in outcome.

Preoperative Planning

- Once the decision for operative treatment is made, preoperative planning begins with evaluation of patient-specific factors that may alter the timing or technique for fixation of the femoral neck fracture.

- In the elderly population, optimization of medical conditions is advisable, including evaluation of hydration and cardiac and pulmonary function, and management of chronic medical conditions. However, delay of surgery beyond the first 2 to 4 days increases the risk of perioperative complications and the length of stay.

- In younger patients, it is important to consider other injuries that may affect operative positioning or fixation. For example, ipsilateral lower extremity injuries at another level may affect the use of the fracture table.

- Good-quality radiographs in two planes are necessary to understand the location and orientation of the fracture. In some cases, radiographs of the contralateral side may help select an implant with the correct length, diameter, or neck–shaft angle.

- The anticipated implants should be verified present before the case. It is useful to have arthroplasty instruments and implants in the hospital in the event of unexpected findings. Fortunately, this will rarely be needed.

- Nondisplaced fractures in the subcapital or transcervical region can be treated with two or three cannulated screws, but most surgeons believe that basivascular fractures should be treated with a fixed-angle device, such as a sliding hip screw or cephalomedullary nail.

Positioning

- The patient is positioned on a fracture table with both hips extended. The contralateral leg is abducted to allow the C-arm to be positioned between the legs (Fig 3A).

- Owing to the risk of compartment syndrome, the surgeon should avoid using the “well leg holder,” which puts the contralateral leg in a hemi-lithotomy position (hip and knee flexed, elevating the leg).

- Intraoperative fluoroscopy is used, and good visualization of the hip and the fracture reduction in both AP and lateral projections should be verified before preparing the leg (Fig 3B).

- A closed reduction may sometimes be obtained by applying gentle traction and internal rotation under fluoroscopic control (Fig 3A). Vigorous and complicated reduction maneuvers are unlikely to be effective and should be avoided. If simple, gentle positioning is not successful in achieving acceptable position, open reduction should be strongly considered. The patient should be well relaxed by the anesthesia team.

- Reduction is anatomic when the normal contours of the femoral neck are re-established in both the AP and lateral projections (see Fig 2A,B), the normal neck–shaft angle and neck length are restored (as judged from a film of the contralateral hip, or AP pelvis), the relative heights of the femoral head and trochanter are symmetrical to the contralateral side, and no gaps are seen in the fracture.

- If the C-arm images are of poor quality because of patient obesity or other factors, the surgeon must not assume or hope it will be better intraoperatively. If adequate visualization to

**FIG 3**

A. Patient positioning on fracture table. Both legs are supported in the extended position in padded foot supports. The injured leg is kept in neutral abduction–adduction, while the uninjured leg is abducted to allow placement of the C-arm between the legs. The injured leg may be internally rotated to assist with reduction. B. Fracture table and C-arm positioning to obtain a lateral view of the femoral neck.
assess reduction or implant position is not achievable, open reduction under direct visualization is the prudent course.

**Approach**
- A standard lateral approach is used for percutaneous fixation of nondisplaced or valgus impacted fractures.
- If an open reduction is planned, a Smith-Peterson or Watson-Jones approach may be used according to surgeon preference to afford visualization of the anterior femoral neck.
- The Watson-Jones approach is the senior author’s preference and is described below.

**CLOSED REDUCTION AND PERCUTANEOUS FIXATION**

- The patient is positioned on the fracture table and reduction is obtained as noted above, C-arm visualization is verified, and the leg and hip is prepared and draped in a sterile fashion.
- Preoperative antibiotics are given.

**Guidewire and Screw Placement**
- Guidewires for cannulated screws are placed in line with the femoral neck axis through poke holes.
  - The wires are placed parallel, using a parallel drill guide.
  - The standard screw arrangement is an inverted triangle of three screws.
  - They should be positioned peripherally in the femoral neck with good cortical buttress, particularly against the inferior and posterior neck. Starting points below the lesser trochanter should be avoided owing to risk of subtrochanteric fracture postoperatively (TECH FIG 1A–C).
- Once the position of the wires is verified in two planes by fluoroscopy, small (1-cm) full-depth incisions are made at each guide pin, and the soft tissues are spread to the bone.
- The lateral cortex may be drilled in patients with dense bone.
- Self-drilling, self-tapping cannulated screws are placed by power over the guidewires.
- Washers should be used in the more proximal, metaphyseal locations (TECH FIG 1D,E).
- Screws should be long enough so that all screw threads are on the proximal (head) side of the fracture.

**TECH FIG 1**
- **A.** Sawbones lateral view of the proximal femur showing configuration for three parallel guidewires before placement of cannulated screws. The wire starting points form an inverted triangle. **B.** Intraoperative AP fluoroscopic view showing position and depth of the guidewires. The inferior wire runs right along the inferior cortex of the femoral neck—the “calcar” (arrow). **C.** Intraoperative lateral fluoroscopic view showing guidewire position. The posterior wire is directly adjacent to and supported by the posterior cortex of the neck. Care is necessary to ensure that the guidewire does not go outside of the neck and then re-enter the femoral head. **D,E.** Intraoperative fluoroscopic views demonstrating cannulated screw insertion over guidewires. **D.** AP view showing use of washers in this metaphyseal location. **E.** Lateral view showing parallel insertion and appropriate depth.
Arthrotomy
- Many surgeons believe that an arthrotomy should be performed to relieve pressure on the blood supply to the femoral head due to intracapsular bleeding. Some consider this to be mostly important in younger patients with minimally displaced fractures, because they reason that more widely displaced fractures have had decompression of the intracapsular hematoma by virtue of the injury. This is controversial.
  - A no.15 blade on a long handle is positioned at the inferior margin of the base of the femoral neck on the AP fluoroscopic image.
  - A small skin incision is made at this level, and the soft tissues are spread down to the joint capsule.
  - With fluoroscopic verification of position, a small capsulotomy is performed to allow drainage of the hematoma from the capsule.
  - A blunt sucker tip can be inserted through this small incision to evacuate any remaining hematoma.

OPEN REDUCTION AND INTERNAL FIXATION THROUGH THE WATSON-JONES APPROACH

The patient is positioned on the fracture table as noted above, fluoroscopic visualization is confirmed, and the leg and hip is prepared and draped in a sterile fashion.
- Circumferential proximal thigh preparation is important.
- Preoperative antibiotics are given.

Fracture Reduction
- A 4.5-mm Schanz pin should be placed in the proximal femoral shaft at the subtrochanteric level to facilitate reduction. The use of a T-handle chuck will allow easier manipulation of this pin.
- A 2.5-mm terminally threaded Kirschner wire is placed in the femoral head at the articular margin to serve as a joystick in the proximal (head) fragment. Sometimes it is necessary to use two such joysticks to accurately position the head, which, because of its spherical nature, may be difficult to position along three axes simultaneously.
- Reduction is performed under direct visualization using the Kirschner wire and Schanz pin to manipulate the fragments.
- Internal rotation of the shaft, along with external rotation and adduction (valgusization) of the head fragment, is usually required.
- Occasionally a bone hook under the medial inferior portion of the neck will help.
- The reduction is verified by keying the opposing cortical surfaces on the anterior, superior, and inferior neck together under direct visualization. A finger can be gently used to feel the surfaces and verify a smooth reduction without gaps or translation. Hard instruments should not be used for this to avoid damage to the delicate blood vessels on the neck.
- The reduction is temporarily stabilized with at least two terminally threaded 2.5-mm Kirschner wires placed from the lateral femoral cortex.
- It is verified by fluoroscopy in two planes.
- When the reduction is anatomic and temporarily stabilized, definitive fixation devices (cannulated screw guidewires, sliding hip screw, or cephalomedullary nail guide) are positioned.

Screw Placement
- Screw fixation is performed as described above for percutaneous stabilization.

Soft Tissue Dissection
- The incision is located laterally over the anterior portion of the greater trochanter.
- It curves slightly anteriorly as it extends proximal from the trochanter toward the crest for about 8 to 10 cm.
- It extends straight distally about 10 cm from the trochanter (TECH FIG 2A).
- The fascia lata is identified and incised just posterior to the tensor fascia lata muscle.
- This incision through the fascia extends the length of the skin incision (TECH FIG 2B).
- The anterior inferior edge of the gluteus minimus is identified.
- The interval between the minimus and the joint capsule is developed.
- A portion of the minimus insertion on the trochanter can be gently released to facilitate retraction with a curved blunt Hohmann retractor.
- The reflected head of the rectus femoris is identified (TECH FIG 2C) and divided (TECH FIG 2D), leaving a stump to repair.
- A Cobb elevator can be used to clean muscle fibers off the anterior capsule.
- The capsule is incised in line with the femoral neck axis (TECH FIG 2E) and then released in a T shape along the acetabular edge (TECH FIG 2F).
- Blunt Hohmann retractors can be moved inside the capsule. The surgeon must take care to be very gentle against the posterior femoral neck (TECH FIG 2G).
- The fracture should be clearly exposed.
- If necessary, the distal part of the capsule, where it inserts anteriorly at the base of the neck, can be released, converting the T arthrotomy to a lazy H (or an l).
TECH FIG 2 - A. Landmarks for Watson-Jones approach: ASIS, anterior superior iliac spine; TFL, tensor fascia lata; GT, greater trochanter; F, femur. The crosshatched line is the incision. B. Interval for Watson-Jones approach, shown here between tensor fascia lata anteriorly and gluteus maximus posteriorly, is indicated by the position of the forceps. C. The anterior surface of the hip joint capsule has been cleared off. The retractor at the top of the picture (anterior on the patient) is under the tensor fascia lata, and the retractor to the left side of the picture (cephalad) is under the leading edge of the gluteus minimus. The reflected head of the rectus femoris, attaching on the top of the joint capsule, is grasped by the forceps. D. The reflected head of the rectus femoris has been divided and tagged with suture. E. The scalpel is in position to perform arthrotomy of the anterior capsule in line with femoral neck. The sutures are in the proximal stump of the reflected head of the rectus. F. A T-capsulotomy has been performed, with the transverse arm toward the acetabulum (proximal). G. The femoral neck is exposed with the gentle use of Hohmann retractors inside the capsule.
- For high-angle transcervical fractures (Pauwels 3), a lag screw should be positioned in a more horizontal orientation, perpendicular to the fracture plane, to provide compression, which will resist the tendency for shear forces to displace the fracture.
- Alternatively, a fixed-angle implant such as a sliding hip screw or cephalomedullary nail could be used and may give better mechanical fixation in a comminuted fracture or Pauwels 3 fracture pattern.
- Reduction and implant position should be verified with the C-arm.

### Wound Closure
- Wound closure includes repair of the capsule, restoration of the reflected head of the rectus, and closure of the fascia lata.
- Layered closure of the skin and sterile dressings complete the job.
- Portable radiographs in the operating room with the patient still asleep, with the back table still sterile, are useful to avoid nasty surprises in the recovery room.

### CEPHALOMEDULLARY NAIL FIXATION
- The patient is positioned on the fracture table as noted above, fluoroscopic visualization is confirmed, and the leg and hip is prepared and draped in a sterile fashion.
  - Circumferential proximal thigh preparation is important.
  - Preoperative antibiotics are given.

#### Incision and Dissection
- A small incision, usually 3 to 4 cm long, is made several centimeters proximal to the tip of the greater trochanter to allow passage of the nail (TECH FIG 3).
- A periosteal elevator can be used to spread the gluteus medius fibers in line with the incision.
- Blunt dissection with an elevator or a finger provides access to the starting point. The tip of the greater trochanter is palpated. The tendon of the gluteus medius attaching to the trochanter can be felt and is protected.

#### Starting Point and Reaming
- Using fluoroscopy, a starting point is obtained for the nail at the medial edge of the greater trochanter for a trochanteric starting cephalomedullary nail.
  - The starting point should be just lateral to the piri-formis fossa (TECH FIG 4A).
  - Alternatively, an awl can also be used to obtain the proper starting point; this can be especially useful in obese patients.
  - An anatomic reduction of the femoral neck must be achieved before reaming.
  - If an anatomic reduction cannot be achieved by closed means, an open reduction must be performed.
  - This can be done by a Smith-Peterson or Watson-Jones approach, as described above.
  - An antirotational pin may be used to maintain reduction (TECH FIG 4B,C).

Once reduction has been obtained, the entry reamer is introduced (TECH FIG 4D).
- For a short cephalomedullary nail, the entry reamer is all that is needed before nail passage.
- If a long cephalomedullary nail is being placed, serial reaming can be performed to 1 to 1.5 cm over the desired nail diameter.

#### Proximal and Distal Interlocking
- After the nail is positioned at the correct depth, the guidewire into the femoral head is placed.
  - Multiple fluoroscopic images are needed to make sure the tip of the guidewire is placed within the center of the femoral head for nails with a single screw going into the head.
  - Newer nails with more than one screw going into the head may necessitate adjustments to this technique to allow passage of both screws (such as placing the first lag screw slightly superior to center to allow passage of the second screw inferior to center).
  - A depth gauge is used to check the length of the guidewire.
  - For rotationally unstable femoral neck fractures, an antirotational guidewire or screw can be placed to prevent rotation of the fracture with tapping (TECH FIG 5A).
  - Many nail systems allow a pin to be placed through a sheath attached to the jig, or have an antirotational bar.
  - A reamer is then used to open the outer cortex of the femur and is continued into the head under fluoroscopic guidance.
The reamer should be checked during passage to ensure the guidewire is not being driven into the pelvis and the reduction is not lost during reaming.

The lag screw is then tapped, and fluoroscopy is again used to ensure the reduction is not lost.

The lag screw is placed and fluoroscopy undertaken in multiple views to rule out penetration of the subchondral surface.

If a distal interlock is desired, it is then placed.

Most nail systems have a set screw that needs to be advanced to give rotational control to the lag screw.

If compression is desired, the set screw then needs to be loosened, usually a quarter-turn of the screwdriver, according to the recommendations of the individual nail system being used.

As above, appropriate films should be taken with the patient asleep. This may include plain films if fluoroscopy is not adequate (TECH FIG 5B, C).

Tech Fig 5 • A. Antirotational screw is placed in addition to guidewire before tapping when using a sliding hip screw or cephalomedullary nail.

B. Preoperative radiograph showing a displaced femoral neck fracture.

C. Final intraoperative AP fluoroscopic view showing anatomic reduction with antirotational screw with cephalomedullary nail.
MINIMALLY INVASIVE FIXATION WITH A SLIDING HIP SCREW

Positioning, Reduction, and Guidewire Placement

- The patient is positioned on the fracture table as noted above and in Chapter TR-8, except that we do not use a well leg holder because of risk of compartment syndrome. Occasionally, in patients with adduction contracture, the well leg cannot be abducted enough with the hip extended to allow access of the C-arm. In these cases, the well leg holder is used as described in Chapter TR-15. Fluoroscopic visualization is performed, and reduction is confirmed to be acceptable in all planes.
- In femoral neck fractures, as opposed to intertrochanteric or pertrochanteric fractures, the reduction must be verified as anatomic if one is to expect stability and healing.
- In this approach, as opposed to the technique described in Chapter TR-15, the guidewire is inserted percutaneously by poking through the skin under the guidance of fluoroscopy and with use of an appropriate angle guide (TECH FIG 6A).
- The guidewire is positioned in the center of the femoral neck and head as described in Chapter TR-15 (TECH FIG 6B).

If the fracture is rotationally unstable (transcervical, comminuted, widely displaced before reduction), an anterotational wire or screw should be placed up the neck across the fracture to prevent loss of reduction (see Tech Fig 5A).

Incision and Preparation of Bone

- An incision is made beginning at the guidewire and extending distally for 4 to 5 cm (TECH FIG 7A).
- A full-thickness skin-to-bone incision is made.
- Soft tissues are gently spread with a clamp, and an elevator is used to clear tissue from the lateral cortex distal to the pin entry site for the length of a two-hole plate.
- The guidewire is measured.
- The reamer is then set to this depth (TECH FIG 7B).
- Fluoroscopy should be checked intermittently during reaming because the guidewire can migrate into the pelvis if bound by the reamer.

Implant Placement

- The lag screw is then placed over the guidewire in standard fashion (TECH FIG 8).
- The femoral neck-shaft angle has been set by placement of the guide pin, but it can be measured intraoperatively with a guide to select the appropriate implant.
- This is usually a 135-degree side plate if placed correctly.
- The side plate is then placed over the lag screw and gently worked through the soft tissues until it is placed into...
contact with the lateral cortex. The skin is quite mobile and elastic, and with a little stretching the plate can be positioned easily.

- Final seating can be done with light blows of a mallet with the aid of a “candlestick” impaction device.
- A two-hole plate is sufficient.
- If lag screw was not placed with the key parallel to the femoral shaft, most systems allow this to be corrected by simply reapplying the T-handle screwdriver to the lag screw and turning the plate and screw as one unit until the plate fits appropriately.
- Usually only two bicortical screws are needed through the side plate into the shaft.
- As above, appropriate films should be taken with the patient asleep. This may include plain films if fluoroscopy is not adequate.

PEARLS AND PITFALLS

Imaging
- The pattern of injury must be recognized preoperatively. A traction film with internal rotation can help with this, as initial plain films are usually externally rotated and may be difficult to interpret.
- If the clinical examination is suspicious despite negative plain films, a screening MRI is indicated to rule out an occult femoral neck fracture.
- Although controversial, a CT scan of the femoral neck should be considered in all trauma patients with femur fractures.

Positioning
- Pelvic rotation: Either scissor legs with the fracture table, or the torso is leaned away from the affected side to prevent pelvic tilt.
- The patients should be draped wide, from the lower ribs to below the knee, to allow complete access to the femur if problems arise.

Reduction
- Internal rotation of the fractured-side leg holder will reduce anterior neck diastasis.
- Guidewire joysticks using 2.5-mm terminally threaded Kirschner wires and Schanz pins can be used to help obtain reduction (usually used when an open reduction is necessary).
- Reduction is facilitated by complete muscle relaxation.
- An anatomic reduction is necessary. An open approach should be used if there is any question that the reduction is not perfect.

Fixation
- The surgeon should avoid starting screws inferior to the lesser trochanter to minimize the risk of subtrochanteric femur fracture.
- Screws are positioned against the femoral neck cortex, especially inferiorly and posteriorly.
- For high-angle fractures (Pauwels type 3), the surgeon should consider using an additional horizontal screw, sliding hip screw, or cephalomedullary nail.
- If the fracture is comminuted or rotationally unstable, the surgeon should consider placing a sliding hip screw or cephalomedullary nail.
- If using a sliding hip screw or cephalomedullary nail, the tip–apex distance should be 25 mm or less, calculated by adding the distance from the center of the femoral head at the level of the subchondral bone to the tip of the screw on both the AP and lateral radiographs.

POSTOPERATIVE CARE
- In the elderly, mentally competent patient with stable fixation, weight bearing is allowed as tolerated.
- For deep vein thrombosis prophylaxis, the length and type of treatment are controversial, but some form of prophylaxis should be given at least during the patient’s hospital stay.
- A first-generation cephalosporin is given for 24 hours postoperatively.

OUTCOMES
- The 1-year mortality rate is about 20% in the elderly.
- About 50% of patients return to their previous level of function.

COMPLICATIONS
- There is a 16% rate of avascular necrosis with displaced femoral neck fractures.
There is a 33% rate of nonunion with displaced femoral neck fractures.²

REFERENCES
Fractures of the proximal femur are usually grouped into four major types reflecting differences in the anatomic and physiologic character of these regions:

- Femoral head fractures
- Intracapsular femoral neck fractures
- Pertrochanteric fractures (also referred to as intertrochanteric and peritrochanteric), which include proximal extracapsular fractures of the femoral neck region to the region along the lesser trochanter before the development of the medullary canal
- Subtrochanteric fractures

Cephalomedullary nailing is the surgical stabilization of the fracture with an intramedullary device usually inserted through the piriformis fossa, the lateral greater trochanter, or the medial greater trochanter.

- The cephalic or femoral head portion of the fixation construct is one or more screw or blade devices interlocked with the nail component of the construct.
- Cephalomedullary nails are most commonly indicated in extracapsular peritrochanteric and subtrochanteric fractures. Although there is occasional overlap of these regions, the personality of the fracture will be predominantly one of these major types.

**ANATOMY**

- The transitional anatomy from the femoral head to the subtrochanteric region affords very different fracture pathogeneses, affecting the surgical opportunity for repair.
- Intracapsular fractures of the femoral neck are critically dependent on the vascular supply from the medial femoral circumflex artery for fracture repair and maintenance of vascularity of the femoral head to avoid avascular necrosis.
- Conversely, the well-vascularized pertrochanteric region is dependent on the structural integrity of an essentially solid cancellous bone block from the triangle of Ward to the lesser trochanter, where the solid nature of the structure changes to a tubular construct with the origin of the femoral medullary canal (FIG 1A).
- Subtrochanteric fractures incur the highest stresses in the proximal femur owing to their tubular anatomy, which places high degrees of stress on the implants used for their fixation.
- The muscular attachments of the gluteus medius in the lateral aspect of the greater trochanter and the iliopsoas insertion in the lesser trochanter are key determinants in the deforming forces associated with fracture displacement and functional recovery after injury (FIG 1B).

**PATHOGENESIS**

- Fractures of the proximal femur fall into three mechanistic categories:
  - Low-energy same-level falls, predominantly in the senior population (50 to 80 years), often associated with osteoporosis and muscular atrophy
  - High-energy trauma in the 18- to 45-year age group from motor vehicle collisions and falls from greater heights, resulting in fractures with marked displacement and comminution
  - Pathologic fractures, often the first indication of a neoplastic process

**NATURAL HISTORY**

- To obtain any real hope of ambulatory recovery, surgical treatment is necessary for complete fractures, as the resulting deformity of a nonoperatively treated hip invariably results in significant shortening and varus deformity.
- Functional recovery is actually very poor despite surgical treatment of these fractures with conventional techniques in the 50- to 80-year age group.
- The American Academy of Orthopaedic Surgeons estimates a 24% mortality rate in patients older than 50 within 1 year after fracture, and only 25% of patients make a full recovery.²

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Pertinent history for a hip fracture patient focuses on the mechanism of injury for insight into the potential quality of bone available for repair and associated injuries in high-energy trauma.
- Associated injuries or premorbid diseases may coexist with the fracture diagnosis. Syncopal episodes resulting in a fall may bring attention to cardiovascular and neurologic disease states.
- A history of any tumor or malignant disease, including the last mammogram and breast examination in women older than 45 and the last prostate examination in men older than 40, may suggest an underlying pathologic etiology for the fracture.
- Drug use, either illicit or prescribed, as a confounding and contributing factor must be sought.
- Unfortunately, nursing home and institutionalized patients must be examined for potential neglect and abuse.
- The physical findings of a displaced hip fracture are shortening of the extremity, deformity of rotation compared to the contralateral extremity, and pain or crepitance with motion at the hip.
- Shortening and rotational deformity may be the result of varus deformity at the hip from associated muscular pull or telescoping of 100% displaced fragments.
- Examination should also include the Lippmann test (auscultation). Decreased tone or pitch implies fracture. Sound conduction through the pelvis and hip from the pelvis is interrupted by any discontinuity from the patella, femur, or pelvic articulations.
Swelling and discoloration with hematoma are signs of injury but are usually not acutely present.
Lacerations, Morel-Lavalle lesions, and decubitus ulcers may complicate the surgical approach.
Extracapsular proximal femur fractures extravasate blood into the surrounding tissues.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Plain radiographs, including an anteroposterior (AP) view of the pelvis, AP and cross-table lateral views of the affected hip, and AP and lateral radiographs, are required for diagnosis and preoperative planning.
- If a long nail implant is a consideration, AP and lateral radiographs of the affected femur to the knee are required, with special attention to femoral bow and medullary canal diameter.
- CT or MRI scans are rarely required for displaced fractures but may be useful in establishing the diagnosis in nonobvious fractures and atypical fractures in high-energy trauma patients.
- If a pathologic etiology is suspected, however, an MRI or PET scan of the body should be considered as part of the initial workup.
- Intraoperative or preoperative traction radiography or fluoroscopic C-arm views may be helpful in delineating the extent of complex fractures.
- Intraoperative length measurements with the C-arm of the normal femur may be helpful in selecting the correct nail length in complex fractures (**FIG 2**).

**DIFFERENTIAL DIAGNOSIS**
- Painful arthropathy (osteoarthritis, rheumatoid arthritis, septic)
- Established nonunion of the proximal femur
- Pathologic deformity (ie, Paget disease, fibrous dysplasia of the hip)
- Pubic rami fracture
- Acetabular fracture
- Contiguous femoral fracture
- Hip fracture-dislocation (rare)

**NONOPERATIVE MANAGEMENT**
- Nonoperative treatment is frequently the best option in non-ambulatory or chronic dementia patients with pain controllable with analgesics and rest, patients with terminal disease with less than 6 weeks of life expected, patients with unresolvable medical comorbidities that preclude surgical treatment, and patients with active infectious diseases that preclude insertion of a surgical implant.
- An exception is incomplete pertrochanteric fractures diagnosed by MRI, which have been shown to heal with nonoperative measures in selective patients.¹

**FIG 1**
- **A.** Radiographic anatomy of the proximal femoral fracture zones. Note greater trochanter and lateral wall and lesser trochanter and medial wall.
- **B.** Muscle attachments in subtrochanteric fractures accounting for the subsequent deformity of the fracture.

**FIG 2**
- Estimate of nail required from intraoperative radiograph of normal femur with nail in box.
Nonoperative management must include attentive nursing care with frequent positioning to avoid decubitus, attention to nutrition and fluid homeostasis, and adequate analgesia or narcotic pain suppression. Patients may be mobilized from bed to chair as tolerated, usually after 7 to 14 days, with careful support and elevation of the affected extremity.

Fracture callus at 3 weeks markedly decreases motion-related pain, and by 6 weeks most patients can be lifted into a wheelchair or reclining chair.

Ambulatory ability should not be anticipated after nonoperative treatment of displaced fractures.

**SURGICAL MANAGEMENT**

Surgical management, once selected, should be performed as soon as any correctable metabolic, hematologic, or organ system instabilities have been rectified. Usually this is within the first 24 to 48 hours for most patients.

The literature is inconclusive as to increased mortality after this time, but patient suffering and hospital efficiencies demand timely intervention.

**Preoperative Planning**

Standard AP pelvis and AP hip radiographs are usually obtained. Cross-table lateral and films in traction are useful if the hip fracture pattern is complex. Hip fractures are three-dimensional entities, and this is readily apparent in high-energy trauma cases. Full-length radiographs of good quality are required before surgery to evaluate the full extent of damage to the femur, to estimate the length and diameter of implant selections, and to avoid neglect of skip lesions or segmental damage to the femur.

Classifications for pertrochanteric and subtrochanteric hip fractures have not been particularly helpful in clinical situations, although increased surgical complexity is associated with unstable fracture patterns.5

- Unstable characteristics include posteromedial large separate fragmentation, basi-cervical patterns, reverse obliquity patterns, and displaced greater trochanteric or lateral wall fractures.
- The Evans, Kyle, AO/OTA, and Russell-Taylor classifications are commonly referred to in the literature.
- The Russell-Taylor classification assists in implant selection for the proximal femur by drawing attention to the high-risk attributes of the proximal femoral anatomy, particularly the absence or presence of fracture extension into the greater trochanter (lateral wall), referred to as group I (intact greater trochanteric region) and group II (fracture extension), and secondly the absence or presence of medial cortical stability in the lesser trochanteric region, referred to as type A (stable contact possible) and type B (fracture instability) (FIG 3).17
- Russell-Taylor type IA fractures are in reality high diaphyseal femoral fractures within 5 cm of the lesser trochanter and are preferentially treated with conventional interlocking nails, with the surgeon’s choice of either trochanteric or piriformis entry devices.
- Russell-Taylor type IB fractures are fractures at the diaphyseal–metaphyseal junction of the proximal femur with medial instability due to fracture comminution. The greater trochanter and lateral wall are intact, and cephalomedullary nails, either of the reconstruction nail class or gamma nail class, are indicated, with either a trochanteric or piriformis entry type of device with the respective portal.
- Russell-Taylor type IIA fractures are fractures involving the greater trochanter and lateral wall but have the possibility of restoration of medial cortical stability. Reverse obliquity patterns fall into this group. If the greater trochanter is displaced, open reduction and stabilization are required. Trochanteric portal cephalomedullary nails are recommended if a nail technique is preferred. Piriformis nails may not obtain sufficient stability of the proximal femur. Open plate and screw reduction with an indirect reduction technique may be preferred in this group of patients.
- Russell-Taylor type IIB fractures are the most unstable fractures, with fracture extension into the greater trochanteric region, and have lost medial cortical stability. Trochanteric cephalomedullary nails are the preferred nail option for this group if a stable nail construct can be obtained, or alternatively a 95-degree angle plate and screws. These are very complex fractures to treat with nail techniques, and new locking plate designs may be advised in the future based on future clinical studies.
- Reverse obliquity patterns and lateral wall fractures occurring in the perioperative period have been identified as

**FIG 3** Russell-Taylor classification. Type IA fractures are in reality high diaphyseal femoral fractures within 5 cm of the lesser trochanter. Type IB fractures are fractures at the diaphyseal–metaphyseal junction of the proximal femur with medial instability due to fracture comminution. Type IIA fractures involve the greater trochanter and lateral wall but have the possibility of restoration of medial cortical stability. Type IIB fractures are the most unstable fractures, with fracture extension into the greater trochanteric region, and have lost medial cortical stability.
high-risk patterns for sliding compression hip screw-type implant failure, with secondary displacement and failure to maintain the reduction. This calls into question our ability to differentiate stable from unstable pertrochanteric fractures.4,12

- Determination of the preoperative neck–shaft angle and medullary canal diameter is paramount to selection of the correct nail device, as different manufacturers have different neck–shaft angle and diameter nails. Another important consideration is nail curvature for long nails. Curved nails with a 1.5- to 2-meter radius are applicable to most situations, but the surgeon must beware of patients with excessive curvature or tertiary curves in the distal third of the femur, as distal penetration of long nails has been reported.10

- Cephalomedullary nailing involves fixation of the femoral head coupled with an intramedullary shaft implant (FIG 4). These implants are designed to have a piriformis portal for insertion, usually with the shaft component straight in the AP plane, or a trochanteric portal with the shaft component laterally angulated proximally.

- Modern trochanteric designs have moved to a 4-degree proximal bend positioned above the lesser trochanteric region, which seems to be most compatible with anatomic restoration of the fracture.11

- Reconstruction design nails (two smaller screws into the head) (Russell-Taylor Reconstruction Nail, TriGen; Smith & Nephew) have the usual advantage of a smaller head diameter (average 13 to 15 mm) and may be of a piriformis or trochanteric portal design, whereas the traditional trochanteric portal (Gamma; Stryker-Howmedica), IMHS (Smith & Nephew) nails have a single large-diameter femoral

![FIG 4](image-url)
head fixation screw and have proximal shaft diameters around 16 to 18 mm.

- New-generation trochanteric nails are moving to smaller geometries of 15.5 to 17 mm in diameter to conserve bone stock.
- New designs in femoral head fixation are also in use, with spiral blade nail devices for femoral head fixation (TFN, Synthes) and integrated interlocking two-screw fixation (InterTan, Smith & Nephew) with the design goal of improving fracture stability.

Positioning

- Intramedullary techniques for the proximal femur are best managed with a modern fracture table with image intensification (C-arm) capabilities.
- Although the lateral decubitus approach may be helpful for reverse obliquity patterns, the supine position is usually preferred because of the ease of setup and radiographic visualization in a familiar frame of reference.
- We prefer bilateral foot traction with knees in extension with the legs scissored, although attachment to the fracture table via skeletal traction through the distal femur or proximal tibia is used if there are other injuries about the knee, leg, or foot.
- The operative leg is raised to about 20 to 30 degrees of flexion and the nonoperative extremity is extended 20 to 30 degrees.
- The legs are pulled in line with the body to avoid varus positioning of the hip.
- The C-arm is brought in from the opposite side with the base parallel to the operative extremity, centered on the mid-femur such that the cephalad–caudad movement of the C-arm gives good visualization of the femoral head and shaft in AP and lateral views.
- With this type of setup, the true AP of the hip is usually obtained with 10 to 20 degrees of rotation of the C-arm over the top and the true lateral corresponds to about 15 to 30 degrees over the horizontal position (FIG 5A–C). The lateral decubitus position will also require adjustment of the C-arm to correct parallax error (FIG 5D).

Approach

- The surgical approach for the entry is common for all antegrade proximal femoral nailing.
- The incision is usually 3 to 4 cm long and is about 2 cm proximal to the greater trochanter, centered over the extrapolated middle third of the trochanter.
- In obese or muscular individuals, this can be referenced by a line drawn transversely from the anterior inferior iliac spine and the lateral position of the incision determined by the C-arm true lateral with a radiographic marker on the skin (FIG 6).
- This approach should not damage the gluteus medius muscle, so aggressive traction or manipulation through the muscle should be avoided. The surgeon should always instrument and ream the femur with soft tissue protection in mind.

FIG 5 • A. AP over-the-top C-arm position. B. Lateral C-arm position for true lateral of hip. C. Scissors position of legs and angulation of C-arm head for true alignment. D. Lateral decubitus position with C-arm.

FIG 6 • Skin incision position referencing the anterior inferior iliac spine.
FRACTURE REDUCTION

- Reduction of the fracture is tantamount to success. My preferred technique for the proximal femur involves a four-step technique.
- After attachment to the foot positioner or skeletal traction with the perineal post attached, posterior sag is corrected at the fracture with a force directed from posterior to anterior and maintained.
- The leg is flexed through the foot holder 20 to 30 degrees from neutral for intertrochanteric personality fractures and 30 to 40 degrees for subtrochanteric personality fractures, maintaining the posterior-to-anterior reduction force at the hip (TECH FIG 1A).
- Traction is applied to restore length in line with the body. No varus!
- The leg is rotated to align with the proximal fragment, 5 to 15 degrees of external rotation for most subtrochanteric personality fractures and 10 to 15 of internal rotation for intertrochanteric personality fractures.
- Acceptable alignment is confirmed with the C-arm in both views. The surgeon ensures there is adequate room in the pelvic and abdominal areas for the insertion of the wires, reamers, and implants in relation to the fracture table. A 3-liter bag of saline may elevate the pelvis high enough to allow room for the instrumentation.
- The reduction can then be fine-tuned with intramedullary instruments or by percutaneous joysticks or pushers (TECH FIG 1B,C).
- If the reduction is not acceptable at this point, the surgeon should stop and re-evaluate the position of the C-arm and the amount of traction (too little or too much). The surgeon should not start reaming the proximal femur until reduction control is demonstrated.
- If reduction cannot be obtained by joysticks and percutaneous bone hooks (TECH FIG 1D), the surgeon should proceed to open reduction using the lower portion of a Watson-Jones-type approach to the hip (TECH FIG 1E-I).
- The surgeon should avoid dissecting the medial soft tissue envelope, where the vascularity is located. A single cerclage wire will be most helpful if there is a coronal split of the proximal fragment. Use of multiple cables or wires is avoided. The clamps and reduction tools are maintained as the implant is inserted.

**TECH FIG 1** • A. Reduction maneuver with force directed posterior to anterior at the fracture to align anterior cortices, flexion of distal fragment to match proximal fragment, and then longitudinal traction. B. Percutaneous Schanz pin as joystick in proximal fragment. C. Percutaneous joystick eccentrically placed to allow passage of reducer. D. Percutaneous joystick and percutaneous bone hook. E. Open reduction Watson-Jones with two clamps for irreducible high-energy hip fracture. F. Open reduction AP radiograph. G. Open reduction lateral radiograph. H,I. AP and lateral radiographs showing final result.
PRECISION PORTAL PLACEMENT AND TRAJECTORY CONTROL

- The rationale for the minimally invasive cephalomedullary surgical technique is based on three concepts to maximize bone and soft tissue conservation during nail implantation and to minimize the potential for malalignment\textsuperscript{16}:
  - Precision portal placement
  - Trajectory control
  - Portal preservation
- A precise starting point is the first criterion in ensuring an accurate reduction of proximal fractures, whether the entry portal is a modified trochanteric entry portal or a piriformis portal as defined by the selected nail geometry (TECH FIG 2A,B).
- The proximal femur is filled with a solid cancellous bone architecture from the femoral head region until the level just below the lesser trochanter, where the medullary canal begins.
- Trajectory control is the development of a precise path for the nail through this solid cancellous bone, which will restore the proximal alignment in the anteroposterior and mediolateral planes.
- This correct trajectory parallels the anterior lateral cortex of the proximal femur and allows nail juxtaposition against a solid cortical structure (TECH FIG 2C).
- An incorrect trajectory will induce malalignment with nail insertion and result in an unstable juxtaposition against cancellous bone only, forcing the nail to migrate to the posterior cortex and resulting in a flexion deformity of the proximal fragment (TECH FIG 2D,E).

PORTAL ACQUISITION AND PROTECTION

- Once the correct trajectory is established, the portal and the lateral wall of the trochanter must be protected from erosion and fragmentation by the subsequent instruments for fracture reduction and canal preparation.
- Typically, with the patient in a supine position, this erosion takes place in a posterolateral direction during reaming of the proximal femoral component, further contributing to a flexed and varus position of the proximal fragment when nail insertion occurs.
- A stepwise approach to canal preparation will simplify the nail insertion technique (TECH FIG 3A–C).
- There are three currently published options for portal placement\textsuperscript{14}:
  - Lateral trochanteric for nails with a proximal lateral angulation of more than 5 degrees
  - Medial trochanteric portal for nails with a proximal lateral angulation of 4 to 5 degrees
  - Piriformis portal for straight proximal segment nails
- The guidewire drill system is inserted with soft tissue protection to the region of the greater trochanter. A 3.2-cm guidewire is inserted about 5 to 10 mm into bone in the lateral aspect of the greater trochanter.
- This is a pivot pin about which a honeycomb type of targeter can be adjusted to precisely place the definitive guidewire pin at the tip of the greater trochanter.

- The definitive guidewire should just lateral to the tip of the greater trochanter for the lateral trochanteric portal, medial to the tip of the greater trochanter for the medial trochanteric portal (see Tech Fig 2A), and medial to the trochanter on the nadir of the superior femoral neck for the piriformis portal on the AP C-arm view, and all portals should be centered in the femoral neck on the lateral C-arm view.
- The definitive guidewire should be inserted 10 to 15 mm into the trochanter and does not have to be in correct canal alignment as the definitive trajectory will be obtained in the next step.
- Insertion of the guidewire too deeply will constrain the reamer usually into a varus fracture reduction position. This is because the flexibility of the wire and the lateral approach vector of the hip will always place the wire in a varus position when nailing in a supine position. One of the real advantages of the lateral position is allowing a more direct vector approach for the guidewire.

- A cannulated rigid reamer, preferably with modular end-cutting capability (TriGen), approximating the proximal nail geometry diameter, is introduced over the guidewire through the protective sleeve (TECH FIG 3D).
- The rigid reamer or channel reamer is directed toward a point projected in the center of the medullary canal just distal to the region of the lesser trochanter (TECH FIG 3E).
- The reamer is advanced in stepwise fashion while confirming maintenance of trajectory.
- After the reamer has been inserted about 20 mm, its trajectory is confirmed with a lateral C-arm view.
- The reamer should be directed along the anterior cortex of the proximal femur. The insertion of the reamer can be adjusted during reaming to approximate the position described and is most helpful in avoiding a varus position of the proximal femur.
- Once the canal is reamed in such a fashion, the distal femur is adjusted with the fracture table to allow correct neck-shaft angulation.
- The reamer is inserted until it reaches the medullary canal just below the region of the lesser trochanter (TECH FIG 3F).
- The inner reamer is removed and the outer reamer is maintained for protection of the proximal reamer during the next step.

**TECH FIG 3**

- **A.** Entry portal tool with honeycomb design targeter for pin placement (TriGen, Smith & Nephew, Inc., Memphis, TN). **B.** Insertion of entry portal tool through incision. **C.** Two-pin technique through honeycomb targeter to precisely acquire entry site of pin. **D.** Channel reamer insertion through entry portal tool for soft tissue protection. **E.** AP radiograph of trajectory for medial trochanteric portal. **F.** Lateral radiograph of correct anterolateral portal with channel reamer. (A: Courtesy of Smith & Nephew, Inc.)
FRACTURE REDUCTION AND CANAL PREPARATION

- A fracture reducer (TriGen) or similar curved cannulated device is inserted through the retained channel reamer to the fracture site and threaded through the fracture site into the distal fragment intramedullary canal, with manipulation in appropriate planes to align the fracture (TECH FIG 4A).
- A long guide rod is inserted to the knee if a long nail is desired, confirming that the wire does not impinge on the anterior cortex distally.
  - Preferably the guide rod should be inserted to the old physeal scar and centered on AP and lateral C-arm views (TECH FIG 4B).
- The reducer is removed and the guidewire position is maintained with an obturator proximally.
- Length is checked with an appropriate ruler, allowing for fracture distraction and nail final position.
- The diaphyseal region is reamed up to 1 mm over the desired nail size (up to 2 mm for excessive anterior bows) (TECH FIG 4C).
  - The proximal expansion of the nail should have already been reamed with the entry portal reamer, but the surgeon should always confirm diameters.
- The channel reamer is removed and the selected nail is inserted (TECH FIG 4D).

- For long trochanteric nails, it is helpful to rotate the nail 90 degrees anteriorly during the first half of the nail insertion to minimize hoop stresses in the proximal femur. After partial insertion, the nail is rotated to the anticipated anteversion required for femoral head fixation.
- The last 5 cm of the nail is inserted after releasing distraction sufficient for fracture apposition, maintaining correct rotational alignment.
- Most commercial guides use reference marks to align with the femoral head on the lateral C-arm view. These same guides may be used for C-arm verification of correct depth of insertion to allow optimal femoral head fixation.
- The long guide rod is removed to proceed with interlocking.
- Proximal interlocking will depend on the type of implant selected, but most designs recommend that the screw be placed as close to center-center position as possible.
- If a secondary screw is included in the nail design constructs (ie, Reconstruction or InterTan), there is usually sufficient room for the second screw inferiorly, but care should be exercised in small patients.

TECH FIG 4 • A. Insertion of reducer through channel reamer, lateral radiographic view. B. Reducer directed guide rod centered on lateral radiograph, avoiding anterior distal cortex. C. Diaphyseal reaming through channel reamer. D. Nail insertion. For trochanteric nail, the surgeon matches the curve of the nail with the proximal femur during initial insertion to minimize hoop stress at entry portal. The nail is rotated into correct position after 30% to 50% insertion.
SINGLE-SCREW OR SINGLE-DEVICE DESIGNS (GAMMA, IMHS, TFN [SYNTHESES, PAOLI, PA])

- The center-center wire is inserted to within 5 mm of subchondral bone. Fracture reduction is confirmed and the length to lateral cortex is measured.
- If compression is desired (usually 5 mm), the surgeon reams for the screw and selects a screw 5 mm shorter than measured. For the TFN, the head is not reamed.
- The surgeon inserts the head fixation screw or nail to the desired depth; position is confirmed on AP and lateral C-arm views (TECH FIG 5A).
- The option of compression and locking of the lag screw with a set-screw within the nail is available on selected systems (TECH FIG 5B,C).

![TECH FIG 5](image1)

A. Gamma nail AP view with lateral trochanteric portal and center-center head screw position. B. Russell-Taylor IIb fracture with short InterTan nail AP. C. Lateral view.

SINGLE-SCREW OR SINGLE-DEVICE DESIGNS (GAMMA, IMHS, TFN [SYNTHESES, PAOLI, PA])

- Using the proximal targeting guide attached to the nail, the surgeon inserts the most distal proximal guidewire along the femoral calcar within 5 mm of the inferior femoral neck, centered on the lateral C-arm view, to within 5 mm of subchondral bone (TECH FIG 6A).
- Through the proximal targeting guide attached to the nail, the surgeon inserts the most proximal guide pin, which will be close to the center position of the femoral head parallel to the first guide pin. Its position is confirmed with the C-arm.
- The surgeon removes the inferior guidewire, drills and reams for the selected lag screw for the system, and inserts the inferior screw (TECH FIG 6B).
- The same steps are repeated for the proximal screw, and final fixation is confirmed on AP and lateral radiographs (TECH FIG 6C).
- Traction is released before final tightening of the lag screws to allow fracture compression.

![TECH FIG 6](image2)

A. Trochanteric reconstruction nail with inferior drill placed first along medial neck. B. Inferior lag screw placed first. C. Lateral radiographic view of head screw position.
INTEGRATED SCREW CEPHALOMEDULLARY NAIL (INTERTAN)

- Whereas the previous techniques for femoral head fixation used devices that gain compression by impaction or compression against the lateral cortex, this device uses a gear drive mechanism that compresses the nail against the endosteal surface of the medial cortex and simultaneously compresses the proximal femoral head and neck to the medial surface of the nail (see Tech Fig 5B,C).
  - This design conceptually improves rotational and translational stability to the proximal femoral construct.
- The 3.2-mm guidewire is inserted through the proximal targeting guide and advanced in a center position of the femoral head to within 5 mm of subchondral bone, after confirming correct depth and anteversion (TECH FIG 7A–C).
- The inferior lateral cortex is drilled through the targeting guide with a step drill to clear away bone from the nail attachment site for the gear drive. The inferior screw hole is then drilled to within 5 mm of the center-center guidewire tip (TECH FIG 7D).
- The derotation bar is inserted into the inferior hole to augment femoral head and neck stability during large lag screw reaming (TECH FIG 7E,F).
- The surgeon confirms the length for the lag screw, subtracting 5 to 10 mm from the measured length for compression if desired.
- The 3.2 wire is overdrilled with the 10.5-mm cannulated drill, and the selected lag screw is inserted to within 5 mm of subchondral bone (TECH FIG 7G).
- The derotation bar is removed and the compression gear drive screw is inserted through the guide. Traction is released from the leg and compression is started (TECH FIG 7H–K).
- Compression though the gear drive does not begin until the head of the gear drive screw contacts the nail.
- Visualization of compression can be confirmed by C-arm and calibrations on the guide.
- Once compression is achieved, the screwdrivers are disassembled. Static locking of the screw assembly can be achieved with the integrated set screw within the nail.

**TECH FIG 7** • Integrated screw cephalomedullary nail (InterTan, Smith Nephew, Inc.). **A.** Pilot drill hole for 3.2-mm wire for center-center position. **B.** AP radiograph with radiolucent alignment tower. **C.** Lateral radiograph with radiolucent guide centered over femoral head. **D.** Inferior screw hole for derotation bar and compression screw. **E,F.** Derotation bar inserted. **G.** Drill for cannulated center lag screw. (continued)
Short nails have distal locking capability, usually in a static or dynamic mode with most modern designs. I prefer dynamic locking.

- Most systems have this hole targeted through the proximal nail guide, and a single bicortical screw is usually sufficient.

- Long nails have distal locking capability with either static holes or a combination of static and dynamic.

- For length-stable proximal fractures, one bicortical screw is sufficient in a dynamic mode.

- Conversely, for segmental fractures or extensive comminution, two screws may be preferred.

- Distal interlocking is most commonly done using the same freehand technique used in the conventional femoral interlocking nail technique (TECH FIG 8).

**DISTAL INTERLOCKING TECHNIQUE**

**WOUND CLOSURE FOR ALL NAILS**

- With attention to detail, minimal damage to the muscle and skin is incurred with nail techniques, so wound irrigation and standard layered closure are performed.
PEARLS AND PITFALLS

Reduction in the lateral position
- The height of the perineal post is adjusted to effect medial displacement of the shaft. This is especially helpful with reverse obliquity pertrochanteric patterns (Russell-Taylor IIA).

Reduction in the supine position
- The surgeon should avoid placing the hip in varus to gain entry into the bone. This leads to a varus trajectory in the proximal bone stock, which will recur with nail insertion.
- The key to reduction is the rotation of the distal fragment to the externally rotated proximal fragment and apposition of the anterior cortex of the proximal and distal fragments. These two points will allow correction of the flexion and malrotation deformities.
- After nail insertion, the rotational alignment of the proximal femur may change, so before distal interlocking, the surgeon should check length on the lateral C-arm view and match of cortex anteriorly and posteriorly for equivalent thickness. I use a C-arm–verified true lateral view of the hip, mark the rotation of the C-arm on its axis, and then move the C-arm to the distal femur and visualize a true lateral of the knee with overlap of the femoral condyles and mark the rotation of the C-arm. Simple subtraction of these two values gives me the approximate anteversion. For most patients, 15 degrees is the average, although some Asian patients have up to 30 degrees. Then, by rotating the distal fragment, alignment is set and the nail is finally fully seated.

Entry portal
- The medial trochanteric portal greatly simplifies the access to the proximal femur, and the use of a rigid reamer system minimizes false trajectories and trochanteric iatrogenic fractures. The surgeon should avoid letting the reamer lateralize in the greater trochanter at any time.
- The medial trochanteric portal uses less radiation and operative time and is preferred in the supine position.15

Trajectory control
- The concept of trajectory control places the nail in apposition to the anterolateral cortex, minimizing flexion deformities at the fracture site, and conserves bone stock proximally by avoiding cutout of the reamer posteriorly.

Nail insertion
- Rotation of the trochanteric design nails during the first half of insertion minimizes stress on the greater trochanter and medial cortex of the femur below the lesser trochanteric region in long nail designs.
- The surgeon should remember to let off traction before final seating of the nail to avoid nailing the femur in distraction.
- Nails must have stability by cortical contact in the proximal and distal femur. Disruption of the lateral wall places more stress on the construct and should be reconstructed separately from the nail if displaced, or a locking proximal plate may be required. Special care is required for Russell-Taylor IIA and B fracture patterns.

Proximal screw targeting
- Guidewire insertion and drilling should always be performed with a high speed rate and a slow feed rate. This means that the guidewires and reamers bend and can be misdirected with excessive axial force during drilling.
- For single-device and integrated screw femoral head fixation, the surgeon should use a center-center position for the large lag screw.
- For two-device femoral head fixation (reconstruction), the inferior screw is placed first along the lateral wall places more stress on the construct and should be reconstructed separately from the nail if displaced, or a locking proximal plate may be required. Special care is required for Russell-Taylor IIA and B fracture patterns.

Distal locking
- Distal locking is usually recommended with a dynamic single screw for short and long nails. Two distal interlocking screws are recommended for comminuted or segmental fractures.

POSTOPERATIVE CARE
- AP and lateral radiographs of the final construct should be obtained in the surgical suite before recovering the patient to assess the construct and ensure stability.
- If there are adjustments to be made, these are best made while the patient is still under anesthesia.
- Radiographs should reveal the entire fracture region, including the entire implant construct.
- Patients are mobilized to a chair upright position the day after the operative procedure.
- Ambulation with supervision is allowed, with weight bearing as tolerated with a walker or crutches and emphasis on heel-strike and upright balance exercises.6
- Multiple trauma or patients with other complications may have delayed ambulation, but it should begin as soon as possible to minimize secondary complications.
- Patients are re-evaluated with an examination and radiographs at 2 weeks and then monthly thereafter until fracture healing is documented and the patients have maximized ambulatory capabilities, usually by 6 months after the injury.
- The surgeon should emphasize good nutrition and hip abductor exercises bilaterally.
- Patients must be counseled to report any increased swelling or respiratory distress as an emergency because of the high risk of thromboembolic disease.

OUTCOMES
- Union of these fractures is high (more than 95%).
- Functional recovery is poor in many patients, however, with more than 60% of patients failing to recover their preinjury level of function.3
- Mortality within the first year in patients older than 55 is 20% to 30%.
Many patients sustain progressive collapse of the hip into varus and shortening of the leg with the current generation of sliding hip screw fixation.9

**COMPLICATIONS**

- Loss of construct stability is one of the most common complications. It is manifested by collapse of the screw and varus migration of the femoral head construct, with final cutout failure in the worst cases.
  - This occurs to a small degree in all cases, as the sliding impaction was designed to minimize catastrophic cutout.
  - A center-center position of single-screw devices minimizes cutout.3
- Nail cutout is a much more serious complication, involving loss of fixation of the nail component in the proximal femur or periprosthetic femoral fracture with short nails; this will result in reoperation with locking construct plates or 95-degree blade plates, exchange for longer nails, or even prosthetic replacement in severe cases (FIG 7A).
- Nonunion, though rare (1% in older patients), is usually treated with total hip replacement and grafting and implant revision in young patients (FIG 7B).
- Infection occurs in 1% to 2% of postoperative cases and is minimized by preoperative antibiotics, usually a cephalosporin class of antibiotic.
  - In immunocompromised and malnourished patients, standard care involves isolation and sensitivity testing of the causative bacteria and appropriate intravenous antibiotics, in consultation with an infectious disease specialist, and standard débridement and irrigation for wound care.
  - If the implant is stable, it should be retained. Rarely will a resection arthroplasty be required.

**REFERENCES**

Peritrochanteric hip fractures are defined as extracapsular hip fractures, always involving the trochanter and frequently with extension into the subtrochanteric region.

- These fractures occur after falls in a substantial number of elderly people (estimated incidence of 250,000 fractures per year) and represent a growing percentage of healthcare expenditures annually.
- These fractures require operative intervention to achieve stable fracture fixation to allow immediate patient mobilization.

**ANATOMY**

- The intertrochanteric region of the hip is notable for the anatomic transition from the femoral neck to the femoral shaft.
  - The angle subtended by the femoral neck and long axis of the femoral shaft in the coronal plane (the neck–shaft angle) is usually between 120 and 135 degrees in adults.
  - Studies have shown that this angle tends to decrease with age.
- The average femoral neck is anteverted between 10 and 15 degrees (range 0 to 50 degrees) and slightly translated anteriorly (5 to 8 mm) from the axis of the femoral shaft.\(^1^4\)
- The peritrochanteric region of the femur is composed of multiple thickenings of trabecular bone distributed in compressive and tensile groups.\(^4\)
  - The thickest and most structural are the primary compressive trabeculae located along the posterior medial aspect of the femoral neck and shaft, also known as the calcar.
  - Multiple muscle groups attach to this region of the femur:
    - Iliopsoas: attaches to the lesser trochanter and exerts a flexion and external rotation force to the hip
    - Abductors and short external rotators: attach to the greater trochanter
    - Adductors: attach to the femoral shaft distal to the peritrochanteric region
- The blood supply to the peritrochanteric region of the femur is rich and abundant. The medial and lateral femoral circumflex arteries supply the cancellous bone of the trochanteric region through muscle attachments at the vastus origin and the insertion of the gluteus medius.

**PATHOGENESIS**

- In the elderly population most peritrochanteric fractures are caused by a fall onto the lateral aspect of the hip, whereas high-energy trauma produces these fractures in younger individuals.
- Numerous factors, such as structurally weak bone, less subcutaneous padding, and slowed protective reflexes, lead to increased forces on the hip with falls in the elderly population.
- Pathologic lesions in the peritrochanteric region are not uncommon and may lead to pathologic fractures after relatively minor trauma.

**DEFINITION**

- Almost all peritrochanteric hip fractures will heal without intervention. However, owing to the pull of the musculature in this region, the fracture will heal in gross malalignment, leading to subsequent functional limitations.\(^1^6\)
- Early operative intervention of these fractures is undertaken to ensure fracture union in anatomic alignment.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- It is important to elicit the cause of the patient’s fall, as many falls in the elderly population that result in hip fractures are due to medical comorbidities.
- Complaints of hip pain before falling may indicate a pre-existing pathologic process that requires further evaluation.
- A thorough global musculoskeletal examination of the patient is necessary because of the high incidence of associated fractures (especially of the wrist and proximal humerus) in the elderly population sustaining hip fractures from simple falls.
- Examination of the soft tissue overlying the lateral hip, sacrum, and heels is necessary to ensure that no pressure ulcers or abrasions have occurred in these areas.
- The classic physical finding in a patient with a peritrochanteric hip fracture is a short, externally rotated affected extremity.
- Patients may have associated musculoskeletal injuries that are not discovered until examined because of the distracting hip injury.
- Hip rotation assessment: Because of the muscular attachments and gravity, the lower extremity tends to rest externally rotated with a peritrochanteric hip fracture.
- Passive log-rolling of the leg will elicit pain (particularly with internal rotation, which tightens the hip capsule and causes pain due to the hemarthrosis). This may be an especially helpful finding in occult hip fractures with no obvious fracture deformity.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs consisting of an anteroposterior (AP) pelvis and cross-table lateral of the injured hip should be obtained initially.
- A traction radiograph (radiograph taken with gentle manual traction and internal rotation of the leg) will provide more information on the fracture pattern and will allow a better comparison to the uninjured hip (FIG 1A,B).
- A fine-cut (2-mm) CT scan with reconstruction images (sagittal and coronal) set to bone windows may help assess the fracture when ipsilateral femoral neck or other fractures are suspected.
- MRI is the modality of choice to assess for the presence of an occult peritrochanteric hip fracture in the setting of normal radiographs (FIG 1C).
DIFFERENTIAL DIAGNOSIS
- Femoral neck fracture
- Femoral shaft fracture
- Greater trochanter fracture
- Septic hip
- Lateral compression-type pelvic fracture, with pubic rami fractures

NONOPERATIVE MANAGEMENT
- Early operative management of peritrochanteric fractures is associated with decreased patient morbidity and improved patient function compared to nonoperative management.
- Relative indications for nonoperative management include nonambulatory or demented patients with little pain, patients with active sepsis, patients with skin breakdown around the surgical site, and patients with severe and irreversible medical comorbidities precluding operative intervention.
- Nonoperative management consists of two regimens:
  - Early mobilization
    - No attempt at axial realignment
    - Used for nonambulatory patients and consists of pain control and early mobilization out of bed to chair as tolerated to avoid systemic complications of recumbency
  - Traction
    - Attempted anatomic realignment with nonoperative management for ambulatory patients
    - Balanced traction for 8 to 12 weeks, with serial radiographs to assess healing
    - Progressive weight bearing as the fracture shows signs of healing

SURGICAL MANAGEMENT
- Once surgical management is chosen, the timing of intervention becomes important.
- The balance between medical optimization and early operative management in this mostly elderly patient population is delicate.
- Although a recent study of more than 2600 patients found that a delay in surgery of up to 4 days did not increase patient mortality up to 1 year postoperatively, most studies suggest that delays of more than 2 days may increase patient mortality postoperatively.11,17

Preoperative Planning
- Radiographs are reviewed to determine the fracture pattern.
- We find the AO/OTA fracture classification system to be useful and reliable for these fractures. It is divided into groups based on fracture geometry (FIG 2):
  - Group 1 has a single fracture line extending to the medial cortex.
  - Group 2 has more than one fracture line extending to the medial cortex.
  - Group 3 has a fracture geometry that runs in a more transverse or reverse oblique pattern, with the fracture line exiting the lateral cortex below the vastus ridge.
- Implant selection for fracture fixation should be guided based on fracture pattern and patient age.
  - OTA 31-A1-type fractures have been shown to be fixed with reliably good results using either a sliding hip screw or intramedullary device.
  - OTA 31-A2-type fractures have been shown to be amenable to treatment with either side plate and screw devices or intramedullary devices.
  - Recent studies have shown improved patient outcomes and better maintenance of fracture alignment with the use of intramedullary devices in this type of fracture.12,15
  - OTA 31-A3-type fractures have been shown to be treated best with intramedullary devices or blade plates.
  - Sliding hip screw devices are contraindicated in these fractures because of the high incidence of implant failure.6
  - In a meta-analysis, intramedullary implants were found to have a lower failure rate than blade plates when used to treat this type of fracture pattern and should be considered the implant of choice for the elderly patient.6
  - Preservation of bone stock in the proximal femur is an important consideration in young patients with this fracture pattern.
A fixed-angle plate (such as a 95-degree blade plate or locked plate), as well as a reconstruction-type nail with a small proximal diameter, will allow for stable fracture fixation, along with preserved proximal femoral bone stock, which is helpful in cases necessitating later revision open reduction and internal fixation.

The neck–shaft angle of the nonfractured femur should be measured preoperatively to estimate the reduction to be achieved (FIG 3).

Preoperative planning is vital for a satisfactory outcome when a peritrochanteric fracture is fixed with a blade plate.

Multiple views of the nonfractured, contralateral hip and femur, as well as multiple traction views of the fractured hip, are required to properly plan the surgical sequence for this type of fixation.

Positioning

When fixing a peritrochanteric fracture with a sliding hip screw device, the patient is positioned on a well-padded fracture table, with the nonfractured leg carefully positioned in flexion and external rotation in a well leg holder. Alternatively, the patient may be placed in the “scissor” position, with the nonfractured leg extended and supported with a boot. This position is helpful in some patients (eg, obesity, stiff contralateral hip, bilateral injuries) who may not be able to flex and externally rotate the contralateral hip to enable use of a well leg holder.

This facilitates access by the fluoroscopic C-arm to the fractured hip (FIG 4A).

We prefer to secure the affected foot to a well-padded heel cup with tape, leaving the posteromedial neurovascular bundle uncompromised. The foot is then dorsiflexed and secured against a well-padded metatarsal bar to lock the transverse tarsal joint and allow strong traction and rotational forces to be transmitted to the fracture (FIG 4B).

Alternatively, if the fracture is to be fixed with a fixed-angle plate, the patient is placed on a completely radiolucent flat-top table. The affected hip is bumped up at a 20- to 30-degree angle and the leg is draped free.

The scissors position is another alternative position for fixation of a peritrochanteric hip fracture (FIG 4C). The patient is placed supine on a traction table and both feet are secured in traction boots. The noninjured leg is then extended to allow a lateral radiograph of the injured hip to be obtained with relative ease.

Some muscular patients may require skeletal traction of the affected leg through the distal femur or proximal tibia to provide adequate fracture length and alignment.

Approach

Because of the muscular forces exerted on the fracture fragments associated with peritrochanteric hip fractures, perfect anatomic reduction of the fracture is close to impossible with indirect methods, especially in the lateral plane, which is often the most difficult plane to control.

Studies have shown, however, that absolute anatomic reduction of all fragments of these fractures is not necessary for a satisfactory functional outcome.13

The primary goal of reduction of peritrochanteric hip fractures is to re-establish a normal anatomic alignment between the proximal head and neck fragment and the distal femoral shaft in the anteroposterior, lateral, and rotational planes.

A lateral approach to the proximal femur is the preferred approach for open reduction and internal fixation of peritrochanteric femur fractures.
INCISION

- The incision is centered over the lateral aspect of the femur. It is started proximally at the palpable vastus ridge for sliding hip screw devices and just proximal to the tip of the greater trochanter for fixed-angle plates.
  - The distal extent of the incision is made long enough to allow application of the plate.
- The incision is carried through the fascia lata, avoiding the tensor muscle proximally and anteriorly. The vastus lateralis fascia and muscle is incised longitudinally 2 to 3 cm anterior to the linea aspera and retracted anteriorly. Care is taken to identify and control any perforating vessels supplying the vastus lateralis muscle.
- Proximally, the origin of the vastus lateralis is sharply released off the vastus ridge to allow atraumatic anterior retraction of the muscle, to facilitate lateral femoral shaft exposure.
- Care should be taken to avoid any medial shaft dissection to maintain the vasculature to the fracture zone.

FRACTURE REDUCTION

- With the patient accurately positioned on the fracture table, the fracture is initially reduced in the anteroposterior plane with axial traction to re-establish fracture length and partially correct the varus malalignment (TECH FIG 1).
  - Abduction of the leg usually corrects the final varus malalignment and establishes the normal neck-shaft angle.
  - Internal rotation of the distal fragment usually corrects the external rotation deformity and will align the femoral neck parallel to the floor to assist in eventual guide pin insertion, but this must be confirmed under fluoroscopy.
  - In some instances, external rotation of the proximal fragment is necessary to achieve reduction of the rotational deformity.
- Fracture reduction is next checked in the lateral plane. These fractures often display an apex-posterior angulation. This can be corrected by placing a crutch under the femoral shaft for support. Alternatively, some fracture tables have padded attachments to support the thigh.
  - Fracture reduction is reassessed in both the anteroposterior and lateral planes and checked for fracture displacement, neck-shaft angle, neck anteversion, rotation, and femoral shaft sag, with a goal of obtaining a near-anatomic reduction in all of these planes (normal or slight valgus reduction, less than 20 degrees of angulation on the lateral radiograph, and less than 4 mm of fracture displacement).1
  - If a near-anatomic closed reduction cannot be obtained, a formal open reduction is necessary.
GUIDE PIN POSITIONING FOR SLIDING HIP SCREW AND FRACTURE PREPARATION

- The entrance point for the guide pin is selected once exposure of the lateral femoral cortex is completed.
- The entrance for a 135-degree plate is typically 2 cm below the vastus ridge, opposite the midpoint of the lesser trochanter, at the level of the femoral insertion of the gluteus maximus tendon (TECH FIG 2).
- The entrance point for the guide pin is adjusted 1 cm proximal (for lower-angled devices) or distal (for higher-angled devices) from the 135-degree starting point for every 5-degree adjustment in the measured neck-shaft angle.
- The femoral anteversion can be estimated by advancing a free guide pin by hand up the anterior femoral neck and securing it in the anterior aspect of the femoral head.
- The correct-angled guide is placed at the guide pin insertion site, centered in the anteroposterior plane on the femoral shaft and seated flush to the lateral cortex.
- The guide pin is advanced under fluoroscopic guidance, in both the anteroposterior and lateral views, to ensure central placement in the femoral head.
- If the pin is not centered in the head on both views, it must be removed and adjusted.
- The fracture reduction should be reassessed and the guide adjusted to ensure that central guide pin placement is obtained.
- The guide pin is inserted to within 5 mm of the joint line in both the anteroposterior and lateral projections.
- The interosseous length of the guide pin is measured with the ruler provided in the instrument set.
- Care must be taken when deciding on a lag screw length, especially in highly unstable fractures reduced with a substantial amount of traction. This traction can cause fragment distraction and overestimation of lag screw length, which will be noticed when traction is eventually released.
- The guidewire is then advanced into the subchondral bone to ensure stability during reaming.
- A second guide pin can then be advanced into the femoral head proximal to the original guide pin in

unstable fractures or in fractures that are reduced in anatomic alignment using excessive traction.  
- This pin acts as a derotational pin to ensure that the proximal neck and head fragment does not rotate with reaming and screw insertion.
- A triple reamer is used to prepare the channel in the lateral cortex, neck, and head for the lag screw and side plate barrel.  
  - The reamer is set to 5 mm less than the measured lag screw length to ensure that the subchondral bone in the femoral head is not violated during reaming.
  - The triple reamer is then advanced and withdrawn under fluoroscopic guidance, ensuring that the guide pin is not inadvertently advanced into the pelvis, the channel is reamed to its proper length, and the guide pin is not withdrawn with the reamer.
- Occasionally the intact lateral wall of the proximal femur may be fractured by the triple reamer. If this occurs, the fracture is essentially converted into a transverse or reverse oblique pattern, and excessive fracture collapse will occur if it is fixed with a simple sliding hip screw. In these cases, the proximal lateral wall may be buttressed with the addition of a trochanteric plate in conjunction with a sliding hip screw or conversion to an intramedullary device for fracture fixation.

IMPLANT INSERTION

- A two- to four-hole side plate is usually chosen for fixation (TECH FIG 3).
  - Multiple clinical and cadaveric studies have shown no difference in the strength of implant fixation with side plates with more than four holes.\textsuperscript{3,9}
  - The implant is set up according to the manufacturer's specifications.
  - The cannulated lag screw is then inserted over the guide pin with a centering sleeve to ensure proper positioning. Careful sizing of the lag screw is required, as noted earlier, to ensure that fracture compression does not lead to excessive screw length and lateral hardware prominence.
- Fluoroscopy and manual fracture palpation is used to ensure that the fracture is not displaced (rotated) while the lag screw is inserted.
  - If the fracture is displaced by the insertion of the lag screw, it is removed, the channel is tapped, and the lag screw is reinserted.
  - Peritrochanteric fractures of the right hip tend to displace to an apex-posterior angulation with lag screw insertion, whereas left hip fractures tend to displace to an apex-anterior angulation owing to the anatomic configuration and subsequent tensioning of the hip capsule with screw insertion.
BLADE PLATE INSERTION

- With the lateral femur and trochanteric block exposed, a soft tissue-sparing reduction of the trochanteric block to the proximal femur is secured with pointed bone clamps and K-wires or small lag screws as needed (TECH FIG 4).
- Guide pins are then introduced into this reconstructed segment to facilitate proper seating of the chisel for the blade plate.
  - The first pin is placed anterior to the femoral neck and secured into the anterior femoral head to demonstrate the femoral anteversion.
  - The second pin is placed with the use of an angled guide, fluoroscopy, or both near the tip of the greater trochanter and directed into the femoral head at a 90-degree angle to the femoral shaft once the fracture has been reduced and the neck-shaft angle restored.
- The chisel is inserted parallel to the two guide pins, just distal to the second pin. Care must be taken to maintain the correct alignment of the chisel with the shaft of the femur because this determines the flexion-extension of the fracture, which is fixed once the blade plate is inserted.
- The chisel is aimed to pass through the center of the neck and seat in the inferior portion of the femoral head. Because of the anterior translation of the femoral head on the shaft, the insertion site is in the anterior half of the trochanter.
- The position of the chisel should be constantly checked with fluoroscopy before and during its insertion.
- The chisel is carefully removed and the appropriate-length blade plate is inserted and gently seated into the proximal fragment.
- The insertion should be frequently checked with biplanar fluoroscopy to ensure that the blade follows the path made by the chisel.
- Once the blade is seated, the most proximal screw is placed through the implant into the medial cortex of the proximal fragment.
- Fracture reduction is now achieved by bringing the plate to the shaft and controlling length and rotation.
- A femoral distractor may be used on the lateral aspect of the femur, with the proximal pin in the head and neck fragment and the distal pin placed distal to the end of the plate.
- Distraction is applied across the fracture to gain fracture alignment and length through soft tissue tensioning using an indirect reduction technique.
- A bone clamp is loosely applied to the distal femoral shaft fragment and plate to counteract the tendency...
for the fracture to be reduced into varus with the femoral distractor.
- Pointed reduction clamps are used to reduce comminuted fragments to the plate without stripping them of soft tissue attachments.
- With the fracture alignment and length restored, it is checked with fluoroscopy.
- If acceptable, the distraction is reduced to allow fragment settling and fracture compression.

The plate is then fixed to the shaft fragments with screws in the standard manner, and lag screws are inserted where the pointed reduction clamps were previously placed.

The final fracture alignment and length, as well as the femoral head, are examined with fluoroscopy to ensure proper fracture reduction and to make sure that there has been no head penetration by the implant.

- Aggressive débridement of devitalized tissue is performed before wound irrigation.

The wound is then closed in a layered fashion; the muscle, fascia, subcutaneous tissue, and skin are repaired separately.

**PEARLS AND PITFALLS**

| Preoperative fracture assessment | The fracture pattern must be studied preoperatively so that the proper device for fixation may be chosen. Improper use of a sliding hip screw in an OTA type 31-3A fracture, for example, will lead to a higher incidence of fixation failure. |
| Fracture reduction | Fracture reduction obtaining anatomic alignment is important. The rate of fixation failure increases, no matter what fixation method is used, for poorly reduced fractures. |
**Implant selection**
- Measurement of the neck–shaft angle of the normal hip is important to ensure that the proper-angled side plate is used. Use of an improperly angled device will prevent central and deep placement of the lag screw in the femoral head and will increase the incidence of fixation failure.
- Many different device systems exist with slight variations of technique and implant design. Familiarity with the selected device is important, and a trial run on a plastic bone model can be helpful.

**Lag screw position**
- Positioning of the lag screw centrally and deep within the femoral head is one of the most important factors to protect against implant cutout.
- The tip–apex distance, as measured on anteroposterior and lateral fluoroscopy intraoperatively, should be under 25 mm to significantly decrease the incidence of fixation failure (FIG 5).

**Lateral cortical wall fracture**
- Careful handling and maintenance of the lateral cortical wall of the femur in the trochanteric region is important to provide a lateral buttress for controlled fracture impaction postoperatively. Fracture of this structure during implant insertion may lead to a higher incidence of fracture collapse and poorer outcomes when a sliding hip screw is used for fracture fixation. When this pitfall is encountered, re-establishing the lateral cortex is critical and can be accomplished by adding a trochanteric plate to the sliding hip screw or conversion to an intramedullary device.

**Lateral view reduction**
- Reduction of peritrochanteric fractures in the lateral view is difficult. Gravity and muscular pull tend to the fracture into an apex-posterior or apex-anterior position, respectively, depending on the fracture pattern. Care must be taken to assess the fracture reduction in this plane and adjust the reduction if it is not anatomic. Pointed reduction clamps or percutaneously placed joysticks can aid in the reduction in this plane while limiting soft tissue disruption of the fracture.

**Rotational fracture reduction**
- Rotational reduction of peritrochanteric fractures can be challenging as well. Rotational reduction of intertrochanteric fractures is usually straightforward, as most times there is a major fracture line to assess. Subtrochanteric fractures in young patients are often quite comminuted and lack definitive anatomy to accurately judge rotation alignment from the fracture alone. In these cases rotation malalignment of the limb can be assessed by aligning the hip and knee in the anteroposterior plane. This will ensure overall reduction of any rotational malalignment of the limb.

---

**POSTOPERATIVE CARE**
- Anteroposterior and lateral radiographs of the operative hip should be obtained immediately postoperatively in the recovery room to assess implant position and fracture reduction and to ensure that no iatrogenic femur fracture was produced intraoperatively. The entire device should be included in the radiograph (FIG 6).
- Patients are mobilized as soon as their cardiopulmonary and mental status will safely allow, usually by postoperative day 1.
- Unrestricted immediate postoperative weight bearing is easiest for the patient to comply with, and multiple investigations have shown no increase in fixation failure as a result of this postoperative rehabilitation protocol.
Koval et al used gait analysis to show how patients effectively autoregulate their weight bearing postoperatively, with the patients who had the least-stable fracture patterns preoperatively putting the least amount of weight on their legs immediately postoperatively.

- Patients should be seen 2 weeks postoperatively to check for uneventful wound healing.
- Follow-up radiographs should be obtained at 2, 6, and 12 weeks to check for controlled fracture impaction, exclude any fixation device complications, and assess fracture healing.

OUTCOMES

- With proper fracture reduction, implant selection, and fixation device positioning, peritrochanteric hip fractures heal in up to 98% of cases.
- One-year mortality rates after fixation of peritrochanteric hip fractures range from 7% to 27%, with most studies finding a rate of 15% to 20%.
- Mortality rates depend on both preoperative and postoperative medical complications and condition, as well as preoperative functional status.
- Postoperative functional status also depends on numerous variables:
  - Socioenvironmental functional status has been shown to be of great importance in determining the postoperative function status of a patient.
- Longitudinal studies comparing the functional status of patients before and after hip fracture fixation have documented that roughly 40% of patients maintain their preoperative level of ambulation postoperatively.
  - Another 40% of patients have increased dependency on ambulation devices but remain ambulatory.
  - Twelve percent of patients become household-only ambulators, and 8% of patients become nonambulators postoperatively.

FIG 6 • Postoperative AP and lateral radiographs showing correct implant positioning and no intraoperative complications.

FIG 7 • A. Varus collapse. B. OTA 31-A1 intertrochanteric hip fracture fixed with a sliding hip screw. C. Follow-up radiograph 6 months postoperatively showing secondary fracture displacement.
COMPLICATIONS

- Loss of proximal fixation is defined as varus collapse of the proximal fracture fragment with cutout of the lag screw from the femoral head (FIG 7A). This complication is seen in 4% to 20% of fractures, usually within 4 months of surgery.
- Although certain fracture patterns have been shown to have a higher rate of proximal fixation loss, the fracture pattern cannot be controlled by the physician.
- The placement of the lag screw, on the other hand, can be controlled by the physician. A central and deep position with a tip–apex distance of less than 25 mm has been shown to significantly reduce the incidence of proximal fixation loss.2
- Nonunion occurs in 1% to 2% of fractures. The low incidence is likely due to the well-vascularized nature of the cancellous peritrochanteric region of the hip through which these fractures develop.
- Secondary fracture displacement
  - Despite adequate fracture reduction and implant positioning, fractures may progress to excessive impaction, with resultant limb shortening and abductor weakening (FIG 7B,C). This can lead to suboptimal patient functional results. This is often seen in cases of unrecognized lateral wall fractures (either iatrogenically induced by implant placement or unrecognized from the original trauma).
  - Use of intramedullary fixation devices and vigilant follow-up may help avoid this complication.
- Infection
- Wound dehiscence

REFERENCES

Retrograde femoral nailing can be defined as any femoral nailing technique with a distal entry from the condyles or through an intercondylar, intra-articular starting point. For this chapter, retrograde femoral nailing will refer to nails with an intercondylar starting point that extend through the shaft region to the proximal femur. In certain fracture situations, shortened nails (supracondylar nails) can be used with the same starting point for fixation of distal femoral fractures.

ANATOMY

- The femoral shaft is tubular in shape over the extent of the isthmus, gradually flaring infra-isthmally into the distal femur, which is trapezoidal in cross section.
- The entry point for the retrograde femoral nail is located at the distal end of the patellofemoral groove, just anterior to the posterior cruciate ligament insertion (FIG 1A).
- Radiographically, this is located in the midline or just medial to the midline between the condyles on the anteroposterior (AP) view, and laterally just anterior to the line of Blumensaat as it meets the trochlear groove (FIG 18.C).4,11,13,14,19 This flat articular area has minimal to no contact with the patella until 120 degrees of flexion.1,4
- Pertinent proximal anatomy includes neurovascular structures anterior to the proximal femur, close to interlocking screw insertion sites.21
  - The femoral artery is medial to the proximal femur, with branches that cross the anterior femur more than 4 cm distal to the lesser trochanter.
  - Branches of the femoral nerve cross more proximal starting 4 cm distal to the piriformis fossa.
  - Damage to neurovascular structures caused by proximal locking screw insertion can be avoided or minimized by avoiding medial dissection and with placement at or above the lesser trochanter (FIG 2).

PATHOGENESIS

- Femoral shaft fractures are markers of high-energy injuries.9,11,12,20,24
- Studies have shown that 38% of trauma patients diagnosed with a femoral shaft fracture have additional injuries.4,6,7,23
  - In femur fracture patients with associated injuries, the most common findings are other musculoskeletal injuries (93%), thoracic injuries (62%), head injuries (59%), abdominal injuries (35%), and facial injuries (16%).7
  - Ipsilateral femoral neck fractures occur in 1% to 6% of all femoral shaft fractures and are initially missed in up to 20% to 50% of cases.26 Recognition of these injuries before intramedullary stabilization is important to minimize potential complications (refer to section on imaging and other diagnostic studies).
- All trauma patients should undergo the standard advanced trauma life support (ATLS) examination to rule out associated life-threatening injuries.
- Although less common, femoral shaft fractures can occur in isolated sports injuries and in low-energy injuries associated with pathologic bone, such as with osteoporosis or metastatic bone disease.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Pain and deformity of the thigh are usually obvious but may be obscured in the morbidly obese patient.
- The fractured limb should be closely examined to avoid missing any open wounds, particularly in the posterior aspect of the thigh. Skin abrasions and apparently minor wounds should be assessed to determine if they communicate with the fracture.
- Swelling is a common finding with femoral shaft fractures. Compartment syndrome of the thigh is rare but can occur.25
- The entire lower extremity and pelvis needs to be evaluated because of the high rate of associated musculoskeletal injuries.
- A thorough neurologic and vascular examination must also be performed. Although femoral nerve damage is very unusual, sciatic nerve damage can occur.1,3,32
- Associated ligamentous injuries of the knee are common but may be difficult to assess until definitive stabilization of the femur has been obtained. Therefore, this examination should be repeated after nailing the femoral fracture.28,29

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Anteroposterior (AP) and lateral radiographs of the full length of the femur are essential, as well as formal AP and lateral radiographs of the hip and knee.
- Lateral knee radiographs should be closely evaluated for subtle patellar impaction fractures or nondisplaced fractures.
- Hip radiographs should be closely examined to rule out an associated femoral neck fracture, which has been shown to occur in 1% to 6% of femoral shaft fractures.26
- Some surgeons recommend a routine CT scan examination of the femoral neck as part of the trauma scan to rule out a femoral neck fracture.
- A reported 20% to 50% of these injuries are missed on the initial plain radiographic examination.26
- Because of the high association of missed coronal fractures in high-energy injuries, a CT scan of the knee should be obtained whenever formal knee radiographs reveal a supracondylar distal femur fracture and there is consideration for retrograde nailing.16
- Any coronal fractures seen on CT examination should be considered a contraindication for retrograde nailing owing to increased risk of compartment syndrome.
to the possibility of compromising the distal interlocking screw fixation.

**SURGICAL MANAGEMENT**

**Classifications and Relative Indications**

- It is important to assess the extent of the fracture both proximally and distally with proper radiographs.

- Proximally, CT scans can supplement plain radiographs to determine fracture line extension into the peritrochanteric region and to check for occult femoral neck fractures.

- Distally, CT imaging is helpful to assess intra-articular extension and to check for coronal plane fractures.

- All femoral shaft fractures, as classified by the Winquist system, are technically suitable for retrograde femoral nailing (FIG 3).

- Retrograde femoral nailing is not considered to be the standard of care for treatment of more proximal subtrochanteric fractures, but in certain patient circumstances it may be the treatment of choice (Table 1).

- Subtrochanteric fractures with the lesser trochanter and piriformis fossa intact, Russell-Taylor IA fractures (FIG 4),
### Table 1: Relative Indications for Retrograde Intramedullary Nailing of the Femur

<table>
<thead>
<tr>
<th>Indication</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>All femoral shaft fractures</td>
<td>Shown in multiple studies to have equivalent union rates and outcomes to antegrade intramedullary nailing</td>
</tr>
<tr>
<td>Pregnancy</td>
<td>Ability to decrease the amount of radiation exposure to the fetus</td>
</tr>
<tr>
<td>Bilateral femur fractures</td>
<td>Decreased overall operative time because the lower extremities can be prepared and draped together, eliminating the need to reposition for the second procedure</td>
</tr>
<tr>
<td>Floating knee injuries</td>
<td>Single surgical approach</td>
</tr>
<tr>
<td>Polytrauma patient</td>
<td>Supine positioning without bump allows for multiple surgical team approach to patient.</td>
</tr>
<tr>
<td>Unstable spine injuries</td>
<td>Supine positioning without bump affords ability to maintain spine precautions throughout the procedure.</td>
</tr>
<tr>
<td>Acetabular or pelvic fractures</td>
<td>Avoids surgical incision about the hip that may limit future surgical approaches</td>
</tr>
<tr>
<td>Ipsilateral hip and femoral shaft fractures</td>
<td>Allows each fracture to be treated with the optimal implant</td>
</tr>
<tr>
<td>Ipsilateral femoral shaft fracture below a total hip replacement stem</td>
<td>Short supracondylar retrograde nails can be used to treat the fracture with a minimally invasive technique.</td>
</tr>
<tr>
<td>Morbid obesity</td>
<td>Easier and more limited surgical approach</td>
</tr>
<tr>
<td>Soft tissue wounds about the hip</td>
<td>Avoids surgical approach of compromised soft tissues</td>
</tr>
</tbody>
</table>

May be amenable to retrograde femoral nailing if other patient factors favor a retrograde approach.

- Ideally, some proximal medial cortex remains intact to act as a buttress against the nail.
- It is important to know how far the proximal interlocking screw holes are from the tip of the nail in the retrograde nail system available in your hospital.
- We recommend being able to obtain two bicortical interlocking screws above the most proximal fracture line for very proximal fractures. If possible, they should be through holes, not slots, in the nail to provide more stability.
- If the subtrochanteric fracture has proximal extension, including either the lesser trochanter or piriformis fossa, or both, then proximal interlocking screw fixation of the retrograde nail would be compromised and alternative fracture fixation methods should be considered.
- Retrograde femoral nailing may be considered in certain supracondylar distal femoral fractures. We find that Muller’s AO classification system of distal femoral fractures best elucidates which of these fractures can be addressed with retrograde femoral nailing (Fig 5).
- Consideration for retrograde femoral nailing can be given for all extra-articular (A subgroup) fractures.
- It is important to know the distance between the distal interlocking screw holes and the tip of the nail in the retrograde nail system available in your hospital.
- We recommend being able to obtain at least two bicortical interlocking screws below the most distal fracture line for distal fractures.
- Nails with oblique distal interlocking options can be advantageous because of increased stability and potentially less screw head prominence.
- Consideration for retrograde femoral nailing can be given to simple transverse articular fracture patterns (C-1 and C-2 subgroups).
- This should be performed with an open medial or lateral parapatellar approach to the knee in lieu of a percutaneous approach. Articular reduction must first be obtained and then maintained with bicortical screw fixation.

**Fig 4** • Russell-Taylor classification system of subtrochanteric femur fractures, with fracture patterns amenable to retrograde femoral nailing highlighted.
Chapter 9 RETROGRADE INTRAMEDULLARY NAILING OF THE FEMUR

FIG 5 • Muller's AO classification system of distal femoral fractures,15 with fracture patterns amenable to retrograde femoral nailing highlighted.

FIG 6 • A. Diagram of lateral aspect of distal femur, with potential sites for intra-articular screw fixation out of the path of the retrograde femoral nail identified. B. Diagram of distal femur end on, with potential sites for intra-articular screw fixation out of the path of the retrograde femoral nail identified. C. Intraoperative lateral radiograph of a supracondylar, intracondylar (C1) distal femur fracture with intra-articular screw fixation and retrograde nail in place.

placed outside of the planned path for the retrograde nail (FIG 6).

• Partial articular fractures (all B subgroups) and complex articular fractures (C-3 subgroups) should not be considered for retrograde femoral nailing.

• Patients with osteoporotic distal fractures may be best treated with some of the newer fixed-angle plate devices, owing to concerns of distal interlocking screw purchase.

• Alternatively, nails designed with multiaxial screws or the use of supplemental blocking screws may help with augmenting fixation.

Contraindications

• Preoperative knee stiffness preventing 40 to 60 degrees of flexion

• Active knee sepsis

• Grossly contaminated soft tissue wounds about the knee

• Skeletally immature patients

Preoperative Planning

• AP and lateral radiographs are used to measure the diameter of the femoral canal isthmus and thus determine the approximate nail diameter. Most intramedullary nail systems come in diameters ranging from 10 to 13 mm.

• Nail lengths are often determined intraoperatively but can be ascertained by imaging the contralateral femur.

• Radiographs are evaluated to determine the location and morphology of the fracture; they should be scrutinized for nondisplaced secondary fracture lines that could become displaced during operative treatment.

• Occasionally, fracture fragments may be stuck in the canal and may need to be pulled out.

• In the case of fractures that show significant shortening preoperatively, it may be difficult to restore length off the fracture table.
A trial reduction should be performed under fluoroscopy before the start of the procedure; the patient must be paralyzed for the procedure.

If length is difficult to restore manually, then a femoral distractor should be used for the procedure. Placement of the femoral distractor is described in the section on fracture reduction.

Before preparing and draping the injured limb, the surgeon should examine the contralateral extremity to determine the patient’s normal leg length and rotation.

Femoral length can be evaluated by using a radiographic ruler and intraoperative fluoroscopy (FIG 7A).

Normal rotation can be determined by flexing the hip and knee and checking the patient’s normal internal and external rotation of the hip, and by examining the normal resting position of the foot as the patient lies supine on the operating room table (FIG 7B).

Positioning

The patient is positioned supine on a radiolucent diving board or flat-top table with no bump under the hip.

The surgeon should ensure that the entire femur, from hip to knee, can be imaged on AP and lateral fluoroscopy.

The extremity should be draped free from the anterior superior iliac spine to the ankle. The entire hip should be included in the preparation in case any femoral neck fractures are identified after treatment of the femoral shaft fracture.

Radiolucent sterile towels, sheets, or a radiolucent triangle are used to create a bump under the knee, allowing for about 40 degrees of knee flexion and placing the patella anterior for correct rotational alignment.1,14

Intraoperative fluoroscopy should come in from the contralateral side.

Approach

The knee should be flexed about 40 degrees to avoid injury to the proximal tibia and the patella.14

Intraoperative fluoroscopy is used to obtain a perfect lateral of the knee. The line of Blumensaat should be clearly identified (see Fig 1C).

A radiopaque guidewire can be used to identify the center of the long axis of the femur in order to determine the correct level of the skin incision.

The guide pin is used to center a 1.5- to 2.5-cm incision just medial to the midline.

A medial flap is created using subcutaneous dissection. A medial paratendinous arthrotomy is then made to allow entrance of the initial starting guidewire into the intracondylar notch.

FIG 7 • A. Schematic lateral view of a patient on a radiolucent operating room table, depicting how to use a radiopaque ruler and fluoroscopy to determine femoral length. B. Schematic anterior view of a patient on the operating room with the uninjured hip and knee flexed, checking the patient’s normal internal and external rotation of the hip.
PLACING THE GUIDEWIRE
- The surgeon confirms the correct placement of the initial starting guidewire on the AP and lateral fluoroscopic radiographs.
  - On the lateral image, the initial starting guidewire should be situated at the apex of the line of Blumensaat, in line with the femoral shaft (see Fig 1C).
  - On the AP image, the guidewire should be centered or just medial to the midline in the trochlear groove, in line with the femoral shaft (see Fig 1B).
  - On the AP image, the fluoroscope is moved proximally to be certain the guidewire is directed at the center of the canal.
  - When starting to drill the initial guidewire, the surgeon’s hand should drop slightly to prevent the wire from falling into the posterior cruciate ligament insertion; the hand is raised once the wire enters the cortex, so as to be in line with the femoral shaft.
  - Once the initial starting guidewire is centered on the AP and lateral images, the wire is passed into the distal femoral shaft.
  - A soft tissue retractor is placed over the initial starting guidewire to protect the patellar tendon during reaming.

CREATING AND REAMING THE STARTING HOLE
- The initial starting reamer is used to create the starting hole. (Alternatively, an awl or a step drill can be used to make the starting hole using the principles described above.)
  - Once the starting hole has been made, a beaded-tip guidewire is passed to the level of the fracture.

FRACTURE REDUCTION
- Traction is used to restore length. The surgeon must ensure that adequate anesthesia (full paralysis) is employed.
  - There are many deforming muscle forces, depending on the level of the fracture. If the fracture cannot be reduced by manual traction, use of bumps, pulling with sheets wrapped around the proximal or distal thigh, or pushing with mallets, then here are some options.
  - The abductor muscles will abduct and externally rotate the proximal femur after high subtrochanteric and proximal shaft fractures. Inserting a unicortical 5-mm Schanz pin through a percutaneous incision in the lateral cortex just above the fracture or in the greater trochanter can gain excellent control of the proximal fracture fragment.
  - The iliopsoas muscle will flex and internally rotate proximal-third femoral shaft fractures by its pull on the lesser trochanter. Again, inserting a unicortical 5-mm Schanz pin through a percutaneous incision in the lateral cortex just above the fracture or in the greater trochanter can gain excellent control of the proximal fracture fragment.
  - The adductor muscles span most shaft fractures and exert a strong axial and adduction force. Sometimes mid-shaft transverse fractures can be the most difficult to reduce. Inserting a unicortical 5-mm Schanz pin through a percutaneous incision in the lateral cortex just above and just below the fracture can gain excellent control of the proximal and distal fracture fragments.
  - Distal fractures tend to angulate into recurvatum through the pull of the gastrocnemius muscle. Bumps placed under the knee to flex the knee can help relax the gastrocnemius muscle. One can also use blocking screws in distal fractures to surgically create a narrow “canal” in the metaphyseal region in line with the canal of the femoral shaft so that the intramedullary nail can help with reduction of the fracture.
  - Alternatively, a femoral distractor can assist with obtaining and maintaining fracture reduction for a fracture at any level. It can be placed laterally, inserted proximally at the greater trochanter and distally in either the posterior aspect of the femoral condyle or in the proximal tibia. Alternatively, some surgeons recommend anterior placement to avoid potential posterior angulation of distal fracture patterns.
  - Lastly, some fractures require opening of the fracture site to obtain reduction, with the finding of the muscle interposed within the fracture. We recommend laterally based incisions unless otherwise dictated by an open fracture wound.
  - Restoration of length and correct rotation can be assessed clinically as well as radiographically by closely scrutinizing the diameter of the medial and lateral femoral cortex, ensuring they are of equal diameter proximal and distal to the fracture.

PASSING THE GUIDEWIRE
- Once the fracture is reduced on the AP and lateral images, the surgeon passes the guidewire to end just below the level of the piriformis fossa.
  - This is done to ensure that reaming is performed past the level of the lesser trochanter, since the reamers stop at the beaded portion of the guidewire.
REAMI NG

- Reaming should begin with an end-cutting reamer (typically size 8 mm or 9 mm in diameter).
- Fracture reduction must be maintained throughout the reaming process to minimize eccentric reaming.
- Reaming should be performed slowly and in 0.5-mm increments to prevent thermal necrosis.
- The approximate nail diameter is selected based on the preoperative measurement of the femoral isthmus. The final nail diameter should be selected based on the size of the reamer that provides the initial cortical chatter.
- The canal is reamed to 1.0 to 1.5 mm over the selected nail diameter.
- Nail length can be determined multiple ways:
  - A radiolucent ruler can be placed on the anterior aspect of the femur. The nail should end above the level of the lesser trochanter on the AP radiograph and should be measured so that it is deep to the apex of the line of Blumensaat on the lateral view (see Fig 1C).
  - Alternatively, a second guidewire of the same length can be inserted into the knee to end just deep to the apex of the line of Blumensaat on the lateral fluoroscopic image.
  - This additional guidewire is clamped at the level of the guidewire already in place.
  - The portion distal to the guidewire in place is measured to equal the amount of guidewire in the femoral canal (TECH FIG 1).
  - In addition, many nailing systems have system-specific measurement guides that are outlined in their technique manuals.
  - If the measurement is between nail sizes, the shorter nail is selected. Length can be added with an end cap if required.

PLACING THE NAIL

- Once the nail size is selected, the nail is inserted over the guidewire.
- Most current systems allow the beaded-tip guidewire to pass through the cannulated nail. If an older system is being used, then the beaded-tip guidewire must be exchanged for a smooth-tip guidewire using an exchange tube.
- If guidewire exchange is required, the surgeon ensures correct placement of the smooth-tip guidewire on the AP and lateral images before nail insertion.
- The nail is inserted over the guidewire and should pass relatively easily.
  - If the nail does not advance easily, the surgeon performs a careful AP and lateral fluoroscopic assessment of the fracture reduction and nail placement.
- Nail insertion depth is assessed on the lateral knee radiograph.
  - The nail should end proximal to the apex of the line of Blumensaat to ensure subchondral placement (TECH FIG 2A).
  - The surgeon confirms that fracture length and alignment have been restored on the AP and lateral radiographs.
- The surgeon confirms that the nail length selected puts the proximal tip of the nail ending at or above the level of the lesser trochanter (TECH FIG 2B).
  - The nail is advanced if the proximal tip does not end at or above the level of the lesser trochanter.
- If this leaves the nail countersunk, end caps can be selected to gain nail length.
- Care must be taken to remain below the piriformis fossa to avoid proximal nail protrusion.
- The nail is locked distally using the distal interlocking guides.
- We typically use one lateral-to-medial distal interlocking screw for transverse midshaft femoral fractures, and a second anterolateral-to-posteromedial distal interlocking screw for comminuted or distal femoral fractures.
- Using live fluoroscopy, the fluoroscopic machine is rotated about the knee to assess the length of the interlocking screws. Because of the trapezoidal shape of the distal femur, screws are often prominent but not well recognized on the AP radiograph.
- The surgeon should consider using washers, a medial locking nut, or a locking end cap (which locks the most distal interlocking screw to the nail) as options for osteoporotic bone.
- Once distal interlocking screw fixation is complete, the surgeon reassesses the fracture reduction fluoroscopically.
- If any shortening has occurred, length can be regained by manual traction or by back-slapping the nail with the insertion guide nail removal attachment (the surgeon must exercise caution when using this technique in patients with osteoporotic bone).
Proximal interlocking screw fixation is performed in the anterior-to-posterior plane using the freehand perfect circle technique. First, a magnified AP image of the proximal femur is obtained. The fluoroscopy machine is rotated until the proximal interlocking hole is seen as a “perfect circle” (also discussed in Chapter TR-10, Anterograde Intramedullary Nailing of the Femur; Tech Fig 4, Distal interlocking screw placement). A 1-cm incision is made in the proximal aspect of the thigh, anteriorly centered over the proximal interlocking hole, as visualized on the AP radiograph. Careful blunt dissection exposes the anterior femur. The proximal femur’s dense cortical bone makes it difficult to start a hole using a standard drill bit. The pointed soft tissue guides from large external fixation systems or a pointed drill bit can be used to prevent slipping off of the anterior cortex. The femoral artery lies 1 cm medial to the femur at the level of the lesser trochanter, so the surgeon must avoid slipping off the femur medially. Once the drill passes through the first cortex, it is removed from the drill bit to confirm radiographically that it will pass through the nail by the appearance of a perfect circle within the proximal interlocking hole. Small changes in the drill angle can be made to ensure correct passage through the interlocking hole. With a mallet, the drill bit can be gently tapped through the nail hole. The drill is then reattached to complete drilling through the posterior aspect of the proximal femur. Because of the proximity of the sciatic nerve, care should be taken to ensure that the drill is not advanced too far past the posterior cortex. Before removing the drill, the surgeon must reconfirm correct rotational alignment by flexing the hip and knee and assessing the hip’s internal and external rotation profile. It is compared with the normal internal and external rotation of the contralateral uninjured hip that was examined preoperatively. Screw length measurement can be confirmed with a frog-leg lateral or a true lateral view with flexing of the hip to clear the contralateral leg. A single proximal interlocking screw is all that is needed for most fractures. The usual length of the proximal interlocking screw is 25 to 35 mm. A second proximal interlocking screw may be selected for more proximal fracture patterns. A locking screwdriver should be used to avoid losing the screw in the proximal soft tissues. Alternatively, a suture can be tied around the head of the screw for retrieval if necessary. An internally rotated magnified view of the hip is obtained to critically reassess for the presence of a femoral neck fracture.
WOUND CLOSURE

- After wound irrigation, the knee fascial layer is closed with a 0 or 1-0 absorbable suture. The subcutaneous layer is then closed with 2-0 absorbable suture. The skin can then be closed with surgical staples.
- The interlocking screw incisions can be closed with 2-0 absorbable subcutaneous sutures and skin staples.
- Soft dressings are applied.
- Once the limb is undraped but before moving the patient off the operating table, it is critical to assess the achieved length and rotation compared to the contralateral limb. If any leg-length discrepancy or rotational deformity is appreciated, the limb should be reprepared, draped, and corrected by changing the proximal interlocking screw or screws.
- A repeat examination of knee stability is performed before leaving the operating room.

PEARLS AND PITFALLS

| Fracture reduction | The surgeon should request full relaxation with anesthesia to facilitate length restoration.
|                    | The surgeon should beware of the potential for shortening of the femur with retrograde insertion. Before placing the proximal interlocking screws, the surgeon should scrutinize the intraoperative radiographs of the fracture site to ensure that correct length has been obtained. Length may be regained by using the femoral distractor, or by using the guide to back-slap the nail after distal interlocking screw placement, or by manual traction. |
| Nail insertion: avoiding poor starting direction | The surgeon should ensure that the initial starting guidewire is centered in line with the femoral shaft on the AP and lateral images. Due to the overhang of the posterior condyles, there is a tendency to err too far posterior; because of the normal valgus of the distal end of the femur, there is a tendency to aim too medial, and a varus deformity can be created. |
| Nail insertion: avoiding slipping off | When starting to drill the initial guidewire, the surgeon should drop his or her hand slightly to prevent the wire from falling into the posterior cruciate ligament insertion; the hand is raised once the surgeon enters the cortex, so as to be in line with the femoral shaft. |
| Nail insertion: avoiding distal nail prominence | Before inserting the distal interlocking screws, the surgeon should confirm the subchondral position of the nail on the lateral intraoperative radiograph just deep to the apex of the line at Blumensaat (see Tech Fig. 2A). |
| Nail insertion: problems with proximal locking screws | The proximal femoral cortex is thick and strong. It is easy to strip proximal locking screws during their insertion. If difficulties are encountered on insertion, the surgeon should replace it with a new screw. This can help avoid significant issues if screw or nail removal is ever required. |
| Use of distal end cap | Some systems have a locking distal end cap that can lock the most distal screw in place; this is a useful feature for osteoporotic bone. End cap insertion can facilitate intramedullary nail removal if a reamed exchanged nailing for femoral delayed union or nonunion occurs. As with any nail insertion, if an end cap is used, it should be specifically mentioned in the operative note for review in the event of future screw or nail removal. |
| Avoiding distal interlocking screw prominence | Before removing the insertion jig, the distal femur is rotated under live fluoroscopy to evaluate the length of the distal interlocking screws. Screw length changes are made if necessary. Accurate measurement for locking screws minimizes postoperative hardware irritation. Off-axis screws are used when the option is available. |
| Associated injuries | The surgeon should always check the preoperative images and intraoperative C-arm images for ipsilateral fractures of the femoral neck. When using a hip screw side plate implant, the surgeon should try to overlap proximal hardware for improved mechanical properties. |
| Specific fracture patterns | Table 2 lists alternative techniques. |

POSTOPERATIVE CARE

- Physical therapy for active and passive knee range of motion may be started on the first postoperative day, as can ambulation, prescribed based on the fracture pattern and associated injuries.
- For most femoral shaft fractures, even those with comminution, weight bearing as tolerated can be safely initiated in the immediate postoperative period.
- Routine postoperative deep vein thrombosis prophylaxis, such as low-molecular-weight heparin, may be safely re-
alternative techniques

Two prospective, randomized trials comparing reamed antegrade and retrograde nailing of femoral shaft fractures showed no difference in knee pain or knee function at time of fracture union. As expected, early postoperative knee pain was more distal supracondylar femur fractures, which have taken longer to achieve union. The retrograde nailing technique appears to produce slightly higher malunion rates, with external rotation, shortening, and distal varus malalignment being the most common deformities. 

COMPPLICATIONS

The most common complications can often be prevented with meticulous surgical techniques. Paying close attention to the proper nail insertion starting point and ensuring that the distal portion of the nail remains subchondral are two key technical points to avoiding potential knee problems.

<table>
<thead>
<tr>
<th>Fracture Type</th>
<th>Pros</th>
<th>Cons</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ipsilateral femoral shaft and neck fractures</td>
<td>Optimal fixation for each fracture pattern</td>
<td>Two separate surgical procedures and implants</td>
<td>Stabilize hip fracture first, using cannulated screws or dynamic hip screw. Select four-hole side plate to overlap nail placement. Do not fill distal three holes until after femoral nail is placed. Select femoral nail length to end at or above lesser trochanter. Use small lateral incisions at the level of the fracture to place pointed reduction clamps without muscle stripping in fracture reduction. Place two proximal interlocking screws.</td>
</tr>
<tr>
<td>Subtrochanteric femoral shaft fractures</td>
<td>Percutaneous treatment compared to plating techniques. Lower incidence of malunion than antegrade nailing technique.</td>
<td>Less stable proximal fixation</td>
<td>Selecting larger-diameter nails based on feedback of cortical chatter during reaming.</td>
</tr>
<tr>
<td>Periprosthetic fractures below a hip stem</td>
<td>Percutaneous treatment compared to plating techniques</td>
<td>Stress riser created between end of hip stem and nail</td>
<td>Judicious use of blocking screws to ensure center placement of guidewire, reamer, and nail. Important to maintain alignment during reaming.</td>
</tr>
<tr>
<td>Supracondylar femur fractures</td>
<td>Percutaneous treatment compared to plating techniques</td>
<td>Longer times to union. Less stable implants than with current locking plate.</td>
<td>As above, with an open parapatellar approach to knee to ensure anatomic knee reduction. (Refer to Fig 6 for screw placement.)</td>
</tr>
<tr>
<td>Supracondylar femur fractures with a simple sagittal fracture</td>
<td>Percutaneous treatment compared to plating techniques</td>
<td>Longer times to union. Less stable implants than with current locking plate.</td>
<td>Preoperatively determine if femoral component has open box design. Routine nail insertion technique.</td>
</tr>
<tr>
<td>Periprosthetic fractures above a total knee</td>
<td>Percutaneous treatment compared to plating techniques</td>
<td>Limited points of distal fixation</td>
<td>Routine insertion technique.</td>
</tr>
<tr>
<td>Ipsilateral femoral shaft and tibial shaft fractures (“floating knee injuries”)</td>
<td>Single approach and incision for treatment of both injuries</td>
<td>None</td>
<td>Routine insertion technique.</td>
</tr>
</tbody>
</table>

COMPLICATIONS

Twenty-four hours of antibiotic prophylaxis is standard for closed fractures. Patients with open fractures remain on antibiotics for 48 hours after the final intraoperative débridement has been performed.

OUTCOMES

The long-term effects of retrograde nailing on knee function are not known. Two prospective, randomized trials comparing reamed antegrade and retrograde nailing of femoral shaft fractures showed no difference in knee pain or knee function at time of fracture union. As expected, early postoperative knee pain was more distal in the retrograde femoral nailing groups, but by the time of union there was no significant difference between the two approaches. Fracture healing rates seem to be equivalent except in the more distal supracondylar femur fractures, which have taken longer to achieve union. The retrograde nailing technique appears to produce slightly higher malunion rates, with external rotation, shortening, and distal varus malalignment being the most common deformities. 

COMPLICATIONS

The most common complications can often be prevented with meticulous surgical techniques. Paying close attention to the proper nail insertion starting point and ensuring that the distal portion of the nail remains subchondral are two key technical points to avoiding potential knee problems.

Distal interlocking screw prominence is common, and a relatively high percentage of patients elect to have these removed as a secondary procedure. Malunions can be avoided when blocking screws are used judiciously for the more distal fracture patterns, and close attention is paid to ensure that the fracture reduction is first obtained and then maintained during the entire reaming process. Shortening and malrotation can be readily assessed at the end of the procedure and corrected immediately by revising placement of the proximal interlocking screw or screws. Selecting larger-diameter nails based on feedback of cortical chatter during reaming seems to improve union rates when the retrograde nailing technique is used.

REFERENCES

DEFINITION
- A femoral shaft fracture is any fracture of the femoral diaphysis from 5 cm below the lesser trochanter to within 6 to 8 cm of the distal femoral articular surface.
- Some fracture lines extend proximal or distal to the shaft and are therefore not considered shaft fractures.
- This description is mostly semantic, as the more important aspect of definition is understanding the “personality” of the fracture.
- Fractures whose essential element is diaphyseal with “extensions” into the outer regions are different than fractures whose essential element is subtrochanteric or supracondylar with extension into the diaphysis.
- In some circumstances there may be enough involvement of proximal or distal aspects that treatment must change.
- For the purposes of this chapter, we will focus on fractures that are amenable to antegrade nailing.10
- The Abbreviated Injury Scale (AIS) score for an isolated femoral shaft fracture is three, thus making the Injury Severity Score for an isolated femoral shaft fracture a nine.
- Open fractures are usually graded according to the Gustilo-Anderson classification, but one must keep in mind that this classification system was designed for the tibia, a subcutaneous bone. Thus, if absorbed energy is considered, theoretically, significantly more energy would be required to fracture a femur and disrupt the soft tissue envelope around a femur than around a tibia. Nonetheless, this system is widely employed in the femur for descriptive purposes.
- The fracture classification system previously used most commonly was the Winquist classification, but it has been modified and standardized with the AO/OTA classification, which is the recommended system.16,27

ANATOMY
- The femur is the longest bone in the body. It is subject to very high stresses in the proximal region because of the need to transition the forces of body weight via a lever arm (femoral neck) into more axial forces distally. As such, the subtrochanteric area is subject to very high stresses.14
- The femur has an anterior bow and is not a circular bone.
  - Anteriorly and laterally there are flattened surfaces, and posteriorly there is a taper that is confluent with the linea aspera.
  - The linea aspera is a very thick fascial structure and frequently remains in continuity but separates from the femur.
  - Entrapment of the linea aspera between the fracture ends may impede closed fracture reduction, especially with simple fracture patterns. The bone ends may need to be “unwound” to effect a reduction.
  - Both anterior and lateral bowing is important to recognize, especially if abnormal (e.g., metabolic bone disease).
  - The anterior bow has an average radius of curvature of about 120 cm.
- If there is excessive bowing, good preoperative planning is needed.
- Surgical options for such abnormal bowing include plate fixation or a controlled osteotomy to allow nail placement.16
- The endosteal diameter is important to recognize, especially with young or sclerotic bone.
- Normal aging and osteoporosis results in a biomechanical adaptation of enlarged inner diameter. Thus, elderly individuals may have a larger-diameter femoral shaft with a thinner cortex. As in other cylindrical tubes, the bending rigidity of the femur is roughly proportional to the radius to the fourth power.
- The vascular supply to the femur is from a nutrient artery off the second perforating branch of the profunda femoris, entering posteriorly along the linea aspera.
- Normally, periosteal branches supply the outer one quarter to one third of the cortex as the direction of blood flow is centripetally outward from the medulla to the cortex.
- Once fracture occurs, a reversal of blood flow occurs from the periosteal vessel, radially inward.
- The linea aspera protects many perforating periosteal vessels, except in severe fractures, and may help explain the high healing rate of femoral shaft fractures (about 95%).
- There are three thigh compartments: anterior, posterior, and medial.
- Thigh compartment syndrome may occur and generally involves the anterior compartment. Frequently, release of the anterior compartment will relieve pressure.
- The proximity of the gluteal compartment places it at risk as well. It should also be considered with compartment syndromes.

PATHOGENESIS
- Femoral shaft fractures are high-energy injuries in the young; in the elderly simple falls from ground level are sufficient to fracture the femur.
- Fracture patterns give clues to the mechanism.
  - For example, a simple transverse fracture with a butterfly fragment is due to a bending force (e.g., T-bone vehicle crash).
  - Spiral fracture patterns are usually due to torsional forces.
  - Indirect high-energy mechanisms, such as a fall from a height or motor vehicle crashes, will usually incur a significant initial deformity during the fracture process.
  - The active and passive recoil of the muscle soft tissue envelope will decrease the initial displacement. Thus, the extent of soft tissue injury can be difficult to appreciate.
  - Open fractures in this setting are usually “inside-out” injuries.
  - Direct mechanism fractures are from ballistic injuries, crush injuries, or other weapons (e.g., chainsaw, axe).
  - With these injuries, there may be less initial displacement of the fracture and soft tissues, but the amount of soft tissue injury can still be extensive.
In ballistic injuries, the shock and cavitation can result in extensive tissue necrosis.

In both mechanisms, it is important to recognize that the zone of tissue injury may extend well beyond the fracture site.

**NATURAL HISTORY**

In the early 20th century, the natural history of femur fractures was poor.

The mortality of wartime femur fracture before and during World War I was approximately 80%. Serendipitous use of a wheeled splint for transport off the battlefield resulted in a precipitous drop in the mortality rate (the Thomas splint was thus developed).

Because surgical techniques were primitive in those times, fears about infection and surgical complications resulted in most fractures being treated in traction.

The outcome was frequently a shortened, rotated, varus malunion of the femur.

Additional problems such as decubiti, venous thromboembolism, and pulmonary infections with prolonged bed rest resulted in high morbidity and mortality by today’s standards.

Kuntschner is considered the father of intramedullary nailing.

Kuntschner’s original technique was an open nailing, exposing the fracture site, and in the Western nations, poor surgical technique resulted in high rates of infection and nonunion.

As a result, this method of fracture care was abandoned until late into the 1970s.16

Kuntschner’s method was resurrected in the United States by early traumatologists, like S. Hansen and M. Chapman, who used Kuntschner’s newer technique of “closed” femoral nailing.

The success rate of femoral nailing using closed technique resulted in low morbidity and began a change in practice to what we perform today.

Early studies outlined the benefits of early reamed femoral nailing.

As survival of more traumatized patients increased, a subset of patients who may benefit from “subacute” nailing developed.

Later studies identified patients at risk (eg, pulmonary injury, incomplete resuscitation, and brain injury) who benefited from stabilization of life-threatening injuries before fixation.

This reflects the paradigm shift from early total care (ETC) to damage control orthopedics (DCO).1,19,22

While some have advocated plating in such cases, there has been no studies demonstrating the superiority of one method over the other in terms of patient survival.4

**PATIENT HISTORY AND PHYSICAL FINDINGS**

Relevant history includes age, sex, mechanism of injury, associated injuries, loss of consciousness, weakness, paralysis, or loss of sensation.

Metabolic conditions and any musculoskeletal conditions should be elucidated if possible.

Patients should be evaluated according to the advanced trauma life support (ATLS) guidelines.

Particular attention should be given to hypotension, since femoral shaft fractures can be associated with up to 3 to 4 L of blood loss. While not solely responsible for hypotension, femur shaft fractures can be a contributory source.

The limb should be aligned and placed in a traction device, such as a Sager splint or a Thomas splint.

These devices should be removed and replaced with skeletal or limb traction because of the risk of skin problems in the perineal or ischial and ankle areas.

It is essential to inspect the affected limb for any open wounds, swelling, and ecchymosis (see Exam Table for Pelvis and Lower Extremity Trauma, page 1).

The extent of the open wound does not always correlate with the degree of soft tissue or fascial stripping due to the fracture.

Vascular evaluation should include manual palpation of the popliteal, posterior tibial, and dorsalis pedis pulses.

It is important to understand that a pulse is a pressure wave and can still be present in the absence of flow.

Alternatively, the absence of pulse does not always mean absence of flow.

Use of Doppler and examination of the contralateral limb are needed.

Hypotension with peripheral vasoconstriction may accompany such injuries.

The limb should be aligned before vascular examination.

Asymmetric or absent pulses warrant a measurement of the ankle-brachial index (ABI).

An ABI less than 0.9 is abnormal.

Arteriography should be considered to rule out vascular injury.

Neurologic evaluation includes motor and sensory function of the femoral and sciatic nerve.

The femoral nerve may be difficult to examine secondary to pain associated with the fracture.

Sciatic nerve function can be evaluated for both peroneal and tibial branches.

The peroneal branch is tested with ankle and toe dorsiflexion and sensation on the top of the foot.

Tibial branch function is tested with ankle and toe plantarflexion as well as sensation to the sole of the foot.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

The tenet of imaging a joint above and a joint below should be followed.

Good anteroposterior (AP) and lateral views of the hip, femur, and knee are required.

Such films can be obtained in the operating room but are essential in planning, since the presence of a femoral neck fracture or a fracture about the knee will greatly change the operative tactic.

Attempts should be made to get an internal-rotation AP view of the femoral neck. However, with current trauma algorithms, the commonality of the pelvic CT scan allows imaging of the femoral neck. The scan should be viewed before deciding on the surgical tactic.

If radiographs are normal but the clinical examination suggests injury (eg, unable to bear weight, pain out of proportion to injury), coronal MRI imaging may elucidate an occult fracture.

CT scanning in these situations may not be sensitive enough to find such fractures.

Occult femoral fractures may be hard to identify with preoperative radiographs.

Use of CT scans of the abdomen that go to the level of the femoral neck have been found to be sensitive enough to
identify such occult femoral neck fractures and should be done for most cases.  

DIFFERENTIAL DIAGNOSIS

- Other injuries may occur concomitantly with femur fractures, including pelvic fractures, acetabular fractures, femoral neck fractures, and ligamentous injuries to the knee.
  - If an effusion is present in the knee, the index of suspicion for a knee injury should be elevated.
  - Distal femur fracture may also occur but may not be radiographically evident, especially in osteoporotic bone.
  - In the absence of a reasonable mechanism, other causes for fracture such as metabolic bone disease or metastatic (or primary) fracture should be ruled out.

NONOPERATIVE MANAGEMENT

- Nonoperative management has typically been reserved for patients who are unfit for surgery, patients who are quadriplegic or paraplegic, patients in whom the benefits do not outweigh the risks, or other precluding factors (e.g., active infection).
  - Truly nondisplaced fractures in a compliant and able patient may also be treated nonoperatively.
  - Infants and young children may also be treated nonoperatively because of their ability to remodel.
  - Nonoperative management consists of bed rest and skeletal traction (either through the distal femur or proximal tibia) with 20 to 30 lb of weight.
  - Attention should be given to mechanical and pharmacologic venous thromboembolism prophylaxis if this treatment is considered.

SURGICAL MANAGEMENT

- Isolated femur fractures are not urgent. Appropriate evaluation and medical clearance should be performed. It is in the best interests of the patient and system to stabilize the patient expeditiously, but when appropriate resources are available (e.g., knowledgeable staff, anesthesia). It is not necessary to stabilize such fractures during off shifts unless indicated for other reasons (e.g., open fracture, polytrauma).
  - Patients with isolated femur fractures should have some form of traction, pain control, and deep vein thrombosis prophylaxis while awaiting surgical intervention.
  - Currently, statically locked femoral nailing with limited reaming is the standard of care.
    - The studies by Brumback et al determined that statically locked nails do not affect healing and avoid the problems of malrotation and shortening. Unreamed nails were proposed to limit effects of canal fill and the theoretical concern of infection. Neither concern was proven, and in fact small unreamed nails had the same problems as in the tibia: higher rates of nonunion. Currently, the “ream to fit” technique is used.  
    - In the multiply injured patient (Injury Severity Score of more than 18), with pulmonary compromise or head injury, fracture fixation should be delayed until suitably cleared for surgical intervention, and damage control methods with use of a temporary external fixator should be considered.
    - Recently, the reamer-irrigator-aspirator has been used to minimize the pressure-induced embolization from the marrow. As studies are ongoing, this method may reduce the risks in the multiply injured patients.
  - Open fractures can be safely nailed if a thorough débridement and irrigation is performed.
  - Absorbable antibiotic beads (calcium sulfate, not calcium phosphate, mixed with vancomycin or tobramycin) can be used at the time of definitive closure to provide local antibiotic delivery.
  - In severely contaminated fractures, a staged approach using temporary antibiotic beads (using polymethylmethacrylate mixed with vancomycin or tobramycin) and temporary external fixation, followed by nailing within 2 weeks (with or without use of absorbable beads), can be employed.
  - Conversion of external fixation to intramedullary nails can safely be performed within 2 to 4 weeks, as long as there is no indication of pin tract problems.
  - In such cases, the risk of infection is increased but acceptable in lieu of prolonged bed rest.
  - Because of deforming forces in proximal fractures, the proximal segment tends to flex and externally rotate.
    - Care should be taken to ensure that the posterior cortex of the proximal fragment is not inadvertently reamed away.
    - In distal fractures, the distal segment tends to flex at the knee (recurvatum of fracture).
    - With distal fractures, care should be taken to avoid varus or valgus reduction. This can occur because the opening of the medullary canal distally does not have intimate contact with the nail and does not “self-align.”
    - Transverse fractures may contain a segment of intact linea aspera that peels off the posterior aspect and may get entrapped in the fracture.
    - It can result in shortening that may be difficult to overcome without either “unwinding” the fracture or opening the fracture site.
  - In skeletally mature children, intramedullary nailing offers the same benefits as in adults.
    - Attention should be paid to adolescents with very valgus neck angles, as some have hypothesized that this can increase the risk of avascular necrosis of the femoral head. However, with modern implants, a trochanteric starting point may alleviate such concerns.
    - Skeletally immature children may still be considered for some form of intramedullary treatment after considering remaining growth, type of fracture, and benefits over other methods of treatment.

Preoperative Planning

- All films should be reviewed, with particular attention paid to the presence of an ipsilateral femoral shaft and neck fracture.
- The overall condition of the patient and any associated injuries should be contemplated before embarking on a surgical tactic.
- In the presence of pelvic or acetabular fracture, pregnancy, or obesity, one should consider a more elegant tactic, such as retrograde nailing, as opposed to antegrade nailing.
- If suitable, antegrade nailing in the supine position can be safely performed with proper positioning and knowledge.
- Several options have to be considered during preoperative planning. They include:
  - Table: fracture table or radiolucent
  - Position: supine or lateral
  - Entry point: piriformis or trochanteric
  - Type of nail: cephalomedullary or standard
  - Use of traction: skeletal, boot, or manual
Strong consideration should be given to checking fine cut CT scans to search for femoral neck fractures when possible. As part of the operative plan, the femoral neck should also be checked radiographically after fixation and prior to leaving the operating suite.

Positioning

Fracture table
- Standard fracture tables (eg, those used commonly for hip fractures) can be used for antegrade femoral nailing but are best used for supine position nailing.
- A large and well-padded perineal post should be used.
- Traction should be used sparingly and only when needed.
- The legs should be scissored to facilitate imaging and allow for appropriate countertraction. Placing the opposite leg in lithotomy position can allow rotation of the pelvis when traction is applied.
- The ability to image all aspects of the femur should be verified before preparing and draping (FIG 1A).

Radiolucent tables
- Newer tables allow free image intensifier access to the lower extremity.
- Some of the tables (Jackson table, OSI, California) also provide traction assemblies. These types of tables are suitable for multiple limb operations (FIG 1B).
- Our preferred method uses a radiolucent Jackson table with traction apparatus and lateral positioning (FIG 1C).

Supine position
- The supine position may be easier for surgeons to visualize anatomic relationships.
- It is more difficult to use supine positioning in obese patients.
- It may be the preferred position in patients with spinal cord injuries or severe chest injuries.
- It can be used with and without traction.
- If the supine (floppy) positioning on a radiolucent table is chosen, it helps to position the patient at the edge of the bed with a small bolster under the pelvis.
- Preparing and draping should include the posterior aspect of the gluteal area, since crossing the leg over will facilitate access to the piriformis.
- Even with the newer trochanteric entry technique and implants, the ability to manipulate the leg in adduction may be useful during the procedure (FIG 1D).

Lateral position
- The lateral position facilitates gaining an entry point, especially with a piriformis starting point in obese patients.
- It can be used with and without traction.
- When using the lateral position, the pelvis is rolled forward about 15 degrees to allow lateral imaging of the proximal femur.
- Care should be taken during positioning for proper padding and spinal precautions if occult spinal injury may be present.

**FIG 1** • A. Supine positioning on a fracture table with legs scissored. Slight obliquity using a bump under the sacrum helps with hip visualization. B. Supine position without traction on flat-top table. The ipsilateral hip should be close to the edge, and a bump under the sacrum will help with visualization. Standard lateral views of the hip for entry points can be used, but so can frog-leg laterals. C. Lateral position with traction. Skeletal traction in the proximal tibia or distal femur can be used. The perineal post is pictured here in the perineum, which is best for proximal fractures. In fact, little traction is usually needed and the post is frequently positioned under the apex of the fracture and used to overcome gravitational sagging. If traction will be needed, we have found that placing a blanket on the “down” leg and securing the contralateral thigh with a sling of tape coursing in a proximal and oblique fashion will resist moderate amounts of traction. D. Preparation and draping of the leg using a flat-top table without traction should include posterior sections of the buttocks. The leg can be crossed over to gain easier access to the piriformis starting point.
▪ Traction
  ▪ If traction is used, it frees an assistant and the length and rotation can be “set.”
  ▪ If manual traction is used, the length and rotation need to be checked before final interlocking.
  ▪ Skeletal traction can be via the proximal tibia or distal femur.
    ▪ The surgeon should be careful if there is any ligamentous instability of the knee, as suggested by a knee effusion or other sign of injury.
  ▪ In such cases, distal femoral traction can be used, and it can be prepared and draped into the operative field.
  ▪ Use of distal femoral traction can complicate distal interlocking because of the proximity of the traction apparatus with the interlocking site.
  ▪ Boot traction is a very common alternative.
  ▪ Unlike tibial or femoral skeletal traction, where the knee is slightly bent, boot traction uses a straight leg (FIG 1A).
  ▪ Care should be taken to avoid nerve traction injury (eg, avoid prolonged and excessive traction).
  ▪ Small perineal posts and long durations of traction have been shown to increase the risk of pudendal nerve injury.
  ▪ If traction is used, it should be first applied to determine the “reducibility” of the fracture. Then it should be reduced during prepping and applied as needed.
  ▪ Large and well padded perineal posts should be used whenever possible.6,15

SOFT TISSUE DISSECTION
▪ Whether using a cephalomedullary nail or piriformis fossa nail, the surgical approach is similar.
▪ The surgeon palpates the greater trochanter.
▪ For trochanteric entry, the skin incision is based about 4 to 10 cm above the trochanter in line with the femur.
  ▪ The tensor fascia is incised and the gluteus maximus is gently separated.
  ▪ The tendinous insertion of the gluteus medius is frequently more distal, and this tendon can be gently spread to identify a bursal area just below the medius and above the minimus.
▪ For piriformis entry, the incision is made about a hand-breadth along the line between the trochanter and the posterior superior iliac spine.
▪ Once the gluteus maximus is gently separated, the access to the piriformis is posterior to the medius.
▪ The piriformis fossa can be easily palpated as a “dimpled ledge” behind the trochanter. This anatomic feature is used during the percutaneous approach for proprioceptive feedback during pin placement.

TROCHANTERIC AND PIRIFORMIS FOSSA ENTRY
▪ After soft tissue dissection, the tip of the greater trochanter is palpated. The piriformis fossa is palpated medially.
▪ The ideal starting point for a piriformis fossa nail is in the fossa along the medial upslope of the greater trochanter, since this is most in line with the shaft.
  ▪ This point may vary between patients and should be confirmed with intraoperative fluoroscopy.
▪ The surgeon can have an assistant adduct the extremity to aid in exposing this spot (TECH FIG 1A).
▪ Once the starting point is identified by palpation and confirmed with fluoroscopy, the cortex is penetrated with either an awl or a threaded Kirschner wire.
▪ Every effort should be given to establishing an accurate starting point (ie, one that is in line with the femoral shaft).

TECH FIG 1 • A. AP image of the correct position of a guide pin for piriformis entry. B. Lateral image of piriformis starting point. The pin need only start in the piriformis; it will frequently course anterior, and care should be taken not to penetrate the anterior cortex. The rigid reamer need only open the top of the bone for access to medullary canal.
The percutaneous method of nailing uses cutaneous landmarks to identify the ideal entry site, which is usually about one full handbreadth (8 cm) from the posterior corner of the trochanter towards the posterior superior iliac spine (TECH FIG 2A).

The incision is a stab wound.

A guide pin is advanced to the trochanteric bursa (TECH FIG 2B).

The pin is "rolled" off the posterior slope of the trochanter and then advanced distally and anteriorly (TECH FIG 2C, D).

A very distinct resistance is felt, as if on a pedestal or ledge of bone. The tip of the pin provides proprioceptive feedback when this occurs, and it can be felt that there are structures anterior and medially, which constitute the "walls" of the fossa.

In these cases, preparing under the buttock and accessing from a more posterior approach may allow access to the fossa.

The lateral positioning allows the easiest access, with very few problems. In fact, nailing can be performed percutaneously (described below) with little problem when using the lateral position.
TECH FIG 2 • (continued) E. The rigid reamer advances over the pin to enter the proximal femur. Use of irrigation will help prevent soft tissue catching. F. Insertion of the nail over the guidewire. With use of a bent guidewire and “ream-to-fit” technique, the likelihood of an incarcerated reamer is very low, and exchange of the guidewire with a chest tube is not needed (unless a ball-tip guidewire is used). G. Intraoperative photo of final wounds. H. Entry site wounds are usually about 1.5 cm.

- At this point image verification is performed.
  - If the pin is not coaxial with the femur, what is most important is that the tip of the pin is centered.
  - The pin is advanced to engage the cortex, and then a 9- to 12-mm rigid reamer is used to open the proximal femoral cortex (TECH FIG 2E).
  - This reamer need only be advanced enough to open the cortex and provide access to medullary contents. Care should be taken not to ream too deeply and perforate the cortex of the proximal femur anteriorly (see Tech Fig 1).
- Once this step is accomplished, the remainder of the procedure can be done with standard methods, and instruments are passed via the keyhole skin incision (TECH FIG 2F–H).

TROCHANTERIC ENTRY, GUIDEWIRE PLACEMENT, AND FRACTURE REDUCTION

- After soft tissue dissection (as described previously), the surgeon palpates the tip of the greater trochanter and its anteroposterior dimensions.
- Because of the inherent anatomy of the proximal femur, the ideal starting spot for a trochanteric entry nail is at the tip of the greater trochanter (mediolateral) and the junction of the anterior one third and posterior two thirds of the greater trochanter.
- This spot may vary from person to person, but the correct starting point is one that is in line with the femoral shaft.
- Once the correct starting spot is identified, the outer cortex is penetrated with either an awl or a pointed guidewire (TECH FIG 3A).
- In this method, because the abductor mechanism is being split, soft tissue protection is important.
- After the starting point is identified, a guidewire is placed into the proximal femur and passed down the canal.
- Forceful and jerking motions can be avoided by firmly twisting the guidewire through the cancellous bone.
- A gentle J bend at the distal 1 cm of the wire allows the wire to be “bounced” off cortices and to be “steered” in metaphyseal areas (TECH FIG 3B).
- The proprioceptive feedback of a wire passing along the medullary canal is similar to the sensation of pushing a stick on a sidewalk.
TECH FIG 3 • A. The entry point for the trochanter is usually on the anterior one-third junction. B. Bent straight guidewire. This helps to “steer” the wire in metaphyseal bone and will prevent reamer heads from disengaging (relevant only in modular designs). C. The “wand.” It is available on some sets, or can be performed with some extraction rods. It is placed over the guidewire into the proximal segment, down to the level of the lesser trochanter. It can manipulate the proximal fragment to aim it into the distal segment, after which the guidewire is advanced into the distal fragment. This is much more desirable than struggling with manual methods. D. F bar. This can be placed around the thigh to effect the desired translation. In out-of-plane deformities, the bar can find the “ideal” orientation and effect a reduction. E. The joystick method. Small terminally threaded wires can be drilled into the cortex of each segment and used to manipulate the fragments into reduction. Small external fixator pins can also be used and have been previously described. F. Intraoperative image of guidewire passed across fracture.

- If the fracture is not reduced sufficiently to easily pass the wire across, there are several techniques available to facilitate reduction and wire passing.
- Some nail systems provide a cannulated rod that is placed over the wire and passed into the proximal femur. This rigid wire holder functions as a wand to manipulate the proximal fragment as the wire approaches the fracture so that it can easily be passed across (TECH FIG 3C).
- An F or H bar, a crutch, or both can also be useful to manipulate the proximal and distal fragments (TECH FIG 3D).
Sometimes the fracture cannot be perfectly reduced, but enough provisional alignment can be established to pass the guidewire. If the fracture is unstable and difficult to reduce after numerous attempts, a small incision can be made along the lateral thigh over the fracture and the fracture can be digitally reduced and provisionally aligned. In some cases, the incision can be lengthened to allow placement of “lobster claw”-type clamps.

Other methods include the use of unicortical “joystick” half-pins from an external fixator set (usually a 5-mm half-pin). Alternatively, 3-mm threaded guide pins can also be used (TECH FIG 3E). The guidewire position in the distal segment is confirmed with intraoperative fluoroscopy. The guidewire should be passed down to the distal femur physeal scar and should be center-center on both the AP and lateral views.

MEASUREMENT AND REAMING

Once the guidewire has been placed, the length of the nail is measured either with a measuring device (usually supplied by the intramedullary nail system) or by using a guidewire of the same length. Placing the second wire at the entry site and measuring what is not overlapping with the inserted wire provides nail length. Before measuring, the surgeon confirms the proximal position of the ruler on the greater trochanter. The surgeon should make sure that there is no soft tissue between the ruler and the top of the greater trochanter, as this can artificially increase the length of the nail chosen. Average nail lengths range from 38 to 42 cm. Using the radiographs of the femur, the surgeon can estimate the beginning reamer size. With “tight” canals, reaming should begin with lower sizes, and sequential reaming can begin starting with the lowest size available (usually 8 or 9 mm). When starting to ream, the surgeon should pay particular attention to keep the reamer medial in the proximal femur to prevent reaming out the posterior or lateral cortex.

If the reamer does not pass easily, the surgeon should check its position with fluoroscopy since the reamer may be hitting cortical bone (usually anteriorly). Reaming can be increased by 1.0-mm increments until distinct “chatter” is encountered, after which it should increase in 0.5-mm increments.

Once endosteal “chatter” is encountered, reaming should continue for another 1.0 to 2.0 mm, and a nail diameter of 1.0 to 1.5 mm smaller than the largest diameter reamed should be used. With modern nail designs, most male patients can be treated with 11- to 13-mm nails and most females with 10- to 12-mm nails. Care should be taken when there is a tendency for a deforming force to allow for “eccentric” reaming (eg, proximal fractures). In these cases, without attention, eccentric reaming can remove cortical bone and create defects that result in deformity or a nail outside the bone.

NAIL PLACEMENT

If a ball-tipped wire is used, the surgeon should confirm that it can be pulled through the nail or exchanged for a smooth-tip wire. After the nail has been inserted, its position is checked distally, at the fracture site, and proximally near its insertion site. The surgeon ensures that the nail is not too proud above the greater trochanter and fossa. If the fracture site is distracted, traction should be reduced or adjusted to effect a satisfactory reduction.

Length and rotation need to be reconfirmed before interlocking. Several methods can be used.12,13,24,25

Cortical characteristics

- The femur diameter is not symmetric. Variances in cortical thickness can be used to estimate rotation.
- Fracture lines can be used to estimate correct rotation.

Radiographic methods

- One method checks the true hip lateral with the distal femoral lateral in the intact contralateral femur. The measured difference is mirrored in the fractured side.
- In cases of comminution or bilateral fractures, another method can be used to determine or set the rotation. A true lateral of the distal femur is obtained, and the intensifier is then moved orthogonal to this position, and the proximal femur is visualized to obtain a profile of the lesser trochanter. The images are saved for reference, and mirrored on the fractured side, or contralateral side if bilateral.

Surprisingly, rotational deformities appear to be well tolerated, with an average of 28% of patients having a deformity of more than 15 degrees.

Internal rotation is tolerated better than external rotation.

In all cases, a clinical examination of rotation of both legs with the pelvis supine and the hip flexed to 90 degrees can be used to estimate symmetry. Unless the patient is in extremis, all nails should be statically locked.

The order of interlocking should be considered.

In axially stable cases, the distal segment should be interlocked, and compression applied by back-slapping the nail.

In unstable cases, traction and alignment should be maintained until interlocking is complete. Usually distal interlocking precedes proximal interlocking.5,28
**PROXIMAL INTERLOCKING SCREW PLACEMENT**

- There are guides with each system that allow placement of proximal screws. In general, at least one screw should be placed.
- Unless the fracture is stable, the static screw hole should be used, and the hole closest to the fracture is preferred.

**DISTAL INTERLOCKING SCREW PLACEMENT**

- Distal screw placement is usually done with a freehand technique. This can be one of the most challenging parts of the case for some surgeons and the easiest for others.
- In general, setup and image positioning can greatly facilitate this part of the procedure.
- Using the concentric circle concept, the image intensifier or the leg is rotated to obtain a perfect circle.
- If the image is oval or shaped like an eye, the image intensifier is not perpendicular to the axis of the nail, or in other words, parallel or co-axial with the axis of the screw hole.
- The goal is to align the axis of the image intensifier with that of the screw hole. Getting perfect circles is the first critical step.

  - In **TECHNIQUES FIGURE 4A**, the image intensifier is not aligned in the coronal plane (varus or valgus to the femoral nail).
  - In **TECHNIQUES FIGURE 4B**, the image intensifier is not aligned in the axial–transverse plane (rotationally to the nail).

- In **TECHNIQUES FIGURE 4C**, both screw holes in the nail line up, giving the “perfect circle” wherein the image intensifier is co-linear to the axis of the screw hole in the nail.

  - Next, a drill or scalpel is used to determine the cutaneous location for an incision, which should go through the fascia and to bone.
  - A drill is centered over the hole and held securely (**TECH FIG 4D**).
  - At this point there are two options: the drill can be gently tapped to engage the near cortex, or it can be drilled.
  - The axis of the drill bit should be aligned with the center of the image intensifier (which is parallel to that of the hole). Thus, if the drill tip is centered over the hole and aligned with the center of the intensifier, it should be co-axial with the axis of the hole.

**TECH FIG 4** • **A.** The perfect circle method for freehand interlocking. If the image appears as two circles overlapped, the shape of an 8 will appear. The central area is elliptical and indicates that the image intensifier axis is not collinear with the axis of the screw holes. The appropriate corrective direction is parallel to the short axis of the central ellipse (or perpendicular to the long axis). In this case, the correction would be in the coronal plane (proximal-to-distal). **B.** In this situation, the rotation of the image does not match. It will need to be corrected along the path of the C. **C.** The image of a perfect circle. (continued)
Chapter 10  ANTEROGRADE INTRAMEDULLARY NAILING OF THE FEMUR

TECHNIQUES

~3 nail diameters
36-40 mm
~5.5 nail diameters
65 mm

D. The drill point should be in the middle of the circle. Then the axis of the drill can be made collinear with that of the image intensifier. E. The drill can pass anterior or posterior to the nail and “feel” pretty good. Care should be taken to make sure the drill point does not drift during this motion. Proprioceptive feedback will frequently indicate when the drill passes through the nail and the contralateral cortex. If the drill “kicks” in one direction (anterior or posterior) it may have missed the nail. If it is not aligned in the coronal plane, it may hit the nail. It is important to verify all implant positions before leaving the operating room. F. A method of measuring using the nail as a “yardstick.” If the diameter of the nail is known, then the diameter of the bone at the level of the interlocking hole can be estimated by seeing how many multiples of the nail will fit in that segment. With some practice the accuracy of this technique is impressive: we estimate our accuracy to exceed 90% using this technique.

- Once the drill is into the bone and advanced, fluoroscopic verification should be obtained, after which the drill is advanced to the far cortex.
- If the drill bit “kicks” or jerks into a different direction or cannot be advanced, it is likely that it either glanced off the nail (missed the hole anteriorly or posteriorly) or is hitting the nail (proximally or distally) (TECH FIG 4E).

Measurement

- The drill can be removed and measured with a depth gauge or in many systems read directly from the drill guide.
- An alternate method, which we have used with surprising accuracy, is to use the known diameter of the nail as a legend.
- Comparing the width of the femoral canal at the level of the screw hole with that of the nail and estimating the number of nail widths in that segment allows for an estimate of the screw length.
- With a little practice, this method is fairly reliable, especially considering that many companies provide screws only in 5-mm increments (TECH FIG 4F).

PEARLS AND PITFALLS

Preoperative
- Correct position and traction are chosen based on patient size and assistant availability.

Intraoperative
- After nail insertion the surgeon should always check limb rotation, limb length, and the femoral neck (iatrogenic fracture).
- Care should be taken when fracture lines are within 6 to 8 cm of the interlocking sites. In these cases, higher stresses can result in complications of the nail or delayed healing, and weight bearing can be initiated with radiographic initiation of healing (callus).
- Patients should be provided with physiotherapy for range of motion of the knee and hip and encouraged to exercise the abductors as well.
- Deep vein thrombosis prophylaxis should be considered for all patients, unless contraindicated.

POSTOPERATIVE CARE

- Postoperative radiographs should be obtained to check fracture alignment, rotation, and nail and screw placement as well as to ensure the integrity of the femoral neck.
- A clinical examination for rotation of the hip and a thorough knee examination are needed to rule out occult knee injury.
- Most femoral fractures, irrespective of comminution, can be allowed weight bearing as tolerated.
OUTCOMES

- The femur can be expected to heal in about 95% of cases, with an infection rate of about 1% (FIGS 2 AND 3).
- Knee motion should return to normal about 12 weeks postoperatively, but may be limited in head-injured or polytrauma patients owing to heterotopic bone formation or lack of early motion.\(^{18}\)
- While healing rates are good, there is almost always an objective deficit in outcomes, which may or may not be clinically relevant.
  - Objective examination can reveal deficits in endurance and strength, weather-related symptoms, or residual hip, thigh, and knee pain.
  - Much like tibial nailing, the causes of such symptoms have not been well elucidated.

COMPLICATIONS

- Iatrogenic femoral neck fracture
- Up to 15 degrees of rotational malalignment can be well tolerated, but greater than 15 degrees should be corrected.
  - Rotational deformity can be prevented by paying close attention to cortical thickness, since the femur is not perfectly cylindrical and cortical thickness varies.
  - Angular malalignment can be defined as greater than 5 degrees of angulation in coronal or sagittal planes.
  - The overall rate of malalignment is 7% to 11%, with most angular deformities occurring at the proximal and distal thirds of the femur.\(^{16}\)

- Up to 1.5 cm of leg-length discrepancy may be well tolerated.
  - Beyond 2 cm, many patients will eventually complain of symptoms of malalignment (eg, back, knee, or ankle pain).
    - While symptoms should resolve with simple shoe modifications, most patients are not able to maintain compliance.
- Infection is an infrequent but devastating complication. It can be treated by several methods.
  - If the infection is early and fixation is stable, local and systemic antibiotic treatment with nail retention may be considered.
  - If the infection is extensive, a staged procedure should be considered with use of a temporary custom-fabricated antibiotic-impregnated intramedullary device, possibly an external fixator, and a course of intravenous antibiotics.
  - If the infection is delayed and the fracture is partially healed, one can also consider an exchange nail with reaming and placement of a nail of greater size (usually 2 mm).
- Most femur fractures should be considered for a combination of mechanical and pharmacologic prophylaxis against deep vein thrombosis.
- Fat emboli are a rare occurrence.
  - Studies on the reamer-irrigator-aspirator are pending. This device may prevent fat emboli.
- Decreased hip function and muscle weakness of the hip abductors and external rotators, along with trochanteric pain, thigh pain, and limp, may occur.
  - There is a small but definite occurrence of hip dysfunction with femur fractures.
While it still occurs with even retrograde nailing, the incidence seems to be greater with antegrade nails, but recent data using a trochanteric starting point appear promising.

Further and more definitive studies are warranted. There is no superior method.

Heterotopic ossification may occur in 9% to 60% of patients, with the most commonly associated factor being head injury.

Failed hardware or refracture usually indicates a nonunion. In some cases, fracture of locking screws serves to “autodynamize” the fracture and healing ensues.

There is no need for hardware removal or additional surgery if the fracture heals with minimal deformity.

Stretch injury of the sciatic nerve due to prolonged traction during intramedullary nailing can be avoided with judicious use of traction.

Treatment consists of expectant and supportive treatments.

Pudendal nerve palsy (if intramedullary nailing is performed on a fracture table) can occur when excessive traction and a small perineal post are used.

Most femur fractures can be brought to length easily, and traction should be limited to the time of reduction and nail passage and interlocking.

Use of a large, well-padded perineal post, judicious traction, or a femoral distractor can avoid this problem.

Compartment syndrome of the thigh (especially in intubated, polytrauma victims) may occur, especially with crush injuries or prolonged hypotension.

Clinical signs should be used to dictate treatment, and release of the anterior compartment is generally sufficient.

If compartment pressures are to be monitored, threshold pressure is 30 or 40 mm Hg or one that is based on the patient’s diastolic blood pressure (within 30 mm Hg).

REFERENCES

DEFINITION
- Distal femur fractures are difficult, complex injuries that can result in devastating outcomes.
- The distal part of the femur is considered the most distal 9 to 15 cm of the femur and can involve the articular surface. The intra-articular injury can vary from a simple split to extensive comminution.
- Articular involvement can lead to posttraumatic arthritis.
- These fractures constitute 4% to 7% of all femur fractures.
- If the hip is excluded, they represent nearly one third of all femur fractures.
- There is a bimodal distribution defined by the mechanism of injury (see below).

ANATOMY
- The supracondylar area of the femur is the zone between the femoral condyles and the metaphyseal–diaphyseal junction.
- The metaphyseal bone has some important structural characteristics.
  - The predominant bone is cancellous.
  - The cortices are especially thin.
  - There is a wide intramedullary canal.
- It is also important to understand the unique bony architecture of the distal femur (FIG 1).
  - It is trapezoidal in shape, and hence the posterior aspect is wider than the anterior aspect. There is a gradual decrease by 25% in the width from posterior to anterior.
  - The medial femoral condyle has a larger anterior-to-posterior dimension than the lateral side and extends farther distally.
  - The shaft is in line with the anterior half of the distal femoral condyles.
- The normal mechanical and anatomic axes of the lower limb must be understood so that the alignment of the limb can be re-established (FIG 2).
  - The mechanical femoral axis, which is from the center of the femoral head to the center of the knee, is 3 degrees off the vertical. The mechanical axis of the entire limb continues to the center of the ankle.
  - The anatomic femoral axis differs from the mechanical femoral axis in that there is 9 degrees of valgus at the knee. This results in an anatomic femoral axis of the lateral distal femur of 81 degrees or an anatomic femoral axis of the medial distal femur of 99 degrees.
  - The mechanical and anatomic axes of the tibia are for practical purposes identical, going from the center of the knee to the center of the ankle.
- The treatment of distal femur fractures can be complicated by the various muscle attachments, which can impede or hamper proper fracture reduction.
  - The quadriceps and hamstrings result in fracture shortening; thus, excellent muscle paralysis must be obtained for proper reduction.
  - The medial and lateral gastrocnemius results in posterior angulation and displacement of the distal segment. The distal femur “extends,” resulting in an apex posterior deformity. If an intercondylar extension is present, rotational deformities of the individual condyles can occur (FIG 3A,B).
  - The adductors, specifically the adductor magnus, which inserts onto the adductor tubercle of the medial femoral condyle, can lead to a varus deformity of the distal segment (FIG 3C).
- The neurovascular structures about the knee are at risk when an injury of the distal femur occurs.
Chapter 11  ORIF OF THE DISTAL FEMUR

Anatomic axis
Knee joint axis
Mechanical axis
Vertical axis

![Diagram showing mechanical and anatomic axes of the lower extremity; the 9 degrees of valgus at the knee is noted.]

- Low-energy injuries usually occur in the elderly patient who falls from a standing height. The axial loading is accompanied by either varus or valgus with or without rotation. The osteoporotic bone in these individuals leads to fracture. The fracture pattern can vary from the most simple extra-articular type to the most complex intra-articular injury. Owing to the gastrocnemius complex, an apex posterior deformity of the condyles occurs as the fragments are flexed because of the muscle attachment.

NATURAL HISTORY
- Fractures of the distal femur that have intra-articular displacement can lead to severe posttraumatic arthritis if left untreated.
- Operative treatment has led to a 32% decrease in poor outcomes.9

PATIENT HISTORY AND PHYSICAL FINDINGS
- Direct physical examination of the knee with a distal femur fracture is limited primarily because of pain and the obvious nature of the injury.
  - The patient presents with a swollen and tender knee after either a fall or some high-energy trauma (motor vehicle or motorcycle accident).
  - A large hemarthrosis is present.
  - Any attempts at range of motion result in severe pain, and significant crepitus is usually noted with palpation.
  - If there is concern for an open knee joint, the joint can be injected after a sterile preparation to see whether the knee joint communicates with any wound.
  - The physical examination is directed primarily at ascertaining the neurovascular status of the lower limb and determining whether any associated injuries exist, especially the hip (see Exam Table for Pelvis and Lower Extremity Trauma, pages 1 and 2).
  - If there are any small wounds or tenting of the skin anteriorly, the fracture should be considered as being open.
  - It is important to check for pulses.
    - If diminished or absent, pulses should be assessed with Doppler.
    - The ankle-brachial indices should be obtained if there is a concern for arterial injury.
    - Any side-to-side difference or value less than 0.9 warrants an arteriogram.
  - Nerve function should be checked. Sensation and both active dorsiflexion and plantarflexion must be assessed.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- The initial imaging study is always plain radiographs. Anteroposterior (AP) and lateral radiographs of the knee should be obtained initially.
  - Traction films should be obtained if there is severe comminution of either the metaphysis or articular surface. This aids in the preoperative planning.
  - Dedicated knee films should always be obtained in the assessment of distal femur fractures. Additionally, the entire femur, to include the hip and knee, should be imaged to look for possible extension and associated injuries and to allow for preoperative planning (FIG 4).
  - In cases of severe comminution, radiographs of the contralateral knee can aid in preoperative planning as well.
FIG 3 • A. Patient with a grade IIIA open distal femur with extruded fragment; the "extension" of the femoral condyles is outlined.
B. Patient with a distal femur fracture with intercondylar extension showing the subtle rotational deformities of the individual condyles.
C. The muscle forces are shown on the distal femur, as is the femoral artery and vein entering the canal of Hunter (arrow). The adductor magnus inserts on the adductor tubercle, leading to a varus deformity of the distal segment.
D. A lateral image of the same patient with the popliteal artery and tibial nerve drawn in to show the relative proximity to the fracture ends.
FIG 4 • A–C. Patient with a spiral distal-third femur fracture that appears to be extra-articular. A. In the AP radiograph, the knee is not fully visualized. B. A dedicated knee AP radiograph shows the spiral distal-third femur fracture. Note the intra-articular injury and the gap at the fracture (arrows). C. Lateral view of the knee. Again note the coronal fracture of the medial femoral condyle (type B3). D–F. Plain radiographs of a patient with a grade II open distal femur fracture. G,H. Patient with a closed femur fracture that was initially thought to be extra-articular.
A dedicated CT scan is an important adjunct to the preoperative planning when there is articular involvement (FIG 5). Generally, extra-articular distal femur fractures do not require a CT scan. However, it has been shown that coronal fractures may be missed on plain films, and thus there is a low threshold for obtaining a CT scan for fractures of the distal femur.4

If the fracture pattern warrants a temporary bridging external fixator, it is best to obtain the CT scan after placement of such a fixator for better definition.

![FIG 5 • A. Axial CT image of patient in Figure 4A–C confirming the type B3 fracture of the medial femoral condyle. B. Axial CT image of the patient in Figure 4D–F. C–E. CT images of the patient in Figure 4G,H show the nondisplaced intercondylar split as well as the low lateral fracture line and extensive posterior metaphyseal comminution (type C2).]

Coronal and sagittal reconstructions should be requested. Three-dimensional images can be created from most CT scans. This can also aid in the preoperative planning (FIG 6A,B).

Subtle sagittal-plane rotational malalignment between condyles can be assessed (FIG 6C).

If associated soft tissue injury is suspected, such as ligamentous tears or tendon ruptures, then MRI may be indicated. Routine use of MRI, however, is not needed.

![FIG 6 • AP (A) and lateral (B) views of a 3D CT reconstruction of the patient in Figure 3B with a distal femur fracture. The fracture is well defined. C. An oblique 3D CT reconstruction view showing the same patient and the rotational malalignment between condyles.]
DIFFERENTIAL DIAGNOSIS
- Proximal tibia fracture
- Femoral shaft fracture
- Septic knee
- Patella fracture
- Anterior cruciate ligament rupture
- Knee dislocation

NONOPERATIVE MANAGEMENT
- There are few relative indications for nonoperative management of distal femur fractures:
  - Poor overall medical condition
    - Patient has severe comorbidities and is too sick for surgery.
    - Patient has extremely poor bone stock.
  - Spinal cord injury (paraplegia or quadriplegia)
  - Some special situations may warrant nonoperative care on case-by-case basis.
    - Nondisplaced or minimally displaced fracture
    - Select gunshot wounds with incomplete fractures
    - Extra-articular and stable
    - Unreconstructable
    - Lack of experience by the available surgeon or lack of equipment or appropriate facility to adequately treat the injury. Transfer is indicated in these situations; otherwise, nonoperative treatment may be the only option.
- There are several methods for nonoperative treatment.
  - Skeletal traction
  - Cast bracing
  - Knee immobilizer
  - Long-leg cast
- There are acceptable limits for nonoperative management:
  - 7 degrees of varus or valgus
  - 10 degrees of anterior or posterior angulation. A flexion deformity is less well tolerated than an extension deformity.
  - Up to 1 to 1.5 cm of shortening
  - 2 to 3 mm of stepoff at the joint surface

SURGICAL MANAGEMENT
- The goal of any treatment, nonoperative or operative, is to maintain or restore the congruity of the articular surface and restore the length and alignment of the femur and subsequently the limb.
- Once surgery is deemed appropriate for the patient and the particular injury, the surgical technique options available are determined by the particular fracture pattern.
- Distal femur fractures have been classified several ways.
  - The AO/OTA classification is probably the most widely accepted classification system and allows some guidance on which techniques are best (FIG 7, Table 1).
- Treatment also must be determined based on factors other than the classification alone.
  - The degree of comminution and injury to both the articular surface and bone
  - The amount of fracture displacement
  - The soft tissue injury
  - Associated injuries, other fractures, and injury to neurovascular structures
  - Patient’s overall condition and injury to other organ systems. This may affect the timing of surgery or the positioning of the patient.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>Extra-articular</td>
</tr>
<tr>
<td>A1</td>
<td>Simple or two-part fracture</td>
</tr>
<tr>
<td>A2</td>
<td>Metaphyseal butterfly or wedge fracture</td>
</tr>
<tr>
<td>A3</td>
<td>Metaphysis is comminuted</td>
</tr>
<tr>
<td>Type B</td>
<td>Partial articular</td>
</tr>
<tr>
<td>B1</td>
<td>Sagittal-plane fracture of the lateral femoral condyle</td>
</tr>
<tr>
<td>B2</td>
<td>Sagittal-plane fracture of the medial femoral condyle</td>
</tr>
<tr>
<td>B3</td>
<td>Any frontal or coronal plane fracture of the condyle (Hoffa type)</td>
</tr>
<tr>
<td>Type C</td>
<td>Intra-articular</td>
</tr>
<tr>
<td>C1</td>
<td>Simple articular split and metaphyseal injury (T or Y fracture configuration)</td>
</tr>
<tr>
<td>C2</td>
<td>Simple articular split with comminuted metaphyseal injury</td>
</tr>
<tr>
<td>C3</td>
<td>Comminuted articular with varying metaphyseal injury</td>
</tr>
</tbody>
</table>
There are several principles for the surgical management of distal femur fractures:

- The articular surface must be reduced anatomically, which usually requires direct visualization through an open exposure (arthrotomy). Simple intra-articular splits may be treated with closed reduction and percutaneous fixation.
- The extra-articular injury should be dealt with using indirect reduction techniques as much as possible to maintain a biologic soft tissue envelope. Avoidance of stripping of the tissues, especially on the medial side, is ideal.
- The surgeon must re-establish the length, rotation, and alignment of the femur and the limb.
- The soft tissue injury and bone quality may dictate treatment decisions.

**Fixation Choices**

- **External fixation**
  - A temporary bridging external fixator across the knee joint can be used if temporary stabilization is required before definitive fixation. This is usually the case where definitive open reduction and internal fixation is planned. This could be in cases where the soft tissues prevent immediate fixation.
  - Definitive management with bridging or nonbridging external fixation can be used for unreconstructable joints, very severe soft tissue injuries, or severe osteopenia.

- **Intramedullary nailing**
  - This can be performed fairly acutely; temporary bridging external fixation is not necessary.
  - Antegrade intramedullary nailing has been described and can be used for distal fractures with a large enough distal segment to allow for two locking screws. Malalignment has been a problem, as has adequate fixation.¹,²
  - Retrograde intramedullary nailing can be used in the following cases:
    - All extra-articular type A fractures greater than 4 cm from the joint. This minimal length of the distal femur allows for multiplanar interlocking in the distal fragment.
    - Type C1 or C2 fractures where the articular fracture can be anatomically reduced closed or with limited exposure. Percutaneous screws are used for the articular injury.
    - Periprosthetic fractures around a total knee arthroplasty with an “open box” femoral component.

- **Plate fixation**
  - Open reduction and internal fixation with plates can be used for all types A and C fractures but is ideal for the following injuries:
    - Very distal type A fractures within 4 cm of the knee joint
    - All articular type C fractures, but always for C3 types
    - Periprosthetic fractures about a “closed box” femoral component of a total knee arthroplasty
    - The partial articular type B1 or B2 if an antiglide plate is needed
  - Plate options (preferred to least preferred; fixed-angle devices preferred)
    - Fixed-angle locking plates (percutaneous jigs are advantageous and allow for minimally invasive techniques)
    - 95-degree condylar screw
    - 95-degree blade plate
    - Nonlocking plates with or without medial support (medial plate or external fixation)

- **Limited internal fixation**
  - Limited fixation with screws only can be used for partial articular type B, especially type B3.
  - The amount of open reduction required depends on the adequacy of closed reduction techniques and obtaining an anatomic reduction of the joint surface.
  - Headless screws are useful for type B3 fractures in which the screws have to penetrate the joint surface (FIG 8).
  - Countersinking the screw heads can also be performed.

**Preoperative Planning**

- Surgical timing can be affected by:
  - Soft tissue issues
  - Medical condition of the patient
  - Adequacy of available operative team
  - Availability of implants
- The approach must take the following issues into consideration:
  - The ability to incorporate lacerations in open fractures into the incision (FIG 9) can be useful and should be considered. However, this is not always necessary or possible.
Soft tissue dissection should be limited.

Adequate exposure is important to anatomically restore the articular surface.

Restoration of limb “anatomy” must be accomplished and allow early range of motion.

Stable internal fixation and length and sizes of implants should be templated. Radiographs of the injury can be templated with implant templates to ensure that proper lengths are available. A tentative plan of the fixation construct can be drawn on the image. Additionally, “preop planning” of the operating room should be performed; this includes a discussion with the operative team about the positioning and equipment needed for the procedure.

The need for bone grafting should be assessed (eg, iliac crest bone graft versus allograft or bone graft substitutes).

Fracture fragments and the anticipated fixation construct should be templated.

The surgeon should check for coronal plane fractures of the condyles (also known as Hoffa fragments) (see Figs 4C and 5).

Associated injuries may affect the treatment options.

An ipsilateral hip or more proximal shaft fracture may alter the implant choice. A longer plate may be needed to address both injuries, or consideration to overlap implants may be warranted to avoid a stress riser.

An associated proximal tibia fracture may alter the approach used. A more lateral incision incorporating a lazy S incision for the proximal tibia injury may be required.

### Positioning

- A radiolucent table should be used to allow adequate visualization with a C-arm.
- The patient is placed supine with a hip bump.
- The rotation of the proximal segment of the fracture (hip) should be aligned before patient preparation.
  - Using the C-arm, the profile of the lesser trochanter with the corresponding knee (patella) straight up is determined on the uninjured side (FIG 10A, B).
  - The injured hip is imaged and internally rotated by the hip bump so that duplication of the profile of the normal side is achieved. The size of the bump may be adjusted as needed for the amount of rotation required.
- The injured knee is placed in the patella-up position to confirm rotation.
- This technique is helpful in comminuted metaphyseal fractures where the rotation is difficult to assess or in cases where the metaphyseal component will not be directly visualized.
- Even though the distal segment is not in “fixed” rotation, this technique is useful to minimize the chance of a malrotation during definitive fixation.
- A sterile tourniquet is used unless a temporary fixator prevents its placement.
- A large bump or a sterile triangle is used under the knee.
  - This allows for knee flexion, relaxing the gastrocsoleus complex and facilitating the reduction.
  - A sterile and removable one is most useful.
- The C-arm is brought in from the opposite side.
  - It should be angled so that it is parallel with the femoral shaft.
  - A notch view is useful for screw trajectories in the distal femur (FIG 10C, D).

### Approach

- The best-known approach for the treatment of distal femur fractures has been the straight lateral approach (FIG 11).
  - This is suitable for all fracture types, mostly types A and C1.
  - The incision may curve distally toward the tibial tubercle, and osteotomy may be performed.
  - Newer approaches include a lateral inverted U to allow better access to the joint and to allow for plate placement.
  - The minimally invasive lateral approach can be used for certain fractures and implants.
  - The joint must be visualized, reduced, and stabilized.
  - The placement of the plate on the shaft is done submuscularly, and reduction and fixation are done percutaneously under fluoroscopic guidance.
  - This is ideal for the LISS plate or plating system with targeting devices for the screws in the plate.
  - A modified anterior approach (the swashbuckler) has been described by Starr et al.7
    - This involves a midline incision.
    - A lateral parapatellar arthrotomy is done with elevation of the vastus lateralis as in the lateral approach.
A medial parapatellar arthroscopy can be used for retrograde intramedullary nailing or limited screw fixation.

- Mini-arthroscopy is used for the retrograde nail.
- Type B injuries may require a formal arthroscopy.
- A medial approach has been described.
- This is appropriate for type B2 and B3 fractures.

- It can be used in type C3 fractures if a second plate is being used (in conjunction with a lateral approach).
- A total knee approach has been described by Schatzker.6
- This is extremely helpful for type C2 or C3 fractures.
- It is used for plates but can be used for retrograde intramedullary nailing once the articular surface is reconstructed.
- A midline approach is used.
- An extended medial parapatellar arthroscopy is done.
- This allows exposure of the condyles for articular reduction.

A midline incision with a lateral parapatellar arthroscopy is my preferred exposure for type C fractures.

- A midline approach is used.
- A lateral parapatellar arthroscopy is done.
- Proximal extension is made into the quadriceps tendon, enough to repair to itself.
- Medial dislocation of patella is done.
- This allows exposure of the condyles for articular reduction and easier lateral plate insertion.
Chapter 11  ORIF OF THE DISTAL FEMUR  591

TEMPORARY BRIDGING EXTERNAL FIXATION

- A large external fixation system is used.
- A small bump is placed under the knee to place the knee in slight flexion.
- The injured extremity is brought out to length with manual traction.
- Two or three 5-mm Schanz pins are placed in the tibia in an anterior-to-posterior direction just medial to the crest to ensure intramedullary placement.
- Two or three 5-mm Schanz pins are placed in the femoral shaft in an anterior-to-posterior direction.
  - These should be placed out of the zone of soft tissue injury if possible.
  - The pins are placed while the limb is out to length so that the quadriceps is not “skewered” in a shortened position.
  - The pins can be placed outside of the anticipated plate location. This, however, has not been empirically found to be a problem. In my experience plates have often overlapped with pin sites and there has not been an associated problem with infections.
- Pin placement in the tibia may be altered if additional uses of such pins are needed, such as traction for an associated acetabular fracture (TECH FIG 1A).
- The bars can be configured in many ways, all of which provide temporary stabilization across the knee joint. I prefer a diamond configuration (TECH FIG 1B).

Reduction of the Metaphyseal Component

- Gross reduction of the metaphyseal component of the fracture should be performed with traction and manipulation of the pins.
- The fracture should be brought out to length.
  - Intraoperatively, the opposite leg can be used to help determine length.
  - Postoperatively, a scanogram can be used to determine whether the length has been regained before definitive fixation if there is extensive comminution, but this is not always needed (TECH FIG 2). Although the knee may be somewhat flexed, the scanogram can still be obtained and the femoral length determined as opposed to the entire leg length.
- The rotation should be checked once again before locking the external fixator construct, as described above under positioning. The same technique should be performed under sterile conditions.
- Varus–valgus alignment should be assessed before final tightening as well.
  - This can be done by using the Bovie cord intraoperatively and assessing the mechanical axis of the limb by fluoroscopically evaluating from the hip to the ankle with the cord centered at the femoral head all the way to the ankle.
  - The point at which the cord crosses the knee allows one to judge the varus–valgus alignment.

**TECH FIG 1**  
A. Bridging knee external fixation in patient with associated acetabular fracture; the tibial pin was used for traction purposes as well.  
B. A diamond configuration for bridging knee external fixation.
This technique can be used regardless of the locking plate system used. Each system’s technique guide should be reviewed before use, as each system has its own idiosyncrasies. Variations in plate application as well as reduction tools and techniques are unique to each system.

The temporary external fixator is prepared using a “double-double” technique.

The fixator is first prepared with a Betadine “scrub” (7.5% povidone–iodine) solution followed by a Betadine “paint” (10% povidone–iodine) solution (Beta–Beta preparation), followed by the extremity, with a second Beta–Beta preparation.

The surgeon then does an alcohol preparation, followed by iodine for the fixator, followed by alcohol and iodine on the skin.

This has been successful in our practice and allows for maintenance of traction during the preparation and aids in the actual surgery, functioning as a femoral distractor. (Chlorhexidine is used in iodine-allergic patients.)

An alternative is to completely remove the fixator components, except the pins, and wash, sterilize, and then reassemble the fixator on the patient after the leg has been prepared.

If there is no temporary bridging external fixator, the metaphyseal component of the fracture can be reduced and brought out to length with a femoral distractor, a temporary simple external fixator, or manual traction if adequate help is available.

Rotation of the proximal segment can be manipulated with the device used.

Midline Approach with an Extended Lateral Parapatellar Arthrotomy

A straight incision is made directly anterior about 5 cm proximal to the superior pole of the patella and distally to the level of the tibia tubercle (TECH FIG 3A).

The lateral skin flap is developed to allow for a lateral parapatellar arthrotomy (TECH FIG 3B).

The arthrotomy is performed, ensuring a cuff of tissue on the lateral aspect of the patella for repair as well as medially on the quadriceps (TECH FIG 3C).

The patella can be subluxed medially or inverted with knee flexion to allow exposure of the condyles (TECH FIG 3D).

Additionally, a blunt Hohmann retractor can be placed on the medial side at the level of the condyle to retract the patella.

The capsule is subperiosteally elevated off the lateral femoral condyle to allow for placement of the plate.

The lateral collateral ligament is preserved because the dissection is limited to the anterior two thirds of the lateral femoral condyle and plate placement is usually proximal to the lateral epicondyle.
The medial side in the metaphyseal region is left undisturbed as much as possible.

**Reduction of the Articular Surface**
- The joint is evaluated to determine comminution.
- Joint reconstruction is then performed with direct reduction. Each condyle is fully assessed first for smaller fracture fragments, with the goal of restoring each condyle anatomically. Small-diameter screws (less than 3.0 mm) may be used and can be countersunk underneath the articular surface.
- Large coronal fracture fragments are best treated with countersunk 3.5- to 4.5-mm lag-type screws. We use headless screws.
- Once each condyle is thought to be restored, or if a simple fracture pattern is present, the condyles should be reduced to each other using a large pointed reduction forceps (**TECH FIG 4A–C**).
- Each fragment can be rotated relative to another; this must be addressed as discussed before.
- The best way to assess this is under direct visualization and evaluating the reduction at the trochlear region of the patellofemoral joint.

Additionally, preoperative evaluation assessing the lateral radiograph can guide the surgeon. Intraoperative fluoroscopy to reassess the lateral view is also useful.
- Temporary Kirschner wires or the guide pins for the locking screws for the plate can be used for additional stabilization of the two condyles (**TECH FIG 4D**).

**Definitive Fixation of the Condyles**
- This can be accomplished outside the plate first and supplemented with screws through the plate. The area around the proposed plate, the “periphery,” can be used for the screw placement to avoid interference with the plate placement itself.
- If this is done, then the metaphyseal fracture does not necessarily have to be properly reduced before initial screw placement.
- Screws can also be placed from medial to lateral to avoid interference with the plate.
- Definitive fixation can be accomplished through the plate also (see next).
- If this is done, the metaphyseal component should be reduced to ensure the proper flexion–extension alignment of the shaft with the condyles.
This will ensure that the plate is collinear with the shaft once fixed to the distal segment. Otherwise, a malreduction in the sagittal plane will occur. The temporary Kirschner wires can be left in place to stabilize the joint.

**Reduction of the Shaft to the Distal Segment**

- Once the articular surface is temporarily stabilized or reduced, the reduction of the shaft to the distal segment should be performed before plate application.
- This can be temporarily stabilized with Kirschner wires or Steinmann pins.
- Alternatively, precisely placed bumps underneath the distal segment can be used to correct the extension of the distal segment and align it with the shaft.
- Adjustment or loosening of the temporary external fixator can aid in reduction if needed.
- The plate can then be placed submuscularly.

**Placement of the Plate**

- Each fixed-angle plating system is designed to help re-establish the valgus alignment of the distal femur.
- The screws in the distal portion of the plate are designed to be parallel to the joint surface.
- Thus, the initial guidewires for these screws should be placed parallel and confirmed by fluoroscopy.
- A distal “joint wire” can be placed to better evaluate this (TECH FIG 5A).
- Placing the distal screws parallel to the joint will help ensure that when the shaft is brought to the plate, the anatomic axis of the femur is restored.
- A distal screw trajectory guide is provided for some systems (TECH FIG 5B). This can be used to help ensure accurate placement of the plate distally, and initial guidewires can be placed through this.
- Once the wires are placed, the guide can be removed and replaced with the plate, using the wires as a guide.
- However, the shaft portion of the plate requires submuscular insertion, and thus the plate cannot be brought to an appropriate position to allow this to occur.
- To solve this, the guidewires can be driven through the medial side of the knee, which is distal enough to be safe (TECH FIG 5C).
- The plate can then be inserted submuscularly and the guidewires driven back through the plate laterally, thus aligning the plate to the distal segment and ensuring proper screw trajectory and plate placement (TECH FIG 5D,E).
- A single guidewire in a central hole will still allow flexion–extension placement of the plate if this needs to be adjusted.

After placing the initial guidewire parallel to the joint distally, and ensuring the fracture is reduced, the surgeon should obtain fluoroscopic visualization of the plate proximally on the shaft to ensure that the plate is on the bone (TECH FIG 5F,G).

To ensure placement of the plate on the bone both proximally and distally, it is best to stabilize the plate distally (where exposure is) using a guidewire in the center hole. This allows for a pivot point around which the anteroposterior positioning of the plate can be manipulated for the shaft. Fluoroscopy to image the lateral is then used to ensure placement.

Once the anteroposterior position is obtained, the plate is stabilized proximally.
The plate should be temporarily stabilized to the bone proximally.

Before the temporary stabilization, the length and rotation must be checked. Ideally, if the temporary fixator is in place, these two parameters have been maintained during the course of the operation.

If no screw targeting guide is present, a percutaneous provisional fixation pin can be used to stabilize the plate.

If a targeting guide is used, then a soft tissue guide for the most proximal hole is placed percutaneously and a drill bit or guidewire is used to stabilize the plate.

Again, the flexion–extension reduction should be checked.

This procedure creates our "box" construct, which aids in the placement of screws through the targeting device (if used) and in temporary stabilization of the fracture construct.
**Screw Placement**

- If the intercondylar split is going to be stabilized by screws through the plate, partially threaded screws or overdrilled fully threaded screws should be used first to provide interfragmentary compression.
  - Specially designed conical screws for certain systems exist, or large partially threaded screws can be used (larger than 4.5 mm). This also compresses the plate to the bone.
- Once the articular injury is addressed, at least two additional locking screws should be placed into the distal segment to secure the plate and the alignment.
- The trajectory of distal locking screws can be assessed on the notch view to ensure that penetration through the intercondylar notch does not occur (TECH FIG 6; see Fig 10C for C-arm setup and position for this image).
- Before placing the locking screws, the length, rotation, and alignment must be checked again if no fixator or distractor is in place holding the fracture alignment.
- The plate can be locked to the distal segment and then used to manipulate the distal segment relative to the shaft for the flexion–extension reduction.
- This, however, is predicated on proper distal alignment of the plate. Otherwise, once the plate is fixed to the distal segment in a malposition and the fracture reduced, the plate may be anterior or posterior on the shaft.

**TECH FIG 6** • Patient seen in Figure 10C,D, with the guidewire now pulled back and an appropriately sized screw placed.

**Attaching the Distal Segment to the Shaft**

- The distal segment is now fixed and can be attached to the shaft.
- If there is malalignment in the coronal plane but the sagittal plane alignment is reduced, the shaft can be “pulled” to the plate by means of various threaded devices or a nonlocking screw that can be placed freehand under fluoroscopic guidance or through a targeting jig (TECH FIG 7).

**TECH FIG 7** • The “whirlybird” device is tightened and the bone pulled to the plate.
Placement of Additional Screws

- Once proper reduction of the fracture is temporarily achieved and the plate in proper position, additional screws can be placed.
- If the targeting screw guide is used, percutaneous locking screws can be placed through the soft tissue drill or screw guides (TECH FIG 8A–C).
- If no targeting guide is available, fluoroscopic guidance and a percutaneous method can be used freehand.
- Depending on the system, locking drill guides can be placed freehand to ensure proper trajectory of the drill so that locking screws can be used.
- If that is not the case, nonlocking screws should be placed.
  - Experience is required for the freehand percutaneous method; otherwise, an open approach to the shaft should be performed.
- The final construct should be checked with fluoroscopy on the lateral aspect as well (TECH FIG 8D,E).

- The restoration of the mechanical axis can be checked intraoperatively after temporary stabilization (preferred) or definitive stabilization using the Bovie cord.
- TECHNIQUES FIGURE 8F–H show the repair after definitive stabilization.
- The exact number of screws in each fragment has yet to be determined in the literature, but we prefer to have at least five screws in each fragment if possible at the end of fixation.
- A longer working length in the shaft can be used, and not all holes need to be filled.
- There is evidence that in young patients with good bone, no locking screws are needed in the diaphysis.
- Multiple locking screws are used in the epiphysis because of the short length of these distal fragments.
- The largest screws available for the epiphysis should be used.

TECH FIG 8 • A. Targeting guide for proximal screws. B. C-arm image of screws placed. C. Stab incisions used for percutaneous method. D,E. Plate placement on the lateral aspect is confirmed. (continued)
TECH FIG 8 • (continued) F–H. Alignment is checked intraoperatively with the Bovie cord. The mechanical axis from the center of the femoral head through the middle of the knee to the middle of the ankle is confirmed.

Bone Grafting
- The metaphyseal comminution may require bone grafting in cases of open fractures with bone loss.
- The exact type and need vary and should be based on the surgeon’s experience (TECH FIG 9).
- Hemostasis is achieved throughout the procedure or after the tourniquet is released. A tourniquet can be used to help minimize bleeding and improve visualization, especially for articular reconstruction. Often a sterile tourniquet is used because of the temporary bridging external fixator that is in place.
- After adequate irrigation (before bone graft or substitute placement if used), a drain is placed in the knee joint and brought out laterally.

TECH FIG 9 • A. Patient with significant metaphyseal bone loss from an open injury shown on CT scan. B. The post-fixation radiograph shows the void. C. Placement of Osteoset beads impregnated with vancomycin (off-label use) to fill the void and provide osteoconductive material for healing.
Chapter 11 ORIF OF THE DISTAL FEMUR

TECHNIQUES

Standard Wound Closure

- Closure of the arthrotomy is performed with figure 8 0 Vicryl sutures. This is reinforced by a running 2-0 Fiberwire suture (TECH FIG 10A).
- The subcutaneous tissue is closed with 2-0 Vicryl.
- The skin is closed with staples, as are the percutaneous stab incisions.
- The knee is flexed and extended fully to ensure restoration of motion as well as to break any adhesions in the quadriceps that may have formed while the temporary bridging external fixator had been in place (TECH FIG 10B,C).
- The final radiographs are taken in the operating room (TECH FIG 10D,E).

TECH FIG 10 • A. Closure of the arthrotomy. B,C. Full flexion and extension of the knee after definitive fixation and closure. As seen in final AP (D) and lateral (E) radiographs, the metaphyseal comminution is bridged and left undisturbed.

Limited Lateral Approach

- A lateral incision measuring about 5 to 6 cm is made starting at the level of the joint and extending proximally in line with the shaft. The distal extent is curved slightly toward the tibial tubercle, as in the lateral approach (TECH FIG 11A,B).
- The iliotibial band is incised in line with the skin incision (TECH FIG 11C).
- The dissection is carried down to the lateral femoral condyle. The lateral aspect is exposed enough for plate placement (TECH FIG 11D).
- A Cobb elevator is used to create a plane submuscularly up the lateral shaft of the femur for placement of the plate.

OPEN REDUCTION AND INTERNAL FIXATION OF THE DISTAL FEMUR WITH LOCKING PLATES (TYPE A OR NONDISPLACED TYPE C1 OR C2)

- This technique can be used regardless of the locking plate system used. Each system’s technique guide should be reviewed before use, as each system has its own idiosyncrasies. Variations in plate application as well as reduction tools and techniques are unique to each system.
- See comments above regarding temporary use of an external fixator or distractor.
TECH FIG 11 • Patient with closed distal femur fracture (also shown in Figs. 4G,H and 5C–E). A. Limited lateral incision, with the tibial tubercle marked. B. Skin incision showing the iliotibial band. C. Incision of the iliotibial band. D. Exposure of the lateral aspect of the femur.

Stabilizing the Articular Surface

- For nondisplaced type C1 or C2 fractures, the first priority is to stabilize the articular surface.
- Visualization of the joint may be accomplished with placement of a blunt Hohmann retractor (or similar Z retractor) (TECH FIG 12A).
- A reduction forceps is placed anteriorly to hold the reduction (TECH FIG 12B).
- Temporary Kirschner wires or guidewires from a cannulated system can be placed for additional stability (TECH FIG 12C,D).
- All clamps, Kirschner wires, or guidewires should be placed outside the zone of plate application (TECH FIG 12E,F).
- Definitive fixation of the condyles should be performed (see technique description above) (TECH FIG 12G).

TECH FIG 12 • A. Visualization of the joint for articular reduction. B. C-arm image of reduction forceps holding the intercondylar split reduced. C,D. Clinical photographs with forceps followed by guidewires for screw placement. E,F. Lateral views showing pins and wires outside the zone for either plate application or intramedullary nail. The anterior and posterior placement of the pins is seen. (continued)
Chapter 11  ORIF OF THE DISTAL FEMUR

Reduction of the Distal Segment and Plate Placement
- Reduction of the distal segment to the shaft can be performed using temporary Steinmann pins (TECH FIG 13).
- The plate can now be applied in a submuscular fashion (see Placement of the Plate, above).

Wound Closure
- Final radiographs are taken in the operating room (TECH FIG 14).
- Standard wound closure is undertaken, as described in the previous section.

Retrograde Nailing
- Refer to Chapter TR-9 on retrograde nailing of the femur.

PEARLS AND PITFALLS

| Articular reduction | • Direct open reduction should be used.  
|                     | • It can be outside the plate or through the plate.  
|                     | • Screws should be out of the way of the plate or nail. |
| Plate application   | • The initial guidewire through the central hole in the plate should be parallel to the joint. Ninety-five degrees is built into the plate. If locking screws are placed parallel to the joint, then once the plate is reduced to the shaft, the proper alignment is restored.  
|                     | • Rotation must be continually assessed.  
|                     | • The fracture should be reduced in the sagittal plane before temporary fixation or creation of a “box construct” with the plate.  
|                     | • In comminuted cases, a scanogram or opposite-side femur film with a ruler can be obtained to help determine the length. |
| Soft tissue handling | • The surgeon should avoid stripping the soft tissues medially. This will obviate the need for bone grafting.  
|                     | • The plate should be placed submuscularly. |
**POSTOPERATIVE CARE**

- The goal of stable fixation is to allow early range of motion. My preference is a hinged knee brace locked in extension for 2 weeks, at which time the wound is healed and full motion is then started.
- A continuous passive motion machine can be used.
- Cold therapy products can be used.
- A drain is used for 48 hours postoperatively.
- Deep vein thrombosis prophylaxis may be indicated for certain patients:
  - Obese
  - Multiply injured
  - History of previous deep vein thrombosis
  - Patient who may not be mobile enough despite an isolated injury
- We provide 2 weeks of deep vein thrombosis prophylaxis for all patients and then reassess in terms of mobility if it is an isolated injury. Otherwise, with significant risk factors or indications for deep vein thrombosis prophylaxis, a full 6-week course is prescribed.
- Early protected weight bearing
  - Toe-touch weight bearing for 6 to 8 weeks for plate fixation
  - Followed by partial weight bearing for 4 to 6 weeks for plate fixation
  - Followed by full weight bearing
  - Immediate weight bearing can be indicated for fixation of type A fractures with intramedullary nailing if the fracture pattern is stable and not comminuted.
  - For type C fractures treated with intramedullary nailing and screw fixation for the articular component, toe-touch weight bearing or non-weight bearing for 6 to 8 weeks is adequate, followed by full weight bearing.
  - In all cases, progression of weight bearing is based on radiographic evidence of healing.
- Patients are prescribed physical therapy for range of motion and strengthening at 2 weeks.

**OUTCOMES**

- Results are good to excellent in 50% to 96% of cases.\(^3,5,9\)
- Average range of motion is about 110 to 120 degrees.
- About 70% to 80% of patients can walk without aids.
- It is difficult to compare the results of studies in the literature.\(^9\)
  - There is no universally accepted classification.
  - There are varying indications.
  - Different grading systems are used.
  - Not all authors adhere to the same principles.

**COMPLICATIONS**

- Neurovascular injuries
  - Can occur from initial trauma
  - Rare after surgery
- Infection
  - 0% to 10% rate after open reduction and internal fixation
  - Predisposing factors:
    - High-energy injuries
    - Open fractures
    - Extensive dissection
    - Prolonged operative time
    - Inadequate fixation
- Nonunion
  - 0% to 6% rate after open reduction and internal fixation
  - Predisposing factors:
    - Bone loss or defect (FIG 12A)
    - High-energy injuries
    - Soft tissue stripping
    - Loss of osseous vascularity
**Inadequate stabilization**
- No bone graft
- Infection

**Malunion**
- More common with nonsurgical treatment, which results in varus and recurvatum
- Operative treatment with newer locking plates can result in valgus.
- Treatment required to restore mechanical axis:
  - Supracondylar osteotomy
  - Stable fixation
  - Early range of motion

**Hardware failure occurs in 0% to 13% of cases** *(FIG 12B,C).*
- Predisposing factors:
  - Communion of metaphyseal area
  - Older age
  - Very distal fracture
  - Premature loading or weight bearing
  - Nonunion
  - Infection
- Knee stiffness: almost all patients exhibit some loss of motion
- Protruding hardware
- Articular malreduction
- Adhesions
  - Intra-articular
  - Ligamentous-capsular contractures
  - Muscle scarring
- Treatment may consist of any of the following or combination of:
  - Manipulation
  - Arthroscopic lysis
  - Formal quadricepsplasty

**Posttraumatic arthritis occurs in 0% to 30% of cases.**
- Predisposing factors:
  - Severe articular comminution
  - Cartilage loss
  - Cartilage impaction or damage
- Surgical factors:
  - Failure of anatomic reduction
  - Malalignment of fracture

**REFERENCES**
DEFINITION
- The patella, the largest sesamoid bone, is a key part of the knee extensor mechanism and provides leverage to the quadriceps mechanism. Fractures of the patella have the potential to disrupt the extensor mechanism.
- Fractures of the patella also affect the knee joint itself by interrupting the articular surface.
- Management of patellar fractures must restore any disruption of the extensor mechanism while ensuring minimal disruption of the articular surface.
- Stellate or comminuted, transverse, vertical, apical or inferior pole, and sleeve fractures are common descriptive terms used in the classification of patellar fractures.

ANATOMY
- The articular surface is composed of medial and lateral facets, with the medial facet having the most variability in size and shape. Horizontal ridges further subdivide the medial and lateral facets. An odd facet lies at the most medial aspect of the articular surface. The distal pole of the undersurface is extraarticular (FIG 1).
- The superior pole of the patella serves as an attachment for the quadriceps tendon. The most superficial portion of the quadriceps tendon courses over the anterior patellar surface and is contiguous with the patellar tendon. The patellar tendon courses from the apex of the patella to the tibial tubercle.
- The patellar retinaculum is composed of thickenings of the fascia lata of the thigh in addition to the aponeurosis of the vastus medialis and lateralis.13 In addition to stabilizing the patella, the retinaculum acts as a secondary extensor.
- Multiple arteries about the knee supply a peripatellar plexus, although the main intraosseous blood supply is from a distal-to-proximal direction.14
- The patella acts to increase the moment arm of the extensor mechanism by displacing the quadriceps tendon anteriorly. This increased moment arm is most critical during terminal extension, when the quadriceps is otherwise at a mechanical disadvantage.9
- Due to the small contact area of the articular surface and the high level of compressive forces generated by the extensor mechanism, the contact stress on the patellofemoral joint has been estimated to be higher than any other major weight-bearing joint.5

PATHOGENESIS
- Fractures of the patella may result from direct force to the anterior knee, indirect forces transmitted through the extensor mechanism, or a combination of both.
- The patella is particularly susceptible to injury from direct blows given its small amount of tissue covering and its prominence.
- The portion of the patella articulating with the femur moves from distal to proximal with increasing degrees of flexion. The fracture pattern for direct blows to the patella has been shown to correspond to the articulating portion of the patella at the time of injury, thus corresponding to the amount of knee flexion at time of injury.1
- Indirect forces causing fracture can be caused by unanticipated and rapid flexion of the knee while the quadriceps is also firing. Fractures from an indirect mechanism tend to be less comminuted than those from direct trauma.5

FIG 1 • Patellar anatomy. The major facets include the medial, lateral, and odd facets. The medial and lateral facets are further subdivided by subtle horizontal ridges.
NATURAL HISTORY

- Depending on the type of fracture and involvement of the retinaculum, various amounts of long-term extensor weakness can be expected. The long-term effect on range of motion is likewise dependent upon fracture pattern and displacement.
- There is an increased incidence of osteoarthritis of the knee after patellar fracture. The increased rate of arthritis may be both from initial cartilage injury and posttraumatic arthritis due to articular cartilage incongruity.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Physical examination findings are as follows:
  - Often a defect can be palpated in the patella.
  - New onset of joint effusion after injury localizes injury to within the capsule of the knee. A knee effusion may not be present if there is disruption of the retinaculum, allowing hematoma to escape from the joint capsule.
  - The placement of the patella and palpation of defects with the patella, quadriceps tendon, or patellar tendon can help differentiate between patellar fracture and ligamentous extensor disruption.
  - Pain can limit the ability to test for active extension of the knee or for extensor lag. Introduction of local anesthesia after aspiration of hematoma can aid in assessment of extensor function. The surgeon should note any extravasation of local anesthetic to evaluate intra-articular extension of skin defects.
  - Aspiration: The surgeon notes the amount of fluid aspirated. The presence of fat lobules in the syringe signifies a fracture extending into the knee capsule.
  - Patients with patellar fractures are able to actively extend the knee in marginal or longitudinal fracture types or with intact secondary extensors (ie, retinaculum). Knee extension is usually not possible with displaced transverse fractures.
  - History is critical in determining a direct versus indirect cause of fracture. Patella fractures caused by a high-energy direct cause (ie, head-on motor vehicle accident with dashboard injury) are often associated with other injuries to the knee.
  - Peripheral pulses and neurologic function must be examined.
  - Knee stability should be evaluated. Patella fractures may be accompanied by cruciate ligament injury.
  - Open fractures will require urgent operative management and are associated with an increased rate of nonunion and infection. Open fractures also connote higher energy and an increased likelihood of associated injury.
- Physical examination must include a thorough secondary survey for other associated injuries. Distal femur fractures and acetabular injuries are commonly associated in high-energy motor vehicle accidents owing to transfer of force through the flexed knee.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Anteroposterior (AP) and lateral views of the knee and an axial view of the patella provide sufficient information for nearly all fracture types.
- In the trauma setting, the Merchant view11 is the best tolerated (FIG 2A).
- A bipartite patella, arising from failed fusion of patellar ossification centers, can be mistaken for a fracture. Bipartite patellae are most commonly located superolaterally and occur more frequently in males. In 40% of individuals with a bipartite patella, the contralateral patella will also be bipartite7 (FIG 2B,C).
- The normal Insall-Salvati ratio (height of the patella over the distal from the inferior pole to the tibial tubercle) is about 1.0. Values less than 1 represent patella alta and possible patellar tendon rupture. Patella alta may also be seen in patellar sleeve fractures in the pediatric population.

DIFFERENTIAL DIAGNOSIS

- Quadriceps rupture
- Patellar tendon rupture
- Bipartite patella
- Ligamentous or meniscal injury
- Distal femur or tibial plateau fracture
- Inflammatory arthritis or septic arthritis
- Osteochondral injury
- Patellar dislocation or retinacular injury

NONOPERATIVE MANAGEMENT

- Fractures must meet two criteria to be managed nonoperatively:
  - No associated extensor mechanism disruption
  - Less than 2 mm of displacement of the articular surface or less than 3 mm separation of the fracture fragments.3,6 (Less
displacement is tolerated by some authors in the presence of transverse fractures.\(^4\)

- The described period of immobilization varies. Historically, patients were kept in a long-leg cast for 4 to 6 weeks. Current nonoperative management involves early functional treatment.
- Our preference for nonoperative treatment includes partial weight bearing with crutches and a hinged knee brace.
  - The leg is maintained in extension for 2 weeks, 0 to 45 degrees of flexion for 2 weeks, and 0 to 90 degrees for 2 weeks, followed by full motion for 2 weeks.
  - After this 8-week course, full weight bearing is allowed.
- Nonoperative management of appropriate fractures results in good overall results, with loss of flexion the most common complication.\(^4,5\)

**SURGICAL MANAGEMENT**

- Operative treatment is the preferred treatment for the majority of fractures not meeting the nonoperative criteria outlined above. Treatment is aimed at anatomic reconstruction of the articular surface and restoration of the extensor mechanism.
- Open reduction and internal fixation is the treatment of choice.
- Cases with severe comminution of the inferior or superior pole may be considered for partial patellectomy.
- Total patellectomy is reserved for cases of severe comminution involving most of the patella in which reconstruction of an articular surface is not possible.
- Methods involving arthroscopy or external fixation have not gained widespread use.
- Soft tissue must be respected as there exists only a thin soft tissue envelope covering the patella. This care for soft tissue begins in the emergency department. Splints or knee immobilizers must be accompanied by copious padding to minimize complications from pressure.

**Preoperative Planning**

- Operative timing is dictated by patient condition, presence of open fractures, and condition of the soft tissues.
- Fracture imaging is reviewed.
- Examination under anesthesia is critical, as evaluation of coexisting ligamentous injuries is often limited by patient pain prior to surgery. Lachman, pivot shift, posterior drawer, and varus-valgus testing should be undertaken before preparing the surgical site.
- Concomitant injuries may be addressed in the same surgery.

**Positioning**

- Patients are placed in the supine position on a radiolucent table.
- If a tourniquet is used, it must be placed as proximally as possible on the thigh. The quadriceps must not be trapped under the tourniquet, as this may retract the patella superiorly, hindering fracture reduction. The knee is flexed to 90 degrees before elevating the tourniquet. If the retinaculum is disrupted and the superior patella is high-riding, the quadriceps should be pulled distally before inflating the tourniquet.\(^18\)

**Approach**

- Longitudinal or transverse incisions may be made.
- We use a longitudinal approach to facilitate exposure and allow extension to the tibial tubercle for wire augmentation when needed. A longitudinal approach may be better tolerated for future reconstructive surgeries and may therefore be beneficial in elderly patients or patients with preexisting osteoarthritis.
- A transverse approach follows the skin lines and may be preferable cosmetically. A transverse approach minimizes risk of injury to the infrapatellar branch of the saphenous nerve.
- Dissection is carried through the patellar bursa to expose the fracture site. Hematoma is often encountered upon opening bursa. Hematoma is cleared from the fracture site with copious irrigation and small curettes. The fracture line is followed to the retinacular tissue; the surgeon identifies the superior and inferior leaves of retinaculum and tags them for later repair.

---

**FIG 2 • (continued) B,C. Bipartite patella. Note the classic superolateral position of this multipartite patella and the sclerotic margins.**

---
TENSION BAND WIRING

- Tension band wiring can be used to stabilize transverse fracture patterns. More complex fracture patterns can use a tension band construct if the fracture can be converted to a transverse pattern by fixation of smaller comminuted pieces with screws or Kirschner wires. Tension band constructs may also be used for more distal pole fractures, with Kirschner wires placed more closely together to capture the fragment.

- Two 1.6- to 2.0-mm Kirschner wires will span the fracture in parallel (TECH FIG 1A). They can be introduced through the fracture site into the proximal fragment in a retrograde fashion or into the distal fragment in an antegrade fashion.

  - The Kirschner wire is delivered until flush with the fracture line, and the fracture reduction is obtained and held with patellar reduction clamps or Weber clamps.

  - Fracture reduction is checked by palpating the articular surface with a Freer elevator (or by finger palpation if the rent in the retinaculum allows). When encountered, small articular fragments without attached subchondral bone may be discarded. Depressed articular fragments are gently reduced by a Freer elevator.

  - Once the fracture is sufficiently reduced, the Kirschner wire is delivered through the opposite fracture fragment.

  - A lateral fluoroscopic view may help to ensure appropriate fracture reduction and Kirschner wire placement.

- Ideally, the Kirschner wires will be about 5 mm below the anterior surface of the patella. The Kirschner wire should be clipped to leave roughly 1 cm of prominence below the inferior pole of the patella.

- A 1.0-mm-thick cerclage wire is passed just deep to the Kirschner wires, abutting the superior pole of the patella. Care must be taken to leave little to no intervening soft tissue between the superior patella and the tension band.

- A 16-gauge angiocath may be passed through the quadriceps mechanism and the wire advanced through the catheter to aid in placement of the wire (TECH FIG 1B).

  - The cerclage wire is passed distally in a similar fashion, ensuring the wire abuts the distal pole of the patella.

  - The wire is looped around the anterior aspect of the patella.

  - Alternatively, the wire may be crisscrossed in a figure 8 pattern.

  - Prior to tensioning, the surgeon verifies that the Kirschner wires capture the cerclage wire.

  - To ensure even tensioning, a two-loop tensioning technique is used. A twist is made in the cerclage wire on the opposite side of the two free ends of the wire. The free ends are gently twisted. These two loops are sequentially tightened with a large needle driver (TECH FIG 1C). The loop is lifted to tension the wire and then twisted.

---

TECH FIG 1 • Tension band fixation. A. Fracture reduction is maintained with a Weber clamp while Kirschner wires are passed. B. A large angiocath is used for ease of wire placement deep to Kirschner wires and beneath the quadriceps tendon. (continued)
As advocated by Carpenter et al, cannulated screws may be used in place of Kirschner wires in a tension band construct for transverse fracture patterns (TECH FIG 2A–C). This construct has shown to be superior biomechanically to the Kirschner wire tension band construct, resisting larger forces and resulting in less fracture gaping with loads.\(^5\)

Wires are sequentially tensioned until appropriate compression is visualized and palpated at the fracture site.
- The ends of the twists are clipped, bent over, and tamped into bone to minimize prominence.
- The superior portion of the Kirschner wire is bent and then cut, leaving a hook to capture the cerclage wire. The Kirschner wire is rotated and tamped into the superior pole of the patella. The inferior tip of the wire is cut to avoid excessive length within the patella tendon while leaving enough wire to maintain position of the cerclage wire (TECH FIG 1D).

Retinacular defects are repaired with absorbable braided suture, a critical step in restoring the extensor mechanism.
- The tourniquet is deflated and hemostasis obtained. A suction drain is placed as needed and the wound is closed with buried absorbable sutures followed by simple nylon sutures.
- A well-padded sterile dressing is applied with padding over the leg from the malleoli to the proximal thigh. A knee immobilizer is placed.

MODIFIED TENSION BAND WITH CANNULATED SCREWS

Reduction is obtained as described above, with the guide-wires for the 4.0- or 4.5-mm partially threaded cannulated screws used in place of Kirschner wires.
- Screws are placed over the guidewires using a lag technique and are left short of the distal cortex. A lateral fluoroscopic view is helpful in verifying screw placement.
INTERFRAGMENTARY SCREWS WITHOUT TENSION BANDING

- Although occasionally used with tension band constructs to convert complex fracture patterns into transverse patterns, screw fixation can also be used alone (TECH FIG 3). This construct is particularly suited for simple fracture patterns with articular displacement and an intact retinaculum.

- Lag screw fixation is often the method of choice for longitudinal fractures requiring operative management. Lag screw fixation for transverse fractures is also a suitable option, especially in patients with good bone stock. Multiple biomechanical studies have shown two cortical lag screws to be nearly as strong as or stronger than tension band alone.

- After obtaining reduction with pointed forceps, 3.5-mm or 4.5-mm cortical screws are used in lagging fashion across fracture sites.

- Closure and retinacular repair are undertaken as described above.
PARTIAL PATELLECTOMY

- Partial patellectomy is often advocated for comminuted fractures of the patella when a portion of the patella is significantly comminuted. Often this comminution occurs at the patellar pole, with inferior pole fractures being more common.
- After a standard approach as above, the comminuted fracture fragments are identified. If restoration of the comminuted site is not possible, the comminuted fragments are removed. Preservation of as large a portion of the articular surface as possible is critical.
- Multiple longitudinal drill holes are made through the remaining portion of the patella such that the entrance point of the tendinous attachment will be as near to the articular surface as possible. The amount of holes is equal to the number of sutures plus one.
- Nonabsorbable suture with a tendon grasping stitch is used to attach the adjacent tendon (usually patellar tendon) through the drill holes. Suture is tied with the knee in neutral or hyperextension (TECH FIG 4).
- Repair may be augmented by a tension band construct through the patella and tibial tubercle or by Mersilene tape, although we do not commonly perform such augmentation.
- Retinaculum is repaired with absorbable suture.
- Closure is as described above.


TECH FIG 4 • Partial patellectomy. A. Comminuted distal pole of patella fracture, an ideal fracture pattern for the construct. B. Suture placement prior to tensioning and tying. Two sutures and three drill holes are used.
PEARLS AND PITFALLS

The surgeon should ensure that tension band wires have little to no intervening tissue between the wire and the patella when passing under the Kirschner wires at the proximal and distal poles. ▪ This common error can cause fracture site distraction. When the fracture is loaded, the fragments can displace on the Kirschner wire until the tension band becomes taut.5

Cannulated screws must be left short of the far cortex if used with a tension band construct. In contrast, when using screw in a lagging fashion, bicortical purchase affords a better construct. ▪ Protrusion of the screw past the distal cortex creates a stress riser in the tension band.5 Additionally, the tension band does contact the screw tip rather than the bone, lessening compression forces on the bone through the tension construct.

There is a delicate balance between early range of motion to promote better long-term range of motion and protection of fixation to avoid loss of reduction. ▪ Passive range-of-motion exercises ought to begin as soon as surgeon comfort allows. Intraoperative knee range of motion resulting in gaping at the fracture site and poor intraoperative bone stock may lead to the decision for delayed passive range of motion.

When possible, complex fracture patterns are converted into simpler or transverse patterns. ▪ Fixation of longitudinal comminuted fragments with interfragmentary screws often allows the fracture pattern to be treated as a simpler transverse pattern.

POSTOPERATIVE CARE

▪ Passive knee range of motion and gentle active range of motion begins once soft tissue healing is ensured. We use an abundance of padding postoperatively underneath any bracing until postoperative soft tissue swelling resolves.

▪ Patients are allowed to bear partial weight with crutches and the knee fully extended in a knee immobilizer or hinged knee brace immediately postoperatively.

▪ We prefer 2 weeks with the knee in extension, 2 weeks of knee flexion from 0 to 60 degrees, and 2 weeks of full knee flexion in a hinged knee brace.

▪ Full weight bearing out of a brace is allowed once signs of fracture healing are evident on postoperative imaging, and not before 6 weeks.

▪ Although straight leg raising and quadriceps sets with the knee extended may begin immediately postoperatively, quadriceps strengthening with resistance is held until signs of fracture healing appear.

▪ For fracture fixation deemed unstable during intraoperative range of motion, initiation of knee motion may be held until fracture healing is evident.

▪ Rehabilitation must keep in mind the compressive forces on the patella during knee flexion. Compressive forces are greater than three times body weight during stair climbing and reach nearly eight times body weight while squatting.10

OUTCOMES

▪ Outcomes depend on maintenance of fracture reduction.

▪ In a review of 320 patients with patellar fractures (212 treated nonoperatively) with a mean follow-up of 8.9 years, Bostrum3 reported that 24% of patients did not consider themselves fully recovered; moderate or severe pain persisted in 31% of patients. The range of mobility was normal in 90% of patients, with the majority of restriction of motion in elderly patients. Ninety-one percent of patients had fracture union.

▪ Functional outcomes after long-term follow-up of tension band wiring have been reported to be the same as age-matched standards.13

COMPLICATIONS

▪ The historical complication rate of operative intervention for patellar fractures varies in the literature. Although a recent study on perioperative complications reported a rate of 25%,16 historical rates are much lower.4

▪ Infection rates are low and can be minimized by the use of perioperative antibiotics and careful soft tissue handling. Few postoperative infections are deep infections involving the joint.3,16

▪ Patients often note palpable hardware, given the thin overlying tissue. Although we do not routinely remove hardware, patients in whom the hardware becomes symptomatic may have hardware removal after fracture consolidation. Hardware removal rates have varied in the literature from 10% to 60% with tension band constructs.15,16

▪ Smith et al16 reported fracture displacement of more than 2 mm in 22% of patients treated with tension band wiring. All patients with significant displacement requiring reoperation were weight bearing without bracing between 3 and 5 weeks. In the remainder of cases with loss of fixation, the most common cause was technical error.

▪ Nonunion with tension band techniques is a rare complication, occurring in less than 1% of fractures fixed in this manner.5

▪ Decreased knee range of motion is another possible complication. Flexion is more commonly lost than extension. At times this loss of motion can be due to intra-articular adhesions and can benefit from arthroscopic release.

▪ As with many intra-articular fractures, osteoarthritis develops in the injured extremity at a rate greater than that of the uninjured extremity. Reported rates of osteoarthritis vary greatly.

REFERENCES

DEFINITION
- Bicondylar tibial plateau fractures involve both medial and lateral plateaus.
- Schatzker type 5 fractures (FIG 1A,B) involve both condyles without complete dissociation from the shaft. Thus, a portion of the joint is still attached to the shaft. They are usually amenable to medial and lateral buttress plate fixation.
- Schatzker type 6 fractures (FIG 1C,D) involve both condyles with complete dissociation of the articular segment from the shaft.
- Lateral fractures with associated posterior medial fragments should be distinguished from other bicondylar types, as they often require posteromedial fixation independent from lateral fixation and may be representative of fracture-dislocation (see Fig 3).

ANATOMY
- In the loaded knee, the medial plateau bears about 60% to 75% of the load.7,8
- The medial plateau is larger than the lateral plateau (FIG 2).
  - The medial plateau is concave, the lateral plateau convex.
  - Stronger, denser subchondral bone is found on the medial side due to increased load.
- The lateral plateau is higher than the medial plateau. The medial proximal tibial angle is 87 degrees relative to the anatomic axis of the tibia (range 85 to 90 degrees).6
  - The proximal posterior tibial angle is 81 degrees relative to anatomic axis of the tibia (range 77 to 84 degrees).6
  - The iliotibial band inserts on the tubercle of Gerdy.
  - The anterior cruciate ligament attaches adjacent and medial to the tibial eminence. It acts to resist anterior translation of the tibia relative to the femur. Recognizing a fracture fragment that contains this attachment can be important to re-establish stability to the knee.
  - The posterior cruciate ligament attaches about 1 cm below the joint line on the posterior ridge of the tibial plateau and a few millimeters lateral to the tibial tubercle.
    - The function of the posterior cruciate is to resist posterior tibial translation of the tibia relative to the femur. This acts as the central pivot of the knee.
  - The medial collateral ligament resists valgus force.
    - The medial collateral ligament originates on the medial femoral epicondyle and inserts on the medial tibial condyle.
  - The lateral collateral ligament resists varus force and external rotation of the femur.
    - The lateral collateral ligament originates on the lateral epicondyle of the femur and attaches to the fibular head.
  - The menisci, medial and lateral, are crescent-shaped fibrocartilaginous structures that act to dissipate the load on the tibial plateau, deepen the articular surfaces of the plateau, and help lubricate and provide nutrition to the knee.
    - The medial meniscus is more C-shaped and the lateral meniscus is more circular in shape.
- The lateral meniscus is more mobile than the medial meniscus.

PATHOGENESIS
- Bicondylar tibial plateau fractures are typically caused by a high-energy mechanism with associated injury to surrounding soft tissue.
- The mechanism responsible for injury is primarily an axial force, which may be associated with a varus or valgus moment.
  - With a valgus force, the lateral femoral condyle is driven wedge-like into the underlying lateral tibial plateau.5
  - The size of the fracture fragments depends on multiple factors, including localization of the impact, the magnitude of the axial force producing the fracture, the density of the bone, and the position of the knee joint at the moment of trauma.
  - Ligament injuries have been found to occur in 20% to 77% of tibial plateau fractures.3,4
  - Repair of ligament injuries at the time of fracture fixation is controversial. Some advocate ligament repair at the time of fracture fixation, while others feel that if the fracture can be reduced there is no need for early ligament repair.

NATURAL HISTORY
- Joint incongruity can predispose to arthrosis.
- Inadequate fracture stability can lead to varus-valgus collapse.
- Joint stiffness
- Joint instability can result from associated ligament injury.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Generally, a bicondylar injury pattern is caused by a high-energy mechanism. It may also be seen with a low-energy mechanism, such as a fall from standing height or in an older patient with osteoporosis.
  - The patient will complain of a painful swollen knee and will have difficulty bearing weight on the extremity. Hemarthrosis will be present if the capsule has not been disrupted.
  - The patient history should include details of the injury mechanism, preinjury ambulatory status, and any previous injury and disability.
  - A complete examination is required to rule out other injuries. The vascular status of the limb proximal and distal to the injury requires evaluation.
  - If there is an abnormality on palpation pulses, a vascular consult may be needed.
  - The ankle–brachial index of the extremity, along with ultrasound examination of the leg, can be helpful in fully evaluating the possibility of vascular injury, which occurs in about 2% of these fractures.1,9 The patient is evaluated for compartment instability, and the vascular status of the limb proximal and distal to the injury is assessed.
**FIG 1** • **A,B.** AP and lateral views of a Schatzker type 5 bicondylar tibial plateau fracture. **C,D.** AP and lateral views of a Schatzker type 6 bicondylar tibial plateau fracture.

**FIG 2** • **A, B.** AP (A) and axial (B) views of the tibia showing the relevant anatomy.
syndrome by palpating the lower extremity compartment for swelling and passively extending the muscles in the lower extremity, noting any increase in pain.

- The strength of dorsiflexion and eversion will help evaluate the peroneal nerve. It is important to examine and document peroneal nerve function before surgery because of the possibility of a stretch injury. Motor and sensory function of the nerve proximal and distal to the injury should be assessed.
- A thorough ligament examination of the knee is needed, although this can be difficult preoperatively owing to difficulty differentiating ligamentous from bony instability.
- Examination of the knee ligaments should therefore take place after operative stabilization and before the patient is awake in the operating room.
- Soft tissues need careful inspection before definitive surgical intervention can take place. The surgeon should note where surgical incisions will be located when evaluating the soft tissue.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Anteroposterior (AP) and lateral radiographs of the knee and tibia, and oblique views of the knee (FIG 3A–C).

  - CT scan with sagittal and coronal reconstruction is helpful to define complex fracture patterns and to plan surgical tactics (FIG 3D,E).
  - MRI is useful in evaluating ligament and meniscal injury around the knee.

**DIFFERENTIAL DIAGNOSIS**

- Unicondylar tibia fracture
- Patella fracture
- Ligament injury at the knee
- Proximal tibial shaft fracture
- Extensor mechanism disruption

**NONOPERATIVE MANAGEMENT**

- A fracture brace, a long-leg cast, or both may be used to treat low-energy nondisplaced fractures.
  - These require close observation to ensure progressive malalignment (particularly varus) does not occur.
- A long-leg cast, a fracture brace, or both can be used in treating low-energy, minimally displaced fracture patterns. It may also be used if patient factors (eg, comorbidities, functional status) would make operative intervention inappropriate.
SURGICAL MANAGEMENT

Preoperative Planning

- The surgeon should thoroughly review all preoperative imaging studies.
- A surgical approach is planned that affords adequate exposure for reduction and stabilization of the fracture.
  - Single lateral, dual incisions and occasionally a posterior approach are most common.
  - Single anterior incisions with stripping should be avoided if medial and lateral exposure is required.
- A tactic for fracture reduction is planned based on preoperative imaging.
  - Consideration should be given as to whether a femoral distractor will be useful.
  - In bicondylar fracture patterns, joint distraction is marginal with use of a femoral distractor, as distraction takes place through the fracture rather than across the joint.
- The surgeon should decide which part of the bicondylar pattern to stabilize first. By approaching the posteromedial side first and obtaining the reduction on the medial side before approaching the lateral tibial plateau, the surgeon may help prevent stabilizing the knee in varus. If the medial side can be reduced percutaneously and the fracture pattern is amenable to lateral locked plating only, the surgeon may be able to avoid dual incisions. These decisions can be made in preoperative planning.
- Patient positioning should be planned to ease surgical exposure. It is usually supine, except when a posterior or posteromedial approach is required. If a posterior approach is required the patient should be positioned prone.
- Implant selection: single lateral locking plate or lateral locking and posteromedial plate.
- The surgeon should consider whether a nonsterile or sterile tourniquet is required.
- Imaging: The C-arm should be placed on the contralateral side of the patient for the lateral exposure. If the surgeon will start with the posteromedial exposure, the C-arm is on the ipsilateral side of the patient. The monitor is positioned for comfortable viewing, usually toward the head of the bed.
- The surgeon should consider a staged protocol with provisional spanning external fixation for high-energy bicondylar injuries with significant soft tissue swelling. Open reduction and internal fixation can be done when swelling has subsided.

FIG 4 • Supine positioning for fixation of bicondylar tibial plateau fractures should provide for unhindered AP and lateral fluoroscopic radiographs and both medial and lateral approaches.

Positioning

- The patient is placed supine with the contralateral limb secured to a radiolucent or fracture table, with a bump under the ipsilateral hip (removed for medial approach) (FIG 4).
- Nonsterile high thigh tourniquet
- C-arm on contralateral side with the monitor near the head of the bed

Approach

- A midline approach with medial and lateral exposure has been associated with high complication rates and should be avoided.
  - When medial and lateral exposure is required, an anterolateral exposure with the addition of a posteromedial approach is therefore preferred.
- An anterolateral approach is the standard approach for most tibial bicondylar fractures. It allows for direct exposure of lateral meniscus and intra-articular fractures and for placement of lateral plates.
  - Metaphyseal fracture components are best treated indirectly, especially when comminuted, to maximally preserve biologic potential for healing.
  - The medial condyle can be stabilized with lateral locking plates, provided multiple locking screws engage the medial fragment.
- Bicondylar fractures with displaced medial articular involvement require more direct reduction and stabilization, usually via a posteromedial exposure.
- Soft tissue dissection should be limited with a dual incision technique.
- A minority of fractures, those with a bicondylar posterior shearing injury pattern, may benefit from a direct posterior exposure.

POSTEROMEDIAL APPROACH

- The incision is started 1 cm posterior to the posteromedial edge of the tibial metaphysis (TECH FIG 1A).
  - The saphenous vein and nerve should be carefully avoided during the superficial dissection.
  - Deep dissection continues to expose the pes anserine tendons (TECH FIG 1B), which can be mobilized anteriorly and posteriorly.
  - If more proximal extension of the incision is needed, the surgeon can proceed posterior and parallel to the pes anserine tendons.
- The medial gastrocnemius is easily dissected from the posteromedial tibia.
- Subperiosteal dissection should be limited to the fracture margins to aid in confirmation of the reduction.
- The plate should be slightly undercontoured to help buttress the posteromedial fragment (TECH FIG 1C,D).
LATERAL EXPOSURE

- The surgeon identifies and marks landmarks (tubercle of Gerdy, tibial crest, patella, fibular head).
- The lower extremity is exsanguinated and the tourniquet inflated to about 300 mm Hg.
  - Tourniquet use is optional.
- The skin incision is marked. The incision should begin distally about 2 cm lateral to the tibial crest, curving over the tubercle of Gerdy, then proceeding superiorly over the femoral epicondyle (TECH FIG 2A).
- The skin incision is marked. The incision should begin distally about 2 cm lateral to the tibial crest, curving over the tubercle of Gerdy, then proceeding superiorly over the femoral epicondyle (TECH FIG 2B).
- The skin is incised along the marked incision. The surgeon sharply dissects to fascia without detaching subcutaneous fat from the fascia (TECH FIG 2C).
- The iliobial band is split longitudinally parallel to the skin incision without disrupting the capsule (TECH FIG 2D).
- The iliobial band is elevated from the tubercle of Gerdy anteriorly and posteriorly.
- If required for lateral articular reduction, a lateral submensical arthrotomy is made by incising the capsule horizontally, including the coronary ligament (TECH FIG 2D).
- The meniscus is elevated and inspected for tears.
- The surgeon directly visualizes intra-articular fracture fragments laterally and obtains reduction.
- The metaphyseal fractures should be indirectly reduced with fluoroscopic guidance.
- Preliminary reduction may be held with Kirschner wire fixation or a large periarticular reduction forcep.
- Simultaneous exposure of the medial side may be required if medial reduction is not obtained by indirect methods.
**FIXATION**

- A laterally applied plate is useful to support lateral split fragments and to support depressed articular fragments (via the raft effect of multiple proximal screws placed subchondrally).
- Support of the medial side can be provided via a lateral plate when the medial fragment is of sufficient size and location that multiple screws from the lateral plate engage the medial fragment (TECH FIG 3).
- Locking screws provide superior resistance to medial subsidence and are preferred to nonlocking screws for this application.

---

**TECH FIG 2**

- A. Landmarks (patella, tibial tubercle, tubercle of Gerdy, and fibula) for the anterior lateral approach.  
- B. Anterior lateral approach superficial dissection.  
- C. Deep lateral exposure with iliotibial band incised parallel to its fibers centered over tubercle of Gerdy.  
- D. Submensical arthrotomy provides direct access to the lateral articular surface.

**TECH FIG 3**

- Bicondylar tibial plateau fracture. Preoperative AP (A) and lateral (B) radiographs and CT scan (C). 
(continued)
An S-shaped incision starts midline superiorly and extends medial distally. The incision is centered on the popliteal fossa, with the transverse component made at the joint line (TECH FIG 4A,B). The surgeon identifies and protects the common peroneal nerve, popliteal artery and vein, tibial nerve, and medial sural cutaneous nerve (TECH FIG 4C).

Full-thickness fasciocutaneous flaps are raised.

The lateral head of the gastrocnemius is dissected bluntly and its blood supply protected distally. The tendon is divided proximally, leaving a stump for repair.

The lateral gastrocnemius is retracted medially (TECH FIG 4D). The popliteus and soleus origin are elevated off the posteromedial aspect of the proximal tibia.

The articular surface is elevated through the fracture site and the reduction assessed with fluoroscopy.

A 3.5-mm plate is contoured to buttress the fragments. Lag screw technique is used to compress the fragments (TECH FIG 4E,F).

When compression is required between the medial and lateral fragment, nonlocked lag screws should be used before placing locked screws across the fracture line.

When the medial fragment is of such size and location that multiple locked screws from a lateral plate cannot engage this fragment, separate medial fixation is required.

This is most commonly the case with posterior medial fragments that are amenable to separate posteromedial buttress plate fixation.

Subchondral defects should be grafted with allograft, autograft, or bone substitute.

It may be helpful in some cases to use allograft bone croutons to help reduce depressed fracture fragments by impacting the graft through a cortical window inferior to the articular surface.

A tamp is used to impact the graft along the inferior surface of the depressed fragment and elevate the fragment to its proper position.

Once the articular surface has been reduced and final fixation achieved, then the meniscus may be repaired if needed.

Most of the meniscal injuries are peripheral rim tears and may be repaired in a horizontal mattress fashion to the capsule.

Layered closure of the lateral wound is done with a lateral drain.

Subchondral defects should be grafted with allograft, autograft, or bone substitute.

It may be helpful in some cases to use allograft bone croutons to help reduce depressed fracture fragments by impacting the graft through a cortical window inferior to the articular surface.

A tamp is used to impact the graft along the inferior surface of the depressed fragment and elevate the fragment to its proper position.

Once the articular surface has been reduced and final fixation achieved, then the meniscus may be repaired if needed.

Most of the meniscal injuries are peripheral rim tears and may be repaired in a horizontal mattress fashion to the capsule.

Layered closure of the lateral wound is done with a lateral drain.

POSTERIOR APPROACH (POSTERIOR SHEARING FRACTURE)

Posterior Approach (Posterior Shearing Fracture)

POSTERIOR APPROACH (POSTERIOR SHEARING FRACTURE)

POSTERIOR APPROACH (POSTERIOR SHEARING FRACTURE)

POSTERIOR APPROACH (POSTERIOR SHEARING FRACTURE)
PEARLS AND PITFALLS

Do not rely on a lateral locked plate to prevent varus collapse of bicondylar fractures with posteromedial articular components.

Posteromedial intra-articular tibial fragments need buttress plates to prevent varus collapse even with newer locking plate technology.

When the medial fragment is of such size and location that multiple locked screws from a lateral plate cannot engage this fragment, separate medial fixation is required. This is most commonly the case with posterior medial fragments that are amenable to separate posteromedial buttress plate fixation.

Failure to recognize meniscal injury and repair.

- A laterally applied plate is useful to support lateral split fragments (via buttress effect) and to support depressed articular fragments (via a raft effect of multiple proximal screws placed subchondrally).

- Support of the medial side can be provided via a lateral plate when the medial fragment is of such a size and location that multiple screws from the lateral plate engage the medial fragment. Locking screws provide superior resistance to medial subsidence and are preferred to nonlocking screws for this application.

- When compression is required between the medial and lateral fragments, nonlocked screws should be used before placing locked screws across the fracture site.
POSTOPERATIVE CARE

- Use of a continuous passive motion (CPM) device should be started immediately after surgery at about 0 to 40 degrees. Flexion is advanced 5 to 10 degrees during each of three 2-hour sessions per day, with the goal being 0 to 90 degrees before hospital discharge.
- Deep vein thrombosis prophylaxis is considered with low-molecular-weight heparin, aspirin, or Coumadin and a sequential compression device on the contralateral limb.
- Initial home physical therapy concentrates on restoring range of motion with closed-chain active range-of-motion exercises.
- Toe-touch weight bearing is permitted for 6 to 12 weeks depending on radiographic and clinical healing response.
- Weight bearing is advanced and strengthening exercises are initiated upon fracture healing, usually about 8 to 12 weeks postoperatively.

OUTCOMES

- Satisfactory articular reduction (step-off or gap of 2 mm or less) in 62.1% of cases
  - 91.2% had satisfactory coronal plane alignment
  - 72.1% had satisfactory sagittal plane alignment
- According to Barei et al., bicondylar tibial plateau fractures have a significant negative effect on leisure activities, employment, and general mobilization. Significant residual dysfunction was observed out to 51 months postoperatively when compared with the general population.
- Decreased arc of motion compared to the uninvolved extremity

COMPLICATIONS

- Compartment syndrome
- Infection (7% to 8.4%)
- Superficial and deep wound complications
- Residual knee joint instability
- Removal of hardware due to local discomfort
- Deep vein thrombosis
- Arthrosis
- Loss of motion

REFERENCES

Tibial plateau fractures are intra-articular fractures that may result in a malalignment of the articular surface and bear the risk of subsequent arthritis.

The lateral plateau is smaller and convex, whereas the medial plateau is larger and slightly concave. Both plateaus are covered by a meniscus, which serves as a shock absorber and improves the congruency of the femorotibial joint. The lateral plateau sits slightly higher than the medial joint surface, forming an angle of 3 degrees of varus with respect of the tibial shaft. This is helpful in identifying the lateral plateau on the lateral radiograph.

The anatomy of the tibial plateau leads to an eccentric load distribution in which the lateral plateau bears 40% of the knee’s load. This asymmetric weight bearing results in increased medial subchondral bone formation and a stronger, denser medial plateau.

The intermediate, nonarticular intercondylar eminence serves as the tibial attachment of the anterior and posterior cruciate ligaments.

The stability of the knee joint is based on the cruciate ligaments, the collateral ligaments, and the capsule.

The lateral plateau is smaller and convex, whereas the medial plateau is larger and slightly concave. Both plateaus are covered by a meniscus, which serves as a shock absorber and improves the congruency of the femorotibial joint. The lateral plateau sits slightly higher than the medial joint surface, forming an angle of 3 degrees of varus with respect of the tibial shaft. This is helpful in identifying the lateral plateau on the lateral radiograph.

The anatomy of the tibial plateau leads to an eccentric load distribution in which the lateral plateau bears 40% of the knee’s load. This asymmetric weight bearing results in increased medial subchondral bone formation and a stronger, denser medial plateau.

The intermediate, nonarticular intercondylar eminence serves as the tibial attachment of the anterior and posterior cruciate ligaments.

The stability of the knee joint is based on the cruciate ligaments, the collateral ligaments, and the capsule.

The lateral plateau sits slightly higher than the medial plateau and may be associated with complex tibial plateau fractures.

The most frequent mechanism causing a lateral plateau fracture is a direct trauma to the proximal tibia and knee joint. This induces a valgus force and drives the lateral femoral condyle into the soft lateral tibial plateau.

Indirect axial forces often develop in high-energy injuries and may be associated with complex tibial plateau fractures.

Twisting injuries account for only 5% to 10% of tibial plateau fractures and are most commonly sports injuries (eg, skiing).

DEFINITION

■ Tibial plateau fractures are intra-articular fractures that may result in a malalignment of the articular surface and bear the risk of subsequent arthritis.

ANATOMY

■ The tibial plateau consists of three osseous structures: the lateral plateau, the medial plateau, and the intercondylar eminence.

■ The lateral plateau is smaller and convex, whereas the medial plateau is larger and slightly concave. Both plateaus are covered by a meniscus, which serves as a shock absorber and improves the congruency of the femorotibial joint.

■ The lateral plateau sits slightly higher than the medial joint surface, forming an angle of 3 degrees of varus with respect of the tibial shaft. This is helpful in identifying the lateral plateau on the lateral radiograph.

■ The anatomy of the tibial plateau leads to an eccentric load distribution in which the lateral plateau bears 40% of the knee’s load. This asymmetric weight bearing results in increased medial subchondral bone formation and a stronger, denser medial plateau.

■ The intermediate, nonarticular intercondylar eminence serves as the tibial attachment of the anterior and posterior cruciate ligaments.

■ The stability of the knee joint is based on the cruciate ligaments, the collateral ligaments, and the capsule.

■ The tibial tuberosity and the tubercle of Gerdy are bony prominences located in the subcondylar region for insertion of the patellar tendon and the iliotibial tract, respectively. These landmarks are important for planning surgical incisions.

PATHOGENESIS

■ Several anatomic factors have been thought to contribute to the higher incidence of lateral as opposed to medial plateau fractures.

■ The relative softness of the subchondral bone of the lateral plateau, the valgus axis of the lower extremity, and the susceptibility of the leg to a medially directed force all lead to a prevalence of lateral plateau fractures in low-energy injuries.

■ Tibial plateau fractures are due to either direct trauma to the proximal tibia and knee joint or to indirect axial forces.

■ The most frequent mechanism causing a lateral plateau fracture is a direct trauma to the proximal tibia and knee joint. This induces a valgus force and drives the lateral femoral condyle into the soft lateral tibial plateau.

■ Indirect axial forces often develop in high-energy injuries and may be associated with complex tibial plateau fractures.

■ Twisting injuries account for only 5% to 10% of tibial plateau fractures and are most commonly sports injuries (eg, skiing).

■ Split or wedge fractures occur in younger patients, whereas depression fractures occur more frequently in older patients with osteoporotic bone, which is less able to withstand compression.

NATURAL HISTORY

■ The natural history of lateral tibial plateau fractures depends on the degree of articular depression and knee stability. Knee instability may result from the fracture itself but may also result from accompanying injuries like meniscal injuries or rupture of cruciate or collateral ligaments.

■ For nondisplaced or minimally displaced fractures, the prognosis is favorable, but displaced fractures, especially in combination with knee instability, tend to result in early posttraumatic arthritis.

■ Meniscal injuries have been reported in up to 50% of tibial plateau fractures. Meniscal injuries are a major determinant of prognosis because meniscal integrity is important for joint stability and may compensate for articular incongruity.

PATIENT HISTORY AND PHYSICAL FINDINGS

■ The physical examination should always include a thorough assessment of the soft tissue envelope.

■ The marginal soft tissue envelope of the proximal tibia predisposes to open fractures and development of tissue necrosis. It is important to assess severe soft tissue injury because it may not allow primary plating of the fracture, requiring external fixation.

■ A compartment syndrome may result from continuous hemorrhage through the metaphysis into the area of the tibial shaft.

■ Clinical findings indicating a manifest compartment syndrome include pain, paresthesia, paresis, pain with stretch, intact pulses, and pink skin coloring.

■ Such findings require immediate fasciotomy.

■ An imminent compartment syndrome requires repeated or continuous compartment pressure monitoring.

■ A pressure difference between the diastolic pressure and the compartment pressure of less than 30 mm Hg is considered to be a manifest compartment syndrome, which requires fasciotomy.

■ The neurovascular status of the extremity must be carefully evaluated, although concomitant injuries of neurovascular structures are rare in proximal tibia fractures.

■ Palpation of peripheral pulses

■ Doppler ultrasound

■ An ankle-brachial index less than 0.9 indicates that vascular injury is very likely.

■ Impaired sensorimotor status may indicate compartment syndrome; impaired dorsal flexion may indicate direct peripheral nerve injury.

■ Examination of knee stability is difficult because of pain, so it should be tested under anesthesia. Assessment of knee stability may be difficult on initial examination because of continuous compartment pressure monitoring.
intracapsular hematoma and pain. Varus and valgus stress radiographs of the knee in near-full extension can be performed with sedation or under general anesthesia. Widening of the femoral–tibial articulation of more than 10 degrees indicates ligamentous insufficiency.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Plain anteroposterior (AP) and lateral radiographs should be centered on the knee, with the AP view angled 10 degrees in a cranio-caudal direction to approximate the posterior slope of the plateau.
- The standard tool in analyzing tibial plateau fractures is the three-dimensional CT scan, because the number and degree of isolated fractures are often underestimated on plain radiographs.\(^{13}\)
- Although MRI evaluates both osseous and soft tissue injuries, it has not yet become a standard tool in analyzing tibial plateau fractures. It may be helpful in identifying meniscal and ligamentous injuries.
- In selected cases (eg, no CT diagnostics available), stress radiographs may be helpful in making decisions about surgical management.

**DIFFERENTIAL DIAGNOSIS**
- Ligamentous injuries of the knee
- Knee dislocation
- Meniscal injury
- Bone bruise
- Compartment syndrome

**NONOPERATIVE MANAGEMENT**
- For nondisplaced or minimally displaced fractures, the indications for surgical treatment are controversial and vary widely in the literature. The range of acceptability for articular depression varies from 2 mm to 1 cm.\(^{3,5,6,17,19,22}\)
- Nondisplaced or minimally displaced tibial plateau fractures with stability of the knee joint can be managed nonoperatively, provided that the patient is compliant.
- Partial weight bearing in a hinged fracture brace for 8 to 12 weeks with regular radiographic controls is recommended.
- Isometric quadriiceps exercises and progressive passive, active-assisted, and active range-of-knee motion exercises are recommended to avoid substantial muscle atrophy.
- Failure to maintain reduction with nonoperative management is an indication for surgical fracture stabilization. Therefore, frequent surveillance radiographs are required for the management of these patients.

**SURGICAL MANAGEMENT**
- The primary management of tibial plateau fractures is usually dictated by the soft tissue injury and by the fracture type.
- Absolute indications for surgery are displaced fractures, open fractures, fractures with vascular or neurologic lesions, fractures with compartment syndrome, and fractures with valgus instability.
- The goals in the surgical treatment of tibial plateau fractures are restoration of articular surface, axis, meniscal integrity, and stability to avoid or postpone posttraumatic arthritis. Fracture stability allows early rehabilitation and supports long-term full recovery.
- The degree of soft tissue injury and the general condition of the patient are important factors in surgical decision making.
- If there is severe soft tissue damage, an open fracture, or a polytraumatized patient, a temporary external fixator is applied. Definitive fracture stabilization with open reduction and internal fixation is delayed until soft tissue damage or the patient’s critical condition has been resolved.

**Preoperative Planning**
- Review of radiographs, CT, MRI
- Surgical approach and placement of implants
- Depression fractures with continuity of the lateral cortex require only screw osteosynthesis.
- Whether a cortical window is required depends on the degree and location of impaction. Condylar widening is a good radiologic sign for the requirement of articular elevation with a pestle via a cortical window.
- Meniscal and ligamentous injuries require open joint or arthroscopic surgery.
- The surgeon should consider the need of bone grafting (iliac crest bone graft, bone graft substitute) when severe depression of the plateau is obvious.
- For surgical decision making, a separate classification of the fracture and degree of soft tissue injury is important.
- Open fractures are classified according to Gustilo et al.\(^{4}\)
- The soft tissue injury is classified according to Tscherne and Oestern.\(^{21}\)
- The AO/OTA classification for proximal tibial fractures distinguishes between extra-articular, partial-articular, and complete-articular fractures, and further subdivides based on the level of comminution (Table 1).
- Schatzker’s classification distinguishes between lateral and medial plateau fractures (Table 2).
- In general, types I through III are low-energy injuries affecting the lateral plateau.
- Types IV through VI involve increasingly higher-energy injuries mostly affecting the medial plateau in combination with ligamentous injuries.\(^{19}\)

**Positioning**
- Supine position
- Bolster under knee to improve internal rotation: the knee should be slightly bent (about 30 degrees) to reduce tension of collateral ligaments (FIG 1)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO-41-A</td>
<td>Extra-articular fractures</td>
</tr>
<tr>
<td>AO-41-B</td>
<td>Partial intra-articular fractures</td>
</tr>
<tr>
<td>B1</td>
<td>Split fracture of the lateral plateau</td>
</tr>
<tr>
<td>B2</td>
<td>Depression fracture of the lateral plateau</td>
</tr>
<tr>
<td>B3</td>
<td>Split-depression fracture of the lateral plateau</td>
</tr>
<tr>
<td>AO-41-C</td>
<td>Complete articular fractures</td>
</tr>
<tr>
<td>C1</td>
<td>Simple bicondylar fracture with simple</td>
</tr>
<tr>
<td>C2</td>
<td>metaphyseal fracture</td>
</tr>
<tr>
<td>C3</td>
<td>Simple bicondylar fracture with comminuted</td>
</tr>
<tr>
<td></td>
<td>metaphyseal fracture</td>
</tr>
<tr>
<td></td>
<td>Comminuted articular and metaphyseal fracture</td>
</tr>
</tbody>
</table>
Table 2  Schatzker’s Classification

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Split fracture of the lateral tibial plateau</td>
</tr>
<tr>
<td>II</td>
<td>Split-depression fracture of the lateral tibial plateau</td>
</tr>
<tr>
<td>III</td>
<td>Pure central depression fracture of the lateral tibial plateau</td>
</tr>
<tr>
<td>IV</td>
<td>Split (type A) or depression (type B) fracture of the medial plateau</td>
</tr>
<tr>
<td>V</td>
<td>Bicondylar tibial plateau fracture</td>
</tr>
<tr>
<td>VI</td>
<td>Comminuted tibial plateau fracture with dissociation between the metaphysis and the diaphysis</td>
</tr>
</tbody>
</table>

- Tourniquet to minimize blood loss and to improve fracture visualization
- Radiolucent operating table to allow intraoperative use of fluoroscopy and image intensification
- Contralateral leg placed in leg carrier
- Ipsilateral iliac crest is prepared and draped if bone graft is needed.

**Approach**
- The surgical approach for lateral tibial plateau fractures demands good visualization of the lateral plateau, combined with preservation of all anatomic structures and minimal soft tissue and osseous devitalization. It can be summarized as:
  - Elevation of the meniscus
  - Reduction of the fracture
  - Temporary retention with Kirschner wire or small fragment lag screw
  - Final stabilization with lag screws, conventional plate, or angular stable plate
- The incision must be planned to avoid implant location directly underneath the skin incision. Important landmarks are the joint line, the tubercle of Gerdy, the tibial tubercle, the fibula head, and the lateral femoral epicondyle (FIG 2).
- The standard approach for lateral tibial plateau fractures is the anterolateral approach, which provides excellent exposure of the lateral plateau and allows good soft tissue coverage of the implant, especially after minimally invasive plate application.
- The posterolateral approach is indicated for fractures of the lateral posterior plateau.

**ANTEROLATERAL APPROACH**
- A straight or a hockey-stick incision (about 10 cm) with the knee in 30 degrees of flexion is made.
- The incision is extended down through the iliobial band proximally and the fascia of the anterior compartment distally.
- The tibialis anterior muscle is elevated off the proximal tibia to the level of the capsule and the coronary ligament is incised (TECH FIG 1).
- To expose the lateral tibial plateau, the lateral meniscus is raised with holding sutures after incision of the coronary ligament.
- The size of the fragment is crucial for the decision of whether soft tissue is stripped off. For small fragments not allowing compression, stripping the displaced fragment for buttress plating is indicated.
POSTEROLATERAL APPROACH
- A longitudinal incision is made along the proximal fibula (TECH FIG 2).
- The extensor muscles are mobilized from the tibial plateau.
- After exposure of the peroneus nerve, osteotomy of fibula head is performed.
- At the end of surgery the fibular head is refixed by tension band wiring or screw fixation.

REDUCTION
- Careful treatment of soft tissue and periosteum is mandatory.
- Reduction is aided by ligamentotaxis and careful manipulation. An external fixator or a distractor may be a helpful tool.
- Displaced fragments are reduced with reduction tools.
- Reduction is temporarily maintained with Kirschner wires or lag screws (TECH FIG 3).

REDUCTION OF IMPACTED SEGMENTS
- Impression fractures need to be elevated with a pestle, which may be inserted through a distal tibial bone window (TECH FIG 4).
- Elevation is achieved by carefully exerting punches on the pestle (eg, with a hammer) under fluoroscopy until the contour of the articular surface is re-established.
- In cases of severe bone loss, the defect must be filled with bone graft or bone substitute.
MENISCAL REPAIR

- Meniscal integrity is important for stability and to avoid posttraumatic arthritis.
- Peripheral longitudinal lesions of the anterior and intermediate part of the meniscus are fixated using the “outside-in suture” technique.
- Peripheral longitudinal lesions of the posterior meniscus are fixated using the “all-inside” technique to avoid injury to the neurovascular structures in the popliteal area.
- Complex meniscal lesions in the avascular area require resection.

OSTEOSYNTHESIS

Implants

- Implants may include cancellous screws, conventional plates, or, most recently, angular stable plates.
- If the lateral metaphyseal shell is intact, a lag screw with a washer or a three-hole conventional plate in the antiglide position is usually sufficient.
- Multifragmentary fractures or fractures with severe bone loss usually require plate osteosynthesis.
- Prefomed locking or nonlocking plates allow an exact alignment and retention of the fracture.
- A minimally invasive technique by sliding the plate with the aiming device underneath the muscle may be selected. The screws can be applied by stitch incisions.

Pure Split Fractures of the Lateral Plateau (AO-41-B1 or Schatzker I)

- For fixation, two large partially threaded cancellous bone screws with washers can be used (TECH FIG 5).

Locking Plates

- In multifragmentary fractures or fractures with severe bone loss, an evidence-based advantage of locking plates versus nonlocking plates has not been reported in the literature.
- However, locking plates in these types of plateau fractures are advisable for the following reasons:
  - Angular stable plates require less bone graft compared to conventional plates in fractures with severe bone loss.
  - The stability of angular stable plates does not depend on friction between the plate and the bone, so less compression of the periosteum, with consequent better blood supply to the fracture area, is achieved.
PEARLS AND PITFALLS

Meniscal repair

- Meniscal repair is crucial to reduce the incidence of degenerative changes after tibial plateau fractures. Even a failed meniscal repair that requires subsequent meniscectomy can be briefly protective to the underlying cartilage.\(^{19}\)

Articular depression

- Articular depression is a major determinant of posttraumatic arthritis. After surgical management, no articular depression should be obvious. However, secondary articular depression may occur due to loss of fixation. To prevent secondary articular depression, sufficient bone graft or bone graft substitute should be used to stabilize tibial plateau depression fractures. However, tibial plateau depression fractures with a poor radiographic reconstruction may still be associated with a good functional outcome if meniscal integrity is preserved.
- Excessive soft tissue stripping may increase the risk for infection and nonunion. Therefore, minimally invasive techniques with the least possible soft tissue stripping and soft tissue irritation should be used.

Bone grafting

- Iliac crest bone grafting is the treatment of choice to maintain the reduction of depressed tibial plateau fragments. Bone substitutes such as coralline hydroxyapatite and calcium-phosphate cements have also been successfully used.

Soft tissue assessment

- Soft tissue assessment is an easy but pivotal step in the management of tibial plateau fractures. An excellent reduction and fixation may be compromised by infection secondary to inadequate assessment of the surrounding soft tissue status. Fractures with severe soft tissue impairment benefit from external stabilization and secondary open reduction and internal fixation.

Pure Depression Fractures of the Lateral Plateau (AO-41-B2 or Schatzker III)

- The depression is elevated through a cortical window and stabilized with two subchondral cancellous bone screws. In cases of severe bone loss, bone graft or bone graft substitute may also be needed for stabilization.
- In osteopenic patients, a third cancellous bone screw with washer is recommended in an antiglide position, whereas in case of fragmentation a lateral buttress plate is used (TECH FIG 6).

Split-Depression Fracture of the Lateral Plateau (AO-41-B3 or Schatzker II)

- The depression is elevated by working through the split component and deposition of bone graft (TECH FIG 7).
- Three position screws are placed subchondrally to support the impacted joint surface (rafting) and a locking plate or buttress plate is applied.


TECH FIG 7 • Stabilization of B3 or Schatzker II fracture with buttress plate.
POSTOPERATIVE CARE

- Rehabilitation must be planned individually and depends on patient age, bone quality, type of osteosynthesis, and concomitant injury.
- Ninety degrees of flexion should be achieved by 7 to 10 days.
- Toe-touch weight bearing is recommended for 4 to 8 weeks, with progression thereafter according to radiographic findings.
- Impression fractures of the lateral plateau managed with a minimally invasive angular plate are allowed weight bearing about 12 weeks after surgery.
- Early mobilization and range-of-motion exercises are key to the successful treatment of proximal tibia fractures to avoid later knee stiffness and muscle wasting.

OUTCOMES

- The outcome depends mostly on knee stability, joint congruity, meniscal integrity, and correct axis.
- A favorable outcome has been reported for surgically treated low-energy tibial plateau fractures. For split and split-depression fractures, adequate surgical techniques yield more than 90% good and excellent results.
- However, concomitant injuries of ligaments and menisci can compromise the outcome. Therefore, maintaining menisci and ligamentous stability is important.
- Satisfactory functional results can be obtained in the face of poor radiographic results, however, and may be due to preservation of the meniscus and its ability to bear the load of the lateral compartment.
- The incidence of wound infection appears to correlate with the amount of hardware implanted and ranges from 0% to 32% for fractures managed with the buttress technique.
- Deep vein thrombosis rates are reported to be 5% to 10%, and pulmonary embolus occurs in 1% to 2% of patients.
- Late complications:
  - Loss of fixation with axial malalignment and valgus deformity
  - Malunion as a consequence of inadequate reduction or loss of reduction
  - Posttraumatic arthrosis, which may result from the initial chondral damage or may be related to residual joint incongruity

REFERENCES

DEFINITION

- Indications for external fixation of the tibial shaft in trauma applications include the treatment of open fractures with extensive soft tissue devitalization and contamination. Other indications include the stabilization of closed fractures with high-grade soft tissue injury or compartment syndrome.
- For patients with multiple long bone fractures, external fixation has been used as a method for temporary, if not definitive, stabilization.
- With the introduction of circular and hybrid techniques, indications have been expanded to include the definitive treatment of complex periarticular injuries, which include high-energy tibial plateau and distal tibial pilon fractures.
- Contemporary external fixation systems in current clinical use can be categorized according to the type of bone anchor used.
- This is achieved either using large threaded pins, which are screwed into the bone, or by drilling small-diameter transfixion wires through the bone. The pins or wires are then connected to one another through the use of longitudinal bars or circular rings.
- The distinction is thus between monolateral external fixation (longitudinal connecting bars) and circular external fixation (wires connecting to rings).
- Acute trauma applications primarily use monolateral frame configurations and are the focus of techniques described here.
- The first type of monolateral frame comes with individual separate components: separate bars, attachable pin–bar clamps, bar-to-bar clamps, and Schanz pins (FIG 1A). These “simple monolateral” frames allow for a wide range of flexibility with “build-up” or “build-down” capabilities.
- The second type of monolateral frame is a more constrained type of fixator that comes preassembled with a multipin clamp at each end of a long rigid tubular body. The telescoping tube allows for axial compression or distraction of this so-called monotube-type fixator (FIG 1B).
- For diaphyseal injuries, the most common type of fixator application is the monolateral type of frame using large pins.
- Simple monolateral fixators have the distinct advantage of allowing individual pins to be placed at different angles and varying obliquities while still connecting to the bar. This is helpful when altering the pin position avoid areas of soft tissue compromise (ie, open wounds or severe contusion).
- The advantage of the monotube-type fixator is its simplicity. Pin placement is predetermined by the multipin clamps. Loosening the universal articulations between the body and the clamps allows these frames to be easily manipulated to reduce a fracture.
- Many high-energy fractures involve the metaphyseal regions, and transfixion techniques using small tensioned wires are ideally suited to this region. They have better mechanical stability and longevity than traditional half-pin techniques.
- Small tensioned wire circular frames or hybrid frames can be useful in patients with severe tibial metaphyseal injuries that occur in concert with other conditions such as soft tissue compromise or compartment syndrome, or in patients with multiple injuries (FIG 1C,D).

ANATOMY

- The bulk of the tibia is easily accessible in that most of the diaphyseal portion is subcutaneous.
- Also, the hard cortical bone found in this location is ideally suited to the placement of large Schanz pins, which achieves excellent mechanical fixation.
- The cross-sectional anatomy of the diaphysis and the lateral location of the muscular compartments allow placement of half-pins in a wide range of subcutaneous locations. This facilitates pin placement “out of plane” to each other, which helps achieve overall frame stability (FIG 2).
- The proximal and distal periarticular metaphyseal regions of the tibia are also subcutaneous except for their lateral surfaces. The bone in these locations is primarily cancellous, with thin cortical walls.
- The mechanical stability achieved with half-pins depends on cortical purchase and therefore may not be adequate for fixation in this cortex-deficient region.
- Excellent stability is afforded in these areas by using small-diameter tensioned transfixion wires in conjunction with circular external fixators.

PATHOGENESIS

- Open tibial diaphyseal fractures are primarily candidates for closed intramedullary nailing, but there are occasions when external fixation is indicated.
- External fixation is favored when there is significant contamination and severe soft tissue injury or when the fracture configuration extends into the metaphyseal–diaphyseal junction or the joint itself, making intramedullary nailing problematic.
- The choice of external fixator type depends on the location and complexity of the fracture, as well as the type of wound present when dealing with open injuries.
- The less stable the fracture pattern (ie, the more comminution), the more complex a frame needs to be applied to control motion at the bone ends.
- If possible, weight bearing should be a consideration.
- If periarticular extension or involvement is present, the ability to bridge the joint with the frame provides satisfactory stability for both hard and soft tissues.
- It is important that the frame be constructed and applied to allow for multiple débridesments and subsequent soft tissue reconstruction. This demands that the pins are placed away from the zone of injury to avoid potential pin site contamination with the operative field.
Fractures treated with external fixation heal with external bridging callus. External bridging callus is largely under the control of mechanical and other humoral factors and is highly dependent on the integrity of the surrounding soft tissue envelope. This type of fracture healing has the ability to bridge large gaps and is very tolerant of movement.

- Micromotion with the external fixator construct has been found to accentuate fracture union. It results in the development of a large callus with formation of cartilage due to the greater inflammatory response caused by increased micromovement of the fragments.
- There appears to be a threshold at which the degree of micromotion becomes inhibitory to this overall remodeling process, however, so hypertrophic nonunion can result from an unstable external frame.

- Temporary spanning fixation for complex articular injuries is used routinely. The ability to achieve an initial ligamentotaxis reduction substantially decreases the amount of injury-related swelling and edema by reducing large fracture gaps.
- It is important to achieve an early ligamentotaxis reduction: a delay of more than a few days will result in an inability to disimpact displaced metaphyseal fragments.
- Once the soft tissues have recovered, formal open reduction and internal fixation can be accomplished with relative ease as the operative tactic can be directed to the area of articular involvement.
- Application of these techniques in a polytrauma patient is valuable when rapid stabilization is necessary for a patient in extremis. Simple monolateral or monotube fixators can be placed rapidly across long bone injuries, providing adequate...
stabilization to facilitate the management and resuscitation of the polytrauma patient (FIG 3).

**NATURAL HISTORY**

- The stability of all monolateral fixators is based on the concept of a simple “four-pin frame.”
- Pin number, pin separation, and pin proximity to the fracture site, as well as bone bar distance and the diameter of the pins and connecting bars, all influence the final mechanical stability of the external fixator frame.
- Large pin monolateral fixators rely on stiff pins for frame stability. On loading, these pins act as cantilevers and produce eccentric loading characteristics. Shear forces are regarded as inhibitory to fracture healing and bone formation, and this may be accentuated with pins placed in all the same orientation.
- After stable frame application, the soft tissue injury can be addressed. Once the soft tissues have healed, conversion to definitive internal fixation can be safely accomplished. In some cases the external device is the definitive treatment. Dynamic
weight bearing is initiated at an early stage once the fracture is deemed stable.

- In fractures that are highly comminuted, weight bearing is delayed until visible callus is achieved and sufficient stability has been maintained. As healing progresses, active dynamization of the frame may be required to achieve solid union.
- Dynamization converts a static fixator, which seeks to neutralize all forces including axial motion, and allows the passage of forces across the fracture site. As the elasticity of the callus decreases, bone stiffness and strength increase and larger loads can be supported. Thus, axial dynamization helps to restore cortical contact and to produce a stable fracture pattern with inherent mechanical support. This is accomplished by making adjustments in the pin–bar clamps with simple monolateral fixators or in releasing the body on a monotube-type fixator.
- Bony healing is not complete until remodeling of the fracture has been achieved. At this stage, the visible fracture lines in the callus decrease and subsequently disappear. The fixator can be removed at this point.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- History should focus on the mechanism of injury.
- Determining whether the injury was high energy versus low energy gives the surgeon an idea of the extent of the soft tissue zone of injury and will help determine the possible location of fixation pins.
- Determining the location of the accident is helpful in cases of open fracture (ie, open field with soil contamination vs. slip and fall on ice and snow).
- These parameters give the surgeon an idea as to the extent of intraoperative débridement that might be required to cleanse the wound and the necessary antibiotic coverage for the injury.
- The neurovascular status should be documented, specifically the presence or absence of the anterior and posterior tibial pulses at the ankle.
- A weak or absent pulse may be an indication of vascular injury and may dictate further evaluation with ankle-brachial indices, compartment pressure evaluation, or a formal arteriogram.
- Evaluation of compartment pressures is often indicated in open fractures and closed high-energy fractures with severe soft tissue contusion.
- Evaluation of soft tissues and grading of the open fracture with regard to the size, orientation, and location of the open wounds aid in decision making about pin placement and the configuration of the fixator to allow access to open wounds (FIG 4).

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Imaging of the tibia should include at least two orthogonal views, anteroposterior and lateral.
- Radiographs of the knee and ankle are necessary to evaluate any articular fracture involvement or associated knee or ankle subluxation or dislocation.
- Identifying any occult fracture lines aids in the preoperative planning of potential pin placement.
- Many patients with high-energy tibial fractures have associated foot injuries, and views of the foot and ankle are necessary to identify this injury pattern.
- Traction radiographs of articular injuries of the tibia are useful to identify the nature and orientation of metaphyseal fragments as well as degree of articular impaction. This aids in determining whether a joint-spanning fixator is necessary.
- Distraction CT scans should be obtained after the knee- or ankle-spanning fixator has been applied. These studies indicate the effectiveness of the ligamentotaxis reduction. This allows the surgeon to determine the preoperative plan for definitive fixation once the soft tissues have recovered (FIG 5).

**SURGICAL MANAGEMENT**

- The surgical decisions relate to the configuration of the external device to be applied. These generally will fall into two categories of treatment options.
- The first category is a temporary device intended to allow the soft tissues to recover or the patient’s overall condition to
improve until definitive fixation of the injury can be safely carried out.

- Temporary frames include knee- or ankle-spanning fixators used in cases of periarticular injuries requiring ligamentotaxis reduction and relative stabilization, and simple frames spanning a tibial shaft fracture in the case of a polytrauma patient who needs emergent stabilization of injuries. These frames are later converted to intramedullary nails once the patient can undergo additional surgery.
- They are simplistic and not intended for long-term treatment times.
- Definitive treatment fixators are primarily applied to diaphyseal injuries with severe soft tissue compromise (open and closed).
- These devices are maintained throughout the entire treatment period to allow access to soft tissues and facilitate secondary procedures such as rotational or free flap coverage as well as delayed bone grafting.
- These frames are more involved and are intended to remain in place for the entire treatment period.

**Preoperative Planning**

- Evaluation of injury radiographs should identify any distal or proximal articular extension into the knee or ankle joint.
- Location of the primary fracture is noted in terms of proximal or distal locations to help decide on a particular fixator construct and to help determine if a joint-spanning fixator is required.

**Positioning**

- The patient’s entire lower extremity is elevated using bumps or a beanbag patient positioner under the ipsilateral hip (FIG 6). This elevates the tibia off the operating table.
The correct insertion technique involves incising the skin directly at the side of pin insertion. After a generous incision is made, dissection is carried directly down to bone and the periosteum is incised where anatomically feasible (TECH FIG 1A). A small Penfield-type elevator is used to gently reflect the periosteum off the bone at the site of insertion (TECH FIG 1B). Extraneous soft tissue tethering and necrosis is avoided by minimizing soft tissue at the site of insertion.

A trocar and drill sleeve are advanced directly to bone, minimizing the amount of soft tissue entrapment that might be encountered during predrilling (TECH FIG 1C,D). A sleeve should also be used if a self-drilling pin is selected. After predrilling, an appropriate-size depth of pin is advanced by hand to achieve bicortical purchase. Any offending soft tissue tethering should be released with a small scalpel (TECH FIG 1E,F).

The foot can be supported with a sterile bump, thus suspending the limb and allowing full 360-degree access and visualization of the limb. Elevating the limb positions the nonoperative leg below the operative limb, which aids in placing out-of-plane pins as well as circular frame components. The image intensifier is positioned opposite the operative leg. This aids in fluoroscopic visualization of the femur and knee, which is important when applying a knee-spanning fixator for a severe tibial plateau fracture.

**Approach**

- The integrity of the pin–bone interface is a critical factor in determining the longevity of an applied external fixation pin.
- Pin insertion technique is important in achieving an infection-free, stable pin–bone interface and thus maintaining frame stability.

**PIN INSERTION TECHNIQUE**

- The correct insertion technique involves incising the skin directly at the side of pin insertion.
- After a generous incision is made, dissection is carried directly down to bone and the periosteum is incised where anatomically feasible (TECH FIG 1A).
- A small Penfield-type elevator is used to gently reflect the periosteum off the bone at the site of insertion (TECH FIG 1B). Extraneous soft tissue tethering and necrosis is avoided by minimizing soft tissue at the site of insertion.
- A trocar and drill sleeve are advanced directly to bone, minimizing the amount of soft tissue entrapment that might be encountered during predrilling (TECH FIG 1C,D). A sleeve should also be used if a self-drilling pin is selected.
- After predrilling, an appropriate-size depth of pin is advanced by hand to achieve bicortical purchase. Any offending soft tissue tethering should be released with a small scalpel (TECH FIG 1E,F).
MONOLATERAL FOUR-PIN FRAME APPLICATION FOR TIBIAL SHAFT FRACTURE

Contemporary simple monolateral fixators have clamps that allow independent adjustments at each pin-bar interface, allowing wide variability in pin placement, which helps to avoid areas of soft tissue compromise.

Because of this feature, simple four-pin placement may be random on either side of the fracture.

Option 1

The initial two pins are first inserted as far away from the fracture line as possible in the proximal fracture segment and as distal as possible in the distal fracture segment (TECH FIG 2A).

A solitary connecting rod is attached close to the bone to increase the rigidity of the system.

Longitudinal traction is applied and a gross reduction is achieved (TECH FIG 2B–F).

The intermediate pins can then be inserted using the pin fixation clamps attached to the rod to act as templates with drill sleeves as guides.

These pins should not encroach on the open wound or severely contused skin in the immediate zone of injury.

TECH FIG 2 • Placement of a simple four-pin monolateral fixator. A. Two pins are placed on either side of the fracture as far from the fracture as possible. A connecting bar is then attached to the two pins (B) and a gradual reduction is performed (C–F). Two pins are then placed as close to the fracture as possible on either side, after longitudinal traction has accomplished a reduction. The inner pins are then attached and the reduction is fine-tuned.
After placement of these two additional pins, the reduction can be achieved with minimal difficulty by additional manipulation of the fracture.

Once satisfactory reduction has been accomplished, the clamps are tightened and reduction is confirmed via fluoroscopy.

**Option 2**

- Alternatively, all the fixation pins can be inserted independent of each other, with two pins proximally and two pins distally (TECH FIG 3).

The two proximal pins are connected to a solitary bar and the distal two pins are connected to a solitary bar.

Both proximal and distal bars are then used as reduction tools to manipulate the fracture into alignment.

Once reduction has been achieved, an additional bar-to-bar construct between the two fixed-pin couples is connected.

Reduction is confirmed under fluoroscopy.

**TECH FIG 3** • Alternative method for simple four-pin monolateral fixator. A, B. Once the bar is attached, two intercalary clamps can be positioned as templates for the placement of the interior pins. C. Final construct after interior pin placement. D. The proximal and distal two pins can be attached to each other by a solitary bar. These bars can then be used as tools to reduce the fracture. E. The two bars are then connected by a solitary bar and the fracture reduction is maintained. F, G. Closed fracture with associated compartment syndrome is reduced and stabilized using a four-pin fixator with a single connecting bar.
MONOTUBE FOUR-PIN FRAME APPLICATION FOR TIBIAL SHAFT FRACTURE

- Use of the large monotube fixators facilitates rapid placement of these devices, with the fixed-pin couple acting as pin templates (TECH FIG 4).
- Two pins are placed through the fixator-pin couple proximal to the fracture. They are inserted parallel to each other at fixed distances set by the pin clamp itself. These are usually oriented along the direct medial or anteromedial face of the tibial shaft.
- Once the pins are inserted, the pin clamp is tightened to secure them in place.

TECH FIG 4 • A. Tibial shaft fracture with displacement. B. Monotube fixator adjusted to length and orientation, with all ball joints and the telescoping central body loosened. C. Proximal two pins applied using pin couple as template. D. Distal pins inserted and fracture reduced with all ball joints locked to maintain reduction. Telescoping body is also locked to maintain axial alignment. E,F. Injury and reduction radiographs using a large-body monotube fixator for an open comminuted tibial shaft fracture.
- The monotube body is then attached to the proximal pin couple and longitudinal traction applied to achieve a “gross” reduction. The fixator body and distal multipin clamp are oriented along the shaft of the tibia.
- The proximal and distal ball joints should be freely movable with the telescoping body extended.
- Two pins are placed through the pin couple distal to the fracture and tightened.
- Care must be taken to allow adequate length of the monotube frame before final reduction and tightening of the body.
- Using the proximal and distal pin clamps as reduction aids, the fracture is manually reduced. The proximal and distal ball joints are then tightened, accomplishing a reduction.
- At this point, the telescoping body can be extended or compressed to dial in the axial alignment. When length is achieved, the body component is tightened to maintain axial length.
- Monotube bodies have a very large diameter, which limits the amount of shearing, torsional, and bending movements of the fixation construct.
- Axial compression is achieved by releasing the telescoping mechanism.
- Dynamic weight bearing is initiated at an early stage once the fracture is deemed stable.
- In fractures that are highly comminuted, weight bearing is delayed until visible callus is achieved and sufficient stability has been maintained.
- The telescopic body allows dynamic movement in an axial direction, which is a stimulus for early periosteal healing.

**KNEE-SPANNING FIXATOR OF TIBIAL PLATEAU FRACTURE**

- Two Schanz pins are placed along the anterolateral thigh. These pins are placed in the midshaft region of the femur (TECH FIG 5).
- Two Schanz pins are then inserted into the midshaft and distal tibia.

- Apply the tibial pins far enough away from the distal extension of the proximal tibia such that any future incisions required to perform definitive open reduction and internal fixation of the plateau fracture would not impinge on the pins.

**TECH FIG 5 • A,B.** Open tibial plateau stabilized with knee-spanning fixator. Two pins each above (distal femur) and below (midtibia) the fracture are applied. Two bars connect each pin couple. Long connecting bars are then used to connect each pin couple, maintaining the reduced fracture. **C,D.** One single bar connects the two pins proximal to the plateau fracture and the two pins distal to the fracture.
- A solitary bar can then be used to span all pins.
  - Longitudinal traction is applied and reduction confirmed under fluoroscopy.
  - Slight flexion of the knee is maintained and all connections are tightened to maintain the ligamentotaxis reduction.
  - Alternatively, the proximal two femur pins can be connected using a single bar and the two tibial pins with a second bar. These two bars can then be manipulated to achieve a reduction of the plateau, and a third bar connecting the proximal femoral and distal tibial bars is then attached and tightened to maintain the reduction.
  - A large monotube fixator can also be used in this fashion to span the knee and maintain a temporary reduction.

**ANKLE-SPANNING FIXATOR FOR TIBIAL PILON FRACTURE**
- Two Schanz pins are placed into the midshaft tibial region (TECH FIG 6).
  - Avoid any compromised soft tissues and possible fracture extension if spanning the ankle for a severe pilon fracture with shaft extension.
  - A centrally threaded transfixion pin is then placed through the calcaneal tuberosity from medial to lateral, avoiding the posterior tibial artery.
  - The appropriate location for this pin is 1.5 cm anterior to the posterior aspect of the heel and 1.5 cm proximal to the plantar aspect of the heel.
  - This location is confirmed via fluoroscopy.
- A solitary bar is connected to the tibial pins.
  - Medial and lateral bars are then connected to each side of the heel pin, making a triangular configuration.
  - Longitudinal traction is carried out to obtain length, and care is taken to achieve appropriate anteroposterior reduction.
  - To maintain a plantigrade foot and to maintain alignment, a pin is placed into the base of the first or second metatarsal.
  - This forefoot pin is then connected to the main frame with a connecting bar and the foot is held in neutral dorsiflexion.

**TECH FIG 6 • Ankle-spanning fixators bridging severe pilon fractures.**
- A. Two pins are placed into the distal tibia, proximal enough to be out of the zone of injury. A calcaneal transfixion pin is placed through the calcaneal tuberosity and subsequent medial-lateral triangulation connecting bars are attached. Longitudinal traction is applied and all bars are tightened to maintain reduction. B,C. A forefoot pin is placed into the second metatarsal to maintain the foot in a neutral position and avoid equinus contracture.

**TWO-PIN FIXATOR: TEMPORARY STABILIZATION FOR TIBIAL SHAFT, PILON, OR PLATEAU FRACTURES**
- This is a temporary frame designed for rapid distraction and gross reduction used for all types of tibial pathology.
  - A proximal centrally threaded transfixion pin is applied one fingerbreadth proximal to the tip of the proximal fibula. It is inserted from lateral to medial (TECH FIG 7A,B).
  - Alternatively, this pin can be placed into the distal femur at the level of the midpatella along the midlateral condyle of the femur.
  - A second transfixion pin is placed through the calcaneal tuberosity, similar to the ankle-spanning frame described above.
- Two long connecting bars are then attached to the pins on each side of the leg.
  - Longitudinal traction is applied and a gross reduction is achieved.
  - In some circumstances, a third pin is placed into the tibial shaft and attached to one of the longitudinal bars by a third connecting bar (TECH FIG 7C,D). This is done to add stability to this very simple frame.
**TECH FIG 7 • A,B.** Application of spanning two-pin fixator “traveling traction” with attachment of medial and lateral bars. This is used as a very temporary frame to stabilize a variety of conditions. **C,D.** Two-pin fixator used to stabilize a severe plateau fracture. A third pin was inserted into the distal third of the tibia to provide additional stability. The frame is prepared directly into the operative field at the time of secondary surgery to definitively stabilize the fracture using a medial buttress plate.

**PEARLS AND PITFALLS**

**Pin placement location**
- Areas of soft tissue compromise, open wounds, and occult fracture lines as identified on CT scans should be avoided. This prevents any associated pin tract infection from involving the fracture site. The frame must be constructed and applied to allow for multiple débridements, subsequent soft tissue reconstruction, and definitive secondary internal fixation conversions. Thus, the pins must be placed away from the zone of injury to avoid potential pin site contamination with the operative field.

**Pin insertion technique**
- Adequate skin release is provided to avoid tethering or bunching of soft tissues around pins. Pins are overwrapped with small gauze wrap to provide a stable pin–skin interface and to avoid excessive pin–skin motion and development of tissue necrosis and infection.

**Temporary frames require adjunctive splinting of knee, leg, ankle, and foot.**
- Temporary spanning frames are not excessively rigid and require additional splinting to maintain the foot in neutral and to avoid the development of equinus contractures.

**POSTOPERATIVE CARE**

- A compressive dressing should be applied to the pin sites immediately after surgery to stabilize the pin–skin interface and thus minimize pin–skin motion, which can lead to the development of necrotic debris.
- Compressive dressings can be removed within 10 days to 2 weeks, once the pin sites are healed.
- If appropriate pin insertion technique is used, the pin sites will completely heal around each individual pin. Once healed, only showering, without any other pin cleaning procedures, is necessary.
- Removal of a serous crust around the pins using dilute hydrogen peroxide and saline may occasionally be necessary.
- Ointments should not be used for pin care. They tend to inhibit the normal skin flora and alter the normal skin bacteria and may lead to superinfection or pin site colonization.
- If pin drainage does develop, pin care should be provided three times per day.
This may also involve rewrapping and compressing the offending pin site in an effort to minimize the abnormal pin–skin motion.

Following a standardized protocol that involves precleaning the external fixator frame, followed by alcohol wash, sequential povidone–iodine preparation, paint, and spray with air drying followed by draping the extremity and fixator directly into the operative field, additional surgery can be safely performed without an increased rate of postoperative wound infection.

Definitive treatment with an external fixator demands closed scrutiny of the radiographs to ensure that the fracture has completely healed before frame removal. Various techniques have been described, including CT scans, ultrasound, and bone densitometry, to determine the adequacy of fracture healing.

In general, the patient should be fully weight bearing with minimal pain at the fracture site. The frame should be fully dynamized such that the load is being borne by the patient’s limb rather than by the external fixator.

OUTCOMES

Staged management of high-energy tibial plateau and tibial pilon fractures using spanning external fixation to allow the recovery of soft tissues has reduced the overall rates of soft tissue complications. With secondary plating procedures after soft tissue recovery, infection rates have been reported to be less than 5% for complex plateau fractures and less than 7% for complex pilon fractures.

No severe complications related to the temporary external fixator alone have been reported.

Immediate external fixation followed by early closed interlocking nailing has been demonstrated to be a safe and effective treatment for open tibial fractures if early (less than 21 days after injury) conversion to intramedullary nailing is performed.

Early soft tissue coverage and closure is the primary determinant of delayed infection, highlighting the need for effective soft tissue management and early closure of open injuries.

Definitive treatment of open tibial fractures with external fixation has a higher rate of malunion compared with intramedullary nailing. No difference in union rates is noted. Slightly higher rates of infection are noted in the external fixation group.

The severity of the soft tissue injury rather than the choice of implant appears to be the predominant factor influencing outcome. External fixation is preferentially used in patients with the most severe soft tissue injuries or wound contamination.

COMPLICATIONS

Wire and pin site complications include pin site inflammation, chronic infection, loosening, or metal fatigue failure.

Minor pin tract inflammation requires more frequent pin care, consisting of daily cleansing with mild soap or half-strength peroxide and saline solution.

Occasionally an inflamed pin site with purulent discharge will require antibiotics and continued daily pin care.

Severe pin tract infection consists of serous or seropurulent drainage in concert with redness, inflammation, and radiographs showing osteolysis of both the near and far cortices.

Once osteolysis occurs with bicornital involvement, the offending pin should be removed immediately, with débridement of the pin tract.

Late deformity after removal of the apparatus usually presents as a gradual deviation of the limb. This often occurs if the patient and surgeon become “frame weary,” which results in frame removal before healing is complete.

One should always err on the conservative side and leave the frame on for an extended time to ensure that the fracture has healed.

When late deformity occurs, it usually has an unsatisfactory outcome unless collapse is detected early and the frame is reapplied.

If untreated, the resulting malunion requires secondary osteotomy procedures.

Early detection of delayed union often requires adjunctive bone grafting for previously open shaft fractures.

REFERENCES

Intramedullary nailing (IMN) techniques typically are used for closed and open displaced diaphyseal tibial fractures. With additional techniques described in this chapter, the indications for intramedullary nailing can be extended to proximal and distal metaphyseal tibia fractures, including those associated with simple articular involvement.

ANATOMY

The triangular-shaped proximal tibia is most narrow medially, and the proximal medial cortex tibia is obliquely oriented to the frontal plane. The medullary canal of the tibia exits at the margin of the lateral articular facet. As a result of this complex proximal anatomy, there is less sagittal plane space for an intramedullary nail within the tibia metaphysis with a medial or central insertion path, and the anterior medial metaphyseal cortex can deflect the nail and create a valgus deformation. Thus, lateral start sites are more favorable.

The patellar tendon inserts on the tibial tubercle and extends the proximal fracture segment in proximal fracture patterns. This displacement is accentuated with further flexion of the knee, which typically is required to attain the proper starting point for intramedullary nailing (FIG 1A).

Gerdy’s tubercle—the origin of the anterior compartment muscles and insertion site of the iliotibial band—is palpable along the proximal lateral tibia. The anterior compartment muscles and the iliotibial band contribute to shortening and the valgus deformity that is typically seen with proximal fractures.

The anterior tibial crest corresponds to the vertical lateral surface of the tibia. When it is palpable, it is an excellent reference for the anatomic axis and nail path (FIG 1B).

The anteromedial tibial surface is subcutaneous and often is the site of traumatic open wounds.

The anterior neurovascular bundle and tibialis anterior tendon are at risk with anterior-to-posterior distal interlocking screw paths; internal rotation of the nail may decrease the risk of iatrogenic nerve injury (FIG 1C).

The Hoffa fat pad and intermeniscal ligament are commonly injured during nail insertion, especially during lateral parapatellar and patellar tendon-splitting approaches.

PATHOGENESIS

Tibial shaft fractures may occur from high-energy mechanisms of injury, as when a pedestrian is struck by a motor vehicle. Many fractures, however, result from low-energy mechanisms such as simple falls in elderly patients or those with poor bone quality, or sports-related injuries (usually in soccer players) in young patients.

In this low-energy fracture group, elderly patients are more likely to have comminuted and open fractures due to simple falls.

NATURAL HISTORY

The long-term outcome of tibial malunion is not clearly defined in the trauma literature.

A weak association is seen between a tibial shaft fracture malunion and ipsilateral knee and ankle arthritis.

Knee pain is reported in up to 58% of cases after intramedullary nailing. This pain typically is anterior, associated with activity, and exacerbated by kneeling activities.

Knee pain improves in about 50% of patients after hardware removal.

Attempts to detect a correlation between start sites and knee pain have been inconclusive, and a comparative evaluation between traditional start sites and newer start sites (ie, suprapatellar) has yet to be completed.

PATIENT HISTORY AND PHYSICAL FINDINGS

Understanding the mechanism of injury and the environment in which the injury occurred is important for evaluating a patient’s risk for associated injuries and compartment syndrome. In open fractures, it can help determine the choice of prophylactic antibiotic therapy.

All patients who sustain tibial shaft fractures from high-energy mechanisms should undergo standard advanced trauma and life support (ATLS) protocol to have a thorough examination for life- and other limb-threatening injuries. Seventy-five percent of patients with open tibia fractures have associated injuries.

To evaluate a patient’s risk for potential complications, other medical conditions should be investigated, eg, a history of diabetes mellitus, renal disease, inflammatory arthropathies, tobacco use (which increases healing time by up to 40%), and peripheral vascular disease.

It also is important to find out about the patient’s normal activities and employment requirements to give them a reasonable expectation for when they will be able to resume those activities.

Pain at the fracture site, swelling, and deformity are common findings in patients with tibial shaft fractures.

A thorough examination of the skin is important to avoid missing open fracture wounds.

Evaluation of the soft tissue envelope for abrasions, contusions, and fracture blisters can help determine whether definitive treatment can be done primarily or if a staged or delayed approach is required.

A thorough neurovascular examination is critical to avoid the devastating complications associated with compartment syndrome, which can occur in both closed and open fractures (see Chap. TR-17).

IMAGING AND OTHER DIAGNOSTIC STUDIES

Full-length (orthogonal) anteroposterior (AP) and lateral plain radiographs are necessary to adequately evaluate the
tibia and fibula for concurrent fractures or dislocation and any preexisting deformity or implants.

- Orthogonal radiographic views of the knee and ankle are required to rule out articular involvement.
- Axial CT scan can be used for proximal and distal fractures to rule out intra-articular fracture extension.
- Nondisplaced fracture lines are common.
- Gunshot wounds may merit CT evaluation to rule out intra-articular bullet fragments.
- MRI is not useful for most diaphyseal or metadiaphyseal fractures.
- Ankle–brachial or ankle–arm indices after fracture reduction should be used to rule out vascular injuries in severely displaced fractures or fractures with severe soft tissue injury. Values of less than 0.9 may be indicative of vascular injury, requiring further investigation.
- Compartment pressure evaluation with a commercially available hand-held single-stick monitor or with a side-ported catheter connected to a pressure monitor (using the arterial line set-up) is indicated in patients who have severe or increasing swelling and are not able to comply with physical examination and questioning (see Chap. TR-17).
- Observe for early signs of compartment syndrome in all patients with tibial diaphyseal fractures.
- Open fracture does not preclude development of compartment syndrome.
- Measure the pressure difference between the diastolic pressure and the intracompartmental pressure—a differential value of less than 30 mm Hg is considered an indication for a four-compartment fasciotomy.

**NONOPERATIVE MANAGEMENT**

- Nonoperative management is indicated in ambulatory patients for closed and open fractures that do not require flap coverage and that do not present with excessive initial shortening or unacceptable angulation when a cast is applied (FIG 2).
An intact fibula with an axially unstable fracture pattern (i.e., short oblique, butterfly, comminuted) is at risk of shortening and varus and is a relative contraindication to nonoperative management. A higher rate of malunion and nonunion with nonoperative management is seen in higher-energy fractures. Joint stiffness, especially hindfoot, is common with all forms of prolonged immobilization. Initial treatment includes 2 weeks of a long leg splint, then a long-leg cast for 2 to 4 weeks. When the initial swelling has subsided, the patient is graduated to a patellar tendon or functional brace with weight bearing allowed and encouraged. Radiographs are evaluated at 1- to 2-week intervals over the first month of treatment to confirm maintenance of acceptable alignment.

### SURGICAL MANAGEMENT

#### Classification and Relative Indications
- Tibia fractures usually are classified according to the AO/OTA classification (Table 1).
- Several relatively well-accepted indications and contraindications have been established for the intramedullary nailing of tibia fractures (Table 2).
- A thorough evaluation of the patient’s soft tissue envelope will determine when the patient can proceed with definitive fixation.
- Complete orthogonal radiographs of the entire tibia and fibula are important to determine whether the patient’s intramedullary canal is large enough to accommodate an intramedullary nail and identify any pre-existing deformity that may preclude nail placement. Complete radiographs also identify any proximal or distal articular involvement.
- Preoperative measurement of the intramedullary canal and the length of the tibia will help determine which size nail can be used.
- The lateral radiograph is the most accurate to use for measuring the appropriate nail length.
- Measuring the narrowest diameter on the AP and lateral views will determine the appropriate nail diameter and whether intramedullary reaming will be necessary.
- Orthogonal radiographs of the uninjured tibia can be used as templates for determining the appropriate length, alignment, and rotation in comminuted fractures or open fractures with bone loss.

#### Positioning
- Supine positioning is standard.
- A fracture table can be used with boot traction, calcaneal traction, or an arthroscopy leg holder that supports the leg and provides mechanical traction when no assistants are available. However, knee hyperflexion is difficult, and the guidewire insertion angle is suboptimal for proximal fractures (FIG 3A).
- The patient is placed on the radiolucent table in one of the following positions:
  - Supine with the leg free (FIG 3B)
  - Mechanical traction is helpful to achieve reduction when the leg is draped free (FIG 3C,D).
  - The proximal posterior transfixion pin (FIG 3E) is inserted medial to lateral and parallel to the tibial plateu.
  - The distal transfixion pin (FIG 3F) is inserted parallel to the plafond and inferior to the projected end of the nail.
  - Supine with the leg flexed over a bolster or radiolucent triangle (FIG 3G)
  - Maximizing knee flexion makes it easier to attain a start site and to determine the optimal insertion vector (which approaches a parallel path with the anterior tibial border).
  - Semi-extended position
  - For proximal fractures, extending the knee to 20 to 30 degrees of flexion counters the pull of the patellar tendon.
<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
<th>Illustration</th>
<th>Classification</th>
<th>Description</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>42-A</td>
<td>Simple</td>
<td></td>
<td>42-B</td>
<td>Wedge</td>
<td></td>
</tr>
<tr>
<td>42-A1</td>
<td>Spiral</td>
<td></td>
<td>42-B1</td>
<td>Spiral wedge</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>42-B2</td>
<td>Bending wedge</td>
<td></td>
</tr>
<tr>
<td>42-A2</td>
<td>Oblique (&lt;30 degrees)</td>
<td></td>
<td>42-C</td>
<td>Complex</td>
<td></td>
</tr>
<tr>
<td>42-A3</td>
<td>Transverse (&lt;30 degrees)</td>
<td></td>
<td>42-C1</td>
<td>Spiral</td>
<td></td>
</tr>
<tr>
<td>42-C1</td>
<td>Spiral</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42-C2</td>
<td>Segmented</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42-C3</td>
<td>Irregular</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42-B3</td>
<td>Fragmented wedge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
and helps reduce the flexion deformity that is typical for these fractures. Either a radiolucent triangle or bolster can be used (FIG 3H).

**Approach**

- Use fluoroscopy to determine which approach will allow the starting point to be placed just medial to the lateral tibial spine on the AP view and at the anterior articular margin on the lateral view.
- For diaphyseal and distal metaphyseal fractures, any of the following approaches is appropriate. As mentioned earlier, the patient’s anatomy can be used to determine which approach allows for appropriate starting point placement.
  - Medial parapatellar
  - Transpatellar tendon. (This approach may be avoided by some surgeons due to previous retrospective series that showed an increased likelihood of knee pain with this approach. However, other retrospective series and more recent prospective trials have found no association between knee pain and the surgical approach used.)
  - Lateral parapatellar
  - Proximal metaphyseal fractures
- The lateral parapatellar approach allows for guidewire and nail placement in the more lateral position, which is beneficial in countering the valgus deformity associated with these fractures. It also allows intramedullary nailing in the familiar hyperflexed knee position.

### Table 2: Relative Indications and Contraindications for Intramedullary Nailing of Tibial Fractures

<table>
<thead>
<tr>
<th>Relative Indications</th>
<th>Contraindications</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-energy mechanism</td>
<td>Intramedullary canal diameter &lt; 6 mm</td>
</tr>
<tr>
<td>Moderate to severe soft tissue injury precluding cast or brace</td>
<td>Gross contamination of intramedullary canal</td>
</tr>
<tr>
<td>Angular deformity ≥ 5 to 10 degrees</td>
<td>Severe soft tissue injury where limb salvage is uncertain</td>
</tr>
<tr>
<td>Rotational deformity ≥ 5 to 10 degrees</td>
<td>Preexisting deformity precluding nail insertion</td>
</tr>
<tr>
<td>Shortening &gt; 1 cm</td>
<td>Ipsilateral total knee arthroplasty or knee arthrodesis</td>
</tr>
<tr>
<td>Displacement &gt; 50%</td>
<td>Significant articular involvement</td>
</tr>
<tr>
<td>An ipsilateral fibula fracture at the same level</td>
<td>Previous cruciate ligament reconstruction</td>
</tr>
<tr>
<td>An intact fibula</td>
<td></td>
</tr>
<tr>
<td>Compartment syndrome</td>
<td></td>
</tr>
<tr>
<td>Ipsilateral femoral fracture</td>
<td></td>
</tr>
<tr>
<td>Inability to maintain reduction</td>
<td></td>
</tr>
<tr>
<td>Older age, inability to manage with cast or brace</td>
<td></td>
</tr>
</tbody>
</table>

**FIG 3**

- A. The fractured leg is positioned in calcaneal skeletal traction on the fracture table. This provides excellent mechanical traction but limits limb mobility, especially knee flexion.
- B. The knee is flexed over a positioning triangle in preparation for the surgical approach.
- C, D. The tibial fracture is distracted and reduced using a mechanical distraction device with proximal and distal half-pins. (continued)
The semi-extended position allows for reduction of the flexion deformity associated with these fractures. The limited or formal medial parapatellar may be used if the surgeon is unfamiliar with the suprapatellar approach and special instrumentation is not available. If the suprapatellar approach is being performed, a superomedial or superior midline is used and special instrumentation is required. All of the surgical approaches are performed with the knee in the semi-extended position.

### SURGICAL APPROACH

#### Medial Parapatellar Tendon Approach

- Palpate and mark the medial border of the patellar tendon ([TECH FIG 1, line A]).
- Incise the skin at the medial border of the patellar tendon.
- Full-thickness skin flaps are developed.
- Dissection is carried down to the retinaculum.
- The retinaculum is then split, and the patellar tendon is retracted laterally.
- Do not incise the capsule.

#### Transpatellar Tendon Approach

- Palpate and mark the medial and lateral border of the patellar tendon, the inferior border of the patella, and the tibial tubercle ([TECH FIG 1, line B]).
- Incise the skin starting at the inferior margin of the patella and continue distally in the middle of the patellar tendon.
- Full-thickness skin flaps are developed.
- Incise the paratenon in the midline, and elevate medial and lateral flaps to identify the margins of the patellar tendon.
- Make a single full-thickness incision in the midline of the patellar tendon. Do not incise the capsule and avoid injuring the menisci at the inferior margin of the incision.

#### Lateral Parapatellar Tendon Approach

- Palpate and mark the lateral border of the patellar tendon ([TECH FIG 1, line C]).
- Incise the skin at the lateral border of the patellar tendon.
- Full-thickness skin flaps are developed.
- Dissection is carried down to the retinaculum.
- The retinaculum is then split, and the patellar tendon is retracted medially.
- Do not incise the capsule.
Semi-Extended Position\textsuperscript{28}

Medial Parapatellar Approach

\begin{itemize}
\item Either a standard midline or limited medial skin incision can be used (\textit{TECH FIG 2}).
\item Full-thickness skin flaps are developed.
\item The distal portion of the quadriceps tendon is incised, leaving a 2-mm cuff of tendon medially for later repair.
\item A formal medial arthrotomy is done extending around the patella, leaving a 2-mm cuff of capsule and retinaculum for later repair, and continuing along the medial border of the patellar tendon.
\end{itemize}

Suprapatellar Approach\textsuperscript{30}

\begin{itemize}
\item The suprapatellar approach requires special nail insertion instrumentation as well as cannulas for guide pin placement and reaming.
\item The skin incision is made at the superomedial edge of the patella (\textit{TECH FIG 3}).
\item Full-thickness skin flaps are developed.
\end{itemize}

\textit{TECH FIG 2} • \textbf{A.} A formal full medial parapatellar approach allows for easy patellar subluxation and start site localization but requires significant dissection. \textbf{B.} The alternative is a limited medial approach. (B: Courtesy of Paul Tornetta III, MD.)

\textit{TECH FIG 3} • A partial medial parapatellar arthrotomy that is carried into the intermedius allows enough subluxation of the patella to perform semi-extended nailing. (Courtesy of Paul Tornetta III, MD.)

\textbf{Standard Intramedullary Nailing}

\textbf{Initial Guidewire Placement}

\begin{itemize}
\item Drape the leg free, including the proximal thigh. Draping the leg more distally can limit knee flexion due to bunching of the drapes.
\item Flex the knee over a bolster or radiolucent triangle
\item A padded thigh tourniquet can be applied and inflated during the surgical approach, but it must not be inflated during reaming because of the risk of thermal injury to the intramedullary canal. For this reason, a thigh tourniquet is usually omitted.
\item The starting guidewire is placed on the skin and radiographically aligned with the anatomic axis and in line with the lateral tibial spine on a true AP fluoroscopic image. The skin can be marked along the guidewire path to allow visualization of the anatomic axis without fluoroscopy (\textit{TECH FIG 4A}).
\item The appropriate surgical approach is performed.
\item The knee is maximally flexed, and the guidewire is aligned with the anatomic axis of the tibia.
\item Typically, achieving an appropriate insertion vector will require the wire to be pushed against the patella or the peripatellar tissues.
\item The anterior tibial crest is palpated for frontal plane wire alignment.
\item Lateral plane fluoroscopy is necessary to place the wire at the proximal and superior aspect of the “flat spot” and near parallel with the anterior tibial cortical line (\textit{TECH FIG 4B}).
\item The guidewire is directed 8 to 10 cm into the metaphysis.
\end{itemize}
Creating and Reaming the Starting Hole

- The opening reamer (matching the proximal nail diameter) is introduced via a tissue sleeve and inserted while carefully maintaining knee hyperflexion and biplanar alignment.
- If the knee is allowed to extend or posterior pressure is not maintained on the tissue sleeve, the starting hole will become enlarged anteriorly, and the proximal anterior cortex will be violated.
- Imprecise reaming technique leads to anteriorization of the nail and violation of the proximal anterior cortex (TECH FIG 5).

Fracture Reduction

Simple Middle Diaphyseal Fractures (Transverse or Short Oblique)

- Manual traction with gross manipulation will reduce simple transverse mid-diaphyseal fractures.
- Medially-based external fixation or distraction with a large universal distractor is helpful for reduction when no assistants are available, in large patients, or when used for provisional fixation.
- Muscular paralysis often is helpful.
- Placement of percutaneous pointed reduction forceps can be helpful in oblique and short oblique patterns to achieve anatomic or near-anatomic reduction.
- Introduce a small or large pointed clamp under fluoroscopic guidance to determine the approximate clamp application angle (TECH FIG 6A–C).
- Typically, the spike on the distal fragment is posterolateral.

Highly Comminuted Middle Diaphyseal Fractures

- Have comparison radiographic images of the uninjured extremity available to be used as a template for length and rotational reduction landmarks.
Mechanical traction with medially based half pin fixation is very helpful.

- A large external fixator or large universal distractor is equally effective.
- The proximal half-pin is placed posteriorly and parallel to the tibial plateau (TECH FIG 7A).
- The distal half pin is placed just above and parallel to the plafond (TECH FIG 7B).
- The intramedullary reduction tool available in most nail or reamer sets can be used to manipulate the proximal fragment in order to advance the tool across the fracture which achieves fracture reduction and guidewire placement.

Open Middle Diaphyseal Fractures

- Large segmental and butterfly fragments that are completely devitalized and void of soft tissue attachments should be removed and cleaned of contamination.
- These pieces can then be reintroduced into the fracture site and used to perform anatomic open reduction following passage of the intramedullary rod and interlocking. These pieces should be removed after fixation is completed because they represent a large amount of nonviable material in a high-risk wound.
- Occasionally, an osteotome is required to free near-circumferential fragments (TECH FIG 8A–C).
- If reduction is difficult, a small-fragment unicortical plate can be used to maintain the reduction during reaming and nail placement. Once interlocking is completed, the plate should be removed (TECH FIG 8D).

Passing the Guidewire

- Once optimal AP and lateral plane reduction is achieved, the wire is advanced past the level of the fracture. Verify that the wire is within the canal on both the AP and lateral views to avoid advancing too far and damaging extramedullary structures.
- In metadiaphyseal fractures, the wire must be centered in the metaphyseal segment.
- In proximal and distal fractures, blocking screws or half-pins may be required to ensure centralized positioning of the guidewire (TECH FIG 9A,C,D).
- Once centralized, the ball-tipped wire must be impacted into the subchondral bone of the tibial plafond at the
level of the physeal scar. This decreases the risk of inadvertently removing the guidewire during reaming.

- Nail length measurement can now be performed using supplied length gauges, and should be verified with lateral fluoroscopic measurement (TECH FIG 9B). The lateral view is used because it is more accurate in determining the level of the articular surface and avoiding nail prominence.

- Alternatively, inserting a guidewire of the same length to the nail entry site and then measuring the length differential between wires also provides an accurate measurement (TECH FIG 9C). However, this introduces the significant cost of a second guidewire.

- Device manufacturers supply nails in variable increments. When a length measurement falls in between lengths, choose the shorter length. A threaded end cap (usually 5, 10, and 15 mm) can be used if it is desired to bring the nail to top of the canal opening.

- Leaving the nail countersunk below the bone surface does not compromise stability in middle and distal fractures, but may complicate future nail extraction.

### Reaming the Canal

- Before reaming, estimate the narrowest canal diameter using both AP and lateral plain radiographs. Alternatively, intramedullary reamer sets typically have a radiolucent ruler that allows for intraoperative fluoroscopic verification, which should be done on both the AP and lateral views. The canal typically is reamed at least 1 mm over the isthmic diameter to minimize the risk of nail incarceration.

- Reaming should begin with an end-cutting reamer—the 8.5- or 9-mm size in most systems.

- Reamer heads should be evaluated before insertion and should be sharp and free of defects.

- Insert the reamer head into the proximal metaphysis with the knee in maximal flexion before applying power to avoid distorting the entrance hole (TECH FIG 10A).

- Reamers are advanced at a slow pace under full power.

- If the reamer shafts are not solid, but are wound, be sure to avoid using reverse when drilling, because that would cause the reamers to unwind if resistance is encountered within the IM canal.
Care must be taken not to inadvertently extract the guidewire when the reamers are removed.

Multiple techniques are utilized. First, manual downward pressure can be applied to the wire with specialized instruments, medicine cups, or cleaning cannulas (TECH FIG 10B).

Once the reamer has cleared the opening, it can be clamped and held in position (TECH FIG 10C).

For the minimally reamed technique, a single end-cutting reamer (usually 9 mm) is passed down the canal to ensure the smallest diameter nail can pass through the narrowest segment of the intramedullary canal.

In an effort to minimize thermal damage to the endosteal cortex, reaming should be discontinued within 0.5 to 1 mm of hearing the reamer head catching (“chatter”) on the endosteal cortex.

Care also should be used when there are butterfly or oblique fracture fragments. Continued reaming after encountering “chatter” may result in iatrogenic comminution and loss of reduction.

Unreamed Technique

Standard preparation technique is used for the starting hole, and the fracture is reduced.

Precise evaluation of the lateral isthmic diameter is repeated, and a small-diameter nail is selected, typically in the 7- to 9-mm range.

A good guideline is to use a nail 1 mm to 1.5 mm smaller than the narrowest measure of the isthmus on the lateral radiograph.

If lateral plane imaging is suggestive of canal diameter very close to nail size, a single pass with an end cutting reamer usually is performed to decrease the possibility of nail incarceration.

The nail is inserted and impacted in standard fashion. If significant resistance is encountered when the nail reaches the isthmus, the nail is removed to avoid incarceration or iatrogenic fracture propagation. A reamer 0.5 to 1.0 mm larger than the nail is passed down the canal, and nail passage is attempted again.

Nail Insertion

After the nail insertion handle is attached, pass a drill through the proximal screw insertion attachment and screw insertion cannulas before inserting the nail to ensure accurate alignment of the attachment.

Maintain nail rotation during insertion by aligning the center of the insertion handle with the tibial crest; consider internal rotation of the nail if distal anteroposterior interlocking bolts are deemed necessary.

Maintain knee hyperflexion during nail insertion to minimize the risk of posterior cortical abutment and iatrogenic fracture.

Impact the nail to the final depth using lateral plane fluoroscopy.

Interlocking Bolt Insertion

In simple transverse fractures, place distal interlocks first to allow for back-slapping for interfragmentary compression and gap minimization.

Usually, distal interlock bolts are placed medial to lateral.

Position the leg in slight extension and stable neutral rotation.

Rotate the C-arm to lateral imaging position and pull the tube back away from the medial side of the leg to allow for drill placement.
Rotate the leg and C-arm individually and sequentially to create a perfect circle image; optimize this view before drilling attempts (TECH FIG 11A).

After localizing the interlocking hole using a clamp and fluoroscopy, make an incision large enough to place the locking bolt. Use blunt clamp dissection until the cortex is reached.

Use a sharp drill point and place the center of the point in the center of the circle

Hold the drill obliquely to the nail axis to simplify repositioning (TECH FIG 11B).

Once the central location is achieved; align hand and drill with imaging axis.

Fluoroscopes with laser alignment guides can be helpful to assist with alignment by centering the laser on the skin incision and then placing the laser in the center of the back of the drill when preparing to drill the hole (TECH FIG 11C).

Drill to the mid-sagittal point in the tibia. Then disengage the drill from the drill bit and check the fluoroscopic image.

If the drill is accurately positioned in the center of the hole, advance the drill bit with power through the far cortex; avoid broaching the far cortex by impacting with a mallet to avoid iatrogenic fracture.

Drill the second interlock hole using the same technique but maintaining a parallel axis with the first successful drill passage.

Replace the drill with the appropriate depth gauge and check an AP image before screw length selection.

Once interlock lengths and position are verified, “back slapping” can occur to optimize compression.

Using the slotted mallet attachment on the insertion handle, superiorly directed mallet blows can be used while pressure is applied to the foot in order to compress the fracture site. Fluoroscopy should be used to monitor the amount of compression and the nail position proximally. If “back slapping” is planned, the nail should be slightly overinserted to avoid nail prominence after compression is performed.

Place proximal interlocks through drill guides.

Because the tibia is a triangle, oblique views may be used to more accurately judge screw length for transverse locking bolt measurement.

If oblique locking bolts are chosen proximally, oblique fluoroscopic views should be used prior to insertion handle removal to avoid placing long screws that are particularly symptomatic on the medial side of the knee and to avoid injury to the peroneal nerve posterolaterally.

PROXIMAL METAPHYSEAL TIBIA FRACTURES

As described in the anatomy section, proximal metaphyseal tibia fractures have a tendency to be displaced in valgus and flexion. Malunion occurs in up to 84% of proximal tibia fractures that undergo intramedullary nailing.

In addition to the technical tricks that we will discuss, nail design can be important in avoiding malunion. Nails with a more proximal bend are less likely to cause displacement of the fracture. Nail designs with oblique proximal locking bolt options have been shown to provide more biomechanical stability than designs with transverse locking bolts alone.

Several current nailing systems allow a fixed angle to be created between the nail and the proximal locking bolt by inserting an end cap that creates an interference fit with the proximal locking bolt, and others have mechanisms to allow the screw to lock into the nail.

Use of a variety of the techniques described in the following sections below often is required to achieve and maintain frontal and sagittal plane reduction. The most important element is the proper starting site and guidewire insertion vector. Posteriorly directed insertion angles will accentuate proximal fragment extension with nail
passage regardless of nail design. Medial deviation of the guidewire will lead to abutment against the steep medial cortex and lead to valgus angulation at the fracture site with nail insertion.

**Lateral Parapatellar Tendon Approach**
- After completing the lateral parapatellar approach described, the standard patient positioning is used.
- The lateral parapatellar approach allows the guide pin to be more easily placed just medial to the lateral tibial spine on the AP view and along the lateral cortex to correct the valgus angulation.
  - If a true AP view is not obtained and the leg is externally rotated, the starting point will be more medial than desired.\(^5\)
  - It is important to get enough knee flexion over the radiolucent triangle or bolster to allow for the guide pin to be placed as proximal as possible and parallel along the anterior tibial cortex to help correct the typical flexion deformity.\(^22\)

**Semi-extended Technique**
- The benefit of the semi-extended technique for proximal metadiaphyseal fractures is that the leg position helps neutralize the associated flexion deformity.\(^28\)
- The patient is placed in the semi-extended position as described earlier.
- The open medial parapatellar approach can be used (see TECH FIG 1, line C).
  - Using the previously described surgical approach, the patella is subluxated to allow for guide pin placement, reaming, and nail placement, with the knee remaining in the semi-extended position.
  - No special instruments are required.
- Suprapatellar approach\(^30\)
  - Either the superomedial or direct superior approach is used.
  - Special instrumentation is required; which instrumentation is needed depends on the specific system used.

**Adjunct Reduction and Fixation Techniques**

**Blocking/Pöller Screws**
- Screws can be placed across the intramedullary canal to create a “false” cortex in the metaphyseal area that narrows the potential space for the nail. This aids in both fracture reduction as the nail is being placed and maintenance of the reduction once the nail is seated.\(^15,26\)
- Locking bolts found in the nailing set or screws made from the same metal as the nail should be used.
- Blocking screws can either be placed prior to initial nail insertion or, if the nail is inserted and residual deformity exists, the nail can be removed and blocking screws can be inserted.
- Coronal and sagittal plane correction can be performed by placing a screw at the concavity of the deformity.
To correct valgus, the screw is placed laterally (TECH FIG 13A). To correct lateral plane extension, the screw is placed posteriorly (TECH FIG 13B).

The appropriately sized drill bit is placed with fluoroscopic assistance.

The appropriately sized screw replaces the drill bit.

The guidewire is then inserted and seated distally.

Intramedullary reaming is necessary to ensure the nail follows the newly created path.

When a screw that blocks the way is encountered, simply push the reamer head past the screw without reaming. This avoids dulling the reamer head and potentially displacing the blocking screw.

Once passed the screw, resume reaming.

After reaming is complete, insert the intramedullary nail.

If the displacement has not been corrected, it will be necessary to remove the nail, and additional screws may be added. Reaming and reinsertion of the guide-wire are required before re-inserting the nail.

Interlocking bolts through the nail are placed in the standard fashion (TECH FIG 13B,C).

Medial Unicortical Plate

If the metaphyseal fracture can be reduced but easily displaces with changes in position of the extremity, a medial unicortical plate can be used.

A medial or posteromedial (more proximally) skin incision is centered at the fracture site.

Full-thickness skin flaps are developed. If the pes anserinus tendons are encountered, they can be elevated anteriorly.

After the fracture is reduced in the coronal and sagittal planes, a plate of the appropriate length plate (either 3.5 mm compression plate, pelvic reconstruction, or one-third tubular) is applied more posteriorly and fixed with two or three unicortical screws on either side of the fracture that are long enough to maintain the reduction, but avoid impeding the passage of the intramedullary reamers and nail (TECH FIG 14).

Ipsilateral Tibial Plateau Fracture

Lag Screw Fixation for Simple Fractures

Reduce and compress the articular surface with periarticular reduction forceps through small incisions medially and laterally.

Provisionally fix the articular fracture with at least two K-wires or cannulated screw guidewires that are parallel to the articular surface.
Either cannulated or solid core screws can be used for lag screw fixation (TECH FIG 15).

If there is comminution, avoid over-compressing the articular surface.

Avoid placing screws anteriorly where the nail will be inserted.

Lateral Tibial Plateau Plate

Reduce and provisionally fix the tibial plateau component as described in Chapters TR-13 and TR-14.

Because of the difficulty of placing bicortical screws in the metaphyseal and diaphyseal areas without impeding nail insertion, a locking plate should be considered, since unicortical locking screws are available distally (TECH FIG 16).

Oblique fracture patterns, which often are encountered, are amenable to percutaneous clamp reduction (TECH FIG 17A).

Half-pin joysticks are helpful for manipulating and reducing the distal fracture segment (see Fig 3E).

With a fibula fracture near the level of the tibial fracture, fibular fixation can be helpful in achieving reduction (TECH FIG 17B). The soft tissues must be tolerant of a lateral or posterolateral approach to fibula, however.

Simple transverse fractures can be fixed with intramedullary technique using flexible titanium nails, typically 2.5 mm in diameter, or 3.5 mm intramedullary screw fixation.

Plate fixation along the lateral or posterolateral surface is used most often.

Anatomic restoration of length and rotation is critical for accurate restoration of tibial length, especially with comminuted tibial fracture patterns or when tibial bone loss is present.

Medially-based external fixation or universal distractor placement with half-pin placement just above the articular surface of the ankle joint or with fixation into the medial calcaneus often is helpful to aid in the reduction of the tibia fracture, even in the presence of stable fibular fixation.
Chapter 16  INTRAMEDULLARY NAILING OF THE TIBIA 657

TECH FIG 17 • A. Distal oblique fractures can be effectively reduced with percutaneous clamp application. B. Anatomic fibular reduction often can align a tibial fracture in near-anatomic position.

PEARLS AND PITFALLS

| Starting point | The starting point should be at the anterior articular margin and just medial to the lateral tibial spine. Starting too medial and distal for proximal metaphyseal fractures results in a valgus and flexed malunion. |
| Centering the guidewire | Center the guidewire distally on the AP and lateral views. If not centered, the nail will follow the path of the reamer and guidewire, which will malreduce the fracture. |
| Measuring nail length | Measure on the lateral view. Measuring on the AP view will potentially lead to a nail that is too long, with articular prominence causing knee pain or articular surface damage. |
| Femoral distractor or external fixator for reduction | Half-pins can be placed outside of the path of the nail. The best positions are posterior in the proximal tibia and distally very close to the subchondral bone of the tibial plafond. Placement of the proximal pin too anteriorly and the distal pin too proximally may impede reaming and nail insertion. |
| Unicortical plates for reduction | Metadiaphyseal plates contribute to stability and maintenance of reduction, and removal can lead to loss of reduction after nail passage. Diaphyseal reduction plates; however, should be removed to prevent rigid fixation of the fracture gap. |
| Blocking screws/Pöller screws | Use interlocking bolts from nail instrumentation rather than small fragment screws to avoid screw breakage during nail passage. Do not remove screws, because they provide stability and help maintain reduction. Use caution when using a drill bit because it is prone to breakage during nail insertion, and removal after nail passage may destabilize the construct. |
| Posterior malleolus | Critically evaluate the posterior malleolus in distal diaphyseal and metaphyseal fractures pre-, intra-, and postoperatively. If a posterior malleolar fracture or articular involvement is missed, ankle subluxation or displacement of the articular surface can occur with weight bearing. |

POSTOPERATIVE CARE

- Weight bearing as tolerated, unless there is articular involvement
- Posterior splint or cam walker
- Early range of motion
- Suture removal at 2 to 3 weeks postoperatively
- Strengthening after at 6-week clinic visit
  - Consider a quadriceps-specific program.
- After the 6-week visit, return clinic visits are made at 6- to 8-week intervals until the bone is clinically and radiographically healed.

OUTCOMES

- Long-term follow-up of patients treated nonoperatively reveals persistent functional deficits and dysfunction, including stiffness, pain, and loss of muscle power.\(^8,17,24,25\)
- Anterior knee pain is common (50% to 60%), and patients should be informed of this preoperatively.\(^7,13\)
- This knee pain is more common in young patients. It typically is mild and may be exacerbated by kneeling, squatting, or running
- Its occurrence is not dependent on surgical approach.
- Nail removal leads to pain resolution in about one half of patients and decreased pain in another one fourth.\(^7\)
- At late follow-up after tibial nailing, patients’ function is comparable to population norms, but objective and subjective evaluation shows persistent sequelae, including knee pain, persistent swelling, muscle weakness, and arthritis—many of which are not insignificant.
- Malunion has an unclear association with development of arthritis.
- Some authors have associated even mild deformity with increased risk of osteoarthritis.\(^14,34\)
COMPLICATIONS\textsuperscript{5,27}

Infection
- Closed fractures: about 1%
- Open fractures
  - Type I: 5%
  - Type II: 10%
  - Type III: over 15%
- Condition of the soft tissues is key for risk of infection and for outcome.

Nonunion
- Closed fractures: 3%
- Open fractures: about 1%, and may be higher, depending on the soft tissue injury
- Risk factors
  - Unreamed smaller-diameter nails with smaller locking bolts are associated with delayed or nonunion and an increased risk of locking bolt breakage.
  - Closed fractures carry a risk of severe soft tissue injury, eg, internal degloving.
- Open fractures may be accompanied by severe soft tissue injury.
  - Delayed bone grafting may be warranted for treatment of bone loss.
  - The use of RhBMP-2 is FDA-approved in open tibia fractures.\textsuperscript{9} It decreases the nonunion rate by 29%, and decreased secondary interventions. BMP-2 combined with allograft for delayed bone grafting procedures in tibia fractures with cortical defects have shown a similar rate of healing to autograft with the benefit of decreased donor site morbidity.\textsuperscript{12}
- Compartment syndrome
- Fracture pattern—transverse
- Host factors
  - Tobacco use
  - Medications: bisphosphonates, nonsteroidal anti-inflammatory drugs
  - Diabetes mellitus
  - Vascular disease
  - Malnutrition—albumin level lower than 34 g/L and a lymphocyte count below 1500/mm\textsuperscript{3}
- Infection

Malunion
- Occurs in up to 37% of all tibial nailing procedures
- Malunion is seen in as many as 84% of patients with proximal metaphyseal tibia fractures.
- These can be avoided with proper surgical techniques.

REFERENCES


Compartment syndrome remains one of the most devastating orthopedic conditions. The potential clinical sequelae and medicolegal implications of a possible missed compartment syndrome make it one of the most important entities in all of orthopedic surgery. 

Compartment syndrome is a condition, with numerous causes, in which the pressure within the osteofascial compartment rises to a level that exceeds intramuscular arteriolar pressure, resulting in decreased blood flow to the capillaries, decreased oxygen diffusion to the tissue, and ultimately cell death. This is a true orthopaedic emergency.

The clinical sequelae of a missed compartment syndrome can be life- and limb-threatening. Myonecrosis can lead to acute renal failure and multiorgan failure if not appropriately managed.20

Richard von Volkmann first documented nerve injury and subsequent contracture from compartment syndrome in 1872 following a supracondylar fracture.

In 1906, Dr. Hildebrand was the first to apply the term “Volkmann ischemic contracture” to define the end result of any untreated compartment syndrome.

In 1909, Dr. Thomas described the major causes of compartment syndrome (fractures being the predominant cause) after reviewing the 112 cases published up to that date.

The first to suggest that fasciotomy may help prevent contracture was Dr. Murphy in 1914.

It was not until 1967 that Seddon, Kelly, and Whitesides described the existence of four compartments in the lower leg and the need to decompress more than just the anterior compartment.

Any situation that leads to an increased pressure within the compartment may result in a compartment syndrome.

The impermeable fascia prevents fluid from leaking out of the compartment and also prevents an increase in volume that could reduce pressure within the compartment.

The incidence of compartment syndrome is 7.3 per 100,000 males and 0.7 per 100,000 females.

In those cases, the most common cause was fracture followed by soft tissue injury.

McQueen et al found that the incidence of compartment syndrome was nearly equal for both high- and low-energy injuries and that open wounds did not decompress the compartments and were not protective.13,14

This chapter describes acute compartment syndrome, in contrast to exertional compartment syndrome.

Exertional compartment syndrome is a transient chronic condition brought on by exercise. Unlike acute compartment syndrome, exertional compartment syndrome is not an emergency and its treatment is beyond the scope of this chapter.

The lower leg has four compartments: the anterior, lateral, superficial posterior, and deep posterior (FIG 1, Table 1).

The anterior compartment is bound anteriorly by fascia, laterally by the anterior intermuscular septum, and posteriorly by the intersosseous membrane between the fibula and tibia.

The four muscles in this compartment are the tibialis anterior, extensor digitorum longus, extensor hallucis longus, and peroneus tertius.

The neurovascular bundle includes the deep peroneal nerve and the anterior tibial artery.

The deep peroneal nerve provides sensation to the first dorsal web space of the foot and motor function to all the muscles in the anterior compartment.

The anterior tibial artery travels in this compartment just anterior to the tibiofibular intersosseous membrane and continues in the foot as the dorsalis pedis artery.

The lateral compartment is bordered anteriorly by the fascia, posteriorly by the posterior intermuscular septum, and medially by the fibula.

There are only two muscles of the lateral compartment: the peroneus longus and the peroneus brevis.

The major nerve supply to the lateral compartment is the superficial peroneal nerve, which supplies the two muscles of the compartment. The nerve supplies sensation to the dorsum of the foot, except the first dorsal web space.

Since the deep peroneal nerve courses proximally around the fibular head, both the deep and superficial peroneal nerves travel within this compartment.

There are no main vessels in this compartment, and the muscles receive their blood supply from the peroneal and posterior tibial arteries.

The deep posterior compartment contains the flexor digitorum longus, tibialis posterior, and flexor hallucis longus muscles.

Although it is not considered a separate compartment, the tibialis posterior muscle can have its own fascial covering.

The deep posterior compartment contains the main neurovascular bundle of the posterior compartment, which consists of the tibial nerve, posterior tibial artery and vein, and peroneal artery and vein.

The superficial posterior compartment contains the gastrocnemius, soleus, and plantaris muscles, which are supplied by branches of the tibial nerve, posterior tibial artery, and peroneal arteries.

There is no major artery that travels in this compartment.

**PATHOGENESIS**

Although the exact pathophysiology is not completely understood, the premise of the syndrome is either a decrease in the space available for the tissues within the fixed compartment or an increase in the size of the tissues within the compartment.
Either case can result in an increase in pressure above a critical value.

- Increased fluid content and swelling of damaged muscles can be caused by the following:
  - Bleeding into the compartment (from fractures, large vessel injury, or bleeding disorders)
  - Fractures are the most common cause of compartment syndrome. It is estimated that 9.1% of tibial plateau fractures develop compartment syndrome.3
  - Blunt trauma is the second most common cause, accounting for 23% of cases.14
  - Increased capillary permeability (e.g., burns, ischemia, exercise, snake bite, drug injection, intravenous fluids)
  - Decreased compartment size can be caused by the following:
    - Burns
    - Tight circumferential wrapping, dressings, casts
    - Localized external pressure, such as lying on the limb for an extended period of time or from pressure on the “well leg” in the lithotomy position on the fracture table
  - Elevated pressure prevents perfusion of the tissue from the capillaries and results in anoxia and necrosis.
  - The impermeable fascia prevents fluid from escaping, causing a rise in compartment pressure such that it exceeds the pressure within the veins, resulting in their collapse or an increase in the venous pressure.17
  - The final event is cellular anoxia and necrosis.20
  - During necrosis there is an increase in the intracellular calcium concentration coupled with a subsequent shift of water into the tissue, causing the tissue to swell further, adding to the pressure.4 This “capillary leakage” adds to the increased pressure in the compartment, thus creating a vicious cycle.
  - The effects on muscle and nerve function are time-dependent.
  - Prolonged delay results in greater loss of function.
  - After sustained elevation of compartment pressures greater than 6 to 8 hours, nerve conduction is blocked.10 In an animal study, irreversible muscle damage occurred after 8 hours.22
  - The exact pressure at which change within the compartment occurs has been subject to debate and has evolved over time.
    - Initially, the pressure of 30 mm Hg was reported to be the maximum pressure above which irreversible muscle damage occurred.27
    - Currently, clinicians have recognized the importance of the patient’s blood pressure when considering the compartment pressure and use an absolute difference between diastolic blood pressure and compartment pressure of 30 mm Hg as a gauge.
Animal studies have highlighted the importance of the systemic pressures relative to the compartment pressure.

- Heckman et al found that irreversible ischemic changes occurred when the compartment pressure was elevated within 30 mm Hg of the mean arterial pressure and within 20 mm Hg of the diastolic pressure.²⁷
- Studies on limb ischemia at the University of Pennsylvania had similar conclusions.
  - They coined the term “delta P” referring to the difference between the mean arterial pressure minus the compartment pressure, with a lower number reflecting less blood flow.¹
  - They found that cellular anoxia and death occur with pressure within 20 mm Hg of the mean arterial pressure; however, at pressures within 40 mm Hg there was reduced oxygen tension but no evidence of anoxia, and aerobic metabolism persisted.
- McQueen and Court-Brown used the cutoff of compartment pressure within 30 mm Hg of the diastolic blood pressure as a fasciotomy threshold.¹⁵
  - There were no adverse clinical outcomes from not releasing compartments with pressures more than 30 mm Hg from the diastolic blood pressure, and this has come to be the value currently used most often as a threshold for compartment syndrome.

### Natural History

- The outcome of compartment syndrome depends on location and time to intervention.
  - Six hours of ischemia is currently the accepted upper limit of viability. Rozarbeck and Macnab reported almost complete recovery of the limb function if fasciotomies are performed within 6 hours of the onset of symptoms.²¹
  - Muscle undergoes irreversible change after 8 hours of ischemia, whereas nerves can have irreversible damage after as short as 6 hours.¹⁰
  - Compartment syndrome may have broad effects on multiple systems.
    - As muscle necrosis occurs, myoglobin, potassium, and other metabolites are released into circulation.
    - As a result, several metabolic conditions can arise, including myoglobinuria, hypothermia, metabolic acidosis, and hyperkalemia. In turn, these biochemical phenomena can cause renal failure, cardiac arrhythmias, and potentially death.

### Patient History and Physical Findings

- The use of physical examination findings to diagnose compartment syndrome has not been well validated.²⁶ However, physical examination findings are widely used in clinical practice.
- The key to successful handling of compartment syndrome is early diagnosis and treatment. Therefore, the orthopedic surgeon must be familiar with the signs and symptoms of the diagnosis and perform a detailed documented history and physical.
- The patient’s history is critical. Certain aspects of the patient’s history may make the syndrome more likely.
  - The existence of any of the following characteristics should heighten the surgeon’s suspicion: high-energy mechanism, a patient on anticoagulation, or a patient with a tight circumferential dressing.
- A patient will often not demonstrate all of the classic “six Ps”: pain, paresthesias, pulselessness, pallor, paralysis, and pressure.
  - Pulselessness has recently been regarded as less of an indicator; patients can suffer extensive compartment syndrome with normal pulses.
  - Likewise, pallor reflects loss of arterial flow and is rarely present on physical examination.
  - Perhaps the most sensitive and earliest sign of compartment syndrome is pain with passive stretch of the muscles of the compartment.⁴
  - Pain out of proportion to the injury is also an early symptom of the diagnosis.
  - Pain may be absent if compartment syndrome is already established and nerve injury has occurred.
  - Since small fiber nerves are affected first, light touch will be affected before pressure and proprioception.
  - The ability to use pain as an indicator may be diminished in patients unable to sense pain or communicate with the caregivers; in this situation the surgeon must use other means to make the diagnosis.
  - Patients in whom pain may be difficult to ascertain include those with head injuries, those using ethanol or drugs, those who are intubated or sedated, those who have major distracting injuries such as a long bone fracture, those receiving large amounts of pain medicine, or any other factor that might alter the patient’s ability to accurately sense and communicate pain levels.
  - Pain perception may also be altered due to anesthesia, and some reports suggest that patients receiving epidural anesthesia are four times more likely to develop compartment syndrome than those receiving other forms of pain control.¹⁹
  - This type of anesthesia results in a sympathetic nerve blockade, thereby increasing the blood flow, compounding the local tissue pressures and extremity swelling.
  - Similarly, local anesthesia combined with narcotics has been shown to increase the risk of compartment syndrome.⁵,¹⁹,²⁰
  - Paresthesia can be a useful, but confusing, symptom of compartment syndrome.
    - It has been shown, however, that nerve function is altered after only 2 hours of ischemia; therefore, it represents a potentially early symptom.⁸
    - With increased pressure in a compartment, the sensory nerves will be affected first, followed by the motor nerves (e.g., in the anterior compartment, the deep peroneal nerve is affected quickly, and patients will report loss of sensation between the first two toes).
  - Paralysis is often less useful since it may be caused by ischemia, guarding, pain, or a combination of these factors, particularly in patients with a distracting extremity injury such as a tibial shaft fracture.
  - Serial examinations are critical. All complaints should be investigated thoroughly, and all findings should be carefully documented in the chart such that subsequent examiners can refer to the record as a tool for diagnosis (see Exam Table for Pelvis and Lower Extremity Trauma, page 1).
- Measurement of the compartment pressure
  - Stryker pressure monitor is most common (FIG 2).
  - Arterial line (16- to 18-gauge needle) is easy to do in the operating room, but the pressure measured with a simple needle is thought to be 5 to 19 mm Hg higher than the pressure measured with a side port or wick catheter.¹⁶
  - Pressure values should be recorded for all four compartments. Typically each compartment is checked twice. If there
that either the flexor or extensor hallucis longus is firing. “NVI” is also not useful as it does not state the exact muscle groups that were tested.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- The diagnosis of compartment syndrome is typically made clinically. There are, however, adjunct investigations that can be used to confirm or rule out the diagnosis.
- Once a patient is diagnosed with compartment syndrome, fasciotomies should be performed emergently. Any workup that could delay this process should be undertaken with great caution.
- If the patient cannot provide clinical clues because he or she is sedated or for other reasons, or if the diagnosis is in question, compartment pressures can be measured.
- Several techniques to measure compartment pressures have been described, including the Whiteside infusion technique, the Stic technique, the Wick catheter technique, and the slit catheter technique. The two most commonly used techniques are the Whiteside side port needle and the slit catheter device.
- There are numerous commercially available digital pressure monitors that are frequently used as well.
- The exact pressure that defines compartment syndrome is still debatable, although a measured pressure should be taken with reference to the diastolic blood pressure.13
McQueen et al did a prospective study on 116 tibial shaft fractures that were monitored continuously for 24 hours. They set the criterion for compartment release at a difference between diastolic and compartment pressures of less than 30 mm Hg. Following this criterion, a total of three had fasciotomies and none of the sample had late sequelae of compartment syndrome 9 months later.

The indications to measure compartment pressures include the following: one or more signs or symptoms of compartment syndrome and a confounding factor (eg, local anesthesia), unreliable examination with firmness in an injured extremity, prolonged hypotension and a swollen extremity with firmness, and spontaneous increase in pain after having received adequate analgesia.

The technique of measuring compartment pressures must be mastered by the surgeon.

Inexperience with the technique may lead to inaccurate data and potentially missed compartment syndrome.

When measuring the pressure, the surgeon must be familiar with the local anatomy and able to accurately measure all of the compartments.

Location of the measurement is important.

Heckman et al reported the highest pressures were within 5 cm of the fracture site; pressures decreased as the measurements were taken distally and proximally to the fracture. They recommended that pressures be measured close to and both distal and proximal to the fracture in all compartments. The highest measurement is compared to the diastolic blood pressure and interpreted accordingly.

Lab studies should include a complete metabolic profile, a complete blood count with differential, creatine phosphokinase, urine myoglobin, serum myoglobin, urinalysis (which may be positive for blood but negative for red blood cells, indicating myoglobin in the urine due to rhabdomyolysis), and a coagulation profile (prothrombin time, partial thromboplastin time, INR).

Obtaining a complete laboratory panel should not delay operative treatment in a diagnosed case of compartment syndrome.

DIFFERENTIAL DIAGNOSIS

Compartment syndrome is diagnosed in a patient with either:

- Suspicious clinical findings as discussed above, or
- Pressure in a compartment within 30 mm Hg of the diastolic blood pressure

Other diagnoses to consider:

- Normal pain response secondary to fracture or other trauma
- Low pain tolerance secondary to preoperative substance abuse
- Muscle rupture
- Deep venous thrombosis and thrombophlebitis
- Cellulitis
- Coelenterate and jellyfish envenomations
- Necrotizing fasciitis
- Peripheral vascular injury
- Peripheral nerve injury
- Rhabdomyolysis

Of special note, in the case of envenomations, recent studies have shown that compartment syndrome is multifactorial and that fasciotomy may not prevent myonecrosis, which may be due to the direct toxic effect of the venom and the inflammatory response.

In these cases, antivenom should be administered; this has been shown to decrease limb hypoperfusion.

NONOPERATIVE MANAGEMENT

- All patients suspected of having acute compartment syndrome should have emergent fasciotomies performed in the operating room or at the bedside.
- “Nonoperative” treatment of acute compartment syndrome is never appropriate, as this is a life- and limb-threatening injury whose successful treatment is based on limiting the time until fasciotomy is performed.
- Nonoperative treatment of compartment syndrome is reserved for patients presenting very late after a missed compartment syndrome who already have irreversible muscle necrosis.
- One school of thought is that these patients should not be debrided, as it will only increase the chance of infection.
- This is controversial and applies only to chronic, missed compartment syndrome.
- There is consensus that all acute compartment syndromes should be treated operatively with fasciotomies.
- Since ischemic injury is the basis for compartment syndrome, additional oxygen should be administered to the patient diagnosed with compartment syndrome because it will increase slightly the blood partial pressure of oxygen (PO2).
- The surgeon must ensure that the patient is normotensive, as hypotension reduces perfusion pressure and leads to further tissue injury.
- Any circumferential bandages or casts should be removed in patients at risk for development of compartment syndrome.
- Compartment pressure falls by 30% when a cast is split on one side and by 65% when a cast is spread after splitting; splitting the padding reduces the pressure by an additional 10%, complete removal of the cast by another 15%. There could be a total of 85% to 90% reduction in pressure by just taking off the cast.
- Elevating the limb above the heart decreases limb mean arterial pressure without changing the intracompartmental pressure. The affected extremity should not be elevated.
- As shown by Styf and Wiger, after an elevation of 35 cm, the mean perfusion pressure decreased by 23 mm Hg but the intracompartmental pressure stayed the same.
- Intravenous fluids should be given to decrease the chance of kidney damage from myoglobin.
- The “crush syndrome” is a sequela of muscle necrosis (ie, high creatine phosphokinase level, above 20,000 IU) and manifests as nonoliguric renal failure, myoglobinuria, oliguria, shock, acidosis, hyperkalemia, and cardiac arrhythmias.
- Treatment is supportive, with ventilatory support, hydration, correction of acidosis, and dialysis.
- It is important in this situation to decrease the metabolic load by preventing ongoing tissue necrosis and debriding all dead tissue.
- The use of narcotics should be closely recorded and monitored in any patient suspected of having compartment syndrome.
- The use of local, spinal, or epidural anesthesia for postoperative pain control is generally discouraged in patients at high risk for compartment syndrome as it limits the ability of the clinician to do serial examinations.
SURGICAL MANAGEMENT

- All patients with acute compartment syndrome should be treated with emergent fasciotomies of the affected compartments, as compartment syndrome is limb-threatening as well as potentially life-threatening if allowed to progress to myonecrosis and renal failure.
- Time to diagnosis and surgical treatment of compartment syndrome is critical, as nerve damage after 6 hours of ischemia may be irreversible.
- Patients with compartment syndrome should be given the highest priority and treated as an operative emergency.
- Fasciotomy of the involved compartment is the standard of care for compartment syndrome.
  - In a trauma setting, typically all four compartments of the leg are released, regardless of evidence of involvement of the other compartments.
  - Fasciotomies should ideally be performed in the operating room.
  - If the patient is too ill to be transported to the operating room or there is no operating room available, fasciotomies can be performed at the bedside in as sterile an environment as possible.
  - The only contraindication to fasciotomy in the face of a compartment syndrome is delayed presentation, in which a patient with missed compartment syndrome presents more than 24 to 48 hours after irreversible injury has set in.
- Operative treatment is hypothesized to increase infection.
- It is often difficult to know when a compartment syndrome occurred, however, so in situations in which it is unclear, it is probably wise to release the compartments.
- One school of thought is that if the compartment syndrome has run its course, fasciotomies should not be performed unless the pressure in the compartment is within 30 mm Hg of diastolic pressure.
- Fasciotomies are also often performed in a prophylactic manner for any patient with an ischemic limb for more than 6 hours to prevent reperfusion injury.

Preoperative Planning

- Once compartment syndrome is diagnosed, every effort should be directed at getting the patient to the operating room as quickly as possible for fasciotomies.
- All further workup should be deferred until fasciotomies are complete, except workup that is needed for a potential life-threatening injury.
- There is little preoperative planning required for this component of the patient’s treatment.
- Radiographs should be reviewed to rule out fractures or dislocations; however, additional radiographs can be taken in the operating room after fasciotomies have been completed.
- Only essential preoperative workup should be done before the patient is taken to the operating room, and the case should certainly not be delayed for additional, nonessential radiographic workup.

Positioning

- The patient is usually positioned supine on the operating room table to facilitate fasciotomies. A small bump may be placed under the affected hip.
- The leg is prepared in a sterile fashion and a thigh tourniquet is applied but not inflated.

Approach

- Two separate techniques have been used for decompression of the lower leg compartments.
  - The two-incision technique is the most commonly used method, but a one-incision technique involving a lateral (perifibular) approach also exists.
  - The two-incision technique is more straightforward and requires less experience to ensure a complete compartment release and therefore is typically advocated.
  - Some have argued that the one-incision technique may be useful in defined anterior tibial artery injuries to help prevent loss of anterior skin.

DOUBLE-INCISION TECHNIQUE

Anterolateral Incision

- The anterolateral incision decompresses the anterior and lateral compartments.
  - The anterolateral incision is made halfway between the fibula and the crest of the tibia and lies just above the intermuscular septum dividing the anterior and lateral compartments (TECH FIG 1A).
  - Fasciotomies have also been accomplished through small incisions. However, we prefer using generous incisions to allow for full decompression of the compartments.
  - We recommend incisions that are typically at least 15 to 20 cm both medially and laterally.
  - A small transverse incision is performed to identify the intermuscular septum, after which scissors are used to split the fascia of the anterior and lateral compartments.
  - Care must be taken to avoid injuring the superficial peroneal nerve by making separate incisions in each compartment and not cutting the intermuscular septum (TECH FIG 1B–F).

Posteromedial Incision

- The posteromedial approach decompresses the superficial and deep posterior compartments.
  - The incision lies about 2 cm posterior to the posterior tibial margin (TECH FIG 2A).
  - Care is taken to avoid injury to the saphenous vein and nerve, which are retracted anteriorly.
  - A small transverse incision is made to allow visualization of the intermuscular septum between the deep and superficial posterior compartments, after which the fascia of each is incised longitudinally in line with the incision (TECH FIG 2B–E).
  - The deep posterior compartment is initially released distally, and then the scissors are oriented proximally through and under the soleus bridge.
  - It is crucial to release the soleus attachment to the tibia more than halfway. Also, the fascia over the posterior tibial muscle should be released.
  - One useful tip is to keep the tips of the scissors away from major neurovascular structures.
TECH FIG 1 • Lateral incision of the two-incision technique. A. The anterolateral incision is made halfway between the fibula and the tibial crest overlying the intermuscular septum dividing the anterior and lateral compartments. B. Close-up picture of the fasciotomy site after skin incision before fascia is open, showing the intermuscular septum between the lateral and anterior compartments as well as the course of the superficial peroneal nerve. C. With a knife, a small transverse incision is made over the intermuscular septum. Care is taken to avoid injury to the superficial peroneal nerve. D. The surgeon inserts the tips of the scissors into the small rent in the fascia, and keeping the tips of the scissors up and away from the superficial peroneal nerve, the surgeon incises the fascia over the anterior compartment distally. E. The scissors are turned with the tips proximally, and the fascia of the anterior compartment is released proximally. F. The tips of the scissors are then inserted into the rent created in the fascia of the lateral compartment. Keeping the tips of the scissors up and away from the superficial peroneal nerve, the surgeon releases the fascia over the lateral compartment proximal and distal.
ONE-INCISION TECHNIQUE

- The one-incision technique often requires more careful dissection around major neurovascular structures and can prove to be more challenging. For this reason it is less often used.
- A straight lateral incision is created that originates just posterior and parallel to the fibula at the level of the fibular head (protecting the peroneal nerve) to a point above the tip of the lateral malleolus (TECH FIG 3A).
- Posterior to the fibula, access is gained to the deep and superficial posterior compartments (TECH FIG 3B).
- The fascia between the soleus and flexor hallucis longus is identified distally and released proximally to the level of the soleus origin (TECH FIG 3C).12
- Anterior to the fibula, the anterior and lateral compartments are decompressed, taking care to avoid injury to the superficial peroneal nerve.
MUSCLE DÉBRIDEMENT

- Regardless of the choice of fasciotomy performed, devitalized muscle is débrided as necessary.
  - Muscle viability is ascertained by the presence of healthy color and the ability to contract when pinched gently or touched with the electrocautery.
  - Necrotic muscle serves no function and must be removed eventually, as it will form a culture medium for infection after fasciotomy.
  - Extensive débridement is not typically undertaken until the second look at 36 to 72 hours, when muscle viability is more readily determined.

- When fasciotomies are performed in the setting of fractures, the fractures are stabilized with either internal or external fixation, which eliminates the need for constricive casts and allows access for clinical examination, repeat pressure measurements, and wound care.
  - Fixation of fractures may trigger compartment syndromes through traction and reaming.

CLOSED OF FASCIOTOMIES

- Fasciotomies are typically not closed acutely because the skin itself can constrict muscle.
  - Most often fasciotomy wounds are either packed with moist dressings (TECH FIG 4A) or covered with a sterile vacuum sponge and kept under suction until the next débridement (TECH FIG 4B).
  - Following a lower leg fasciotomy, a useful technique has been the shoelace closure, which involves using a vessel loop and skin staples to gradually close large areas of gaping skin.
    - This allows gradual approximation of the skin edges over the course of several days, thus potentially obviating the need for a skin graft (TECH FIG 4C).

- If two surgical wounds are present, the surgeon should attempt to close the medial wound secondarily before the lateral.
  - The lateral side of the leg has better soft tissue coverage and consequently is easier to skin graft over if one of the wounds cannot be closed.
  - Sometimes small relaxing incisions around the fasciotomy wound can decrease the tension, enhancing the chance of healing (TECH FIG 4D).
POSTOPERATIVE CARE

Once decompressed, the extremity should be covered in a bulky dressing, splinted with the foot in neutral, and elevated above the level of the heart to promote venous drainage and reduce interstitial fluid.

- The foot should be splinted in neutral to prevent equinus contracture.
- The patient must be closely monitored for the systemic effects of compartment syndrome. See the discussion in the nonoperative section regarding administration of supplemental oxygen, intravenous hydration, mannitol, and hyperbaric oxygen.

In 1993 the average litigation award was $280,000 for eight cases of missed compartment syndrome (in all eight no compartment pressures were ever measured).24

PEARLS AND PITFALLS

- Medicolegal pitfalls: When in doubt, the surgeon should measure and document pressure in all compartments of the involved extremity. The surgeon should clearly document in the patient’s chart that the patient does not have compartment syndrome at this time if the clinical examination findings and pressures are negative.

- The surgeon should consider the possibility of equipment error.

- The surgeon should fully release all four compartments along with the soleal leash and posterior tibial fascia.

- No tight postoperative dressings should be used.

- Skin can cause increased pressure, so the surgeon should not close acutely.

- In 1993 the average litigation award was $280,000 for eight cases of missed compartment syndrome (in all eight no compartment pressures were ever measured).24

- Needles can be misplaced in tendons, fascia, or wrong compartment. All pressure readings must be interpreted within the context of the clinical presentation.

TECH FIG 4 • Closure of fasciotomies. A. Moist dressings covering the fasciotomy wound. B. Sterile vacuum system applied to the fasciotomy site, with vacuum suction set between 100 and 125 mm Hg. C. Small relaxing incisions made around the fasciotomy site to release tension and allow an easier closure. D. Bootlace technique for approximating the edges of a fasciotomy wound.
granulation and to lessen exposure of muscle and tendon. A flap may be needed if nerves, vessels, or bone is exposed.
- If delayed primary closure is planned, small relaxing incision can be done.
- Hyperbaric oxygen has been used because it reduces tissue edema through oxygen-induced vasoconstriction while maintaining and increasing oxygen perfusion.
- However, its opponents argue that hyperbaric oxygen leads to reperfusion injury following compartment syndrome.
- Other agents that have been found to affect recovery from compartment syndrome include allopurinol and oxypurinol, superoxide dismutase, deferoxamine, and penta fraction of hydroxyethyl starch. These agents are antioxidants and scavengers for damaging free radicals.

OUTCOMES
- Outcomes are generally poor if the compartment syndrome is diagnosed and treated in a delayed fashion. Results are better with earlier treatment.
- In a study by Sheridan et al, 50% of patients were decompressed within 12 hours and 50% were decompressed after 12 hours. Sixty-eight percent of the patients decompressed within 12 hours had normal leg function, whereas only 8% of the delayed group had normal function.
- If untreated, Volkmann ischemic contractures develop, leading to claw toes, weak dorsiflexors, sensory loss, chronic pain, and eventually amputation.

COMPLICATIONS
- Most patients (77%) complain of altered sensation within the margins of the wound. Fortyeight percent report dry, scaly skin, 33% pruritus, 30% discolored skin, 25% swollen extremity, 26% tethered scars, 13% recurrent ulcerations, 13% muscle herniation, 10% pain related to the wound, and 7% tethered tendons.
- Severe prolonged tissue ischemia resulting in necrosis of the muscles leads to fibrosis of the muscles and contracture that may continue over a period of several weeks.
- This is known as Volkmann ischemic contracture.
- The late sequelae of compartment syndrome are weak dorsiflexors, claw toes, sensory loss, chronic pain, and eventually amputation.
- Delayed fasciotomy after 12 hours has a reported infection rate of 46% and an amputation rate of 21%.
- The complication rate for delayed fasciotomies is also much higher (54%) than that for early fasciotomies (4.5%). Therefore, the current recommendation is that if the compartment syndrome has existed for more than 24 to 48 hours and the compartment pressures are not within 30 mm Hg of diastolic pressure, supportive treatment for acute renal failure should be considered, the skin is not violated, and plans should be made for a later reconstruction.

REFERENCES
In orthopedic surgery, the terms *pilon* and *plafond* have been loosely translated and interchangeably used to describe the weight-bearing portion of the distal tibial articular surface. These injuries account for about 1% of all lower extremity fractures and 5% to 10% of tibial fractures. Most orthopedic surgeons will encounter these injuries during the course of their practice; thus, a basic understanding of their characteristics and their management possibilities is important for any practicing orthopedist exposed to trauma. Open reduction with internal fixation (ORIF), even if through a limited approach, remains the basis by which most plafond fractures are operatively stabilized. As established by Ruëdi and Allgöwer, the goals of any surgery for plafond fractures should include precise articular reconstruction, restoration of extremity length and alignment, stable fracture fixation, and early joint motion. Despite its widespread application in this respect, open treatment presents some difficulties in the management of these fractures because it can compromise the thin soft tissue envelope surrounding the distal tibia. Modern techniques in fracture care are useful in minimizing complications associated with such open treatment in this unique location.

### ANATOMY

Pilon fractures involve the weight-bearing articular surface of the distal tibia. In about 90% of cases, there is an associated distal fibula fracture. The talus is predominantly cartilage-covered and sits in the ankle mortise beneath the tibial plafond. It is restrained medially and laterally by the malleoli.

### PATHOGENESIS

The mechanism of injury for articular fractures of the distal tibia usually involves some degree of axial compression as the dense talus impacts into the tibia’s distal articular surface. The distinction between fracture patterns is thus attributed to a number of other associated variables, such as the amount of rotational force involved, foot (talus) position during loading, bone quality, and energy of impact. Highly comminuted articular injuries usually occur because of high-energy axial loading forces, while spiral fractures with minimal articular injury are presumed to result from lower-energy rotational forces. True bending injuries are seen less commonly and may be caused by low- or high-energy causes. Despite the absence of a clear spectrum of injury severity, an estimation of the energy involved in a plafond fracture can be assumed from aspects other than the tibial fracture pattern itself (eg, history, soft tissue injury, associated injuries).

About 20% to 40% of plafond fractures are open, reflecting the severity of the injury and the need for aggressive soft tissue management.

Associated injuries should be carefully investigated because 5% to 10% of plafond fractures are bilateral, 30% of patients have ipsilateral lower extremity injuries, and 15% have injuries to the spine, pelvis, or upper extremities. Although a number of injury combinations are possible in the distal tibia, characteristic patterns can often be identified. Understanding the pattern of injury is critical to formulating an optimal treatment plan. Lower-energy metaphyseal or diaphyseal involvement of the tibia is spiral in nature with a cortical spike that can guide the reduction.

Metaphyseal comminution just above the articular plafond is frequently produced under high-energy axial loading, as the talus impacts into the corresponding weight-bearing surface of the tibia. In such injuries, the anterior plafond is often comminuted and impacted into the adjacent metaphysis. The degree of anterior articular plafond involvement is related to foot (talus) dorsiflexion at the time of impact.

The Orthopaedic Trauma Association’s Committee for Coding and Classification has developed its alphanumeric system from the AO/ASIF. This alphanumeric system is popular among fracture surgeons and is used in most current reports of fracture treatment.

Distal tibial fractures are designated as types 43-A, B, and C, with further subgrouping based on specific fracture characteristics (FIG 1).

- The three major types—A (extra-articular), B (partial articular), and C (intra-articular extension with complete separation between the articular fracture fragments and the tibial shaft)—are further divided into subgroups based on the amount of fracture comminution, articular depression, and overall displacement.
- Cole et al mapped 38 consecutive AO/OTA 43-C3 (complex articular) plafond fractures with CT scans and found that all plafond fractures in this category exited the tibiofibular joint laterally and at two separate locations medially to create a coronally oriented Y pattern with three major fragments (FIG 2A). There were also varying amounts of articular comminution anterolaterally or anteromedially (FIG 2B).

The three “major” plafond fragments seen in comminuted complete articular (AO/OTA 43-C) injuries can be described as follows:

- First, a posterior plafond fragment develops with a fracture line exiting 1 to 4 cm proximal to the articular surface (in partial articular injuries [AO/OTA 43-B], the posterior plafond often remains intact).
- An anterolateral plafond fracture fragment of varying size separates with its anteroinferior tibiofibular ligament attachment. This anterolateral tubercle of Chaput requires fixation to restore the anatomy and function of the syndesmosis complex.
- A medial malleolar fracture is identified as the third characteristic fragment.
In the Orthopedic Trauma Association's alphanumeric classification, distal tibia fractures (OTA 43) are grouped into types 43-A (extra-articular), 43-B (partial-articular), and 43-C (complete-articular). Each type is subgrouped based on specific fracture characteristics.
In contrast to high-energy patterns, rotational injuries (Fig 3) cause spiral fractures of the distal tibia and fibula originating at the articular level. Intra-articular injury, if present, is typically simple and without comminution or impaction.

**NATURAL HISTORY**

- On one end of the spectrum, high-energy vertical compression injuries result in comminuted articular fractures with compromised surrounding soft tissues. On the other end, low-energy rotational injuries with minimal axial compression produce more straightforward spiral fractures with less soft tissue damage and a more favorable prognosis.
- Where a particular fracture pattern falls within this spectrum can often predict the eventual outcome of the injury.
- Unfortunately, determining the outcomes from these fractures is not straightforward as existing classification systems fail to clearly distinguish the spectrum of injury, making a fair comparison of published outcomes difficult to achieve.
- What is clear is that the surgeon maintains an important role in affecting the final outcome of these injuries, principally by designing a treatment plan that accomplishes the surgical goals set out above while minimizing the risks of complications.
- Established variables that clearly affect outcome include avoiding complications while restoring a congruent articular surface and the axial alignment of that articular surface relative to the shaft.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The injury history is usually clear and often involves a fall from heights, a motor vehicle crash, a motorcycle crash, or a sports injury. Occasionally, a patient will simply miss a step on stairs or a curb; this atypical history should initiate an investigation for osteoporosis.
- These patients are usually injured by high-energy means and should be evaluated as trauma patients and according to ATLS protocols.
- All associated injuries must be identified and formulated into the global treatment plan.
- Low-energy mechanisms should alert the surgeon to suspect osteoporosis and initiate an osteoporosis evaluation.
Comorbidities such as diabetes mellitus, vascular disease, tobacco use, chronic immune or inflammatory diseases, and others may affect treatment and risk stratification. The medication profile should be assessed for blood thinners, anti-inflammatories, and others that may affect surgical risk or bone metabolism.

A meticulous examination with special attention to soft tissue and neurovascular status is important in the evaluation and classification of these fractures (Tables 1 and 2).

With wound complication rates having a historic potential of 50%, recognition and appropriate management of the soft tissue injury cannot be overemphasized.

The physician should inspect for wounds, swelling, blisters, ischemic skin, and chronic skin and vascular changes.

The physician should identify open fractures and establish the “personality” of the injury.

Areas of swelling or ecchymosis, breaks in the integument, and the presence or absence of fracture blisters should be identified and documented preoperatively.

A careful vascular examination is important in evaluating patients with high-energy pilon injuries, as arterial compromise appears to be more common than previously appreciated (which may help explain the relatively high complication rates seen with early ORIF).

Findings of vascular compromise may be subtle (such as a one-vessel injury [eg, anterior tibial artery]) owing to collateral or retrograde flow patterns. Arterial compression testing (Allen test) about the ankle or the addition of angiography to CT may be a useful tool to further evaluate the local vasculature.

Rarely, compartment syndrome may also occur, creating the need for urgent operative intervention.

### Table 2: Gustilo and Anderson System for Grading Open Fractures

<table>
<thead>
<tr>
<th>Grade</th>
<th>Type of Trauma</th>
<th>Wound Size</th>
<th>Soft Tissue Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Low energy</td>
<td>&lt;1 cm</td>
<td>Minimal</td>
</tr>
<tr>
<td>II</td>
<td>Intermediate energy</td>
<td>&gt;1 cm</td>
<td>Moderate</td>
</tr>
<tr>
<td>III</td>
<td>High energy</td>
<td>&gt;10 cm</td>
<td>Severe, with crushing</td>
</tr>
</tbody>
</table>

The diagnosis of tibial plafond fracture is initially evaluated with three radiographic views of the ankle (anteroposterior [AP], mortise, and lateral; **FIG 4A,B**).

These views should be repeated after all “reductions,” including application of temporizing external fixation.

CT scans have been clearly shown to improve a surgeon’s understanding of the injury (**FIG 4C**) and are critical to preoperative planning for complex injuries.\(^1^5\)

For displaced, comminuted pilon fractures, the best time to obtain a CT scan is after temporizing external fixation is performed (**FIG 4D**), when the fracture is brought out to length with traction. This tends to grossly reduce many parts of the fracture, making the pathoanatomy of the injury more understandable (**FIG 4E,F**).

The addition of angiography to CT is sometimes useful for assessing the arterial tree of the distal leg before plafond reconstruction, if vascular injury is suspected (**FIG 4G**). Occult vascular injuries, especially of the anterior tibial artery, are not uncommon in patients with high-energy plafond fractures.

### Differential Diagnosis

- Tibial shaft fracture
- Ankle fracture or dislocation
- Talus fracture

### Nonoperative Management

Nonoperative treatment should be reserved for nondisplaced or minimally displaced fractures that are determined to be stable and have little comminution and soft tissue injury.

This scenario is uncommon, however, as the amount of energy necessary to fracture the tibial plafond typically results in significant fracture displacement and resultant instability.

Some consideration may be given to nonoperative treatment in the infirm or neuropathic patient, although the risks of splinting or casting are often greater than for operative treatment.

Attempts at casting or splinting unstable plafond fractures in patients considered to be poor candidates for operative treatment (eg, elderly, diabetes, vasculopathy) are fraught with risks for progressive deformity, skin breakdown, and amputation.

The presence of other musculoskeletal injuries becomes a strong indication for surgical treatment to the tibia as surgical stabilization may allow for easier mobilization and rehabilitation.

Reasonable nonoperative treatment options include non-weight bearing with casting or bracing until radiographic signs of healing are visualized.

Regular follow-up radiographic vigilance is recommended to ensure that articular congruity and axial alignment of the lower leg remain satisfactory.

Protected weight bearing must be individualized in each case, but usually at least 10 to 12 weeks is necessary to safely expect alignment to be maintained.

### Surgical Management

Displaced tibial plafond fractures generally require surgery. ORIF is the preferred method of treatment for such displaced fractures to achieve the goals previously outlined by Ruédi and Allgöwer.\(^1^1\)
Preoperative Planning

Understanding the personality of the injury, including soft tissue problems, patient problems, and the fracture configuration, is critical to formulating an optimal treatment plan.

Preoperative planning allows the surgeon to work through the case “on paper” while minimizing risk and often preventing unnecessary delays during the surgery.

A preoperative tracing (FIG 5) can help with instrumentation needs, surgical approaches, anticipated reduction methods, and implant strategies (selection and placement).

CT data often allow the surgeon to choose the optimal approach to address the articular pathology and apply implants (eg, anteromedial versus anterolateral approaches for most AO/OTA 43-C fractures).

Positioning

Most pilon fractures are approached anteriorly; thus, the patient is typically positioned supine on a radiolucent table.

A roll behind the hip may help control external rotation of the leg during surgery.

Tourniquet control is often helpful to allow for visualization, particularly of the ankle joint.

The preparation and draping is carried above the knee to make the Gerdy tubercle region available if any autogenous bone graft is needed.

The temporary external fixation pins are incorporated into the preparation and draping. These pins are used intraoperatively for distraction through the external fixator itself or, alternatively, through a universal (femoral) distractor. The pins are isolated with Ioban.

Such distraction is helpful in obtaining reduction and provisional stabilization of the articular surface and can also be used during initial plate placement and screw fixation.

For posteromedial approaches the patient may still be positioned supine, but in this case the surgeon may desire the leg to be externally rotated, and a bump under the contralateral hip may be helpful.

When the posterolateral approach is used, the patient is best positioned prone (or lateral) to allow the surgeon comfortable access to the posterior leg.

Approach

Although historically a single “utilitarian” approach was popular in the reconstruction of the tibial plafond, a variety of surgical approaches are currently used to treat these fractures (FIG 6).

In principle, less dissection and soft tissue retraction, as well as optimal implant placement, should be possible using more direct approaches.

As with other complex injuries, the selection of an approach that addresses the personality of each injury is recommended for plafond fractures.

These more customized approaches should adhere to the following principles:

- Effective soft tissue handling
- Maintenance of a reasonable skin bridge between incisions (especially if these incisions are long or extensile)
- Placing skin incisions directly over bone should be avoided if possible. Thus, if skin problems occur, resultant tissue defects can be reconstructed with a simple skin graft or fasciocutaneous flap as opposed to a free soft tissue transfer.

Howard et al recently reported a series of 46 plafond fractures in 42 patients in which 106 skin incisions were used, creating 60 skin bridges. The mean skin bridge size was 5.9 cm; only 16% were greater than 7 cm. All incisions other than two healed uneventfully, and no deep infections or skin bridge compromises were recorded.
Chapter 18 ORIF OF THE PILON

Anterolateral approach

Anteromedial approach

Posteromedial approach

Posterolateral approach

Sural n.

Anterior tibial artery and vein

Posterior tibial artery and vein

Deep peroneal n.

Fibula

Peroneus longus m.

Peroneus brevis m.

Saphenous v.

Tibialis anterior tendon

Tibial n.

Flexor hallucis longus m.

Achilles tendon

Extensor hallucis longus

Extensor digitorum communis

Anterior tibial artery and vein

FIG 6 • Approaches to the tibial plafond are probably best tailored to match the injury pattern. More than 90% of plafond fractures are well approached anteriorly (anteromedially or anterolaterally), but other approaches are sometimes useful.

ANTEROMEDIAL APPROACH

The traditional “AO,” or anteromedial, approach to the tibial pilon uses an anteromedial incision directed longitudinally a centimeter or so lateral to the anterior tibial crest and crossing in a gentle oblique fashion over the tibialis anterior tendon to allow for careful medial column exposure (TECH FIG 1).

We use this anteromedial approach for injuries in which the bulk of the articular injury is medial and the anterior cortex fracture propagates medially along the distal tibia.

Accessing the far lateral joint surface using this approach requires a fairly vigorous retraction of the anterior ankle soft tissues (a small anterolateral incision can sometimes be used concomitantly with the anteromedial approach to reduce or stabilize the anterolateral fragment).

TECH FIG 1 • A–C. Imaging of 43-C3 plafond injury with anteromedial cortical split allowing best access to injury through anteromedial approach. (continued)
- Dissection is full thickness and carried medial to the tibialis anterior tendon so as not to create multiple tissue dissection planes.
- Careful handling of the subcutaneous tissue is mandatory.
- The paratenon of the tibialis anterior tendon should not be disrupted.
- Extensive periosteal stripping of fracture fragments is avoided and fragments are carefully hinged on their soft tissue attachments to preserve their vascularity.
- Hinging open the anterior fragments like a book using a small lamina spreader reveals the involvement and displacement of the central and posterior articular plafond and metaphysis.
- Once the extent of the fracture is appreciated, reduction and fixation can be performed.

Many surgeons have recently begun using an anterolateral approach for plafond injuries in which the essential features of the injury are more laterally located (TECH FIG 2).
- This approach to the ankle has been nicely described by Herscovici et al.5
- The dissection proceeds just lateral to the extensor digitorum longus and peroneus tertius. The anterior tibial neurovascular bundle remains medial.
- Superficial peroneal nerve branches will be encountered and should be protected.
- If a narrow skin bridge occurs between this approach and the fibular incision, this approach should be kept short (eg, 4 to 5 cm) and used for the articular reduction.

In some cases, the articular injury can be addressed through a small anterolateral approach and attachment of the reconstructed articular segment to the intact diaphysis is accomplished by inserting an anterolateral submuscular or anteromedial subcutaneous plate.
- Proximal fixation can then be applied in a more “open” manner outside the zone of injury.
- Alternatively, if the fibula and plafond are being repaired at the same operative visit, a single gently curved skin incision placed over the syndesmosis can be used to access both bones.
- Here, too, the superficial peroneal nerve will be encountered and should be protected.
**TECH FIG 2 • A–C.** Imaging of 43-C3 pilon fracture with mostly anterolateral injury pathology. **D.** Anterolateral approach. This is a modification of Bohler’s incision, in line with the fourth metatarsal and extending proximally between the tibia and fibula.
POSTEROMEDIAL AND POSTEROLATERAL APPROACHES

- Additional approaches include the posteromedial and posterolateral approaches.
  - These methods are not commonly employed but may be most useful in combination with other approaches.
  - Both allow for minimal access to the articular surface such that complex intra-articular injuries are not well addressed through these approaches alone.
  - They are effective, however, for aiding in reduction of hard-to-reduce posterior fragments and applying small buttress plates that may improve the fixation stability of individual posterior articular segments.
- The posteromedial approach uses a skin incision posterior to the medial face of the tibia and requires mobilization of (and inherent risk to) the posterior tibial tendon and posterior tibial neurovascular bundle (see Fig 6).
  - There are essentially three intervals to access the posteromedial tibia via this approach, depending on the fracture configuration and how far posterior the surgeon must reach:
    - Anterior to the posterior tibial tendon
    - Between the posterior tibial tendon and the flexor digitorum communis tendons
    - Between the flexor digitorum communis tendon and the posterior tibial neurovascular bundle
  - The retinaculum is incised and repaired at the time of wound closure.
- The posterolateral approach to the distal tibia creates some logistical problems as the patient is best positioned prone (or lateral).
  - The skin incision is placed 1 to 2 cm posterior to a standard fibular incision and can easily be combined with fibular repair.
  - This approach uses the interval between the peroneal tendons and flexor hallucis longus (TECH FIG 3). Fairly extensile and safe exposure to the posterior aspect of the distal tibia is possible using this approach.
  - The posterior cortex fracture is usually fairly simple and can be used to gauge reduction. Small or mini-fragment buttress plates are often useful here.

TECH FIG 3 • The posterolateral approach uses the interval between the peroneal and extensor hallucis longus muscles and allows for wide exposure of the posterior distal tibia. Access to the fibula can also be easily gained through this incision.

REDUCTION AND FIXATION OF THE FIBULA

- Consideration about placing and timing of the fibular repair must be thoughtful to prevent limiting approaches to the tibia.
- The fibula is often reduced and fixed first to indirectly reduce the tibia fracture. It is sometimes repaired at the time of the external fixator application during staged treatment.
- In this context, the fibula must be well reduced or the tibial reduction will be impaired.
- If staged treatment is employed with external fixation applied at a referring hospital, most tertiary centers prefer the fibula to remain unfixed, thus allowing for maximal flexibility for the surgeon providing definitive treatment.
- If separate approaches are to be used for tibial and fibular repair, the fibular incision is often made more posteriorly than for most fibular repairs to maintain an optimal distance from anticipated anteromedial or anterolateral incisions.
- The posterolateral approach to the distal fibula is also a good option because it falls between the major distributions of the sural and superficial peroneal nerves. The patient can be discharged and remain mobile for daily activities while awaiting soft tissue improvement.
ARTICULAR REDUCTION AND FIXATION OF THE PILON

- The first priority in ORIF of complex articular injuries, such as with pilon fractures, is accurate realignment of the joint surface and rigid internal fixation.
- Once stabilized, the articular segment can then be attached to the tibial diaphysis through open or minimally invasive plating (or external fixation).
- Many times, reduction of the articular segment and reduction of the metadiaphysis are performed simultaneously.
- Nonreconstructable loose bodies are débrided.
- Regardless of the approach chosen as the most appropriate by the surgeon, careful and precise articular reconstruction must be achieved.

- Less than 2 mm of articular incongruity is typically considered acceptable.
- With joint distraction (femoral distractor or external fixator), the anterior two thirds of the joint should be readily accessible through an anterior approach.
- A lamina spreader is often helpful for “booking open” vertical cortical fractures to access impacted articular fragments (TECH FIG 4A–D).
- One articular fragment is reconstructed to another until all important fragments are addressed.
- Sometimes the talar dome can be used as a template for articular plafond reduction.

**TECH FIG 4** • **A–C.** Imaging of a typical 43-A3 plafond injury. (The a and b in C correspond to the fragment labeling in E.) **D.** The anterior cortical split is opened like a book and held with a lamina spreader. Dissection is limited to that necessary for reduction and plating. Direct visualization of the anterior two thirds of the joint is typically available and may be enhanced with use of a distractor (or external fixator). **E.** In some extreme cases such as this, major articular fragments are reconstructed with Kirschner wires, mini-fragment screws, or absorbable pins on the back table. **F.** Clamps and provisional fixation with Kirschner wires can be placed through the wounds or percutaneously (carefully).
This reconstruction should be provisionally stabilized with multiple Kirschner wire fixation (TECH FIG 4E).

- Direct visualization of the joint and radiographic guidance should be critically evaluated.
- The posterior plafond can be difficult to reduce from an anterior-based exposure. Ankle positioning often affects the position of this fragment.
- Sometimes, wire joystick manipulation or the use of a sharp pick or careful pointed clamp application is necessary to obtain an adequate reduction of posterior fragments.
- Posterior approaches may also be necessary, especially if displaced posterior fracture lines exit "low" (ie, they do not extend proximally).
- Provisional wires can be used as guidewires for cannulated screws if needed.
- Small and mini-fragment screws are useful and should be placed before removal of the provisional wires.
- Once articular reconstruction is complete, the disimpressed metaphyseal area is evaluated for bone grafting needs.
- For autograft, the Gerdy tubercle region is easily accessible and less painful than the iliac crest and can provide an adequate amount of graft in most cases.
- If additional graft is required or the patient does not want to risk autograft morbidity, a synthetic graft or allograft chips are usually a suitable alternative (operative consent should reflect the potential for graft use).

### EXTRA-ARTICULAR (METAPHYSEAL) REDUCTION AND FIXATION OF THE PILON

- Once the articular reduction is completed, reattaching the distal articular segment to the diaphysis is accomplished (in many cases, this is done simultaneously).
- We prefer plate fixation, although some surgeons use external fixation after a limited ORIF of the articular surface.
- Currently, “anatomically” contoured low-profile, small-fragment plates (with locking capability) designed for the distal tibia are available from most implant vendors.
- The anatomic design of these implants affords a satisfactory match to the anteromedial or anterolateral (TECH FIG 5) surface of the distal tibia.
- Traditionally, we have used the small fragment plates, which allow easy and precise contouring for an appropriate bony fit.
- Nonlocking screws are used first to bring the plate in close apposition to bone to minimize the plate’s prominence against the soft tissues.
- Subsequent insertion of locking screws, creating a “hybrid” internal fixation construct, is determined based on factors such as bone quality, comminution, and expected time to healing.
- An anterior plate location is often best for neutralization or buttressing of complex intra-articular fractures.

**TECH FIG 5** • A,B. Lag screws are used and anterior plating is performed to optimize fixation of the articular segment with a raft of anterior–posterior screws. Autograft from the tubercle of Gerdy was used above the disimpressed articular surface, but allograft or substitutes may be used. (continued)
WOUND CLOSURE AND CARE

- Once intraoperative radiographs reveal a satisfactory reduction and position of implants, the incision is closed.
- Retinacular layers are reapproximated to cover the underlying bone and implants.
- A drain may be considered to minimize pressure on the incision line from fluid accumulation under the wound.
- The subcutaneous layer is closed with an absorbable suture before skin closure.
- We use fine (4-0) nylon interrupted sutures and atraumatic soft tissue handling during wound closure (TECH FIG 6).
- Closing the anteromedial incision without tension is critically important. Any substantial tension on the anterior skin edges after closure will likely result in some degree of soft tissue necrosis. Rarely, accomplishing this step may require relaxation of the lateral incision or a return trip to the operating room for delayed closure.
- A lightly compressive bulky dressing and splint are applied with the ankle in neutral position.
- Finally, elevation is resumed before leaving the operating room to minimize swelling.

PEARLS AND PITFALLS

Minimizing risk for major complications

- Before modern methods of soft tissue handling, open treatment of high-energy tibial plafond fractures was directly associated with high complication rates (about 50%).
- Many of these complications are preventable; thus, tibial pilon fractures present the orthopedic surgeon with a real opportunity to influence a patient’s ultimate outcome.
- Contemporary fracture treatment principles (eg, staged treatment protocols, tailored surgical approaches, careful soft tissue handling, indirect reduction, and biologic fixation) have reduced the rate of complications to an acceptable level (about 0% to 10%) for these fractures.
### Surgical goals
- As established by Rüedi and Allgöwer, the goals of surgery for pilon fractures include precise articular reconstruction, restoration of extremity length and alignment, stable fracture fixation, and early joint motion.
- The avoidance of complications is critical to consistently achieving optimal clinical results.

### Soft tissue management
- The soft tissues must be quiescent at the time of plafond open reduction and internal fixation.
- Staged treatment protocols, tailored surgical approaches, careful soft tissue handling, and indirect reduction should be used routinely for these injuries.

### Articular reduction tricks
- The articular reduction is of paramount importance and is usually performed first, followed by the metaphyseal–diaphyseal reduction.
- Longitudinal traction with an external fixator or femoral distractor allows for indirect fracture reduction and joint visualization.
- Articular fragments may be disimpacted with small osteotomes or elevators. These fragments should be kept as thick as possible, and voids created by disimpaction should usually be grafted.
- A well-positioned talar dome may be useful as a template to reduce articular fragments.
- Multiple Kirschner wires and carefully placed pointed clamps may help in gaining and maintaining reduction.
- Fracture reduction should be carefully scrutinized using direct visualization and radiography before and after fixation so that changes can be made before definitive fixation or leaving the operating room.

### Metaphyseal reduction tricks
- Often reducing the joint fragments will simultaneously realign the metaphysis.
- Pointed clamps, small push plates, and lag screws are very useful for the metaphyseal reduction.
- Axial alignment must be carefully scrutinized clinically and radiographically.
- A well-repaired fibula is an excellent guide for restoring tibial length.

### Fixation problems
- 2.4-, 2.7-, and 3.5-mm lag screws and occasionally absorbable pins are useful for fixation of the articular fragments. These are often placed in subchondral bone to gain optimal stability of osteochondral fragments.
- Anatomically contoured pilon plates with locking capability are nice tools for use in complete articular injuries or osteoporotic bone but are not always necessary (or desirable).

### POSTOPERATIVE CARE
- Elevation of the extremity should continue for the next few weeks to protect the incisions.
- Patient education is important to maximize understanding of wound risks and compliance with elevation and other postoperative treatments.
- Aggressive respiratory care and supplemental oxygen are continued until the patient is fully awake and off intravenous narcotics (respiratory depressants).
- Immobilization is maintained for about 10 to 14 days or until the incisions have healed adequately.
- At the time of suture removal, ankle range-of-motion exercises are taught, and the limb is placed in a removable fracture brace.
- Strict non-weight bearing is continued, with advancement in weight bearing made when radiographic evidence of fracture consolidation is adequate, typically at 10 to 12 weeks after surgery.

### OUTCOMES
- The philosophy for open reduction and rigid internal fixation of plafond fractures is a direct extension of Rüedi and Allgöwer’s original recommendations.11
- Historically, early poor results with ORIF were primarily related to the disruption of the soft tissue envelope and not the fixation of the bony fracture itself.7,14
- These failures were the result of the inherent fragility of the thin soft tissue envelope in this area, misunderstandings of the soft tissue injury severity, overly aggressive soft tissue stripping during surgery, and the use of prominent, large fragment implants for stabilization.
- More modern techniques of plafond fracture management have led to much more satisfactory complication rates for pilon fractures.
- Sirkin et al13 retrospectively analyzed a staged protocol for management of 56 C-type plafond fractures treated using a protocol of immediate (within 24 hours) stabilization of the fibula fracture with temporary spanning external fixation of the tibia across the ankle joint. Formal open reconstruction of the tibial fracture with plating was performed when soft tissues normalized (average 13 days). Three patients developed deep infections (6%) and five patients had superficial necrosis that was well treated with local wound care and oral antibiotics.
- Patterson and Cole9 published results of a similar two-staged technique for the treatment of C3 plafond fractures. Twenty-one patients underwent early fibular fixation and construction of the tibial fracture with plating was performed when soft tissues normalized (average 24 days). Patients underwent ORIF of the plafond fractures. There were no infections or soft tissue complications.
- There are a few limited studies that have compared staged ORIF to other methods for treating tibial plafond fractures.
- Blauth et al2 retrospectively compared results of three different management protocols for severe plafond fractures (92% 43-C fractures):
  - Primary ORIF (n = 15, reserved for patients with closed fractures without severe soft tissue trauma)
  - Primary minimally invasive osteosynthesis of the articular surface with long-term (minimum of 4 weeks) transarticular external fixation of the ankle (n = 28)
  - Two-stage procedure with primary minimally invasive osteosynthesis of the articular surface and ankle-spanning
external fixation, followed by staged subcutaneous plat- 
ing (n = 8).
- While the incidence of wound infection did not differ significantly among the three groups, this study found that patients who had undergone two-stage surgery did better in terms of pain, ankle motion, activities of daily living, and the need for secondary arthrodesis compared to the other groups.
- Babis et al\(^1\) retrospectively compared 50 tibial plafond fractures treated by ORIF to 17 patients treated with minimally invasive osteosynthesis or external fixation. They found that three parameters significantly influenced results: the severity of fracture, the quality of surgical reduction, and the procedure by which the fracture was managed (ORIF did better).
- Harris et al\(^4\) compared functional outcomes after operative treatment of 43-B or C plafond fractures with ORIF (n = 63) versus limited open articular reduction and wire ring external fixation (n = 16). The greatest impairment in outcome was noted after type C3 fractures regardless of the method of treatment employed. ORIF was associated with fewer complications and less posttraumatic arthritis than external fixation, but this finding possibly reflected a selection bias, as open injuries and the more severely comminuted fractures were all managed with external fixation.
- Two studies have reported intermediate or long-term patient outcomes after ORIF of tibial plafond fractures.
- Sands et al\(^12\) reported on 30 patients who completed the SF-36 more than 18 months after ORIF of a tibial plafond fracture. There were deficits in every SF-36 subcategory, with the largest differences in outcomes seen in the areas of physical function and physical role function.
- Pollak et al\(^10\) similarly evaluated 80 patients with the SF-36 more than 2 years after ORIF of a pilon injury. They also found diminished scores in all eight functional domains of the SF-36, including markedly abnormal scores for physical function, physical role function, and bodily pain. They also reported that 35% of patients reported substantial ankle stiffness, 29% had persistent swelling, and 33% described ongoing pain. Of the participants who had been employed before the injury, 43% were not working at final follow-up.

**COMPLICATIONS**

- Tibial pilon fractures are often complex injuries that have a high potential for complications if not managed thoughtfully.
- As many of these complications are somewhat preventable, tibial plafond fractures present the orthopedic surgeon with an opportunity to improve a patient’s ultimate outcome.
- While we cannot alter the severity of a particular injury, appropriate surgical timing and soft tissue handling, along with exact articular reduction and stable fixation to allow for early motion, offer the best chance of obtaining good results with few complications for patients with these fractures.
- Wound problems resulting from these procedures should be treated aggressively to prevent deep infection.
  - Superficial marginal wound necrosis can be successfully managed with local wound care with or without oral antibiotics.
  - Full-thickness necrosis (eschar) can be followed as well in reliable patients who can be followed closely and educated to return immediately for any wound problems. Once the eschar begins to detach or drain (becomes “unstable” eschar), it will need to be removed immediately and débrided and antibiotics given. If healing beneath the eschar is inadequate at the time of its unroofing, the patient may require formal débridement and soft tissue coverage with a simple skin graft, fasciocutaneoues flap, or free soft tissue transfer, depending on the area and size of the wound and how much “biology” will be necessary to aid healing and prevent infection.
  - Anteromedial wounds of this sort are more problematic than anterolateral wounds or others, because the underlying tibia and fracture will be exposed in the anteromedial case.
  - Established deep infection is a limb-threatening problem and usually requires intravenous antibiotics, staged surgeries including external fixation support, soft tissue coverage (often through free-tissue transfer), and possibly late bone grafting.
  - Importantly, not all patients are good candidates for such complex reconstructive procedures. In these cases, early below-the-knee amputation is a useful means for restoring predictable function in an expeditious manner.
  - Malunion typically occurs in varus and usually occurs if malalignment is accepted or unrecognized or union is not achieved or fixation fails.
  - Prevention is important and should focus on providing adequate initial and ongoing medial column support against an intact, plated, or healed fibula.
  - Some surgeons avoid fixation of the fibula entirely. This method is typically coupled with external fixation for the tibia fracture after limited open articular reconstruction.
  - Avoiding fibular stabilization, however, does not convincingly decrease and perhaps even increases the chance of angular deformity. Also, maintaining appropriate length is more difficult with the use of external fixation alone.
  - Malalignment of the tibia or fibula may adversely affect ankle function and result in painful ankle arthrosis.
  - Most authors use less than 5 degrees of varus–valgus and less than 5 or 10 degrees of recurvatum–procurvatum as a limit for acceptable alignment.
  - Malunion surgery is typically associated with adjustment of the fixation and requires careful preoperative planning and perhaps referral to a surgeon with experience in posttraumatic reconstruction.
  - Nonunion or delayed union occurs in about 5% or more of patients and may occur in combination with malalignment.
    - Injury and host factors are implicated in problems with union of the tibial pilon.
    - Significant metaphyseal comminution, open fractures, and bone loss are factors prone to causing healing problems; adju nctive measures should be considered in these cases.
    - Smoking cessation and avoidance of nonsteroidal anti-inflammatory medications should be routinely discussed with patients to decrease the likelihood of these complications.
    - Immediate or early staged (4 to 8 weeks) bone grafting may advance tibial metaphyseal healing in high-risk fractures. External bone stimulation can also be considered early (for acceleration of fresh fracture healing) or late (as an adjunct to nonunion surgery) in the treatment course.
    - Treatment of an established distal tibial nonunion requires a comprehensive plan including consideration of the soft tissues, local biology and mechanics, presence of infection, condition of the ankle joint, and others.
Repair frequently requires realignment of the limb axis, followed by rigid fixation with or without bone grafting. Posttraumatic arthritis should be addressed by an initial course of conservative care. Ankle arthrodesis (method by surgeon preference) is often chosen once nonoperative treatment measures have been exhausted. Recent advances in total ankle arthroplasty may hold promise in carefully selected patients, but this is not currently recommended. Rarely, a primary arthrodesis is considered for limb salvage in severe fractures in which the articular surface cannot be salvaged. The combination of metaphyseal nonunion and ankle arthritis is particularly difficult because the intercalary segment of tibia (between the nonunion site and the ankle joint) is often small and of poor bone quality. Treatment options for this condition include amputation (especially if infection is present), resection with distraction osteogenesis, or internal fixation spanning both the nonunion and arthritic ankle along with bone grafting.

REFERENCES
DEFINITION

- The ankle is a modified hinge joint, which relies on a congruently reduced mortise to provide optimal function.
- Maintenance of normal tibiotalar contact is essential if one is to maintain function.
- Surgical treatment of displaced, unstable ankle fractures centers on anatomic restoration of the bony and ligamentous relationships that make up the ankle mortise.
- This chapter will focus on the treatment of a specific pattern of injury to the ankle, specifically the bimalleolar fracture pattern.

ANATOMY

- The anatomy of the distal tibia and ankle joint must be taken into account when considering ankle fractures. As the tibial shaft flares in the supramalleolar region, the dense cortical bone changes to metaphyseal cancellous bone (FIG 1A).
- The shape of the tibial articular surface is concave, with distal extension of the anterior and posterior lips.
  - This surface has been called the tibial plafond, which is French for ceiling.
  - The talar dome is wedge-shaped and sits within the mortise. It is wider anteriorly than posteriorly.
  - The medial end of the tibia is the medial malleolus.
  - The medial malleolus is composed of the anterior and posterior colliculi, separated by the intercollicular groove (FIG 1B).
  - The anterior colliculus is the narrower and most distal portion of the medial malleolus and serves as the origin of the superficial deltoid ligaments.
  - The intercollicular groove and the posterior colliculus, which is broader than the anterior colliculus, provide the origin of the deep deltoid ligaments.
  - The insertions of the deltoid ligaments (medial tubercle of the talus, navicular tuberosity, and sustentaculum tali) can also be considered part of the medial malleolar osteoligamentous complex.
  - The lateral malleolus is the distal end of the fibula. It extends about 1 cm distal and posterior compared to the medial malleolus.
  - The syndesmotic ligament complex unites the distal fibula with the distal tibia. The following ligaments make up the syndesmotic complex: the anteroinferior tibiofibular ligament, the posteroinferior tibiofibular ligament, the inferior transverse ligament, and the interosseous ligament (FIG 1C).

PATHOGENESIS

- The majority of bimalleolar ankle fractures are secondary to rotation of the body about a supinated or pronated foot. They are best defined by the classification of Lague-Hansen (FIG 2).
- The supination-external rotation pattern of ankle fracture is divided into four stages.
- The stage 1 injury is tearing of the anterior inferior tibiofibular ligaments.
- As the external rotation force continues laterally, a spiral fracture of the fibula occurs. On lateral radiograph, the fracture line will pass from the anteroinferior cortex to the posterolateral cortex.
- The third stage occurs when the posteroinferior tibiofibular ligaments avulse or fracture off the posterior malleolus.
- The final stage results in a medial malleolar osteoligamentous complex injury with either a deep deltoid ligament tear or a fracture of the medial malleolus.
- The pronation-external rotation variant also has four stages. Because of the pronated position of the foot at injury, however, the medial structures are injured in the early stages.
- The fibula fracture pattern seen with this mechanism is usually supras Syndesmotic, and the fracture pattern is an anterolateral-to-posterolateral fracture line as seen on the lateral radiograph.
- The supination-adduction pattern is heralded by a low transverse fibular fracture and a vertical shearing pattern medially. This pattern is also associated with tibial plafond impaction.
- Finally, the pronation-abduction pattern is identified by the avulsion of the medial malleolus and a transverse or laterally comminuted fibular fracture above the syndesmosis secondary to a direct bending moment.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Most patients who present with ankle pain following trauma will describe a twisting type of injury. Less frequently they will report a direct blow to the ankle.
- Proper medical history should include the patient’s current comorbid medical conditions, such as peripheral vascular disease, diabetes, or peripheral neuropathy.
- Physical examination should center on inspection, palpation, and neurovascular examination.
  - It is important to note any gross deformity, which may signify dislocation. If dislocation is present, the ankle should be reduced and splinted as soon as possible to prevent skin tenting and neurovascular compromise.
  - Inspection for any open wound about the ankle is critical as well. Open fractures imply a surgical urgency. Swelling, ecchymosis, and tenderness about the malleolus should be recorded.
  - For patients with a supination-external rotation pattern isolated fibula fracture who present with an intact mortise, the gravity stress examination can be revealing. More than 5 mm of medial clear space widening in association with a lateral malleolar fracture signifies an unstable pattern.
  - Pain at the ankle along the syndesmosis during a squeeze test implies injury to the syndesmosis.
  - The proximal fibula, knee, and tibia should also be examined. Palpation of pulses, detection of capillary refill, and a
Part 2 PELVIS AND LOWER EXTREMITY TRAUMA • Section IV FOOT AND ANKLE

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiographic examination includes the ankle trauma series: anteroposterior (AP), lateral, and mortise view (FIG 3A–C).
- In patients with isolated lateral malleolar fractures with clinical signs of medial injury, or if there is any question of ankle stability in a supination–external rotation fracture pattern, a manual external rotation stress radiograph should be obtained to assess for instability.
  - The tibia is held internally rotated 15 degrees with the ankle in dorsiflexion to produce a gentle external rotation moment at the ankle under fluoroscopy (FIG 3D).
  - More than 5 mm of medial clear space widening in association with a lateral malleolar fracture signifies an unstable pattern (FIG 3E).
  - If clinically warranted, full-length tibia–fibula radiographs should be obtained.
- Restoration of medial ankle stability depends on the size and location of the medial malleolar fragment.
  - The size of the medial fragment is key to stability.
  - Anterior collicular fractures will have only the superficial deltoid attached. In about 25% of supination–external rotation type 4 injuries there will be an associated deep deltoid rupture. Thus, fixation of this fragment will not enhance stability.
  - The lateral radiograph is the key. If the fragment is greater than 2.8 cm wide, the deep deltoid will be attached and stability is restored. If the fragment is less than 1.7 cm wide, then stability is not restored with fixation. For fractures in between, an intraoperative external rotation stress examination should be performed following malleolar fixation.
- CT scanning may be helpful in assessing posterior malleolar fragment size in rotational ankle fractures.
- MRI may have some utility if there is an isolated lateral malleolus fracture with signs of medial injury and an equivocal stress examination.
NONOPERATIVE MANAGEMENT

- Ankle fractures in which the ankle mortise remains stable can be treated nonoperatively.
- Isolated lateral malleolus fractures without evidence of medial-sided injury are considered supination external rotation type 2 injuries and can be treated with functional bracing and weight bearing as tolerated.
- Unstable patterns such as supination-external rotation type 4, either ligamentous or a true bimalleolar or trimalleolar ankle fracture, can also be treated nonoperatively in patients who are poor surgical candidates (e.g., insulin-dependent diabetics), who have severe soft tissue problems, or who do not wish to undergo surgical stabilization.
- If nonoperative treatment is chosen, it is crucial to ensure anatomic mortise reduction throughout treatment until healing.
- Unstable injuries should be treated in a well-molded short-leg cast and checked on a weekly basis to ensure continued mortise reduction.

SURGICAL MANAGEMENT

- Any fracture of the ankle in which there is residual talar tilt or talar subluxation such that the ankle mortise is not anatomically reduced is an indication for surgical stabilization.

Preoperative Planning

- Surgical anatomy should be reviewed prior to entering the operating room, including the bony and ligamentous structures.
  - The neurovascular anatomy about the ankle should be reviewed, including the course of the saphenous vein medially and the superficial peroneal nerve laterally.
- Equipment to be used includes a small fragment plate and screw set, large pelvic reduction clamps, small-diameter Kirschner wires, and 3.5- to 4.0-mm cannulated screw sets. If
the nature of the fracture is still in question, radiographic stress examination may be performed under anesthesia.

**Positioning**
- The patient is positioned supine with a small bump under the ipsilateral hip to ease access to the fibula.
- A pneumatic tourniquet can be applied to the affected thigh if desired for use during the surgical procedure. The affected limb is prepared and draped free.
- The bump may be removed after lateral fixation for easier access to the medial side.
- In rare cases, if a posterior approach is chosen, the patient may be placed in the prone position to allow access to the posterior tibia via the posterolateral approach.

**Approach**
- The fibula is approached via a direct lateral incision.
- The medial malleolus is approached via a gently curved anteromedial incision.
- Direct access to the posterior malleolus can be obtained through a posterolateral approach to the fibula.

**DIRECT LATERAL APPROACH TO THE FIBULA**

**Exposure**
- The incision is kept just off the posterior border of the fibula but may be adjusted slightly based on soft tissue considerations (TECH FIG 1A).
- Deeper tissues are incised in line with the skin incision (TECH FIG 1B).
- Care must be taken proximally in the wound to avoid injury to the superficial peroneal nerve, which crosses...
Chapter 19  ORIF OF THE ANKLE 691

TECHNIQUES

the field about 7 cm proximal to the distal tip of the fibula (TECH FIG 1C).

■ Next, the peroneal fascia is divided and the peroneal tendons and musculature are retracted posteriorly.
■ With gentle elevation of the peristeam about the fracture site, the fibula should be exposed.
■ Care should be taken to avoid excessive stripping of fracture fragments as well as iatrogenic disruption of the syndesmotic ligaments as they insert anteriorly on the fibula.

Lateral Plating

■ Following exposure of the fracture, the first step involves cleaning the fracture site (TECH FIG 2A), followed by fracture reduction.
■ Usually reduction is afforded by a small “lion jaw” clamp or pointed reduction forceps.
■ If reduction is difficult, manual traction with pronation and external rotation will afford fracture alignment in supination–external rotation patterns.
■ Care should be taken to avoid placing clamps over fracture spikes to prevent inadvertent comminution (TECH FIG 2B).

■ If the clamps make it difficult to place a lag screw, provisional Kirschner wires may be placed across the fracture and the clamps removed (TECH FIG 2C).
■ At this point, if a lateral plate is chosen, the lag screw is placed in the anterior-to-posterior direction, perpendicular to the fracture.
■ If a posterior plate (antiglide) is chosen, the lag screw is placed through the plate in a posterior-to-anterior direction.
■ In either case, the near cortex is overdrilled with a 3.5-mm drill bit, followed by drilling of the far cortex with a 2.5-mm drill bit (TECH FIG 2D).
■ The length of the screw is measured and a self-tapping 3.5-mm screw is placed across the fracture in the screw track.
■ Next a one-third tubular plate is placed directly lateral on the fibula (neutralization).
■ The proximal screw holes are filled with bicortical 3.5-mm screws after drilling with the 2.5-mm drill bit (TECH FIG 2E).
■ Distally, unicortical cancellous screws are placed, with care not to penetrate the distal tibia–fibula joint (TECH FIG 2F).
■ The wound is closed (TECH FIG 2G).

Exposure

■ The medial malleolus is approached via a gently curved anteromedial incision (TECH FIG 3A).
■ An incision is made parallel to the saphenous vein that is either concave anterior or concave posterior to allow visualization of the anteromedial joint.
TECH FIG 3 • A. For a medial-side injury, the skin incision is curved about the medial malleolus. B. Fracture site is exposed and cleaned of hematoma and the talar dome is inspected for signs of chondral injury.

- After dissection of the skin, the subcutaneous tissues should be carefully dissected to prevent injury to the saphenous vein and nerve.
- With the dissection carried down sharply to the bone, the periosteum is elevated for 1 mm proximally and distally.
- The fracture should be booked open to allow visual inspection of the talar dome for chondral injury.
- The joint and medial gutter should be irrigated through the fracture for any loose hematoma or debris that may impede reduction (TECH FIG 3B).

Operative Stabilization
- Following exposure, the medial malleolar fragment (usually one large piece) can be reduced with the aid of a dental tool or small pointed reduction clamp (TECH FIG 4A).
- The fragment can be provisionally stabilized with small-diameter Kirschner wires placed in parallel (TECH FIG 4B).
- After radiographic documentation of the reduction and wire placement, cannulated screws of appropriate length may be placed over the wires after drilling of the outer cortices with a cannulated drill. Alternatively, noncannulated screws may be used independent of the provisional stabilization.
- Usually, a 4.0-mm partially threaded cancellous screw can be placed. If the fragment is small, however, 3.5- or 3.0-mm cannulated screws are now available.
- More recent studies have advocated for the use of two bicortical 2.7-mm screws placed in lag mode.
- Two screws are recommended for rotational control. If the fragment is too small, however, one screw may suffice owing to the inherent stability of the undulating fracture line.
- Countersinking the screw heads medially may help to alleviate painful prominent hardware.
- Comminuted fractures that are not amenable to screw fixation may benefit from a small buttress plate or a “suture tension band” technique using the deltoid ligament for fixation.
- The suture or wire tension band is anchored about a more proximal screw placed parallel to the articular surface.

POSTEROLATERAL APPROACH TO THE TIBIA
- Direct access to the posterior malleolus fracture (TECH FIG 5A) can be obtained through the posterolateral approach to the fibula (TECH FIG 5B).
- The interval between the Achilles and the peroneal muscle is developed (TECH FIG 5C).
- The flexor hallucis longus is taken off the fibula down to the interosseous membrane, and then the rest of the deep posterior compartment is taken off the posterior tibia (TECH FIG 5D).
POSTERIOR MALLEOLUS FIXATION

- If an adequate reduction can be achieved via closed, indirect reduction, the fracture can be stabilized with cannulated lag screws placed in the anterior-to-posterior direction.
- If an open approach is used for reduction, screws placed posterior to anterior may be placed across the fracture site.

- If the fracture fragment is of sufficient size, an antiglide plate (one-third tubular) may be placed with undercontouring of the plate to provide a satisfactory buttress effect (TECH FIG 6).

TECH FIG 5 • Direct posterior plating is well suited for fractures involving large portions of the posterior malleolus. A. Postreduction lateral radiograph showing a posterior malleolus fracture involving more than one third of the articular surface. B. Patient in prone position, incision between Achilles and posterior fibula border. C. Access is via the interval between the flexor hallucis longus and the peroneal muscle belly. D. Posterior malleolar fragment following fibular plating.

TECH FIG 6 • Postoperative AP and lateral radiographs demonstrating posterior plating of the tibia to buttress the posterior malleolar fracture fragment.
POSTERIOR PLATING OF THE FIBULA

- In this case, the surgical approach is similar to the lateral plating technique.
- When application of a posterior or antiglide plate is chosen, placement of a lag screw is optional.
- My preferred method is to apply the plate along the flat posterior surface of the bone, using it as a reduction aid with a bone reduction clamp (TECH FIG 7A).
- I prefer to place a posterior-to-anterior–directed lag screw through the plate.
- Because of the biomechanical properties of this plate construct, this lag screw is optional.
- Next, at least two or three bicortical screws are placed in the plate. A bicortical screw placed posterior to anterior in the distal screw is optional.
- If a posterior plate is applied, the proximal screws are placed bicortically from posterior to anterior, both proximal and distal to the fracture. This is an advantage in osteoporotic bone (TECH FIG 7B).

SYNDESMOSIS FIXATION

- After stabilization of the medial and lateral sides of the ankle, syndesmotic integrity should be assessed.
- The Cotton test involves providing a lateral force on the fibula with a bone hook or bone clamp (TECH FIG 8A).
- Lateral displacement that allows more than a few millimeters of tibiofibular widening is considered pathologic and an indication for syndesmotic fixation.
- The lateral radiograph should be scrutinized to assess the relationship of the fibula to the articular surface of the ankle joint. In general, on a true lateral view of the ankle, the tip of the fibula should be anterior to the posterior border of the diaphyseal tibia, but comparisons to the contralateral ankle can be assessed.
- With a bolster behind the ankle, a large tentaculum clamp is placed across the tibiofibular joint, with one tine on the distal tibia and the other on the fibula (TECH FIG 8B).
- Reduction is confirmed on the AP, mortise, and lateral radiographic views.
- While dorsiflexion of the talus has been recommended in the past to prevent overtightening of the syndesmosis, more recent studies have shown that it is virtually impossible to overtighten an anatomically reduced mortise.
- Fixation choices range from one or two screws, with three or four cortices drilled and 3.5-mm or 4.5-mm screw diameters used. Although the size and number of screws remain controversial, some parameters are agreed on.
- The screw should be placed 1.5 to 2 cm proximal and parallel to the joint.
- The screw should not be placed in lag mode.
- If a lateral plate is used, the screw is placed through one of the distal holes.
- If a posterior plate is used, the syndesmosis screw will likely be placed outside the plate on the lateral cortex.
### POSTOPERATIVE CARE
- All ankles should be splinted in the neutral position and elevated for at least 24 hours postoperatively.
- We remove the splint at 10 to 14 days and remove the sutures.
- Patients are then placed into a removable functional brace that allows them to begin early active-assisted and passive range of ankle motion.
- Patients are also allowed to begin isometric strengthening exercises.
- All patients are kept non-weight bearing for at least 6 weeks.
- At 6 weeks patients are progressed to weight bearing as tolerated based on radiographic criteria.
- Weight bearing can be delayed for slow healing and presence of a syndesmotic screw. In general we do not alter the weight-bearing status because of syndesmotic injury or routinely remove the syndesmosis screw, but we advise patients of the possibility of screw breakage following weight bearing.
- Patients are restricted from operating an automobile for 9 weeks following right-sided ankle fracture.

### OUTCOMES
- One year after ankle fracture surgery, patients generally do well, with most experiencing little or mild pain and few restrictions in functional activities. They have significant improvement in function compared with 6 months after surgery.
- Younger age, male sex, absence of diabetes, and a lower American Society of Anesthesia class are predictive of functional recovery at 1 year following ankle fracture surgery.
- It is important to counsel patients and their families on the expected outcome after injury with regard to functional recovery.
- Looking specifically at elderly patients (older than 60 years), functional outcomes steadily improved over 1 year of follow-up, albeit at a slower rate than in the younger patients.
- Our results suggest that operative fixation of unstable ankle fractures in the elderly can provide a reasonable functional result at the 1-year follow-up.

### PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Damage or entrapment of superficial peroneal nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Care must be taken to expose and mobilize the nerve proximally if in the surgical field (<a href="#">FIG 4A</a>). This will help minimize the chance of damage during surgery and closure.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Failure to obtain fibular length</th>
</tr>
</thead>
<tbody>
<tr>
<td>This will lead to persistent medial widening.</td>
</tr>
<tr>
<td>A plate is used to push the distal fragment with a laminar spreader. The distal tibiofibular anatomic relationship is assessed and the contralateral ankle is used for comparison.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Presence of osteoporotic bone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplementary Kirschner wires</td>
</tr>
<tr>
<td>Multiple syndesmosis screws</td>
</tr>
<tr>
<td>Posterior-placed fibula plate</td>
</tr>
<tr>
<td>Locked plate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intra-articular hardware penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Careful intraoperative radiographic assessment is important.</td>
</tr>
<tr>
<td>Distal screws in the lateral fibular plate must be unicortical.</td>
</tr>
<tr>
<td>AP radiograph is best to evaluate medial malleolus fixation.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Malreduction of the syndesmosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolster is placed under ankle, not foot. This will cause anterior displacement (<a href="#">FIG 4B</a>).</td>
</tr>
<tr>
<td>A good lateral radiograph is obtained to assess reduction.</td>
</tr>
<tr>
<td>It is impossible to overtighten an anatomically reduced syndesmosis.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peroneal tendinitis and painful hardware</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laterally placed fibular hardware is associated with a higher incidence of painful hardware.</td>
</tr>
<tr>
<td>Posteriorly placed fibular fixation is associated with a higher incidence of peroneal tendinitis.</td>
</tr>
</tbody>
</table>

![A](#) **Identification and protection of the superficial peroneal nerve within the anterior flap.**

![B](#) **CT scan showing malreduction of the syndesmosis.**
COMPICATIONS

- Minor complications include epidermolysis (FIG 5A), superficial infection, and peroneal tendinitis with painful hardware.
- Major problems include nonunion (FIG 5B), hardware failure, deep infection, and compartment syndrome.

REFERENCES

DEFINITION
- Fractures of the talus are severe injuries affecting ankle and hindfoot joint function.
- Displaced fractures of the talus are a surgical challenge to orthopedic surgeons. The injuries are infrequent and the fracture anatomy is partially concealed by adjacent osseous structures.
- Open reduction and internal fixation is generally mandatory to restore talar anatomy precisely.
- Outcomes of talus fractures correlate with injury severity. These results include ankle and subtalar joint stiffness, post-traumatic arthritis, and osteonecrosis of the talus.

ANATOMY
- Two anatomic factors play significant roles in the outcome of talus fractures.
  - Sixty percent of the bone is covered by articular cartilage, significantly limiting extraosseous perfusion to the bone.
  - Disruption of circulation to the talus correlates with open or comminuted talus fractures, leading to an increased risk of avascular necrosis. The blood supply to the talar body enters through the inferior talar neck via the artery of the tarsal canal. This key vessel originates from the posterior tibial artery. Secondary blood supply to the body is derived from the deltoid branch of the posterior tibial artery, entering the talar body along its medial surface. Circulation to the neck, head, and lateral body is supplied via the dorsalis pedis, tarsal sinus, and lateral tarsal sinus arteries. This last artery is an anastomosis between the peroneal and dorsalis pedis arteries.
- The talus has seven articulations.
  - Three main surfaces articulate with the plafond and lateral malleolus, while three surfaces articulate with the calcaneus.
  - The final articulation of the talar head with the tarsal navicular represents an important articulation for midfoot motion.
- Predictable stiffness with range of motion and posttraumatic arthritic changes is experienced with severe fractures of the talus.

PATHOGENESIS
- Fractures of the talus present in varying patterns depending on the mechanism of injury.
- Fractures of the talar head are intra-articular and the result of axial load to the talonavicular joint with the foot positioned in plantarflexion.
  - These fractures constitute up to 10% of all fractures of the talus.
  - They are uncommon but must be looked for in the event of an isolated subtalar dislocation.
- Talar neck fractures occur in the frontal plane and result from dorsiflexion of the foot against the anterior lip of the distal tibia. The fracture begins transversely along the medial talar neck due to an associated supination force to the hindfoot.
- The fracture line extends laterally. The fracture may be extra-articular, intra-articular, or a combination of both. With increased energy, the hindfoot supination force generates a fracture of the medial malleolus of the ankle.
  - After completion of the neck fracture, continued hyper-dorsiflexion and axial load to the body of the talus may force dislocation of the talar body posteriorly, disrupting significant extraosseous circulation.
- Fractures of the body of the talus involve up to 23% of talus fractures. The mechanism of injury is the same for body fractures as for fractures of the talar neck.
- Fracture patterns of the body of the talus include coronal, sagittal, horizontal shear, and crush fractures of the weight-bearing surface.
- Process fractures of the talar body are described by anatomic location.
  - Lateral and posterior process fractures are sustained by inversion and eversion mechanisms of the ankle, respectively. These fractures are often missed on plain film radiographs of the ankle and diagnosed as ankle sprains.
  - Hawkins classified lateral process fractures into avulsion, isolated, and comminuted types.
  - Posteromedial and posterolateral process fractures lie to each side of the flexor hallucis longus tendon. These are commonly intra-articular fractures of the inferior surface of the posterior talus.

NATURAL HISTORY
- The postoperative prognosis for any displaced talus fracture should be guarded because of significant postinjury potential for complication.
- Fractures of the head of the talus are commonly nondisplaced because of powerful capsular and talonavicular ligamentous attachments.
- Displaced fractures of the talar head have a 10% incidence of osteonecrosis and can lead to secondary posttraumatic arthrosis.
- Fractures of the neck of the talus are defined as fractures anterior to the lateral process of the talus. Hawkins’ work on vertical fractures of the neck of the talus helped clarify injury of vascular perfusion to the bone by delineating three types of fractures of the neck of the talus.
  - The type I fracture is nondisplaced. Disruption of blood flow is limited to the anterolateral region of the bone. I recommend a computed tomography (CT) scan to confirm no displacement of the fracture before diagnosing a type I fracture. Historically, Hawkins reported a 13% incidence of osteonecrosis in type I injuries (FIG 1A).
  - In the type II talar neck fracture there is displacement of the talar dome fragment, which is routinely posterior, often depicting clear subluxation of the talar body. Blood flow to the medial body and head is preserved. The type II talar neck fracture has a 20% to 50% risk of avascular necrosis (FIG 1B).
In the type III injury, the transverse fracture of the talar neck is associated with dislocation of the talar body. The incidence of osteonecrosis of the talar body is 50% to 100%. All major perfusion to the body of the talus is damaged (FIG 1C).

A type IV injury of the talar neck has been documented; it is a type III fracture-dislocation with associated talonavicular dislocation. All extrasosseous blood flow to the talus is considered disrupted. The value of the Hawkins classification is that it allows the orthopedic surgeon to predict what to expect with a specific talar neck injury. Open reduction and rigid internal fixation is the recommended treatment (FIG 1D).

Talar body fractures are defined as fractures extending into or posterior to the lateral process.

PATIENT HISTORY AND PHYSICAL FINDINGS

Fractures of the talus are commonly associated with vehicular trauma and falls.

The relationship of severe lower extremity trauma and airbags is well known. After airbag deployment, the torso and lower extremities are directed toward the floor panel of the car.

I believe that the incidence of high-energy hindfoot trauma will increase over time. Globally, transport related injuries remain the leading cause of disability from injury. By 2020, traffic injuries will increase from a current 9th position to 3rd disability-adjusted life years lost.

The history and the clinical status of the talar injury must be carefully recorded because the injury severity is likely to correlate with the long-term patient outcome.

On the initial examination the physician should note pain, motion, crepitus, deformity, soft tissue swelling, open fractures, and associated fractures of adjacent bones to the foot and ankle and should perform a complete neurovascular evaluation of the extremity.

Detailed documentation of the talus fracture pattern and local soft tissue injury is paramount.

Soft tissue local pressure phenomenon, commonly found anterolaterally in closed type III fractures of the talar neck, may precipitate full-thickness pressure necrosis of the skin if not decompressed early.

Severe swelling of the ankle is common in the acute fracture of the talus and may progress to fracture blister formation, precluding safe execution of operative incisions.

The physician should examine the skin for swelling, ecchymosis, fracture blisters, and deformity; these are signs of a closed fracture.

A closed injury with mild or moderate swelling (bony landmarks palpable) indicates talar neck type I and II fractures and process fractures.

A closed injury with severe swelling indicates talar neck type III and IV fractures and body fractures.

Open fractures will be apparent by the transverse, medial, or supramalleolar traumatic laceration of the ankle. Lateral, posterior, and plantar wounds are uncommon.

The physician should perform vascular, neurosensory, and myotendinous examinations of the foot and ankle.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Three plain radiographic views are necessary to radiographically evaluate talus fractures: anteroposterior (AP), mortise (15-degree internal rotation view), and lateral images of the ankle.

The AP and mortise views of the ankle demonstrate alignment of the talar body in the ankle mortise. The lateral view depicts the sagittal outline of the talus.

The Canale view is used to assess varus or valgus malalignment of the talar neck, particularly with Hawkins type I and II injuries. The knee must be flexed and the foot in equinus and everted, with the x-ray tube directed 15 degrees caudad (FIG 2A).
Because of the high-energy nature of fractures of the talus, AP and oblique views of the foot should be a standard addition to the three-view plain film ankle protocol so as not to miss associated midfoot and forefoot injuries (FIG 2B).

Computed tomography (CT) provides important additional information to the three-view plain film series of the ankle. Thirty-degree coronal and paraxial CT imaging is important to confirm Hawkins type I fractures of the talar neck and plan treatment of talar body fractures with extension posterior to the lateral process. Reconstructions of both sagittal and coronal CT studies provide valuable information about incremental pathoanatomy of the entire talus, medial to lateral and anterior to posterior, respectively. In addition, confirmation of a process fracture that is not clearly viewed by plain film is easily diagnosed by CT (FIG 2C).

DIFFERENTIAL DIAGNOSIS

- Process fracture of the talus
- Lateral process fracture
- Medial process fracture
- Head of talus fracture
- Neck of talus fracture
- Body of talus fracture
- Neck and body of talus fracture
- Fracture-dislocation of talus
  - Involving body
  - Involving neck and body
- Extruded talus

(Any of these injuries to the talus may be open fractures, affecting management.)

NONOPERATIVE MANAGEMENT

- Fractures of the talus include a spectrum of injury patterns ranging from isolated regions of the talus (e.g., lateral process) to severely comminuted talus fractures involving all parts of bone, making nonoperative management inappropriate.
- High-energy injury mechanisms that cause talus fractures precipitate fracture displacement and joint surface incongruity.
- Medial and lateral process fractures, minimally displaced (less than 2 mm) and involving less than 1 cm of bone, are commonly managed nonoperatively.
- These injuries are treated acutely in well-padded, compressive dressings with posterior splints and non-weight bearing. Swelling and immediate pain in the ankle improve significantly by 7 to 10 days. The patient is subsequently converted to a short-leg non-weight-bearing cast for 6 weeks, followed by progressive range of ankle and subtalar motion and return to weight bearing in a removable fracture-boot.
- If the process fracture is severely comminuted, precluding surgical reconstruction, the same initial and definitive nonoperative management is employed.
- Isolated fractures of the head of the talus without dislocation and without displacement are largely stable fractures. These injuries require plain radiographic evaluation of both the ipsilateral foot and ankle to confirm the isolated nature of the injury. I recommend CT scanning (axial and transverse views of foot and ankle) of this injury to rule out associated midfoot pathology.
- Acutely, an isolated, nondisplaced talar head fracture is splinted for 7 to 10 days with subsequent short-leg casting in neutral plantarflexion with non-weight bearing for 4 weeks. Intermittent daily ankle and subtalar motion with Achilles tendon stretching should follow with application of a removable fracture boot. The patient remains non-weight bearing until 6 to 8 weeks after injury. Next, progressive weight bearing, range of motion, stretching, and strengthening of the entire lower extremity are recommended.
- The Hawkins type I fracture of the neck of the talus is a nondisplaced talar neck fracture. The talus remains anatomically positioned in the ankle and subtalar joint with minimal potential for disruption of perfusion to the bone.
- A subgroup of these injuries may present with displacement of the talar neck on initial injury plain radiographs. After closed manipulation of the fracture in plantarflexion, the talar neck fracture may reduce. A true Hawkins type I talar neck fracture will not displace even with gentle dorsiflexion. The type I fracture strongly warrants a CT scan,
with sagittal reconstruction, to confirm anatomic alignment of the talar neck.

- If there is displacement of the neck fracture, the injury must be reclassified as a type II, which requires surgical treatment to obtain, and maintain, the reduction.
- Truly nondisplaced fractures of neck of the talus can be treated nonoperatively in a short-leg non-weight-bearing cast for 6 to 8 weeks. Close follow-up is recommended to watch for any displacement of the neck fracture. At 6 to 8 weeks after the injury, progressive weight bearing, range of motion, stretching, and strengthening are initiated.
- Injury forces precipitating fractures of the dome of the talus are universally severe, causing articular displacement, and are an indication for surgery. Open fractures of the talus, even with no displacement, are best managed with rigid surgical stabilization to allow for wound care and early motion.

**SURGICAL MANAGEMENT**

- The timing of operative management of talus fractures has been an area of controversy, specifically whether the displaced talus fracture is an orthopedic emergency.
- One recent study indicates that orthopedic trauma surgeons do not believe a displaced fracture of the neck of the talus is an orthopedic emergency.
- However, it is important to differentiate the potential of vascular injury to the talar body from soft tissue and neurovascular compromise of the foot because of injury to the talus. In particular, fracture-dislocation of the body of the talus is associated with compromised blood flow to the bone, the threat of pressure phenomenon to the skin, and possible tibial nerve dysfunction.
- The acute severity of soft tissue swelling or the impact of an open hindfoot wound may preclude safe, immediate reconstruction of the talus fracture after reduction of the dislocation.
- Foot and ankle external fixation is a suitable treatment option, with staged definitive fixation applied accordingly.
- Any open talus fracture must be treated as an orthopedic emergency.
- Preoperative antibiotics may be selected on the basis of wound contamination. These include a cephalosporin and possibly gentamicin. Penicillin is added if gross or farm contamination is present. All patients should receive a tetanus toxoid booster.
- The patient is taken to the operating room and after soft tissue debridement the wound receives at least 3 to 9 L of normal saline using pulsed lavage.
- At this time, in addition to partial or complete fixation of the talus fracture, provisional foot and ankle external fixation may be used to provide soft tissue and osseous stabilization before delayed closure.
- Regarding general guidelines for fractures of the body, neck, and head of talus fractures, surgical management is indicated with fracture displacement, malalignment, subluxation, dislocation, or instability.
- Recent studies indicate that displacement or malalignment will have a negative impact on foot function. Two millimeters of fracture displacement has been shown to affect subtalar joint mechanics.
- There is less agreement regarding surgical indications for process fractures of the talus. Acute, displaced fractures with large fragments showing extension into the subtalar joint by CT imaging are best treated with open reduction and internal fixation.
- A displaced fracture of the neck of the talus is one of the most common indications for surgery on the talus. The fracture is known to start, in the coronal plane, along the medial neck and extend laterally until completion.
- There are two common types of neck fractures: an extra-articular pattern and an intra-articular type that extends into the subtalar joint.
- The displaced extra-articular vertical neck fracture is routinely amenable to closed reduction by applying dorsal-to-plantar pressure on the head of the talus associated with longitudinal traction and plantarflexion of the forefoot. Immediate reduction of this fracture diminishes concerns for soft tissue, neurovascular, and osseous compromise.
- The intra-articular pattern is less likely to cooperate with closed manipulation owing to the obliquity of the fracture as it extends posterior into the subtalar joint. This fracture pattern is more deserving of immediate or early surgery.
- For patients with severe open fractures of the talus, or closed injuries in which soft tissue compromise precludes immediate open management, temporizing external fixation may be effective.
- The goals of temporary external fixation are to maintain the length of the talus for reconstruction, facilitate soft tissue management, and restore general alignment. External fixation is rarely definitive management for talus fractures.
- Displaced, open or closed, fractures benefit most from rigid internal fixation for bone healing and early motion. However, a recent report evaluating results of the extruded talus identified definitive external fixation as an option to manage the purely dislocated talus. This is an excellent treatment option to stabilize the ankle and subtalar and talonavicular articulations of the talus.

**Preoperative Planning**

- Operative planning for talus fractures requires evaluation of imaging studies to clearly understand the relationships of all major fracture fragments.
- A preoperative CT scan of the fracture is standard when confronted with a comminuted talar neck or body fracture. The surgeon must become familiar with the morphology of the bone and its many contours to facilitate reconstruction.
- Intraoperative visibility and access to talar fragments are routinely challenging, but these variables can be largely facilitated by correct patient positioning, surgical approaches, adequate operating room lighting (headlamp), attention to reduction techniques, and implants selected. All play a key role in preoperative planning.
- The principles of open treatment are restoring articular congruity, maximizing the revascularization potential of the bone, and allowing early motion of the ankle and subtalar joints.
- The use of a radiolucent table and a headlamp promotes optimal visualization.
- A tray of fine-tipped, sharp and strong bone elevators, dental probes, Freer elevators, small bone clamps, mini/small lamina spreaders, and small distractors or external fixation equipment is routinely needed not only for talus fracture fixation but also all fine articular fracture reconstructions.
Small interfragmentary (3.5 mm) cortical screw fixation and mini-fragment (2.7 or 2.0 mm) screw/plate instrumentation is commonly needed for talus fracture fixation.
- An extra-long mini-screw (2.7 or 2.0 mm) inventory is recommended, with screws up to 60 mm long.
- The use of mini-implants is particularly helpful when reconstructing comminuted fractures.
- Contemporary mini-fragment systems are predominantly stainless steel.
- Some authors have suggested using titanium implants to allow use of magnetic resonance imaging to assess osteonecrosis.
- Osteochondral fragments too small for mini-fragment fixation can be fixed with bioabsorbable pegs or headless articular screws.

Positioning
- Displaced fractures of the head, neck, body, and lateral process of the talus are best reconstructed with the patient in the supine position.
- Supine positioning allows medial, anterolateral, and direct lateral incisions to be performed with ease (FIG 3A,B).
- Intraoperative fluoroscopy is conveniently performed with the patient in this universal position.
- The patient should have an adequate bump placed preoperatively under the ipsilateral gluteal region to avoid external rotation of the ankle.
- Fractures of the posterior body of the talus are performed through posteromedial or posterolateral surgical approaches. These approaches are achieved most efficiently with the patient in the prone position (FIG 3C).
- The prone or lateral recumbent position is effective for occasional posterior-to-anterior fixation associated with minimal or no displacement of the fracture.
- A radiolucent table without attachments at the foot allows for all required radiographic views.

Approach

Medial and Anterolateral Approach
- Anatomic reduction of displaced head, neck, and body fractures requires visualization of both medial and lateral surfaces of the talus. A medial and anterolateral (two-incision) approach effectively prevents a malreduction of the articular surfaces and neck.
- A surgeon’s initial impression of the dual-incision approach to talus fractures may be perceived to disregard the biology of the bone and its limited extraosseous blood supply. With attention to detail, neither the plantar nor the direct dorsal blood supply to the talus is violated.
- Landmarks for the medial incision are the dorsomedial tip of the medial malleolus extended, in line with the axis of the foot to the tarsal navicular (FIG 4A).
- This incision is 5 mm dorsal to the axis of the posterior tibial tendon.
- Its extension continues just distal to the navicular tuberosity, allowing exposure of the medial surface of the talar head, neck, and distal body.
- The approach may be lengthened in both directions to improve visibility.
- The anterolateral incision is parallel and 5 to 6 cm lateral to the medial approach (FIG 4B).
Part 2 PELVIS AND LOWER EXTREMITY TRAUMA • Section IV FOOT AND ANkle

This incision should begin just medial or in line with the syndesmosis of the ankle.

The lateral neck of the talus is difficult to access and reconstruct if the incision is made too lateral.

If comminution of the lateral process is to be addressed, the incision can be shifted slightly lateral.

After completing the skin incision, the surgeon must beware of the lateral branch of the superficial peroneal nerve when incising deep to the subcutaneous tissues.

The lateral retinaculum must be sharply incised, and the extensor digitorum tendons are retracted medially, exposing the extensor digitorum brevis muscle.

The muscle belly is reflected distally off its proximal origin, allowing easy access to the lateral capsule of the talus.

The lateral capsulotomy is made in line with the axis of the neck of the talus.

Anatomic reduction of complex talus fractures is achieved by working from side to side through both incisions.

Transmalleolar Approach

An important modification of the medial approach to the talus is the medial malleolar osteotomy. In displaced body or complex talar neck fractures, the procedure may be greatly facilitated by this increased exposure.

I prefer to continue the medial incision longitudinally, directly in line with the axis of the medial malleolus, extending just proximal to the supramalleolar region (FIG 5A).

After exposing the malleolus, without violating the periosseum, the distal tip of the anterior and posterior colliculus of the medial malleolus must be predrilled (FIG 5B) and tapped retrograde for two parallel, 3.5-mm interfragmentary cortical or 4.0-mm partially threaded cancellous screws.

An oblique osteotomy directed toward the shoulder of the medial ankle mortise is performed using a very thin oscillating saw blade.

This osteotomy is incomplete, advancing only to the level of the medial subchondral bone.

The osteotomy is completed by gentle levering of a thin wide osteotome on the inner cortex (FIG 5C).

At this time, an anterior and partial posterior capsulotomy of the medial malleolus is needed to allow inferior mobilization of the malleolus. The deltoid vessels perfusing the medial body of the talus are protected with gentle retraction.

Patients requiring this transmalleolar approach will routinely benefit from the associated anterolateral incision for optimal visualization of the proximal neck and body of the talus during reconstruction.

Posterior Approach

An isolated posterior body fracture of the talus or displaced Hawkins type III fracture may require a posteromedial or posterolateral approach for fracture reduction and management.

The incision is longitudinal, beginning at the midpoint of the calcaneus and extending a fingerbreadth medial or lateral to the Achilles tendon for approximately 6 to 8 cm (FIG 6).

When making the incision through the deep posterior compartment fascia, the surgeon must take care to identify and gently retract the medial neurovascular structures.

The posterior tibial nerve and artery may be tethered over a posteriorly dislocated talar body fragment in a Hawkins type III fracture-dislocation, warranting extreme caution during the approach.

After safely retracting the nerve and artery, the flexor hallucis longus (FHL) tendon represents a landmark directly posterior to the body of the talus.

The FHL tendon is then retracted laterally to begin the reconstruction.

Lateral Approach

Lateral process fractures of the talus are easily accessed using a direct lateral approach.

A longitudinal 6- to 8-cm direct lateral incision is started 3 cm proximal to the distal tip of the lateral malleolus of the fibula, extending anteriorly in a curvilinear incision, in line with the axis of the foot.

The lateral retinaculum and subtalar capsule are incised longitudinally, exposing the lateral process fracture (FIG 7).
FIG 5 • A. Transectal medial malleolar osteotomy. B. Predrilling of medial malleolus. C. Malleolar osteotomy complete.

FIG 6 • A. Posteromedial incision. B. Flexor hallucis longus concealing posterior talus. C. Hemarthrosis of posterior capsule.
OPEN REDUCTION AND INTERNAL FIXATION OF THE NECK OF THE TALUS

Reduction
- After completion of the medial approach, limited sharp dissection is performed only along the medial neck and head to remove extraosseous soft tissue attachments and expose the talar body, neck, and head and the talonavicular joint.
- The medial fracture line is commonly found to have comminution that affects understanding of the true length and alignment of the medial column of the bone.
  - Inserting a mini-lamina spreader to gently disimpact the medial talar neck fracture allows restoration of length and alignment of the medial and dorsal surface of the neck.
  - Anatomic alignment is achieved using the dental probe and small elevators as reduction tools.
- If the talar neck fracture is intra-articular with extension into the subtalar joint, the body fragment routinely assumes a flexed, malrotated position.
  - To derotate the talar body’s flexed position, the surgeon should firmly secure a percutaneous 4.0-mm external fixation half-pin into the body fragment through a posterolateral stab incision, acting as a joystick.

Trial Fixation
- Once the talar neck is reduced, the next step is to advance a single smooth Kirschner wire retrograde through the talar head, directed across the fracture into the posterior body, to hold the position of the medial talar neck fracture.
  - If no bony reduction keys are visible along the medial talar neck, due to comminution, the mini-lamina spreader is inserted in the fracture medially while the surgeon patiently reduces the medial talar neck alignment.
  - Talar neck fluoroscopy is necessary to evaluate translation and alignment of the fracture. This important step establishes the true length and alignment of the medial talar neck.
  - Again, a retrograde smooth or threaded wire is advanced across the fracture.

- The surgeon then exposes the lateral neck of the talus.
  - The extra-articular fracture line reveals the lateral shoulder of the talus.
  - Comminution is rare; the fractures are simple, discrete patterns that reduce relatively easily by rotating around the medial Kirschner wire.
  - After reduction, a retrograde Kirschner wire is advanced through the lateral talar head and across the fracture, provisionally fixing the lateral side of the talus fracture.
  - Intraoperative fluoroscopy is performed to confirm the precise reduction of the fracture.
  - Close attention is paid to the Canale image of the talar neck to be sure there is no malalignment of the neck fragment.

Screw Fixation
- Definitive fixation of the medial talar neck fracture is achieved by gently subluxing the medial talonavicular joint to expose the articular surface of the talar head (TECH FIG 1).
  - A countersunk interfragmentary 3.5-mm screw is advanced to the posterior body of the talus.
  - Laterally, very dense cortical bone along the proximal neck presents an excellent extra-articular location for advancing a second interfragmentary screw.
  - Fracture patterns of the talus make it difficult to insert parallel interfragmentary screws.
  - The medial screw is easily directed posterolaterally and the lateral screw posteromedially.
  - This pattern of fixation has never been found to affect healing.

Plate Fixation
- Talar neck fractures that are not amenable to interfragmentary screws because of comminution perform well with mini-plate fixation.
  - Four- or five-hole 2.0-mm mini-plates are easily contoured and applied along either the medial or lateral neck surfaces for fixation in these cases (TECH FIG 2).
  - Plate fixation is especially helpful in cases with lateral comminution, or when the lateral shoulder is proximal to the fracture.
Chapter 20  ORIF OF THE TALUS 705

A
B
C

TECH FIG 1 • A. Bone model highlighting medial intra-articular, lateral extra-articular, and posterior screw fixation. B. Hawkins type II fracture. C. Postoperative fixation.

■ Talar neck fractures with associated posterior dislocation of the body fragment (Hawkins type III) present an increased challenge to the surgeon.
■ Fracture-dislocation of the body and talar head fragments (Hawkins type IV) is a severe pantalar injury, but reduction of the talonavicular joint is easily achieved through medial and anterolateral approaches.

OPEN REDUCTION AND INTERNAL FIXATION OF THE NECK OF THE TALUS WITH A DISLOCATED TALAR BODY

■ Reduction of the body fragment is an immediate goal with either injury type to diminish stretch on neurovascular structures and decompress local pressure phenomenon of the skin envelope.
■ The body commonly dislocates posteromedially because of the retained tether from the deep deltoid ligament. However, the body may dislocate directly posteriorly or posterolaterally.

■ A open Hawkins type III fracture-dislocation allows the surgeon access to the body fragment through the common transverse medial traumatic wound.
■ A closed Hawkins III injury may warrant a posteromedial or posterolateral incision to access the body fragment if it cannot be retrieved through the medial approach.
■ An associated medial or lateral malleolar fracture of the ankle helps reduction of the talar body dislocation immensely, particularly with disruption of the syndesmotic ligament.
■ Reduction of the dislocated body fragment may be attempted in the emergency room using radiographic information and conscious sedation.
■ A well-controlled, single attempt at closed reduction is reasonable.
■ The hindfoot is positioned in equinus and the subtalar joint is distracted by gripping the heel and applying traction.
Next, the dislocated talar body fragment is pushed anteriorly.

The main tether, if one exists, to the dislocated talar body fragment is the deep deltoid ligament medially. If intact, the deep deltoid ligament, which is short and nonelastic, allows for little motion, minimizing the yield of successful closed reduction.

If the closed reduction is unsuccessful, manipulation and reduction under general anesthesia is recommended immediately in the operating room.

**Percutaneous Reduction**

- A percutaneous reduction can be an effective and quick next step, particularly if the dislocated talar body is a single fragment.
- With the patient in the supine position, a large, firm sterile bump must be positioned under the calf of the patient.
- A 4-mm external fixation half-pin is advanced through the posterior tuberosity of the calcaneus, in line with the long axis of the bone, to the subchondral surface of the anterior process of the calcaneus.
- Next, a medial-to-lateral 4-mm half-pin is advanced across the dense subchondral distal tibia bicortically.

**Reduction of the Talar Dome Fragment**

- A final 4-mm half-pin is manually, and carefully, advanced deep into the body of the talus through a 1.5-cm longitudinal incision.
- The rationale of the pin placement should be clear.
- The long calcaneal pin has terrific mechanical advantage with traction to the torn posterior capsule of the ankle.
- The surgeon distracts the distal tibial and calcaneal pin while a surgical assistant attempts to reduce the talar body anteriorly using the half-pin as a joystick.

**OPEN REDUCTION AND INTERNAL FIXATION OF THE BODY OF THE TALUS**

- Reconstruction of talar body fractures is best performed using dual medial and anterolateral approaches with the addition of the medial malleolar osteotomy.
- Unless the fracture line is transverse and very anterior, allowing reasonable access by a standard dual approach, a transmalleolar approach is planned.
- Fracture patterns to the body of the talus occur in both sagittal and coronal planes. Regardless of the fracture plane, the principle is to work through the fenestration provided by the medial malleolar osteotomy, using fine-tipped dental probes, reducing the posterior portion of the body to the anterior body fragments.

- Small, smooth Kirschner wires are inserted from medial and lateral portals, provisionally fixing the body.
- Associated fractures of the neck of the talus are provisionally fixed after reduction of the body fracture.
- Interfragmentary, countersunk, mini-screws (2.7 or 2.0 mm) are sequentially inserted, fixing the body fragment.
- Headless screws can also be used for this fracture.
- Finally, countersunk, interfragmentary small fragment (3.5 mm) screws or mini-plate and screw constructs are used to fix the talar neck fracture (TECH FIG 3).
Displaced, intra-articular posterior talar body fractures present largely in the coronal plane (TECH FIG 4).

I prefer to position the patient prone, on a sterile bump, and access the fracture through the posteromedial approach.

Before inflation of a tourniquet, I recommend inserting medial, distal-third tibial and calcaneal external fixation half-pins. This will allow for application of a small femoral distractor, which aids in ankle and subtalar joint distraction.

A headlamp worn by the operating surgeon aids visualization in this approach.

OPEN REDUCTION AND INTERNAL FIXATION OF THE POSTERIOR BODY OF THE TALUS

- Narrow Hohmann retractors are gently applied medially and laterally within the ankle joint, retracting the posterior tibial nerve and artery and FHL tendon, respectively. This allows exposure of the posterior talar fragment.
  - The fracture is reduced using dental probes.
  - Smooth Kirschner wires are inserted, posterior to anterior, provisionally fixing the fracture.
  - The fracture is fixed either by interfragmentary, parallel screw fixation or a well-contoured mini-plate and interfragmentary screws.
  - The posterior mini-plate is contoured in a curvilinear fashion to securely buttress the posterior talus.
OPEN REDUCTION AND INTERNAL FIXATION OF THE LATERAL PROCESS OF THE TALUS

- Open reduction and internal fixation of fractures of the lateral process of the talus may be performed with the patient positioned either supine or direct lateral.
  - Intuitively, the patient should be supine if other surgery is to be performed on the foot and ankle.
  - After completing the lateral approach, the surgeon carefully evaluates the lateral process fracture (TECH FIG 5A,B).
  - I gently displace the fracture and assess the condition of the subtalar joint.
  - Small fragments are commonly devoid of soft tissue attachments. Only very small fragments should be removed.
  - Larger fragments, even those without soft tissue attachments, are needed to restore the structure of the lateral process in any closed fracture of the lateral process of the talus.
- Any anterior or posterior osteochondral fragments are reduced and provisionally fixed with small, smooth Kirschner wires.
- A Freer elevator is helpful to determine the anatomic subtalar joint line.
- Final reduction of the direct lateral fragments of the lateral process is provisionally fixed by Kirschner wires.
- Isolated lateral process fractures are best fixed by interfragmentary mini-screw fixation.
- Comminuted fractures should be buttressed by mini-screw and plate fixation to resist displacement against axial loads to the process (TECH FIG 5C,D).

OPEN REDUCTION AND INTERNAL FIXATION OF THE LATERAL PROCESS OF THE TALUS

- A talus devoid of soft tissue attachments should be immediately placed in a Bacitracin solution and transported to the operating room.
- After preparation and draping, the talus is placed in two or three Bacitracin and saline baths and gently scrubbed before reimplantation.
- A foot and ankle external fixator must be constructed (TECH FIG 6).
  - Initially, two 4-mm external fixation half-pins are inserted bicortically into the anterior distal third of the tibia.
  - A 4-mm half-pin is inserted bicortically into the base of the first and fifth metatarsals.
  - Finally, a 4-mm half-pin, or transfixion pin, is advanced from medial to lateral, bicortically, through the tuberosity of the calcaneus.
  - An external fixation rod connects the two metatarsal base pins, forming a midfoot unit. It is important to leave excess rod on each end of the midfoot unit for further tibial-rod attachment.
  - Next, an isolated, long external fixation rod is attached to the medial end of the midfoot unit and to the distal

EXTERNAL FIXATION

- A talus devoid of soft tissue attachments should be immediately placed in a Bacitracin solution and transported to the operating room.
- After preparation and draping, the talus is placed in two or three Bacitracin and saline baths and gently scrubbed before reimplantation.
- A foot and ankle external fixator must be constructed (TECH FIG 6).
  - Initially, two 4-mm external fixation half-pins are inserted bicortically into the anterior distal third of the tibia.
  - A 4-mm half-pin is inserted bicortically into the base of the first and fifth metatarsals.
  - Finally, a 4-mm half-pin, or transfixion pin, is advanced from medial to lateral, bicortically, through the tuberosity of the calcaneus.
  - An external fixation rod connects the two metatarsal base pins, forming a midfoot unit. It is important to leave excess rod on each end of the midfoot unit for further tibial-rod attachment.
  - Next, an isolated, long external fixation rod is attached to the medial end of the midfoot unit and to the distal
tibial half-pin, restoring neutral plantarflexion of the ankle.

- A second, long external fixation rod is attached to the lateral end of the midfoot rod and connected to the proximal tibial pin, controlling ankle varus and assisting dorsiflexion.

- Finally, external fixation rods are added, connecting the calcaneal pin to both the medial, midfoot rod and either tibial half-pin for increased frame rigidity and possibly to distract the subtalar joint.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Avoid a medial approach to the neck of the talus plantar to the insertion of the posterior tibial tendon.</th>
<th>The tuberosity of the tarsal navicular is an important landmark identifying the plantar limit to the medial approach. Immediate swelling obscures palpation of this landmark.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The neck of the talus is aligned eccentrically medial in the hindfoot.</td>
<td>The anterolateral surgical approach should not be lateral to the syndesmosis unless to address fixation of the lateral process of the talus or débridement of subtalar comminution.</td>
</tr>
<tr>
<td>A medial malleolar osteotomy performed distal to the shoulder of the medial ankle mortise gives poor visualization of the talar dome.</td>
<td>The osteotomy should be made at the level of the joint using a thin saw blade. The surgeon should protect the soft tissues posterior to the malleolus during the osteotomy.</td>
</tr>
<tr>
<td>Beware of fixing the neck of the talus in varus malalignment.</td>
<td>The surgeon should view the Canale image intraoperatively with C-arm fluoroscopy (flexed knee, everted foot in equinus and C-arm tube directed 15 degrees caudad).</td>
</tr>
<tr>
<td>Medial screw fixation of talar neck fractures, not countersunk in the talar head, commonly achieves poor fixation in the metaphyseal bone.</td>
<td>The surgeon should avoid medial percutaneous fixation of talar neck fractures.</td>
</tr>
<tr>
<td>Do not use posterior-to-anterior screw fixation, with the patient in the prone position, for a displaced talar neck fracture.</td>
<td>Posterior-to-anterior fixation does not allow reduction of a displaced fracture.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- The goal of operative and nonoperative treatment of talus fractures is to achieve bone union and restore hindfoot function.
- Return to preinjury status is commonly not achieved secondary to posttraumatic arthrosis and joint stiffness, but good functional outcomes are attained even in the most severe cases of talar neck and body fractures.
- Immediate postoperative treatment requires application of sterile ankle dressings and a well-padded, short-leg dressing with a posterior plaster splint.
- The ankle is positioned in neutral plantarflexion. Rigid internal fixation safely allows early postoperative ankle and subtalar motion.
- Before hospital discharge, the patient is taught to perform daily dressing changes and application of a foot and ankle compression Ace wrap to control swelling.
- The patient is to wear a removable short-leg fracture boot and remain absolutely non-weight bearing for 8 weeks.
- The fracture boot should be worn during the night for the initial 3 to 4 weeks after surgery to prevent an early Achilles tendon contracture.
- Active ankle and subtalar motion exercises are recommended.
- Immediate outpatient physical therapy after a talus injury routinely leads to excessive pain and ankle swelling.
- However, upper and contralateral lower extremity strengthening may be valuable during the initial, subacute, 6-week postinjury period.
- Partial avascular necrosis of the lateral dome of the talus is common. This may be seen because only the medial deep deltoid blood supply to the talus body remains intact after the injury.
- The Hawkins sign is an early subchondral radiolucent line indicating blood supply to the body of the talus. Its presence, seen on an AP radiograph at 6 to 8 weeks, indicates bone resorption, which is an active process requiring vascularity.
- Fortunately, patients with isolated regional osteonecrosis of the talar dome rarely experience late collapse.
- The lack of a Hawkins sign does not confirm osteonecrosis and may not be confirmed by plain radiographs until up to 3 months after the injury.
- There are no data to support extended periods of non-weight bearing in patients with partial avascular necrosis. Currently, the impact of weight bearing on the progression of osteonecrosis is unknown. Procedures designed to revascularize the talus, such as core decompression, are not recommended.
- Protected weight bearing with a patellar tendon-bearing brace to alleviate axial load to the hindfoot and refraining from repetitive-loading sports are reasonable early concerns to discuss with the patient.
- I recommend formal outpatient physical therapy starting at 6 weeks after surgery. The patient is non-weight bearing for 2 weeks, performing passive range of motion of the ankle and subtalar joints, isometrics of the leg, and possibly pool therapy.
- At 8 weeks, progressive weight bearing, strengthening, proprioception, and range-of-motion exercises ensue.
- Patients routinely display increased swelling of the injured extremity with weight bearing.
- Application of a 20- to 30-mm Hg compression stocking helps reduce swelling.
- By 3 months the patient should be weaned from the fracture boot and the transition made to an ankle brace applied within a shoe.
- Physical therapy can easily continue for up to 3 months with these injuries.
- The patient must be counseled on the importance of long-term exercise after the end of formal physical therapy.
- Nonoperative management of talus fractures requires cast immobilization for 6 weeks.
- After cast immobilization, the injury should be treated with a removable fracture boot and an outpatient physical therapy protocol.
- Progression to weight bearing is determined accordingly.
- Follow-up postoperative management requires a three-view plain radiographic ankle series.

OUTCOMES

- If the patient does not develop a complication of a talus fracture or its management, requiring secondary reconstructive surgery, the functional outcome should be considered a success.
- Recent data evaluating the surgical timing of talus fractures maintain that the time to surgery does not correlate with outcome. There is no association between delay of operative management and avascular necrosis. This makes a strong case for provisional external fixation of reduced talus fractures as immediate treatment, particularly if the condition of soft tissues does not allow early open management.
- Risk factors that lead to lower functional outcomes include comminution, a higher Hawkins classification, open fracture, and associated ipsilateral lower extremity injuries.
- Osteonecrosis of the talus, posttraumatic arthrosis, joint stiffness, and varus malalignment can have a negative impact on the outcome.
- The incidence of avascular necrosis of the talar body has been shown to increase with the severity of injury. The Hawkins sign has an accuracy of 75%. This sign is considered a good predictor of a vascularized talar dome; however, the absence of a Hawkins sign does not necessarily indicate progression of avascular necrosis.
- Recent studies evaluating talar neck fractures identify an overall 50% incidence of avascular necrosis, with evidence of collapse of the talar dome in 31% of the cases.
- Posttraumatic arthrosis secondary to these injuries is more common than avascular necrosis and most often presents in the subtalar joint.
- Ankle arthrosis does not occur as an isolated outcome; it is seen in association with subtalar arthritis.
- Recent reports of talar body fractures show a 20% rate of early superficial wound complications. All patients were treated effectively with oral antibiotics and local wound care. Thirty-eight percent of cases developed avascular necrosis. Evidence of talar dome collapse presented in half of these cases by 14 months after the injury. Patients with talar dome fractures with osteonecrosis and posttraumatic arthrosis had the lowest functional scores.
- No consensus exists regarding the most appropriate treatment of the extruded talus. This is a rare injury with an intuitively poor prognosis.
- A recent study evaluating reimplantation of the talus promoted the consideration of retaining the talus if possible. In the study, 8 patients had pure dislocations and 11
presented with various major and minor fracture patterns associated with talar extrusion. All fractures and dislocations were stabilized and no wound was allowed to granulate to closure. Talar collapse occurred within 1 year in all eight patients with major fractures. At an average of 42 months follow-up, there were two infections. Seven patients required secondary surgical procedures, including hardware removal, ankle arthroplasty with subtalar fusion, ankle fusion, bone grafting, débridement, and flap revisions. The authors clearly did not experience a high infection rate, supporting their conclusion that reimplantation is an effective solution to the challenging problem of traumatic tectomy.

COMPLICATIONS

- Fractures of the talus have known complications associated with soft tissue and fracture healing, malunion, arthrosis, and avascular necrosis.
  - Open fractures must be managed by a standard protocol including débridement, prophylactic antibiotics, fracture stabilization, and delayed closure.
  - Soft tissue complications associated with talus fractures are predominantly superficial.
    - If full-thickness slough occurs, however, a formal wound débridement is mandatory, followed by rotational or free flap coverage.
  - The incidence of delayed union or nonunion of fractures of the talar neck varies in the literature between 0% and 10%. The presence of avascular necrosis is a primary cause of nonunion. Nonunion of the talar neck fracture may also result from poor fixation.
  - If the cause of nonunion is unclear, the nonunion should be studied by magnetic resonance imaging or CT scan. Every effort should be made to revise fixation with autogenous bone graft when possible.
  - Nonunion due to total osteonecrosis of the body of the talus requires removal of the bone fragment and a tibiocalcaneal fusion.
  - Nonoperative management of comminuted lateral or posteromedial process fractures can be unpredictable.
    - If pain persists long after the patient has returned to full weight bearing and radiographic or CT imaging suggests nonunion, surgical resection of these fragments is routinely helpful. Pain is commonly linked to fibrous nonunion of these avulsion fragments.
  - Malunion of the talus is predominantly due to varus malalignment. Malalignment of the talar neck is best prevented using dual medial and anterolateral approaches in combination with the Canale image intraoperatively when performing the patient’s initial surgery.
  - Subtalar and ankle arthrosis is the most common complication associated with fractures of the talus. The incidence of subtalar arthrosis is greatest.
  - Arthritic symptoms can be managed effectively with non-steroidal anti-inflammatories. The hindfoot is also benefited by custom ankle bracing. The patellar tendon-bearing brace can effectively unload weight to the injured ankle, giving the patient increased relief.
  - If symptoms of arthrosis are not improved nonoperatively, the patient should be evaluated by selective hindfoot and ankle lidocaine injection. Relief of joint pain, whether unifocal or bifocal, will allow the surgeon to counsel the patient on further reconstructive treatment.

REFERENCES

DEFINITION

- An intra-articular calcaneal fracture is an injury that involves the joint surfaces of the calcaneus, usually with displacement.
- A fracture-dislocation of the calcaneus occurs when the posterior facet dislocates from beneath the talus and ends up displaced beneath the fibula. It carries a poor prognosis if treated nonoperatively.
- “Soft tissue” damage refers to the injury to the skin, adipose, tendinous, muscular, and nerve structures that surround the calcaneus and ranges from mild bruising to near-amputation in open fractures.
- Fracture blisters and varying degrees of skin contusion occur most commonly.
- “Wrinkle sign” refers to the skin wrinkles that appear when the injury swelling response is resolving.
- A primary fracture line is one that occurs early in the mechanism of the calcaneal fracture. There are two that occur, and if their pathogenesis is understood, this can explain the majority of the pathology observed. This will be defined further in the Pathogenesis section.

ANATOMY

- The calcaneus is the largest bone in the foot. It has a complex shape that makes exact surgical reconstruction difficult.
- The calcaneus functions to transmit weight-bearing forces of the leg into the foot.
- The calcaneus has a shock absorber function by assisting in mobility of the ankle and subtalar joints, thus allowing the foot to accommodate to variations in terrain.
- The calcaneus has four articular facets that produce this mobility: posterior, anterior, middle, and cuboid. Exact articular alignment is required for full function of this four-joint complex.
- The internal structure of the calcaneus reflects its weight-bearing role.
  - There is particularly dense trabecular bone in the juxta-articular regions, especially below the posterior facet (the thalamic trabecular system).
  - The tendo Achilles insertion also has dense trabecular bone.
- Cortical bone of 3 to 4 mm in thickness occurs in the superior-medial region (sustentaculum area) and in the superior-lateral strut of bone that runs between the cuboid and posterior facets (anterolateral fragment). These regions of cortical bone will come into play when discussing the internal fixation of the calcaneus (FIG 1).
- The soft tissues of the calcaneus are easily damaged by trauma. Management of this injury component is essential to avoid iatrogenic surgical complications.

PATHOGENESIS

- Despite the seemingly infinite varieties of fractures that occur, stereotypic fracture lines, fragments, and displacements can be recognized.
- The calcaneus is fractured by a combination of shear and compression forces generated by the talus descending upon the calcaneus.
- Two primary fracture lines occur.
  - The first occurs in the angle of Gissane and divides the calcaneus into anterior and posterior fragments. It can split either the middle or anterior facet, and the fracture continues on the lateral wall in an inverted Y shape (FIG 2).
  - The second fracture divides the calcaneus into medial and lateral halves and shears the posterior facet into two or more fragments.
    - As the talus continues to compress the calcaneus, the lateral half of the posterior facet is impacted into the body of the calcaneus, with the recoil producing a step-off in the posterior facet.
    - This same fracture line commonly continues into the cuboid facet and, in combination with the first primary fracture line, produces the anterolateral fragment and superomedial fragment.
    - In this way, these two fracture lines produce fracture components that include the superomedial fragment, anterolateral fragment, posterior facet, and tuberosity.
  - Characteristic displacements of these components occur.
    - The tuberosity is driven up between the pieces of the posterior facet, can tilt into valgus or varus, and is usually translated laterally.
    - The lateral posterior facet fragments are impacted and rotated plantarily into the body of the calcaneus (FIG 3A).
    - The posterior facet breaks into one of three patterns, which form the basis of the Sanders classification:
      - Sanders II: two main pieces (FIG 3B)
      - Sanders III: three main pieces (FIG 3C)
      - Sanders IV: multifragmentary
    - The superomedial fragment retains alignment to the talus by means of its ligamentous attachments but can be subtly displaced by overlap with the anterior process. This overlap occurs along the primary fracture line that occurs in the sinus tarsi.
    - The anterolateral fragment displaces superiorly a variable amount. It typically extends into the cuboid facet, with varying degrees of displacement (FIG 3D).
    - The lateral calcaneal wall is displaced outward in the area of the trochlear tubercle. This, in combination with tuberosity translation, accounts for the heel widening and peroneal impingement that occur.
The first fracture types recognized were the joint depression and tongue-type patterns, which are readily identified on a lateral heel radiograph. The tongue fracture maintains a connection between the tuberosity and the posterior facet, while the joint depression separates the fractured joint surface from the tuberosity (FIG 4).

Because of this anatomy, certain tongue fractures have a large portion, or even the entire posterior facet, in continuity with the tuberosity (AO-OTA 73 C1). Thus, reduction of the tongue fracture is important to maintain the connection with the tuberosity.

FIG 1 • A lateral radiograph of a calcaneus specimen sectioned in the sagittal plane. The trabecular systems are visualized and numbered 1 through 4. The densest bone is in the juxta-articular regions. Thick cortical bone also is present in the anterolateral fragment and medial wall in the sustentacular region. 1, thalamic trabecular system; 2, anterior apophyseal trabecular system; 3, anterior plantar trabecular system; 4, posterior plantar.

FIG 2 • Pattern of calcaneal fracture-dislocation and reduction.

FIG 3 • A. The posterior facet displaces and rotates in a plantar direction (arrow). B,C. CT scans showing a Sanders II fracture with a large superomedial fragment (B) and a Sanders III fracture (C). D. The primary fracture line extends into the calcaneal cuboid facet. The anterolateral fragment is represented by the most lateral piece (arrow). (D: Courtesy of Paul Tornetta III, MD.)
the tuberosity will reduce indirectly the posterior facet and restore the angle of Bohler. This particular pattern is well suited for small incision or percutaneous techniques.

- Reduction of a joint depression pattern is best performed with an open reduction.

**NATURAL HISTORY**

- An intra-articular fracture of the calcaneus is a serious injury that will diminish foot function.
- Nonoperative treatment is with early motion and delayed weight bearing 6 to 8 weeks after injury. This method has the least chance of iatrogenic injury.
- In a classic review by Lindsay and Dewar, only 17% of patients had no foot symptoms with long-term follow-up.
- The loss of ability to perform manual labor is common, with an average time off work of 4 to 6 months for laborers.
- Loss of subtalar motion to varying extents will occur.
- Tibiotalar impingement and anterior ankle pain can be produced if the crush deformity is severe enough.
- It can take 18 to 24 months for the foot symptoms to maximally improve after this injury. Most improvement occurs in the first 12 months.
- The key concept here is that patients who continue to improve symptomatically can be observed until maximum improvement occurs.
- A recent randomized, prospective study found that the need for late subtalar arthrodesis is five to six times greater if nonoperative treatment is used on all injuries. The overall rate was approximately 17%.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The history is typically one of a fall or vehicle crash. Occasionally in a diabetic, a seemingly trivial ankle sprain-type mechanism can occur. Important risk factors for operative treatment complications include smoking, diabetes, peripheral vascular disease, and steroid use. The foot and ankle are visually inspected.
- Swelling is graded as mild, moderate, or severe.
- Operative treatment in the face of severe soft tissue swelling is prone to wound healing complications.
- Fracture blisters are graded as fluid-filled or blood-filled. If unhealed, fracture blisters are a source of skin bacterial colonization. Blood-filled blisters denote a deeper dermal injury.
- Skin contusion is noted.
- If present, the wrinkle sign is noted. It means the swelling is resolving and surgical incisions are less likely to experience complications.
- Open wounds are noted.
- The physician palpates the foot and ankle, looks for spine injuries or ipsilateral fractures, and performs a secondary survey for other injuries.
- Spine injuries are said to accompany up to 10% of all calcaneal fractures.
- The physician assesses for compartment syndrome, including passive flexion and extension of the toes, tenseness of the foot swelling, and compartment pressure measurement.
- Positive results are degree of pain elicited and pressures within 30 mm of diastolic blood pressure.
- Compartment syndrome can occur in 5% to 10% of all calcaneal fractures.
- The physician performs a neurologic examination to check the sensory function of foot and toes, including light touch and pinprick.
- Calcaneal fractures can damage the posterior tibial nerve and occasionally sensory nerves. Findings may be altered with compartment syndrome.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Anteroposterior and lateral (FIG 5A,B) foot radiographs are the initial screening study.
- The axial (Harris) view should also be obtained (FIG 5C). This view will demonstrate the medial wall and show the relation of the superomedial fragment to the tuberosity.
- Broden views are radiographs that focus on the subtalar joint. They are taken with the foot internally rotated, and the x-ray beam angled to varying degrees cephalad (FIG 5D,E). By using different degrees of cephalad angulation, different parts of the posterior facet may be imaged. They are best used intraoperatively to judge the reduction of the posterior facet and the medial wall of the calcaneus.
If the fracture is displaced, a computed tomography (CT) scan is recommended to define the anatomy (see Fig 3B,C).

A CT scan with biplanar cuts and reconstructions is recommended. This will best delineate the fragments and displacements.

DIFFERENTIAL DIAGNOSIS

- Fracture of the talus
- Lateral process of talus fracture
- Fracture of the midfoot (eg, navicular fracture)
- Severe ankle sprain
- Subtalar dislocation
- Stress fractures of the calcaneus can masquerade as a soft tissue disorder of the hindfoot (eg, plantar fasciitis).

NONOPERATIVE MANAGEMENT

- The indications for nonoperative treatment include posterior facet displacement less than 2 mm, and medical conditions such as peripheral vascular disease or diabetes.
- Some surgeons consider smoking a relative contraindication; it certainly predisposes to a higher wound complication rate.
- Severe fracture blisters or closed soft tissue injury can preclude operative treatment, although open reduction and internal fixation can be performed as late as 4 weeks after injury.

The recommended nonoperative treatment is compression wrapping, early motion, and delayed weight bearing at 6 to 8 weeks after injury. This offers the least iatrogenic risk to the patient while optimizing chances for subtalar motion.

- Once weight bearing is started, the patient continues with range-of-motion exercises.
- Strengthening of the foot and ankle muscles is added as fracture consolidation progresses.
- A well-cushioned shoe usually offers the best pain relief. Two different shoe sizes may be needed in extreme cases.
- A rocker-bottom sole can be added to assist with the toe-off stance phase of gait.
- A double upright brace with a rocker-bottom-soled shoe can assist ambulation in patients with severe injury who have impairment upon fracture healing.

Nonoperative treatment is not recommended for calcaneal fracture dislocations, as a painful deformed foot is practically guaranteed if it is left unreduced.

SURGICAL MANAGEMENT

- The displaced intra-articular calcaneal fracture presents a difficult challenge.
- Foot pain and stiffness are common even with the best of treatment, and iatrogenic problems such as infection can result in loss of limb in extreme circumstances, and at the least predispose to a poor result.
Thus, a careful, individualized approach is recommended, with a priority on avoiding iatrogenic problems while attaining an anatomic alignment of the calcaneus.

- Indications include displacement of the posterior facet of more than 2 mm, and calcaneus fracture dislocation.
- Research shows that certain patient groups, such as those receiving worker’s compensation, are predisposed to a poor result with operative treatment, but that does not obviate the benefits of obtaining anatomic foot alignment and lessening the chances of late subtalar fusion.
- Operative restoration of at least the calcaneal shape should be considered for fractures with severe displacement (e.g., tuberosity displaced superiorly behind the ankle joint), as late reconstructions can be difficult.
- The choice of any surgical approach or technique should always have the goal of total anatomic restoration, although extreme comminution can compromise attainment of this goal.

Preoperative Planning

- Once operative treatment has been elected, the surgical approach is chosen based on a number of factors, including the surgeon’s training and experience and the pathoanatomy present.
- The timing is in general when the wrinkle sign develops, typically 7 to 14 days after injury. Fracture blisters should be epithelialized.
- The injury pathoanatomy is analyzed first by looking at the posterior facet pattern (Sanders II, III, or IV), displacement, and location of the primary fracture line in the posterior facet.
- Fractures that are more medial are more difficult to visualize, and more fragments involving the posterior facet are more difficult to fixate anatomically.
- Fractures that separate the entire posterior facet and have a tongue pattern are amenable to percutaneous Essex-Lopresti techniques.
- Conversely, joint depression fractures require open reduction of the posterior facet.
- A highly comminuted Sanders IV fracture may alter the goals to restoration of the calcaneal body shape and primary fusion.
- The other fracture components to be analyzed for displacement are the superomedial fragment, anterolateral fragment, and tuberosity. The surgical plan should address each of these pathologies for reduction strategy and fixation.
- The typical reduction order is first to correct any superomedial fragment subluxation.
- Next, the superomedial fragment is reduced and held to the tuberosity.
- The posterior facet is then reduced and fixed.
- Finally, the anterolateral fragment is reduced and fixed.
- The size and integrity of the superomedial fragment is critical, as fixation techniques largely center on screw placement into its substance. A small or comminuted superomedial fragment makes rigid fixation harder to achieve and may call for alternative techniques.
- Restoration of the superomedial fragment to the tuberosity will restore the calcaneal shape and make room for reduction of the displaced posterior facet fragments.
- The superomedial fragment may be incarcerated in the sinus tarsi and subtly subluxated. This is recognized by the preoperative CT scan on the sagittal reconstructions, and by the lack of congruence of the superomedial fragment with the undersurface of the talus.
- Failure to correct this subluxation makes posterior facet reduction very difficult.
- The anterolateral fragment should key into location just in front of the reduced posterior facet and restores lateral column length.
- It can be fixed with either lag screws into the superomedial fragment, or a mini-fragment plate. Some of the perimeter plates have a small extension to pull this fragment into place.
- The fixation chosen depends on the approach taken. Fractures splitting the posterior facet will require lag screws inserted from lateral to medial; they range in size from 2 to 4 mm, depending on the fractures present.
- Sanders III fractures are converted into two major pieces with the use of countersunk mini-fragment screws that fix the intermediate piece to the more medial piece.
- Extra-long mini-fragment screws are desirable to reach the medial cortical bone.
- The plate chosen depends on the approach.
- The extensile lateral approach will require some type of low-profile “perimeter” plate.
- Strategic placement of small and mini-fragment plates, and occasionally lag screws alone, is used in small-incision techniques.
- Plans must be made for imaging, most typically fluoroscopy. This will allow control of the AP, lateral, axial, and Broden views intraoperatively.
- Arthroscopy can also help visualize the posterior facet, especially in its anterior portions.

Positioning

- The extensile lateral approach is performed in the lateral decubitus position with the injured foot on top. A thigh tourniquet is applied.
- The fluoroscope is brought in from the side opposite the surgeon regardless of the surgical approach.
- The same position can be used for percutaneous manipulations of tongue fractures. This allows conversion to the extensile lateral approach, as recommended by Tornetta.
- Small-incision approaches are performed supine with a bump under the ipsilateral hip. A tourniquet is placed but not routinely inflated.
- For small-incision techniques, the patient is pulled down to the end of the table. The point of the heel should project slightly beyond the end of the bed. This allows for placement of axially directed implants.
- If used, the arthroscope is placed with the monitor on the same side as the C-arm, toward the head of the bed.

Approach

- Small-incision techniques will address most calcaneal pathologies but require a firm understanding of the fragments, displacements, and deforming forces present.
- They are ideally suited to Sanders II fractures with a large superomedial fragment and only mild to moderate posterior facet displacement.
- The extensile lateral approach is applicable to all fracture patterns and displacements. Its use in open fractures warrants caution with respect to soft tissue complications.
PERCUTANEOUS REDUCTION AND FIXATION OF TONGUE FRACTURE

- If performed acutely, percutaneous reductions can be technically easier and do not increase the risk of infection in my experience.
- If there is any question, the surgeon should use the presence of the wrinkle sign and healing of fracture blisters.
- This technique is ideally indicated for tongue patterns that have a large percentage of the posterior facet connected to the tuberosity (Sanders IIC) (TECH FIG 1A).

- The technique can be used for Sanders IIA and IIB patterns, but the facet reduction is more difficult if done percutaneously.
- I prefer to perform this surgery supine, with the addition of a sinus tarsi incision for failure of the percutaneous reduction.
- Tornetta prefers the lateral position, with conversion to the extensile lateral approach if percutaneous manipulations are unsuccessful.

**TECH FIG 1**

A. A displaced tongue fracture demonstrates the typical displacement and location of an injury amenable to percutaneous reduction. The anterior process is not comminuted. The medial fragment was small.

B. Introduction of a large smooth pin to manipulate the fracture. Note the incomplete reduction in the angle of Gissane, and posteriorly where the tongue fracture exits.

C. Multiple wires for cannulated screws have been placed. The anterior process is not comminuted and can be used for screw purchase.

D. Reduction obtained and screw placement.

E–G. For this Sanders II fracture, after repair of the navicular fracture, a small incision was made in the plantar lateral foot, localizing the area beneath the angle of Gissane. E. A 5-mm pin was placed on a Synthes (Paoli, PA) T-handled chuck. The pin was then placed through the stab incision and advanced just inside the lateral wall of the calcaneus. At the same time, a cannulated screw guidewire was placed in the plantar portion of the calcaneus.

F. With the manipulating pin applying a firm upward pressure with the foot plantarflexed, the wire was driven from the tuberosity into the tongue fragment. This was replaced with a 4.0-mm cannulated screw.

G. A second cannulated screw was placed from the lateral calcaneus into the superomedial fragment.
The patient is placed supine with a generous bump under the ipsilateral hip to assist access to the heel.

0.25% Marcaine with epinephrine is injected into the fracture hematoma and soft tissues. A popliteal block is also placed by the anesthesia team. The combination of these two blocks will allow for outpatient surgery management of this injury.

A 1/8 Steinmann pin is introduced into the calcaneus from the posterior tuberosity into the region just beneath the posterior facet.

The pin is then used as a levering tool to restore the Bohler angle of the fractured calcaneus (TECH FIG 1B).

Taking a lateral view of the normal heel and saving it on the fluoroscope provides a comparison to judge reduction. Once the fracture is reduced, one or two cannulated screws are introduced from the tuberosity into the anterior process of the calcaneus (TECH FIG 1C,D).

Alternative or adjunctive fixation strategies include placing a 4.0-mm screw from the plantar tuberosity into the dorsal calcaneus surface. This resists plantar displacement of the tongue fragment.

Another lag screw possibility is one directed from the lateral calcaneus into the superomedial fragment (TECH FIG 1E–G). This is more difficult in this pattern because by definition it has a small superomedial fragment.

OPEN REDUCTION

If the Bohler angle is not reducible or if a step-off remains in the posterior facet, an open reduction is performed.

I prefer a small sinus tarsi incision approach to aid in the reduction.

A 4- to 6-cm sinus tarsus incision is made to expose the posterior facet, the anterolateral fragment, and a portion of the lateral calcaneal wall (TECH FIG 2).

The posterior facet is reduced under direct vision, and the reduction is confirmed with fluoroscopy. An arthroscope is helpful as well.

A traction pin in the tuberosity can help restore calcaneal height.

Lateral to medially directed lag screws are placed across the posterior facet. A mini-fragment plate is used to bridge the posterior facet to the anterolateral fragment.

The lateral wall should be manually compressed at this point.

Consideration can be given to adding a calcium phosphate cold hardening composite to provide extra support.

Layered closure is performed.

TECH FIG 2 • Lateral approach for the small incision technique.

SIMULTANEOUS MEDIAL AND LATERAL APPROACHES

In general, except for open fractures, timing should be guided by the presence of the wrinkle sign and healing of fracture blisters.

This technique is ideally indicated for Sanders II fractures with 2 to 10 mm of displacement of the posterior facet, and a large superomedial fragment. It can be applied to nearly any fracture pattern, but the limited exposure makes posterior facet reduction more difficult for Sanders III and IV patterns.

A generous bump is placed under the ipsilateral hip. The heel is left slightly off the end of the bed to facilitate the placement of axially directed fixation.

0.25% Marcaine with epinephrine is injected into the fracture hematoma and soft tissues. A popliteal block is also placed by the anesthesia team.

The combination of these two blocks will allow for outpatient surgery management of this injury.

Injuries and Dissection

The medial approach is posterior and parallel to the neurovascular bundle (TECH FIG 3A).

The medial calcaneal sensory branch is identified deep to the flexor retinaculum and preserved. This directly exposes the superomedial fragment and keeps the neurovascular bundle in the anterior flap.

The lateral approach extends anteriorly 4 to 6 cm from the tip of the fibula (see Tech Fig 2).

This will provide exposure of the posterior facet and anterolateral fragment.

It is performed after the medial approach.
■ At this point, all fracture fragments are identified and cleaned of debris.
■ The posterior facet is partly reduced to avoid obstruction of the superomedial fragment and tuberosity reduction.
■ A 1.6-mm Steinmann pin is introduced into the tuberosity of the calcaneus in a medial-to-lateral direction. Tensioned with a Kirschner bow, it allows for correction of shortening (TECH FIG 3B).
■ The medial fracture fragments are cleaned of debris, and landmarks for reduction are identified.

### Medial Reduction and Fixation
- Reduction and fixation can be done with one of two strategies.
- The first is with an antiglide 2.7-mm plate.
  - One can predrill a hole on the tuberosity fragment next to the fracture site and to the length measured.
  - With use of distraction and manipulation, an approximate reduction of the superomedial fragment and tuberosity is obtained, particularly with respect to length.
  - A 2.7-mm five-hole T plate is then placed on the bone and the premeasured screw inserted. As the plate tightens to the bone, it will help reduce any tuberosity translation (TECH FIG 4).
- The reduction is checked by fluoroscopy in all planes.
- If satisfactory, additional screws can be inserted, taking care to avoid the posterior facet.
- The second method is to obtain a reduction by traction and translation of the tuberosity.
  - One can then introduce axial cannulated screws—one up the inside of the medial wall and the other as a lag screw from the inferior lateral tuberosity into the superomedial fragment.
  - This latter lag screw is a useful adjunct to a medial antiglide plate.

### Lateral Reduction and Fixation
- Once the medial side is reduced, the lateral side is addressed.
The posterior facet is manipulated and reduced. The reduction is checked with Broden views and the arthroscope (TECH FIG 5).

It is common to approximate one portion of the facet, only to have another portion malreduced.

Once an anatomic reduction is obtained, provisional fixation with Kirschner wires is performed. Two lateral-to-medial-directed lag screws are then inserted just beneath the articular surface of the posterior facet.

The anterolateral fragment will now reduce anatomically to the posterior facet. It can be fixated with either a mini-fragment plate that bridges from the posterior facet to the anterolateral fragment, or a lag screw from the anterolateral fragment to the superomedial fragment.

The lateral wall should be manually compressed at this point.

Consideration can be given to adding a calcium phosphate cold hardening composite to provide extra support.

Layered closure is performed.

EXTENSILE LATERAL APPROACH

Timing should be guided by the presence of the wrinkle sign and healing of fracture blisters. This can take up to 3 weeks.

This technique is indicated for all types of calcaneal fractures with intra-articular displacement. Open fractures are best approached in a staged fashion.

The lateral decubitus position is used, with the injured side up. The C-arm comes in opposite the surgeon.

0.25% bupivacaine with epinephrine is injected into the fracture hematoma and soft tissues. A popliteal block is also placed by the anesthesia team. Tourniquet control is required.

An L-shaped incision is made parallel to the Achilles tendon and curves anteriorly along the border of the plantar skin of the heel (TECH FIG 6A).

The incision is made to bone, with a subperiosteal and periosteal flap raised along its entire extent. In the region of the peroneal tendon sheath attachment, the tendons are retracted anteriorly and the dissection is continued on the deep layer, above the abductor fascia.

Once the entire lateral side of the calcaneus is exposed, two Kirschner wires can be driven into the talus to provide retraction of the flap (TECH FIG 6B).

The lateral wall is entered and the posterior facet elevated from its displaced position (TECH FIG 6C).
If the superomedial fragment is subluxated by the anterior process, this is corrected by leverage and a Kirschner wire driven across the reduced fragments.

- A Schanz screw is driven into the tuberosity to facilitate manipulation of the fragments. Alternatively, a tensioned wire can be used.

- Attention is turned to the medial wall, where the superomedial fragment is identified.

- With traction and manipulation of the pieces, the medial wall is reduced and pinned with axial Kirschner wires that travel just inside the medial wall of the calcaneus.

- The posterior facet can now be reduced and provisionally fixated with Kirschner wires, and lateral-to-medial—directed lag screws are placed. Broden views are essential to ensure anatomic reduction.

- The anterolateral fragment is reduced to the posterior facet and pinned into the superomedial fragment.

- A perimeter plate is now applied to the lateral surface of the calcaneus (TECH FIG 6D,E). Contouring of the plate is not recommended, except in the area next to the curved posterior portion of the posterior facet if needed. It functions in a sense as a giant washer, serving to compress the calcaneus from lateral to medial.
PEARLS AND PITFALLS

| Indications | • Less invasive approaches require an accurate definition of the pathoanatomy, then matching the pathoanatomy with an operative plan.  
• Extensile approaches should be used cautiously with open fractures. |
| --- | --- |
| Fracture reduction | • With open approaches, the order of reduction is the same: superomedial fragment to anterior process, superomedial fragment to tuberosity, posterior facet to superomedial fragment, anterolateral fragment to posterior facet, lateral wall.  
• Exact posterior facet reduction is difficult to achieve but required to achieve excellent results. Adjuncts of fluoroscopy and arthroscopy help visualize the highly congruent subtalar joint.  
• In Sanders III fractures, the intermediate piece can be fixated to the superomedial fragment with 2.0-mm lag screws, thus converting it to a Sanders II pattern. |
| Fracture implants | • Extra-long mini-fragment screws are essential to allow matching of screw and fragment size, especially in the posterior facet.  
• The application of a straight plate to the lateral calcaneal surface will avoid varus of the heel. |
| Complications | • Strict foot elevation until suture removal is recommended to assist in wound healing. |
| Postoperative care | • Reliable patients without diabetes can safely perform touch-down range-of-motion exercises to assist in recovery of subtalar motion. |

POSTOPERATIVE CARE

• A well-padded short-leg cast is applied, split, and overwrapped with a loosely applied elastic wrap.  
• The patient is instructed to maintain strict elevation as much as possible until the sutures are removed.  
• The same cast is retained until the sutures are removed 2 weeks postoperatively.  
• In reliable nondiabetic patients, the cast can be discontinued and range-of-motion exercises begun.  
• Touch-down weight bearing to promote ankle and subtalar motion can be started at the same time.  
• Physical therapy is prescribed on an individualized basis.  
• At 6 weeks, a radiograph is obtained and weight bearing progressed as pain allows. Full weight bearing is expected by 12 weeks postoperatively.

OUTCOMES

• Despite appropriate care, most patients with a calcaneal fracture will lose some degree of foot function and have permanent symptoms.  
• While nonoperative treatment yields the fewest iatrogenic complications, it accepts malunion in nearly 100% and a higher incidence of later subtalar fusion.

• Symptom improvement can take up to a year to plateau.  
• In a recent randomized study, visual analog pain scores between nonoperative and operative groups were similar, but nonoperative treatment resulted in a 5.5 times greater incidence of late subtalar fusion.  
• In that same study, females, non-workmen's-compensation cases, and nonmanual laborers had improved results with operative treatment.  
• Better results were also seen with an anatomic reduction versus a nonanatomic one.  
• Soft tissue complications frequently lead to a poor result.  
• Amputations have been reported with extensile lateral approaches.  
• Open techniques should be used cautiously in diabetic patients, although injuries such as fracture-dislocation are best treated with operative reduction and fixation.

COMPLICATIONS

• The complications of nonoperative treatment include malunion, persistent foot pain, and a higher chance of later subtalar fusion.  
• Severe crush deformities affect not only the subtalar joint, but the midfoot and ankle as well. They can be difficult to
reconstruct, so initial management to avoid such a malunion is recommended.

- Smoking, diabetes, and open fracture are the most significant risk factors for soft tissue complications.
- Infection occurs in about 2% of fractures treated operatively with open incisions.
- Flap necrosis can occur with any incision but is most likely with the extensile lateral approach. Débridement and closure by secondary intention is often successful for minor flap losses. If a large portion of the flap is lost, consultation with a plastic surgeon is recommended.
- Deep infection is managed with débridement and intra-venous antibiotics based on culture results.
- Retention of hardware (if providing bone stability) until bone healing is optimal.
- Removal of the hardware to eradicate the infection once the bone is healed is sometimes needed.
- Posterior tibial nerve injury can result from the fracture and commonly presents with severe pain nonresponsive to narcotics in the postinjury period.
- Administration of medications aimed at neuropathic pain is recommended, and consultation with a pain specialist is considered.
- Cushioned shoe inserts are often comforting to individuals with postfracture plantar heel pain. A rocker-bottom shoe can also reduce discomfort.
- Late implant-related symptoms are rare with percutaneous or small-incision techniques. They are lessened by the use of low-profile “perimeter” plates with the extensile lateral approach.

REFERENCES

DEFINITION
- A Lisfranc injury refers to bony or ligamentous compromise of the tarsometatarsal and intercuneiform joint complex and includes a spectrum of injuries ranging from a stable, partial sprain to a grossly displaced and unstable fracture or fracture-dislocation of the midfoot.

ANATOMY
- The bony elements of the medial three tarsometatarsal joints (medial, middle, and lateral cuneiforms and first, second, and third metatarsal bases) feature a unique trapezoidal shape in cross-section, creating a concave arrangement plantarly resembling a Roman arch (FIG 1A).
- The second metatarsal is recessed between the medial and lateral cuneiforms in the axial plane and is positioned at the apex of the Roman arch in the coronal plane. It thus functions as the keystone of the entire midfoot complex (FIG 1B).
- The tarsometatarsal joints are stabilized by dorsal and plantar tarsometatarsal ligaments.
- Dorsal and plantar intermetatarsal ligaments provide further stability between the second through fifth metatarsal bases.
- There are no intermetatarsal ligaments between the first and second metatarsals, which may predispose the area to injury.
- The Lisfranc ligament courses from the plantar portion of the medial cuneiform to the base of the second metatarsal (FIG 1C).
- The unique bony arrangement of the medial midfoot imparts inherent bony stability to the medial and middle columns of the foot, which in combination with the stout plantar ligaments prevents plantar displacement of the metatarsal bases and facilitates the weight-bearing function of the first ray (FIG 2).
- The medial three tarsometatarsal joints and the adjacent intercuneiform and naviculocuneiform articulations (medial and middle columns) have limited inherent motion, making these joints nonessential to normal foot function and therefore relatively expendable.
- The medial column refers to the first tarsometatarsal and navicular–medial cuneiform articulations; the middle column includes the second and third tarsometatarsal joints, and articulations between the navicular and middle and lateral cuneiforms, respectively.
- The fourth and fifth tarsometatarsal (lateral column) joints have distinctly more inherent motion and are critical in accommodation of the foot to uneven surfaces.
- These joints are considered essential joints to normal foot function and therefore nonexpendable.

PATHOGENESIS
- Lisfranc injuries are generally the result of a high-energy injury, such as a fall from a height or a high-speed motor vehicle accident, but depending on the position of the foot, they may also result from a lower-energy injury, such as a slip and ground-level fall.
- These injuries result from a combination of axial load, and dorsiflexion, plantarflexion, abduction, or adduction (or variable combinations thereof) of the midfoot.
- The pathoanatomy is individually specific and highly variable and may consist of a pure ligamentous injury, a pure bony injury (fracture), or a combination.
- While the injury classically includes the first, second, and third tarsometatarsal joints, there may be involvement of all five tarsometatarsal articulations, extension into the intercuneiform joints, or even fracture lines into the navicular or cuboid proximally, or metatarsal shafts or necks distally.
- In pure ligamentous patterns, the stability of the injury depends on the status of the plantar tarsometatarsal ligaments. Disruption of these stout structures makes the injury unstable.
- Partial injuries (sprains) occur as a result of lower energy and are more common with axial load and plantarflexion, such as in competitive sports.
- In this instance, by definition the plantar tarsometatarsal ligaments remain intact, making the injury stable.

NATURAL HISTORY
- Stable injuries (partial sprains, extra-articular fractures) often require prolonged recovery time. When accurately diagnosed, however, patients with these injuries can generally expect full recovery and return to activity with minimal long-term implications.
- Unstable injuries that are misdiagnosed or inadequately treated generally go on to a poor result with persistent pain, activity limitations, and progressive posttraumatic arthritis in the involved joints, necessitating arthrodesis as salvage.
- A high index of suspicion must therefore be maintained; historically up to 20% of unstable Lisfranc injuries are misdiagnosed on plain radiographs.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The physician should obtain a history of trauma and details of the exact injury mechanism (position of foot, direction of force, extent of energy involved).
- The physician should observe any initial swelling and inability to bear weight.
- A thorough examination of the involved foot and ankle also includes assessment of associated injuries and any other areas of swelling or tenderness to palpation.
- The physician should observe the skin and soft tissue envelope. Diffuse swelling of the midfoot or plantar ecchymosis at the midfoot suggests a Lisfranc injury.
- The physician should palpate the midfoot joints; pain at the midfoot with palpation suggests a Lisfranc injury (see Exam Table for Pelvis and Lower Extremity Trauma, pages 1 and 2).
The physician should test midfoot stability with passive flexion of the metatarsal heads and passive abduction and adduction through the forefoot. Pain at the tarsometatarsal joint region with passive forefoot range of motion suggests a Lisfranc injury.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Initial radiographic evaluation consists of non-weight-bearing anteroposterior (AP), oblique, and lateral views of the foot, which, depending on the extent of intra-articular displacement, may provide sufficient diagnostic information (FIG 3A–C).
- Fluoroscopic stress views may be helpful in more subtle injuries; however, these studies are painful and generally require anesthesia.
- We therefore prefer weight-bearing radiographs of the foot for more subtle injuries (FIG 3D–H); comparison weight-bearing radiographs of the contralateral foot may also be obtained where necessary.
- The weight-bearing AP view of the foot will demonstrate intra-articular displacement through the first and second tarsometatarsal joints (so-called Lisfranc joint), intercuneiform joint, and naviculocuneiform joint; fractures through the first and second metatarsal bases, medial and middle cuneiforms, and proximal extension into the navicular; and the extent of columnar shortening or asymmetry.
- The medial border of the second metatarsal should align with the medial border of the middle cuneiform (FIG 3D).
- The oblique view will reveal intra-articular displacement through the third, fourth, and fifth tarsometatarsal joints, and fractures of the third, fourth, and fifth metatarsal bases, lateral cuneiform, and cuboid.
- The medial borders of the third and fourth metatarsals should align with the medial borders of the lateral cuneiform and cuboid, respectively (FIG 3E).
- The lateral view may reveal dorsal–plantar displacement of fractures or dislocations, as well as any flattening of the medial longitudinal arch, thereby reflecting the status of the weight-bearing medial column and first ray (FIG 3F).
- Computed tomography (CT) scanning may also be beneficial in the instance of a subtle Lisfranc injury, particularly in a polytrauma patient or a patient with multiple extremity injuries that preclude weight-bearing radiographs; and to delineate proximal fracture line extension into the navicular, cuboid, or cuneiforms (FIG 4).

**DIFFERENTIAL DIAGNOSIS**

- Partial Lisfranc injury (sprain)
- Isolated metatarsal fracture
- Navicular–cuneiform fracture
- Anterior process of calcaneus fracture
- Lateral ankle sprain

**NONOPERATIVE MANAGEMENT**

- Nonoperative treatment is indicated for partial Lisfranc injuries (sprains), which by definition are stable and therefore nondisplaced on weight-bearing radiographs.
- Nonoperative treatment is also indicated for nondisplaced or minimally displaced extra-articular metatarsal base fractures with no intra-articular involvement (displacement) on weight-bearing radiographs.
- Because of the often subtle nature of Lisfranc injuries and the negative consequences of misdiagnosis, if the findings are inconclusive, weight-bearing radiographs may be repeated 2 to 3 weeks after the injury.
- Nonoperative management consists of immobilization in a venous compression stocking and prefabricated fracture boot.
- The patient is allowed to bear weight to tolerance, and early progression to range of motion is encouraged.
- The patient continues in the fracture boot for 5 to 6 weeks, at which point maintenance of alignment or radiographic union is confirmed on repeat weight-bearing radiographs.
- The patient is then allowed to wear regular shoes, and activities are advanced as tolerated thereafter.
- Full recovery and return to sports or other rigorous activity may require up to 3 to 4 months.
FIG 3 • Non-weight-bearing AP (A), oblique (B), and lateral (C) radiographs of grossly unstable, purely ligamentous, Lisfranc dislocation involving all five tarsometatarsal articulations. Marked lateral subluxation through all five tarsometatarsal joints is evident on the AP and oblique views, and significant dorsal displacement is evident on the lateral view. Weight-bearing lateral (D), AP (E), and oblique (F), and non-weight-bearing (G) and oblique (H) radiographs of more subtle Lisfranc injury. Lateral and plantar subluxation (black arrows) is evident on the weight-bearing radiographs, and displacement of normal radiographic landmarks (black lines) confirms injury.
Surgical management is indicated for unstable (displaced) injuries of the midfoot, including pure ligamentous, bony, or variable combinations. Recent studies suggest that pure ligamentous Lisfranc injuries are best managed with open reduction and primary arthrodesis of the medial and middle columns. Any dislocation producing tension on the overlying skin and soft tissue envelope should be immediately reduced and immobilized. Definitive surgery is generally delayed 10 to 14 days to allow adequate resolution of soft tissue swelling.

Preoperative Planning

- The injury and weight-bearing radiographs and CT images are reviewed and the injury is classified, which allows planning for the anticipated pathoanatomy of the injury.
- Pure ligamentous injuries require rigid screw fixation for the medial and middle column joints and Kirschner wire fixation for the lateral column joints; bony injury patterns, particularly those with more comminution, may require minifragment bridge plate fixation.

Positioning

- The patient is placed supine with a bolster beneath the ipsilateral hip. Protective padding is placed around the contralateral limb, primarily to protect the peroneal nerve, and the contralateral limb is secured to the table.
- A sterile bolster is placed beneath the operative limb at the knee to facilitate access to the midfoot and intraoperative fluoroscopy.

Approach

- We prefer the dual-incision approach. The medial incision courses directly over the extensor hallucis longus (EHL) tendon and is centered over the first tarsometatarsal joint. It affords access to the first and second tarsometatarsal joints.
- The lateral incision is centered over the lateral border of the third tarsometatarsal joint. If extended, it also provides exposure to the fourth and fifth tarsometatarsal joints where necessary.
- A third, more proximal and lateral incision may be required to stabilize the cuboid where necessary.
- Because of the limited soft tissue envelope overlying the midfoot, the importance of meticulous soft tissue handling and maintaining full-thickness soft tissue flaps cannot be overemphasized.
MEDIAL INCISION

- The medial incision is made directly over the EHL tendon and is centered over the first tarsometatarsal joint.
  - The tendon sheath is incised dorsally, and the EHL is retracted laterally (TECH FIG 1A).
- The floor of the tendon sheath is then incised and subperiosteal dissection commences medially, extending to the medial margin of the first tarsometatarsal joint and producing a full-thickness flap.
- Subperiosteal dissection then extends laterally to the lateral margin of the second tarsometatarsal joint, again producing a full-thickness flap, while preserving the adjacent neurovascular bundle within the soft tissue flap (TECH FIG 1B).
- The status is noted of each of the tarsometatarsal and intercuneiform joint capsules dorsally, and therefore the extent of instability of each joint (TECH FIG 1C,D).
- We prefer using the medial (EHL) incision for access to the second tarsometatarsal and intercuneiform joints, even if the first tarsometatarsal joint is not involved, because the neurovascular bundle remains protected within the full-thickness flap.

LATERAL INCISION

- A Freer elevator is placed beneath the full-thickness flap to the level of the third tarsometatarsal joint, and the lateral incision is made overlying the lateral border.
- Dissection extends through the overlying extensor retinaculum, exposing the extensor digitorum communis tendon and medial margin of the extensor digitorum brevis muscle, both of which are retracted laterally (TECH FIG 2).
  - Care is taken not to violate the adjacent neurovascular bundle, which is maintained within its soft tissue envelope.
- The underlying third tarsometatarsal joint capsule is identified and a full-thickness subperiosteal flap is developed extending medially toward the lateral portion of the second tarsometatarsal joint, and laterally toward the fourth and fifth tarsometatarsal joints where necessary.
- Again, the status is noted of each of the tarsometatarsal and intercuneiform joint capsules dorsally, and therefore the extent of instability of each joint.
ARTICULAR SURFACE ASSESSMENT AND DECISION MAKING

- The fracture lines and articular surface of the involved joints are then débrided of residual hematoma and assessed for chondral damage.
- If more than 50% of the articular surface of the medial and middle column joints is involved, primary arthrodesis should be considered, although this is controversial.
- Arthrodesis of the fourth and fifth tarsometatarsal joints should be avoided if possible.
- If primary arthrodesis is elected, the involved joints are meticulously débrided of residual articular cartilage, preserving the underlying subchondral plate.
- The joints are irrigated and the subchondral plate is perforated with a 2.0-mm drill bit to stimulate vascular ingrowth.
- Supplemental allograft mixed with highly concentrated platelet aspirate is then placed within the involved joint spaces.

PROVISIONAL REDUCTION AND DEFINITIVE STABILIZATION

First Tarsometatarsal Joint

- The provisional reduction begins medially at the first tarsometatarsal joint if injured. Although the exact reduction maneuver may vary depending on the injury pattern, the first metatarsal is typically supinated (externally rotated) relative to the medial cuneiform.
- Correction of this rotational deformity is crucial in restoring the medial column and the weight-bearing function of the first ray. The reduction of the remaining midfoot joints depends on an anatomic reduction of the first tarsometatarsal joint.
- The provisional reduction is held with a 2.0-mm Kirschner wire and confirmed under fluoroscopy (TECH FIG 3A).
- Definitive stabilization is then obtained at the first tarsometatarsal joint with 3.5-mm solid cortical position screws (TECH FIG 3B–D).
- The first screw is placed from distal to proximal, starting at the dorsal crest and distal to the metaphyseal–diaphyseal junction, and is angled toward the plantar–proximal cortex of the medial cuneiform; this screw is generally 45 to 50 mm long.
- A second screw is placed from proximal to distal starting at the edge of the naviculocuneiform joint, and similarly angled to exit at the plantar cortex distal to the metaphyseal–diaphyseal junction. This screw typically measures 40 to 45 mm.
- In a primary arthrodesis, these screws are placed in lag fashion.
- For larger patients, 4.0-mm cortical screws may be used for further stability.

![TECH FIG 3](image-url) - Reduction and stabilization of first tarsometatarsal joint. A. Provisional reduction. B. Distal-to-proximal screw. C. Proximal-to-distal screw. D. Long bicortical trajectory of screws for enhanced stability.
Lisfranc Joint

- A pointed reduction forceps is then placed from the medial cuneiform to the lateral border of the second metatarsal to anatomically reduce the so-called Lisfranc joint; care is taken to ensure accurate dorsal-plantar alignment of the second tarsometatarsal joint.
- The reduction is confirmed under fluoroscopy, and a 2.0-mm Kirschner wire that mirrors the intended path of the screw is placed to provide further rotational control (TECH FIG 4A,B).
- There is typically a distinct cortical “shelf” on the medial cuneiform that provides an excellent buttress for screw purchase.
  - A 3.5-mm cortical screw is placed through a stab incision overlying this cortical shelf medially, angling toward the proximal metaphysis of the second metatarsal; for a primary arthrodesis, this screw is placed in lag fashion (TECH FIG 4C).

Other Joints

- If the intercuneiform joint is involved, it is first reduced and stabilized before stabilizing the Lisfranc joint (TECH FIG 5A). Alternatively, this joint may also be reduced and stabilized before stabilizing the first tarsometatarsal joint.
  - A 3.5-mm cortical screw is again used, coursing parallel to the plane of the naviculocuneiform joint. It is placed in lag fashion for a primary arthrodesis.
  - Care is taken not to violate the articulation between the middle and lateral cuneiform.
The second tarsometatarsal joint is then provisionally reduced and provisionally stabilized with a 1.6-mm Kirschner wire.

Definitive fixation is obtained with a countersunk 2.7-mm cortical screw from distal to proximal; it is placed in lag fashion for a primary arthrodesis (TECH FIG 5B).

The third tarsometatarsal joint is reduced and stabilized in identical fashion (TECH FIG 5C).

For a metatarsal base fracture or fracture-dislocation pattern precluding transarticular fixation, bridge plate fixation may be required.

We prefer a low-profile (2.0 or 2.4 mm) reconstruction plate and 2.4-mm cortical screws (TECH FIG 6).

The fourth and fifth tarsometatarsal joints are then reduced and definitively stabilized with 1.6-mm Kirschner wires.

Because the intermetatarsal ligaments between the third, fourth, and fifth metatarsals are often preserved, these joints may anatomically reduce indirectly, thereby allowing percutaneous stabilization.

The Kirschner wires are contoured and buried beneath the skin layer through separate stab incisions, which facilitates removal at 6 weeks postoperatively, either in the office under local anesthesia or in the operating room under sedation (TECH FIG 7).

For a cuboid fracture, the cuboid is reduced and definitively stabilized to ensure restoration of lateral column length before stabilizing the fourth and fifth tarsometatarsal joints; by definition, this is then an open reduction (TECH FIG 8A).

Final fluoroscopic images are obtained, confirming articular reduction and implant placement (TECH FIG 8B).
PART 2 PELVIS AND LOWER EXTREMITY TRAUMA • SECTION IV FOOT AND ANKLE

POSTOPERATIVE CARE

- The patient is converted to a venous compression stocking and prefabricated fracture boot, and early progression to motion is initiated.
  - The Kirschner wires traversing the lateral column joints are removed 6 weeks postoperatively.
  - Weight bearing is not permitted until 10 to 12 weeks postoperatively, at which point weight-bearing radiographs are obtained to confirm maintenance of reduction.
  - The patient is gradually allowed to resume regular shoes, and activity is advanced as tolerated thereafter.
  - In a primary arthrodesis, the limb is immobilized in serial short-leg non-weight-bearing casts for 10 to 12 weeks after surgery, at which point radiographic union is confirmed on weight-bearing radiographs.
  - The patient is then converted to a venous compression stocking and prefabricated fracture boot, and weight bearing is advanced as described previously.

OUTCOMES

- Outcomes after open reduction and internal fixation of Lisfranc injuries are generally good overall, as patients have relatively few activity limitations. An accurate diagnosis and anatomic reduction are crucial to ensuring satisfactory results.†
- Outcomes for pure ligamentous patterns are less predictable after open reduction and internal fixation; these patients tend to have higher rates of posttraumatic arthritis.† Primary arthrodesis appears to be especially beneficial in this situation: one recent study reported a greater than 90% return to preinjury level after primary arthrodesis.†
- Late arthrodesis as salvage for posttraumatic arthritis provides predictable pain relief and functional improvement.†,9

PEAKLS AND PITFALLS

<table>
<thead>
<tr>
<th>Misdiagnosis of proximal joint injuries (medial, middle, or lateral cuneiform; intercuneiform joint; cuboid fracture)</th>
<th>Because of the highly variable injury patterns, a high index of suspicion must be maintained. Injury radiographs must be closely scrutinized preoperatively for proximal joint involvement. If radiographs are inconclusive, CT evaluation is warranted. During surgery, the status is noted of each of the intercuneiform joint capsules dorsally, and therefore the extent of instability of each joint.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correcting plantar displacement or malalignment of the first and second tarsometatarsal joints</td>
<td>Strict attention is paid to dorsal–plantar alignment of the first and second metatarsals and their respective cuneiforms, because plantar displacement or malalignment greater than 2 mm may affect the weight-bearing metatarsal cascade, potentially resulting in a transfer (metatarsalgia) lesion.</td>
</tr>
<tr>
<td>Correcting supination malrotation of first tarsometatarsal joint</td>
<td>There is typically a distinct dorsal crest on both the first metatarsal and medial cuneiform. They should be precisely aligned to ensure an accurate reduction.</td>
</tr>
<tr>
<td>Definitive fixation of first tarsometatarsal joint</td>
<td>Because of the hard cortical bone at the diaphysis of the first metatarsal, the screwhead of the distal-to-proximal screw is specifically countersunk to avoid compromise of the dorsal cortex and loss of fixation.</td>
</tr>
<tr>
<td>Definitive fixation of Lisfranc joint</td>
<td>With fixation of the Lisfranc joint, the screw must angle slightly dorsally (relative to the plantar foot) to accommodate the normal “Roman arch” configuration in the coronal plane.</td>
</tr>
</tbody>
</table>

We do not routinely remove hardware unless symptomatic or specifically requested by the patient, in which case the implants may be removed at 1 year after surgery.
Chapter 22  ORIF OF LISFRANC INJURY

COMPLICATIONS
- Delayed wound healing, wound dehiscence, deep infection
- Malunion or nonunion
- Late displacement (premature implant removal)
- Neurovascular compromise
- Chronic pain

REFERENCES
DEFINITION
- A Jones fracture represents an acute injury at the metaphyseal-diaphyseal junction of the fifth metatarsal. The fracture should not have extension distal to the fourth-fifth intermetatarsal articulation (FIG 1).
- This fracture is often seen as a result of sporting or athletic activities.
- The fracture begins on the lateral aspect of the fifth metatarsal and may propagate into the metatarsocuboid joint.
- Three subsets of the fracture exist, as described by Torg (FIG 2):
  - Type 1: Acute fracture where the fracture line has sharp margins and no intramedullary sclerosis. Often involves only the lateral cortex.
  - Type 2: Delayed union where fracture line involves both cortices with associated periosteal bone formation, widening of the fracture line, and evidence of intramedullary sclerosis.
  - Type 3: Nonunion demonstrated by bone resorption with radiolucency at the fracture line and obliteration of the medullary canal by sclerotic bone

ANATOMY
- There are two major motor insertions onto the fifth metatarsal:
  - The peroneus brevis inserts onto the dorsal aspect of the fifth metatarsal tubercle.
  - The peroneus tertius inserts onto the dorsal aspect of the metatarsal at the metaphyseal–diaphyseal junction.
- The plantar fascia has a strong insertion along the plantar aspect of the fifth metatarsal.
- The shaft is supplied by a single nutrient artery that enters from the medial cortex at the junction of the proximal and middle thirds of the diaphysis. The base and tuberosity are supplied by secondary epiphyseal and metaphyseal arteries (FIG 3).

PATHOGENESIS
- Acute Jones fractures are the result of plantarflexion at the ankle and adduction of the forefoot.
- Tensile forces along the lateral border of the metatarsal result in a transverse fracture.
- They are typically the result of sporting or athletic events, with many instances described in football and basketball players.
- This should not be confused with a diaphyseal stress fracture, where the athlete describes prodromal symptoms that have existed for weeks to months. Radiographic assessment of this type will demonstrate signs of a stress reaction.

NATURAL HISTORY
- The Jones fracture was originally described in 1902 by Sir Robert Jones, who described a transverse fracture at the metaphyseal-diaphyseal junction in four individuals, including himself.
- The natural history and outcomes of nonoperative and operative treatment are difficult to determine because many published reports include a mixture of acute Jones fractures and diaphyseal stress fractures.
- Various studies have examined nonoperative versus operative treatment.
- Operative treatments have included internal fixation with or without bone grafting and bone grafting alone.
- Nonoperative treatment of the acute fracture is associated with an increased risk of delayed or nonunion due to the watershed blood supply at the metaphyseal–diaphyseal junction in the metatarsal.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The patient may describe participation in an athletic event where, after a particular maneuver, there is an acute onset of pain over the lateral border of the foot.
- The patient may have swelling and ecchymosis over the lateral border of the foot.
- Pain will be elicited with direct palpation over the base of the fifth metatarsal.
- Physical examination should include:
  - Direct palpation over the base of the fifth metatarsal: Pain in this region increases suspicion of injury.
  - Direct palpation over the tarsometatarsal joint complex: Pain indicates possible injury to the Lisfranc complex.
  - Passive dorsiflexion–plantarflexion of individual metatarsal heads: Pain indicates possible injury to the Lisfranc complex.
  - Attempted single-limb heel lift: Pain indicates possible injury to the Lisfranc complex.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographs of the affected foot, including anteroposterior, lateral, and oblique, are sufficient to diagnose an acute Jones fracture.
- Weight-bearing radiographs of the affected foot are obtained to rule out a Lisfranc injury.

DIFFERENTIAL DIAGNOSIS
- Diaphyseal stress fracture
- Avulsion fracture of the base of the fifth metatarsal
- Lisfranc sprain or subluxation
- Cuboid fracture

NONOPERATIVE MANAGEMENT
- Non-weight bearing in a short-leg cast for 6 weeks, followed by weight bearing in a walker boot for an additional 6 weeks
Torg’s series of 15 patients demonstrated a 93% union rate at an average of 6.5 weeks.\(^{14}\)

Clapper reported union in 72% of acute Jones fractures treated with a non-weight-bearing short-leg cast for 8 weeks followed by weight bearing in a cast or walker boot.\(^{1}\)

**SURGICAL MANAGEMENT**

- The indications for surgical fixation of an acute Jones fractures have not been clearly defined.

- High-performance athletes or individuals desiring a quicker return to activity may benefit from intramedullary screw fixation, as this provides a more predictable and shorter recovery period.

---

**Preoperative Planning**

- If percutaneous screw fixation of the fifth metatarsal is planned, preoperative measurement of the intramedullary canal will ensure that the proper hardware is available.

**Positioning**

- The patient should be placed in the supine position on a radiolucent table.

- A bolster should be placed under the ipsilateral buttock to increase the exposure to the lateral aspect of the foot.

- A C-arm image intensifier is used to assist in the operative procedure. It is helpful to have the entire limb draped free so that the knee may be flexed past 90 degrees. This will also facilitate imaging of the foot (FIG 4).

---

**FIG 1** • Acute Jones fracture. The fracture line is at the junction of Zones 1 and 2; there is no cortical hypertrophy or periosteal reaction.

**FIG 2** • Torg type II diaphyseal stress fracture. Widening of the fracture line and periosteal bone formation are shown.
A tourniquet is not required but may be chosen based on surgeon preference.

**Approach**
- A dorsolateral approach to the base of the fifth metatarsal is preferred.

### PERCUPTANEOUS INTRAMEDULLARY SCREW FIXATION

**Incision and Dissection**
- A 2- to 3-cm incision is made parallel to the plantar surface of the foot.
- The incision should begin 2 cm proximal to the tip of the fifth metatarsal tuberosity. The location should be confirmed with a C-arm image (TECH FIG 1).
- Blunt dissection is used to expose the tuberosity.

**Screw Portal Creation and Guidewire Placement**
- With a drill guide used to protect the soft tissues, a 2.5-mm drill is used to open the entry portal for the screw.
  - The correct entry site is one that is in line with the medullary canal just medial to the tip of the tuberosity (TECH FIG 2A).

**Screw Placement**
- The surgeon reams the intramedullary canal with a 3.2-mm cannulated drill, leaving the drill sleeve in place to protect soft tissues (TECH FIG 3A,B).
  - The drill should be passed distal to the fracture site.
  - The proximal end is then reamed with a 4.5-mm drill. This facilitates countersinking the screw to avoid soft tissue irritation.
  - The surgeon uses the guidewire to measure the proper length of the screw required (TECH FIG 3C).
  - The surgeon places an appropriately sized 4.5-mm, partially threaded AO screw with a small profile head into the intramedullary canal (TECH FIG 3D,E).
  - In larger individuals, a 6.5-mm screw may be substituted, using the appropriately sized drills to create the starting portal and to overream the proximal cortex.
TECH FIG 2 • **A.** Creation of the starting portal with a 2.5-mm drill bit and drill guide. **B.** Fluoroscopic confirmation of entry placement. **C.** Insertion of a flexible guidewire down the intramedullary canal. **D,E.** Fluoroscopic confirmation of guidewire placement.

TECH FIG 3 • **A.** Preparation of the intramedullary canal with a 3.2-mm cannulated drill and protective drill sleeves. **B.** Fluoroscopic view. **C.** Measurement of the correct screw length. **D,E.** Final radiographs.
INLAY BONE GRAFTING WITHOUT INTERNAL FIXATION

- The technique is similar to the Russe technique for scaphoid nonunion.\textsuperscript{11,14}
- The base of the fifth metatarsal is approached through a curvilinear dorsolateral incision (TECH FIG 4A).
- The fracture site is exposed subperiosteally and a rectangular section of bone measuring 0.7 \times 2.0 cm centered over the fracture is outlined by four drill holes.
- A sharp osteotome is used to remove the outlined section of bone (TECH FIG 4B).
- The medullary canal is then curetted, drilled, or both until all of the sclerotic bone has been removed and the canal has been re-established.
- An autogenous corticocancellous bone graft with the same measurements as the removed fragment is then removed from the anteromedial aspect of the distal end of the tibia.
- The graft should be contoured so that the cortical portion of the graft fits accurately into the rectangular defect and does not obstruct the medullary canal (TECH FIG 4C).
- The periosteum, subcutaneous tissue, and skin are then closed.
- To avoid a stress riser, the bone removed from the fifth metatarsal is placed into the tibia defect before wound closure.
- The patient is then immobilized in a non-weight-bearing cast.

TECH FIG 4 • A. Curvilinear incision over dorsolateral aspect of foot. B. The fracture site is exposed and a rectangular area is outlined in the bone using drill holes. C. The graft is shaped and placed into the defect created.

PERCUTANEOUS INTRAMEDULLARY SCREW FIXATION WITH LOCAL BONE GRAFT

- The procedure is performed as described for percutaneous intramedullary screw fixation.\textsuperscript{8}
- Once the medullary canal has been overdrilled over the guidewire, the wire is removed.
- A slender curette is advanced to the depth of the fracture and manipulated to add a mass of cancellous bone to the fracture site.
- Care should be taken to limit procurement of bone to within 7 mm of the fracture site.
- Once the local bone grafting has been completed, the wire is reintroduced into the canal.
- The intramedullary screw is placed as described for percutaneous intramedullary screw fixation.
PEARLS AND PITFALLS

Failure of hardware • A 4.5-mm screw or larger is used when possible.

Failure of hardware • Touch-down weight bearing in a walker boot is used for 6 to 8 weeks. Weight bearing is advanced only when radiographic evidence of fracture healing is observed.

POSTOPERATIVE CARE

• Immediately after surgery, the patient should be immobilized in a walker boot and should be limited to touch-down weight bearing for 6 to 8 weeks.
• During this period, range of motion and gentle strengthening may be allowed.
• After 6 to 8 weeks, weight bearing and boot removal are allowed when radiographic evidence of healing is observed.
• Return to full activity, especially competitive athletics, is allowed only when complete healing is observed on radiographs in three planes: anteroposterior, lateral, and oblique.
• Functional bracing or orthosis is recommended for individuals returning to athletic activities.

OUTCOMES

• Portland et al10 treated 15 patients with acute Jones fracture or Torg type I fracture and achieved 100% union at an average of 6.25 weeks.
• DeLee et al3 reported 100% success in acute Jones fractures treated with percutaneous intramedullary screw fixation. No complications were reported.
• Mindrebo et al9 treated nine patients with acute Jones fractures with outpatient intramedullary screw fixation and had 100% union at an average of 6 weeks. One patient had the screw removed because of theoretical concerns over screw breakage.

COMPLICATIONS

• Refractures and nonunions may occur when small-diameter screws are used. Screws less than 4.5 mm have been shown biomechanically to be weaker than larger screws. Using the largest-diameter screw where all of the screw threads cross the fracture site has been demonstrated to provide the best biomechanical fixation.
• Refractures and nonunions may occur when the patient returns to early weight bearing and when the Jones fracture is fixed in elite-level competitive athletes who may push themselves to return to activities before union has occurred.

REFERENCES

Part 3  Adult Reconstruction

Chapter 1
Cemented Total Hip Arthroplasty 744

Chapter 2
Uncemented Total Hip Arthroplasty 756

Chapter 3
Hip Resurfacing 763

Chapter 4
Hemiarthroplasty of the Hip 782

Chapter 5
Total Hip Arthroplasty for Malignant Lesions 798

Chapter 6
Revision Total Hip Arthroplasty With Well-Fixed Components 808

Chapter 7
Revision Total Hip Arthroplasty With Femoral Bone Loss: Fluted Stems 815

Chapter 8
Revision Total Hip Arthroplasty With Femoral Bone Loss: Proximal Femoral Replacement 823

Chapter 9
Revision Total Hip Arthroplasty With Acetabular Bone Loss: Impaction Allografting 831
Chapter 10
Revision Total Hip Arthroplasty With Acetabular Bone Loss: Antiprotrusio Cage 836

Chapter 11
Resection Arthroplasty and Spacer Insertion 843

Chapter 12
Hip Reimplantation Surgery 853

Chapter 13
Periacetabular Osteotomy 859

Chapter 14
Femoral Osteotomy 869

Chapter 15
Femoroacetabular Impingement and Surgical Dislocation of the Hip 877

Chapter 16
Treatment of Anterior Femoroacetabular Impingement Through an Anterior Incision 887

Chapter 17
Unicondylar Knee Arthroplasty 895

Chapter 18
Upper Tibial Osteotomy 905

Chapter 19
Cemented Total Knee Arthroplasty 918
Osteonecrosis may also be idiopathic.

For the past 40 years, cemented total hip arthroplasty (THA) has been the most successful surgical solution for end-stage hip disease.

Cemented THA is appropriate for treatment of hip pathology caused by a variety of degenerative, inflammatory, traumatic, vascular, developmental, and metabolic disorders.

ANATOMY

The hip is a diarthrodial synovial joint, consisting of the articulation of the femoral head with the acetabulum. It functions as a ball-and-socket joint, with inherent bony constraints that define the range of motion. The laxity or tightness of the associated soft tissue also affects kinematics and function.

The acetabulum develops at the junction between three embryologically distinct bones—the ilium, ischium, and pubis—which fuse at the triradiate cartilage during adolescence.

The acetabulum typically demonstrates 15 to 20 degrees of anteverision, as does the femoral neck. Normal combined anteverision is therefore 30 to 40 degrees, although the degree of anteverision varies considerably between individuals.

PATHOGENESIS

Degenerative joint disease (DJD) constitutes a final common pathway for various hip disorders of distinct etiologies.

Developmental abnormalities of the hip can lead to femoroacetabular impingement, abnormal joint reaction forces and articular shear forces, and consequent mechanical joint degeneration. These abnormalities include:
- Developmental dysplasia
- Coxa profunda
- Protrusio acetabuli
- Acetabular retroversion
- Pistol-grip deformity of the proximal femur
- Legg-Calvé-Perthes disease
- Slipped capital femoral epiphysis
- Posttraumatic arthritis can develop after fractures of the femoral head, femoral neck, or acetabulum.
- Osteoarthritis may also be idiopathic.
- Rheumatologic conditions such as rheumatoid arthritis and the seronegative spondyloarthropathies are caused by autoimmunity.
- Osteonecrosis of the femoral head can result from many etiologic factors:
  - Alcoholism
  - Corticosteroid use
  - Chemotherapy
  - Sickle cell disease
  - Systemic lupus erythematosus
  - Vasculitis
  - Human immunodeficiency virus infection
  - Coagulopathy

Cemented THA is appropriate for treatment of hip pathologies caused by a variety of degenerative, inflammatory, traumatic, vascular, developmental, and metabolic disorders.

NATURAL HISTORY

The natural history of degenerative joint disease is progression of disease. Although clinical symptoms may wax and wane, they generally become more severe, more frequent, and more debilitating over time.

Although medications can help control the progression of rheumatoid arthritis and other inflammatory conditions, no medical therapies currently have been proved to act as disease-modifying agents in degenerative joint disease.

When osteoarthritis is a consequence of anatomic abnormalities, there is hope that surgical correction of these abnormalities may unload the joint, halt progression of disease, and even allow for biologic repair.

Periacetabular osteotomy may positively impact the natural history of joint degeneration in acetabular dysplasia, but the long-term effect of osteotomy on hip function and progression of arthrosis is unknown. In the presence of moderate DJD, progression of disease commonly occurs in spite of a well-performed osteotomy.

Similarly, osteochondroplasty of the femoral neck and acetabular rim may relieve symptoms associated with femoroacetabular impingement, but it is not known whether these procedures will reduce the progression of arthrosis.

PATIENT HISTORY AND PHYSICAL FINDINGS

Initial evaluation should focus on identifying the extent to which hip pain can be attributed to intra-articular hip pathology. Hip pain may be referred to the groin, the peritrochanteric region, the thigh, the knee, or, occasionally, below the knee. Lumbar spine disease may also cause pain in these regions.

Although the source of the pain usually can be identified on the basis of physical examination, occasionally selective anesthetic injection is necessary to elucidate the relative contributions of overlapping pathologies to a patient’s symptoms.

Palpation is performed to assess for areas of tenderness, warmth, fluctuance, or mass.

Trochanteric bursitis is a common cause of hip area pain that can be ruled out by identifying a nontender bursa.

An inguinal mass may suggest that groin pain is related to a hernia.

Active and passive range of motion should be assessed.

Flexion contracture commonly is encountered, as are limited internal rotation and abduction.

Limited external rotation, if present, impairs activities of daily living.
DIFFERENTIAL DIAGNOSIS
- Lumbar spine pathology
- Spinal stenosis and neurogenic claudication
- Herniated nucleus pulposus
- Degenerative disc disease or spondylitis
- Sacroiliac joint pathology
- Trochanteric bursitis
- Tendinopathy of the gluteus medius or minimus
- Iliopsoas bursitis
- Inguinal hernia
- Vascular claudication

NONOPERATIVE MANAGEMENT
- Options include weight loss, activity modification, physical therapy, injections, pain management, and the use of walking aids. These interventions do not alter the underlying disease process, but they may substantially diminish pain and disability.

SURGICAL MANAGEMENT
- Cemented THA has been a highly successful operation. Significant early complications are uncommon, and patient outcomes are outstanding in the short and intermediate term. Long-term outcomes beyond 10 to 15 years are limited by component wear, fixation failure, and biologic reaction to wear debris.
- In most reported series, fixation has been the limiting factor for the survival of hip implants in patients with long life expectancies.
- The durability of cement fixation is highly dependent on meticulous surgical technique. Bone cement is vulnerable to failure under tension and shear, which can be caused by gaps in the cement mantle. Stress risers place cement at high risk of fracture.
- Improvements in cement technique have resulted in a reduction in the rates of aseptic loosening of femoral components.
- Acetabular cement fixation remains challenging for many surgeons, with variable results over the long term. The appearance of the bone–cement interface on the immediate postoperative radiograph can predict the durability of cemented acetabular fixation.
- This supports our contention that a surgeon who is able to achieve good cement technique consistently can expect reproducible long-term results.

Preoperative Planning
Indications
- Reproducible, durable, long-term outcomes using cement fixation have been achieved in older, lighter patients, particularly women, with low to moderate activity levels and relatively normal anatomy of the pelvis and proximal femur. If THA is indicated for such a patient, cement fixation remains an excellent option for both components.
- When distorted femoral anatomy precludes the use of standard press-fit prostheses, cement fixation may be the best or only option.
- Cement fixation may also be the best option in pathologic bone associated with tumor or radiation, or in any other situation in which bone in- or ongrowth cannot be anticipated.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs should be obtained, as weight-bearing films if possible.
- Low anteroposterior (AP) view of the pelvis centered over the pubic symphysis and including the proximal third of the femora. Slight internal rotation of the hips allows accurate assessment of the neck shaft angle. The coccyx should be pointing directly to the symphysis pubis and located about 3 cm above the symphysis pubis if pelvic rotation is not present.
- AP and false-profile views of the involved hip.
- AP and lateral lumbar spine, lateral lumbosacral spine
- CT, MRI, and other supplemental studies rarely are needed.
Implant Selection

- Choice of prosthesis should be based on critical review of the published outcomes and the surgeon’s familiarity with an implant. This includes design features and rationale, instrumentation, and potential technical pitfalls.
- It is generally agreed that the optimal cemented acetabular component is all polyethylene (Fig 1), with multiple pegs to ensure concentric insertion within a cement mantle of appropriate thickness, and a peripheral flange to optimize pressurization of cement during component insertion. Recent data challenge the value of polyethylene pegs, demonstrating an association with radiographic evidence of loosening.10
- On the femoral side, there is some debate as to whether the optimal prosthesis is roughened to allow interdigitation of cement and rigid fixation at the cement–prosthesis interface, or polished and tapered to allow slight subsidence into a stable position without generating wear particles.
- Both design philosophies have resulted in good to excellent long-term results when properly employed.12,16
- Conversely, simply roughening the surface of a successful smooth stem has led to a surprising number of early failures of fixation.12
- The consensus seems to be that either philosophy can work if it is applied consistently in all aspects of component design, but that “mixing and matching” elements from the two design philosophies gives unpredictable results.

Templating

- Once the implant system has been chosen, templates can be compared to patient radiographs to predict implant size and determine the implant placement that will best reconstruct the patient’s center of rotation, offset, and leg length.
- A horizontal reference line is drawn between the inferior tips of the acetabular teardrops (Fig 2A). Both lesser trochanters are marked at their medial points (the medial tip of the lesser trochanter is the most reproducible landmark on the proximal femur radiographically). The perpendicular distance between the inter-teardrop line and the medial point of the lesser trochanter is measured for each hip (represented by the solid vertical lines in Fig 2A).
- The leg-length discrepancy is calculated by subtracting the value measured for the nonoperative hip from the value obtained for the operative hip.
- The centers of the femoral heads are marked—these are also the centers of rotation of the hip joints. A mark is also placed...
on the superior aspect of the lesser trochanter on the operative hip (this can be identified intraoperatively). The distance between the superior aspect of the lesser trochanter and the center of the femoral head (represented by the dashed lines in Fig 2A) is measured and recorded for each hip; this lesser trochanter-to-center distance is referred to as the LTC.

- Selection of the appropriate acetabular component requires a measurement of acetabular size. Cemented socket templating accounts for a 2-mm cement mantle in approximating the reamed hemispherical cavity. Implant size is estimated most accurately on the false-profile radiograph (FIG 2B).
- The acetabular template is positioned on the AP radiograph in 40 to 45 degrees of abduction,17,24 with its inferomedial border placed approximately 10 mm lateral to the teardrop (FIG 2C). The prosthesis should remain at or lateral to the medi- al floor of the acetabulum, and the superolateral corner of the component should fall near the superolateral border of the acetabulum.
- Slightly incomplete coverage of the acetabular component (up to 20%) may be acceptable.
- Once the desired position of the acetabular component is selected, the new center of rotation of the hip can be determined using the template. In most cases, the goal is to recreate the normal anatomic center of rotation, although changing the center of rotation by up to 10 mm may be accepted for the sake of optimal component fixation. Such a change may be necessary in cases of dysplasia with a high hip center.
- Attention then is turned to templating the femoral component. The goal is to choose an implant that permits an adequate cement mantle without excessive removal of cancellous bone, and restores anatomic leg length and offset.
- The template is placed in neutral position in the femoral canal. Its proximal–distal position should be selected on the basis of the bony constraints, the desire for a circumferential 2-mm cement mantle, and the goal of restoring leg length (FIG 2D).
- Most implant systems are available with standard or enhanced offset necks; the implant that optimizes the patient’s offset in relation to the new center of rotation of the socket is chosen.

- Modular femoral heads with the option of plus and minus sizes allow the surgeon to lengthen or shorten the femoral neck, affecting both leg length and offset.
- Once the optimal component position is selected, the level of the femoral neck cut is marked, and the distance from the lesser trochanter is recorded.
- After marking socket and femoral component positions on the radiograph, the vertical distance between the center of the acetabular component and the center of the femoral head will approximate the leg-length correction (FIG 2E).
- We seek an increase in leg length of 2 to 5 mm in most cases.22

### Positioning

- Positioning of the patient depends on choice of surgical exposure. For the posterolateral approach to the hip, we use the lateral decubitus position on a specially designed table.
- An axillary roll is used to prevent injury to the brachial plexus, and all bony prominences are carefully padded to avoid pressure-related complications.
- Many surgeons attempt to establish a fixed relationship between the pelvis and the floor to allow positioning of the acetabular component in reference to the plane of the floor.
- The use of internal landmarks may be more reproducible and also permits the surgeon more freedom in positioning.
- We prefer to tilt the table toward the surgeon during acetabular preparation and component insertion, optimizing visualization. A backrest is used to stabilize the patient during this maneuver.

### Approach

- Multiple surgical approaches can adequately expose the hip joint for THA.
- The posterolateral approach is desirable for its excellent, ex tensile exposure and avoidance of trauma to the abductor mechanism.
- With modern techniques of posterior soft tissue repair and implant positioning that restores the center of rotation, offset, leg length, and combined anteversion,2 dislocation rates are comparable to those observed with other approaches.20

---

### EXPOSURE

- A gently curved skin incision is made starting posterior and slightly proximal to the tip of the greater trochanter, passing about 1 cm posterior to the most prominent point of the greater trochanter on the lateral aspect of the femur, and distally along the shaft of the femur to approximately the level of the gluteus maximus insertion.
- The iliotibial band is incised slightly anterior to the line of the skin incision so that the fascial incision passes directly over the most prominent point of the trochanter and remains 5 to 10 mm anterior to the insertion of the gluteus maximus tendon into the proximal femur.
- The gluteus maximus muscle is encountered in the proximal portion of the fascial incision, and divided in line with its fibers.
- Partial or complete release of the gluteus maximus insertion into the linea aspera can be performed at this time.

This seldom is necessary for exposure, but may reduce the small risk of postoperative sciatic nerve palsy.14

- Release of the quadratus femoris off the posterior femur is performed with the electrocautery. This step is complete when the lesser trochanter is well exposed.
- The first perforator off the profunda femoris artery is often encountered during this step. It is easily cauterized before it is transected, but hemostasis can be more difficult if it is transected before it is recognized.
- The gluteus medius is then retracted anteriorly and proximally so that an incision may be made along the superior border of the piriformis tendon all the way down through the hip capsule.
- The sciatic nerve should be palpated and protected with the surgeon’s finger.
Intraoperative Assessment of Leg Length

- Prior to dislocation of the hip, a Steinmann pin is placed into the obturator foramen at the level of the infracotyloid groove. This landmark can be reproducibly identified by passing the pin just distal to the ischium at the level of the acetabulum.
- The surgeon should appreciate a pop as the pin pierces the obturator membrane, at which point the pin should be inserted no further.
- The femur is placed in neutral position on the operating table, and the position of the vertical Steinmann pin is marked on the femur using the electrocautery and a marking pen (TECH FIG 1).
- The Steinmann pin can be replaced later in the case, and the mark on the femur provides a reference for assessment of change in leg length.

Dislocation of Hip and Osteotomy of Femoral Neck

- The hip is dislocated posteriorly using gentle flexion, adduction, and internal rotation.
- The center of the femoral head is then estimated and marked, and the distance from the center to the highest point of the lesser trochanter (LTC) is measured and recorded (TECH FIG 2).
- Reconstruction of the anatomic geometry of the hip, including leg length and offset, is aided by approximate reproduction of this distance.
- In general, a slight increase in the LTC will optimize hip stability without overlengthening the leg or overstretching the iliotibial band.
- The femoral neck cut is made perpendicular to the inferior surface of the neck, aiming at the junction of the femoral neck with the greater trochanter. The cut neck should be left a few millimeters longer than predicted on preoperative templating, to allow for measurement error and imprecision in templating.
- Additional bone can be removed easily after femoral preparation using either the sagittal saw or the calcar planar.

Acetabular Exposure

- Wide exposure of the acetabulum is achieved by translating the femur anteriorly. This often requires release of the anterosuperior capsule, with or without release of the reflected head of the rectus femoris muscle, depending on the underlying ligamentous laxity.
- Release of the tendinous insertion of the gluteus maximus into the linea aspera allows further anterior translation.
- The labrum should be resected in its entirety; the transverse acetabular ligament should be preserved to provide a landmark for the placement of the inferior portion of the acetabular component and a restraint to the extrusion of cement inferiorly during cement pressurization and component insertion.
- The pulvinar should be removed from the fovea using the electrocautery to allow visualization of the medial wall of the acetabulum.
ACETABULAR PREPARATION

- A slightly undersized reamer is used initially to ensure appropriate medialization without penetrating the medial wall, followed by sequential concentric reaming until the blush of cancellous bone is seen in the pubis anteriorly and the ischium posteriorly.
- Most of the strong subchondral bone of the ilium in the superior aspect of the acetabulum should be preserved to provide support for the prosthesis. However, sclerotic bone must be penetrated sufficiently to permit cement interdigitation using multiple holes with a high-speed burr.
- Alternatively, a recent randomized, controlled clinical trial demonstrated significantly improved radiographic appearance of the cement mantle with careful removal of most of the subchondral bone to allow cement interdigitation into cancellous bone of the roof of the acetabulum.\(^\text{11}\)
- The appropriate position for the acetabular component is selected using a trial prosthesis. Insertion of the trial component should be easy and free of bone or soft tissue obstruction to allow for unencumbered insertion of the actual component. If the margins of the acetabular cavity remain tight, it can be reamed up by 1 mm at the periphery.
- Internal landmarks used for positioning the acetabular cup include the anterior wall and pubic ramus, the posterior wall, the transverse acetabular ligament, and the superior acetabular rim.
- With normal acetabular morphology, positioning the prosthesis just within the confines of the acetabulum ensures appropriate component abduction of 40 to 45 degrees and anteversion of 10 to 20 degrees.
- In cases with large anterior osteophytes or preoperative acetabular retroversion, as noted by a positive crossover sign, the posterior wall and the transverse acetabular ligament are used preferentially to guage proper anteversion. Anterior osteophytes should be debulked using a burr or an osteotome; this reduces the risk of anterior bony impingement with hip flexion and internal rotation.
- Once the appropriate component position is selected using the trial, it can be marked on the bone using methylene blue, and the relationship of the component to the aforementioned landmarks can be noted visually to assist in placement of the final component (TECH FIG 3A).
- A high-speed burr is then used to create holes in the pubis, ischium, and ilium for cement intrusion and “macrolock” to complement the “microlock” achieved by interdigitation in bony trabeculae of cancellous bone.
- If acetabular cysts are present, these are débrided and the sclerotic margins removed using the burr.
- A dry operative field free of debris is necessary for maximal cement interdigitation into cancellous bone (TECH FIG 3B).
- This is achieved by the use of hypotensive regional anesthesia with mean arterial pressure in the range of 45 to 70 mm Hg, and pulse-irrigation to remove fat and blood followed by drying with a sponge, with or without local use of epinephrine.
- Although it is not our practice, a recent study demonstrated improved cement intrusion when suction aspiration of the ilium was performed at the time of cementing to help maintain a dry bone surface.\(^\text{13}\)

CEMENTING THE ACETABULAR COMPONENT

- Cement should be doughy but still relatively low in viscosity when it is placed in the acetabulum. Uniform simultaneous cement pressurization then is achieved using a rubber balloon that is pressed into the acetabulum (TECH FIG 4A).
- After pressurization has been maintained for 30 to 60 seconds, the balloon is removed, and the transverse acetabular ligament is cleared of cement (TECH FIG 4B). This minimizes intra-pelvic extrusion and allows visualization of the floor of the acetabulum to guide placement of the acetabular component.
- The acetabular component is then inserted, with care to match the abduction and anteversion selected at the time the trial prosthesis was inserted. The component should have an outer diameter 2 mm smaller than that of the final reamer, allowing for an adequate cement mantle.
- Extra cement is removed while pressure is maintained on the acetabular component using a Charnley pusher centrally to minimize angular forces on the cement mantle until the cement has hardened.
FEMORAL PREPARATION

- Exposure requires proper delivery of the proximal femur out of the wound by flexion, adduction, and internal rotation. Difficulty achieving this position may be remedied by release of the gluteus maximus tendon.
- The starting point for entry into the femoral canal is in the posterior lateral femoral neck. This allows cylindrical reamers and straight broaches to be inserted along the anatomic axis of the proximal femoral diaphysis while maintaining a uniform cement mantle despite the proximal femoral bow.
  - To achieve the appropriate starting point, all residual soft tissue must be removed from the posterior lateral femoral neck, and remaining bone must be removed using a high-speed burr or other tool.
  - Many surgeons successfully use a box osteotome to achieve this goal, although it does not have the precision of the burr (TECH FIG 5).
  - Once the starting point has been prepared, a conical canal-finding reamer is introduced to aid in the identification of the anatomic axis of the femur. The entry point into the femur is opened, while reaming of the diaphyseal endosteum is minimized. Broach preparation of the canal without extensive reaming preserves cancellous bone to permit optimal cement interdigitation.
  - Sequential broaching is then performed, with care to insert the broaches in appropriate anteversion. This is achieved by following the patient's native version, unless the patient has significant deformity of the proximal femur or the acetabular component is known to be in excessive anteversion or retroversion.
  - The degree of anteversion is best assessed visually if the assistant holds the tibia perpendicular to the plane of the floor.
  - Sequential broaching is continued until torsional stability is achieved at a depth of broach insertion that brings the proximal surface of the broach into the plane of the neck cut.
  - If careful preoperative templating was performed, this should result in restoration of leg length and offset with the implant system being utilized. This can be confirmed following the attachment of trial necks and heads.
  - Many hip systems have options for standard or extended offset necks; these can be defined by the amount of offset or by the neck–shaft angle.
  - In general, the neck that best recreated the anatomic geometry on preoperative templating should be selected.
  - Be aware, however, that radiographs may underestimate offset if the hip is not internally rotated to bring the femoral neck perpendicular to the x-ray beam.

ASSESSMENT OF THE RECONSTRUCTION AND SOFT TISSUE BALANCE USING TRIAL COMPONENTS

- A trial reduction is then performed, and the adequacy of the reconstruction is assessed by four principal maneuvers:
  - First, the hip is internally rotated until the femoral head trial and acetabular component are coplanar (TECH FIG 6A,B) and the knee is bent 90 degrees.
  - If the coronal plane of the pelvis is perpendicular to the floor, the angle between the tibia and the floor is the combined anteversion of the femoral and acetabular components.15
Fourth, the hip is flexed and internally rotated, and the stability is assessed. The surgeon should feel a clear soft tissue resistance prior to dislocation, rather than a smooth unimpeded motion.

Some additional information may be gained from the Ober test, in which the knee is flexed 90 degrees and the hip is extended to neutral and abducted. The knee is then released, while the examiner continues to support the foot.

If the offset has been substantially increased, the knee will remain elevated (ie, the hip will remain abducted), indicating tightness of the iliotibial band.

Results of this test are meaningless unless compared to the preoperative findings, as some hips have a positive Ober test preoperatively.

A final test that provides more limited information is the “shuck” or “push-pull” test, in which an assistant applies traction on the femur with the hip reduced but internally rotated, and the surgeon subjectively assesses the extent to which the femoral head can be distracted from the acetabulum.

There should be some give with push-pull, but the assistant should be unable to completely dislocate the hip with simple traction.

Used in isolation, this test may lead the surgeon to over-lengthen the leg.

If the hip is found to be too loose, a plus-sized modular head can be used or the size of the femoral stem can be increased such that the stem sits more proudly within the femoral canal. Larger stems may also have longer necks, depending on the implant system.

If leg length is appropriate but offset is insufficient, the surgeon can switch from a standard to an extended-offset stem.

If the anterior capsule is found to be tight in a hip with an otherwise acceptable reconstruction, we advocate anterior capsulotomy to balance the hip.

If the hip is too tight—ie, with excessive anterior capsular tightness, a positive Ober test, and excessive leg-lengthening—the femoral trial can be downsized or implanted deeper into the femur, or the minus-sized femoral head can be selected.

We recommend against planning to use the minus-sized femoral head initially, because most implant systems have only a single minus size. Consequently, if the final reconstruction varies from the trial reconstruction, the surgeon is left without the option of further decreasing leg length and offset.

Combined anteversion of 35 to 45 degrees is optimal in women, whereas somewhat less anteversion is desirable in men, who usually have less lumbar lordosis.

Second, the hip is externally rotated with the hip and knee in extension. The anterior capsule should be loose enough to allow external rotation of the femur such that the greater trochanter approaches one fingerbreadth away from the ischium, but not so loose as to allow impingement of the trochanter against the ischium, or of the prosthetic neck against the posterior socket.

Third, the Steinmann pin is replaced in the obturator foramen at the level of the infracotyloid groove, and the relative lengthening or shortening of the leg is measured and noted.

In general, the goal is to increase the leg length by less than 5 mm to optimize hip stability without generating leg-length inequality. However this varies with preoperative clinical leg-length discrepancy and other factors.

The femoral trials are removed, and the femur is prepared for cement fixation. A distal cement restrictor (TECH FIG 7) is placed approximately 1 cm past the anticipated depth of stem insertion.

This helps avoid unnecessarily long cement mantles that are difficult to remove at revision, and it enhances cement pressurization.

The femoral canal is then irrigated using pulse lavage, dried using suction, and packed with vaginal packing or a surgical sponge.

Cement for the femoral side should be prepared under vacuum or using centrifugation, both of which increase cement strength by reducing cement porosity. Cement is then poured into a cement gun. The cement is ready to
be injected when it has reached an intermediate viscosity, low enough to be inserted with the cement gun and to easily interdigitate in cancellous bone, but high enough to allow pressurization.

- After ensuring that there is no air in the tip of the cement gun, cement is injected in a retrograde fashion from distal to proximal, allowing the cement to push the cement gun out of the canal.
- Once the canal is filled to the level of the neck cut, the tip is removed from the cement gun and replaced with a cement pressurizing device that occludes the proximal femoral canal.
  - Any holes in the femoral shaft must be occluded prior to cement pressurization.
  - As pressurization is performed, cement, fat, and marrow contents should be seen extruding from small vascular foramina in the femoral neck. When the pressurizer is removed from the femur, the void created should be filled with more cement.
- The surface of the cement is then dried with a sponge, and cement is used to coat the femoral stem, concentrating on the metaphyseal region. Both of these measures are intended to diminish the amount of blood, fluid, and other debris present in the cement and at the cement–prosthesis interface. Such impurities have been shown to have significant effects on cement strength.
  - If the femur has a relatively wide diaphysis, the addition of a distal centralizer to the stem is advised to reduce the risk of varus malpositioning.
  - The stem is best inserted when the cement is in the “medium dough phase.” The amount of time required for the cement to reach this state varies with room temperature and rate of mixing.
  - Pre-heating the stem will further reduce cement porosity and accelerate cement polymerization.\(^ {17}\)
  - To avoid the creation of voids in the cement mantle, the stem should be inserted in one continuous smooth motion, without adjusting varus/valgus or rotational alignment. Insertion is started by hand, impacting the insertion device with a mallet as needed.
  - Once the position of the trial stem has been reproduced, gentle pressure is maintained on the stem while excess cement is removed, and cement around the stem is pressurized by finger pressure.
  - When the cement has polymerized, the previously selected trial head is placed on the stem and the LTC, leg-length and soft tissue balance, and combined anteverision are reassessed.
  - Once the appropriate head is selected, the trunion of the stem is carefully cleaned and dried, and the implant is gently impacted in place.
  - The acetabulum is cleared of debris using irrigation and suction, and reduction is performed.

**TECH FIG 7 • A cement restrictor placed distal to the tip of the stem allows for cement pressurization. The appropriate depth of insertion is marked on the insertion device.**

**SOFT TISSUE REPAIR AND WOUND CLOSURE**

- Injection of the deep soft tissues (ie, hip capsule, gluteus medius tendon, vastus lateralis, and iliotibial band) with a combination of local anesthetic, narcotic, and either corticosteroid or nonsteroidal anti-inflammatory medication results in decreased postoperative pain and narcotic requirements.\(^ {18}\)
- After copious irrigation of all exposed tissues, an extended posterior soft tissue repair is performed (**TECH FIG 8**).
- The quadratus femoris is repaired to its insertion using nonabsorbable suture, along with repair of the gluteus maximus insertion if this tendon was released.
- A figure-8 suture is placed approximating the superior aspect of the piriformis to the abductor musculature; this suture is not tied initially.
- Repair of the short external rotators and posterior capsule to the posteromedial aspect of the greater trochanter is facilitated by two steps performed earlier in the case.
  - A nonabsorbable suture is passed through the superior lateral portion of the posterior capsular flap and the piriformis tendon in a single pass, with a second pass through the capsule and the conjoint tendon.
  - A second nonabsorbable suture is passed through the inferior lateral portion of the capsular flap and...
the obturator externus tendon, and then again through the capsule. These sutures typically are placed after acetabular cementing and before femoral preparation.

- During closure, the two sutures are passed through drill holes in the greater trochanter and tied to each other.
- To reduce operating time, the drill holes are created while waiting for the femoral cement to dry.
- Prior to tying the sutures, the leg is abducted and externally rotated, taking tension off the posterior soft tissue flap being repaired to the greater trochanter.
- The suture connecting the piriformis to the abductors is tied last.
- The repair should be inspected carefully to make sure that the posterior flap is in contact with the femur, rather than hanging by suture or sutures, before the fascia is closed.
- An inadequate repair can be revised easily if it is noticed at this time.
- The wound is once again copiously irrigated and routine closure of the fascia, subcutaneous tissue, and skin is performed.

### PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Leg length and offset</th>
<th>Optimal function requires restoration of leg length and offset. Patients with particularly high offset should be warned that mild lengthening of the leg may be necessary to achieve appropriate soft tissue tension.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indications</td>
<td>Concomitant spine pathology can lead to persistent symptoms after otherwise successful THA. Older, lighter, less active women with osteoporosis generally have excellent outcomes after cemented THA and may be spared the thigh pain that remains common after noncemented femoral fixation.</td>
</tr>
<tr>
<td>Exposure</td>
<td>Effort should be made to minimize soft tissue trauma. However, small skin incisions that limit exposure may place important deeper structures at risk for increased trauma.</td>
</tr>
<tr>
<td>Hypotensive anesthesia</td>
<td>Optimal cement fixation of the acetabular component is difficult to achieve without a dry surgical field, making hypotensive anesthesia a crucial aspect of cement technique.</td>
</tr>
</tbody>
</table>

### POSTOPERATIVE CARE

- Blood management
  - We currently recommend preoperative autologous blood donation to reduce postoperative exposure to allogenic blood.
  - Preoperative recombinant human erythropoietin may be considered in patients unable to donate blood.
  - Allogenic transfusion may be used as indicated for symptomatic anemia.
- Pain control
  - Patient satisfaction is improved by the use of multimodal analgesia protocols, combining soft tissue injections at the time of surgery, acetaminophen, nonsteroidal anti-inflammatory medications, and both long- and short-acting narcotics.
  - These regimens reduce both pain and narcotic requirements, thereby reducing perioperative nausea, emesis, sedation, and confusion, and enabling more rapid rehabilitation.
- Intravenous antibiotics
  - Antibiotics are given within 1 hour before surgery and continued postoperatively for 24 hours
  - Cefazolin is the preferred antibiotic.
  - Vancomycin or clindamycin typically are used in the patient allergic to penicillin or cephalosporins. Vancomycin may be preferable, as *Staphylococcus epidermidis* isolates often are resistant to clindamycin.
- Prophylaxis against venous thromboembolic disease
  - Sequential compression devices provide mechanical prophylaxis, which has been proven to reduce the risk of deep vein thrombosis (DVT), both as the sole mode of prophylaxis and as an adjunct to pharmacologic prophylaxis.
  - The optimal pharmacologic prophylaxis remains a matter of debate, but some form of prophylaxis should be continued after hospital discharge. We use a single dose of warfarin preoperatively on the day of surgery, a single dose of intravenous heparin given intraoperatively prior to hip dislocation, and adjusted-dose warfarin postoperatively for the first 2 to 3 days in all patients. Patients with a history of thromboembolic disease or who are otherwise deemed to be at high risk for thrombosis, as well as those with a prior indication for warfarin, are kept on extended warfarin prophylaxis after discharge.
  - A screening Doppler is performed prior to patient discharge. If it is negative, patients without any of the previously mentioned indications for warfarin are discharged on aspirin, 325 mg daily. If the Doppler is positive, patients are continued on warfarin at treatment doses.
  - Accelerated rehabilitation protocols further reduce the risk of thromboembolic disease, and are an important part of most multimodal prophylaxis regimens.
- Physical therapy
  - Posterior hip dislocation precautions are recommended for all patients undergoing total hip replacement through a posterior approach. A recent study challenging the need for precautions was performed at a center where the anterolateral approach is used. Surgeons employing the posterior approach should not assume that these findings can be generalized to all patients after THA.
outcomes

- Relief of hip pain and restoration of function are remarkable after THA. Thigh pain is rare after cemented THA, whereas it is relatively common after noncemented femoral fixation.
- The clinical success of cemented THA has been documented at long-term follow-up (FIG 3). Although function may decline with age and comorbidities, 94% of patients followed for 30 years were free from hip pain or reported minimal discomfort.26
- Minimum 25-year follow-up data after cemented THA using first-generation cement techniques is available from institutions in Minnesota1 and Iowa.5,6 Each center has reported a single-surgeon series consisting of consecutive cases performed in the late 1960s and early 1970s.
- Implant survivorship was 94% at 10 years, 90% at 15 years, 84% to 85% at 20 years, 77% to 81% at 25 years, and 68% at 30 years.
- Revision with removal of at least one component was required in 12% of hips at 30-year follow-up,6 with the remainder of the original implants either still functioning well in vivo (7%) or in place at the time of patient death (81%).
- Minimum 20-year follow-up data after cemented THA using improved cement technique in the 1970s and early 1980s is available from institutions in Iowa4,23 and Ontario.3,25
- Revision with removal of at least one component has been required in 3% to 10% of patients at 10 to 15 years and in 5% to 12% of patients at 20 to 25 years.
- Reasons for revision
  - Aseptic loosening accounts for most revision procedures after cemented THA, with reports ranging from 62% to 100%.1,3,16,23
  - Deep infection, recurrent dislocation, and periprosthetic fracture account for most other revisions.
  - Less common reasons for revision after cemented THA include osteolysis, isolated polyethylene wear, and technical errors such as leg-length discrepancy.
- Component fracture, which was a major cause of revision with early implant systems, is very uncommon with modern implants.

complications

- Embolism of fat and bone marrow occurs whenever the marrow space of a long bone is instrumented, but it results in fat embolism syndrome. Cement fixation of the femoral component may increase the quantity of fat displaced, the consequent pulmonary shunt, and the risk of fat embolism syndrome.23 For this reason, we prefer to avoid cement fixation in patients with significant cardiopulmonary disease.
- Venous thromboembolism is common in THA if prophylaxis is not used. Most prophylactic regimens are associated with low rates of symptomatic DVT and pulmonary embolism, with fatal pulmonary embolism occurring in fewer than 0.5% of patients. Aggressive pharmacologic anticoagulation has been proven to reduce the rate of asymptomatic DVT, but no regimen has been found to decrease the low rate of fatal pulmonary embolism.
- Cardiopulmonary complications are uncommon with appropriate preoperative medical optimization and conservative surgical indications, but at-risk patients should be monitored carefully in the perioperative period.
- Clinically meaningful leg-length inequality is an avoidable complication in most patients. In a prospective study,22 the methods for equalizing leg lengths described in this chapter resulted in postoperative leg-length inequality that averaged +2.6 mm (range, −7 mm to +9 mm), with 87% having inequality of 6 mm or less. None of the patients reported symptoms of leg-length inequality or required the use of a shoe lift.
- Infection can be a devastating complication after total hip replacement. The use of perioperative antibiotics and of antibiotic-laden bone cement3 have both been associated with decreased risk of deep infection.
  - Other interventions such as the use of laminar flow and body exhaust suits have been demonstrated to decrease the risk of infection in the setting of inconsistent antibiotic use, but no additive benefit in the setting of consistent use of prophylactic antibiotics has been proved.
  - The use of iodine-impregnated adhesive plastic drapes and the minimization of operating room traffic may also reduce bacteria counts in the surgical wound.
  - Dislocation after total hip replacement can cause significant aggravation to the patient and the physician, and is one of the more common causes of revision surgery. The risk of dislocation is minimized when the reconstruction restores leg length, offset, and center of rotation, with appropriate femoral and acetabular anteversion.
  - Anterior, anterolateral, and direct lateral approaches have been associated with the lowest risk of dislocation. We prefer the posterior approach for the reasons already stated. Although posterior approaches may increase the risk of dislocation slightly, this risk can be mitigated by a careful posterior soft tissue repair.
  - Periprosthetic fracture can occur intra- or postoperatively. The key to management of intraoperative fractures is intraoperative recognition, as most can be managed expeditiously at the time of surgery. If an appropriate starting point is used for femoral preparation, intraoperative fractures in primary

Figure 3: Radiograph of cemented total hip arthroplasty.
cemented THA are uncommon. Postoperative fractures typically are associated with trauma, often in the setting of osteolysis, and their management is beyond the scope of this chapter.

- Aseptic loosening is the most common cause of failure after cemented THA. The risk of aseptic loosening can be decreased by use of well-designed implants and modern cement technique. Nevertheless, several patient factors influence rates of aseptic loosening after cemented THA.
  - Male gender is strongly associated with increased risk of revision for aseptic loosening. The risk of aseptic loosening is inversely correlated with risk of revision for aseptic loosening. Twenty-five-year survivorship free of revision for aseptic loosening was 68.7% in patients who were younger than 40 years of age at the time of primary arthroplasty, and 100% in patients older than 80 years of age, with incremental increases in survival observed for each decade of increased age between 40 and 80.
  - Osteolysis, a common cause of failure in uncemented implants, is reported less commonly after cemented THA, possibly related to decreased polyethylene wear in cemented THA. Although “ballooning” osteolysis is uncommon when cement is used, fixation failure in cemented THA seems to be related to the biologic reaction to wear debris.
  - Sciatic nerve palsy is an uncommon complication after cemented THA. It most commonly occurs when the operated extremity is lengthened substantially after a longstanding (especially congenital) shortening of the limb, resulting in traction-related nerve ischemia. We routinely palpate the sciatic nerve before the hip is dislocated and again after the arthroplasty is performed, to assess whether the tension in the nerve has been excessively increased.
  - The sciatic nerve may also be compressed under the tendon of the gluteus maximus during surgery if the hip is maintained in severe flexion and internal rotation. For this reason, Hurd et al recommended routine release of the gluteus maximus tendon during THA.

REFERENCES

DEFINITION
- Total hip arthroplasty is the standard of care for symptomatic degenerative joint disease of the hip that is unresponsive to nonoperative treatment.
- Cementless total hip arthroplasty has demonstrated excellent mid- to long-term results.
- The acetabular component obtains initial fixation through a press-fit and has a surface that allows for in- or on-growth of bone.
- The femoral component obtains initial fixation through a press-fit in either the metaphysis or diaphysis and has a surface that allows for in- or on-growth of bone. The metaphyseal-fit prosthesis may be either wedge-shaped or fit-and-fill.

ANATOMY
- The acetabulum must be exposed so that the anterior and posterior walls, superior dome and rim, and teardrop are visualized.
- The proximal femur must be exposed so that the periphery of the proximal femoral neck cut is visualized.

PATHOGENESIS
- Degenerative joint disease of the hip is the endpoint of many hip disorders, including osteoarthritis, inflammatory arthritis, dysplasia, osteonecrosis, trauma, and sepsis.

NATURAL HISTORY
- Degenerative joint disease of the hip often follows a variable symptomatic course. It is unknown why some patients progress more rapidly than others and why some patients are more symptomatic than others.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The history should be directed to determine whether the patient's pain is extrinsic or intrinsic.
- The patient's pain may be extrinsic (eg, lumbar radiculopathy, intrapelvic pathology), and hip arthroplasty may fail to relieve the patient's pain completely, even in the face of severe degenerative changes of the hip.
- Pain usually is located in the groin but may be located in the medial thigh, buttock, or the medial knee.
- Range of motion (ROM) should be observed. Normal ROM of the hip is an arc of motion of 120 to 140 degrees of flexion–extension, 60 to 80 degrees of abdution–adduction, and external–internal rotation of 60 to 90 degrees. Loss of motion may be due to pain, contracture, or abnormal biomechanics.
- Nonoperative treatment must be optimized before consideration is given to surgery.
- Leg lengths should be measured and recorded preoperatively, and the patient should be counseled as to reasonable postoperative expectations.

Examinations to perform include:
- Trendelenburg test. The test is positive if the contralateral hip drops inferiorly; this may indicate that the hip abductors are compromised.
- Hip flexion–internal rotation. The test is positive if the patient's pain is recreated. Pain that is not recreated with this examination may be from an extrinsic source.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs, including anteroposterior (AP) views of the pelvis and AP and true lateral views of the hip, should be obtained to evaluate the anatomy, assess for deformity, and devise an adequate plan preoperatively (FIG 1).

DIFFERENTIAL DIAGNOSIS
- Lumbar radiculopathy
- Spinal stenosis
- Sacroiliac degenerative joint disease
- Intra-abdominal pathology
- Intrapelvic pathology
- Neuropathy
- Meralgia paresthetica
- Complex regional pain syndrome
- Vascular claudication
- Primary bone tumors
- Metastasis
- Infection

FIG 1 • AP radiograph of the hip demonstrates advanced degenerative changes of osteophytes and joint space obliteration.
NONOPERATIVE MANAGEMENT
- Acetaminophen
- Nonsteroidal anti-inflammatory drugs
- Glucosamine
- Chondroitin sulfate
- Physical therapy

SURGICAL MANAGEMENT
- The primary indication for cementless total hip arthroplasty is painful, severe degenerative joint disease of the hip that has been nonresponsive to appropriate nonoperative treatment modalities.

Preoperative Planning
- Preoperative planning for routine cementless primary total hip arthroplasty can be accomplished with plain radiographs at standard magnifications.
  - Standard templates are available for the components, and many are available for digital templating as well.
  - The acetabular component is placed so that the inferomedial edge of the cup is at the radiographic “teardrop.” The inclination is 35 to 45 degrees, and the cup should contact the superolateral rim of the acetabulum.
  - The femoral component is placed so that the center of rotation is at the level of the greater trochanter. The femoral offset should be reproduced. However, the femur must be internally rotated 10 to 15 degrees on the radiograph to bring the femoral neck into the plane of the radiograph. Externally rotated femora will appear to be in coxa valga.
  - Proximal-fit femoral prostheses are designed to obtain fit in the metadiaphyseal region.
  - Diaphyseal-fit femoral prostheses are designed to obtain fit in the diaphysis.

Positioning
- The patient is positioned according to surgeon preference and in accordance with the surgical approach.
  - The hip should be draped in such a fashion as to allow a wide surgical exposure should an extensile approach be required in the event of a complication.
  - The pelvis must be stabilized in a secure fashion to avoid pelvic tilt, which may affect the surgeon’s perception of the acetabular position.

Approach
- The hip can be exposed for primary routine arthroplasty via a variety of approaches:
  - Anterior
  - Anterolateral
  - Direct lateral
  - Posterior
  - Two-incision
  - Small-incision variants of these approaches

ACETABULAR EXPOSURE
- The approach to the hip is chosen according to the surgeon’s preference. The approach illustrated here is the direct lateral (modified Hardinge) approach in the supine position.
  - Retractors are placed in the anterior, superior, and inferior positions, thereby exposing the entire periphery of the acetabulum (TECH FIG 1).
  - The labrum is resected.
  - The soft tissue in the cotyloid fossa is removed, allowing exposure of the medial wall and teardrop.

TECH FIG 1 • Acetabular exposure.
A. Supine position for modified Hardinge approach. B. Completed acetabular exposure. The medial wall and native acetabular anatomy are easily visualized. C. Labrum is resected. D. Osteotome removes osteophytes from cotyloid fossa. E. Currette removes remaining tissue to expose teardrop.
ACETABULAR PREPARATION

- Before reaming, the entire periphery of the acetabulum, medial wall, and teardrop must be directly visualized (TECH FIG 2).
- The initial reaming must be done with moderate pressure until the quality of bone is assessed. The goal of the initial reaming is to medialize the reamer fully. The cotyloid fossa should be eliminated without penetrating the medial wall.
- Reaming then proceeds sequentially. The goal is to recreate the center of rotation by placing the inferomedial aspect of the socket at the level of the teardrop with the component inclined at 35 to 45 degrees and with 10 to 20 degrees of anteversion and with good initial fixation obtained through a press-fit.
- The templated size should be used as a guide; intraoperatively, an increase or decrease in cup diameter may be found to be appropriate.
- Failure to recognize the need for a different cup diameter may lead to iatrogenic fracture or a failure to achieve initial fixation.
- The bony bed should be bleeding but not devoid of sclerotic bone.
- The pelvis must remain in a stable position to avoid malpositioning of the acetabular component.

![TECH FIG 2](image1)

TECH FIG 2 • Acetabular preparation. A. Initial reaming to medialize acetabulum fully. B. Reaming completed to medial wall. C. Reaming proceeds sequentially at 35 to 45 degrees of abduction and 10 to 20 degrees of anteversion.

ACETABULAR COMPONENT IMPLANTATION

- The position of the pelvis is reassessed. Any tilt is corrected.
- The trial component or reamer is used to assess bone coverage of the component and position (TECH FIG 3). If the trial or reamer is not seated properly, then further reaming may be necessary. If deemed appropriate, implantation of the actual component may proceed.
- The actual implant should be 1 to 2 mm larger than the last reamer. The surgeon must know the actual

![TECH FIG 3](image2)

TECH FIG 3 • Acetabular component implantation. A. Final reamer is used to assess component position, bone coverage, and seating. B. Acetabular component is implanted. C. Central hole is used to verify that the cup is fully seated. D. Actual liner is inserted into the cup.
diameter of the implant, taking into account any rim or coating.
- Implants that are larger than the size of the last reamer by 4 mm or more are associated with risk of fracture.
- The acetabular component is then implanted, with care taken to medialize the implant. The inferomedial aspect of the cup should be at the level of the teardrop in 35 to 45 degrees of abduction and 10 to 20 degrees of anteversion.
- A trial liner or the actual liner is then inserted.

**FEMORAL EXPOSURE**

- The femur is exposed by elevating it out of the wound with a retractor (Bennett or double-footed).
- The periphery of the femur is exposed with another retractor (**TECH FIG 4**).
- The soft tissues must be protected so that iatrogenic damage by reamers or broaches is avoided.

**TECH FIG 4** • Femoral exposure. The femur is elevated and exposed with two double-footed retractors to allow atraumatic broaching.

**FEMORAL PREPARATION (PROXIMAL-FIT PROSTHESIS)**

- The femur is prepared as delineated by the surgical protocol for each prosthesis (**TECH FIG 5**). The surgeon should be familiar with the prosthesis and all of the available options and idiosyncrasies.
- The proximal-fit prosthesis usually requires a starter reamer, which is used as a canal-finder. In addition, the reamer should be laterialized to avoid broaching and subsequent varus positioning of the implant.
- The femur then is broached sequentially, with care taken to lateralize the broach. Broaching is complete when the broach ceases to advance, the pitch of impaction increases, and good cortical contact is obtained.

**TECH FIG 5** • Femoral preparation.  
A. Rongeur is used to clear tissues and lateral cortical bone.  
B. Curette used to find canal.  
C,D. Canal is reamed to open canal, and care is taken to lateralize.  
E. Broaching proceeds. (continued)
The implant chosen usually matches the size of the last broach.

- The proximal-fit femoral component is inserted, with care taken to avoid varus positioning (TECH FIG 6).

- The implant is impacted until it ceases to advance, the pitch of impaction increases, there is good cortical contact, and the implant has reached the level of the last broach.

- The templated size should be used as a guide, and an increase or decrease in stem size intraoperatively may be appropriate.

- Failure to recognize the need for a different size may lead to iatrogenic fracture or failure to achieve initial fixation.

- A standard or varus neck is selected based on the soft tissue tension and the patient’s anatomy.

**FEMORAL COMPONENT IMPLANTATION (PROXIMAL-FIT PROSTHESIS)**

- Improper broaching can lead to fracture, malposition, or undersizing.
- The component should be anteverted 10 to 15 degrees.
- The greater trochanter can be used as a reference to recreate the center of rotation.
- It may be necessary to adjust the neck cut to allow for further seating of the prosthesis.

**SOFT TISSUE TENSION/LEG-LENGTH DETERMINATION**

- The hip is trial reduced and assessed for soft tissue tension, stability, ROM, impingement, and leg length.
- The soft tissue tension should allow for no more than 1 to 2 mm of toggle (TECH FIG 7).
- The hip should be stable within the patient’s physiologic ROM. If instability exists, the position of the components must be reassessed.
- The ROM should be physiologic for the patient.
Postoperative Care

- Weight bearing after cementless total hip arthroplasty is controversial. Some surgeons routinely restrict weight bearing for 6 weeks, whereas others allow weight bearing as tolerated.
- Hip precautions are prescribed according to the approach.
  - Posterior approaches avoid flexion, internal rotation, and adduction, whereas anterior approaches avoid extension, external rotation, and adduction.
  - The hip precautions are discontinued at 6 weeks.
  - Some surgeons who perform the anterior approach have discontinued the use of traditional hip precautions.20

Outcomes

- The survivorship of cementless total hip arthroplasty components generally has been excellent, although isolated reports of high failure rates exist for certain designs, which have subsequently been abandoned. Most modern, uncemented acetabular and femoral components have reported survivorship of 95% to 100% at mid- to long-term follow-up.1–19, 21–23
Overall survival of cementless acetabular components has ranged from 83% to 99.1% at 8.5 to 16.3 years of follow-up.\textsuperscript{1,3,6,7,10–12,15,21,23} The reported survivorship of cementless femoral components has ranged from 82% to 100% at 6.6 to 17.5 years of follow-up.\textsuperscript{1,2,4,5,8,9,12–14,16–18,22} The main limitation to long-term clinical success has been wear and subsequent osteolysis.

**COMPLICATIONS**

- Iatrogenic fracture
- Stress shielding of proximal bone
- Blood loss
- Infection
- Neurovascular injury
- Anesthetic and medical complications
- Loosening
- Osteolysis

**REFERENCES**

Surface replacement is a significant development in the evolution of hip arthroplasty. Hip resurfacing is based on the premise that femoral bone can be preserved. The femoral head is “resurfaced” by insertion of a cemented component. The cup is press-fit.12

**Resurfacing Systems**

Several hip resurfacing devices of various designs are available, but the most critical factor in resurfacing is the surgeon’s level of expertise. These various devices differ in terms of material, surface treatments, cup design, manufacturing process, carbide content, component thickness, clearance, possibility of including a cement mantle under the femoral component, fixation methods, and size ranges offered (Table 1).

**SURGICAL MANAGEMENT**

**Indications**

- Hip resurfacing is used optimally in younger, active patients with good bone quality.
- This procedure is indicated for a degenerative hip joint with pain and decreased range of motion.
- When joint-preserving procedures such as femoral osteotomy, acetabular osteotomy, or vascularized bone grafting are not ideal for an early stage of unambiguous coxarthrosis, hip resurfacing can be considered.
- Resurfacing usually is reserved for patients with good bone stock, high activity level, and a need for a high degree of motion.
- Hemiresurfacing, in which only the femoral head is resurfaced, has largely been abandoned because it provided suboptimal results.
- Resurfacing recently was approved by the U.S. Food and Drug Administration.
- General indications for hip resurfacing are as follows:
  - Primary osteoarthritis
  - Secondary osteoarthritis as sequel of childhood disease, including hip dysplasia or infection
  - Osteonecrosis of the femoral head
  - Post-traumatic arthritis
  - Ankylosing spondylitis
  - Rheumatoid arthritis

**Contraindications**

- Abnormal anatomy of femoral head or neck
- Severe limb-length discrepancy that may require some correction during arthroplasty
- Severe bone deficiency
- Large and cystic lesions of the femoral head
- Severe dysplasia, because screw fixation for the acetabulum cannot be performed with resurfacing

**Special Considerations**

**Osteonecrosis of the Femoral Head**

- Osteonecrosis of the femoral head presents a special problem for hip resurfacing.
- The presence of a necrotic lesion of the femoral head can compromise fixation of the component.
- In general, survival of hip resurfacing is lower for avascular necrosis than for osteoarthritis in the counterpart hip.3

**Use of a Computer-Assisted Navigation System**

A computer-assisted navigation system is an intraoperative image-guided localization system used to enable proper cutting of bone and exact location of the implants in total knee or total hip arthroplasty (THA) and in minimally invasive surgery.

Although hip resurfacing arthroplasty has been used for a long time with acceptable results without any navigation system, one of the main concerns following resurfacing arthroplasty is femoral neck fracture.

- In general, slight valgus positioning of the implant is recommended to reduce the tension and shear stresses across the head–neck junction, but intraoperative neck notching during femoral cutting often is a consequence of extreme valgus position.
- Many mechanical femoral alignment guides have been developed to help surgeons achieve optimal positioning of the femoral implant.
- As for THA, early loosening or dislocation resulting from impingement due to the malposition of both components should be prevented.12
- In hip resurfacing arthroplasty, avoidance of femoral notching by the femoral component and the position of the stem of the femoral component are critical. This may be technically difficult, even for an experienced surgeon, and it adds time to the procedure.
- Computer-assisted navigation systems have been developed to surmount the intrinsic limitations of manual techniques.

Intraoperative navigation can demonstrate real-time positioning of instrumentation by imaging, thereby improving the accuracy of component positioning in hip resurfacing arthroplasty.

- Specific surface landmarks may be difficult to make out, however, and registration procedures often are the most time-consuming and accuracy-related segment of the procedure.
- Irregular soft tissue distribution around the femoral neck also can affect navigation precision.

Surgical navigation may be especially helpful during femoral procedures.

- To reduce the potential risk of femoral neck fracture, we perform total hip resurfacing arthroplasty using computer-assisted navigation.
- We have used the hip resurfacing systems with Vectorvision (BrainLAB, Munich, Germany) since 2005 (FIG 1).10
### Table 1: Comparative Table for Representative Hip Resurfacing Systems Currently Available

<table>
<thead>
<tr>
<th>Resurfacing System</th>
<th>Material</th>
<th>Acetabular Fixation</th>
<th>Femoral Fixation</th>
<th>Available Femoral Size (mm)</th>
<th>Available Acetabular Size (mm)</th>
<th>Cups for Dysplastic Hip</th>
<th>Surface Finish</th>
<th>Clearance (Diametral)</th>
<th>Cup Design</th>
<th>Cup Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cormet (Corin, Cirencester, UK)</td>
<td>Cast and heat-treated high-carbon CoCr</td>
<td>Uncemented</td>
<td>Press-fit equatorially, or uncemented Ti + HA internal coating</td>
<td>5 sizes, from 40 to 56 in 4-mm increments</td>
<td>10 cup sizes, from 46 to 62 in 6-mm increments, with 2 cup sizes for every head size</td>
<td>Pegged and unpegged acetabular cups</td>
<td>10 nm</td>
<td>150–400</td>
<td>Full-hemisphere OD with 2-mm equatorial expansion with 3.5-mm offset bore</td>
<td>3–4 mm</td>
</tr>
<tr>
<td>Birmingham Hip Resurfacing (BHR; Smith &amp; Nephew, Andover, MA)</td>
<td>As cast high-carbon CoCr beads with HA</td>
<td>Cast in CoCr</td>
<td>Press-fit equatorially</td>
<td>6 sizes, from 38 to 58 in 4-mm increments</td>
<td>12 sizes, from 44 to 66 in 2-mm increments Two cups for every femoral size</td>
<td>Acetabular cups in congenital hip dysplasia and bridging range</td>
<td>20 nm</td>
<td>250–400</td>
<td>Full-hemisphere OD with 3.5-mm offset bore</td>
<td>3–4 mm</td>
</tr>
<tr>
<td>Bone Cemented</td>
<td>Conserve Plus (Wright Medical, Arlington, VA)</td>
<td>Cast and heat-treated high-carbon CoCr</td>
<td>Uncemented sintered CoCr beads with HA</td>
<td>Cemented, full mantle</td>
<td>11 heads, from 36 mm to 56 mm in 2-mm increments</td>
<td>12 components, from 42 mm to 64 mm in 6-mm increments</td>
<td>Two cups for every femoral size</td>
<td>Does not offer dysplasia and bridging cups</td>
<td>10 mm</td>
<td>200–350 (est)</td>
</tr>
</tbody>
</table>

| Bone Cemented | Articular Surface Replacement (ASR; Depuy, Warsaw, IN) | Cast and heat-treated high-carbon CoCr | Uncemented sintered CoCr beads with HA | Cemented, thin mantle | Femoral sizes from 39 to 63 in 2-mm increments | Sizes from 44 to 70 in 2-mm increments | Does not offer dysplasia and bridging cups | 10 mm | 200–300 | 170-degree truncated hemisphere | 2.5–3.5 mm |

| Bone Cemented | Durom (Zimmer/Centerpulse, Warsaw, IN) | Forged high-carbon CoCr | Uncemented Ti VPS | Cemented, full mantle | 12 sizes, from 38 to 60 in 2-mm increments | 12 sizes from 44 to 66 in 2-mm increments | Does not offer dysplasia and bridging cups | 5 mm | 110–220 | 165-degree truncated hemisphere | 4 mm |

CoCr, Cobalt-Chromium; HA, hydroxyapatite; OD, Outer diameter; TiVPS, Vacuum plasma sprayed pure titanium.
When using an image-free hip navigation system, the surgeon must digitize the pelvic and femoral planes of the patient to determine the individual pelvic and femoral coordinate system for prosthesis positioning.

**Preoperative Planning**
- Templates are used to determine approximate component sizes. Standard-sized conventional radiographs must be used rather than digital films, and the magnification factor must be taken into account.
- The femoral component must be sized such that there is no over-reaming of the femur or risk of notching of the neck. Oversizing also should be avoided to preserve acetabular bone stock.
- Femoral component alignment is the most important preoperative consideration. Varus positioning must be avoided—neutral or slight valgus alignment is preferred (FIG 2).
- When optimum femoral template positioning has been achieved, the distance from the tip of the greater trochanter to the pin insertion point on the lateral femoral cortex is measured with the ruler printed on the template.
- The relation between the exit-point of the guidewire on the template relative to the lesser trochanter should be noted and reproduced during surgery.
- An acetabular component should be selected of the size that fills the acetabular fossa and accommodates the selected femoral component.

**Approach**
- All of the standard exposures of the hip have been successfully used to perform surface replacement.
- Hip resurfacing is technically demanding, and the surgical approach used should allow adequate exposure of the acetabulum and proximal femur without compromising postoperative muscle function.
- The posterior approach is the most popular approach for total hip resurfacing.
- The anterior approach, the exposure advocated by Wagner, is not popular.
- The anterolateral approach was described by Hardinge and modified by Learmonth.
- Exposure of the femoral head is achieved by flexion, abduction, and external rotation of the lower extremity.

Exposure of the acetabulum is accomplished by depressing the femoral head into a posterior and inferior position.
- This approach has the advantage of preserving the posterior retinacular vessels, which reduces the possibility that an iatrogenic avascular state will develop postoperatively in the remaining femoral head.
- Critics of this approach believe that the exposure offered is inadequate, leading to a greater risk of complications and improper component positioning of both implants in total hip resurfacing. There may be a higher incidence of heterotopic new bone formation, and decreasing abductor muscle function often is compromised following this approach.
- The trans-trochanteric approach for hip resurfacing was popularized by Amstutz.
- This approach provides excellent exposure, but it rarely is used for this operation, primarily because of problems associated with trochanteric osteotomy and a higher incidence of heterotopic ossification.
- The posterior or posterolateral approach is the standard approach used for total hip resurfacing.
In this approach, the tendon of insertion of the gluteus maximus is released to allow easy anterior displacement of the femur. The capsule and synovium around the femoral neck are preserved as much as possible to prevent further vascular damage to the femoral neck and head. The femoral head then is dislocated (FIG 3).

The femoral neck is sized using neck gauges. Sizing also gives an idea about the minimum acetabular size required. Usually, the acetabular preparation is done first, unless the femoral head is especially large, which results in inadequate acetabular preparation. In such cases the femoral head is prepared to one or two sizes larger than the targeted femoral component size.

POSTEROLATERAL APPROACH

Exposure

- The patient is placed in the lateral position.
- The hip is flexed to 45 degrees, and a straight incision is made centered on the posterior edge of the greater trochanter.
- Alternatively, the hip is extended and a conventional incision, curved posteriorly, is made (TECH FIG 1A).
- The fascia lata is incised, the fibers of the gluteus maximus are split, and a Charnley retractor is inserted (TECH FIG 1B).
- The tendon of insertion of the gluteus maximus usually is released to allow subsequent easy anterior displacement of the femur; the underlying perforator vessels may require coagulation (TECH FIG 1C).
- The trochanteric bursa is divided and swept posteriorly, after which the sciatic nerve may be easily seen or palpated.
- The posterior edge of the gluteus medius is retracted anteriorly to reveal the piriformis tendon.
- The fibers of the gluteus minimus are separated from the superior border of the piriformis tendon.
- The interval between the gluteus minimus and the superior acetabulum and superior hip capsule is developed with electrocautery.
- The hip is held in internal rotation, and the piriformis tendon is divided as close as possible to its insertion, along with the hip capsule.
- The other external rotators and the hip capsule are divided with electrocautery, leaving a cuff of quadratus femoris for later suturing.
- The joint capsule is incised along the line formed by the superior margin of the piriformis muscle. The posterior capsule is detached cautiously, along with the base of the femur neck, to save intracapsular blood vessels around the femoral neck.
- The femoral head is dislocated, the hip is fully extended (by bringing the knee to the midline), and maximum internal rotation of the leg is performed (TECH FIG 1D).

TECH FIG 1 • A. Posterolateral approach. The patient is in the lateral position with the affected hip flexed 45 degrees. A straight incision is made at the posterior border of the greater trochanter. B. The gluteus maximus fibers are split proximally and the iliotibial band is incised distally. C. A diathermy is used to release the insertion of the gluteus maximus tendon, leaving behind a small fringe for later suturing. Perforator vessels in this area may cause furious bleeding, requiring ligation or cauterization. D. Circumferential capsulotomy. With the hip fully extended and in maximal internal rotation, the anteroinferior capsule is divided inferiorly. The hip is then flexed to 45 degrees in maximum internal rotation and the anterosuperior hip capsule is divided superiorly. The capsulotomy is extended down to meet the previous inferior cut, giving a full circumferential capsulotomy. E,F. Diagram illustrating sizing of the femoral neck. The neck is sized in its maximum diameter.
- The anteroinferior hip capsule is divided, beginning inferiorly, just in front of the psosas tendon, using Muller capsular scissors or electrocautery.
- The femoral neck is sized using neck gauges or templates (TECH FIG 1E,F); this also gives an idea about the minimum acetabular size required.
- An anterolateral soft tissue pocket is created using a curved periosteal elevator or a Cobb elevator.
- A Hohmann retractor is placed over the anterosuperior acetabulum and impacted into the anteroinferior iliac spine, and the leg is externally rotated to allow the femoral head to prolapse under the abductors into the pocket.

**Acetabular Preparation**
- A pin retractor (Judd pin) is inserted into the ischium, retracting the posterior capsule and external rotators.
- Two Hohmann retractors are placed from inferior to the teardrop, directed antero- and posteroinferiorly (TECH FIG 2A).
- The labrum, transverse acetabular ligament, and other soft tissue in the cotyloid fossa are excised, giving a complete view of the bony acetabulum.
  - Sequential reaming is performed (TECH FIG 2B), with under-reaming by 1 to 2 mm.
- An acetabular component that provides the best possible fit without reaming excess acetabular bone is preferred; this choice then determines the size of the femoral component.
  - A trial cup is inserted and tested for stability (TECH FIG 2C).
- The true acetabular component is then inserted in “native” version, usually 20 degrees, and at a 45-degree angle (TECH FIG 2D).
- Any protruding acetabular osteophytes should be removed.
- The Hohmann retractors and pin retractor are removed.

**Inserting the Guide Pin**
- The limb is then hyperrotated to expose the femoral head.
- Lines are drawn on the center of the femoral head and neck in both anteroposterior (135–140 degrees of neck-shaft angle) and lateral planes (normal anteverision) and are extended up into the femoral head, where they intersect (TECH FIG 3A,B).
  - The intersection point should be the entry point for the guide pin.
- A guide pin is drilled into the femoral head and neck using a guide instrument (TECH FIG 3C).
  - A stylus is placed over the guide pin. This should pass around the femoral neck without impingement (TECH FIG 3D) to avoid notching of the femoral neck.
- The guide pin normally is inserted from the superior part of the femoral head about 1 to 2 cm above the fovea.
  - In the coronal plane, 5 to 10 degrees of valgus is desirable; a 135- to 140-degree angle must be maintained with the long axis of the femoral neck (TECH FIG 3E).
  - Because a deformed femoral head or osteophytes around the femoral head and neck may make it difficult to recognize the actual state and relation of the femoral head and neck junction, excessive osteophytes should be removed carefully before femoral pinning.

**Femoral Head Resurfacing**
- In most systems, femoral head preparation is done using cannulated reamers that pass over the previously inserted femoral guide pin (TECH FIG 4A).
- Consecutive reaming or milling using specialized instrumentation forms the femoral head into a chamfer-cut cylindrical shape (TECH FIG 4B–D).
- Non-impinging osteophytes present on the femoral neck are best left untouched.
  - Any necrotic bone should be removed.
- The femoral head is then pulse lavaged, and a suction vent is placed into the lesser trochanter to keep the femoral head dry and to prevent embolism (TECH FIG 4E).
- A number of cement keyholes are drilled into the femoral head (TECH FIG 4F).
- A final check is made to confirm that there has been no notching from the trial component (TECH FIG 4G).
TECH FIG 3 • A, B. Planning the guidewire entry point in the AP plane. A line is drawn in the mid-lateral plane of the femoral neck. A second line is drawn in the center of the femoral neck such that it is parallel to the calcar femorale. This gives the guide pin a valgus orientation of about 5 to 10 degrees. The point where the two lines intersect, usually 1 to 1.5 cm superior to the fovea, should be the entry point for the guidewire. C. Planning the guidewire entry point in the superoinferior plane using guide instruments from various companies. D. Planning for slightly valgus placement for the femoral guide pin and checking for notching in the femoral neck. The stylus on the guide pin should move freely around the femoral neck at the head–neck junction without impingement. Moreover, the surgeon can confirm the head size through this procedure. E. The angle in the coronal plane is checked intraoperatively using a goniometer.

TECH FIG 4 • A. The guide rod is inserted after drilling over the guide pin, and the head cutter is advanced through the guide rod. During this procedure the surgeon should check for and avoid femoral notching at the head–neck junction. A head cutter one size larger may be used initially. B. After safe cutting has been accomplished, all instruments are removed, and the top of the head guide is placed through the prepared femoral head. The inferior margin of the guide is placed next to the superior margin of the head–neck junction. The locking lever is securely fixed, and the top area is resected using a saw. C. The chamfer cutter for the femoral head then is used on the reinserted guide rod. D. The final shape of the chamfer-cut femoral head. E. The prepared femoral head is irrigated using a motorized pulsatile lavage instrument. F. Multiple cement keyholes are made, being sure to keep the femoral head dry. G. A head trial is used to recheck the possibility of femoral notching and to determine the point between inferior margin of the trial and femoral head–neck junction.
Cementing

- Bone cement is placed into the femoral component, which is then impacted onto the resurfaced femoral head (TECH FIG 5A,B).
- Alternatively, in case of femoral head defect after curettage of necrotic bone, cement is applied to give a uniform 2-mm cement mantle around the femoral head (TECH FIG 5C), and the femoral component is placed over the head and lightly tapped into place (TECH FIG 5D).

- Excess cement is removed and pulse lavage is used.
- The joint is then reduced and tested for stability and range of motion.

Wound Closure

- Good closure of the capsule and the external rotators is important.
- The tendinous insertion of the gluteus maximus also is repaired, and the fascia lata, subcutaneous fat, and skin are closed.

SPECIAL TECHNIQUE FOR OSTEONECROSIS OF THE FEMORAL HEAD

- Because the surgical approach and acetabular preparation are almost the same, only the technique for the femoral side is described.

Femoral Preparation

- Accurate placement of the guide pin can be accomplished using pin alignment guides or a navigation system (TECH FIG 6A,B).
- In most systems, femoral head reaming is performed by cannulated reamers that pass over the central guide pin.

- A series of reaming or milling devices form the femoral neck into a cylindrical shape (TECH FIG 6C).
- To reduce the stress resulting from femoral notching, reaming should be stopped before the peripheral rim of the distal part of femoral head is cut.
- The remaining distal rim of the femoral head is carefully removed using a rongeur (TECH FIG 6D).
- After chamfer cutting, the remaining necrotic area of the femoral head can be seen clearly (TECH FIG 6E).
- Using a small curette and rongeur, the remaining necrotic area is removed and irrigated with aseptic...
saline to remove tiny fragments of bone debris (TECH FIG 6F).

- The trial femoral head is inserted, and the percentage of volume loss after removal of necrotic bone in the trial is measured (TECH FIG 6G).

- In our experience, if the volume loss is less than 50% and the necrosis does not extend to the lower margin of the trial in any circumference of the femoral head and neck junction, resurfacing can be accomplished.

- Otherwise, we recommend either metal-on-metal THA with a modular large-diameter femoral head or the surgeon’s preferred conventional THA if the acetabular side is not yet finished for hip resurfacing.

**Cementing**

- Using pulsatile lavage, thorough saline irrigation is repeated, taking care to keep the femoral head dry. A special suction system is used during the preparation of bone cement (TECH FIG 7A).

- The bone defect is filled with bone cement and pressurized.
The femoral component is placed on the femoral head and impacted gently, with the cement inside the femoral component removed as a volume half using a cement syringe (TECH FIG 7B–D).

The femoral component is applied to the femoral head with an impactor, and extruding cement is removed with a curette, continuing until the bone cement hardens (TECH FIG 7E–H).

The femoral component is applied to the femoral head with an impactor, and extruding cement should be removed with a curette, continuing until the bone cement becomes solid.

**HIP RESURFACING USING A NAVIGATION SYSTEM**

**Patient Positioning**

At our institution, we use a posterolateral approach for hip resurfacing arthroplasty. When we use the hip resurfacing systems with image-free navigation for an acetabular procedure, certain initial maneuvers must be done with the patient in the supine position before moving the patient to the lateral position and undertaking the posterolateral approach, because pelvis registration cannot be performed conveniently in the lateral position.

Once the pelvis registration has been completed, the patient can be moved to the lateral position.

If the surgeon uses the navigation system only on the femoral side, the supine position for acetabular registration is not needed, and femoral registration is performed during surgery with the patient in the lateral position.
Precise location of the registration points is a key factor in ensuring proper matching at every step.

**Pelvis Registration**

- A small-step incision is made on the iliac crest of the operative side, and the fixation pin is inserted for the reference array using an automatic drill at low speed (TECH FIG 8A,B).
  - The second pin is inserted in the same manner using a drill template (TECH FIG 8C).
- Once two pins have been inserted, the bone fixator and the pelvis reference array are attached (TECH FIG 8D).
- The bone fixator should remain attached until the end of the entire navigation procedure.

- The plane of the pelvis is defined by entering points on the pelvis according to the navigation software (TECH FIG 8E,F).
  - Bony landmarks of interest are the left and right anterior superior iliac spine and the most anterior parts of both pubic bones, which, in most patients, are the pelvic tubercles (TECH FIG 8G,H).
- Once registration has been completed, the pelvis reference array is removed without dislodging the fixation pins and bone fixator (TECH FIG 8I).
- The reference array is stored in a sterile location until it is reattached.

**TECH FIG 8**

- A. The anterior pelvic plane is defined using four points: the operated and contralateral sides of the anterior superior iliac spine and the most prominent pubic points on both the operated and the contralateral sides. 
- B. After local sterilization, a small stab incision is made on the operated iliac crest, and the fixation pin is inserted with a low-speed automated drill. The fixation pins should not be inserted near the anterosuperior iliac spine point, because this point is required for pelvic registration. 
- C. The second pin is inserted in the same manner using a drill template. 
- D. Once the second fixation pin has been inserted correctly, the bone fixator is attached and the pelvic reference array is corrected to it. The reference array should be detected by the cameras both in supine and ateral positions during the operation. 
- E. The pelvic plane is defined by entering points on the pelvis as prompted by the software. 
- F. The pointer is put in the left anterosuperior iliac spine. 
- G, H. The pointer is placed on the right pubic point according to the navigation system. 
- I. Once registration has been completed, the pelvis reference array is removed without dislodging the fixation pins and bone fixator.
TECH FIG 9 • A. When the pelvis registration procedure is finished, the patient is moved into the lateral decubitus position. During this change in the patient’s position and draping, the surgical team should pay attention to the acetabular fixator and pins to protect them from contamination or loosening. B. With the patient repositioned and secured, the surgical area is sterilized and the patient is draped.

Repositioning the Patient

- When the pelvis registration procedure is finished, the patient is moved into the lateral decubitus position, and the surgical area is sterilized and draped thoroughly (TECH FIG 9).

- During draping, the surgical team should pay attention to the acetabular fixator and pins to protect against contamination or loosening.

Acquiring Acetabular Landmarks

- The skin is incised in a routine manner, and the acetabulum is exposed.

TECH FIG 10 • A,B. Multiple point acquisition on the cotyloid fossa, the deeper part of the acetabulum, is used to register bony areas. Points acquired in this way are used to calculate the three-dimensional model. The number of points to be acquired is shown in the center of an acquisition clock. C,D. Acquiring points on the acetabular wall. E,F. Once the bone model has been calculated, pelvis registration is verified.
■ Multiple landmark acquisition is used to register the cotyloid fossa and acetabular surface, including margins (TECH FIG 10A–D).
■ To begin multiple landmark acquisition, the tip of the pointer is touched to the required structure and pivoted slightly.
■ Points are acquired by sliding the pointer tip along the defined structure.
■ Once the bone model has been calculated in the navigation monitor, pelvis registration should be verified immediately (TECH FIG 10E,F).

Inserting the Acetabular Cup
■ To insert the cup at the desired angle, the bone must be reamed at the same angle as the planned cup (TECH FIG 11A).
■ The acetabulum initially is reamed with an 8-mm diameter reamer, which is smaller than the planned cup size (TECH FIG 11B,C).
■ Subsequent reaming can then continue in increments of 2 mm.
■ The planned inclination and version values for the implant are shown during reaming, and the values are updated dynamically (TECH FIG 11D).
■ Once the reamer has been navigated to the planned position and reaming has been completed, a trial cup generally is used to confirm that the selected cup size is correct (TECH FIG 11E).
■ The cup is calibrated with the trial cup or cup inserted (TECH FIG 11F,G).
■ The cup inserter is navigated to the planned position, and the cup is inserted according to the manufacturer's
recommendations until correct cup placement has been achieved (TECH FIG 11H).

- The cup should be positioned using the anatomy as a reference and aligned with the bone.
- To verify cup position, the pointer is used to acquire four or five points along the margin of the cup (TECH FIG 11I).
- The navigation screen shows various values for the position of the cup implant (TECH FIG 11J).
- Once cup verification has been finished, the pelvic reference array, bone fixator, and two pins are removed, and femoral preparation proceeds.

### Acquiring Femoral Landmarks

- For femoral pin insertion, two pins are inserted to the lesser trochanteric area (TECH FIG 12A).
- The location of the pins varies. They can be inserted into the proximal diaphyseal area, but the lesser trochanteric area is more comfortable and requires a smaller incision.
- Once two pins have been inserted, the bone fixator and femoral reference array are attached (TECH FIG 12B).
- Before starting registration, as many osteophytes are removed as possible, because the presence of osteophytes will affect the femoral notching calculation.
- The first step in femur registration is marking of the medial and lateral epicondyles using a sterile pointer (TECH FIG 12C,D). The pointer then is held to the piriformis fossa and head-neck junction (TECH FIG 12E,F).
- To acquire femoral head points, the pointer is slid across the surface of the bone following the navigator’s direction (TECH FIG 12G,H).

**TECH FIG 12 • A.** The fixation pin is inserted to the lesser trochanter using an automated drill at low speed. The second pin is inserted in the same manner using a drill template. The fixation pins should be placed bicortically for stability. **B.** Once the second fixation pin has been inserted correctly, the bone fixator is attached and the femoral reference array connected to it. Sufficient space should be available to facilitate drilling, reaming, and implant positioning without moving the reference array. **C,D.** Medial and lateral condyle points are acquired using single landmark acquisition. Each point is acquired by holding the tip of the pointer to the surface of the skin at the required location. **E,F.** Acquiring a point on the piriformis fossa. This point is essential for navigation to define the proximal endpoint of the shaft axis. If this point is not defined correctly, the calculated neck axis and implant position may not be accurate. (continued)
Once the femoral head points have been acquired, points are acquired on the anterior, superior, posterior, and inferior neck in sequence (TECH FIG 12, J).

Finally, it is necessary to ensure that there are sufficient points in the most critical area of the bone, where notching is more likely to occur (TECH FIG 12, K, L).

Once registration has been accomplished, a three-dimensional bone model is made on the navigation monitor based on the points acquired (TECH FIG 12, M).

Once the bone model has been made, registration of the femur is verified (TECH FIG 12, N, O).

The current neck–shaft angle (ie, varus or valgus, anteversion or retroversion) and calculated inner diameter of

TECH FIG 12 • (continued) G, H. Acquiring points on the femoral head. To acquire points, the pointer is simply slid across the surface of the bone. This step is important for precise morphologic estimation and for determining the center of rotation and the required implant size. I, J. Acquiring points on the anterior, superior, posterior, and inferior neck. These points are used for estimating the neck axis and required implant size and for generating the femoral bony model. K, L. Acquiring points in the superior notching zone. This step is used to ensure that sufficient points have been acquired in the most critical area of the femur, where notching is most likely to occur. M, N, O. Once the bone model has been calculated, the femoral registration is verified. P. After verification of the femoral model, the current neck–shaft angle is shown automatically, and the surgeon can adjust the angle if necessary. Q. The size of the femoral component is calculated automatically, and the position of the component is planned per the surgeon’s request.
The drill guide pin is moved along the varus-valgus axis and along the antegrade–retrograde axis. The drill guide pin then is relocated to the entry point selected following the navigation system so that it will not result in femoral notching (TECH FIG 13A,B). Once the final adjustment has been made, drilling begins via the centering guide pin, and femoral notching is rechecked using a stylus (TECH FIG 13C,D). Once the hole is successfully drilled and the implant positioned, femoral verification is undertaken (TECH FIG 13E,F). The remaining procedures for femoral component are done in the same manner as those for conventional resurfacing procedures described earlier.
### PEARLS AND PITFALLS

| Acetabular position | - Retract the femoral head sufficiently anterior to the acetabulum to provide a better view and to prevent unequal acetabular reaming or malposition of the component when the impactor handle meets the protruded anterior Hohmann retractor and femur.  
  
- Because the acetabular component has no screw holes, and the inner surface consists entirely of polished area, the surgeon cannot see the inner acetabular surface during insertion of the acetabular component.  
  
- Furthermore, when acetabular osteoporosis is present, the surgeon should be careful to obtain a secure fit of the acetabular component, because additional screw fixation is impossible.  
  
- To prevent under-seating of the acetabular cup, put the trial cup into the fully reamed acetabulum first and check the relation between the peripheral rim of the trial and the acetabulum. Then, when the cup is fully seated in the acetabulum, insert a real cup seated at the same depth as the trial.  
  
- I prefer to use a 1-mm under-reamer rather than the 2-mm under-reamer to easily achieve a fully seated acetabular cup. |
| Prevent femoral notching | - Thorough preoperative templating to determine the ideal inlet point for the femoral guide pin is mandatory.  
  
- Avoid extreme valgus position of the femoral component.  
  
- Do not ream the entire femoral head all the way to the distal rim of the femoral head.  
  
- Use a rongeur to carefully remove any remaining distal rim of the femoral head to prevent further damage to the cervical blood supply and possible notching by a motorized reamer.  
  
- Check notching with the stylus several times during femoral preparation, especially in the anterior and superior portion of the femoral head, which is the most vulnerable for notching.  
  
- The patient must use crutches and then a cane to support weight bearing for 2 months to resist mechanical stress and permit femoral neck remodeling. |
| Femoral component seating | - Use a custom-made femoral trial before insertion of the real component and check the relation (gap) between the lower peripheral margin of the trial and the distal rim of the femoral head when the trial is fully seated. Then insert a real femoral component of the same depth as the trial.  
  
- Insert the femoral component before the “dough” stage of cement is finished; cement that is too hard may prevent the femoral component from being seated. |
| Femoral side first? | - **Pros:** Retracting the femoral head for acetabular preparation is relatively easy, because the femoral head is smaller after femoral preparation.  
  
- If the femoral head is not fit for resurfacing after preparation, the surgeon’s preferred conventional THA can be used.  
  
- **Cons:** A mismatch between the acetabular and femoral components can develop after femoral preparation.  
  
- An already prepared, mainly cancellous, femoral head may be damaged during retraction. |
| Acetabular side first? | - **Pros:** Avoid mismatch between acetabular and femoral components. Acetabular cup size dictates the femoral component size.  
  
- **Cons:** It is not easy to obtain sufficient anterior retraction of the whole femoral head during acetabular preparation.  
  
- If, after preparation, the femoral head is not suitable for resurfacing, a modular, large-head, metal-on-metal THA should be performed, regardless of the surgeon’s preference. |

### POSTOPERATIVE CARE

- The patient receives a second-generation cephalosporin before anesthesia induction and for 48 hours postsurgery.  
  
- An antithromboembolic stocking is applied immediately after the operation to prevent deep vein thrombosis and permit mobilization on the first day after the operation.  
  
- Coumadin can be administered for several weeks for medical prevention of deep vein thrombosis.  
  
- Various protocols for rehabilitation may be followed.  
  
- We continue partial weight bearing with crutches for 4 to 6 weeks to allow initial bony ingrowth on the acetabular side and to allow the patient to regain normal gait and balance.  
  
- To allow femoral remodeling around the neck area, we usually recommend that the patient use a cane until the end of the second month after the operation, after which full weight bearing is permitted. Light sports activity may begin no sooner than 3 months after the operation, after which the patient may even squat on the floor.  
  
- Patients are allowed to ride in a car as a passenger, drive a car, sleep on their side, or engage in any activities if able and so desired.  
  
- Regular sports activities are allowed after 6 months.  

### OUTCOMES

- Daniel and McMinn reported on the results of metal-on-metal resurfacing in patients younger than 55 years with hip osteoarthritis.  
  
- 446 resurfacings were performed in 384 patients, with a maximum follow-up of 8.2 years (mean 3.3 years).  
  
- Of the remaining 440 hips, there was only one failure (0.02%), giving a survival of 99.8%.  
  
- 31% of the men with unilateral resurfacings and 28% with bilateral resurfacings could do heavy or moderately heavy jobs; 92% of men with unilateral resurfacings and 87% of the whole group could participate in leisure-time sports activity.  
  
- DeSmet reported on a Belgian experience of hip resurfacing.
Of 1114 resurfacings performed between 1998 and 2004, the author presented a consecutive series of 252 patients with a follow-up of 2 to 5 years (mean 2.8 years).

Three failures required revision or reoperation: one femoral neck fracture (at 3 weeks); one progressive avascular necrosis of the femoral head that failed at 2 years; and one low-grade infection leading to failure at 2 years.

Two traumatic dislocations were incurred by an inebriated patient; these were reduced without anesthesia.

Sixty-one percent of patients could perform regular strenuous activities.

Nineteen percent of the patients experienced a clicking, locking, or clunking noise or feeling in the first 6 months after surgery, but it was painless and disappeared gradually.

Lilikakis and Villar reported the results of uncemented resurfacings with a hydroxyapatite-coated femoral implant with a minimum of 2 years of follow-up.

Seventy resurfacings were done in 66 patients.

At a mean of 28.5 months of follow-up, the overall survival rate of the prosthesis was 97.1%; the survival rate of the femoral component alone was 98.6%.

Itayem et al.11 used radiostereophotogrammetric analysis to study the stability of 20 resurfacing arthroplasties over a follow-up period of 20 months.

This analysis found no evidence of excessive early migration or loosening of the components.

Yoo et al.16 prospectively investigated the effect of resurfacing arthroplasty on the bone mineral density (BMD) of the femur by comparing 50 patients with hip resurfacing to 50 patients with uncemented THA.

The resurfacing patients demonstrated BMD loss of 2.6% in Gruen zone 1 and 0.6% in zone 7, whereas the THA patients had BMD loss of 7.8% in Gruen zone 1 and 7.7% in zone 7 at 1 year after surgery.

On the acetabular side, the resurfacing patients demonstrated BMD loss of 8% in Delee and Charnley zone 1 and 17.5% in zone 2, whereas the THA patients had BMD loss of 9.8% in zone 1 and 22.3% in zone 2. These results suggest that the hip resurfacing system transfers load to the proximal femur in a more physiologic manner than conventional long-stem devices, that it may prevent stress shielding, and that it preserves the bone stock of the proximal femur.

Shimmin and Back14 carried out a national review of fractures associated with Birmingham Hip Resurfacing systems implanted between 1999 and 2003 in Australia.

3497 Birmingham hips were inserted by 89 surgeons.

Fracture of the neck of the femur occurred in 50 patients, an incidence of 1.46%.

The relative risk of fracture was higher for women than for men.

The mean time to fracture was 15.4 weeks, and it often was preceded by a prodromal phase of pain and limping.

Significant varus placement of the femoral component, intraoperative notching of the femoral component, and technical problems were the common factors in 85% of cases.

Amstutz et al.1 presented their experience with femoral neck fractures that occurred after metal-on-metal hybrid surface arthroplasty.

In a series of 600 resurfacings, five femoral neck fractures occurred (incidence 0.83%).

Four of the fractures occurred in the first 5 months after surgery.

All five fractures were associated with structural or technical risk factors, which may have weakened the femoral neck.

We suggest avoiding or minimizing notching of the femoral neck by performing the cylindrical reaming at the recommended angle of 140 degrees and by stopping reaming before the reamer touches the lateral cortex.

**COMPLICATIONS**

- Femoral neck fracture
- Neck notching (impingement)
- Neck narrowing
- Femoral loosening
- Femoral head collapse
- Acetabular loosening
- Stem tip condensation
- Metal hypersensitivity
- Metal ion release into the bloodstream
- Infection
- Femoral/sciatic nerve palsy
- Deep vein thrombosis
- Dislocation
- Heterotopic ossification
- Spur formation

**REFERENCES**

DEFINITION

- Femoral neck fractures are classified according to the Garden classification11 (Table 1).
- Further simplification of this classification divides these fractures into displaced versus nondisplaced fractures. Guidelines for treatment of nondisplaced femoral neck fractures are beyond the scope of this chapter.
- The indications for a hemiarthroplasty of the hip include displaced femoral neck fractures and salvage for massive acetabular osteolytic defects in revision hip replacement.
- Published reports suggest that bipolar hemiarthroplasty has poor outcomes when used as a primary prosthesis for failures with degenerative joint disease, and this technique currently is not recommended.
- The two types of hemiarthroplasty implants are the unipolar type (eg, Austin-Moore; FIG 1A), and the bipolar type (FIG 1B).
- The bipolar prosthesis has been favored because of its theoretical reduction of wear on the acetabular side, because motion between the inner and outer heads of the prosthesis leads to less motion at the acetabulum–implant interface.15

ANATOMY

- The neck–shaft angle is about 130°/7 degrees in adults and does not vary significantly between genders.
- The femoral neck is anteverted 10.4°/6.7 degrees with respect to the femoral shaft in Caucasians.
- Some ethnic groups (eg, Asians) have a propensity for higher degrees of anteverision, up to 30%.
- Femoral head diameters range from 40 to 60 mm.
- Femoral neck length and shape vary considerably.
- In cross section, the femoral neck is cam-shaped, with a shorter anteroposterior than mediolateral diameter.
- The calcar femorale is a condensed, vertically oriented area of bone that originates superiorly toward the greater trochanter and fuses with the cortex at the posterior aspect of the femoral neck.
- The major vascular supply of the femoral head comes from the lateral epiphyseal branch of the medial femoral circumflex artery.

PATHOGENESIS

- In elderly persons, a femoral neck fracture usually is the result of a fall.
- Several mechanisms have been proposed:
  - A direct blow to the lateral aspect of the greater trochanter
  - A sudden increase in load with the head fixed in the acetabulum along with a lateral, rotatory force. This causes impaction of the posterior neck on the acetabulum.
  - Completion of a fatigue fracture that precedes and causes a fall
  - The incidence of femoral neck fractures increases as bone density falls to osteoporotic levels.
- Femoral neck fractures in young patients typically are the result of high-energy mechanisms.
- The mechanical explanation is axial loading of the distal femur or the foot if the knee is extended.
- The amount of bony displacement and associated soft tissue injury can be much higher.
- Displacement of a femoral neck fracture can lead to disruption of the vascular supply of the femoral neck.
- This vascular compromise may contribute to the high incidence of avascular necrosis (AVN) with this injury.
- If femoral neck fracture occurs, the intraosseous cervical vessels are disrupted.
- The risk of AVN generally corresponds to the degree of displacement of the fracture of the femoral neck on initial radiographs.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Incomplete fracture with varus malalignment</td>
</tr>
<tr>
<td>II</td>
<td>Nondisplaced fracture through femoral neck</td>
</tr>
<tr>
<td>III</td>
<td>Incompletely displaced fracture through femoral neck</td>
</tr>
<tr>
<td>IV</td>
<td>Completely displaced fracture with no engagement of fragments</td>
</tr>
</tbody>
</table>

FIG 1 • A. Austin Moore prosthesis. B. Cemented bipolar prosthesis.
In displaced fractures, most of the retinacular vessels are disrupted. Femoral head blood supply is then dependent on remaining retinacular vessels and those functioning vessels in the ligamentum teres.

The role of early fixation and joint capsulotomy in prevention of AVN remains controversial.

The incidence of nonunion following a displaced fracture is as high as 60% with nonoperative treatment in some reports.

Femoral neck fractures can be divided into subcapital, transcervical, and basicervical types, based on the location of the injury.

Basicervical fractures often can be treated in a manner similar to intertrochanteric fractures with regard to fracture fixation (FIG 2).

**NATURAL HISTORY**

- Femoral neck fractures are most commonly seen in patients over the age of 50 years.17
- Patients with a single femoral neck fracture have an increased risk of sustaining a second hip fracture.
- Bateman3 and Gilberty12 reported the use of a bipolar prosthesis.
  - The rationale was that less erosion and protrusion of the acetabulum would occur because motion is present between the metal head and polyethylene socket, inner bearing.
  - Acetabular wear is diminished by reduction of the total amount of motion that occurs between the acetabular cartilage and metallic outer shell with interposition of the second low-friction inner bearing within the implant.
  - Overall hip motion also may be greater, because of the compound bearing surface.
  - Barnes et al1 showed that mortality in the first month postoperatively was substantial: as high as 13.3% in men and 7.4% in women.
  - More importantly, delaying surgery beyond 72 hours led to a substantial increase in mortality rate.
  - Factors influencing mortality in cemented bipolar hemiarthroplasty include cardiac history, residence in a nursing home, chronic pulmonary disease, elevated serum creatinine, pneumonia, history of myocardial infarction, duration of surgery, and gender.10
  - Associated injuries may include subdural or epidural hematoma and ipsilateral upper extremity injury for low-energy fractures.

- High-energy fracture patterns have a higher incidence of associated injury, including closed head injury, pneumo- or hemothorax, spinal fracture, visceral injury, and ipsilateral lower extremity bony injury.7

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- A complaint of groin, proximal thigh, or, rarely, lateral hip pain following a fall in an elderly patient should raise suspicion for a low-energy femoral neck fracture.
- Finding a demented patient down on the floor and unable to ambulate also should raise suspicion for a femoral neck fracture.
- The patient’s preinjury ambulatory status must be ascertained when the history is taken. His or her preoperative activity level can help determine the most appropriate type of surgical management.
- Care must be taken to evaluate other possible sources of injury about the hip as well as associated ipsilateral injury.
- Pelvic fracture: Associated injury to the pelvic rami is common. Radiographs are useful in diagnosing these associated injuries.
- Acetabular fracture: In a low-energy injury, acetabular fracture is an uncommon association with a femoral neck fracture. This, however, is not the case in high-energy injury patterns. Thin-slice CT may be useful for diagnosing this injury.
- Inter- and subtrochanteric fracture: Injury to the intertrochanteric area is commonly seen about the hip in elderly patients. Subtrochanteric fractures are less common. Usually, the limb is held in extension, not in a flexed, externally rotated position. Radiographs again are useful for establishing the diagnosis.
- A thorough physical examination should include:
  - Observation of the lower extremity. If it is shortened, externally rotated, and painful to move, a joint effusion secondary to fracture hematoma is most likely responsible, which increases the available space in the joint capsule.
  - Logroll maneuver, which is the most sensitive physical finding. A positive result elicits pain at the groin due to the side-to-side movement of the lower extremity, which creates shear forces across a femoral neck fracture, leading to exquisite pain.
  - Axial load test, which is positive if the maneuver elicits pain at the groin. This test is less specific than the logroll test.
  - Range-of-motion tests. Pain at endpoints of the range of motion may be the only clue to a nondisplaced occult fracture.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs of the AP pelvis and injured hip should be obtained.
- If possible, the legs should be immobilized in internal rotation for the film.
- A shoot-through lateral radiograph is useful for determining the degree of displacement of the fracture fragment, especially for fractures that appear minimally displaced on an AP view.
- A radiograph taken while applying axial traction is helpful to determine location of the fracture along the femoral neck if
displacement of the fracture fragments obscures view of the fracture pattern.
- CT scanning is useful for identifying nondisplaced fractures when clinically suspected as well as associated injuries. It usually is not employed for an isolated, low-energy femoral neck fracture, however.
- Radionuclide uptake bone scans are helpful in identifying occult femoral neck fractures, but may take up to 72 hours to be apparent on film.
- MRI is more sensitive to identifying occult femoral neck fractures than CT scan or bone scan within the first 72 hours.
- It also is highly sensitive to identifying occult fractures at the ipsilateral intertrochanteric area.

**DIFFERENTIAL DIAGNOSIS**
- Intertrochanteric fracture
- Subtrochanteric fracture
- Pelvic fracture
- Acetabular fracture
- Hip contusion or traumatic trochanteric bursitis

**NONOPERATIVE MANAGEMENT**
- Femoral neck fractures rarely are managed nonoperatively. Both nondisplaced and displaced fracture patterns have better functional and overall outcomes when treated surgically.
  - Nonoperative management may be relatively indicated in the patient with severe medical comorbidities who would be unable to tolerate anesthesia for surgery intervention.
  - Because nondisplaced fractures can be internally fixed with percutaneous techniques under local anesthetic and monitored sedation, nonoperative treatment usually is not indicated for this fracture type.
  - In most cases nonoperative treatment should be limited to initial management of the injury before surgical stabilization.
  - A soft pillow should be placed under the patient’s knee and leg to keep him or her in a comfortable position.
  - All patients with femoral neck fractures should be placed on strict bed rest, with a Foley catheter, and intravenous fluids on admission.
  - Axial traction of the injured lower extremity is contraindicated for femoral neck fractures, because it can increase displacement of the fracture fragments.

**SURGICAL MANAGEMENT**
- The best method of surgical fixation of femoral neck fractures is controversial. The debate between internal fixation versus hemiarthroplasty versus total hip arthroplasty continues and is beyond the scope of this chapter.
- General indications for surgical management using hemiarthroplasty include the older patient with low functional demands, or poor bone quality not amenable to internal fixation.
- Hemiarthroplasty is indicated for patients with displaced femoral neck fractures who meet the following criteria.
  - Reasonable general health
  - Pathologic hip fractures
  - Neurologic diseases including Parkinson disease, previous stroke or hemiplegia, or other neurologic diseases
  - Physiologic age greater than 70 years
  - Severe osteoporosis with loss of primary trabeculae in the femoral head
  - Inadequate closed reduction
  - Displaced fracture
  - Preexisting hip disease on the femoral side, namely osteonecrosis, without any acetabular disease.
  - Contraindications include the following:
    - Preexisting sepsis
    - Young age
    - Failure of internal fixation devices, mainly because of acetabular damage that often occurs in that situation
    - Preexisting acetabular disease. Even patients with normal preoperative cartilaginous space may become symptomatic after about 5 years due to degradation caused by friction between the metal and the acetabular cartilage.
    - Indications for cementing a femoral stem vary from surgeon to surgeon and institution to institution.
    - Primary candidates for this approach are patients with poor bone quality, such as those with a “stovepipe” femur or Dorr type C femur. These patients can be difficult to manage with uncemented implants, because they require either massive, canal-filling, uncemented implants that often produce significant stress shielding of the femur or have proximally filled implants that can make accurate adjustment of limb lengths very difficult.
    - Antibiotic-impregnated cement may be advisable for certain high-risk groups of patients. Some patients, such as those on dialysis, may be more prone to sepsis, so use of antibiotic-impregnated cement should be considered for them.
    - Appropriate antibiotics include tobramycin, vancomycin, cefazolin, and erythromycin.
    - Cemented stems also should be considered for patients with pathologic fractures. For these patients, the use of cement with a bone-replacing prosthesis may be the preferred treatment, regardless of age or bone quality.
    - The first-generation cementing technique involved finger-packing without the use of pressurization and a reduction of porosity. Modern cementing techniques use a medullary brush, a cement restrictor, medullary pulsatile lavage, the insertion of epinephrine-soaked sponges, a reduction of cement porosity (ie, vacuum mixing), cement centralizers, and a cement gun for retrograde cement insertion, after which pressurization can be performed with a surgeon’s gloved finger or, alternatively, with a wedge-shaped pressurization device.
    - Because of the embolic load secondary to pressurization, many surgeons avoid cemented components in patients with a history of cardiopulmonary disease.

**Preoperative Planning**
- It is important for preoperative planning that the preoperative x-rays are reviewed and templated for appropriate size and for fixation.
- Pending those findings, appropriate implant selection should be undertaken as well, whether to proceed with a tapered stem, a fully coated medullary-locking stem, or include a cemented stem.
- The patient should undergo an appropriate preoperative workup including medical, cardiac, and anesthesia evaluations.
  - Banked blood should also be available.
  - Important preoperative laboratory studies include complete blood counts, electrolytes, and coagulation studies.
  - Additional blood tests could include total protein, albumin, and appropriate liver studies to evaluate overall the patient’s nutritional status.
Positioning
- Patient positioning is important and should be done very carefully.
- General positioning principles include padding all bony prominences, positioning in a stable position for implant placement, and providing a range-of-motion arc so that implant position and stability can be tested intraoperatively.

Supine Position
- Once the patient is adequately anesthetized, he or she is placed in a supine position, which allows for direct measurement of leg length.
- The operating table is placed in a flat position. A bump is placed beneath the sacrum.
- The patient is brought to the edge of the table, so that the operative hip slightly overhangs the edge of the table.
- A sacral pad is constructed of folded sheets and placed directly beneath the sacrum.
- The modest elevation of the sacrum allows the fat and soft tissues from above the trochanter to fall posteriorly away from the incision, thereby minimizing the amount of tissue that must be dissected in a lateral approach.
- It also allows hip stability to be evaluated in extension.
- A footrest is fixed to the operating table, so that the surgical hip is flexed 40 degrees.
- Both arms are placed on armboards secured at 90 degrees of abduction.
- The operating room table is then inclined 5 degrees away from the operating surgeon to improve visualization of the acetabulum.

Lateral Position
- The lateral position is used for a posterolateral approach to the hip and also can be used for an anterolateral approach.
- Once the patient is adequately anesthetized and a Foley catheter is inserted, he or she is placed in the desired position in a gentle, organized fashion.
- The anesthesiologist controls the patient’s head and neck, holding the endotracheal tube securely.
- One surgical team member controls the patient’s hands and shoulders, and another controls the patient’s hips.
- The ipsilateral arm is positioned in no more than 90 degrees of forward flexion and slight adduction.
- An axillary pad is placed by lifting the patient’s chest and positioning the pad distal to the contralateral axilla.
- The contralateral arm must be kept in no greater than 90 degrees of forward flexion.
- Extrremities are padded over all bony protuberances.
- The operating room table must be kept in an absolute horizontal position, parallel to the floor.
- A number of holders can be used to hold the patient in a lateral decubitus position.
- A beanbag can be used, although it is not as rigid as a variety of other holders. The pubis and sacrum must be secured in the holder.
- Placement of the pubic clamp must be done cautiously, with the pad directly against the pubic symphysis.
- Placement of the pad more inferiorly causes occlusion or compromise of the femoral vessels in the opposite limb, which may go unrecognized.
- Placement of the pad superiorly may compromise ipsilateral femoral vessels, and may prevent adequate flexion and adduction of the operated hip.
- A sacral pad is placed over the mid-sacrum. It should be at least 3 to 5 inches away from the most posterior end of the skin incision (FIG 3A).
- When the patient is securely positioned in lateral decubitus, the position of the pelvis is checked, to make sure that it is not tilted in the anteroposterior direction (FIG 3B).
A chest positioner and pillows between the arms are helpful in preventing anterior displacement of the torso. The perineum is isolated using an adhesive U-shaped plastic drape.

**Approach**

Hemiarthroplasty can be performed through a number of different approaches.

- There are four commonly employed approaches to the hip joint:
  - Anterior (Smith-Petersen)
  - This approach uses the interval between the sartorius and the tensor fascia lata.
  - Risks include injury to the lateral femoral cutaneous nerve.
  - Femoral preparation is difficult and may require traction, hip extension, and the use of a hook to deliver the femur anteriorly for preparation.
  - Anterolateral (Watson-Jones)
  - Lateral (modified Hardinge)
  - Posterior (Southern)
  - Choice of approach is highly dependent on surgeon preference.
  - We use a modification of the lateral muscle-splitting approach to the hip, as originally described by Hardinge, and the use of a cementless tapered stem.4
  - A cemented stem can be implanted through a number of surgical exposures.

**LATERAL APPROACH (MODIFIED HARDINGE)**

**Preparation of the Surgical Site**

- Plastic adhesive drapes are used to isolate the operative field from the perineum and adjacent skin.
  - A large U-drape is placed isolating the perineum and abdomen from the hip.
  - A second drape is placed transversely above the level of the iliac crest, completing the isolation of the wound area from the abdomen and thorax.
  - The foot also is sealed, with a plastic 10 x 10 drape isolating the foot above the level of the ankle.
  - The operative field is scrubbed with a Betadine soap, followed by a preparation with Betadine solution and alcohol (TECH FIG 1A).
  - The incision area is dried to allow better adherence of Ioban drapes (3M, St. Paul, MN).
  - The limb is removed from the leg holder, and the surgeon grasps the foot with a double-thickness stockinette.
  - Impermeable drape is placed across of the bottom of the operating table up to the level of the patient’s buttck.

- The stockinette is unrolled to the level of the mid-thigh and secured with a Coban dressing (3M).
- The limb is draped steriley using two full-sized sheets brought beneath the leg and buttock and held above the level of the iliac crest.
- A double sheet is placed transversely across the abdomen above the level of the iliac crest.
- A clean air room is then sealed at the head of the operating table with sterile adhesive drape.
- The hip area is marked using a sterile pen.
- The greater trochanter is outlined.
- The iliac crest and femoral shaft are palpated, and the skin incision, centered over the trochanter and slightly anterior, is drawn with large cross-hatchings (TECH FIG 1B).
- The hip is flexed to 40 degrees and slightly adducted. The foot is placed on the footrest.

**Incision**

- The skin incision is approximately 5 inches in length.
  - The incision is slightly anterior to the apex of the vastus ridge.
  - The length of the incision also depends on the patient’s degree of obesity.
  - The skin incision is taken sharply through subcutaneous tissues down to the tensor fascia lata (TECH FIG 2A).
  - The fascia is exposed to a small degree, just to allow the incision and subsequent closure.
  - Hemostasis is achieved in the subcutaneous tissue with electrocautery and bayonet forceps.
  - The incision through the fascia lata is in line with the skin incision.
  - A scalpel is used to penetrate the fascia lata and allow a safe entrance to the compartments.
  - The incision is continued with the use of heavy Mayo-Noble scissors. It is not undermined beyond the skin incision or distal or proximal to the skin incision (TECH FIG 2B).

**Proximal Dissection**

- More proximally, the fibers of the gluteus maximus muscle are split using firm thumb dissection.
A Hibbs retractor is used to retract the anterior flap of the fascia lata.
Once that is done, the gluteus medius, greater trochanter, and vastus lateralis are clearly visualized.
The abductor mass is split.
The basic premise of the modified Hardinge approach is to develop an anterior flap, composed of the anterior portion of the vastus lateralis, anterior capsule, anterior third of the gluteus medius muscle, and most of the gluteus minimus muscle to allow exposure of the hip joint.

- The muscle split usually is located in the anterior third of the gluteus medius.
- The muscle split is made using electrocautery through the gluteus medius (TECH FIG 3A,B).
- Once the gluteus medius is penetrated, the surgeon encounters a fatty layer, beneath which is found the gluteus minimus.
- The gluteus minimus is isolated, and a more posterior incision is made with the electrocautery through the gluteus minimus and the capsule onto the acetabulum. (TECH FIG 3C).
- A blunt Hohmann retractor is placed posteriorly to expose the gluteus minimus and capsule. The blunt end of the Hibbs retractor is used to retract the anterior aspect of the gluteus medius.
- The capsule then is visualized in the depths of the wound.
  - The capsule is incised parallel to the superior aspect of the femoral neck, and the incision is extended to the bony rim of the acetabulum with care not to damage the labrum.
  - This area is then packed with an E-tape sponge (TECH FIG 3D).

**Distal Dissection**

- Attention is next turned to the more distal aspect of the wound and the vastus lateralis.
- The anterior third of the vastus lateralis is incised longitudinally using electrocautery, beginning at the trochanteric ridge and extending 2 to 3 cm beyond.
- Once this is dissected subperiosteally in the anterior direction, a blunt Hohmann retractor is placed around the femur medially to reflect the vastus lateralis anteriorly.
- An anterior bridge of soft tissue remains along the greater trochanter between the incision in the vastus lateralis and the incision in the gluteus medius and superior capsule. This bridge consists of the anterior fibers of the gluteus medius, minimus, and capsule.
Attention is turned to the acetabulum.

- The first retractor is placed in the anterior acetabulum.
- A small plane is created between the anterior wall of the acetabulum and the anterior capsule using a Cobb elevator.
- A blunt-tip Hohmann retractor is placed in the 12 o'clock position anterior to the acetabulum beneath the capsule.
- An assistant can then easily retract the anterior soft tissues.
- The second spiked Mueller acetabular retractor is placed in the superior aspect of the acetabulum, retracting the superior capsule in the cranial direction.
- The retractor is placed at 10 o'clock for the right hip and 2 o'clock for the left hip.
- The exact placement of the retractor is outside the labrum and inside the capsule.

- This bridge is incised through the tendon in a gentle arc along the anterior aspect of the greater trochanter, connecting the incisions.
- Healthy soft tissue must be present on both sides of this arc to allow effective repair during closure.
- The bridge is dissected using electrocautery, in the anterior aspect of the greater trochanter, to develop a flap in continuity consisting of the anterior portion of the gluteus minimus and going around the gluteus medius, anterior hip capsule, and gluteus minimus. This exposes the femoral neck and head.
- The dissection is carried medially until the medial aspect of the neck is exposed (TECH FIG 4).
- Exposure usually is adequate to allow for dislocation of the hip, femoral neck, or proximal femur.
- A bone hook is placed around the neck of the femur anteriorly, and the leg is externally rotated to allow for dislocation of the hip, i.e., the hip is placed in the figure-4 position.
- At this point, with a femoral neck fracture, the proximal femur often will dissociate from the femoral neck.
- An initial rough cut of the femoral neck can be performed in line with appropriate preoperative templating.
- Two blunt-tip retractors are placed around the femoral neck to protect the soft tissues.
- Electrocautery is used to mark the femoral neck, and an initial cut of the femoral neck is made with an oscillating saw.

**Placement of Acetabular Retractors**

- Using the impactor mallet, the surgeon drives this retractor into the ilium in a slightly cranial direction.
- The tip is not driven perpendicular to the axis of the body, because it may perforate the dome of the acetabulum.
- To facilitate appropriate exposure prior to placement of the third retractor and to allow posterior mobilization of the proximal femur, a medial capsular release must be performed.
- A curved hemostat is placed between the iliopsoas and capsule, anterior and in line with the pubofemoral ligament.
- The capsule is incised medial to lateral, thereby increasing the mobilization of the femur in a posterior direction.
- A third, double-angled acetabular retractor is placed inferiorly.
- It is placed in the ischium inferiorly, with the blade of the retractor resting on the neck of the femur rather than on the cut surface.

**Femoral Head Removal and Implant Sizing**

- At this point, the femoral head and neck are clearly visualized in the acetabulum.
- The femoral head and neck fracture can be removed using a corkscrew in combination with a Cobb elevator or a tenaculum.
- This should be done carefully so as not to damage the acetabular cartilage or the labrum (TECH FIG 5A,B).
- Once the femoral head is removed, it should be measured to enable the surgeon to estimate the size of the acetabulum.
- The acetabulum should be sized with a trial bipolar or unipolar component to ensure that there will be good fit without overfilling the acetabulum.
- This can be achieved with a good suction-tight feel with placement of the trial component.
- It should move freely without resistance.
- If it floats freely in the acetabulum, the trial component is undersized (TECH FIG 5C).

**Femoral Reaming**

- The femur is exposed with the use of two double-footed retractors, one beneath the greater trochanter and a second retractor medially in the area of the calcar.
- The leg is placed in a figure-4 position, crossed over the opposite thigh.
- The femur should be easily exposed.
- If there is difficulty in this exposure, the leg should be placed in a greater degree of figure-4 and rotation.
- Excess soft tissue is removed from the tip of the greater trochanter to allow for reaming and broaching. This will prevent varus positioning of the component.
- A large rongeur is used to open the femoral canal slightly.
- A small, straight curette is introduced into the femoral canal in neutral orientation.
- The second assistant should use his or her hand to create a target at the distal femur in line with the femur.
- As the surgeon is placing the small curette, he or she can use the opposite hand on the patient’s knee to
■ The femoral broach is introduced in neutral position, and neutral version of the rotation is judged in relation to the position of the knee.
■ Broaching is begun with the smallest broach and then increased until appropriate fit and fill is achieved. This can be gauged by preoperative templating and tactile feedback.
■ The broach is then introduced each time to its full depth.
■ If significant resistance is met, broaching should continue with a series of small inward and then outward taps.
■ Broaching is continued until full cortical seating has been accomplished. This is indicated by an upward change in pitch as the broach is being seated.
■ Final seating and sizing is determined by pitch, tactile feedback, and lack of progression (TECH FIG 7A).
■ Once the final seating of the femoral broach is accomplished, an initial reduction with the appropriate-sized hemiarthroplasty bipolar or unipolar trial component is performed (TECH FIG 7B).

**Femoral Broaching**

- The femoral broach is introduced in neutral position, and neutral version of the rotation is judged in relation to the position of the knee.
- Broaching is begun with the smallest broach and then increased until appropriate fit and fill is achieved. This can be gauged by preoperative templating and tactile feedback.
- The broach is then introduced each time to its full depth.
- If significant resistance is met, broaching should continue with a series of small inward and then outward taps.
- Broaching is continued until full cortical seating has been accomplished. This is indicated by an upward change in pitch as the broach is being seated.
- Final seating and sizing is determined by pitch, tactile feedback, and lack of progression (TECH FIG 7A).
- Once the final seating of the femoral broach is accomplished, an initial reduction with the appropriate-sized hemiarthroplasty bipolar or unipolar trial component is performed (TECH FIG 7B).
Part 3 ADULT RECONSTRUCTION • Section I HIP RECONSTRUCTION

Evaluation of Trial Prosthesis

- The hip is reduced for evaluation.
  - Hip stability is evaluated in full flexion and in internal and external rotation.
  - One finger is kept in the joint to evaluate for anterior impingement.
  - Anterior stability is evaluated with external rotation, adduction, and extension.
  - Leg lengths are measured directly.
  - The position of the pelvis, shoulders, and the knees must be evaluated as the assistants help with orientation (TECH FIG 8).
- Stability also is evaluated with a longitudinal shuck test, with a goal of 1 or 2 mm of shuck.
- Excessively tight soft tissues about the hip cause difficult or incomplete extension of the hip; excessive laxity leads to increased shuck.
- For inadequate soft tissue tension and appropriate leg-length restoration, a lateral offset also can be used.
- It is important to achieve stability, which takes precedence over leg length.

Placement of the Femoral Stem

- Once stability is satisfactory, the trial components are removed.
  - The wound and the femur are irrigated with pulsatile lavage.
  - Excessive debris is removed.
  - The femur is prepared again, with the curette only, to clear any soft tissue debris from the lateral aspect of the femur.
  - The femoral canal must be copiously irrigated.
  - The surgeon and assistant change outer gloves.
  - The appropriately sized femoral component is placed in the femoral canal with the use of an impactor.
  - Varus positioning must be avoided. It can be prevented with appropriate valgus positioning of the stem on insertion, with attention also paid to maintaining the appropriate version.
  - The femoral component is seated into position using firm taps with a mallet.
  - A pause between taps may allow some plastic deformation of the femur.
  - Final seating is determined in relation to the last broach, tactile feedback, pitch change, and lack of progression (TECH FIG 9).

Completion of Implant Placement

- Once the stem is placed, a second trial reduction can be performed with the trial next segment and trial bipolar shell, or a final component can be placed if the broach and stem achieve the same position.
  - If the trial bipolar shell is desired, trial reduction is performed again.
  - The reduction is performed with the patient held in position by the second assistant and the first assistant.
  - The surgeon reduces the hip with distraction, internal rotation, and adduction.
  - The surgical technician can assist the reduction with longitudinal traction.
  - The bipolar is assembled on the back table with the outer acetabular bipolar shell impacted on the appropriate size head.
  - This can be a 22-, 28-, or 32-mm head, depending on the implant system, with a polyethylene insert and bipolar shell that sits over that (TECH FIG 10A).
- Once that is assembled on the back table, the trunion is cleaned and dried, and the bipolar shell is then impacted on to the trunion of the neck of femoral prosthesis.
Once the hip abductor is adequately repaired, the tensor fascia lata is approximated with absorbable sutures in figure-8 fashion.

- This must be done to both the proximal and distal extents of the fascia lata.
- The potential dead space is then obliterated with heavy absorbable sutures, and then smaller, absorbable 2-0 sutures are placed in subcutaneous tissue (TECH FIG 11B).
- Skin staples are applied.
- Sterile dressing is applied with Microfoam surgical tape (3M, St. Paul, MN).
- An abduction pillow is placed between the legs and loosely secured.
- The patient is awakened from anesthesia and brought to the recovery room if, or as soon as, his or her condition is stable.
- Postoperative radiographs are taken in the recovery room (TECH FIG 11C).

The acetabulum is checked one last time before final reduction for any debris or any soft tissue (TECH FIG 10B).

Once it is checked and cleared, the hip is reduced, and the bipolar shell is reduced and checked for appropriate position, after which the wound is thoroughly irrigated and copiously irrigated with pulsatile lavage (TECH FIG 10C).

At this point, drains can be used according to the preference of the surgeon. We prefer not to use drains.

**Wound Repair and Closure**

- The abductor mass is then repaired.
- The vastus lateralis is repaired to the remaining tissue sleeve with interrupted absorbable sutures in figure-8 fashion with no. 1 Vicryl.
- The gluteus medius tendon and capsule are repaired to the tissue sleeve on the bridge of the trochanter.
  - This is done with heavy absorbable sutures in figure-8 fashion.
  - The repair is done at the corner of the gluteus medius tendon and then extended into the proximal split with simple sutures (TECH FIG 11A).

---

**TECH FIG 10** • A. Assembly of bipolar head. B. Placement of bipolar head onto femoral stem. C. Relocation of the prosthetic hip into the native acetabulum.

**TECH FIG 11** • A. Repair of the abductor mass. B. Repair of the tensor fascia lata. C. AP radiograph of an implanted bipolar prosthesis.
Incision and Dissection
- Exposure of the hip begins with appropriate identification of the bony landmarks.
  - The posterolateral corner of the greater trochanter and the anterior and posterior borders of the proximal femoral shaft are marked 10 cm below the greater trochanter (TECH FIG 12A,B).
  - The incision begins at this point and extends obliquely over the posterolateral corner of the greater trochanter, continuing proximally, so that the acetabulum is centered in the incision.
  - The incision usually is 15 to 20 cm, although this will vary, depending on the patient’s body habitus (TECH FIG 12C).
- Once the subcutaneous tissue is divided, the fascia lata is identified and incised in line with the incision.
- The fibers of the gluteus maximus belly are bluntly separated with firm finger pressure (TECH FIG 12D,E).
- A Charnley self-retaining retractor is placed to retract the gluteus maximus and tensor fascia. The gluteus maximus tendon may be released from the femur.
- The hip is internally rotated to offer exposure to the posterior structures.
- The piriformis tendon is identified by palpation, and a curved retractor is placed deep to the abductors just superior to the piriformis (TECH FIG 12F).
- A cobra retractor is then placed inferiorly, inferior to the femoral neck.
- The short external rotators and piriformis may be released separately from the capsule and tagged.
- The piriformis and conjoint tendons should be divided as close to their insertions as possible.
- Alternatively, the external rotators and capsule can be taken down as one continuous sleeve off the trochanter and femoral neck (TECH FIG 12G).

TECH FIG 12 • A. Palpation of bony landmarks for posterior approach. This is created by the midpoint of the anterior superior iliac spine and the ischial tuberosity. B. Incisional line. Note its placement with respect to the axis of the femur, the proximal extent of the greater trochanter, and the previous line created by bony palpation. C. Skin incision. D. Identification and incision of the tensor fascia lata. E. Exposure of the deep posterior structures of the hip after blunt separation of the gluteus maximus. F. Deep posterior structures of the hip. G. Reflection of the short external rotators. (A–E, Courtesy of Norman A. Johanson, MD.)
Following the reflection of the short external rotators, the capsule is isolated by repositioning the superior and inferior retractors.
- The curved superior retractor is placed deep to the gluteus minimus just over the superior femoral neck and capsule.

Site Preparation
- A capsulotomy is performed from this posterosuperior acetabulum and continued to the tip of the trochanter in line with the posterior border of the abductors.
- It is continued inferiorly along the femoral neck instead of making oblique posterior limit of the capsulotomy in favor of reflecting this capsule as continuous sleeve to the level of the lesser trochanter (TECH FIG 13).
- The quadratus femoris can be released along with the capsule leaving a small muscular cuff with later reattachment. The capsule can be tagged with a suture.
- The hip is gently dislocated using a combination of flexion, internal rotation, and adduction.
- The leg is held at 90 degrees of internal rotation so that the femoral neck is parallel to the ground.
- At this point, the proximal femur usually dissociates from the femoral neck and head, which often remain in the acetabulum.
- Two retractors can be placed around the proximal femur, and a fresh cut of the femoral neck can be performed with an oscillating saw.
- Alternatively, if this is a low femoral neck fracture, this area can be smoothed with a rongeur and attention turned to the acetabulum.
- At this point, the retractors are placed around the acetabulum. Initially a curved retractor is placed anteriorly, retracting the proximal femur out of the view of the acetabulum.
- The operated extremity is placed in slight flexion, which aids in exposure.
- Occasionally, the reflected head of the rectus femoris must be released.
- A Steinmann pin can be placed in the ilium to reflect the abductors, and a small capsulotomy can be made inferiorty to allow for placement of a cobra retractor deep to the transverse acetabular ligament.
- A bent Hohmann retractor can be placed posteriorly, taking care to first palpate the sciatic nerve to ensure that it is out of harm’s way.
- At this point, the acetabulum is exposed, and the femoral head can be removed again with a corkscrew and a Cobb elevator.
- This step should be done very carefully, to avoid damaging the acetabular cartilage.

Component Placement
- The femoral head is measured. A trial shell can be placed in the acetabulum for appropriate sizing, which is performed as described for the modified Hardinge approach.
- Once an appropriate size has been determined, the leg is flexed and internally rotated to expose the proximal femur.
- The leg is held at approximately 90 degrees of internal rotation and 70 degrees of flexion, bringing the osteotomized neck into the surgeon’s view.
- A trochanteric elevator is placed with the teeth under the anterior aspect of the femoral neck, lifting it out of the wound. This allows for unencumbered preperation of the femoral neck (TECH FIG 14A).
- The femur is then prepared in a fashion similar to that described for the modified Hardinge approach (TECH FIG 14B-F).
- In cases where cemented femurs are preferred, a trial of reduction for leg lengths can be performed, and then a final component can be cemented into place.
- The component must be cemented in the appropriate version, and the neck of the prosthesis must sit on the femoral neck, which can be additionally prepared with a calcar planer.

Completion of the Procedure
- Once the final components are placed and the hip is reduced, two drill holes can be made in the posterior aspect of the greater trochanter for repair of the capsular and short external rotators.
- Once the hip is reduced, two nonabsorbable sutures are placed in the capsular flap.
- The capsular and external rotator tagging sutures are then brought through the drill holes and the greater trochanter tied in layers.
- The quadratus femoris and gluteus maximus tendon also can be repaired if that is the surgeon’s preference (TECH FIG 15).
- Subsequently, the Charnley retractor is removed, and the tensor fascia lata and gluteus maximus fascia are reaproximated.
- Dead space is closed with absorbable sutures in the subcutaneous fat, and then absorbable sutures are placed in the subcutaneous tissue.
- Skin staples are applied at the skin level, and a sterile compressive dressing is applied.
- The hip must be held in abducted position. An abduction pillow is placed, and the patient is taken from the lateral position and placed in the supine position at the end of the operation.

TECH FIG 13 • Exposure of the hip capsule. (Courtesy of Norman A. Johanson, MD.)
The trochanteric fossa is cleared of soft tissue, and a pilot hole is made in it with a small metal curette. An entry reamer is inserted along this pilot hole to seek the long access of the femoral canal. The residual femoral neck is cleared with a rongeur or box osteotome. Sometimes a lateralizing reamer is used to ensure direct access to the femoral canal and minimize the possibility of varus implantation. Broaches often are oversized relative to the final implant size, thereby ensuring a minimum cement mantle all around the implant.

The final broach is determined when it adequately fills the proximal femur; it also serves as a trial component for reduction. Once the stability, limb length, and offset are satisfactory, cementation can be performed. The canal is gently curetted to remove any loose cancellous bone. The canal is irrigated with a long pulsating irrigating tip. High-quality cancellous bone remains in the femoral canal following this preparation. It is important to centralize the prosthesis to ensure an uninterrupted cement mantle around the implant. A plug is placed after the canal is irrigated.
The prosthesis is then inserted into the doughy mass of cement with the centralizer attached to the tip. The leg is placed in a secure position, and the prosthesis is inserted. The prosthesis must be inserted with the appropriate anteversion from insertion all the way down. It is preferred not to rotate the femoral component within the canal, because this will create undesirable cement voids. The prosthesis must be inserted with great care to avoid varus malposition. All the excess cement is then removed, and the stem is held in place until the cement has fully hardened. The femoral trunion should be cleaned at this point, and the hemiarthroplasty component should be inserted onto the stem. The hip is then reduced and the appropriate closure is performed.

We prefer to allow 1 to 2 cm of cement below the tip of the implant so that the plug may be placed at that level. It must be secure enough to withstand pressurization. Three 40 gram packs of cement are typically mixed with a vacuum system. The canal is then packed with sponges to keep it dry during the cementation. Alternatively, continuous suction may be used. The viscosity of the cement is an important consideration. The cement should be somewhat doughy and delivered through a cement gun. Appropriate cement viscosity has been reached when the cement no longer sticks to the surgical gloves. Once the cement reaches the appropriate viscosity, the packing sponges are removed and the canal is suctioned. Cement is delivered in a retrograde fashion into the canal. Once the canal is filled with cement, a pressurizing unit can be placed over the proximal femur, or pressurization can be achieved with a gloved finger.

The prosthesis is then inserted into the doughy mass of cement with the centralizer attached to the tip. The leg is placed in a secure position, and the prosthesis is inserted. The prosthesis must be inserted with the appropriate anteversion from insertion all the way down. It is preferred not to rotate the femoral component within the canal, because this will create undesirable cement voids. The prosthesis must be inserted with great care to avoid varus malposition. All the excess cement is then removed, and the stem is held in place until the cement has fully hardened. The femoral trunion should be cleaned at this point, and the hemiarthroplasty component should be inserted onto the stem. The hip is then reduced and the appropriate closure is performed.

We prefer to allow 1 to 2 cm of cement below the tip of the implant so that the plug may be placed at that level. It must be secure enough to withstand pressurization. Three 40 gram packs of cement are typically mixed with a vacuum system. The canal is then packed with sponges to keep it dry during the cementation. Alternatively, continuous suction may be used. The viscosity of the cement is an important consideration. The cement should be somewhat doughy and delivered through a cement gun. Appropriate cement viscosity has been reached when the cement no longer sticks to the surgical gloves. Once the cement reaches the appropriate viscosity, the packing sponges are removed and the canal is suctioned. Cement is delivered in a retrograde fashion into the canal. Once the canal is filled with cement, a pressurizing unit can be placed over the proximal femur, or pressurization can be achieved with a gloved finger.

ANTEROLATERAL (WATSON-JONES) TECHNIQUE

One major difficulty with the Watson-Jones technique is dealing with the gluteus medius and minimus. The hip abductors lie over anterior hip capsule and could be damaged in an effort to obtain adequate exposure. The original approach used by Charnley placed the patient in a supine position and required a trochanteric osteotomy. This approach is used less commonly now because of problems associated with trochanteric reattachment. The skin incision is made 2.5 cm behind the anterior superior iliac spine to the tip of the greater trochanter, then extended vertically along the anterior margin of the trochanter. The intraneural interval is between the tensor fascia lata and gluteus medius. An incision is made in the underlying iliotibial band, after which the tensor fascia lata is retracted medially and the gluteus medius is retracted laterally. Deep dissection may require release of the anterior parts of the gluteus medius and minimus, which are raised from the femur and retracted posteriorly.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Acetabular reaming</th>
<th>Not recommended for hemiarthroplasty, because it leads to poor results. Appropriate femoral head size should be chosen intraoperatively to avoid reaming.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varus malalignment</td>
<td>Care should be taken to broach the lateral cortex of the proximal femur adequately to prevent varus malalignment of the implant.</td>
</tr>
<tr>
<td>Implant orientation (anteversion)</td>
<td>Ideally, the patient's hip should be reoriented to its native position. Ideal anteversion of the hip in adults is 10 to 30 degrees, dependent on multiple patient-specific factors. If the patient has pathology that affects hip orientation (eg, DDH), a modular total hip arthroplasty implant could be considered.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- All patients are placed into a soft hip abduction pillow, and bilateral thromboembolic stockings are put on with sequential venous compression devices.
- Antiembolic prophylaxis is started according to the surgeon’s preference.
- Extended prophylaxis may be considered for these patients.

OUTCOMES

- Bipolar hemiarthroplasty was introduced in the 1970s in an effort to prevent or retard acetabular wear.
  - These femoral prostheses have a 22- to 32-mm head that articulates with a polyethylene liner.
  - The liner is covered with a polished metal outer shell that articulates with the acetabular cartilage.
  - Depending on implant design, about 45 degrees of angular motion is available before the prosthetic neck impingements on the liner and axial rotation is restricted.
  - Theoretically, hip motion occurs primarily at the prosthetic joint and only secondarily at the metal-cartilage interface.
  - The polyethylene liner may help to protect the native acetabular cartilage by cushioning the high-contact pressures that occur across the bearing.
  - LaBelle et al.14 reported no acetabular protrusio or articular cartilage wear greater than 2 mm in 49 femoral neck fractures treated with cemented bipolar hemiarthroplasties at 5- to 10-year follow-up.
  - Wetherell and Hinves19 reported a 50% reduction in acetabular erosion for patients treated with a cemented bipolar prosthesis when compared to those treated with a unipolar prosthesis.
  - Research attempting to demonstrate that motion occurs within a bipolar prosthesis has yielded conflicting results.
  - Drinker and Murray9 fluoroscopically evaluated 13 hips in 10 young patients following bipolar reconstruction for AVN and noted that only a minor amount of motion occurred at the inner bearing and that motion tended to decrease over time.
  - They further demonstrated that in this group most implants functioned as a unipolar prosthesis and concluded that motion will occur at the interface where there is the least frictional resistance. They found that this location is not the same in arthritic hips as in fractured hips.
  - These patients with acute hip fracture proved that with normal articular cartilage, primary intraoperative or intraprostatic motion occurred in only 25%, and most implants again functioned as unipolar.
  - Brueton et al.6 whose radiographic analysis of 75 bipolar prostheses, were equally divided between 32-mm and 22-mm heads, showed that the smaller head was associated with more motion.

COMPLICATIONS

- Thromboembolism (eg, deep vein thrombosis, pulmonary embolism)
  - Kenzora et al13 reported a mortality rate of 14% during the first year following hip fracture.
  - When compared to 9% mortality in population of similar age, the mortality after hemiarthroplasty is 10% to 40%.
  - The incidence of intraoperative femur fracture is 4.5%. Most are nondisplaced and involve either the trochanter or calcar.
  - When an intraoperative femur fracture occurs, treatment options include methylmethacrylate combined with long-stem prosthesis or, alternatively, with a fully coated cementless stem and cables.
  - The rate of dislocation is less than 10%. Dislocation is more common with incorrect version, posterior capsulotomy, and excessive postoperative flexion or rotation with the hip adducted.
  - Postoperative sepsis has been reported to range from 2% to 20% and may be more common with the posterior surgical approach. Infections may be superficial or deep.
  - Loosening or migration may be suspected with the presence of a radiolucent line around the prosthesis.
  - If clinical signs and symptoms are present, or loosening or migration is present, a revision arthroplasty may be considered.
  - Cementation does present some hazards, and in some cases the application of pressurized cement is associated with an embolization phenomenon with cement elements (ie, monomer, polymethylmethacrylate elements, or fat). Embolization of these materials may result in hypoxia, cardiac arrest, or death.
  - The risk factors include older age or patent foramen ovale.
  - The use of pulsatile lavage can reduce that risk by removing fat and marrow from the femoral canal.
  - In older patients with substantial medical comorbidity, it may be wise to avoid pressurization of the cement within the canal, because the risk of acute embolization may be high.

REFERENCES

Metastatic bone disease (MBD) afflicts more than half of the 1.2 million patients newly diagnosed with cancer annually.\(^3\)\(^,\)\(^5\) Bony involvement can be a major source of morbidity and mortality if not treated appropriately. The femur is the long bone most commonly affected, with 25% involving the proximal third of the femur.\(^3\)\(^,\)\(^13\)\(^,\)\(^14\) Seventy-five percent of all surgery for cancer that has metastasized to bone is performed in the hip area.\(^14\)

**ANATOMY**

Metastatic foci to any part of the areas around the hip substantially compromise the mechanical integrity of the bone, placing the patient at high risk for fracture and subsequent nonunion. The bony structure of the acetabulum consists of the anterior and posterior columns with their respective walls, which jut over laterally to cover the femoral head. The anterior column is defined as the bone that extends from the iliac crest to the pubic symphysis. The posterior column starts from the articulation of the superior gluteal notch with the sacrum and extends through the acetabulum and ischium to the inferior pubic ramus. The acetabular dome, the superior weight-bearing region, consists of both the anterior and posterior columns and is contributed to by both walls. The femoral head is not truly spherical; it is congruent only along the weight-bearing portion. The principal and secondary bony trabeculations of the head, neck, and intertrochanteric area enable the head and neck arcade to withstand tremendous compressive and tensile forces.

**PATHOGENESIS**

The mechanism by which metastases occur is accounted for in a modified “seed/soil” theorem. Fewer than one in 10,000 neoplastic cells that escape into the circulation from the primary site are able to set up a metastatic focus. Metastasis, a complex, multistep process in which the cell first must break free, is a function of degradative enzymes such as collagenases, hydrolases, cathepsin D, and proteases. Once the cell invades the vascular channel, it circulates through the body. It is theorized that the cell is protected by a fibrin platelet clot. Clinical trials with heparin have not shown a significant change in metastatic outcome, however. Local factors such as integrins are instrumental in attracting the circulating metastatic cell to a particular remote tissue site. Once within the new tissue, the metastatic cell releases mediators such as tumor angiogenesis factor, inducing neovascularization, which, in turn, facilitates growth of the metastatic focus.

Patients with advanced metastatic disease often experience dysfunction of hematopoietic and calcium homeostasis. They may develop a normochromic, normocytic anemia with leukocytosis. The increased number of immature cells, produced in response to the anemia and noted on the peripheral blood smear, is termed a leukoerythroblastic reaction. Hypercalcemia may be seen in up to 30% of patients with extensive metastases, most commonly in myeloma, breast cancer, and non–small cell lung cancer. Blastic metastases often are painless and are associated with a lower incidence of pathologic fracture because the bone is not as severely weakened. Not all tumors that metastasize from the prostate to bone are blastic in nature, however. The lytic variants are painful and can cause pathologic fractures.

Most tumors that metastasize from the breast to bone are blastic, but some demonstrate mixtures of blastic and lytic areas in the same bone. By taking serial radiographs and noting the appearance of bone metastases, it is possible to follow the progress of treatment with systemic hormone therapy or chemotherapy agents plus local radiation therapy. A favorable response may show a gradual conversion from a lytic to a blastic appearance as the pain decreases.

Bone destruction in lytic lesions occurs as a result of the biologic response by native osteoclasts to the tumor. Neovascularization is common. Among the tumors that are characteristic for this hemorrhagic response are thyroid carcinomas, renal cell carcinoma, and multiple myeloma. Before surgical intervention is undertaken for these tumor types, it may be beneficial to perform a prophylactic embolization of the area to reduce perioperative bleeding. If a lesion is unexpectedly found to be aneurysmal at the time of surgical exploration, the friable tumor mass should be debulked rapidly down to normal bone, and the area should be packed until it can be stabilized with bone cement.

**NATURAL HISTORY**

Metastatic involvement of the musculoskeletal system is one of the most significant clinical issues facing orthopedic oncologists. The number of patients with metastasis to the skeletal system from a carcinoma is 15 times greater than the number of patients with primary bone tumors of all types. About one third of all diagnosed adenocarcinomas include skeletal metastases, resulting in about 300,000 cases per year. Furthermore, 70% of patients with advanced, terminal carcinoma demonstrate bone metastases at autopsy.

The carcinomas that commonly metastasize to bone are those of the prostate, breast, kidney, thyroid, and lung. One study showed that nearly 90% of patients with these types of carcinoma had bone metastases. Among the carcinomas that less commonly metastasize to bone are cancers of the skin, oral cavity, esophagus, cervix, stomach, and colon.

Because patients with metastatic bone disease are surviving longer, surgeons must strive to perform an optimal reconstruc-
tion that can provide functional outcome for many years. Once a pathologic fracture has occurred, however, a patient’s life expectancy is considerably shorter. Stringent surveillance by medical oncologists for bony metastases must be encouraged, therefore, with early referral to the orthopedic surgeon before pathologic fractures occur.

PATIENT HISTORY AND PHYSICAL FINDINGS
- In any patient with a history of cancer, especially those cancers that are well documented to metastasize to bone, any bone pain should raise suspicion for a metastatic focus.
- Pain at rest or at night that is or is not exacerbated with activity should heighten this suspicion.
- The hip examination may or may not be abnormal.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- A methodical approach is mandatory in the workup of a patient with presumed metastatic disease to bone to locate the primary tumor.
- A thorough history and physical examination must be completed before laboratory and radiographic analyses are done. The primary carcinoma may be detected on physical examination in as many as 8% of patients.
- Laboratory analysis should include a complete blood count, erythrocyte sedimentation rate, renal and liver panels, alkaline phosphate, and serum protein electrophoresis.
- Radiographic examination should follow with a plain chest radiograph and radiographs of known involved bones.
- For metastases to the hip, an anteroposterior radiograph of the pelvis and full anteroposterior and lateral radiographs of the entire femur should be obtained.
- About 45% of all primary tumors will be detected in the lung on the chest radiograph.
- The workup also should include a staging bone scan.
- If this scan is negative, myeloma should be suspected.
- If the scan is positive, a lesion may be found at a more convenient biopsy site.
- Bone scanning is more sensitive than plain radiographs in detecting early lesions.
- CT scans of the chest, abdomen, and pelvis should be performed.
- CT of the lung can detect up to 15% of primary tumors missed on the plain radiograph.
- The use of PET scanning, either in isolation or in conjunction with CT, is becoming more common in the workup of patients with possible metastatic cancer.
- These studies, in combination with a well-planned biopsy, will reveal the primary cancer for most patients.
- Routine radiographic screening studies in search of early metastatic disease are not very helpful. Lytic changes become evident on routine radiographs only when cortical destruction approaches 30% to 50%.
- If a lesion is detected about the hip in the anatomic areas as described earlier, and a detailed pelvic and hip CT has not been performed within the past 6 to 8 weeks, one should be ordered.
- Intravenous contrast medium is not necessary.
- A recent CT scan is particularly important in the preoperative planning for an acetabular reconstruction.

DIFFERENTIAL DIAGNOSIS
- Prostate cancer
- Breast cancer
- Kidney carcinoma
- Thyroid carcinoma
- Lung carcinoma
- Myeloma
- Lymphoma of bone, while less common, can mimic these diagnoses.
- For a patient over the age of 40 years, with no known history of metastatic carcinoma to bone, the osteophilic malignancies mentioned earlier must be considered and evaluated as described.

NONOPERATIVE MANAGEMENT
- Nonsurgical management of metastatic carcinoma to bone includes observation, radiation treatment, and hormonal or cytotoxic chemotherapy.
- Radiation is reserved for palliative intervention. Each patient’s suitability for radiation therapy must be carefully determined. The histologic type of disease, extent of disease, prognosis, marrow reserve, and overall constitution must be assessed.
- Impending lesions about the proximal femur and acetabulum should dissuade the orthopedist from nonoperative management, particularly in renal cell and thyroid carcinoma, where bony destruction is likely to progress despite the best nonsurgical modalities.
- For a patient who has sustained a pathologic fracture secondary to metastatic carcinoma, the average survival time is 19 months.
- Each histologic type has varying lengths of survival: prostate—29 months; breast—23 months; renal—12 months; lung—4 months.
- Moreover, each type of carcinoma exhibits varying radiosensitivity: prostate and lymphoreticular carcinomas, excellent; breast carcinoma, intermediate; and renal and gastrointestinal carcinomas, poor.
- When radiation therapy is used appropriately, 90% of patients gain at least minimal relief, with up to two thirds obtaining complete relief. Seventy percent of patients who are ambulatory retain their ability to ambulate after radiation therapy to the lower extremities.
- Systemic radioisotopes also may be used. Strontium Sr 89 imitates calcium distribution in the body and has shown promise in clinical applications.
- When a patient has sustained a true pathologic fracture (rather than an impending lesion), surgical stabilization usually is indicated, with subsequent radiation therapy. Because of poor bone quality, bone cement often must be used to augment the fixation.
- Hormonal therapy has an important role in the management of metastatic breast and prostate cancer. Fortunately, these agents are easy to administer and have few side effects.
- For breast cancer, medical hormonal manipulation can be done by use of antiestrogens, progestins, luteinizing hormone–releasing hormone, or adrenal-suppressing agents.
- Tamoxifen is effective in 30% of all breast cancer cases; its effectiveness increases to 50% to 75% of cases in which the tumor is known to be estrogen receptor– and progesterone receptor–positive.
Surgical ablation (oophorectomy) also may have a role in certain cases.
In some cases of prostate cancer, reduction in testosterone levels via bilateral orchidectomy or administration of estrogens or antiandrogens may produce dramatic results.
Estrogens are no longer used as a first-line agent because of the risk of cardiovascular complication.
Cytotoxic chemotherapy is used extensively in treatment for adenocarcinoma. In older patients with advanced disease, however, the side effects of the drugs may be too severe.

**SURGICAL MANAGEMENT**

For cases involving the periacetabular area, femoral head, neck, and intertrochanteric area, cemented femoral arthroplasty components are an important surgical option for impending and realized fracture management.
The goals for surgical intervention in the patient with metastatic carcinoma to bone are relief of pain; prevention of impending pathologic fracture; stabilization of true fractures; enhancement of mobility, function, and quality of life; and, for some, improved survival.
It is generally agreed that a patient must have a life expectancy of at least 6 weeks to warrant operative intervention.
Cancer patients, regardless of their age, may have increased difficulty protecting their fixation device or prosthesis secondary to systemic debilitation. Accordingly, rigid fixation, with polymethylmethacrylate (PMMA) augmentation as needed, is mandatory.

**Preoperative Planning**

In many cases, the diagnosis of metastasis to the proximal femur will be made before a fracture occurs. In these cases, it is the responsibility of the orthopedic surgeon to decide whether the patient should receive some form of internal stabilization before radiation therapy is begun. A CT scan of the involved area will help make this decision.

Criteria for the performance of a prophylactic stabilization procedure include the following:
- 50% cortical lysis
- A femoral lesion greater than 2.5 cm in diameter
- An avulsion fracture of the lesser trochanter
- Persistent pain in the hip area 4 weeks following the completion of radiation therapy
- A Mirels score (Table 1) also may help in decision-making for hip and femoral lesions.

As elucidated in the Mirels score, the peritrochanteric area in general is at high risk for fracturing.
These criteria are not perfect, and large errors arise in estimation of the load-bearing capacity of the bone. For example, no system takes into account the histologic subtype, pre-existing osteoporosis, and functional demands. Objective quantification of pain in the Mirels score is controversial as well.

**Periacetabular Lesions and Impending and Realized Fractures**

Class I (minor): lateral cortices, superior, medial wall intact (FIG 1). Treat with conventional cemented acetabular component with or without rebar (anchorage with large fragment screws) as needed.

<table>
<thead>
<tr>
<th>Variable</th>
<th>1 point</th>
<th>2 points</th>
<th>3 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>Upper limb</td>
<td>Lower limb</td>
<td>Peritrochanteric</td>
</tr>
<tr>
<td>Pain</td>
<td>Mild</td>
<td>Moderate</td>
<td>Functional</td>
</tr>
<tr>
<td>Lesion</td>
<td>Blastic</td>
<td>Mixed</td>
<td>Lytic</td>
</tr>
<tr>
<td>Extent</td>
<td>Less than one third</td>
<td>One to two thirds</td>
<td>Greater than two thirds</td>
</tr>
</tbody>
</table>

A mean score of 7 or below indicates a low risk of fracture; radiation therapy should be considered. A score of 8 or above suggests a substantial risk, and surgical intervention is recommended.

**FIG 1** Periacetabular lesions, class I (minor). Depiction of lesion (A) and repair (B). C. Left supracetabular lesion as seen on CT scan. D. Postoperative radiograph demonstrating reconstruction. Steinmann pin augmentation of the anterior and posterior columns was performed.
Class II (major): deficient medial wall (FIG 2) requires an antiprotrusio device, medial mesh, or rebar.

Class III (massive): deficient lateral cortices and dome (FIG 3) mandate rebar augmentation of the posterior and sometimes the anterior columns; 6.5-mm cancellous screws or 5/16-inch Steinman pins are recommended.

Class IV: resection is mandatory for attempted cure. Such cases should be referred to an orthopedic oncologist and are beyond the scope of this chapter.

**Femoral Head and Neck**

- Impending fractures
  - Femoral head involvement is a reason to perform arthroplasty (FIG 4).
  - Modest femoral neck lesions may be stabilized with a reconstruction nail, with the exception of renal cell and thyroid carcinoma, in which cases arthroplasty is recommended.

- Realized fractures
  - Rarely heal

- Internal fixation device failure is common.

- Procedure of choice: replacement arthroplasty
  - The decision regarding bipolar versus total hip arthroplasty is a function of acetabular involvement, preexisting arthritis, and life expectancy.
  - Acetabular disease may go unrecognized on plain radiographs in up to 83% of cases. Pelvic CT is imperative.
Long-stem prostheses may be used for extensive femoral involvement, but attention must be paid to cement deployment during the early cure stage, use of a long laparoscopic sucker, or venting.

**Peritrochanteric Neck**
- Impending fractures
  - An intramedullary reconstruction-type device is strongly recommended. Screw and side plate constructs have a high failure rate (FIG 5A).
  - For renal cell and thyroid cancer, the surgeon should proceed with cemented calcar-replacing arthroplasty.
- Realized fractures
  - Cemented calcar-replacing arthroplasty is the only appropriate option (FIG 5B-E).

**Subtrochanteric**
- Impending fractures
  - With the exception of renal cell and thyroid carcinoma, a cephalomedullary nail reconstruction is appropriate when bone loss is not extensive (FIG 6A-E).
  - Otherwise, proximal femoral replacement is necessary.
- Realized fractures
  - Cemented proximal femoral replacement is the only option.

**FIG 5**
- A. Peritrochanteric metastatic lung cancer treated with screw and side-plate construct that failed within 4 months. For realized and large impending peritrochanteric lesions (B), the surgeon should have a low threshold for replacement arthroplasty (C). D. A realized intertrochanteric pathologic fracture from metastatic breast cancer was inappropriately treated with a reconstruction nail that went on to hardware failure within 3 months. E. The case shown in D was converted to a calcar-replacing hemiarthroplasty.

**FIG 6**
- Subtrochanteric femoral lesion (A) and cephalomedullary nail reconstruction (B). AP (C) and lateral (D) radiographs of an impending peri-subtrochanteric metastasis of breast carcinoma to bone treated with prophylactic stabilization (E). F. A patient with documented metastatic breast cancer to bone presented with a several-week history of progressive aching in the upper thigh. She was walking when she felt a snapping sensation and immense pain and was no longer able to ambulate. G. Treatment was with a proximal femoral replacement.
viable option to restore the patient to ambulatory status (FIG 6F, G).
- Long-stem cemented femoral arthroplasty use in patients with MBD remains controversial. Some surgeons remain trepid in the general use of cemented long-stem femoral arthroplasties in patients with MBD because of the risk of cardiopulmonary insult and collapse.
- Combining the use of bone cement with a long-stem femoral component further increases the possibility of complications, especially in a patient with MBD who has poor-quality bone and severe preexisting medical conditions. Deciding whether femoral stability from a cemented long-stem arthroplasty is worth the increased risk of a life-threatening cardiopulmonary embolic event is difficult. Certain steps listed in the following sections have been shown to minimize this risk, warranting long-stem use in cases of extensive femoral disease.12

Positioning
- Hip arthroplasty can be performed in either the supine or lateral decubitus position, but it is strongly recommended that the patient be placed in the decubitus position for anything other than a routine arthroplasty. This enables the surgeon to perform arthroplasty as well as extensive instrumentation of the posterior column when necessary.
- Reconstruction of impending proximal femoral lesions can be performed with the patient in the supine position, placed on a fracture table that allows insertion of a cephalomedullary device and interlocking screws.

Approach
- Standard, but sometimes expanded, anterior, anterolateral, and posterior approaches may be used to access the acetabulum.
- For posterior column instrumentation, an extensible posterior approach is recommended.

PERIACETABULAR RECONSTRUCTION

- Rigid fixation of the acetabular component is critical to success. The preoperative CT and plain radiographs must be evaluated carefully before surgery (TECH FIG 1A, B).
- Class I defects can be managed with a conventional cemented acetabular component, with or without augmentation of fixation with large fragment screws (TECH FIG 1C–E).
- Class II defects
  - An anti-protrusio cage or a similar device must be used.
  - Any flanges or screws must be attached to healthy bone.

- A posterior approach without a trochanteric osteotomy usually is adequate.
- Nonunion of a trochanteric osteotomy is a major concern in patients with cancer and should be avoided unless absolutely necessary.
- Visualization of the posterior column, however, is critical to confirm its mechanical integrity; therefore, an incision of adequate size must be used.
- Class III defects
  - An extensive posterolateral or lateral approach usually is chosen to deploy 6.5-mm cancellous screws or

TECH FIG 1 • A. AP pelvic radiograph demonstrates a periacetabular metastatic focus. B. CT scan reveals the extent of posterior wall involvement of this class I defect. C, D. Posterior wall/column screws are used to augment the reconstruction. E. The screws are then incorporated in the cement mantle of the acetabular component. F. Intraoperative photos demonstrating adequate positioning of a combination of pins and screws to augment the cement fixation.
Although anterior column fixation is less important than posterior column fixation, if the anterior column is compromised, Steinmann pins may be deployed antegrade from the anterior crest into the acetabular defect.

Some surgeons use targeting jigs, but I prefer to use a careful freehand technique with the nondominant hand in the defect to target the pin.

These anterior pins are cut flush with the crest after they are deployed to the appropriate depth in the defect, ideally capturing the ilium.

With the rebar in place and sunk to a depth that does not interfere with the acetabular component also being sunk to the correct depth, version, and verticality, mesh or similar material is placed to limit cement extrusion.

The acetabular component is then cemented into place, making sure to get the PMMA fully interdigitated with the rebar.

LONG-STEM CEMENTED FEMORAL COMPONENTS

- I prefer to use long-stem femoral components during hip arthroplasty for metastatic bone disease, with a minimum stem length of 300 mm (TECH FIG 2A).
- Various surgical techniques have been proposed to reduce perioperative canal debris or IM pressurization.
- Low-viscosity cement, IM venting, retrograde injection, thorough IM lavage, and intraoperative canal suctioning during cementing may decrease embolic events and decrease perioperative complications.
- Femoral preparation and component placement are performed in a similar systematic fashion.

- After the femoral neck cut is completed with an oscillating saw, the canal is prepared with flexible reaming and broaching.
- The canal is suctioned between subsequent reamers with a long laparoscopic suction device (Conmed Corp, Utica, NY; TECH FIG 2B,C). The canal then is thoroughly brush-lavaged using the Pulsavac (Zimmer, Warsaw, IN) system.
- Three batches of Surgical Simplex P bone cement (Stryker, Mahwah, NJ) are mixed with 3.6 g of tobramycin for femoral cementation because of the
patient’s immunocompromised condition. I prefer Simplex P bone cement because of its low viscous qualities on immediate mixing. Once the cement is mixed (≤ 1 minute), it is immediately injected into the femur in its early, liquefied cure state using a long cement gun.

- The long laparoscopic suction device (Conmed Corp, Utica, NY) is used to aspirate the canal immediately before and during insertion of the PMMA.

### CALCAR-REPLACING HIP ARTHROPLASTY

- In the presence of peritrochanteric bone loss without subtrochanteric extension, a cemented calcar-replacing implant may be used.

### PROXIMAL FEMUR REPLACEMENT

- For proximal femoral replacement, a long posterolateral incision is made to expose the proximal quarter to third of the femur.
  - The iliotibial band is incised longitudinally to permit anterior and posterior exposure.
  - The gluteus maximus is carefully split, with concurrent meticulous ligation of perforating arterioles.
  - Time is taken to localize and protect the sciatic nerve in the retrogluteal area, where it lies immediately behind the external rotators.
  - The abductors are defined, and the greater trochanter is osteotomized and preserved if it is not extensively involved with tumor.
  - If the greater trochanter is too compromised, the abductors are transected at their tendinous attachment.
  - The vastus lateralis muscle is reflected anteriorly, ligating the perforators serially. The main blood supply enters anteriorly.
  - The external rotators are taken down using the surgeon’s preferred standard technique.

- The hip capsule, however, should be preserved as carefully as possible, because it is instrumental in stabilizing the endoprosthetic reconstruction. It is recommended that the capsule be incised longitudinally, with the incision extending anteriorly over the neck, and detached circumferentially.
  - It is strongly recommended that the entire limb, including the foot, be prepped in sterile fashion so that a distal pulse examination may be performed intraoperatively.
  - The hip is dislocated anterolaterally.
  - The acetabulum is inspected and assessed for possible reconstruction.

- Femoral resection level is determined by the lesion or fracture (TECH FIG 3A,B).
  - If the fracture being managed is a realized fracture, a fresh transverse osteotomy should be performed at the level of healthy, uninvolved bone.
  - A malleable retractor is placed medially after the soft tissues have been emancipated with a Cobb or similar elevator.

**TECH FIG 3**

A. Resection of isolated renal cell carcinoma metastasis to the proximal femur. B. The femoral osteotomy is just below the lesion, to provide disease-free bone stock for fixation of the proximal femur replacement. The size of the modular bodies available per the manufacturer is taken into account. C. The modular prosthesis in situ, corresponding to the length of the resected specimen. D. Durable abductor mechanism is critical to functional restoration. I prefer to use a soft tissue washer drilled through any residual greater trochanter that might be available.
Intraoperatively, the surgeon must carefully determine the appropriate version, which is about 95 to 100 degrees off the midsagittal plane as determined by the linea aspera. The prosthetic neck should be angled anteriorly 95 to 100 degrees off this plane.

The prosthesis is assembled as described by the manufacturer.

I strongly recommend against deploying the cement in too viscous a state.

A long laparoscopic-type suction device should be used continously throughout instrumentation of the femoral canal, and consideration should be given to venting if a long stem is to be deployed.

The canal should be brushed as well.

As the cement matures after prosthetic deployment, the surgeon must immediately and carefully confirm the selected version.

Soft tissue reconstruction is of paramount importance for a sound functional result.

The hip capsule should be purse-stringed about the prothetic neck using a no. 5 polyfilament, nondissolving stitch.

Once repaired, it should not be possible to dislocate the hip anteriorly, posteriorly, or laterally.

The tagged psoas tendon may be sewn to the anterior capsule. Likewise, the external rotators may be sewn to the posterior capsule.

At this point, the sciatic nerve is again checked to make sure it is not compromised.

Numerous techniques have been described for reattaching the abductor mechanism to the implant. Vendors also have various capture mechanisms. The surgeon must pay close attention to the reattachment mechanism, because this is the limit of the functional reconstruction.

I prefer to use a soft tissue washer specific to the implant that can either be drilled through the residual trochanteric bone or harness the tendon itself (TECH FIG 3D).

The vastus lateralis muscle is repaired, as are the gluteus maximus and iliotibial band.

For metastatic cases, a drain is not mandatory unless the lesion is highly vascular (eg, renal cell and thyroid).

### PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Potential cardiopulmonary collapse secondary to cementation of femoral components</th>
<th>The use of low-viscosity cement, IM venting, retrograde injection, thorough IM lavage, and intraoperative canal suctioning during cementing all are intended to decrease embolic events and decrease perioperative complications.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensive periacetabular bone loss</td>
<td>Rebar augmentation in the form of long, 6.5-mm cancellous screws or Steinmann pins should provide purchase for any posterior column bone and the sacral ala to gain fixation for cementation. Anterior augmentation also may be performed. The construct must be anchored in relatively healthy, noncontiguous bone so that if there is any local progression (such as that which may occur in thyroid and renal cancer) the reconstruction does not fail.</td>
</tr>
<tr>
<td>Instability of proximal femoral replacements</td>
<td>Intraoperatively, the surgeon must carefully determine the appropriate version, which is about 95 to 100 degrees off the midsagittal plane as determined by the linea aspera. Meticulous capsule repair with no. 5, nondissolving polyfilament suture is imperative. Overall length and offset also must be assessed carefully.</td>
</tr>
<tr>
<td>Abductor weakness in calcar- and proximal femoral–replacing reconstructions</td>
<td>Fixation of the residual abductor mechanism must be as rigid as possible. These patients will not be able to protect this reconstruction effectively. I prefer to use two smaller-diameter soft tissue washers to screw down the mechanism. The larger-bore bolts that are available tend to destroy any residual greater trochanter in this compromised patient population.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE
- In this patient population, all reconstruction must permit weight bearing as tolerated, with an assistive device as needed.
- If a drain has been placed for metastatic cases, it should be discontinued within 72 hours.
- Depending on the approach and the extent of the dissection, hip precautions should be implemented for 6 to 12 weeks.

OUTCOMES
- Periacetabular lesions have 70% to 75% satisfactory pain relief and return to at least partial mobility.
- Cemented total or hemiarthroplasty for femoral head, neck, and peritrochanteric lesions remains, in general, the procedure of choice in this patient population, with good to excellent outcomes relative to the omnipresent comorbidities.

COMPLICATIONS
- Periacetabular reconstructions are associated with complication rates of 20% to 30%.
- Cemented femoral arthroplasty is not without inherent risk.
  - Perioperative cardiopulmonary complications associated with cementing hip arthroplasty components are well described.\(^9,11-13\)
  - Cement-associated desaturation and hypotension, pulmonary hypertension, cardiogenic shock, cardiac arrest, and intraoperative death are complications during femoral cementation and component placement secondary to canal pressurization.\(^1,4,7\)
  - Cemented arthroplasty has been shown to be associated with more embolic events than noncemented arthroplasty, with higher IM pressures noted with cementation.\(^9,10\)
  - Any factor that increases extrusion of femoral IM contents has been suggested to elevate the risk of cardiopulmonary embolic complications. In addition to cementation, this includes porous bone and the use of long-stem femoral implants. Long-stem components have been proposed to increase pressurization of the canal, producing more embolic events, with the rate of cardiopulmonary complications reported to be as high as 62%.\(^4,8\)
  - Metastatic bone allows greater extrusion of emboli because of its permeative qualities and increased vascular supply. Thus, patients with MBD undergoing long-stem cemented femoral arthroplasty are at particularly high risk for cardiopulmonary compromise.
- Proximal femoral replacement is associated with complication rates as high as 28%.\(^6\)
- Most experienced surgeons believe that proximal femoral replacement remains the best option for subtrochanteric involvement in proximal femur pathologic fractures secondary to metastatic bone disease.
- No better alternatives with lower risks than proximal femoral replacement exist for this difficult patient population.

REFERENCES
DEFINITION
- Well-fixed femoral and acetabular implants often have to be removed during revision total hip arthroplasty (THA).
- Conditions that necessitate removal of well-fixed implants include:
  - Infection
  - Recurrent dislocations (malpositioned components)
  - Limb-length discrepancy
  - Severe osteolysis
  - Polyethylene wear
  - Locking mechanism failure
  - Failure of other components in the hip such as a femoral stem fracture (FIG 1)
- The key point is to determine which components should be removed and which are well fixed and can be left at the time of revision THA.

ANATOMY
- Important anatomic considerations include the pelvic landmarks and the proximal femoral and diaphyseal anatomy.
- The pelvic landmarks that assist in component removal and positioning include the ischium, pubis, anterior and posterior acetabular columns, anterior inferior iliac spines, transverse acetabular ligament, sciatic notch, and acetabular walls.
- Neurologic structures at risk include the sciatic nerve, which can be identified in three distinct anatomic locations:
  - As it exits the sciatic notch
  - Lying over the ischium posterior and inferior to the posterior acetabular column
  - Beneath the femoral insertion of the gluteus maximus tendon insertion into the posterior femur.
- The superior gluteal nerve is at risk during component removal as it travels anteriorly along the ilium, approximately 4 to 5 cm superior to the tip of the greater trochanter, to innervate the gluteus medius muscle.
- The femoral nerve is well anterior to the hip for most approaches but may be at risk with further anterior dissection and retraction and with anterior supine approaches to the hip.
- The femoral artery and vein are well anterior to the dissection and usually are protected by the iliopsoas tendon and muscle belly.
- The proximal femoral anatomy includes the greater and lesser trochanter and the vastus ridge, which is a point of relatively weak bone in most revisions due to osteolysis, previous trochanteric osteotomies, or previous surgery in this area.
- The femoral diaphyseal anatomy includes the attachments of the vastus musculature at the vastus ridge and posteriorly at the linea aspera.
  - These attachments often must be reflected during extended trochanteric osteotomies to aid in removal of well-fixed femoral implants (FIG 2).

FIG 1 • AP radiograph of a broken T-28 femoral stem. An extended trochanteric osteotomy (ETO) is used for distal well-fixed stem removal.

FIG 2 • Bilateral acetabular component failure with superior displacement on the right hip and medial protrusio on the left. Both are indications for trochanteric osteotomy to facilitate exposure of the acetabulum and possible stem removal.
PATHOGENESIS

- Well-fixed implants may be removed because of polyethyl-
ene wear or in response to osteolysis that occurs as a result of
particulate debris generating an inflammatory (macrophage)
response and subsequent cellular activation with resulting
bone resorption (FIG 3).
- Sepsis around a THA most commonly is caused by a gram-
positive organism and is best eradicated by component re-
moval and two-stage treatment with intravenous antibiotics
and a delay in reimplantation.
  - The sepsis usually progresses rather quickly to the implant
    interfaces despite well-fixed implants and usually cannot be
    treated effectively with irrigation and joint débridement alone.
  - Component removal with attention to bone preservation
    for subsequent reconstruction is crucial.

NATURAL HISTORY

- Retention of well-fixed components has been shown to lead
to acceptable long-term performance on both the acetabular
and femoral side during isolated component revision.2,5

PHYSICAL FINDINGS

- The physical examination of the patient undergoing revision
THA includes:
  - Gait
  - Leg length
  - Distal neurovascular examination
  - Muscle strength about the hip and leg
  - Skin examination and scars over the hip

IMAGING AND OTHER
DIAGNOSTIC STUDIES

- The goal of diagnostic imaging studies is to identify which
implants are well fixed, confirm that there is no infection, and
see what bone stock is available for the revision reconstruction.

- Multiple plain radiographs, CT scanning with possible 3D
reconstruction, scintigraphy (bone scans), and laboratory
screening usually are sufficient.
- Biplanar radiographs of the entire implant and the joint
above and below the prosthesis are essential.
  - These should include the entire cement mantle on ce-
  mented femoral stems.
  - Signs of ingrowth on uncemented stems have been well
described3 (FIG 4A).
- Oblique, or Judet, views of the pelvis can demonstrate the
anterior and posterior columns, because some defects may
not be readily appreciated on routine anteroposterior (AP)
radiographs (FIG 4B).
- In cases that demonstrate significant polyethylene wear or
osteolysis, CT scanning may better demonstrate osteolytic
lesion location and size.
  - These findings are helpful in guiding plans for bone graft-
ing of lytic lesions and identifying remaining bone stock.
  - Plain radiographs usually greatly underestimate the extent
of osteolysis involvement in the pelvis from polyethylene
debris.
- Bone scan examination may demonstrate subtle implant
loosening that may not be appreciated on plain radiographs
or at the time of surgery and may help the surgeon decide
whether to retain or remove implants that appear well
fixed.
- Confirmation of a noninfected arthroplasty is critical prior
to the revision THA.
  - Confirmation is best accomplished by laboratory evalua-
tion, including erythrocyte sedimentation rate (ESR) and
C-reactive protein (CRP). The combination of a normal ESR
and normal CRP has been demonstrated to have a very low
(<1%) likelihood of being infected.6
  - In cases of elevated ESR or CRP, aspiration of the hip is
warranted, with examination of the cell count with differen-
tial and culture of the fluid.
Preoperative Planning

- Appropriate removal instruments and surgical techniques are important considerations as one approaches the revision THA with well-fixed implants.
- When performing revision THA, multiple options for the implant must be on hand to match defects or needs that may be discovered intraoperatively.

Positioning

- In general, patients can be positioned supine or in the lateral decubitus position.
- In the anterior supine approach, the patient is positioned in the supine position and an anterior approach to the hip is performed in the interval between the tensor fascia lata and the sartorius muscles.
- An anterior or anterolateral approach to the hip can be performed in the supine or lateral position and is extensile in both the proximal and distal directions should additional exposure be required.
- The posterior approach to the hip is performed in the lateral decubitus position.
- At our institution, we use a pegboard positioner.
- An axillary roll is used to provide protection for the brachial plexus during surgery.

**TECHNIQUES**

**APPROACH**

**Anterior Supine**

- The patient is positioned in the supine position and an anterior approach to the hip is performed in the interval between the tensor fascia lata and the sartorius muscles (TECH FIG 1A,B).
- This technique is suitable for polyethylene exchange alone, in which the femoral component is well fixed and there is no significant need for bone grafting in the posterior aspect of the acetabulum (see Fig 3).
- Bone grafting is possible through the holes in the acetabular component or through a small “trap-door” above the acetabulum (TECH FIG 1C).
- This approach retains much of the posterior capsule and structures, which likely reduces the incidence of dislocation after revision.
- The femoral head is retracted posteriorly (TECH FIG 1D), and a new liner is inserted (TECH FIG 1E).

**Lateral**

- A direct lateral approach to the hip involves a split in the anterior third of the gluteus medius and minimus musculature.4
The length of the osteotomy is determined by the amount of prosthesis that is well fixed or the distal extent of the cement column that needs to be removed. Approximately a third of the lateral portion of the femoral circumference is part of the osteotomy (TECH FIG 2A).

The vastus lateralis remains attached to the lateral portion of the osteotomy but is reflected anteriorly to allow visualization of the lateral and posterior femoral cortex.

An oscillating saw is used to perform the posterior portion of the osteotomy just superior to the linea aspera. The gluteus medius remains attached.

The distal extent of the osteotomy is beveled in the distal and anteroposterior direction. Alternatively, the osteotomy can be performed with a high-speed burr with a thin tip (TECH FIG 2B).

The anterior portion of the osteotomy is made with a small (¼-inch) osteotome perforated through the vastus musculature. Multiple perforations are made in the same plane to create the osteotomy.

The capsule surrounding the prosthesis below the greater trochanter is released or excised and the “shoulder” of the prosthesis exposed.

The entire extended trochanteric fragment is reflected anteriorly with care not to fracture the tip of the trochanteric fragment, because this is the weakest point in the osteotomized fragment (TECH FIG 2C).

**EXTENDED TROCHANTERIC OSTEOTOMY**

- The length of the osteotomy is determined by the amount of prosthesis that is well fixed or the distal extent of the cement column that needs to be removed. Approximately a third of the lateral portion of the femoral circumference is part of the osteotomy (TECH FIG 2A).
- The vastus lateralis remains attached to the lateral portion of the osteotomy but is reflected anteriorly to allow visualization of the lateral and posterior femoral cortex.
- An oscillating saw is used to perform the posterior portion of the osteotomy just superior to the linea aspera. The gluteus medius remains attached.
- The distal extent of the osteotomy is beveled in the distal and anteroposterior direction. Alternatively, the osteotomy can be performed with a high-speed burr with a thin tip (TECH FIG 2B).
- The anterior portion of the osteotomy is made with a small (¼-inch) osteotome perforated through the vastus musculature. Multiple perforations are made in the same plane to create the osteotomy.
- The capsule surrounding the prosthesis below the greater trochanter is released or excised and the “shoulder” of the prosthesis exposed.
- The entire extended trochanteric fragment is reflected anteriorly with care not to fracture the tip of the trochanteric fragment, because this is the weakest point in the osteotomized fragment (TECH FIG 2C).
Curved Bennett-type retractors are inserted distal to the osteotomy for soft tissue retraction and the Charnley-type hip retractor anterior arm is carefully secured to the trochanteric fragment anteriorly to expose the femoral prosthesis (TECH FIG 2D).

Anterior and medial capsular attachments are taken down to the level of the psoas tendon. All tissue lateral to the psoas tendon can be removed at this point if needed to allow visualization of the stem.

Osteotomes, ultrasonic devices, or high-speed burrs now have access to the cement–implant and cement–bone interfaces or the ingrowth interface, as needed for removal.

The femoral preparation for long-stem implant insertion is completed with flexible reamers and proximal femoral tapered reamers.

The trial implants are inserted and a trial reduction performed before the trochanteric fragment is reattached. The osteotomy is reduced and secured with looped Luque wires (TECH FIG 2E).

ACETABULAR REMOVAL

The goal in acetabular removal is to preserve as much of the remaining bone as possible. It is important not to gouge the acetabulum or to break off large pieces by aggressively twisting or pulling a well-secured cup.

Acetabular osteotome systems facilitate cup removal by using the center of the acetabular polyethylene as a reference for osteotome insertion. Osteotomes match the radius of curvature of the cup. The center of rotation of the acetabular component allows thin osteotome insertion precisely in the bone implant interface (TECH FIG 3A).

The osteotome blade is inserted and turned in a firm, controlled manner, maintaining its orientation to the rim of the cup.

First, a small osteotome is inserted that matches the radius of the acetabular component. It is used to enter the bone–implant interface only around the rim of the ingrown acetabular component (TECH FIG 3B,C).

Successively longer acetabular osteotomes are then used around the entire rim of the component to divide more medial ingrown interfaces (TECH FIG 3D).

A handle permits the acetabular explant chisel to be rotated around the circumference of the component to further loosen the implant and remove the cup with minimal bone loss (TECH FIG 3E).
**TECH FIG 3**  •  **A.** The acetabular osteotome used to remove cups allows thin osteotome insertion precisely in the bone implant interface. **B.** A small osteotome is first used to enter the bone–implant interface around the rim of the acetabular component. **C.** Osteotome shown with the implant removed. **D.** A longer acetabular osteotome removes the medial ingrown interfaces. **E.** Using the acetabular explant chisel on a handle, the implant is removed with minimal bone loss. (Courtesy of Zimmer, Inc., Warsaw, IN.)

### PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Acetabular deficiencies</th>
<th>▪ Osteolysis and bone loss behind well-fixed acetabular components is underestimated on plain radiographs. A simple polyethylene exchange may become a much more extensive revision if proper preoperative evaluation such as CT scanning has not been completed.</th>
</tr>
</thead>
</table>
| Extended trochanteric osteotomy | ▪ Bevel the distal transverse arm of the osteotomy to prevent distal fracture propagation.  
▪ Pass a cerclage wire distal to the osteotomy before femoral preparation and trial and final implant insertion.  
▪ Pay careful attention to trochanteric osteolysis and fracture risk at the vastus ridge at the junction of the vastus lateralis and the abductor attachment into the trochanter.  
▪ Have adequate bone graft available, including morselized cancellous graft and cortical struts for contained and uncontained defects.  
▪ With distally fixed stems combined with an ETO, a tight distal diaphyseal fit must be obtained, achieving three-point fixation.  
▪ Postoperative radiographs are needed, because the intraoperative fracture rates are higher for revision THA and ETO cases.  
▪ An ETO can be combined with a proximal reduction or angular osteotomy.  
▪ Leave vastus muscle attached to the trochanteric fragment to provide adequate blood supply for osseous healing and implant stability. |
Acetabular removal

- Thin osteotomes based on the cup and head size reduce bone loss during removal of well-fixed acetabular components.
- The polyethylene should be removed from the acetabular component to allow screw removal, then replaced for a guide or reference for removal instruments.
- Cementing an acetabular polyethylene shell is an option if the locking mechanism is not functional after polyethylene component removal.

POSTOPERATIVE CARE

- Weight bearing is restricted to about 50% for 6 to 8 weeks if an implant has been reinserted and bone graft has been used.
- With polyethylene exchanges and component retention of osseointegrated implants, weight bearing as tolerated is recommended.
- When an implant is removed and an antibiotic-impregnated static spacer is inserted, foot-flat (essentially non-weight bearing) weight bearing is recommended. We combine this with a hinged knee brace locked in extension, which allows wound care but limits motion and provides additional support while allowing mobilization during the time of IV antibiotic therapy.

COMPLICATIONS

- Femoral fractures are common about the trochanteric region and in the diaphysis during removal of well-fixed femoral implants.
- Isolated component revision has a higher dislocation rate than primary revision THA.
- Acetabular deficiencies may be extensive in the face of polyethylene wear and osteolysis.

OUTCOMES

- Aribindi et al\textsuperscript{1} reported on the outcomes associated with THA revision with an extended trochanteric osteotomy in 122 cases with a minimum of 1 year of follow-up (average, 2.6 years).
  - No non-unions, no migration greater than 2 mm
  - All healed by 3 months
  - 92% bone ingrowth, one stem revised for loosening
  - Dislocation rate 10% (three required revision)
  - 20% intraoperative fracture rate

REFERENCES

DEFINITION
- A fluted stem can be used to revise a loose femoral implant with one or more of the following:
  - Cavitary or segmental defects
  - Femoral malalignment
  - Periprosthetic fracture
  - Stress-shielded or sclerotic bone secondary to prior fracture fixation

ANATOMY
- The anatomic structures most relevant to revision arthroplasty in patients with femoral bone loss are the proximal aspect of the femur and the femoral shaft, as well as the surrounding soft tissues.
- The proximal aspect of the femur is composed of the head, the neck, and the greater and lesser trochanters.
- Important soft tissues include the iliotibial band and the tensor fascia lata, the gluteal muscles, the short external rotators and the joint capsule, the iliopsoas, and the quadriceps musculature (FIG 1A).
- Vascular and neurologic structures include the femoral artery and vein and the sciatic nerve.
- The AAOS classification is used to describe femoral bone loss5 (Table 1; FIG 1B).

PATHOGENESIS
- Normal wear of the acetabular liner produces particulate polyethylene debris. The presence of this debris increases over time, leading to a macrophage response that results in periprosthetic bone loss. Aseptic loosening may occur secondary to this particle-induced periprosthetic osteolysis.
- This mode of failure is the primary reason for revision hip arthroplasty.

NATURAL HISTORY
- The implant loosens as a result of progressive bone loss.
- The loose implant leads to further bone loss.
- Cortical thinning frequently occurs.
- Angular deformation (often varus) results.
- Progressive cortical thinning may result in fracture.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patient history should involve an in-depth conversation related to the location and type of pain that the patient is experiencing (Table 2).
- A complete medical and surgical history is necessary to document all information pertaining to the index procedure, including the initial diagnosis, date of surgery, complete operative notes with detailed descriptions of the components used, and the dates of any postoperative complication.
- Other systemic medical conditions and recent surgical or medical treatments should also be documented to ensure that the patient can tolerate and will benefit from hip revision.
- The physical examination should include the following:
  - Gait evaluation. Painful total hip arthroplasty (THA) may result in shortened stance phase or stride length, or abnormal pelvic rotation. A Trendelenburg gait or abductor lurch may raise concern regarding hip abductor function that can limit success of revision.
  - Trendelenburg test is considered positive if pelvis on the nonstance side moves into a position of relative adduction; this may indicate abductor weakness or trochanteric nonunion.
  - Range of motion should be pain-free throughout range. Pain suggests mechanical dysfunction. A palpable or audible click or clunk may indicate head subluxation or a loose component.
  - Hip abductor strength may indicate abductor weakness, trochanteric bursitis, abductor avulsion, trochanter fracture, or a loose femoral component.
  - A slight difference of less than 1 cm in true leg length is considered normal, though it may cause symptoms in some patients. Progressive leg-length discrepancy suggests implant subsidence.
  - Apparent leg length may be affected by atrophy, obesity, or asymmetric positioning of the legs. Values may indicate abductor or adductor contractures, or pelvic obliquity due to scoliosis.
  - Evaluate the skin around the hip to gauge the risk for infection and to assess its ability to heal postoperatively.
  - A careful neurologic and vascular evaluation should be performed to rule out extrinsic etiology for hip or thigh discomfort. It will also serve as a baseline for the postoperative exam.

Bone
- Careful evaluation of the preoperative radiographs is imperative to identify bony deficiencies. The greater trochanter is commonly sclerotic and fragile and is easy to fracture. Nonunion can result despite rigid fixation of intraoperative fractures. Hardware over the trochanter can result in a painful bursitis.
- Proximal bone deficiencies around the lesser trochanter can be so profound that a fluted stem is not suitable for femoral revision and a fully porous coated stem for diaphyseal fixation is preferable.
- Diaphyseal defects in the femur are important to identify since it is critical for the stem to bypass cortical deficiencies by at least two cortical diameters.

Soft Tissue
- The hip abductors require careful preoperative evaluation and intraoperative inspection since they are critical to postoperative hip stability and gait. Prior hip surgery may result in a weakened gluteus medius.
The gluteal sling refers to the insertion of the gluteus maximus on the posterolateral border of the proximal femoral shaft. The 5-cm insertion frequently needs to be partially or completely released to gain exposure or correct leg length. It should be repaired to a tendon stump at the end of the surgery.

The vastus lateralis may be elevated from its posterior border to give the surgeon access to the femoral shaft for correction of bony deformity, fracture repair, and cable placement.

Neurovascular Structures
- The sciatic nerve is frequently encased in scar during revision hip surgery. It is located 1 to 2 cm posterior to the posterior hip joint capsule and the short external rotators are often scarred together. They need to be tagged and preserved for later repair if a posterior approach to the hip has been used. Many times, the anterior joint capsule is scarred and must be completely resected to correct offset and leg-length abnormalities.
- Polyethylene debris may be located in the iliopsoas sheath and should be eliminated during the hip revision. The iliopsoas may require anterior release to correct leg length and preoperative flexion contractures.

### Table 1
**AAOS Classification of Femoral Bone Loss**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Type of defect</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>Segmental defects, or lesions in the supporting shell, further categorized as proximal, intercalary, or involving the greater trochanter</td>
<td></td>
</tr>
<tr>
<td>Type II</td>
<td>Cavitary defects, categorized as cancellous (mild), cortical (moderate), and ectatic (medullary expansion)</td>
<td></td>
</tr>
<tr>
<td>Type III</td>
<td>Combined segmental and cavitary defects</td>
<td></td>
</tr>
<tr>
<td>Type IV</td>
<td>Malalignment</td>
<td></td>
</tr>
<tr>
<td>Type V</td>
<td>Femoral stenosis</td>
<td></td>
</tr>
<tr>
<td>Type VI</td>
<td>Femoral discontinuity or fracture</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level of defect</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level I</td>
<td>Defect proximal to the inferior border of the lesser trochanter</td>
</tr>
<tr>
<td>Level II</td>
<td>Defect &lt;10 cm distal to the inferior border of the lesser trochanter</td>
</tr>
<tr>
<td>Level III</td>
<td>Defect &gt;10 cm distal to the inferior border of the lesser trochanter</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grade of bone loss</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade I</td>
<td>Minimal bone loss with maintenance of bone–implant interface that does not require bone grafting</td>
</tr>
<tr>
<td>Grade II</td>
<td>Some loss of bone–implant interface with sustained support of implant</td>
</tr>
<tr>
<td>Grade III</td>
<td>Marked loss of bone–implant interface that required structural grafting</td>
</tr>
</tbody>
</table>

- The posterior hip joint capsule and the short external rotators are often scarred together. They need to be tagged and preserved for later repair if a posterior approach to the hip has been used. Many times, the anterior joint capsule is scarred and must be completely resected to correct offset and leg-length abnormalities.

### Table 2
**Patient Description of Pain and Potential Diagnoses**

<table>
<thead>
<tr>
<th>Description of Pain</th>
<th>Potential Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain-free interval after THA</td>
<td>Implant failure or indolent infection</td>
</tr>
<tr>
<td>Rest and/or night pain</td>
<td>Sepsis</td>
</tr>
<tr>
<td>Pain on weight bearing and painful range of motion</td>
<td>Deep pyogenic infection</td>
</tr>
<tr>
<td>Movement-elicited pain</td>
<td>Aseptic loosening</td>
</tr>
<tr>
<td>Start-up pain that resolves after several steps</td>
<td>Loose femoral component, tendinitis, or heterotrophic ossification</td>
</tr>
<tr>
<td>Severe acute pain</td>
<td>Periprosthetic femur fracture, acetabular cup disassociation, or hip dislocation</td>
</tr>
<tr>
<td>Failure to achieve pain relief following THA</td>
<td>Extrinsic source unrelated to the hip</td>
</tr>
</tbody>
</table>
Step-by-Step Procedure for Templating Prior to Revision Hip Arthroplasty With a modular, fluted stem.

<table>
<thead>
<tr>
<th>Step</th>
<th>Primary Objective</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mark and measure leg lengths</td>
<td>Compare location of the lesser trochanter of the operative and nonoperative leg in relation to either the transischial or transobturator lines. Be sure to measure with a magnified ruler.</td>
</tr>
<tr>
<td>2</td>
<td>Identify acetabular landmarks</td>
<td>Assess position of the teardrop, superolateral lip, and the medial wall (Kohler’s line).</td>
</tr>
<tr>
<td>3</td>
<td>Template acetabulum</td>
<td>Assess bony anomalies and decide what acetabular reconstruction is most reliable. Position the hemisphere to contact the appropriate landmarks with the proper abduction, medializing as needed without passing Kohler’s line.</td>
</tr>
<tr>
<td>4</td>
<td>Determine center of rotation</td>
<td>Lateralized acetabular implants can be used to compensate for medial bone loss. Mark center of rotation.</td>
</tr>
<tr>
<td>5</td>
<td>Draw lateral femoral line</td>
<td>Draw straight line up the endosteum of lateral femoral cortex, which represents the final lateral position of the implant. Failing to respect or address this line can lead to lateral perforation or varus implantation.</td>
</tr>
<tr>
<td>6</td>
<td>Select stem diameter</td>
<td>With magnified ruler, measure narrowest isthmic endosteal diameter. This measurement determines the diameter of the prosthesis. For example, if the canal diameter is 17 mm, then a 22 × 17 stem would be selected.</td>
</tr>
<tr>
<td>7</td>
<td>Select stem length</td>
<td>Four lengths available: standard, long, extra-long, and extra-extra-long. Review the entire femoral length, and attempt to bypass the lowest femoral defect by 2.5 to 3 canal diameters. Also, attempt to bypass level of previous stem or cement plug.</td>
</tr>
<tr>
<td>8</td>
<td>Position stem and select neck</td>
<td>Judge center of rotation for stem/neck/head combination to obtain appropriate length. Consider calcar-replacing stems and be careful if losing offset.</td>
</tr>
<tr>
<td>9</td>
<td>Determine level of sleeve</td>
<td>Mark proximal level of sleeve as indicated on the template. Make certain to mark both the AP and lateral radiograph at the desired level, which may be difficult with the lateral film.</td>
</tr>
<tr>
<td>10</td>
<td>Select sleeve size</td>
<td>Use anteroposterior and lateral views for sleeve sizing. Overlay sleeve template for best anteroposterior fill at the correct level. Position the sleeve on the anteroposterior view, and choose position and size of triangle.</td>
</tr>
<tr>
<td>11</td>
<td>Select neck length</td>
<td>Mark neck length for the +0 head so less likely to need a skirt.</td>
</tr>
<tr>
<td>12</td>
<td>Final review</td>
<td>Recheck leg lengths and verify neck style and length.</td>
</tr>
</tbody>
</table>
Most fluted stems have a proximal sleeve of varying length that allows for optimal fit and fill of the proximal femur. The flutes increase distal fill and increase resistance to rotational stress.

Preoperative Planning

- Template using recent preoperative anteroposterior (AP) and lateral radiographs (Table 3). AP and lateral radiographs of the femoral shaft are required if long, extra-long, or extra-extra-long stems are going to be used.
- A pathologist must be available to look at the frozen section.
- Materials needed include previous surgery notes, possible polyethylene liner exchange options, revision acetabular components (even if the socket looks stable), fully porous coated femoral component if proximal fixation is insufficient for use of a fluted stem, particulate and structural allografts, and cables.

Positioning

- Following application of general anesthesia and insertion of a Foley catheter, the patient should be positioned on a pegboard in the lateral decubitus position with bony prominences padded.
- Perfect positional stability of the patient’s pelvis is ensured before preparation and draping.
- Wide skin preparation is performed, with access to the distal femur.

Approach

- Posterolateral/posterior approach
- Anterolateral/Harding approach

### ROUTINE REVISION WITHOUT DIAPHYSEAL DEFECT

#### Site Preparation

- Use trochanteric osteotomy/slide if needed for exposure or for cement/implant removal.
- Avoid extended trochanteric osteotomy, since this will compromise proximal fixation.
- Carefully assess the proximal femur above the lesser trochanter.
- Perform straight reaming of the proximal diaphysis until cortical chatter is achieved. Reaming should be done to a depth determined by comparing a line on the reamer to the tip of the trochanter1 (TECH FIG 1A).
  - The diameter of the last reamer will determine the size of the implant and reflects the diameter of the distal end of the implant.
- Prepare the metaphysis with the conical reamers that correspond with the last straight reamer. Cone reaming should stop whenever contact with structurally sound cortical bone is obtained. A small cortical edge should be palpable at the inferior end of the conically reamed bone.
  - Take care to insert the conical reamer to the level that corresponds to the preoperatively templated level of the upper portion of the sleeve.
- If using the S-ROM system, use the calcar miller to prepare the femur for the triangular modular sleeve (TECH FIG 1B).

#### Implant Placement

- Perform trial reduction after placing the trial sleeve and femoral stem to assess version, range of motion, and laxity. The modular system allows complete freedom to vary antversion regardless of proximal femoral geometry (TECH FIG 2A–D).
- Insert sleeve, and then finish by inserting femoral stem (TECH FIG 2E).

**TECH FIG 1**  •  A. Straight reaming of the femur is carried out until contact with diaphysis is obtained. B. Calcar miller that is used for preparation of proximal femur as part of this prosthesis.
**ROUTINE REVISION WITH DIAPHYSEAL DEFECT**

- Plan to bypass the diaphyseal defect by two cortical widths with a long, extra-long, or extra-extra-long bowed stem.
- Pass a long guidewire to ensure that there are no holes in the cortical bone.
- Flexibly ream until good cortical chatter is achieved in the diaphysis. You must flexibly ream to 1.5 mm greater than the minor diameter of the shaft of the implant (e.g., ream to 14.5 mm for an 18 ¥ 13 stem) when using a long, extra-long, or extra-extra-long stem.
- Straight ream proximally to the same diameter as the minor diameter of the implant.
- Conical and miller reaming is performed in the manner described in the previous section.
- Place trial implants.
- When inserting the true implants, do not completely seat the proximal sleeve prior to placing the stem when using a long, extra-long, or extra-extra-long sleeve. The sleeve should be inserted to within 1 to 2 mm of the intended location. The stem should then be inserted through the sleeve and it should engage the sleeve as they are finally seated together.
- The bowed implant has 15 degrees of anteversion built into it. The surgeon can actually place up to 25 to 30 degrees of anteversion on the femoral stem if necessary.
- Struts are usually not needed, though they can be used to improve bone stock.

**EXTENDED TROCHANTERIC OSTEOTOMY NEEDED OR DIAPHYSEAL OSTEOTOMY OR OPEN REDUCTION AND INTERNAL FIXATION OF A PERIPROSTHETIC FRACTURE DISTAL TO A LOOSE STEM**

- Remove stem and cement if necessary through the top of the femur or through the fracture site if present.
- Perform exposure posterior to the vastus lateralis to expose the femoral shaft.
- Perform the osteotomy or expose the fracture and place a cable around the distal diaphyseal fragment.
- Straight ream or flexibly ream the distal diaphyseal fragment until cortical chatter is noted. The size of the last reamer will dictate the size of the implant.
- Use bone clamps to gain control of the proximal segment and then straight ream to the diameter of the last reamer used on the distal fragment. Conical reaming and proximal milling should be performed as described earlier. It may be advisable to place a cable at the level of the sleeve at this point to prevent fracture.
- Reduce the proximal fragment to the distal fragment with bone clamps if needed.
- Place the trial implant crossing the fracture or osteotomy with the stem.
- Reduce the hip and assess leg lengths, offset, and soft tissue tension. Rotational stability will not be obtained at the fracture or osteotomy site at this time, so a true stability examination is not possible.
- Place cables around structural allograft and begin to tighten if allograft struts are needed.
TECH FIG 3 • Preoperative and postoperative AP radiographs of a patient with severe proximal deformity that necessitated a cortical osteotomy for insertion of the prosthesis and femoral realignment.

USE OF A FLUTED STEM WITH A PROXIMAL FEMORAL ALLOGRAFT

- Choose a large proximal femoral allograft (critical).
- Expose the femoral diaphysis by proceeding posterior to the vastus lateralis.
- Decide on the level of the graft–host junction and divide the femur at that level. A step cut is not necessary because of the rotational stability of the bowed, slotted stem.
- Ream the distal diaphysis line to line with a straight or flexible reamer until cortical chatter is achieved. The last reamer determines the size of the implant.
- Place the allograft in a bone vise and prepare the allograft with a flat neck cut followed by straight reaming to 1 to 2 mm larger than the distal diaphysis diameter. Conical reaming and proximal milling then occur on the proximal femoral allograft as previously described.
- Make a provisional distal cut on the allograft, leaving it 1 cm long.
- Make a longitudinal cut on the proximal native femur to open it up so the allograft can be inserted within it. Do not remove any soft tissue attachments from the native proximal femur.
- Perform a trial reduction by placing the trial within the allograft and inserting the distal portion of the stem into the native femoral diaphysis. Attempt to reduce the hip and assess leg lengths. Remove bone from the distal tip of the allograft to equalize leg lengths. Make sure there is good bone contact at the allograft–host bone junction. Also, remove bone from the allograft greater trochanter to allow the native trochanter to be placed in an anatomic position overlying the allograft.
- Remove the allograft and stem and roughen the exterior minimally in the areas where the allograft will have contact with host bone.
- Remove the stem from the allograft and pulse lavage and dry the interior of the allograft. Pass two cables through the lesser trochanter; these will later be used with a claw to fasten the native greater trochanter.
- Downsize the sleeve to allow for a cement mantle and assemble the stem and sleeve on the back table.
- Cement the fluted stem and sleeve into the allograft, making sure that all of the cement is wiped off the distal portion of the stem. Keep cement off the distal portion of the allograft to allow complete contact with the host distal femur.
- After cement hardening, insert the allograft–stem composite into the native femur. It is rarely necessary to ream the distal femur an additional 0.5 mm to prevent fracture. Rotational stability at the graft–host junction should be complete at this time (TECH FIG 4A).
- Use native bone at the graft–host junction to serve as struts. A claw is typically placed on the native trochanter to help fasten the native greater trochanter to the allograft (TECH FIG 4B).
- The remainder of the native proximal bone is attached to the allograft with the soft tissue attachments maintained.
- Remove trial and place implant. If the implant will not fit in the distal fragment, it may be necessary to ream up 0.5 mm to avoid fracture (TECH FIG 3).
- Tighten cables.
- Inspect for iatrogenic fracture.
- Consider additional bulk allograft.
- Perform a gentle stability examination.
- Perform routine closure using posterior capsular repair.
- Administer antibiotics for 3 days or until cultures are negative.
- Brace for 6 to 12 weeks.
- Leg lengths are assessed by soft tissue tension, preoperative templating, and comparison with down leg.
PEARLS AND PITFALLS

Avoid trochanteric osteotomy and extended trochanteric osteotomy (ETO) if possible. Patients get well quickly if osteotomy can be avoided and the risk of sleeve subsidence reduced.

Ensure complete cement removal. If cement is not completely removed, reamers will take away bone since it is often less hard and cause perforations.

Confirm no perforations have occurred. Use long guidewire down diaphysis or fluoroscopy if needed.

If perforation occurs, expose perforation and treat fracture appropriately. Bypass with stem, strut graft, etc.

If using a long stem, consider AP and lateral radiography of distal femur prior to leaving OR.

Do not be afraid to use larger heads in older patients. Reduce dislocation risk.

POSTOPERATIVE CARE

- Weight bearing as tolerated in simple cases with standard, straight stems
- Knee immobilizer while sleeping to help prevent dislocation
- Touchdown weight bearing and bracing for 6 to 12 weeks in complex cases with osteoporosis or if fracture or osteotomy healing is needed
- Pharmaceutical and mechanical deep vein thrombosis prophylaxis
- Follow cultures.

OUTCOMES

- When used for proximal femoral bone loss or other complex revisions, previous authors have reported excellent radiographic and clinical outcomes with the S-ROM system, including no evidence of osteolysis, mean postoperative Harris hip score of 82, and 84% patient satisfaction.3,4
- The S-ROM system has been reported to have a 5-year survival rate of 96%, with a 5% rate of mechanical failure.9,11
- Inferior outcomes have been associated with the use of large stem diameters.
One study attributed persistent thigh pain to the use of stems greater than 17 mm in diameter.\(^3\)

A second study reported a significantly increased incidence of stress shielding, as well as a lack of bony ingrowth, with stem diameters greater than 16 mm.\(^11\)

**COMPlications**

- Aseptic loosening
- Infection
- Dislocation
- Leg-length discrepancy
- Fracture or osteotomy nonunion
- Trochanteric fracture

**References**

DEFINITION
- Proximal femur replacement is a salvage limb-sparing surgery for nononcologic and oncologic indications that in the past were treated with a major amputation.
- During the past decade remarkable advances in the field of revision hip reconstruction have been made. One such improvement has been the introduction of second-generation modular prosthetic components (FIG 1), which provide improved ability to restore limb length and achieve optimal soft tissue tension, both of which may reduce the incidence of instability that often followed insertion of a monolithic megaprosthesis. A new generation of megaprostheses also provides a better environment for soft tissue reattachment and the ability to reapproximate the retained host bone to the prosthesis.

ANATOMY
- The abductors are the gluteus medius and minimus muscles, the tensor fascia lata muscles, and the iliotibial band. The adductors are the adductor brevis, adductor longus, and gracilis muscles, and the anterior part of the adductor magnus muscle. The external rotators are the piriformis, quadratus femoris, superior gemellus, inferior gemellus, obturator internus, and obturator externus muscles.
- Abductors are important stabilizers of the hip that are innervated mainly by the superior gluteal nerve. The nerve exits the pelvis via the suprapiriform portion of the sciatic foramen along with the superior gluteal vessels. Palsy results in abductor lurch, a Trendelenburg gait.

PATHOGENESIS
- Femoral bone loss is a constantly rising, predominantly complex and challenging problem in revision arthroplasty.
- Numerous factors may contribute to the loss of femoral bone stock encountered in revision hip arthroplasty:
  - Osteolysis secondary to particle debris
  - Stress-shielding with adaptive bone-remodeling
  - Previous infection
- Natural processes of aging
- Periprosthetic fracture
- Multiple previous failed reconstructive procedures with insertion and removal of implants also compromise the integrity of the bone stock and adversely affect the integrity and function of the abductor muscles.
- Options available for dealing with severe femoral bone loss include the use of a long cemented stem or press-fit stems, impaction allografting, resection arthroplasty, allograft prosthetic replacement, and modular replacement.
- An allograft–prosthesis composite potentially increases bone stock in the proximal part of the femur and provides sites for soft tissue attachment, including the abductor muscles. The use of an allograft–prosthesis composite is limited due to the risks of infection, junctional nonunion, dislocation, and aseptic loosening.
- A proximal femoral replacement probably is more available to most surgeons than a proximal femoral allograft, and it is less technically demanding to implant.
- Zehr et al28 conducted a comparative study in which the use of an allograft–prosthesis composite was found to be marginally better than proximal femoral replacement for reconstruction after tumor resection.

NATURAL HISTORY
- The megaprosthesis is valuable in the armamentarium of the reconstructive hip surgeon who treats patients with extensive bone loss for whom other available reconstructive procedures cannot be utilized.
- This prosthesis will have an unacceptably high failure rate in younger patients, and other reconstructive options should be explored.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Assessment of the present and past medical history, physical examination results, and radiographic findings lead to a correct diagnosis of hip pathology in most patients.
- Intra-articular or acetabular pathology usually presents as groin pain.
- Thigh pain (especially start-up pain) is more indicative of a loose femoral stem.
- Patients may present with severe knee pain as a result of hip pathology. Any patient with knee pain should be evaluated for hip pathology.
- Neurovascular examination and examination of the spine and abdomen should be conducted to exclude other reasons
of hip pain, such as neuropathies, vascular claudication, and spinal stenosis.

- Specific tests for the hip with evaluation of range of motion and leg lengths should be documented.
  - Leg-length assessment for apparent or functional leg length discrepancy; a deficiency may be due to pelvic obliquity, contractures, or scoliosis.
  - Trendelenburg test: inability to stabilize the pelvis indicates abductor weakness.
  - Straight leg raise: radicular pain may be felt along the leg.
  - Thomas test: evaluates for hip flexion contracture.
  - Stinchfield test: groin pain or weakness may indicate intra-articular hip pathology.

- Initial history taking should begin with a discussion of the patient’s chief complaint. The location and nature of the patient’s pain can guide the surgeon to the proper diagnosis.
- A thorough review of the patient’s medical history along with a complete review of systems will help the surgeon to identify any potential factors that may lead to perioperative complications and provides an opportunity to medically treat or optimize the patient before the planned operation.
- Sources of potential or concurrent infection must be discovered, and proper evaluation and treatment should be performed well in advance of the surgical procedure.
- Negative hip aspirations do not completely rule out infection and should be followed up with intraoperative tissue sampling with frozen sections after alerting the appropriate pathology department personnel well before the planned surgical date.
- Patients with any history of chronic venous stasis ulcers, previous vascular bypass surgery, or absent distal pulses should be evaluated by a vascular surgeon.
- The physical examination should begin with the analysis of the patient’s gait. Use of ambulatory assistive devices, a limp, or a deformity of the lower extremity should be noted.
- The antalgic gait is a result of pain in all phases of ambulation with weight bearing and is characterized by a shortened stance phase indicating hip-joint disease.
- The Trendelenburg gait or abductor lurch indicates either paralysis or loss of continuity of the abductor musculature and is identified by observing the shift of the patient’s center of gravity over the affected extremity during the stance phase of gait.
- Inspection of previous surgical wounds should be routinely performed. Planning of the surgical incision is important in determining the approach for the surgical reconstruction, and, although skin flap necrosis after hip surgery is rare, the maximum distance and angles used should be optimal to avoid this complication.
- The active and passive ranges of motion of the hip should be identified along with the strength of the hip girdle musculature.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Proximal and total femur resections are major surgical procedures that necessitate a detailed preoperative evaluation.
- Physical examination and imaging studies aid in determination of the extent of bone resection and dimensions of the required prosthesis; the extent of soft tissue resection and reconstruction possibilities; and the proximity of the scarred-in femoral vessels, femoral nerve, and sciatic nerve.
- Most complications can be avoided by anticipating them before surgery and modifying the surgical technique accordingly.
- Plain radiographs are used to evaluate the extent and level of bone destruction. If needed, CT scanning can be added for further delineation of the femur and acetabulum bone structure.
- MRI is used to evaluate the medullary canal and soft tissue around the hip joint.
- Three-phase bone scan is essential to determine the presence of metastatic bone disease.
- Angiography of the iliofemoral vessels is essential before proximal femoral replacement if distortion of the anatomy following multiple previous surgeries is suspected.

**DIFFERENTIAL DIAGNOSIS**

- Osteomyelitis
- Metastatic lesions
- Primary bone tumors, eg, multiple myeloma, chondrosarcoma
- Periprosthetic fracture
- Osteolysis
- Aseptic loosening
- Paget disease
- Metabolic disease

**NONOPERATIVE MANAGEMENT**

- For the indications discussed in this chapter, the only reasonable option would be a surgical one. If the patient’s medical problems are serious enough to put off the surgery, however, an antidislocation brace with protected weight bearing can be used.

**SURGICAL MANAGEMENT**

- Use of the megaprostheses (ie, proximal femoral replacement and total femur replacement) is reserved to expedite recovery for elderly or sedentary patients with massive bone loss that may have occurred after failed total hip arthroplasty (FIG 2A,B), deep infection, periprosthetic fracture (FIG 2C,D), fracture nonunion with failed multiple attempts at osteosynthesis, and hip salvage after a failed resection arthroplasty.
- In younger patients with bone loss of high magnitude that cannot be reconstructed by conventional means, an allograft prosthetic composite is preferred over femoral prosthetic replacement.
- An important prerequisite for the use of prosthetic femoral replacement and allograft prosthetic composite is the availability of sufficient distal femoral length (less than 10 cm) for secure fixation of the cemented or uncemented femoral stem.
- When distal bone is severely deficient, total femoral replacement may be considered.
- The presence of superficial or deep infection around the hip is an absolute contraindication.
- Additional contraindications include lack of cooperation on the part of the patient, vascular insufficiency that may prevent healing, and the presence of significant medical comorbidities precluding administration of anesthesia.

**Preoperative Planning**

- The importance of preoperative planning in hip arthroplasty in general, and in proximal femur reconstruction in particular, cannot be overstated. These cases can be technically demanding, requiring meticulous attention to detail to achieve success.
■ Proximal femur reconstruction is performed for metaphyseal–diaphyseal lesions that extend below the lesser trochanter, cause extensive cortical destruction, and spare at least 3 cm of the distal femoral diaphysis.
■ Total femur resection is performed for diaphyseal lesions that extend proximally to the lesser trochanter and distally to the distal diaphyseal–metaphyseal junction and cause extensive bone destruction.
■ Preoperative clinical and radiographic (standing films) assessment of limb length are carried out and recorded.
■ Intraoperative monitoring of the sciatic and femoral nerves may be required in patients in whom extensive limb lengthening (more than 4 cm) is anticipated.
■ Preoperative templating to select the appropriate stem length and diameter is essential.
■ Problems with removal of existing hardware, specific needs for acetabular reconstruction, the potential need for insertion of constrained liners, and determining the absence of previous infection should be anticipated and addressed appropriately.
■ Even with the most accurate preoperative measurements, a variety of prosthesis sizes should be available in the operating room, because intraoperative adjustments with change in the anticipated size of the prosthesis are common.
■ The representative of the company that manufactured the prosthesis to be used in the proximal femur reconstruction should be present in the operating room.
■ The operating room personnel, particularly the scrub person, who assist with this procedure should be experienced. An experienced anesthesia team should administer anesthesia, because these patients often are elderly and frail, and invasive monitoring often is warranted.
■ Regional anesthesia is preferred. Intraoperative blood salvage (ie, with a cell saver) should be used in these patients.
■ The anesthesia team should be prepared for the possibility of large volume loss and encouraged to monitor this closely.
■ Invasive monitoring with arterial lines or pulmonary catheters may be necessary in some patients.

Positioning
■ We place the patient in the lateral decubitus or supine position.
■ Nonpermeable U-drapes are used to isolate the groin.
■ The distal third of the extremity also is isolated from the field using impermeable drapes. The knee must be included in the operative field, even in patients undergoing proximal femoral replacement.
■ Extension of the incision and arthrotomy of the knee to address intraoperative problems such as fractures extending distally is not uncommon.
■ The skin is scrubbed with povidone-iodine solution for at least 10 minutes and DuraPrep (3M, St. Paul, MN) applied before application of Ioban (3M) to the skin.

Approach
■ We use the direct lateral approach (Hardinge approach) or the posterolateral approach with trochanteric slide osteotomy to gain access to the hip and maintain a low threshold to extend the incision as needed (FIG 3).

FIG 2 • A. AP radiograph of a patient with multiple previous surgeries for deep infection that had resulted in massive proximal femoral bone loss. B. A megaprosthesis was used for reconstruction. C. A 72-year-old patient presenting with periprosthetic fracture. D. Because of severe bone loss, reconstruction with megaprosthesis was carried out.

FIG 3 • Diagram showing the placement of incision.
EXPOSURE

- When extensile exposure of the femur is needed, a vastus slide osteotomy, as described by Head et al.,\(^1\) mobilizes the anterior abductor, vastus lateralis, and vastus intermedius muscles anteriorly in unison and exposes the anterior and lateral aspects of the femur (TECH FIG 1).
- Meticulous soft tissue handling helps the tissues to heal and minimizes postoperative complications.
- Deep tissue specimens for frozen section and culture are obtained in all cases. Meticulous débridement of the hip is carried out to remove previous metal debris and hardware around the femur, if present.
- When a posterolateral incision is routinely used for proximal femur resections, the incision can be extended to the anterolateral aspect of the patellar tendon if a total femur resection is required.
- The abductors are identified, as are their anterior and posterior intervals. The abductors are transected through their tendinous attachments and retracted, exposing the hip joint and acetabulum.
- The vastus lateralis is reflected distally from its origin, and the posterior perforating vessels are ligated. The vastus lateralis has to be preserved because of its future role in soft tissue coverage of the prosthesis; it will be advanced proximally and sutured to the abductors.
- Care is taken not to ligate its main pedicle, which crosses anteriorly and obliquely along the rectus femoris fascia.

TECH FIG 1 • Exposure of the femur in a patient who has sustained a periprosthetic fracture.

PROXIMAL FEMORAL REPLACEMENT

- If the femur is intact, an osteotomy to split the proximal femur may be required to facilitate removal of the previous prosthesis or hardware.
- A transverse osteotomy first is made in the host bone at the most proximal area of bone with good circumferential quality.
- Because the outcome of this procedure is influenced directly by the length of the remaining femur, maximum length of the native femur is maintained at all costs.\(^1\)
- We then use a longitudinal Wagner type of coronal plane osteotomy to split the proximal femur if the bone quality is poor.
- Soft tissue attachments to the proximal femur—particularly the abductor mechanism, if present—should be retained if at all possible. Once the femur is exposed, the distal portion of the canal is prepared by successive broaching. The cancellous bone, when present, is preserved for better cement interdigitation.
- After completion of femoral preparation and determination of the size of best-fit broach, trial components are inserted, and the stability of the hip is examined.
- A distal cement restrictor is used whenever possible. The restrictor is introduced and advanced distally to allow for at least 2 cm of bone cement at the tip of the stem.
- The cement is pressurized and the final component implanted, with care taken to ensure that the porous coated portion of the stem is placed directly and firmly against diaphyseal bone with no interpositioning cement.
- The prosthesis can be assembled and then cemented distally or, alternatively, the stem can be cemented and then the body assembled onto it.

TECH FIG 2 • Demonstration of how the rotational positioning or version of the femoral component is determined. The version of the femoral stem is judged by appropriate positioning of the knee.
TOTAL FEMUR REPLACEMENT

- Indications for total femoral replacement are rare and generally include inadequate length (less than 10 cm) or such poor quality of distal femoral bone that fixation of a femoral stem is precluded. In most cases, the distal femur is of adequate length and quality to allow secure fixation.
- Total femoral replacement includes an arthrotomy of the knee to allow prosthetic replacement of the knee.
- Once exposure of the femur is completed using a lateral vastus reflecting approach, the entire femur is split longitudinally in the coronal plane.
- Again, even if it is of extremely poor quality, as much of the bone with its soft tissue attachment as possible is retained.
- The subvastus approach is extended to include a lateral or medial arthrotomy of the knee and eversion of the patella.
- The amount of tibial bone resected is kept to a minimum, but it must be of adequate thickness to allow implantation of the components and insertion of polyethylene without elevating the joint line. The tibia is prepared in the same manner as for total knee arthroplasty. Once appropriate tibial component size is determined, preparation of the tibia followed by insertion of the trial component is carried out.
- A full-length trial femur is assembled, ensuring that appropriate limb length is restored. Unless constrained liners are to be used, we prefer to use a large femoral head size to improve arc of motion and minimize instability.
- The tibial polyethylene usually is between 15 and 20 mm thick, but it may be necessary to adjust the thickness to obtain appropriate length of the extremity and restore the joint line.
- A linked articulated knee design is necessary because of loss of the stabilizing ligamentous structures. Once the prosthesis is assembled, a trial reduction is carried out and tested for stability.
- We usually do not resurface the patella unless severe wear of the articular cartilage is noted.

DETERMINATION OF LIMB LENGTH

- The length of the femoral component is determined through careful preoperative planning and intraoperative assessment.
- Two methods may be used for proper leg length determination.
  - The first method is to apply traction to the limb with measurement from the cup to the host bone osteotomy site (for proximal femoral replacement).
  - The second and preferred method is to place a Steinmann pin in the iliac crest to measure a fixed point on the femur before dislocation.
- With the long-stem trial prosthesis in place, proper leg length can be accurately restored. For patients with total femur replacement, radiographs of the opposite, normal femur may be obtained preoperatively and used for accurate templating for length.
- The length of the prosthesis usually equals the length of the bone being resected, although in many patients the integrity of the bone has been breached and the anatomy markedly altered.
- Ultimately, the femoral prosthesis length depends on the soft tissue tension about the hip. Balancing tension, restoration of limb length, and avoiding excessive tension on the sciatic nerve are of utmost importance if complications are to be avoided.

ACETABULAR RECONSTRUCTION

- The acetabulum is exposed at the beginning of the operation and examined carefully. If a previous acetabular component is in place, the stability and positioning of the component are scrutinized.
- If the component is appropriately placed and stable, it is left in place, and the liner is exchanged. If a previous acetabular component is not in place, a new component is inserted in a press-fit manner with screw fixation.
- More complex acetabular reconstruction, eg, the use of an antiprotrusio cage, occasionally is needed.
- The type of acetabular liner is determined after reconstruction of the femur has been completed, because it may be necessary to use constrained liners in patients with poor soft tissue tension and a high probability of instability.
- The constrained liners can be either snap-fit or cemented into the shell, depending on the type of the acetabular component implanted. In our experience, constrained liners are required in approximately half of patients receiving a megaprosthesis.
- Our absolute indication for the use of a constrained liner is for patients with properly positioned components and equal or near equal leg length who have intraoperative instability secondary to soft tissue deficiency.
CLOSURE

- The femur, however poor in quality, is maintained and wrapped around the megaprostheses at the conclusion of implantation.
- The muscle–tendon attachments are preserved whenever possible.
- The soft tissues—especially the abductors, if present—are meticulously secured to the prosthesis (TECH FIG 3).
- Multiple loops of nonabsorbable sutures are passed around the trochanter remnant and the attached soft tissue.
- The leg is brought to abduction and the trochanter firmly fixed onto the proximal portion of the prosthesis by passing the sutures through the holes in the prosthesis or around the proximal body and the deep tissues.
- We occasionally suture the abductors to the vastus lateralis, the tensor fascia lata, or the host greater trochanter, if available.
- Two surgical drains are inserted before the wound is closed in layers using interrupted resorbable sutures. Meticulous skin closure, with excision of hypertrophic prior scar, if necessary, is carried out to minimize postoperative wound drainage.

PEARLS AND PITFALLS

**Preoperative**
- Examine the patient thoroughly. Note previous scars, the status of the abductors, and limb length.
- Discuss the procedure with the patient and help him or her form realistic expectations.
- Perform detailed preoperative templating.
- Have the company representative available to review your templating and to ensure that correct components, and neighboring sizes, are available on the day of surgery.
- Ask for an experienced scrub and anesthetic team.

**Intraoperative**
- Minimize soft tissue dissection off the native bone and retain as much of the host bone as possible.
- Restore appropriate leg length and soft tissue tension.
- Have a low threshold for the use of constrained liners.
- Ensure good hemostasis and perform a meticulous wound closure.

POSTOPERATIVE CARE

- Intravenous prophylactic antibiotics are given and maintained until final cultures are obtained. Thromboembolic prophylaxis also is administered for 6 weeks.
- Patients are allowed to commence protected weight bearing on postoperative day 1.
- We recommend the use of an abduction orthosis for all patients and protected weight bearing for 12 weeks, until adequate soft tissue healing occurs.
- Patients usually are able to ambulate with the use of a walking aid during this time. Patients receiving total femur replacement may require the use of continuous passive motion machines for rehabilitation of the knee replacement.
- Daily physical therapy for assistance with ambulation and range-of-motion exercise for the knee are recommended.

OUTCOMES

- The first experience with use of a megaprostheses for reconstruction of the proximal femur in nonneoplastic conditions was reported in 1981. Although all 21 patients in that cohort had significant pain relief, there were two failures. One patient required acetabular component revision, and the
second patient needed revision of the femoral component for recurrent instability.

- Malkani et al\textsuperscript{16} reported the outcome of 50 revision hip arthroplasties using prosthetic femoral replacement in 49 patients with nonneoplastic condition. All patients had massive proximal bone loss, and some patients had multiple failed attempts with other reconstructive procedures. The mean follow-up was 11 years. The mean preoperative Harris hip scores of 43 ± 13 points improved significantly, to 80 ± 10 points at 1 year, and had improved to 76 ± 16 points at the latest follow-up. Before surgery, 86% of the patients had moderate to severe pain. Pain relief was achieved in 88% of patients at 1 year and 73% of patients at the latest follow-up. However, there was some deterioration in all parameters with time.

- Detailed radiographic analysis revealed an increase in the incidence of progressive radiolucent lines on the femoral and acetabular sides. Progressive radiolucency was seen around 37% of the acetabular components and 30% of the femoral components. Aseptic loosening constituted the main reason for revision surgery. Using revision as an end point, overall survivorship in the aforementioned series was 64% at 12 years. The most common complication was dislocation, with an overall rate of 22%.

- The results of 11 patients undergoing total femur replacement at the Mayo Clinic were recently evaluated. Six of these patients had total femur reconstructions performed for multiply failed ipsilateral TKA and total hip arthroplasty. Five patients, four of whom had pathologic fractures, underwent total femur replacement as limb salvage for musculoskeletal malignancy. Of the six patients who had total femoral replacement for failed arthroplasties, hip instability in two necessitated conversion to a constrained acetabular liner. Of two patients with previous infections, one developed recurrent infection despite staged total femoral reimplantation, and one has an elevated sedimentation rate on chronic antibiotic suppression but no evidence of clinical infection. All patients ambulated with either a walker or a cane. Of the five patients who had total femoral replacement for treatment of tumor, one developed hip and knee pain within 3 years, had wear of the knee hinge bushings, and is seeking disability. One patient developed wound dehiscence and sepsis in the postoperative period and died. Two patients ambulate with a cane and three without the routine use of any gait aids.

- Klein et al\textsuperscript{11} reported the outcomes of revision total hip arthroplasty with use of a proximal femoral replacement in a cohort of patients who had Vancouver type B3 periprosthetic fracture. A modular femoral replacement with proximal porous coating had been used in all cases. Twenty-one patients (mean age 78.3 years; range 52 to 90 years) were included in the cohort. At follow-up (mean 3.2 years) all but one of the patients were able to walk and had minimal to no pain. Complications included persistent wound drainage that was treated with incision and drainage (two hips), dislocation (two hips), refracture of the femur distal to the stem (one hip), and acetabular cage failure (one hip).

- Parvizi et al\textsuperscript{21} reported on 48 patients from two institutions (mean age 73.8 years) who had undergone placement of a modular megaprosthesis, with or without bone-grafting. The indications for proximal femoral replacement were as follows:
  - Periprosthetic fracture: 20 patients
  - Reimplantation because of a deep infection: 13 patients
  - Failed arthroplasty: 13 patients

- Malkani et al\textsuperscript{16} reported the outcome of 50 revision hip arthroplasties using prosthetic femoral replacement in 49 patients with nonneoplastic condition. All patients had massive proximal bone loss, and some patients had multiple failed attempts with other reconstructive procedures. The mean follow-up was 11 years. The mean preoperative Harris hip scores of 43 ± 13 points improved significantly, to 80 ± 10 points at 1 year, and had improved to 76 ± 16 points at the latest follow-up. Before surgery, 86% of the patients had moderate to severe pain. Pain relief was achieved in 88% of patients at 1 year and 73% of patients at the latest follow-up. However, there was some deterioration in all parameters with time.

- Detailed radiographic analysis revealed an increase in the incidence of progressive radiolucent lines on the femoral and acetabular sides. Progressive radiolucency was seen around 37% of the acetabular components and 30% of the femoral components. Aseptic loosening constituted the main reason for revision surgery. Using revision as an end point, overall survivorship in the aforementioned series was 64% at 12 years. The most common complication was dislocation, with an overall rate of 22%.

- The results of 11 patients undergoing total femur replacement at the Mayo Clinic were recently evaluated. Six of these patients had total femur reconstructions performed for multiply failed ipsilateral TKA and total hip arthroplasty. Five patients, four of whom had pathologic fractures, underwent total femur replacement as limb salvage for musculoskeletal malignancy. Of the six patients who had total femoral replacement for failed arthroplasties, hip instability in two necessitated conversion to a constrained acetabular liner. Of two patients with previous infections, one developed recurrent infection despite staged total femoral reimplantation, and one has an elevated sedimentation rate on chronic antibiotic suppression but no evidence of clinical infection. All patients ambulated with either a walker or a cane. Of the five patients who had total femoral replacement for treatment of tumor, one developed hip and knee pain within 3 years, had wear of the knee hinge bushings, and is seeking disability. One patient developed wound dehiscence and sepsis in the postoperative period and died. Two patients ambulate with a cane and three without the routine use of any gait aids.

- Klein et al\textsuperscript{11} reported the outcomes of revision total hip arthroplasty with use of a proximal femoral replacement in a cohort of patients who had Vancouver type B3 periprosthetic fracture. A modular femoral replacement with proximal porous coating had been used in all cases. Twenty-one patients (mean age 78.3 years; range 52 to 90 years) were included in the cohort. At follow-up (mean 3.2 years) all but one of the patients were able to walk and had minimal to no pain. Complications included persistent wound drainage that was treated with incision and drainage (two hips), dislocation (two hips), refracture of the femur distal to the stem (one hip), and acetabular cage failure (one hip).

- Parvizi et al\textsuperscript{21} reported on 48 patients from two institutions (mean age 73.8 years) who had undergone placement of a modular megaprosthesis, with or without bone-grafting. The indications for proximal femoral replacement were as follows:
  - Periprosthetic fracture: 20 patients
  - Reimplantation because of a deep infection: 13 patients
  - Failed arthroplasty: 13 patients

- Nonunion of an intertrochanteric fracture: 1 patient
- Radiation-induced osteonecrosis with a subtrochanteric fracture: 1 patient
- Three patients died before the minimum 2-year follow-up interval had elapsed, and two additional patients were lost to follow-up. The mean duration of follow-up for the remaining study group of 43 patients was 36.5 months. At the time of follow-up, there was a significant improvement in function as measured with the Harris hip score. The major complications were instability (8 patients), failure of the acetabular component (4 patients), and infection (1 patient). Of the eight patients with instability, six required reoperation because of dislocation and two, who had subluxation, required no further intervention. With revision used as the end point, the survivorship of the implant was 87% at 1 year and 73% at 5 years.

### COMPLICATIONS

- The major complications encountered following the use of a megaprosthesis are early dislocation and aseptic loosening. The cause of instability in this group of patients is multifactorial. First, these patients often have had multiple previous reconstructive procedures that have led to compromised abductors around the hip. Furthermore, the inability to achieve a secure repair of the residual soft tissues to the metal prosthesis predisposes these patients to instability.\textsuperscript{9} The problem is further exacerbated in patients in whom the proper leg length and appropriate soft tissue tension is not achieved.

- We have implemented changes in our practice to minimize instability. These include the use of constrained cups in selective cases, routine use of a postoperative abduction brace, and augmentation of the proximal bone with the use of strut allograft that imparts more rigidity for soft tissue attachment. It is conceivable that the problem of soft tissue to metal attachment may be better addressed in the future with the use of trabecular metals such as tantalum, with its excellent potential for soft tissue ongrowth. The use of a modular prosthesis has provided a better strategy for dealing with this problem. The proximal femoral bone, however poor in quality, should be retained and reapproximated to the prosthesis to minimize dislocation. In addition, all efforts should be made to achieve equal limb lengths and to obtain acceptable soft tissue tension. Another important factor in the prevention of instability is the use of larger femoral heads in elderly patients who have a low level of activity if instability is encountered intraoperatively.

- The other common complication of megaprosthesis reconstruction is the relatively high incidence of acetabular and femoral radioluency in most reported studies. The reason for this complication lies in the biomechanical aspect of this reconstructive procedure. The diaphyseal cement fixation predisposes the bone-cement-prosthesis unit to high torsional and compressive stresses, leading to early loosening. Cemented long-stem revision implants are known to have limited success and currently are recommended only for elderly and sedentary patients.\textsuperscript{18} As would be expected, the incidence of radiolucency after the use of press-fit or proximally or extensively coated ingrowth stems is markedly lower than that with a megaprosthesis.\textsuperscript{2,20}

- The incidence of radiolucency after megaprosthesis reconstruction at our institution has declined somewhat. This may be the result of improved cementing techniques, namely, the use of pulse lavage and plugging of the canal for better cement
interdigitation. However, the more likely explanation for the reduction in the incidence of radiolucency is that we have narrowed the indications for the use of megaprosthesis to elderly and sedentary patients who place lower demands on the prosthesis.

REFERENCES

DEFINITION
- Acetabular bone loss remains a challenge to the joint reconstruction surgeon.
- Bone loss may be the result of trauma, acetabular dysplasia, tumor, infection, implant loosening, or osteolysis.
- Primary reconstruction methods often are inadequate to restore bone loss.
- Acetabular impaction grafting restores bone stock by using tightly impacted, well-contained cancellous bone graft.
- The goal of impaction bone-grafting is to achieve immediate implant stability with the use of compacted, morselized bone graft. In turn, this allows the restoration of bone stock through bone remodeling.
- Impaction bone grafting is suitable for simple cavitary defects as well as extensive segmental defects.
- Stainless steel mesh is used to convert segmental defects (medial wall or peripheral) into contained cavitary defects suitable for impaction grafting.
- Impacted bone graft provides an excellent bed for cement interdigitation, which confers immediate mechanical stability and acts as a substrate promoting bone remodeling, allowing bone stock restoration.
- Acetabular impaction grafting has shown good long term results.\textsuperscript{7-10}
- Standard implants and current cement techniques often are used.

ANATOMY
- The acetabulum is a complex three-dimensional structure.
- It is important to identify relevant landmarks intraoperatively, such as the transverse acetabular ligament, medial wall, anterior and posterior walls and columns, and superior dome (FIG 1).
- Bone impaction grafting combined with a cemented polyethylene cup allows for the restoration of the hip center and normal hip biomechanics.

PATHOGENESIS
- Animal studies show that impacted, morselized fresh-frozen allograft bone incorporates into new bone.\textsuperscript{6}
- Twenty-four acetabular bone biopsy specimens were obtained from 20 patients who had undergone acetabular reconstruction with impaction bone grafting.\textsuperscript{11}
  - Biopsy specimens were obtained at 3 months to 15 years.
  - Histology showed rapid revascularization of the graft followed by osteoclastic resorption and woven bone formation on the graft remnants.
  - A mixture of graft, new bone, and fibrin remodeled completely into a new trabecular structure, with normal lamellar bone and only scarce remnants of graft material.
- Localized areas of nonincorporated bone graft surrounded by fibrous tissue remained, irrespective of the follow-up period.
- Large nonincorporated fragments of cartilage also were found, particularly in cases in which femoral head bone chips were produced by a bone mill.
- Despite the contact between bone graft and cement, the bone graft retains its biologic and mechanical viability and healing potential.\textsuperscript{5}

NATURAL HISTORY
- Reports on acetabular impaction grafting show promising intermediate and long-term results.\textsuperscript{4,7-10}

PATIENT HISTORY AND PHYSICAL FINDINGS
- It is important to obtain a thorough history from the patient with a failed acetabular component.
- A history of persistent infection should be ruled out.
- Physical examination should include examination of previous incisions, sinus tracts, range of motion, leg-length discrepancy, neurovascular status, and contractures.
- Records of previous surgeries should be obtained.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- The initial diagnostic imaging examination should begin with standard AP pelvis and AP and lateral radiographs of the affected hip.
A CT scan may be useful in identifying bone loss and structural defects.

The actual bone defects or bone loss may be more severe than preoperative radiographic studies reveal.\(^\text{12}\)

A preoperative work-up for infection should be performed.

Laboratory studies, including a complete blood cell count with differential, erythrocyte sedimentation rate, and C-reactive protein, should be obtained.

If laboratory values are elevated or suspicious for infection, a fluoroscopic guided aspiration should be performed and sent for cell count, Gram stain, and cultures to rule out infection.

**DIFFERENTIAL DIAGNOSIS**

Alternative methods of fixation include cemented acetabular revision, revision with structural allograft, uncemented acetabular components with structural allograft, uncemented components with metal augments, jumbo acetabular components, and trabecular metal acetabular components.

In cases of pelvic discontinuity or severe anterior or posterior column defects, alternative techniques of reconstructions such as cages, plates and screws, or trabecular metal implants may be necessary.

**NONOPERATIVE MANAGEMENT**

No nonoperative techniques are available for reconstruction of the failed acetabulum.

**SURGICAL MANAGEMENT**

**Preoperative Planning**

Precise preoperative templating is necessary to restore the acetabular component to its anatomic position to reestablish the native hip center.

**Positioning**

The patient is positioned according to the surgeon’s preference and planned surgical approach. This technique is applicable to most patient positions and surgical techniques.

**Approach**

Any surgical approach that allows full acetabular exposure can be used. It is important that the surgeon use an approach that is both familiar and extensile.

Wide exposure and identification of the major landmarks of the acetabulum are necessary.

**ACETABULAR EXPOSURE**

A wide exposure of the acetabulum is necessary. The femur may be mobilized or a femoral osteotomy performed to improve acetabular exposure. Removal of the femoral stem may be necessary to gain unimpeded exposure of the acetabulum.

- Circumferential capsulotomy often is necessary.
- Iliopsoas release may be necessary.

The previous acetabular components are removed using traditional implant removal techniques and care must be taken to avoid additional bone damage.

Any residual cement must be removed.

Fibrous tissue and necrotic bone are débrided until viable bleeding bone is encountered.

Acetabular bone defects are identified.

**ACETABULAR PREPARATION**

An acetabular reamer is used to remove sclerotic cortical bone to expose bleeding trabecular bone. Multiple drill holes (2 mm) may be used to create bleeding in areas of extremely sclerotic bone.

The acetabulum is irrigated with pulsatile lavage.

The anatomic position for the acetabular component is identified.

- Because there may be severe anterior, posterior, or superior bony deficiencies, this is best done by first locating the inferior portion of the acetabulum and transverse acetabular ligament.
- A trial acetabular component may be used to identify bone deficiencies and estimate the amount and location of bone graft needed.

Segmental defects are converted into cavitary defects with flexible wire mesh and screws (X-change Revision Instrument System, Stryker Orthopaedics, Mahwah NJ).

This mesh is precontoured but may be trimmed and adapted to fit the identified acetabular defects.

Medial segmental defects may be covered with metal mesh.

- Usually the mesh is stable without screws; however, small screws may be used for initial mesh stability.
- If the medial wall is found to be intact but weak, mesh may be used to support or prevent dorsal graft migration during impaction (TECH FIG 1A).

Peripheral wall defects are identified.

Complete exposure of the peripheral rim with subperiosteal dissection is performed to avoid injury to surrounding neurovascular structures such as the superior gluteal nerve and vessels.

Peripheral mesh is applied to the outer side of the acetabular rim with bicortical screws at a minimum of three points (TECH FIG 1B).

If necessary, the wire mesh may be applied to the inner surface of the acetabulum and fixed with screws.
**TECH FIG 1** - After removal of a failed acetabular component, stainless steel wire mesh and screws are used to reconstruct a central medial wall defect (A) and a peripheral superolateral defect (B).

**PREPARATION OF BONE GRAFT**
- Allograft bone from fresh-frozen femoral heads is used. If autogenous bone is available, this may be mixed with the allograft bone. Usually at least two femoral heads are needed. Large defects require more graft material. The allograft is thawed and débrided of all soft tissue before it is used.
- A 7- to 10-mm bone chip is recommended, in contrast to the smaller bone graft size used with femoral impaction grafting.
- Soft tissue and cartilage must be removed from the bone graft.
- The femoral head is divided into four parts with a saw and morselized using a rongeur into 7- to 10-mm bone chips.
- Alternatively, commercially available bone mills may be used. Most bone mills produce graft sized for femoral impaction grafting, which may be too small for acetabular impaction grafting.
- Larger bone graft size and the removal of excess fat and soft tissue with mechanical débridement and warm saline lavage enhances initial stability.

**ACETABULAR BONE RECONSTRUCTION**
- The acetabulum is irrigated with pulsatile lavage.
- Small cavitary defects are first packed with graft. Then bone graft is impacted into the acetabular cavity layer by layer to construct an anatomically located neoeacetabulum.
- Vigorous impaction using specialized impactors is necessary. A small impactor should be used initially for graft impaction and gross acetabular reconstruction, and then progressively larger impactors should be used to shape the neoeacetabulum (TECH FIG 2).
- Reverse reaming with an acetabular reamer should be avoided, because this technique has shown inferior results.
- When performed correctly, the bone graft will be stable in the acetabulum even after the impactors are removed.
- At least 5 mm of impacted graft is necessary to prevent overpenetration of cement into the host bone–graft interface.
- The last impactor should be approximately 4 mm larger than the acetabular cup to be placed. This allows for an adequate cement mantle.
- Once impacted, the bone graft and bed should not be irrigated with pulsatile lavage.
Cemented Cup Insertion

- The acetabular bed is thoroughly dried. Hydrogen peroxide may be used to clean and dry the acetabular bed.
- Vacuum-mixed antibiotic-loaded cement is prepared using the technique of choice. While still in a relatively viscous state, the cement is placed in the acetabular bed. A cement pressurizer is used to introduce the cement into the impacted bone graft (TECH FIG 3A).
- An all-polyethylene cup is implanted using the alignment guide and insertion handle of the surgeon’s choice (TECH FIG 3B). The cup is held in position with a cup pusher until the cement hardens.

TECH FIG 2 • A. The defect is filled with allograft bone chips. B. The bone chips are vigorously impacted using specialized bone impactors of progressively larger size.

TECH FIG 3 • A. After a stable bone graft thickness of at least 5 mm has been obtained, antibiotic-impregnated cement is pressurized into the bone graft. B. An all-polyethylene cup is then inserted into the cement mantle.
Commercial bone mills often produce smaller graft sizes.

Sclerotic bone should be reamed or drilled with a 2-mm drill.

Bone graft should be 7 to 10 mm³. Overimpaction may cause fractures.

Remove all soft tissue and cartilage.

Optimal cup placement is necessary to restore the anatomic center, thereby limiting instability.

Reverse reaming with acetabular reamers should be avoided.

Fresh-frozen bone femoral head is the ideal graft.

Wide acetabular exposure is necessary to identify and contain bone defects with wire mesh. Be cautious of neurovascular structures.

Interval-appropriate radiographs are recommended.

Complications generally related to revision hip arthroplasty, such as infection, instability, hematoma, and neurovascular injury, can occur.

Wide acetabular exposure puts neurovascular structures such as the superior gluteal nerve and vessels at risk.

Intraoperative fractures may occur due to overimpaction of the bone graft.

Potential infection or graft-versus-host disease theoretically may occur as a result of the bone graft material. Eradication of infection may require resection arthroplasty.

PEARLS AND PITFALLS

Acetabular exposure

- Wide acetabular exposure is necessary to identify and contain bone defects with wire mesh. Be cautious of neurovascular structures.

Acetabular preparation

- Sclerotic bone should be reamed or drilled with a 2-mm drill.

Bone graft preparation

- Fresh-frozen bone femoral head is the ideal graft.
- Remove all soft tissue and cartilage.
- Bone graft should be 7 to 10 mm³.
- Commercial bone mills often produce smaller graft sizes.
- Irrigate graft with warm saline prior to impaction.
- Do not irrigate the graft once it is impacted.

Acetabular bone reconstruction

- Vigorous impaction with specially designed impactors is necessary to provide initial mechanical stability of the graft.
- Overimpaction may cause fractures.
- Reverse reaming with acetabular reamers should be avoided.

Cemented cup insertion

- Optimal cup placement is necessary to restore the anatomic center, thereby limiting instability.

REFERENCES


DEFINITION

- Acetabular bone deficiency may occur primarily (e.g., dysplasia, inflammatory arthritis, seronegative arthropathy) or secondarily (e.g., aseptic or septic loosening of acetabular components, osteolysis, trauma, iatrogenic loss during removal of well-fixed components).
- The use of antiprotrusio cages is indicated in situations where an uncemented porous-coated acetabular component will not gain reliable initial stability.

ANATOMY

- The confluence of the ilium, the ischium, and the pubis forms the hemispherically-shaped acetabulum, each contributing to the anterior and posterior walls and columns.
- Surgical landmarks include the anterior and posterior walls, dome, and medial wall “teardrop.”
- The acetabulum is normally oriented with 45 degrees of inclination and 15 degrees of anteversion relative to the pelvic plane.

PATHOGENESIS

- Acetabular bone deficiency may occur primarily due to dysplasia. This type of deficiency usually does not require the use of an antiprotrusio cage.
- Certain conditions (e.g., rheumatoid arthritis, juvenile rheumatoid arthritis, ankylosing spondylitis, Paget disease) may predispose to acetabular protrusion but usually do not require the use of an antiprotrusio cage.
- The antiprotrusio cage is used most often in cases of secondary bone stock deficiency so massive that the use of a cementless press-fit acetabular component is precluded.

NATURAL HISTORY

- The natural history of massive acetabular bone defects that would require an antiprotrusio cage is not known. Patients usually require revision surgery to return to functional activities.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The history should be directed to determine whether the source of pain is extrinsic or intrinsic.
- The patient’s pain may be extrinsic (e.g., lumbar radiculopathy, intrapelvic pathology), in which case revision surgery may fail to relieve pain completely.
  - Pain usually, but not always, is located in the groin.
  - Infection always must be assessed with careful questioning about previous infections, fevers, chills, wound drainage, and pain at rest.
  - Start-up pain is a characteristic indication of loosening.
- Medical comorbidities must be assessed to determine the presence of any that may compromise the outcome of the surgery or place the patient at increased risk of complications.
  - The skin should be inspected visually for placement of prior incisions and signs of infection.
  - The appropriate incision for the surgical approach must be used with an adequate (6 cm) skin bridge.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs, including AP of the pelvis and AP and true lateral of the hip should be obtained to classify bone loss and to adequately preoperatively plan (FIG 1).
- CT scans may be used to assess the remaining bone stock.
  - This is especially important in cases of superior or posterior bone loss that may require allograft reconstruction.
  - The CT scan can help determine the need to have allograft bone available to reconstruct the defect and may help to dictate the approach if a posterior column reconstruction or plating is necessary.
- CT scans with intravascular contrast are useful in situations in which a prior implant is medial to Kohler’s line and proximity of the implant to the vessels and intra-abdominal contents is unknown.
- Erythrocyte sedimentation rate and C-reactive protein are useful screening tools to detect infection.
- Aspiration of the hip to assess for infection is valuable if either the erythrocyte sedimentation rate, C-reactive protein, or clinical suspicion is elevated.
- Nuclear medicine studies such as technetium Tc 99m diphosphonate in combination with gallium citrate, indium 111–labeled leukocyte scans, positron emission tomographic scans with 18F-fluorodeoxyglucose (PET-FDG), and sulfur colloid scans may help differentiate aseptic from septic loosening.

DIFFERENTIAL DIAGNOSIS

- The following conditions may contribute to pain and may be the cause of continued pain after the surgery:
  - Lumbar radiculopathy
  - Spinal stenosis
  - Sacroiliac degenerative joint disease
  - Intra-abdominal pathology
  - Intrapelvic pathology
  - Neuropathy
  - Meralgia paresthetica
  - Complex regional pain syndrome
  - Vascular claudication
  - Primary bone tumors
  - Metastasis

NONOPERATIVE MANAGEMENT

- Nonoperative management of severe acetabular bone loss is reserved for those patients for whom surgical management is contraindicated. These include patients with substantial medical comorbidities and patients with active infection.
SURGICAL MANAGEMENT

- Surgical management begins with preoperative planning.
- The radiographs are assessed and it is determined whether the defect can be reconstructed with a cementless acetabular component or will require an antiprotrusio cage.
- The surgical approach is planned.
  - If posterior column plating is anticipated, a posterior approach is indicated.
  - If this is not required, a direct lateral or posterior approach may be used, according to the surgeon’s preference.
- The acetabulum is exposed, bone loss is assessed, and the determination as to the appropriate reconstructive choice is made.

Preoperative Planning

- Planning for the antiprotrusio cage begins with appropriate radiographs.
- The radiographs allow for classification of the defect and aid in planning for the reconstruction.
- We have found the Paprosky classification to be helpful in defining bone deficiency and in predicting the method of reconstruction (FIG 2).
- Paprosky type 1 acetabular defects have minimal bone loss and usually can be reconstructed using just a cementless component.
- Type 2A defects have an intact superior rim, and the acetabulum is oval in shape. The anterior and posterior columns are intact. The implant has migrated less than 2 cm. These defects may be reconstructed with so-called “jumbo” cups or cementless reconstruction with additional bone grafting or trabecular metal augments. The socket also may be placed in a more superior position to attain greater contact with host bone.
- Type 2B defects are similar to type 2A defects, with the exception of loss of the superior rim. The implant has migrated less than 2 cm. The superior rim can be reconstructed with an uncemented socket in association with bone grafting or trabecular metal augmentes.
- Type 2C defects involve medial bone loss with intact anterior and posterior columns. The medial bone loss may be reconstructed with bone grafting or trabecular metal augmentes and an unce-mented socket.
- Type 3A defects generally migrate more than 2 cm superolaterally. The medial wall and ischium usually are still present, but damaged. These defects can be reconstructed with bone grafting or trabecular metal augmentes and an unce-mented socket.
- Type 3B defects generally migrate more than 2 cm supra-medially. There is loss of the teardrop and severe damage to the ischium. Pelvic discontinuity should be suspected. These defects can be reconstrucrted with bulk allograft, trabecular metal, antiprotrusio cage, or a combination. Posterior column plating may be needed in cases of acute discontinuity. If this is a possibility, then a posterior approach should be selected.
- Pelvic discontinuity should be suspected if a fracture is noted that involves both the anterior and posterior columns, the inferior hemipelvis has migrated medial to the superior hemipelvis, or the inferior hemipelvis is rotated in relation to the superior hemipelvis.
- Large posterior column defects may predispose to cage failure, and reconstruction of the defect should be included in preoperative planning.
- An appropriate device should be selected.

FIG 1 • AP radiograph of the hip demonstrates medial migration of the acetabular cup with significant loss of acetabular bone stock.

FIG 2 • Preoperative radiographs of a patient with severe acetabular bone loss due to superior and medial migration of construct as well as pelvic discontinuity (Paprosky type 3B defect). An AP radiograph of the pelvis (A), an AP view of the hip (B), and a frog-leg lateral view of the hip (C) are obtained. Occasionally more specialized views of the pelvis, such as the Judet view, may be necessary to assess integrity of the acetabular columns.
The flanges should be malleable to allow the cage to be shaped to the bone.
- The implant must have sufficient strength.
- We believe that an inferior flange that gains fixation in or on the ischium is superior to a hook that gains fixation on the teardrop.

**Positioning**
- The patient is positioned according to surgeon preference, as dictated by the surgical approach. The hip should be draped in such a fashion as to allow wide surgical exposure.

**Approach**
- The surgeon should select a posterior approach if he or she anticipates the need for posterior column plating or reconstruction. Otherwise, the surgeon should select the approach that is most familiar and comfortable.
- A trochanteric ostetomy, either conventional or extended, may improve exposure of the acetabulum and pelvis.
- Exposure of the sciatic nerve (posterior approach) is left to the judgment of the surgeon.

**ACETABULAR EXPOSURE**
- The acetabulum is exposed, and the failed construct and any soft tissue that interferes with visualization should be retracted or removed (TECH FIG 1A–E).
- The anterior and posterior walls/columns, superior dome/rim, medial wall, teardrop, and ischium are identified, and bone loss is noted (TECH FIG 1F–H).

**TECH FIG 1** • Acetabular exposure.
A. The acetabulum after exposure with a direct lateral (modified Hardinge) approach in the supine position. B. The polyethylene cup is removed. C. Unstable cage construct is removed in one piece with cement. D,E. Failed construct after removal. Once all material is removed, the acetabular landmarks are clearly exposed and evaluated: teardrop (F), posterior column (G), superior dome/rim (H).
INTRAOPERATIVE DETERMINATION OF RECONSTRUCTIVE TECHNIQUE

- The remaining bone stock is assessed and corroborated with the preoperative assessment of bone loss.
  - Paprosky types 1, 2A, 2B, 2C, and 3A defects usually can be reconstructed with an uncemented acetabular component with or without bone grafting or trabecular metal augments.
  - All acetabuli, especially Paprosky type 3B defects, should be tested for pelvic discontinuity.
- If a pelvic discontinuity exists (TECH FIG 2), the surgeon may then elect to use an antiprotrusio cage with or without posterior column plating or additional bone grafting.
  - Alternatively, the surgeon may elect to distract the discontinuity with an uncemented socket and bridge the defect in this manner.
- The acetabulum should be assessed for the remaining bone’s ability to support an uncemented component. To support an uncemented cup, the remaining bone stock should allow for at least partial inherent stability of the reamer or trial.
  - Reamers or trials that are inherently unstable may not be appropriate for cementless reconstruction.

- The reamers are not used initially to shape the acetabulum but, rather, are used to assess the ability of the remaining bone to support a socket.
  - If it is determined that the remaining bone stock cannot support a socket, then an antiprotrusio cage should be used.

BONE PREPARATION

- The ilium must be exposed with care to avoid the superior gluteal neurovascular bundle (TECH FIG 3A).
- The size of the defect can be assessed with a standard acetabular reamer. The reamer can then be used to remove small amounts of bone that may prevent complete seating of the cage (TECH FIG 3B).
  - It should not be necessary to remove significant bone, because the indication for use of this device is severe bone loss.
  - The outer diameter of the reamer that best fits the acetabulum determines the outer diameter of the cage.
  - The trial cage or the actual implant can be used to determine the removal of small amounts of bone that interfere with complete seating of the cage (TECH FIG 3C).

BONE GRAFT AND TRABECULAR METAL AUGMENTATION

- The cage may not be stable in situations with severe superior dome or posterior bone loss.
  - It may be necessary to augment the acetabulum with either structural or particulate bone graft (TECH FIG 4) or trabecular metal to provide the cage with support.
  - Severe superior dome or posterior wall or column bone loss may be reconstructed with structural allograft.
Bone graft and trabecular metal augmentation.

A. Allograft cancellous bone is placed into the prepared acetabulum. B. Large reamer is used in reverse to crush and distribute the graft.

TECH FIG 4

CAGE IMPLANTATION

- The ischial flange can be placed on or in the ischium (TECH FIG 5A, B).
  - The advantage of placing the flange on the ischium is that screws can be used to fix the cage to the ischium (TECH FIG 5C, D).
  - The advantage of blade-plating the flange in the ischium is avoidance of the sciatic nerve (TECH FIG 5E).
  - Both methods allow for stable fixation.

- The cage is shaped to the contour of the ilium and ischium while allowing for seating of the socket portion of the cage into the remaining acetabulum. Usually the ischial flange must be bent laterally to follow the contour of the ischium.
- The ischial flange is fixed to or in the ischium using the surgeon’s preferred method.

TECH FIG 5

- Cage implantation. A. The cage is shown in the orientation in which it will be inserted. B. Cage being inserted. C, D. Screw fixation to ischium. E. Blade plate fixation of the ischium flange. (continued)
Chapter 10 REVISION THA WITH ACETABULAR BONE LOSS: ANTI-PROTRUSION CAGE

The socket portion of the cage must be fully seated within the acetabulum to maximize the stability of the construct.

The flange must be contoured to the ilium to minimize cage motion. Usually this requires the flange to be bent medially with some rotation.

Once the cage is appropriately contoured to the ischium, ileum, and acetabulum and fixed to the ischium, it is fixed with screws through the dome of the cage.

Fixation usually can be obtained in the posterior and anterior columns, with care to stay within the recognized safe zones.

Additional screws should then be passed through the superior flange into the ilium (TECH FIG 5F,G). The number of screws is limited by the amount of bone that can safely provide fixation.

A polyethylene liner is then cemented into the cage construct.

The cement is placed in the socket and pressurized (TECH FIG 5H–K).

A liner designed for cementation or a liner appropriately modified for cementation is then cemented into place in the appropriate position (TECH FIG 5L).

A 2-mm cement mantle is desirable.

Care must be taken not to leave large areas of the liner uncovered.

---


---

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Preoperative planning</th>
<th>Thorough preoperative planning enables the surgeon to have the appropriate instrumentation, implants, bone graft, staff, and assistants available.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A complete plan includes contingency plans in case the primary plan is inadequate or the bone loss is worse than anticipated.</td>
</tr>
<tr>
<td>Preoperative work-up</td>
<td>Infection must be excluded.</td>
</tr>
<tr>
<td></td>
<td>The patient’s medical status must be optimized.</td>
</tr>
<tr>
<td></td>
<td>The patient must be compliant.</td>
</tr>
</tbody>
</table>
**Intraoperative bone assessment**
- The remaining acetabulum must be assessed for ability to support an uncemented socket. If partial inherent stability is not possible, then an antiprotrusio cage should be used.

**Bone preparation**
- Minimal additional bone should be removed.
- The cage should be supported by adequate superior and posterior bone, which may require augmentation to achieve.

**Cage fixation**
- The ischial flange may be fixed on or in the ischium.
- The socket portion of the cage must be fully seated.
- The ilial flange must be contoured to the ilium.
- Screws should be passed through the dome and ilial flange.
- Care should be taken to remain within the “safe zones.”

**POSTOPERATIVE CARE**
- Radiographs are taken to confirm appropriate cage positioning (**FIG 3**). Intraoperative radiographs may be beneficial to confirm cage positioning prior to final fixation of the device.
- The patient is allowed protected weight bearing as tolerated if bone augmentation was not necessary.
- The patient is restricted to toe-touch weight bearing for 6 to 12 weeks if bone augmentation was necessary. He or she is then allowed to increase weight bearing progressively on a schedule that is individualized to each patient.

**OUTCOMES**
- The survivorship of antiprotrusio cages has been acceptable in short- to mid-term follow-up.
- However, because most of these devices cannot achieve biologic fixation, it is assumed that they will loosen over time, although one series reported 92% survivorship at 21 years.4
- Other series have shown 100% survivorship at 7.3 years5 and 93.4% survivorship at 10.9 years.2
- The success of these devices also will depend on the environment in which they are placed.
- Most surgeons in North America are selectively using these devices in cases of severe acetabular deficiency in which a press-fit uncemented socket is not appropriate. This may predispose these devices to failure.
- A recent report on the use of the cage in the setting of discontinuity revealed a 31% revision rate at 46 months.1

**COMPLICATIONS**
- The use of antiprotrusio cages is accompanied by the complications inherent to significant revision surgery:
  - Blood loss
  - Infection
  - Neurovascular injury
  - Construct failure
  - Anesthetic and medical complications

**REFERENCES**
Resection Arthroplasty and Spacer Insertion

Mark J. Spangehl and Christopher P. Beauchamp

DEFINITION
- Resection arthroplasty and insertion of a spacer is used for the management of chronic deep periprosthetic infection of the hip.
- The discussion in this chapter pertains to the diagnosis and management of late chronic infection. Acute infection, described below, has a different presentation, methods of diagnosis, and management algorithm.
- Antibiotic-loaded spacers are an adjuvant treatment for the management of deep infection by providing elusion of antibiotics into the local tissues.³
  - Historically, deep periprosthetic infection was treated by resection arthroplasty alone.
  - Depending on the type used, however, spacers allow for improved function between resection and reimplantation when compared with resection arthroplasty alone by providing soft tissue tension and an articulating surface and in most cases allowing weight bearing through the lower extremity.
  - Spacers can be grouped into articulating spacers or nonarticulating (static) spacers.
    - Articulating spacers can resemble either a total hip replacement, with antibiotic-loaded implants inserted on both the acetabular and femoral sides, or a hemiarthroplasty spacer, with an antibiotic-loaded implant inserted only on the femoral side.
    - Static spacers are blocks and dowels of antibiotic-loaded cement placed into the acetabulum and femoral canal after removal of the implants.

ANATOMY
- The pertinent anatomy of the hip is shown in FIGURE 1.
- The fasciae latae cover the musculature of the hip.
- Distally the fibers condense and form the iliotibial band, which inserts onto the lateral aspect of the proximal tibia (Gerdy’s tubercle).
- Proximally the fascia splits and envelops the gluteus maximus (inferior gluteal nerve) and the tensor fascia lata (superior gluteal nerve).
- Deep to the fascia lata, over the lateral aspect of the hip are the major abductors: the gluteus medius and minimus (superior gluteal nerve).
- More posteriorly, deep to the gluteus maximus, are the short external rotators.
  - From proximal to distal: piriformis (branches from S1 and S2), superior gemellus (nerve to obturator internus), obturator internus (nerve to obturator internus), inferior gemellus (nerve to quadratus femoris); slightly deeper is the obturator externus (posterior branch obturator nerve); distally is the quadratus femoris (nerve to quadratus femoris).
  - The sciatic nerve usually emerges from the lower border of the piriformis and is posterior to the short external rotators.
  - When approaching the hip posteriorly, retracting the short rotators posteriorly will provide some protection to the sciatic nerve.

- An ascending branch from the medial femoral circumflex courses over the posterior aspect of the quadratus femoris; this may produce bleeding during dissection.
- Anterior to the hip capsule is the iliopsoas tendon on which the femoral nerve lies as it crosses under the ilioinguinal ligament and enters the thigh.
- Retractors placed over the anterior wall need to be placed directly on bone to avoid injury to the nerve.

PATHOGENESIS
- Periprosthetic infections are classified as acute or chronic infections (Table 1).⁶,⁸,⁲⁴
- Acute infections are either acute postoperative infections or acute hematogenous infections.
  - If diagnosed early, acute infections can be managed with débridement and irrigation with component retention.
  - Chronic infections generally present in a delayed manner, usually months or occasionally years after the index procedure. The infection has likely been present since the original procedure, but because of the low virulence of the infecting organism, classic signs of infection are lacking, and hip pain may be the only presenting symptoms.
  - Chronic infections also include a missed or delayed diagnosis of an acute infection. A missed or delayed diagnosis of an acute infection must now be treated as chronic and no longer managed as an acute infection.

NATURAL HISTORY
- Chronic periprosthetic infection will continue to cause pain and disability.
- The severity of symptoms depends on the virulence of the organism, the overall health or comorbidities of the patient, and the status of the implants and surrounding soft tissues.
- Low-virulence organisms (eg, coagulase-negative \textit{Staphylococcus}) may present with chronic pain, whereas more virulent organisms (eg, \textit{Staphylococcus aureus}) or hosts that are immunocompromised may present with more obvious signs of infection.
- Untreated patients are at risk for seeding other joint replacements. The incidence is unknown and likely depends on the virulence of the organism and the host’s medical comorbidities.
- Patients who have multiple medical comorbidities or are infected with more virulent organisms may be at greater risk for signs or symptoms of systemic infection and, subsequently, seeding of other joints by hematogenous spread.
- With time, chronic infection can cause bone loss and loosening of implants.
- In addition to increased pain from implant loosening, the osteolysis, which may be secondary to both infection and loose implants, can result in an increased risk of periprosthetic fracture.
PATIENT HISTORY AND PHYSICAL FINDINGS
- In most cases, a careful history will lead one to suspect a diagnosis of chronic infection.
- Often patients give a history of poor wound healing, with prolonged drainage, prolonged antibiotic use, or surgical débridement.
- These cases represent missed or failed treatment for acute postoperative infections. Similarly, missed acute hematogenous infections, which are now chronic infections, present with a history of sudden deterioration in hip function, without other obvious causes.
- Another subset of patients with chronic infection present only with pain. Often it has been present since the time of the initial hip replacement procedure.
- There may also be a history of poor wound healing or prolonged drainage.
- The pain is usually different in character than the preoperative activity-related arthritic pain. It may be more constant, present at rest, and a dull ache in character.

![Antomy of the lateral aspect of the hip joint.](FIG 1)

**Table 1**

| Classification of Deep Periprosthetic Infection (based on timing of presentation) |
|---------------------------------|---------------------------------|
| Type of Infection               | Timing of Presentation          | Treatment                          |
| Acute postoperative infection   | 1–3 weeks after index operation| Débridement and component retention|
| Acute hematogenous infection    | Sudden onset of pain in well-functioning joint | Débridement and component retention |
| Late chronic infection          | Low-grade chronic infection presenting >1 month after index operation (includes missed or delayed diagnosis of acute infection) | Removal and reimplantation of implant |

- The physical examination is often nonspecific in the setting of chronic infection.
- The examination findings range from nearly normal, with only mild pain with range of motion, to more obvious signs of infection, such as a chronically draining sinus.
- Examinations to perform include the following:
  - Observe gait pattern. Pain or muscle weakness may cause limp. Trunk may shift over affected hip.
  - Trendelenburg sign. A positive result may indicate abductor dysfunction or pain or a neurologic problem (superior gluteal nerve or L5 nerve root).
  - Inspect any old incision sites and surrounding skin. Plan to incorporate all or as much of the old incisions as possible. A draining sinus generally indicates a deep infection.
  - Examine the soft tissue for thickness and compliance. Poor tissue integrity may require rotation flap for closure.
  - Passive range of motion. Significant stiffness may make surgical exposure more difficult. Excessive motion may increase the risk of instability.
  - Straight-leg raising may be limited by pain from infection or loose implants.
  - Assess true and apparent leg lengths.
  - Perform a neurovascular examination. Check and document status of motor group function, sensation, and pulses preoperatively in case of any change following surgery.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Radiographs
  - In most cases, radiographs do not show signs of chronic infection. Radiographs are necessary to exclude other causes of aseptic failure and for surgical planning.
  - In a few cases, radiographs from patients with longstanding chronic infection will show signs of deep infection. A periosteal reaction is considered pathognomonic for deep infection. Sinus tracks, extending through bone, may rarely be seen (FIG 2).
Laboratory investigations
- The most useful laboratory tests, both to confirm and to exclude a suspected diagnosis of deep infection, are the erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP).
  - Various values have been considered positive (indicative of infection). It is generally accepted that an ESR above 30 mm/hr and a CRP above 10 mg/L are indicators of potential infection, provided the patient does not have other diagnoses that lead to elevated inflammatory markers.21
  - The sensitivity of the ESR or CRP, used individually, is diminished in the setting of nonvirulent chronic indolent infections.18 When used in combination, however, if both values are strongly negative (low normal) it is unlikely that the patient is infected, and other diagnoses should be considered.
- White blood cell count is rarely abnormal in chronic infection and is not helpful for diagnosing deep infection.
- Hip aspiration for culture and cell count is indicated if there is any clinical suspicion of infection, or if there is elevation of either the ESR or CRP. Any antibiotics that the patient may be receiving should be discontinued at least 2 to 3 weeks before aspiration to reduce the risk of false-negative cultures.1
  - The specimen should be separated into two, or preferably three, specimens for culture. If all cultures are positive for the same organism and the results correlate with the clinical presentation and elevation of inflammatory markers, then the diagnosis is confirmed.
- The aspiration is routinely sent for aerobic and anaerobic cultures. In patients who have been previously investigated, or managed for presumed infection with negative cultures, or in patients who are immunosuppressed (eg, transplant patients, HIV-positive patients, cancer patients undergoing chemotherapy), the specimen is also sent for fungal and mycobacterial cultures.
- Synovial cell count has become a useful investigation to help diagnose deep infection. Although currently values that are suggestive of infection are based on knee aspiration, it is likely that these values would hold true for infected hip replacements as well. A synovial white cell count of greater than 2000 cells/mL or over 65% polymorphonuclear leukocytes is suggestive of infection.12,23
- Frozen section is a helpful intraoperative test, but as with other investigations it must be interpreted within the context of the clinical presentation and the results of other investigations: no single test is 100% reliable. The sensitivity and specificity of frozen section are approximately 0.80 and 0.90, respectively.19
  - Tissue for frozen section should be obtained from the areas that look most inflamed. A positive result, indicative of infection, is considered when there are more than 5 polymorphonuclear leukocytes per high-power field.15
- Intraoperative Gram stain should not be used to determine the presence or absence of infection. In late chronic infection it has an extremely poor sensitivity.20

DIFFERENTIAL DIAGNOSIS
- Intrinsic
  - Aseptic loosening
  - Fibrous ingrowth (uncemented implants)
  - Polyethylene wear with synovitis
  - Modulus mismatch
  - Tendinitis (eg, psoas tendon impingement)
  - Bursitis or abductor avulsion
  - Heterotopic ossification
  - Stress fracture
- Extrinsic
  - Spinal pathology (eg, L2 nerve root impingement)
  - Vascular claudication
  - Hernia
  - Lateral femoral cutaneous nerve impingement

NONOPERATIVE MANAGEMENT
- In established cases of chronic infection, nonoperative management is rarely indicated for definitive treatment.
- Once the organism has been identified, antibiotic suppressive therapy may be used as a temporizing measure.
- Antibiotic treatment may be able to suppress the infection and will likely prevent bacteremia if surgical treatment has to be delayed.
- Antibiotic suppression may be considered in patients with very limited life expectancy, who have a reasonably well-functioning joint, provided that the infecting organism has been identified and the infection can be suppressed with a well-tolerated oral antibiotic.
- The use of antibiotics alone will not eradicate an established chronic infection, and they should not be used if curing the infection is the goal.

SURGICAL MANAGEMENT
- The favored method of management of chronic periprosthetic hip infection is a two-stage exchange: removal of all implants and foreign material, followed by delayed implantation.
- The time between stages allows the surgeon to observe the patient’s response to therapy, thereby allowing him or her to assess for the possibility of recurrence of infection after the antibiotics have been stopped and before implantation.
- The principles of surgical management during the first stage are removal of the implants and all foreign material, thorough débridement of the joint, and insertion of a high-dose antibiotic cement spacer (either articulating or static).
The patient is then treated with the appropriate antibiotic therapy, in addition to medical and nutritional management. This is ideally followed by period of time off all antibiotics to ensure clinical resolution of infection, after which the second-stage reimplantation is performed.

The principles of reconstruction during the second stage are as for aseptic revisions and independent of the infection.

If infection is suspected at the time of reimplantation, definitive reconstruction should not be performed and the patient should instead be treated with repeat débridement and insertion of a spacer.

Otherwise, if the prereimplantation workup is negative and if there is no suspicion of infection at the time of reimplantation, it is assumed that the patient is free of infection, and reconstruction should be performed in a manner that is likely to give the best long-term functional outcome.

In most cases, an uncemented reconstruction is favored.4,5,14,16,22 The use of cement is not specifically indicated for the second stage of reconstruction when a two-stage approach is used.

A variety of techniques have been described to create spacers after removal of the implants.4,5,9,13,25 The common principle involves using high-dose antibiotics in the bone cement to obtain high local concentrations such that the spacer does not act as a foreign body.

Prefabricated commercially available spacers currently contain only low doses (generally considered prophylactic levels) of antibiotics. The efficacy of these commercially available spacers has not been established. Currently we recommend against the use of these spacers and instead favor making spacers intraoperatively with high-dose antibiotics.

We use the Prostalac molds,2 which are described later. The technique can be adapted to other mold systems, however.

**Preoperative Planning**

Preoperative planning is as for any revision hip replacement procedure. Planning the steps used for managing the infection and inserting an antibiotic spacer is also required.

These steps include ensuring that the patient is medically stable to undergo the procedure, having the appropriate equipment available to remove the implants (eg, high-speed burrs, thin blade saws, ultrasonic cement removal equipment, trephines, acetabular removal systems) and having the equipment for making the antibiotic-loaded spacer intraoperatively.

Management of a chronically infected total hip replacement requires that every reasonable attempt be made to identify the organism preoperatively.

Although in most cases the antibiotics used in the bone cement will be the same, occasionally an atypical organism will be identified preoperatively, requiring alteration in the content of antibiotics mixed into the bone cement.

It is unlikely that nonimmunosuppressed patients with late chronic infections will become bacteremic if antibiotics are stopped for a short period of time. Therefore, antibiotics that the patient may be receiving preoperatively should be discontinued about 2 weeks before surgery to improve the yield of positive cultures at the time of surgery.

Occasionally, a second organism or an organism with a different antibiotic sensitivity profile than that obtained preoperatively will be identified from intraoperative cultures. If the patient complains of increasing pain or becomes febrile, however, the antibiotics should be resumed to prevent systemic sepsis.

The appropriate molds and antibiotics should be mixed into the cement need to be available for making the spacer intraoperatively.

The most commonly used antibiotics are vancomycin and gentamicin or tobramycin. Other antibiotics can be used as well (Tables 2 and 3).

Intrapelvic cement, if present, needs to be identified preoperatively.

Small amounts can be removed from the defect within the floor of the acetabulum.

**Table 2 Antibiotics Used in Antibiotic-Impregnated Cement**

<table>
<thead>
<tr>
<th>Can Be Mixed with Cement</th>
<th>Dose for Spacers</th>
<th>Dose for Prosthetic Fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amikacin</td>
<td>2 g</td>
<td>1 g</td>
</tr>
<tr>
<td>Amoxicillin</td>
<td>4–8 g</td>
<td>Not reported</td>
</tr>
<tr>
<td>Ampicillin</td>
<td>Not reported</td>
<td>3 g</td>
</tr>
<tr>
<td>Bacitracin</td>
<td>Not reported</td>
<td>1.5–3 g</td>
</tr>
<tr>
<td>Cefamandole</td>
<td>4–8 g</td>
<td>Not reported</td>
</tr>
<tr>
<td>Cefazolin</td>
<td>Not reported</td>
<td>0.5–1 g</td>
</tr>
<tr>
<td>Cefuroxime</td>
<td>2–5 g</td>
<td>1 g</td>
</tr>
<tr>
<td>Cefuzonam</td>
<td>5–13 g</td>
<td>Not appropriate</td>
</tr>
<tr>
<td>Cephalothin</td>
<td>2.4–9.6 g</td>
<td>1.2 g</td>
</tr>
<tr>
<td>Ciprofloxacin</td>
<td>3–9 g</td>
<td>1 g</td>
</tr>
<tr>
<td>Clindamycin (powder)</td>
<td>1 g</td>
<td>Not reported</td>
</tr>
<tr>
<td>Colistin</td>
<td>0.5–1 g</td>
<td>Not appropriate</td>
</tr>
<tr>
<td>Erythromycin</td>
<td>1 g</td>
<td>Not reported</td>
</tr>
<tr>
<td>Gentamicin</td>
<td>1 g</td>
<td>Not reported</td>
</tr>
<tr>
<td>Tobramycin</td>
<td>0.5–1 g</td>
<td>Not appropriate</td>
</tr>
<tr>
<td>Vancomycin</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3 Doses of Antibiotics Used in Antibiotic-Impregnated Cement (per 40 g of cement)**

<table>
<thead>
<tr>
<th>Antibiotic</th>
<th>Dose for Spacers</th>
<th>Dose for Prosthetic Fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amikacin</td>
<td>2 g</td>
<td>1 g</td>
</tr>
<tr>
<td>Cefazolin</td>
<td>4–8 g</td>
<td>Not reported</td>
</tr>
<tr>
<td>Cefotaxime</td>
<td>Not reported</td>
<td>3 g</td>
</tr>
<tr>
<td>Cefuroxime</td>
<td>Not reported</td>
<td>1.5–3 g</td>
</tr>
<tr>
<td>Clindamycin</td>
<td>4–8 g</td>
<td>Not reported</td>
</tr>
<tr>
<td>Erythromycin</td>
<td>Not reported</td>
<td>0.5–1 g</td>
</tr>
<tr>
<td>Gentamicin</td>
<td>2–5 g</td>
<td>1 g</td>
</tr>
<tr>
<td>Ticarcillin</td>
<td>5–13 g</td>
<td>Not appropriate</td>
</tr>
<tr>
<td>Tobramycin</td>
<td>2.4–9.6 g</td>
<td>1.2 g</td>
</tr>
<tr>
<td>Vancomycin</td>
<td>3–9 g</td>
<td>1 g</td>
</tr>
</tbody>
</table>

Large amounts of cement require a preoperative contrast CT scan to assess the location of cement relative to intrapelvic structures. A separate retroperitoneal approach may be required and should be planned.

Radiolucent bone cement also requires CT evaluation preoperatively, to determine its distal extent within the femoral canal or within the pelvis.

Positioning

- Patients are positioned as for other revision hip procedures.
- The lateral decubitus position, with the affected hip upward, is favored. The extremity is free draped with sufficient exposure of skin to allow for extension of the incision as required.
- If a retroperitoneal approach is required for removal of medial cement, the patient is positioned supine for this portion of the procedure.

Approach

- The approach depends on the fixation status of the implants, length of the cement column if present, quality of bone, and stiffness of the hip joint.
- The primary goals of the exposure are to allow for safe, efficient, and thorough removal of the implants and cement or other foreign material, and to allow for thorough débridement of the joint.
- An extended trochanteric osteotomy is usually used. This provides for excellent exposure of the acetabulum and allows for safe removal of the femoral component.
- If the femoral component is loose or has minimal proximal fixation, a standard approach can be used. Radiographs must be carefully inspected to ensure that removal of the femoral component can be accomplished from above.
- Varus remodeling of the proximal femur, or cement that is wider distally than proximally and still well fixed to the implant within the canal, impedes removal of the femoral component and increases the risk of fracture (FIG 3).
- A posterior approach is favored as this approach is more extensile and still allows for an osteotomy should removal of implants become more difficult than expected.
- The skin incision should be made through the previous incision, unless the old incision significantly compromises exposure of deep structures. A portion of the old incision can usually be incorporated; however, when joining the old incision, avoid acute angles to reduce the risk of wound edge necrosis.
- The old incision can be excised to give fresh, nonscarred skin edges that may improve wound healing.
- Sinus tracts should be excised as an ellipse.
- Once the joint has been exposed, at least three samples are obtained for culture.
- Removal of the implants is then carried out as per techniques of nonseptic revision cases and will not be detailed here (please see corresponding chapters).
- Removal of implants and débridement is more thorough than in aseptic revisions, however, and every attempt should be made to remove all foreign and potentially infected material.
- The presence of intrapelvic cement may require a separate retroperitoneal exposure if the cement cannot be gently removed through the medial defect within the floor of the acetabulum.

FIG 3 • AP radiograph of loose femoral component. The stem has failed at the bone–cement interface and the cement is still well fixed to the implant. Removal from above would be difficult as the cement becomes wider in the metaphyseal region (white arrows). An extended trochanteric osteotomy is required to remove the stem safely.

ARTICULATING ANTIBIOTIC SPACER

- After exposure and removal of the implants, the joint is thoroughly débrided. It is important to remove all foreign material, which is potentially infected.
- Retention of cement or other foreign material is associated with an increased failure rate for curing the infection.
- Intraoperative radiographs can be used to look for retained cement. An arthroscope passed down the femoral canal can also be used to inspect the canal for remaining cement.
- The steps to using a system of molds to make an articulating spacer and to maximize efficiency are as follows:
  - Remove infected femoral component (and cement if applicable).
  - Size and make the antibiotic-loaded femoral implant in the appropriate mold.
  - While the cement for the femoral component is hardening in the mold, remove and débride the acetabulum.
- Cement the acetabular component into the acetabulum with antibiotic-loaded cement.
- Remove the femoral component from the mold and insert into the femoral canal.
- Perform trial reduction.
- If the femoral component is not stable within the femoral canal and if there is obvious rotation or risk of significant subsidence, a third batch of antibiotic-loaded cement is mixed. When doughy, the cement is packed anterior and posterior to the femoral implant to provide rotational and axial stability.
- Reduce the hip and close.

**Spacer Creation**

- For most infections, including methicillin-resistant organisms, the antibiotic mixture used in the cement is 3.6 g of gentamicin or tobramycin, 3 g of vancomycin, and 2 g of cefazolin per pack (40 g) of cement. Palacos is favored, as most studies have indicated superior elution compared with other cements.\(^7\)
- Most cases require a total of two mixes of cement (one for the acetabulum and one for the femoral mold). If more than two batches are required and the patient is renally impaired (serum creatinine above 1.5 mg/dL), the dose is decreased to 2.4 g of gentamicin (or tobramycin), 2 g of vancomycin, and 2 g of cefazolin per batch of cement.
- The Prostalac molds are available in variety of sizes and lengths (120, 150, 200, and 240 mm). The length of implant to be made depends on the length of the extended trochanteric osteotomy that is usually required for exposure, the amount of bone loss, and the size of the canal.
- In most cases a middle (200 mm) or long (240 mm) stem is chosen as a longer length also helps achieve better rotational and axial stability within the canal.
- Antibiotics are mixed with one batch of cement in a mixing bowl and then placed into the mold.
- The mold is closed but not fully tightened (to allow for cement to extrude), and the stem is inserted. The mold is then fully tightened and extruded cement is removed from its outer aspect (TECH FIG 1).
- Alternatively, after filling the open mold with cement, the implant is laid into the mold, which is closed over the implant.

**Implant Placement**

- While the cement is hardening in the femoral mold, the infected acetabular component is removed and the socket débrided. Acetabular reamers can be used to help with débridement, but excessive bone loss from reaming should be avoided.
- A second mix of antibiotic-loaded cement is prepared, and, when it is doughy, the polyethylene acetabular implant is cemented into the socket.
- A “perfect cement technique” should be avoided, since this can make removal, at the time of reimplantation, more difficult.
- Waiting until the cement is doughy and applying some but not excessive force when cementing in the liner will provide a stable cup that can be readily removed.

TECH FIG 1 • A. The femoral component is inserted into the mold, which has been filled, before closing, with antibiotic-loaded cement. B. The femoral component is being removed from the mold. The extruded cement seen on the implant medially and laterally can be removed with a ronguer.

- If there are large acetabular defects, extra cement removed from the femoral mold can be shaped over a reamer of approximate size to make an “antiprotrusio-like” cup that can be placed into the floor of the acetabulum before cementing in the polyethylene cup (TECH FIG 2A).
- Warm saline can be poured into the acetabulum to decrease the setting time.
- Once the acetabular cement has hardened, the femoral component is removed from the mold (see Tech Fig 1B) and inserted into the femoral canal.
- In many cases, the stem is press-fitted into the canal, and good rotational and axial stability is obtained and no further adjustment is required.
- In some cases, the fit may be too tight and the antibiotic-loaded implant will not fully seat to the desired level.
- A high-speed burr is used to remove high points or areas of impingement to allow the stem to seat at the desired level.
- In other cases, especially with significant bone loss or very large canals, the femoral component is loose within the femoral canal.
- A trial reduction is performed to estimate leg lengths, and the desired position of the stem within the femoral canal is noted.
The hip is again dislocated and the stem is placed at the desired position. A third batch of antibiotic-loaded cement is mixed and when in a doughy consistency, cement is packed anterior and posterior to the implant to provide rotational and axial stability (TECH FIG 2B–D).

Once the stem is stable within the femoral canal, a trial reduction can be performed to assess leg lengths and stability.

The appropriate femoral head is then placed onto the stem and the hip is reduced and closed.

The Prostalac articulating antibiotic spacer uses a snap-fit all-polyethylene acetabular implant into which the femoral head is snap-fitted into the cup when reduced, enhancing hip stability (TECH FIG 2E).

The snap-fit poly liner may reduce the risk of dislocation, particularly in situations of proximal femoral bony or soft tissue deficiency.

The initial steps for using a nonarticulating spacer are as for the articulating spacer.

This involves ensuring that all the foreign material is removed and the hip is thoroughly débrided.

The same antibiotic concentrations are used in the bone cement.

For an unusual organism, the antibiotics can be adjusted to be organism-specific, but for most infections, the mixture is outlined above.

Two mixes of antibiotic-containing bone cement are required: one for the acetabulum and one for the femur.

Once the hip is débrided, one mix of antibiotic-loaded cement, in a partially polymerized doughy consistency, is placed into the socket. It is gently molded into the acetabulum, matching the bony contour to give some stability to the cement block, to prevent it from migrating or dislodging spontaneously.

The second mix is made into a tapered dowel. Once hardened, the dowel is placed down the femoral canal.

It is important to make a taper, so as to be able to easily extract the dowel at the time of reimplantation.

The nozzle from a cement gun can be used to make a long tapered dowel (TECH FIG 3).

An alternative method is to wrap cement around a threaded pin, again making sure that a taper is created with cement larger proximally to keep the dowel from migrating down the canal.

Once the spacers are inserted, the hip is closed.
TECH FIG 3 • A. A nonarticulating static spacer can be made from the nozzle of a cement gun. The nozzle provides a gentle taper and a larger area of cement proximally to prevent the cement dowel from migrating down the femoral canal. B. AP radiograph of a nonarticulating static spacer. Note the antibiotic-loaded cement block within the acetabulum and the cement around the Steinmann pin within the femoral canal.

PEARLS AND PITFALLS

Cementing polyethylene liner for articulating spacer
- Avoid overly aggressive pressurization, which can make removal more difficult.
- Apply modest insertion pressure to the poly cup with partially polymerized doughy cement.

Large medial acetabular defect
- To avoid intrapelvic cement from a large medial defect, an “antiprotrusio” cement block can be made by shaping cement over an appropriate-sized reamer. Place into acetabulum, covering the defect before cementing poly cup in place.

Femoral stem that is rotationally unstable
- Femoral implant may be rotationally or axially unstable in very large canals. Mix additional antibiotic-loaded cement, and when it is partially polymerized and doughy, pack it around the proximal portion of the implant to make it rotationally and axially stable.

Severe proximal femoral bone loss
- With severely deficient or absent proximal femoral bone, place the implant at the desired position during trial reduction. After redislocation, position the implant at the noted position, and place a mix of antibiotic-loaded cement that is partially polymerized and doughy at the implant–host bone interface. Overlap cement onto host bone to make the implant rotationally and axially stable (FIG 4).

Femoral dowel for nonarticulating spacer
- The nozzle of a cement gun has a slight taper that allows it to be used as a mold for a femoral dowel.

Mixing antibiotics into cement
- When mixing high-volume antibiotics into cement, depending on which antibiotics are used (eg, Nebcin [tobramycin], which is a very high-volume powder), the handling properties can become difficult because of poor viscosity. The cement has a very dry, powdery feel, making it difficult to handle.
- To improve the handling properties, two techniques are helpful:
  - Add a few extra milliliters of monomer liquid from an extra package of cement.
  - Mix slightly cooled monomer and polymer together. When well mixed but still in a very liquid phase, add the antibiotic powder to the mixed cement.

FIG 4 • An example of severe proximal femoral bone loss with deep infection. A. Preoperative radiograph showing severe proximal bone loss with infected bone. B. Postoperative articulating spacer radiograph. The femoral component is placed at the desired level and an extra mix of antibiotic-loaded cement is placed at the bone–implant junction to provide rotational and axial stability.
POSTOPERATIVE CARE
Management of the Infection
- Infection management consists of medical support, nutritional support, and the appropriate antibiotics to treat the infecting organism(s).
- The optimal duration and route of antibiotics remain controversial.
  - Most authors recommend 6 weeks of intravenous antibiotic therapy, although there is considerable variability in published reports, ranging from 0 to 9 weeks of intravenous antibiotics and none to more than 2 years of oral antibiotics.
  - The choice of antibiotics depends on the organism, but there is a tendency, such as with methicillin-resistant staphylococcal infections, to use multiple antibiotics for synergistic effect (eg, vancomycin and rifampin).10
- We favor 6 weeks of antibiotics, at which time the antibiotics are discontinued. Inflammatory markers (ESR and CRP) are followed and repeated at 6 weeks (at the time the antibiotics are stopped). The inflammatory markers have often returned to normal and reimplantation is planned for around 3 months from insertion of the spacer, provided that the inflammatory markers remain normal prior to reimplantation.
- If the ESR and CRP remain elevated at 6 weeks, however, we still favor stopping the antibiotics and following the patient’s course clinically.
  - The ESR and CPR are repeated at 4-week intervals. If they return to normal or have markedly decreased from very high levels preoperatively to near-normal, and there are no clinical signs of ongoing infection, then reimplantation can be planned for 3 to 4 months after insertion of the spacer.
- If the inflammatory markers remain elevated at 3 months, the options are as follows:
  - Continue to follow the patient clinically, particularly if he or she is functioning well with an articulating spacer, and reinvestigate prior to the planned reimplantation with repeat ESR and CRP, as well as a hip aspiration for cell count.
  - Repeat the debridement and insertion of a new antibiotic spacer.
- Multiple debridements at short intervals, based solely on elevated inflammatory markers, should be avoided.
- Routine reaspiration for culture is of limited value, as periarticular antibiotic levels are often still above minimum inhibitory concentrations at 3 months. Synovial white cell count differential may be of greater value, but data to recommend this routinely are limited.

Management of the Hip (Spacer)
- Postoperative weight bearing and mobility depend on the type of spacer used.
  - Most patients with an articulating spacer are very functional between stages, often having minimal pain and ultimately ambulating near full weight bearing with a cane or walker prior to reimplantation.
  - Patients with articulating antibiotic spacers that have a stable press fit, with good rotational stability, are allowed to mobilize touch to light partial weight bearing for 6 weeks, followed by 50% weight bearing for 4 to 6 weeks.
  - If follow-up radiographs show no significant change in implant position and the patient is functioning well with minimal symptoms, full weight bearing as tolerated is allowed until the time of reimplantation.
- If there is concern about the stability of the femoral component within the femoral canal (eg, large canal with difficulties getting good rotational or axial stability of the implant in the canal), then the patient is maintained at 50% weight bearing until the time of reimplantation.
- If a nonarticulating spacer is used, then patients generally cannot bear weight through the lower extremity and are kept touch weight bearing until reimplantation.

OUTCOMES
- The overall success for curing periprosthetic hip infection using a two-stage exchange technique is approximately 90% to 93%.4,5,7,8,14,25,26
- Numerous variables influence the success of treatment:
  - Depth of infection
  - Time from index operation
  - Prosthetic status (fixation and position)
  - Soft tissue status
  - Host status (medical comorbidities)
  - Pathogen (virulence)
  - Surgeon capabilities
  - Patient expectations
- Without the use of antibiotic-loaded cement spacers and without antibiotic-loaded cement at the time of reimplantation, the cure rate for infection using two-stage (delayed) reconstruction is approximately 82%.7
- This cure rate is also similar to a one-stage (direct) exchange in which antibiotic-loaded cement is used at the time of the direct exchange. This implies that delayed reconstruction and the use of antibiotic-loaded spacers are in part responsible for the improved success rate when treating infected total hip replacements.
- Combining series of patients treated with a two-stage (delayed) reconstruction without antibiotic spacers, but with antibiotic-loaded cement at the time of reimplantation, reveals a success rate of approximately 90%.7
- Patients treated with a two-stage (delayed) reconstruction using antibiotic-loaded spacers and uncemented reconstruction show a similar success rate to those treated with spacers and antibiotic-loaded cement at the time of reconstruction. This success rate is approximately 90% to 93%.7,8,25,26
- Uncemented reconstruction at the time of reimplantation, when used with antibiotic-loaded spacers, has not resulted in a lower infection cure rate.5,7,14 Also, uncemented reconstruction will likely result in a better long-term mechanical survival.
- Using the articulating Prostalac antibiotic-loaded spacer has an infection cure rate of 93% (45/48 patients).26 In this series of patients, three became reinfected—two with new organisms and one with the same organism.
- The use of the articulating spacer allows patients to be more functional and thereby reduces the urgency to proceed with reimplantation. This delay between resection and reimplantation allows the surgeon to monitor the patient and assess for possible recurrence after the antibiotics have been stopped.
- The optimal time from resection to reimplantation remains controversial; however, the longer the patient remains clinically free of infection between insertion of the spacer and reimplantation, the more likely one has cured the infection.
COMPlications

- General medical complications are similar to other revision procedures (eg, thromboembolic disease, postoperative ileus, cardiac ischemia) and will not be further detailed.
- Local complications can occur with removal of the implants or with the spacer.
- Removal of the implants, particularly well-fixed implants (as in other revision procedures), can result in bone loss, fracture, or canal perforation. These complications are not reported to be any greater in septic versus aseptic revisions.
- Complications related to the spacer depend on the type of spacer used.
- Static spacers, in addition to functional problems experienced by the patient, can result in difficulties at the time of reimplantation because of contractures or excessive shortening. Excessive shortening may make re-establishment of leg lengths more difficult.
- Articulating spacers may cause polishing or sclerosis of the endosteum, resulting in bone that is less suitable for cementing should a cemented reconstruction be chosen at the time of reimplantation. However, cementless reconstruction is widely used and is not associated with an increased risk of infection. Cementless reimplantation will likely result in better long-term prosthetic fixation, particularly in younger or more active patients. We rarely use cemented femoral reimplantation at the time of reimplantation and reserve its use for very low-demand patients with limited life expectancy.
- Articulating spacers, as with conventional hip replacements, can lead to hip instability. This may be more common if there is bony or soft tissue deficiency. A snap-fit polyethylene liner is routinely used in the Prostalac system and markedly reduces this problem.
- Complications of the infection are failure to cure the infection and side effects or toxicity related to antibiotic use. Although there is some variation in the literature, one can generally conclude that the results for curing the infection are about 90% to 93%.4,5,7,8,14,25,26
- The ability to cure the infection relates to a number of factors: the status of the local soft tissues, systemic comorbidities, the virulence of the organism, and surgical technique.
- The surgeon can improve outcomes by identifying the organism, performing a thorough débridement, and using the appropriate high-dose antibiotics in the spacer. As noted above, the dose of antibiotics in cement may require adjustment in patients with renal insufficiency. Proper medical and nutritional support may also improve the outcome. Depending on which systemic antibiotics are used, monitoring serum levels is required to avoid toxicity.

REFERENCES

**DEFINITION**

- **Hip reimplantation** refers to the insertion of another prosthesis after removal of the original, infected prosthesis. It may be single- or two-staged, cemented or uncemented.

**ANATOMY**

- The posterolateral approach is the most versatile approach in hip reimplantation surgery. Extended trochanteric osteotomy (ETO) occasionally may be required.
- The sciatic nerve is the major nerve most commonly at risk during the posterolateral approach to the hip. In patients with severe scarring, it may be necessary to expose the nerve as it emerges deep and inferior to the piriformis muscle and superficial to the obturator internus muscle.
- In a direct lateral (ie, transgluteal) approach, function of the abductors may be compromised if sufficient care is not taken to avoid injury to the superior gluteal nerve, located 5 cm proximal to the greater trochanter.
- The selection of prostheses for both femoral and acetabular reconstruction is determined by a number of factors, primarily including femoral and acetabular bone defects, quality and quantity of remaining host bone for osseointegration or cementation, status of the soft tissues and abductors, and surgeon preference.
- For acetabular reconstruction, screw fixation often is necessary. The safest zone for insertion of acetabular screws is the posterior superior quadrant.

**PATHOGENESIS**

- Prosthetic reimplantation usually is performed following resection arthroplasty or first-stage revision arthroplasty for infection. It is essential to ensure a sterile surgical field prior to hip reimplantation surgery, as discussed later in this chapter.
- Usually this requires the patient to demonstrate normal values for erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), and hip aspiration for culture. Occasionally, test results may be equivocal, in which case nuclear medicine imaging is required to confirm absence of infection.
- The organisms most commonly isolated in infected total hip replacements are *Staphylococcus aureus*, *Staphylococcus epidermidis*, and gram-negative bacteria, with increasing prevalence of antibiotic-resistant bacteria.

**NATURAL HISTORY**

- Eradication of infection is key to the success of hip reimplantation surgery, regardless of the method of hip reconstruction.
- Persistent or recalcitrant infection, suggested by raised CRP and ESR values and confirmed by tissue or fluid culture (aspiration or biopsy), is a contraindication to reimplantation surgery.
- The options in such a scenario are to continue with antibiotics, repeat the first-stage procedure, or perform resection arthroplasty.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The main presenting symptom of patients with a periprosthetic infection is pain, particularly constant pain while the patient is at rest.
- Delayed wound healing, persistent wound drainage, and a history of superficial wound infection after the primary procedure are highly suggestive of infection.
- Risk factors for infection include history of diabetes mellitus, chronic skin lesions, the use of corticosteroids, and any type of immunocompromise.
- Initial assessment should begin with a general medical examination.
  - The hip wound is examined for warmth, erythema, fluctuance, discharging sinuses, and the presence of any hematoma.
  - An erythematous, warm wound with draining sinuses indicates persistent, ongoing infection.
  - Defects in the underlying fascia often are palpable, and may indicate a higher risk of wound dehiscence postoperatively.
  - The abductors should be palpated and their function assessed.
  - Full neurologic examination and palpation of pulses are performed.
  - Preoperative weakness of leg extensors or a partial foot drop may indicate scarring around the sciatic nerve.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Infection is excluded by serial assessment of the ESR (normal <30 mm/hr) and CRP (normal <10 mg/mL).
- ESR and CRP may be elevated if the patient has other inflammatory systemic diseases (eg, rheumatic disease) and therefore may not be completely reliable in such cases.
- Preoperative hip aspiration, culture or biopsy, and sensitivity may be necessary if the ESR and CRP remain elevated. Antibiotics should be stopped for a minimum of 2 weeks before aspiration to avoid false-negative results.
- Three samples are obtained at the time of hip aspiration, including a tissue sample if feasible. A positive result is considered to be one in which growth is obtained in two separate specimens.
- Radiographs are obtained, including an anteroposterior (AP) view of the pelvis, lateral view of the hip, and Judet views, if necessary, to assess integrity of acetabular columns. In some cases, AP and lateral views of the full length of the femur may be necessary. Bone defects should be estimated on plain radiographs and appropriate reconstructive prostheses made available.
- CT scans occasionally are helpful to ascertain the magnitude of acetabular bone defects.
- Radiographs should be used together with the physical examination to estimate appropriate techniques for leg length restoration or for restoration of hip stability.
The abductors be inadequate, and to minimize risk to neurovascular structures.

**SURGICAL MANAGEMENT**
- The aims of surgical treatment are to eradicate infection, minimize morbidity, and restore function.
- Typically, the hip is flail, but it may contain an antibiotic-loaded spacer. The goal is to remove any temporary spacer and implant a permanent hip replacement prosthesis.

**Preoperative Planning**
- It is important to anticipate the need for specialized implants and instruments before surgery.
- Careful preoperative templating is essential to anticipate implant size, length, and offset (**FIG 2**).
- The template is used to restore leg lengths, medial hip offset, and hip center of rotation.
- Insufficiency of hip abductors may require constrained acetabular implants or large-diameter femoral head components.
- The microbiology laboratory should be informed of the possibility that intraoperative frozen section analysis may be required in equivocal cases of persistent infection.
- Alternative surgical plans are useful to have at hand in case of unexpected intraoperative findings or complications.

**Positioning**
- The patient is positioned in the lateral decubitus position with anterior and posterior supports (**FIG 3**).
- The pelvis must be vertical, and it must be confirmed that the supports are stable.
- Patient positioning must be performed under surgeon supervision, because errors in positioning may result in acetabular component malalignment.

**Approach**
- The surgical approach is chosen after careful preoperative consideration of important factors, including:
  - Previous approach
  - Anatomic location and extent of bone loss
  - Anticipated instability
  - Function of the abductors
  - Surgeon preference and training
- The main options are:
  - Direct lateral (transgluteal) approach
  - Posterolateral approach
  - Trochanteric osteotomy
  - Trochanteric slide osteotomy
  - ETO

**FIG 1** Preoperative radiographs.  
A. Pelvis. B. AP view of the femur.  
C. Obturator oblique view. D. Iliac oblique view.

**FIG 2** Preoperative templating is essential to determine the diameter and length of the implant that may be needed.

**FIG 3** Patient positioned in the lateral decubitus position.
HIP EXPOSURE AND REMOVAL OF ANTIBIOTIC SPACERS

- The posterior approach can be used for surgical exposure.
- The sciatic nerve is identified and is protected throughout the procedure. This is facilitated by placement of the foot on a padded stand with the hip in internal rotation during exposure.
- The short external rotators and posterior capsule are identified and incised as a composite flap. These are tagged with sutures for later repair. The gluteus maximus tendon must be released in most cases due to severe scarring and the need to mobilize the femur.
- Samples are obtained from within the hip joint, for bacteriology.
- Intraoperative frozen sections are obtained if persistent infection is suspected.
- The hip is dislocated, with internal rotation of the femur.
- The femur is further mobilized by incising the anterior scar tissue that tethers it onto the acetabular bone. It may be necessary to release the anterior femoral capsule with cautery, with a femoral retractor placed anteriorly to expose the femoral canal (TECH FIG 1A).
- Removal of cement, soft tissue, and bone from the shoulder of the prosthesis and greater trochanter facilitates removal of the preexisting antibiotic implant spacer, and reduces the risk of greater trochanter fracture (TECH FIG 1B).
- A femoral extractor should be used to remove the femoral antibiotic spacer (TECH FIG 1C), ensuring complete removal of the antibiotic-loaded cement and implant (TECH FIG 1D).
- The acetabular antibiotic spacer is removed with a Cobb elevator, ensuring no further bone loss (TECH FIG 1E).
- Acetabular débridement is performed using a combination of curettes, rongeurs, and Cobb elevators to remove any residual necrotic tissue, ensuring complete exposure of the acetabulum (TECH FIG 1F).

**TECH FIG 1** • A. Incising the anterior femoral capsule with electrocautery to allow exposure of the proximal femur. B. Removal of bone and soft tissue from the collar of the femoral prosthesis. C. Femoral extractor facilitates safe removal of the femoral component. D. Complete removal of the antibiotic cement-coated femoral prosthesis is confirmed. E. Safe removal of the acetabular antibiotic spacer with a Cobb elevator. F. The acetabulum is fully exposed after complete débridement.
ACETABULAR REIMPLANTATION

- The acetabulum is reamed sequentially in 2-mm increments to obtain a concentric, hemispheric surface, taking care to preserve the rim of the acetabulum (TECH FIG 2A).
- Press-fit of an implant 1 to 2 mm larger than the last reamer is used.
- The implant is inserted in 40 degrees of lateral opening and 15 to 20 degrees of anteversion (TECH FIG 2B).
- It is ascertained that the component is uniformly in contact with the underlying host bone.
- Supplementary screw fixation is required in most cases.
- The appropriate trial liner is placed into the acetabulum, for later trial reduction after femoral canal preparation.

Two-Stage Reimplantation with Uncemented Extensively Porous-Coated Femoral Stem

- Femoral preparation may begin after a thorough débridement and after acetabular reconstruction. The length and diameter of the femoral canal are anticipated by careful preoperative templating.
- Femoral débridement is performed with reverse hooks, curettes and brushes, and pulsed lavage.
- The femoral canal is sequentially reamed, guided by preoperative templating, until cortical resistance is encountered over a length of at least 5 to 6 cm (TECH FIG 3A).
- Trial reduction is performed, ensuring satisfactory leg lengths, soft tissue tension, range of motion, and a stable hip (TECH FIG 3B).
- Under-reaming the femoral canal by 0.5 mm compared with the diameter of the actual femoral implant is confirmed by checking with a “hole gauge.”
- In an extensively porous-coated femoral component, 5 to 6 cm of diaphyseal fit (so-called “scratch fit”) is required to provide axial and rotational stability.
- The final implant is inserted into the femoral canal. It should be inserted to within 5 cm of its final position by hand, otherwise it should be reamed line to line to avoid inadvertent femoral fracture (TECH FIG 3C).
TWO-STAGE REIMPLANTATION WITH UNCEMENTED TAPERED FLUTED FEMORAL STEM

- Femoral preparation may begin after a thorough débridement and after acetabular reconstruction.
- Femoral débridement is performed with reverse hooks, curettes and brushes, and pulsatile lavage (TECH FIG 4A).
- Femoral canal reaming is performed with tapered reamers, with the depth and diameter guided by preoperative templating until endosteal contact is made (TECH FIG 4B).
- The aim of diaphyseal reaming is to ensure implant stability, which will resist stem subsidence.
- The length of the stem, as determined by preoperative templating, should be at least 2 cortical diameters distal to any potential stress risers, eg, the tip of an ETO.
- Unlike fully porous-coated cylindrical stems, underreaming the femoral canal by 0.5 mm compared with the diameter of the actual femoral implant is not recommended. Line-to-line reaming is preferred.
- Proximal femoral preparation is then performed using conical reamers.
- Trial reduction is performed for assessment of correct femoral stem anteversion, limb length, soft tissue tension, range of motion, and hip stability (TECH FIG 4C).
- The modularity of the uncemented tapered fluted femoral stem allows adjustment of femoral anteversion (TECH FIG 4D).
- Torsional and axial stability of the implanted prosthesis may be ensured by test torquing the femoral component.


PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Implant removal and acetabular reconstruction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal of acetabular cement may be necessary by pie-crusting of cement beginning at the cement bone interface</td>
<td></td>
</tr>
<tr>
<td>Gentle acetabular reaming can be used as mechanical débrider</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Femoral reimplantation with extensively porous-coated femoral stem</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentric and central reaming of the femoral canal is crucial during femoral preparation.</td>
<td></td>
</tr>
<tr>
<td>A minimum of 5 to 6 cm of “scratch fit” is required to provide immediate, initial component stability.</td>
<td></td>
</tr>
<tr>
<td>The use of a hole gauge to confirm actual differences between the femoral implant and final reamer may reduce the rate of intraoperative femoral fracture.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Femoral reimplantation with an uncemented, tapered, fluted stem</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sufficient bone stock in the diaphyseal region is a prerequisite for an uncemented fluted stem.</td>
<td></td>
</tr>
<tr>
<td>Fixation 2 cortical diameters distal to any potential stress risers is crucial to ensure implant fixation.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cemented reimplantation surgery</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Performed as a single- or two-staged procedure (see Outcomes)</td>
<td></td>
</tr>
<tr>
<td>The preferred method of hip reimplantation in some units in Europe, but rarely performed in North America</td>
<td></td>
</tr>
</tbody>
</table>
PART 3  ADULT RECONSTRUCTION • SECTION I  HIP RECONSTRUCTION

POSTOPERATIVE CARE
- Postoperative care is individualized, depending on the complexity of the reimplantation procedure.
- The quality of implant fixation, severity of preoperative bone loss, hip stability, technical factors encountered during the operation, and patient compliance influence the amount of weight bearing permitted and restrictions on hip range of movement.
- If a transgluteal (direct lateral) approach was used, restriction of active abduction may be necessary.
- Clear postoperative instructions and frequent communication with the multidisciplinary team are essential. Instructions include postoperative blood work, deep venous thrombosis prophylaxis, and perioperative antibiotic requirements.

OUTCOMES
- An uncemented two-stage procedure may successfully eradicate infection in 92% to 93% of cases.4,5,7
- Single-staged reimplantation with the use of antibiotic-loaded cement has a success rate of 77% to 86%,1,10
- A two-reimplantation procedure with the use of antibiotic-containing bone cement in the reimplantation procedure attains a success rate of 90% to 95%.6,8
- A two-staged hip reimplantation is the procedure of choice in most cases.

COMPLICATIONS
- Recurrent infection after reimplantation is a devastating complication, and is associated with a poor outcome.9
- Recurrent infection may be either recurrence of the initial infection, which typically is due to failure of the reimplantation procedure, or a new infection by a different organism, which often is due to multiple patient risk factors and indicates host failure.7
- Hip dislocation, leg-length discrepancy, venous thromboembolism, nerve and vessel injury, fracture, and a small mortality risk are potential complications, as they are for any revision arthroplasty.

REFERENCES
DEFINITION

- According to the prefix peri (meaning “around”), a periacetabular osteotomy (PAO) is defined as an osteotomy that involves dislodging the hip socket from its bony bed in the pelvis without disturbing the normal pelvic anatomy. The socket is then reoriented in a more appropriate position, reducing the deleterious effects of some unfavorable conditions.
- Closure of the acetabular growth plate is a precondition.
- Although the purpose of all reconstructive pelvic osteotomies is the same, the PAO modifies only the orientation of the acetabulum.
- Ideally, the site of the periacetabular osteotomy should be as close to the acetabulum as needed to mobilize it, to preserve the blood supply, and to avoid joint penetration.
- By definition, PAOs include the spherical or rotational osteotomies described by Eppright, Nynomiya, and Wagner, the polygonal Bernese osteotomy as described by Ganz, and their modifications.
- The osteotomy described by Eppright is barrel-shaped and is oriented along an anteroposterior axis. This osteotomy allows for excellent lateral coverage, but only a limited amount of anterior coverage can be achieved.
- The Wagner type I osteotomy is a single, spherical osteotomy that provides simple rotatory displacement without lengthening, shortening, medialization, or lateralization. The relative disadvantage, which involves simple acetabular realignment, is that the intact medial buttress of the quadrilateral plate prevents medialization of the joint.
- The Wagner type II osteotomy is a spherical acetabular osteotomy that combines rotation of the isolated acetabular fragment with a lengthening effect. It is accomplished by placing an iliac bone graft in the cleft between the rotated acetabular fragment and the overlying ilium.
- The Wagner type III osteotomy is a spherical acetabular osteotomy that involves both acetabular realignment and medialization. It is achieved by the creation of the initial basic spherical acetabular osteotomy followed by an additional Chiari-like cut proximally. Fixation usually is obtained with a special construct of tension Kirschner wires connected by a semitubular plate.
- The Bernese osteotomy involves a series of straight cuts to separate the acetabulum from the pelvis. It is the preferred acetabular procedure at many centers for several reasons:
  - It can be done through one incision with a series of straight, relatively reproducible, extra-articular cuts.
  - It allows for large corrections of the osteotomized fragment in all directions that are needed, including lateral rotation, anterior rotation, medialization of the hip center, and version correction.
  - It is inherently stable, in part because the posterior column remains intact.

- Minimal internal fixation is required.
- Early ambulation with no external immobilization is possible.
- The vascularity of the acetabular fragment through the inferior gluteal artery is preserved.
- Arthroty can be done without risk of further devascularization of the osteotomized fragment.
- The shape of the true pelvis is not markedly changed, allowing women who become pregnant after the procedure to have normal vaginal delivery.
- It can be done without violation of the abductor mechanism, facilitating a relatively rapid recovery.

ANATOMY

- The basic anatomy around the hip consists of the superficial surface anatomy and deep bony, muscular, and neurovascular anatomy.
- The clinically relevant surface anatomy of the hip consists of several superficial bony prominences.
- The anterior landmarks consist of the prominent anterosuperior iliac spine and anterior inferior iliac spine, which serve as insertion points for the sartorius and direct head of the rectus femoris, respectively.
- The greater trochanter and the posterior superior iliac spine also are easily identified on the posterolateral aspect of the hip.
- The proximal femur and the acetabulum constitute a very stable and constrained bony articulation, which can be classified with regard to:
  - Histology: synovial (diarthrodial)
  - Morphology: enarthrodial (ball and socket)
  - Axes of movement: polyaxial
- The acetabulum is formed by the confluence of the ischium, ilium, and pubis, which usually are fused by 15 to 16 years of age.
- It is oriented approximately 45 degrees caudally and 15 degrees anteriorly. It is hemispherical in shape and covers 170 degrees of the femoral head.
- The articular surface is horseshoe-shaped and is lined with hyaline cartilage, except at the acetabular notch.
- The acetabular labrum is a fibrocartilaginous structure that runs circumferentially around the periphery of the acetabulum. It increases the depth of the bony acetabulum and contributes to its stability. It is attached to the acetabular articular cartilage via a thin transition zone of calcified cartilage on the articular side. The nonarticular side of the labrum is attached directly to bone. Only the peripheral one third or less of the labrum has a rich blood supply, provided by branches from the obturator, superior gluteal, and inferior gluteal arteries. Pain fibers are most concentrated anteromedially and anterosuperiorly.
The transverse acetabular ligament connects the anterior and posterior portions of the labrum.

The ligamentum teres originates from the transverse ligament over the acetabular notch and inserts into the fovea of the femoral head.

The proximal femur is formed by the femoral epiphysis and the trochanteric apophysis, both of which ossify by 16 to 18 years of age. The femoral head is approximately two thirds of a sphere and is covered with hyaline cartilage, except at the foveal notch.

The angle between the shaft and the neck is approximately 125 degrees, with 15 degrees of anteversion related to the posterior femoral condyles.

The joint capsule attaches to the margins of the acetabular lip as well as the transverse ligament and extends like a sleeve to the base of the femoral neck. Three major ligaments reinforce it.

The iliofemoral ligament of Bigelow lies anteriorly and has an inverted Y-shape. It tightens with hip extension.

The pubofemoral ligament, which covers the inferior and medial aspect of the hip joint capsule, tightens with hip extension and abduction.

The ischiofemoral ligament lies posteriorly, and its fibers spiral upward to blend with the zona orbicularis, a band that courses circumferentially around the femoral neck. It also tightens with extension, which explains why some degree of hip flexion increases capsular laxity.

The hip joint is least stable in the flexed position, in which the capsular ligaments slacken.

Normal hip range of motion includes the following (FIG 1):
- Abduction and adduction (50/0/30 degrees)
- Internal and external rotation (40/0/60 degrees)
- Flexion and extension (15/0/120 degrees)
- The muscular attachments surrounding the hip are extensive: a total of 27 muscles cross the joint.
- The primary flexors are the iliacus, psoas, iliocapsular, pectineus, rectus femoris (direct and indirect heads), and sartorius muscles.

The extensors are the gluteus maximus, semimembranosus, semitendinosus, biceps femoris (short and long heads), and adductor magnus (ischiocondyle part) muscles.

The abductors are the gluteus medius and minimus muscles, the tensor fascia lata, and the iliotibial band.

The adductors are the adductor brevis, adductor longus, and gracilis muscles and the anterior part of the adductor magnus muscle.

The external rotators are the piriformis, quadratus femoris, superior gemellus, inferior gemellus, obturator internus, and obturator externus muscles.

The blood supply originates from the common iliac arteries, which diverge and descend lateral to the common iliac veins and slightly posterior and medial to the common iliac veins. At the pelvic brim, the common iliac artery divides into the internal and external iliac arteries.

From the internal iliac system, the superior and inferior gluteal arteries and the obturator artery supply the psoas major and quadratus lumborum muscles, the pelvic viscera, and parts of the bony pelvis.

The acetabulum receives its blood supply from branches of the superior and inferior gluteal arteries, the pudendal artery, and the obturator anastomoses, all of which are branches of the internal iliac artery.

The external iliac artery continues to follow the iliopectineal arch divides the space between the inguinal ligament and the coxal bone. The lacuna musculorum, which is lateral to the iliopectineal arch, contains the iliopectineal muscle and femoral nerve. The lacuna vasorum, which is medial to the iliopectineal arch, contains the femoral artery and vein.

From the external iliac system, the medial and lateral femoral circumflex artery anastomoses around the proximal femur.

The medial femoral circumflex artery has three main branches: ascending, deep, and trochanteric.
- The deep branch is the primary blood supply to the femoral head. Its course starts between the pectineus and iliotibial band along the inferior border of the obturator externus.
- The trochanteric branch sprouts off at the proximal border of the quadratus femoris to the lateral trochanter.
- Posteriorly, the deep medial femoral circumflex artery enters between the proximal border of the quadratus femoris and inferior gemellus, then travels anterior to the obturator internus and superior gemellus, where it perforates the capsule. It then gives rise intracapsularly to two to four superior retinacular vessels. The deep branch of the medial femoral circumflex artery has several anastomoses: with the descending branch of the lateral femoral circumflex artery at the base of the femoral neck; with the deep branch of the superior gluteal artery at the insertion of the gluteus medius; with the inferior gluteal artery along the inferior border of the piriformis, posterior to the conjoined tendon; and with the pudendal artery near the retroacetabular space.
- The lateral femoral circumflex artery, the metaphyseal artery, and the medial epiphyseal artery contribute little to the vascularity of the femoral head.
Pelvic innervations of the lumbar plexus: L1, L2, L3, L4
- The femoral nerve, located on the anteromedial side of the iliopsoas muscle, passes under the inguinal ligament as it enters the thigh.
- The lateral cutaneous nerve emerges from the lateral border of the psoas major at about its middle, and crosses the iliacus muscle obliquely, toward the anterosuperior iliac spine. It then passes under the inguinal ligament and over the sartorius muscle into the thigh, where it divides into an anterior and a posterior branch.
- The anterior branch becomes superficial about 10 cm below the inguinal ligament, and divides into branches that are distributed to the skin of the anterior and lateral parts of the thigh, as far as the knee. The terminal filaments of this nerve often communicate with the anterior cutaneous branches of the femoral nerve and with the infrapatellar branch of the saphenous nerve—forming, with them, the patellar plexus.
- The posterior branch pierces the fascia lata and subdivides into filaments, which pass backward across the lateral and posterior surfaces of the thigh, supplying the skin from the level of the greater trochanter to the middle of the thigh.
- The obturator nerve is located in the fascia directly under the pubic bone. The femoral and obturator nerves also travel with their arteries anteriorly and medially, respectively.

Pelvic innervations of the lumbosacral plexus: L4, L5, S1, S2, S3
- The sciatic nerve travels without any significant arterial counterpart out to the greater sciatic foramen, with the posterior femoral cutaneous and other small nerves, to the short external rotators.
- The superior gluteal nerve exits the pelvis via the suprapiriform portion of the sciatic foramen along with the superior gluteal vessels.
- Palsy results in abductor lurch, also known as a Trendelenburg gait.
- The inferior gluteal nerve exits the pelvis via the infrapiriform portion of the sciatic foramen along with the superior gluteal vessels.
- Palsy results in difficulty in rising from a seated position and climbing stairs due to weakness of hip extension.

PATHOGENESIS
- The mechanical cause of osteoarthritis is secondary to several conditions, including:
  - Developmental dysplasia of the hip. A maloriented articular surface with deficient anterior or global coverage of the femoral head and decreased contact area leads to excessive and eccentric loading of the anterosuperior portion and subsequently promotes the development of early osteoarthritis of the hip.\(^{10,17,26}\)
  - Acetabular retroversion can result from posterior wall deficiency or excessive anterior coverage, or both, and contributes to osteoarthritis.\(^{1,2,20,22}\)
  - Abnormal contact between the proximal femur and the acetabular rim during terminal motion of the hip leads to lesions of the acetabular labrum or the adjacent acetabular cartilage. This phenomenon is more common in young and physically active adults. The early chondral and labral lesions continue to progress, resulting in degenerative disease. It has been found in a variety of hip conditions more commonly than has been previously noted, including dysplasia, Legg-Calvé-Perthes disease, and post-pelvic osteotomies.
  - The posterior aspect of the acetabulum is subjected to high loads during the activities of daily living. With acetabular retroversion, theoretically greater unit loads are imposed on the available posterior cartilage, which may be responsible for the development of osteoarthritis of the hip.\(^7\)
  - Joint hyperlaxity, as in Down syndrome
- These patients have hips with a substantial structural deformity that predisposes the hip to dynamic instability, localized joint overload, impingement, or a combination of these factors, which results in intra-articular disease and premature secondary osteoarthritis.

NATURAL HISTORY
- The anatomy of the hip joint and the development of degenerative joint disease are related.
  - Femoroacetabular impingement is caused by overcoverage of the acetabulum (ie, retroversion). The repeated insult leads to degenerative arthritis, rendering a joint-preserving procedure much less predictable and quality of the results dependent on the extent of cartilage damage.
  - Developmental dysplasia of the hip
    - Dysplasia without subluxation. Patients usually present because of an incidental finding of dysplasia on a radiograph or because they become symptomatic. Evidence supports the idea that dysplasia will result in degenerative joint disease in adults, particularly in women.\(^4\) Increased contact stresses at the joint interface are postulated to be the cause of articular degeneration.
    - Dysplasia with hip subluxation usually is accompanied by significant degenerative changes around the third or fourth decade of life.
    - The prevalence of osteoarthritis by the age of 50 years has been reported to be 43% to 50%\(^{26}\) in patients who have dysplasia and 53%\(^{15}\) in those who have Perthes disease.
- Using a technique that respects the blood supply to the acetabular fragment and promotes adequate reorientation can modify the natural history of the osteoarthritis. Improvement of the insufficient coverage of the femoral head, reduction of mediolateral displacement, and correction of the version of the fragment are the main approaches to correcting malalignments of the hip.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Determining the etiology of hip pain can be difficult. Both extra- and intra-articular hip structures can give rise to pain, which can be referred to the groin, the lateral trochanteric region, or the lateral, medial, or anterior thigh, as well as the posterior pelvis, buttock, and lower back.
- The history for patients with intra-articular hip pathology can range from an acute twisting or falling episode to the insidious onset of pain that increases over months to years. Many important symptoms may not be readily volunteered by the patient, but must be sought by the orthopedist.
The mechanically abnormal hip can either be asymptomatic or present with pain, limping, a sense of weakness, or feelings of instability, snapping, and locking.

- The pain from arthritis occurs with weight bearing, with the first few steps after a period of immobilization, and is localized to the groin.
- The pain from abductor fatigue is localized to the posterior iliac crest or over the abductor muscles. It may radiate as far distally as the knee.
- Earlier stages of osteoarthritis secondary to dysplasia
- Imbalance due to overgrowth of the greater trochanter: coxa breva and coxa vara, Legg-Calvé-Perthes disease
- The pain caused by osteoarticular impingement depends on the activity and on the position of the limb.
- May be exacerbated by combining flexion, adduction, and internal rotation
- Occurs after the person has been sitting for a long period
- The “C sign” is diagnostic: the patient places the index finger over the anterior aspect of the hip and the thumb over the posterior trochanteric region to indicate the location of their pain.
- The acute pain related to acetabular rim syndrome is a sharp, sudden pain in the groin, often associated with a strong sense of instability or locking.
- Instability is described as a feeling that the joint is unstable.
- Snapping, locking, and clicking are common symptoms. A true locking of the hip is a sign of labral disease. Painless clicking can occur as the iliopsoas tendon snaps over the uncovered anterior femoral head, an occurrence that may be associated with dysplasia.

The physical examination includes the evaluation of stance, gait, limb lengths, strength, and range of motion, and special tests.

- Patients with intra-articular pathology may stand with the hip flexed and walk with an antalgic gait with a shortened stance phase and shortened stride length.
- In the presence of acetabular dysplasia, internal rotation of the hip often is increased because of excessive anteversion of the femoral neck.
- If internal rotation is decreased, the patient may have secondary osteoarthritis.
- The Trendelenburg test
- Specific tests include:
  - The impingement test. The hip is rotated internally as it is flexed to 90 degrees and adducted 15 degrees. This brings the anterior femoral neck in contact with the anterior rim of the acetabulum, which is the usual site of overload in acetabular dysplasia. The test is positive in patients with acetabular rim syndrome. The patient’s pain typically is in the groin.
  - The apprehension test. The hip is extended and externally rotated. This produces a feeling of discomfort and instability in patients who have anterior uncovering of the femoral head.
  - Moving the hip from full flexion, external rotation, and abduction to a position of extension, internal rotation, and adduction can recreate pain and snapping in patients with anterolateral labral tears and iliopsoas snapping hip.
  - Pain with supine log-rolling of the hip is the most specific test for intra-articular pathology.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiography includes an AP view of the pelvis, a false-profile view, a cross-table view, and a functional view in abduction of the affected hip (FIG 2).
- The AP radiograph of the pelvis is the view that gives the most information.
  - It is taken with the patient standing, allowing an assessment of the hip during load-bearing.
  - It must be in neutral rotation and without any pelvic tilt.
  - Shenton’s line is assessed, because discontinuity suggests hip subluxation secondary to hip dysplasia (FIG 3).
  - The presence of an acetabular rim fracture may suggest rim overload.
  - The hip space and the presence of any degenerative changes also are assessed.
  - The degree of dysplasia is assessed by the following measurements:
    - The center-edge angle of Wiberg: an angle subtended by a line from the center of the femoral head to the lateral acetabular margin, and a vertical line from the center of the femoral head. It also is known as the lateral center edge angle, and is greater than 25 degrees in nondysplastic hips.
    - The Tonnis angle: the inclination of the weight-bearing zone of the acetabulum. In normal hips, it should be less than 10 degrees (see Fig 3).
Acetabular version: assessed by identifying the anterior and posterior rims of the acetabulum. If the anterior line crosses the posterior line (the cross-over sign), the acetabulum is retroverted.

The false-profile view of Lequesne and de Sèze is obtained with the patient standing with the affected hip on the cassette, with the pelvis rotated 65 degrees from the plane of the radiographic film and with the ipsilateral foot parallel to the film. The beam is centered on the femoral head perpendicular to the cassette.

This view allows assessment of the anterior coverage of the femoral head. The ventral inclination angle can be measured by a line from the center of the femoral head to the anterior acetabular margin, and a vertical line from the center of the femoral head. It also is known as the anterior center edge angle. In normal hips the angle will be greater than 25 degrees.

The functional view in abduction is taken with the hip in maximal abduction. It simulates the potential correction for osteotomy. The hip should be congruent, reduced, and covered.

CT scans provide three-dimensional information with a clearer indication of the lack of coverage than plain radiographic indices.

The ideal position of the hip is full extension and 15 degrees of external rotation.

MRI
- MR arthography helps to analyze the acetabular labrum and the features related to abnormal loading.
  - Hypertrophy, dysplasia
  - Degeneration
  - Tears
- Findings such as cartilage loss, labral lesions, and cyst formation can be predicted based on preoperative radiographic findings.
- These findings may be useful in alerting the surgeon to the location and nature of intra-articular disorders that could be addressed at the time of arthrotomy.

SURGICAL MANAGEMENT
- Indications for PAO
  - Symptomatic severe acetabular dysplasia (grade IV or V) according to Severin’s classification
  - Symptomatic anterior femoroacetabular impingement due to acetabular retroversion
  - Minimal or no secondary osteoarthritis
  - Young, healthy patient
  - Adequate congruency of the hip joint
  - Adequate hip flexion (100 degrees) and abduction (30 degrees)

- Contraindications for PAO
  - Moderate to advanced secondary osteoarthritis-grade 2 or 3
  - Older age
  - Major hip joint incongruity
  - Obesity
  - Major restriction of hip motion (hip flexion of less than 100 degrees or abduction of less than 30 degrees, unless a proximal femoral procedure is planned to address femoroacetabular impingement)
  - For rotational osteotomy
    - CE angle lower than 40 degrees
    - Acetabular roof inclination greater than 60 degrees
    - Femoral head deformity inaccessible for correction
  - Major medical comorbidities
  - Patient noncompliance

Preoperative Planning
- A complete history is obtained, and a physical examination is performed.
  - The location of, quality of, and activities associated with hip pain are recorded.
  - Gait pattern, leg length, and range of motion are documented.
- Appropriate medical and anesthetic evaluation is performed.
- Preoperative neurovascular status is documented.

- Radiographic examination
  - AP view of the pelvis
  - True lateral: Dunn views, 45 and 90 degrees
  - False-profile: Lequesne and de Sèze view
  - The functional view in abduction with internal rotation may indicate the amount of correction possible.

Positioning
Bernese Periacetabular Osteotomy
- The patient is positioned supine on a radiolucent table.
- A footrest is secured to the table to assist in holding the extremity in a position of hip flexion.
- The ipsilateral upper limb rests over the chest.
- The limb is prepared and draped from above the iliac crest to the foot to allow wide access to the hemipelvis.
- If needed, nerve-monitoring leads are placed and secured on the involved extremity, over-wrapped with stockinette and an adhesive wrap.

Approach
- The Bernese PAO is a modified Smith-Petersen approach, a direct anterior approach that combines the iliofemoral and ilioinguinal approaches, preserving the abductor muscle attachments.
BERNESE PERIACETABULAR OSTEOTOMY

Incision, Dissection, and Iliac Spine Osteotomy

- The Bernese PAO is a modified Smith-Petersen approach that starts with a skin incision that describes a gentle medial curve from 3 cm proximally to 10 cm distally to the anterosuperior iliac spine (TECH FIG 1A).
- Subcutaneous flaps are raised medially and laterally, aiming to identify the fascia over the tensor fasciae latae muscle belly.
- The interneural space between the tensor fasciae and the sartorius is developed by incising the fascia in line with the muscle fibers, protecting the lateral femoral cutaneous nerve, which stays within the sartorius fascia.
- The aponeurosis of the external oblique muscle is reflected medially off the iliac crest.
- The anterosuperior iliac spine is osteotomized about 15 mm proximally on the iliac crest, preserving the origin of the sartorius and the ilioinguinal ligament (TECH FIG 1B).
- Proximally to the osteotomized site, the periosteum on the medial edge of the iliac crest is incised and reflected medially with the origin of the iliacus muscle.
- The conjoint tendon of the rectus muscle is transected and reflected distally, leaving a stump of tendon in the anterior inferior iliac spine for later repair.
- A plane over the anterior hip capsule and under the psoas tendon is developed by reflecting off the iliacus muscle fibers.
- The hip capsule is exposed anteriorly and inferomedially, with the exposure facilitated by hip flexion.

Ischial Osteotomy

- Following the capsule posteriorly, the anterior aspect of the ischium is palpated with scissors that dissect the infractyloid groove and identify the limits:
  - Hip capsule, superiorly
  - Obturator foramen, medially
  - Origin of the ischiotibial muscles, laterally
  - The scissors are used to protect and favor the entrance of a curved (or angled), pronged, 1.27-cm osteotome.
  - The osteotome is positioned in the infractyloid groove and is checked with AP and 45-degree oblique fluoroscopy views.
  - The infra-acetabular osteotomy starts just distal to the inferior lip of the acetabulum and aims toward the middle of the ischial spine.
- At the same AP plane, the osteotome progresses as follows:
  - Through the medial cortex up to approximately 1 cm anterior to the posterior cortex
  - Through the central part of the ischium
  - Onto the lateral cortex, which is the least deep portion and needs no more than 20 mm of penetration (TECH FIG 2). Abduction of the hip minimizes the risk of sciatic nerve injury during this cut.

Pubic, Iliac, and Posterior Column Cuts

- Hip flexion and adduction now facilitate exposure of the pubic ramus.
- The periosteum is incised along the superior cortex, and a pair of narrow curved retractors are placed around the anterior and posterior aspects of the pubic ramus, protecting the obturator nerve. A third spiked retractor is impacted into the superior cortex at least 1 cm medial to the medial-most extent of the iliopsoas muscle, retracting the iliopsoas and the femoral neurovascular bundle medially.
- The pubic cut is oriented from anterosuperior and lateral to posteroinferior and medial, avoiding creating a bony spike in the mobile fragment (TECH FIG 3A). It can be initiated with a small oscillating saw or a burr into the anterosuperior cortical, just lateral to the spiked retractor.
- The posteroinferior cortical cut is completed with a straight or angled osteotome.
- The periosteum must be released all around, allowing the correction.
- To make the iliac cut, the ileum and the quadrilateral surface of the pelvis are stripped subperiosteally. The sciatic notch is identified with a large Hohmann retractor.
- The lateral cortex of the ileum is assessed from its crest by detaching a small portion of the periosteum, allowing the insertion of a blunt retractor to protect the abductor muscles during the iliac osteotomy.
- A high-speed burr is used to make a target hole approximately 1 cm superolateral to the pelvic brim.
- The iliac cut is then made with an oscillating saw, first along the medial cortex and then, with the lower extremity abducted, into the lateral cortex (TECH FIG 3B).
- For the posterior column cut, the column is exposed with the straight cobra retractor along the inner aspect of the true pelvis toward the ischial spine.
■ The cut into the medial cortex is made by a straight osteotome at an angle of 120 degrees to the iliac cut (TECH FIG 3C) under fluoroscopic monitoring.
■ The cut is then completed with a straight osteotome that extends 5 to 6 cm down or an angled osteotome that goes from medial to lateral in three or four steps (TECH FIG 3D).

Mobilization and Correction
■ A Schanz pin is placed in the supra-acetabular region, and the mobility of the fragment is tested (TECH FIG 4).
■ Lack of full mobility indicates the need to review three sites:
  ■ The periosteum around the pubic ramus
  ■ The posterior cortex at the 120-degree pivot point
  ■ The infra-acetabular cut

■ A bone spreader inserted into the iliac cut can be used as an auxiliary to the Schanz pin.
■ The correction is then carried out in whatever plane, aiming for a suitable position.
■ The superior pubic ramus is accessed, and the acetabular fragment is tilted anterolaterally to ensure that it can be completely unlocked.
■ The acetabulum is then repositioned with internal rotation and some forward tilt extension.
■ Translation of the fragment should be:
  ■ Medially, as desired. This can be achieved with some direct pressure from the lateral side with a pointed Hohmann retractor. Care is taken to maintain or restore anteversion.
  ■ Superiorly, in an attempt to achieve bone-to-bone contact with the overlying ilium and to minimize
The definitive fixation is carried out using three or four 4.5-mm cortical screws (TECH FIG 5). One screw is placed into the anterolateral aspect of the acetabular fragment to act as a “blocking” screw. Two or three additional screws are placed progressively more medially. Fluoroscopic images are made again to confirm the acetabular reduction and the position of fixation hardware. Range of motion is assessed to rule out secondary femoroacetabular impingement and instability. Hip flexion must be greater than 90 degrees. Joint stability is assessed by extension, abduction, and external rotation.

Wound Closure

The prominent aspect of the anterior acetabular fragment is trimmed with an oscillating saw; the trimmings are used to fill up the iliac gap. The lateral femoral cutaneous nerve is better protected when retracted medially with the sartorius muscle. Subperiosteal dissection at the superolateral pubic ramus protects the obturator nerve. A pubic osteotomy must be performed medial to the iliopectineal eminence. AP radiographs must be evaluated for the lateral center edge angle, the acetabular inclination, the medial translation of the hip-joint center, the position of the teardrop, and the version of the acetabulum. Slight undercorrection is preferred to excessive correction.

PEARLS AND PITFALLS

Approaching through the anterosuperior iliac spine osteotomy anticipates the bone quality. The lateral femoral cutaneous nerve is better protected when retracted medially with the sartorius muscle. Subperiosteal dissection at the superolateral pubic ramus protects the obturator nerve. A pubic osteotomy must be performed medial to the iliopectineal eminence. A periosteal sleeve around the pubic ramus may prevent free mobilization of the acetabulum fragment. Fluoroscopic images may lead to suboptimal correction. Joint violation may occur in the pubic, ischium, and posterior column cuts.
Free mobility of the fragment is essential. Lack of mobility is more likely to be an incomplete osteotomy. The patient should be well positioned to obtain a radiograph in the correct AP pelvis view.

If the lateral femoral cutaneous nerve is damaged in the course of the procedure, it is better to resect and cauterize it because of the morbidity associated with its recovery. An oscillating saw is less likely to cause uncontrolled fracture in the ilium cut.

Hip flexion–adduction protects anteromedial vascular structures (ie, femoral, obturator, superior gluteal). Hip extension protects the sciatic nerve. Releasing the anterior rectus femoris from the anterior inferior iliac spine reduces the risk of femoral nerve injury. The center of rotation should be corrected by medializing the acetabular fragment.

**POSTOPERATIVE CARE**

- **Pain control**
  - The hip is placed in neutral position in a soft splint.
  - Pain control should be compatible with the perioperative regimen.
  - A multimodal analgesic regimen utilizing regional blockade, nonsteroidal anti-inflammatory drugs, and other peripheral and centrally acting analgesics, including α-2 agonists, ketamine, α-25 ligands, and opioids is one of the most efficacious strategies for reducing pain following the surgery.
  - Use pain-rating scales—visual or color analogues—before discharging the patient at the 5th or 6th day.
  - The suction drains are removed after 48 hours.
  - Thromboembolism prophylaxis follows many protocols.
    - Chemoprophylaxis
      - Low-molecular-weight heparin during hospitalization
      - Mechanical prophylaxis
      - Intermittent pneumatic compression to the calves
  - Heterotopic ossification prophylaxis—facultative
    - Not necessary when preserving the soft tissue around the hip
    - For at-risk situations: indomethacin, 25 mg three times per day
  - Physical therapy
    - Should be simple, emphasizing function more than strengthening or range of motion
    - The patient is out of bed on the third postoperative day.
    - Partial weight bearing (10 kg) is begun with crutches.
    - Active movements that could jeopardize the reinsertion of the musculature are discouraged for 6 weeks.
    - Resistive exercises are avoided for 12 weeks.
    - After 8 to 10 weeks, walking is allowed with a cane, which should be used until the abductors are strong enough to stabilize the hip.
  - Consolidation
    - Radiographs should be taken and analyzed immediately postoperatively, at 6 weeks, and again at 12 weeks.

**OUTCOMES**

- Reduction in pain and preoperative limp has been universal, though the degree of reduction has depended on the amount of preoperative osteoarthritis.

**COMPLICATIONS**

- Complications can be classified as trivial, moderate, or major:
  - Trivial—those of little clinical importance that require no treatment
    - Pubic non-union
    - Reduced lateral femoral cutaneous sensation
    - Asymptomatic heterotopic ossification
  - Moderate
    - Minor wound complications
    - Minor medical complications
    - Peroneal nerve neuropraxis
    - Fractures not requiring treatment
  - Major—those with the potential for significant morbidity
    - Nerve palsy with permanent impairment
    - Major bleeding
    - Reflex sympathetic dystrophy
    - Loss of fixation
    - Deep venous thrombosis
    - Deep infection
- Complications, and their severity, are commonly linked with the surgeon’s learning curve.
- Technical complications have been analyzed and correlated with some specific steps of the procedure.

- **Surgical approach**
  - Nerve injury: the lateral femorocutaneous is most commonly injured (30% of patients).
  - Acetabular necrosis: inferior branch of the superior gluteal artery and the acetabular branches, from inferior gluteal artery injuries
  - Previous procedures increase the risk.

- **Osteotomy**
  - Intra-articular osteotomy
    - Ischium: most common on superolateral femoral head migration
References


DEFINITION

- This chapter focuses on the use of intertrochanteric adduction (varus) osteotomy to reorient the proximal femur to improve femoral head coverage and hip joint congruency. Clinical conditions that constitute good indications for this operative technique are:
  - Mild epiphyseal dysplasia of the femoral head with the lateral part of the head intact
  - Circumscribed anteromedial necrosis or osteochondritis dissecans of the femoral head
  - Valgus head, in particular when the fovea lies within the weight-bearing zone of the hip joint
  - Developmental dysplasia of the hip, when the procedure is performed in conjunction with pelvic osteotomy to obtain better joint congruences
  - Posttraumatic joint incongruence
  - The prerequisite for a successful operative treatment is the possibility that the joint incongruence can be improved.
  - The same operative technique can be used for correction of the proximal femur in abduction, flexion and extension, and rotation, and every combination thereof.

ANATOMY

- The hip joint is a strong and stable multiaxial ball-and-socket synovial joint. In the standing position, the entire weight of the upper body is transmitted through the hips to the lower extremities.
- Because the depth of the acetabulum is increased by the fibrocartilaginous labrum, more than half of the femoral head fits within the acetabulum.
- The femoral head is covered with articular cartilage, except for the fovea.
- The central and inferior part of the acetabulum, the acetabular fossa, does not participate physiologically in transmission of weight force.
- The main blood supply of the femoral head is from the circumflex femoral arteries, especially the medial circumflex femoral artery, a fact that must be considered when operating in this area.

PATHOGENESIS

- A variety of pathologic processes can affect hip joint congruence. The most important of these are listed earlier in this chapter.
- Incongruences of the hip joint are associated primarily with a reduced weight-bearing area, which increases the load on the remaining joint surface.

NATURAL HISTORY

- If the joint load constantly exceeds the resistibility of the articular cartilage, arthrotic changes begin to develop. If untreated, this condition results inevitably in a progressive destruction of the hip joint.
- Current surgical treatment for advanced stages of this degenerative process is dominated by total hip replacement due to the overwhelming success of this intervention.

PATIENT HISTORY AND PHYSICAL FINDINGS

- To assess duration and severity of symptoms as well as potential actuating circumstances, a complete history must be taken, including childhood disorders such as developmental hip dysplasia, sustained Perthes disease, or slipped capital femoral epiphysis.
- General examination of the hip always should include active and passive range of motion as well as gait inspection and leg length comparison.
- Specific physical examination methods include:
  - Anterior impingement. The test is positive if the passive movement provokes groin pain, which relates to a femoroacetabular impingement at the anterior wall or a labral tear.
  - Apprehension test. The test is positive if the patient complains about a feeling of imminent joint luxation, which indicates an insufficient coverage of the femoral head.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- A plain, anteroposterior (AP) radiograph of the entire pelvis is needed to determine the type of pathology in the femoral head or the femoral neck. The patient is positioned with slight internal rotation of the hip to compensate for the femoral antetorsion.
- Other helpful projections are (1) an axial view, (2) the false-profile view as a true lateral projection of the femoral head and neck, and (3) an oblique view on the acetabulum tangential to its superoanteromedial edge (FIG 1).
- An AP radiograph of the hip in maximal abduction also may be helpful to determine the optimal degree of correction.
- It simulates the postoperative position of the femoral head and the expected joint congruency.
- Pelvic MRI or CT scans are optional. They may offer additional information on accompanying lesions on labrum or cartilage or the extent and stage of a femoral head necrosis.

SURGICAL MANAGEMENT

Preoperative Planning

- A preoperative drawing is mandatory. It should make it possible to determine the level and localization of the osteotomy, as well as entry point and direction of the implant in relation to reference points that can be identified intraoperatively.
- Because preoperative drawing is a crucial part of the operative technique, it is covered fully in the Techniques section.
Positioning
- A lateral decubitus position on the contralateral side is preferred, allowing unimpeded access to the operation field and free movement of the afflicted leg (FIG 3).
- Intraoperative fluoroscopy is strongly recommended. Therefore, a radiolucent operating table must be used, and the position of the C-arm and image intensifier should be checked before washing and draping.

Approach
- The standard procedure uses a lateral approach with an L-shaped detachment of the vastus lateralis muscle, thus increasing the gap medial to the abductors.
- Optionally a transgluteal approach also can be used, allowing a better view of the anterior joint capsule, but this approach is not recommended when an osteotomy of the greater trochanter is planned.
Preoperative Drawing

- Outlines of the femur and pelvis are transferred from the radiograph to drawing paper. Alternatively, computer programs are available that allow preoperative planning directly on digital images within a PACS (picture archiving and communications systems) viewer on the computer.
- The drawing should focus on the following (Tech Fig 1):
  - Identification of the innominate tubercle as the lateral, intraoperatively detectable reference point
  - Drawing of the planned osteotomy, perpendicular to the femoral shaft axis. The level of the osteotomy is determined by aiming at the cranial extension of the lesser trochanter.
  - Measurement of the distance between the osteotomy and the innominate tubercle
  - Determination of the point within dense bone trabeculae for optimal blade placement.
  - Blade position is now determined by that point and the designated correction angle relative to the planned osteotomy.
- The intersection point of the outlined blade position and the lateral cortex marks the entry point of the blade. Its distance to the innominate tubercle is measured and can be reproduced intraoperatively.
- An additional trochanteric osteotomy is recommended in intertrochanteric osteotomies (ITOs) with a correction angle of more than 25 degrees.
- The osteotomized trochanter should be at least 10 mm thick, and the angle of the resected wedge should be equal to the resection angle to allow an accurate apposition of the trochanter fragment.
- When transferring the plan to the surgical situs, it must be remembered that radiographs show a magnified projection of the real anatomy.
- Therefore, all measured distances (not angles) must be reduced by around 10%.

Tech Fig 1 • A. The osteotomy level is determined in relation to the innominate tubercle (IT), the point of dense bone trabeculae (D), and the blade position with the desired correction angle (l), after which the blade entry point (E) can be determined. The gray area represents the optional trochanteric osteotomy, which is recommended only when the correction angle exceeds 25 degrees. B. Final plate position after intertrochanteric adduction osteotomy without trochanteric osteotomy. C. Final plate position after an additional trochanteric osteotomy.
**TECH FIG 2 • Approach.** A. The skin incision is centered over the greater trochanter, starting 3 to 4 cm cranial of the tip of the trochanter and reaching 20 to 30 cm distally along the axis of the femur. B. Intraoperative view of the incision. The greater trochanter is marked as an anatomic landmark. C. The fasciotomy is performed longitudinal to the axis of the femur. D. After retraction of the fascia, the greater trochanter is exposed. E. L-shaped detachment of the vastus lateralis at its origin. F. Transgluteal approach as a variant. G. This approach allows a better view of the anterior capsule.
The mobilized muscle is retracted anteriorly to expose the lateral aspect of the femur up to the first perforating arteries, which usually are found 8 to 10 cm distal to the innominate tubercle. The vessels are ligated.

A transgluteal approach may be used as an alternative.
- Here, the anterior part of the gluteus medius and the anterior insertion of the gluteus minimus are detached, and the incision is continued into the vastus lateralis.

### BLADE CHANNEL PLACEMENT

- The anterior capsulotomy is performed in line with the femoral neck and extended to the labrum, which is preserved (TECH FIG 3).
  - This approach does not affect blood supply to the femoral head.
- Capsulotomy and exposure of the femoral neck and head are facilitated by insertion of as many as three Hohmann retractors (8 mm), which are inserted on the acetabular rim just proximal to the labrum with the hip in a slightly flexed position.
- At this time direct visual assessment of the femoral anteversion and part of the articular cartilage is possible, if the leg is externally rotated.
- At the level of the blade entry point, which was determined on the preoperative drawing in relation to the innominate tubercle, a cortical fenestration measuring $15 \times 5\,\text{mm}$ is made.
  - It lies almost completely anterior to an imaginary line dividing the lateral aspect of the greater trochanter into two equal parts.
- Previous marking of the window with a scalpel or an osteotome is recommended.
- The direction of the blade, which also was determined by the preoperative drawing, can now be measured with quadrangular positioning plates and marked with a K-wire inserted into the trochanter cranial to the cortical window.
- An additional K-wire is placed along the femoral neck and pushed into the femoral head to indicate the anteverision of the neck.
- Measurement should not be done too close to the origin of the vastus lateralis, because the diameter of the femur decreases significantly over a distance of 2 to 3 cm.
- The U-shaped seating chisel is inserted into the cortical windows with the direction defined by the two K-wires.
- It is recommended that the chisel be introduced only until it has obtained some purchase.
- The position is than checked in all planes and the chisel readjusted if necessary.
- The seating chisel is advanced under continuous control of all three alignments into the femoral neck and head until the desired depth has been reached (generally 50 to 60 mm).
- Before the osteotomy is performed, the chisel is withdrawn slightly to make it easier to remove it later.

**TECH FIG 3** - Blade channel placement. A. Anterior capsulotomy in line with the femoral neck. After visualization of the anteverision of the femoral neck, a cortical fenestration is made at the blade entry point. B. Placement of two K-wires shows the desired direction of the blade, along which the seating chisel is inserted into the cortical window.
OSTEOTOMY

- The level of the osteotomy is identified in relation to the innominate tubercle, according to the preoperative drawing.
  - An exact drawing obviates the need for palpation of the lesser trochanter.
- Two K-wires are placed into the femur in an anteroposterior direction, one proximal and one distal to the planned osteotomy to allow later rotational realignment (TECH FIG 4).
- The osteotomy is performed perpendicular to the long axis of the femur under continuous irrigation.
  - The surrounding soft tissues, in particular posteriorly, must be protected with blunt retractors.
  - The medial femoral circumflex artery runs approximately 15 mm proximal to the lesser trochanter, close to the bone, and can be easily injured.
  - If an additional trochanteric osteotomy is performed, anastomoses from the internal iliac artery may be severed, invariably causing necrosis of the femoral head.
  - It is recommended, therefore, that the anterior cortex be osteotomized first and the osteotomy completed posteriorly thereafter.
  - A broad chisel (20 mm) is inserted to spread the osteotomy gap.
  - The chisel and the patient’s foot are used as levers to mobilize the fragments in opposite directions.
  - Manipulation with the seating chisel in the femoral neck must be avoided, because this could lead to loosening.

TECH FIG 4 • Osteotomy. A. After placing two parallel K-wires proximal and distal of the planned osteotomy for later rotational control, the osteotomy is performed under protection of the surrounding soft tissue. B. Insertion of a broad chisel to spread the osteotomy. The chisel and the patient’s foot are used as levers to mobilize the fragments.

BLADE INSERTION

- Before the seating chisel is withdrawn, the blade-plate must be readily mounted on the inserter. Blade and inserter must be in line with each other.
  - For the first 2 to 3 cm, the blade is advanced manually with repeated pushes (TECH FIG 5).
  - As long as the blade follows the channel, easy advancement should be possible.

TECH FIG 5 • A. Insertion of the blade into the channel formed by the seating chisel. B. For the final 10 mm, the blade is advanced with the impacter.
Chapter 14  FEMORAL OSTEOTOMY

TECHNIQUES

CORRECTION AND PLATE PLACEMENT

- Achievement of the desired approximation between plate and lateral cortex of the femoral shaft can be facilitated by manipulation of the leg. For rotational realignment, the previously inserted K-wires are used as references.
- After the plate is positioned, it is held against the bone with a reduction forceps (Verbrugge forceps; TECH FIG 6).
- Fixation of the plate to the distal fragment can be achieved in three ways:
  - Without interfragmentary compression
  - With interfragmentary compression obtained by use of the gliding holes
  - With interfragmentary compression obtained with a plate tensioner
- The amount of compression depends on the degree of optimal stability as well as the surgeon’s preference.
- When using a plate tensioner, compression must be applied judiciously, because strong compression may cause a loss of correction, especially in a case of reduced bone quality.
- If no intertrochanteric osteotomy is performed, the use of gliding holes is recommended.
- Such contact is best prevented by positioning the thigh in adduction until ¾ of the blade has been introduced.
- Once the distance between offset of the plate and bone has reached 1 cm, the inserter is removed, and the blade is further advanced with the impactor until full contact with the bone is achieved.
- If an additional trochanteric osteotomy has been performed, the trochanter fragment is flipped over the blade through an already prepared window. The blade with the trochanter is then pushed into the femoral neck.
- Care must be taken not to split the trochanter fragment.

If the force necessary for insertion of the blade increases dramatically, the plate should be removed, the seating chisel again should be reintroduced, the direction should be checked, and the plate insertion repeated.

Hammer blows to advance the plate are allowed only after the direction of the blade has been confirmed. Otherwise, the blade can be pushed in the wrong direction or even perforate the femoral neck.

During blade insertion, contact of the plate with soft tissue or the femoral shaft must be avoided, because this might change the direction of the blade.

If further stability is needed, an additional screw can be inserted through the hole in the offset and engaged into the proximal fragment.

While the screws are being tightened, rotational alignment of the fragments must be closely observed.

External malrotation may occur when only the posterior rim of the plate is in contact with bone.

The stability of the fixation is checked once the first screw has been tightened and the reduction forceps is still in place.

The hip is put through a full range of motion, in particular of rotation with the hip in 90 degrees of flexion.

If the fixation proves to be stable, the second screw is inserted.

With good bone stock, two bicortical screws are sufficient.

In cases in which an additional intertrochanteric osteotomy is performed, the removed bone wedge is inserted into the lateral gap between the two main fragments.

The use of a plate tensioner is preferable, because its use reduces the risk of revalgization.

TECH FIG 6  *Correction and plate placement. A. After the desired correction is reached and full contact of the plate with the lateral femur is achieved, the plate is held in place with a reposition forceps, and the first screw is placed through the plate. B. With good bone quality two screws distal to the osteotomy are sufficient. If bone quality is reduced, another screw can be inserted through the offset of the plate for additional stability.
POSTOPERATIVE CARE
- The leg is positioned on a splint with hip and knee in slight flexion.
- The patient is taken off bed rest on day 1 or 2, with partial weight bearing (15 kg) for 8 weeks.
- Non-weight bearing, which necessitates that the operated hip be held in flexion, leading to increased strain on the osteotomy, should be avoided.
- Physical therapy is required only for gait training using canes.
- Indomethacin (75 mg once daily) is given for 3 weeks for the prevention of heterotopic ossifications.
- Radiographic follow-up is done after 6 weeks.
- At 6 weeks after the operation, strengthening exercises of the abductor muscles can be started.
- Final radiographic follow-up is done 1 year after surgery.
- The implant is removed only in case of symptoms such as soft tissue irritation or trochanteric bursitis, and not before 1 year since the surgery.

OUTCOMES
- Published studies after intertrochanteric adduction osteotomy for the treatment of hip dysplasia have reported good long-term outcomes, ranging from 63% to 87% after 21 to 26 years.
- Treatment of an avascular necrosis of the femoral head with an ITO can be expected to achieve good results in 65% to 90% of cases, depending on the radiographic stage of the AVN.
- Data are limited on patients with osteochondritis dissecans treated with an ITO. Radiologic incorporation was achieved in more than two thirds of all patients.

COMPLICATIONS
- Unsatisfactory correction
- Incorrect blade placement
- Malrotation
- Femoral head necrosis
- Delayed or non-union
- Heterotopic ossifications
- Femoral or sciatic nerve injury

REFERENCES

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Contraindications</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe osteoporosis</td>
<td></td>
</tr>
<tr>
<td>Advanced osteoarthritis with marginal osteophytes</td>
<td></td>
</tr>
<tr>
<td>Spasticity or extensive loss of range of motion</td>
<td></td>
</tr>
<tr>
<td>Inflammatory arthritis</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Un satisfactory correction or unexpected leg-length discrepancy</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meticulous preoperative planning is mandatory.</td>
<td></td>
</tr>
<tr>
<td>Intraoperative use of image intensifier to check the resulting correction angle and change of leg length</td>
<td></td>
</tr>
<tr>
<td>If the achieved correction angle does not reflect the preoperative planning, the seating chisel should be replaced.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Un stable placement or cutting out of the blade</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loosening of the blade is best avoided by a correct, one-time placement of seating chisel and blade.</td>
<td></td>
</tr>
<tr>
<td>Under rare exceptional circumstances, augmentation of the blade with bone cement can be considered.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Incorrect blade length</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>If the blade is too short, the stability of the proximal fragment is reduced, which may cause tilting of the femoral neck and head.</td>
<td></td>
</tr>
<tr>
<td>If the blade is too long, perforation of the femoral head may result.</td>
<td></td>
</tr>
<tr>
<td>If intra- or postoperative radiographs show that an improper blade length was used, the implant must be replaced</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Endangered blood supply to the femoral head</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proper placement of the blade has to be confirmed by visualization with the image intensifier.</td>
<td></td>
</tr>
<tr>
<td>If the blade is placed too posteriorly, the deep branch of the medial femoral circumflex artery can be injured.</td>
<td></td>
</tr>
<tr>
<td>Heavy bleeding from posterior soft tissues should not be addressed by blind coagulation but, rather, by hemostasis under direct vision. The use of clips should be considered.</td>
<td></td>
</tr>
</tbody>
</table>
DEFINITION

- Femoroacetabular impingement (FAI) is a pathologic condition in which structural abnormalities of the femoral head–neck junction or the acetabulum result in early degenerative changes in the nondysplastic hip.
- FAI is one cause of osteoarthritis of the hip, particularly in young people.
- Impingement of the femoral head upon the acetabular rim takes place during motion of the hip, particularly with flexion and internal rotation.
- Currently, surgical dislocation for the correction of intraarticular pathology is the gold standard for the treatment of FAI.

ANATOMY

- Treatment via surgical dislocation of the hip requires thorough knowledge of the course of the deep branch of the medial femoral circumflex artery (MFCA).
  - Any surgeon performing this surgery must be familiar with this specific vascular anatomy.
  - Failure to respect the deep branch of the MFCA will result in avascular necrosis of the femoral head.
- After branching off from the deep femoral artery, the deep branch of the MFCA runs between the pectineus and psoas muscles laterally and follows the inferior border of the obturator externus muscle. It then reaches the trochanter just proximal to the quadratus femoris muscle, where it gives off a trochanteric branch. It then crosses the tendon of the obturator externus muscle posteriorly and continues its course anterior to the superior and inferior gemellus muscles and the obturator internus tendon.
  - The MFCA perforates the capsular fold at the level of the piriform muscle and continues as the lateral epiphyseal arteries to the dorsolateral femoral head, where it enters the epiphysis proximal to the former growth plate.

PATHOGENESIS

- Depending on the site of the deformity, two mechanisms of impingement can be distinguished.
  - Cam FAI is caused by deformities of the femoral head (eg, pistol grip deformity, aspheric femoral head, slipped capital femoral epiphysis).
    - The aspherical head–neck junction is jammed into the acetabulum, leading to a labrocartilaginous separation and shearing of the acetabular cartilage from the subchondral bone (FIG 1A).
    - Cartilage damage can be extensive, with flaps or defects involving as much as 15 mm toward the center of the joint.
  - Pincer FAI is caused by local (eg, acetabular retroversion) or general (eg, coxa profunda, protrusio) acetabular overcoverage in the presence of a normal proximal femur, leading to a linear contact between the acetabular rim and femoral neck that results in degenerative tears and ossification of the labrum.
    - Only a narrow strip of acetabular cartilage is involved along the acetabular rim (FIG 1B).
  - Isolated cam or pincer FAI is rare. In most cases, a combination of both types is present.

NATURAL HISTORY

- The evidence increasingly indicates that FAI is a major cause of osteoarthritis. Although the specific identification of FAI as a cause for early osteoarthritis is new, earlier studies suggested that abnormal anatomic shapes of the femoral head and neck lead to osteoarthritis.

PATIENT HISTORY AND PHYSICAL FINDINGS

- FAI usually presents in active young adults with slow onset of groin pain that often starts after a minor trauma.
  - During the initial stages of the disease, the pain is intermittent and may be exacerbated by excessive demand on the hip, such as athletic activities or after extensive walking.
Often the pain is present after sitting for a prolonged period.

These symptoms often are thought to be of muscular origin and treated by physical therapy, including stretching.

The leading symptoms of FAI are groin pain with motion and limited internal rotation, although overall hip function is almost unaffected according to established scores.

Clinical examination of the hip usually is normal except for a positive impingement test and a limitation of internal rotation of the flexed hip.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

Plain radiographs, including anteroposterior (AP) views of the pelvis and a lateral cross-table view, should be obtained.

Acetabular orientation (eg, anteversion, retroversion) and the depth of the acetabulum (eg, coxa profunda, protrusio) are assessed on the AP pelvic view (FIG 2A).

For proper assessment of the acetabular shape and version, the central x-ray beam must be centered about 2 cm above the symphysis pubis.

Any rotation to the right or left must be avoided, because this can lead to over- or underestimation of acetabular retroversion.

The lateral cross-table view shows the anterior contour of the head–neck junction with offset deficiencies or anterior bumps (FIG 2B).

A Lauenstein or Dunn view is an acceptable alternative to a lateral cross-table view.

MR arthrography is highly sensitive for the detection of labral tears and less sensitive for cartilage damage.

Radial reconstructions along the axis of the femoral neck are important for verifying anterolateral offset problems.

Radial reconstructions in axes other than along the femoral neck are useless.

**DIFFERENTIAL DIAGNOSIS**

- Adductor strains
- Iliopsoas bursitis
- Osteitis pubis
- Sports hernias
- Nerve compression (eg, lateral femoral cutaneous nerve, iliounguinal nerve, obturator nerve)
- Referred lumbosacral pain
- Intra-abdominal disorders (eg, appendicitis, diverticulosis)
- Genitourinary disorders (eg, urinary tract infection, nephrolithiasis, scrotal and testicular abnormalities, gynecologic abnormalities)

**NONOPERATIVE MANAGEMENT**

Conservative treatment may include rest until symptoms subside together with the administration of nonsteroidal inflammatory drugs.

Activities that lead to groin pain should be discontinued, and modification of activities is necessary, avoiding flexion and internal rotation.

Physical therapy, with the aim of improving range of motion, is contraindicated; it most often leads to an increase of symptoms and occasionally may accelerate joint degeneration.

Muscle-strengthening exercises can be beneficial.

**SURGICAL MANAGEMENT**

Preoperative Planning

All imaging studies are reviewed.

On the standardized AP view of the pelvis, the acetabulum is scrutinized for global (ie, coxa profunda, protrusio) or localized (ie, retroversion) overcoverage, rim fractures, labral ossifications, and osteophytes.

Acetabular coverage is assessed. Measuring the preoperative lateral center edge angle (LCE) and drawing the lowest acceptable LCE (usually 25 degrees) makes it possible to determine the amount of bone (in millimeters) that can be resected from the lateral acetabular rim.

The femoral side is observed for lateral asphericity (ie, pistol grip deformity), coxa vara or valga, and osteophytes.

The lateral cross-table view is assessed for the presence of an anterior offset deficiency (alpha-angle) or a bump.

The MR arthrograph is reviewed for the presence and location of labral and cartilage damage, and the exact location and size of the asphericity or bump are determined on the radial reconstruction in the axis of the femoral neck.
The patient is stabilized with three or four side-supports. The posterior support is placed against the sacrum, and the anterior support is slightly cephalad to the pubic symphysis.

The lower leg is placed in a tunnel bolster to avoid pressure sores and to provide a flat bearing for the upper mobile leg.

Disinfection includes the entire leg and is extended up to the lowest rib.

The leg is draped mobile, starting from the iliac crest and ending at the mid-thigh.

Both the anterior superior iliac spine and the posterior superior iliac spine should be freely palpable.

A sterile bag is placed anteriorly at the level of the knee for later positioning of the leg during dislocation of the hip.

### Approach

- Kocher-Langenbeck or Gibson approach with osteotomy of the greater trochanter

### Incision and Dissection (Gibson Approach)

- A straight skin incision is made, centered over the greater trochanter and running through the anterior third.
  - The length of the incision is about 20 cm, depending on the patient’s size and body mass index.
  - The subcutaneous tissue is cut, using careful hemostasis, down to the iliotibial band and the fascia over the gluteus maximus muscle.

- The anterior border of the gluteus maximus muscle is identified, marked by perforating branches of the superior gluteal artery that run within a thin fascia between the gluteus medius and maximus muscles and perforate the fascia lata overlying the gluteus maximus and medius.

- Because the blood vessels are accompanied by branches of the inferior gluteal nerve for the anterior portion of the gluteus maximus, the fascia is kept with the gluteus maximus to protect these structures.

- Proximally, the gluteus maximus muscle is detached from the gluteus medius almost up to the iliac crest, but the skin incision does not necessarily extend so far proximally.
  - Distal to the greater trochanter, the fascia is split in line with the femur.
  - The space between the gluteus medius and maximus muscles is opened, and the posterior border of the gluteus medius is visualized.

- Alternatively, the fibers of the gluteus maximus muscle can be split, as in a Kocher-Langenbeck approach. In this case, the skin incision has to be matched.

- The gliding tissue of the greater trochanter, including the bursa, is incised at the posterior border of the greater trochanter and is then reflected anteriorly, allowing visualization of the vastus lateralis ridge (TECH FIG 1).

- At this point, the trochanteric branch of the MFCA can be seen and coagulated before the trochanteric flip osteotomy is performed.

- The hip is rotated internally (20 to 30 degrees), and the posterior borders of the gluteus medius muscle and the greater trochanter are identified.

![TECH FIG 1](image1) • Right hip. The posterior border of the gluteus minimus muscle and the greater trochanter is prepared. The trochanteric branch of the MFCA is visible.

### Trochanteric Osteotomy

- Using a thin, oscillating saw blade, the osteotomy starts at the posterosuperior edge of the greater trochanter, about 5 mm anterior to the most posterior insertion of the gluteus medius muscle onto the tip of the trochanter, and runs distally toward the posterior border of the vastus lateralis muscle, ie, the vastus lateralis ridge (TECH FIG 2A,B).

- The osteotomy should stop at the anterior cortex.

- The fragment is levered with an osteotome, and a controlled fracture is obtained, leaving an anterior ridge, which increases stability of the trochanter after fixation.

- The correct inclination of the osteotomy is parallel to the leg. The fragment is about 15 mm thick.

Alternatively, a stepcut osteotomy can be performed (TECH FIG 2C).

- Using a thin, narrow, oscillating saw, the osteotomy starts proximally as already described, but stops at the midpoint between the tip of the greater trochanter and the vastus lateralis ridge.

- A second osteotomy is then performed, starting 3 to 4 mm posterior to the end of the proximal cut, aiming at the posterior border of the vastus lateralis muscle.

- The bone bridge between the two saw cuts is osteotomized using a 5-mm osteotome.

- A controlled fracture of the anterior cortex is obtained as described earlier in the chapter.
**Exposure**

- A small Hohmann retractor is placed over the anterior edge of the stable trochanter.
  - The remaining fibers of the gluteus medius and vastus lateralis muscles are released from the stable trochanter proximally and from the femur distally.
- Anterior to the posterosuperior tip of the trochanter, a fat pad becomes visible.
  - After it is incised, the piriformis tendon and its insertion onto the stable trochanter can be seen.
- Occasionally, fibers of the piriformis tendon remain attached to the trochanteric fragment and must be cut to allow further mobilization of the trochanter.
- The leg is now flexed and externally rotated, allowing more anterior retraction of the trochanter.
  - The vastus lateralis and the vastus intermedius are lifted off the lateral and anterior aspects of the proximal femur.
- The gluteus medius muscle is gently retracted in an anterosuperior direction, providing exposure of the piriformis and gluteus minimus muscles.
  - Note that the sciatic nerve crosses underneath the piriformis and avoid injuring it.
  - However, variations of the course of the sciatic nerve with respect to the piriformis muscle are common.
- The interval between the piriform and gluteus minimus muscles is developed.
  - Care must be taken to remain proximal to the piriform tendon to avoid damaging the deep branch of the MFCA.
  - The gluteus minimus is sharply dissected from the underlying capsule and is retracted anteriorly. Anteriorly, the tendinous insertion into the joint capsule must be divided.
  - Now the posterior, superior, and, finally, the anterior joint capsule are exposed (TECH FIG 3A).
  - The insertions of the short external rotator muscles and the piriformis muscle are left intact to protect the deep branch of the MFCA.
- A Z-shaped capsulotomy for the right hip and an inverse Z-shaped capsulotomy for the left hip are performed (TECH FIG 3B), taking care not to injure labrum and cartilage.
  - The longitudinal limb of the capsulotomy is performed parallel to the axis of the femoral neck, starting at the anterosuperior edge of the stable trochanter. Medially, the capsulotomy is in line with the anterior intertrochanteric line, leaving a cuff of capsular tissue for later reattachment, and extends down toward the lesser trochanter, but stops anterior to it to avoid injury to the MFCA, which runs posterosuperior to the lesser trochanter.
  - The proximal transverse limb of the incision is performed by incising the capsule along the superior acetabular rim until the piriform muscle is reached.
  - These steps keep the limb away from the capsular perforation of the MFCA.
  - The femoral head is dislocated anteriorly to allow inspection of the acetabulum.
  - Flexion and external rotation are used to place the leg in the sterile side bag (TECH FIG 3C,D).
  - With traction on a bone hook around the calcar, the femoral head is dislocated, and curved scissors are used to cut the ligamentum capitis femoris.
  - External rotation aids in opening up the anterior joint space and tensioning the ligament for easier transsection.
  - Lowering the knee lets the femoral head rise automatically out of the surgical site, allowing its full inspection.
  - Two blunt Hohmann retractors are placed around the neck (TECH FIG 3E).
  - To view the acetabulum, the knee is brought higher than the pelvis, and a gentle axial push allows the head to...
come posteriorly, creating enough space to visualize the entire acetabulum.
- Three retractors are inserted.
  - One double-angled Hohmann retractor is placed over the anterior rim of the acetabulum between labrum and capsule.
  - A second straight Hohmann retractor (8- or 16-mm) is placed on the anterosuperior rim, close to the anterior inferior iliac spine.
- An easy rider or cobra retractor is placed with the tip into the teardrop, retracting the femoral neck posteroinferiorly to gain further access to the posterior and inferior parts of the acetabulum.
- Now, a full view of the acetabulum is obtained (TECH FIG 3F).

**TECH FIG 3** • A. The trochanteric fragment is mobilized anteriorly. The joint capsule is prepared. The insertion of the piriformis tendon onto the trochanter is intact. B. Schematic of the capsulotomy. C. By flexion and external rotation, the leg is placed in the anterior side bag. This maneuver allows anterior dislocation of the hip. D. Overview across the acetabulum after dislocation of the hip. E. Dislocated femoral head. For better visualization, two blunt Hohmann retractors are placed around the femoral neck. The anterior asphericity and the fibrillated cartilage in the area of impingement are visible. F. Intraoperative view of a left acetabulum. A labral ganglion extending into the soft tissues is visible at the anterosuperior acetabular rim, and the anterosuperior acetabular cartilage flap is seen.

**INTRA-ARTICULAR SURGERY FOR FEMOROACETABULAR IMPINGEMENT**

**Site Assessment**
- Before the hip is dislocated, the presence and amount of effusion and synovitis are noted.
- The head-neck junction is observed for the presence of a nonspherical extension (TECH FIG 4).
- The site of femoroacetabular impingement is evaluated by flexion-internal rotation movements.
- The femoral head is dislocated anteriorly, making it possible to fully evaluate the femoral head-neck junction as well as the acetabulum.
Acetabular version is assessed and compared with the preoperative radiographs.
- With a blunt probe, the integrity of the labrum and the articular cartilage is determined, and the quality and quantity of any damage or injury is documented.

**Acetabular Rim Trimming and Labral Refixation**
- If there is acetabular retroversion, resection of the excessive anterior rim is performed.
- The labrum is sharply detached in a bucket-handle shape and preserved for later refixation (TECH FIG 5A–C). In most instances, it can be detached at its base.

**TECH FIG 4** Inspection of the femoral head in situ. The anterior asphericity can be seen. Dynamic inspection with flexion and internal rotation shows the area of impingement.

**TECH FIG 5** A, B. Labral detachment is undertaken in a case of acetabular retroversion. C. Intraoperative view in a left hip, where the degenerate labrum has been detached from anteroinferiorly to superiorly. D, E. The acetabular rim is resected. F. Intraoperative view. G. Labral refixation using a bone anchor.
on the acetabular rim, and the degenerated labral base and the osseous overcoverage are resected.

- The amount of acetabular rim resection is determined by the magnitude of the damage to the acetabular cartilage and the degree of overcoverage.
- Resection should not be too excessive, to avoid instability of the hip.
- Resection of the excessive acetabular rim, including the area with damaged cartilage, is performed using a curved 10-mm osteotome (TECH FIG 5D–F).
- If a zone of cartilage damage persists, microfracturing is performed.

- Most acetabular rim lesions are located anterosuperiorly, close to the anterior inferior iliac spine.
- Two to four bone anchors are required to reattach the labrum.
  - Titanium anchors are smaller and fit better to the thin anterior rim.
  - Positioning of the anchors is performed under direct vision, about 2 mm from the bone–cartilage interface.
- In the case of general overcoverage (eg, coxa profunda, protrusio), circumferential detachment of the labrum and resection of the acetabular rim can be necessary.
  - In these cases, up to eight bone anchors may be necessary.
  - Nonabsorbable sutures are used to avoid potential resorption-induced inflammatory reactions.
  - Knots are tied on the outer (capsular) surface, with the suture being passed through the base of the labrum (TECH FIG 5G).

Further Femoral Preparation

- After acetabular rim trimming and labral refixation, the acetabulum is irrigated carefully to remove all bony and fibrous debris, and the retractors are removed to proceed with femoral preparation.
- The cartilage of the exposed femoral head is constantly irrigated.
- The nonspherical portion of the femoral head is assessed using transparent spherical templates (TECH FIG 6A).
  - Usually, the nonspherical part of the head–neck junction is located anterolaterally. The transition from the aspherical to the nonspherical part usually is characterized by a reddish appearance of the cartilaginous surface.
  - Excess bone is removed, and a smooth femoral neck waist is created (TECH FIG 6B,C) using small curved osteotomes.
  - Excessive bone removal during the offset procedure should be avoided, although a resection of less than 30% of the neck diameter does not weaken the femoral neck.
  - An excessive resection can compromise the sealing function of the labrum.
  - Anterior and anterolateral osteochondroplasty are relatively safe, because most terminal branches of the MFCA enter the femoral head through vascular foramina at the lateral and posterolateral head-neck junction.
  - Protecting these vessels is essential for preservation of the blood supply to the femoral head.
  - If the nonspherical portion is very lateral and posterolateral, the osteotome is advanced carefully into the cartilage or bone, aiming toward the expected entry point of the lateral retinacular arteries.
  - Before reaching that point, the osteotome is withdrawn, and the remaining bone bridge is broken off.
  - Using a knife, the bony fragment is detached subperiosteally from the inside out.
  - In this way, even very lateral and posterolateral offset alterations can be removed.
  - Perfusion of the femoral head is checked by observation of the bleeding coming from the foveolar artery or the resection surface, but laser Doppler flowmetry also may be used.
  - The hip is reduced by manual traction and internal rotation on the flexed knee.
  - Sliding of the femoral head over the area of labral refixation should be avoided, because this could avulse the sutured labrum.
  - With the head reduced, range of motion is reevaluated, and the hip is checked to determine whether flexion and internal rotation still leads to a femoroacetabular conflict.

**TECH FIG 6** • A. The sphericity of the femoral head is checked using a spherical template. When the end of the template reaches the aspheric part, or bump, it is lifted off from the cartilage. B. Femoral osteochondroplasty. C. Intraoperative view in a left hip. The lateral retinacular arteries enter the femoral head just posterior to the posterior end of the osteochondroplasty. In this case the offset deficiency is mostly anterior.
PEARLS AND PITFALLS

Blood supply to femoral head
- A thorough knowledge of the blood supply in the adult hip is mandatory to allow safe execution of surgical dislocation of the hip.
- The MFCA, the primary source of blood to the adult femoral head, arises from the deep femoral artery. The MFCA courses posteriorly between the psoas and pectineus muscles before approaching the posterior aspect of the proximal femur, running along the inferior border of the obturator externus muscle and just proximal to the quadratus femoris.
- A constant trochanteric branch separates at the level of the external obturator tendon and curves anteriorly over the greater trochanter. This vessel can be used to locate the deep branch of the MFCA, the superior border of the quadratus femoris, and the tendon of the obturator externus. The deep branch of the MFCA crosses the tendon of the obturator externus posteriorly and continues anterior to the conjoined tendon, which consists of the superior and inferior gemellus and the obturator internus tendon. Its course explains why the short external rotators must be protected. It perforates the capsule at the superior margin of the superior gemellus tendon and divides into several terminal branches, the so-called “retinacular” vessels.
- Almost 80% of all foramina are located at the posterosuperior head–neck junction. A mobile wad of loose connective and synovial tissue, the retinaculum, covers these vessels. During dislocation of the femoral head, the external rotators, especially the obturator externus, protect the MFCA from stretching or rupture. If the capsulotomy is performed strictly anterior, damage to the retinaculum can be avoided.

Nerve injury
- The sciatic nerve runs in close proximity to the piriformis muscle and is at risk when the capsular exposure is erroneously performed distal to the piriformis muscle. This is even more dangerous in the rare case of a double-branched sciatic nerve that encloses the piriformis. Under such circumstances, the insertion of the piriformis tendon at the greater trochanter should be released to avoid stretching of the branches during dislocation.
- In patients who have had previous hip surgery, the sciatic nerve may be entrapped within scar tissue. This again places the nerve at higher risk for traction injury during dislocation. In such a condition the nerve is preferably identified and released from scar tissue before continuing with the procedure.

CLOSURE
- A running suture or single stitches can be used to close the capsule.
- It is important to avoid any tension, because this may stretch the retinaculum and adversely influence perfusion of the femoral head.
- The trochanteric fragment is anatomically reduced and fixed with two or three 3.5-mm cortical screws (TECH FIG 7).
- Screw heads are countersunk to avoid irritation of the fascia lata.
- Thereafter, the various soft tissue layers are closed by running or single-stitch sutures.
- Drains rarely are used, because there is almost no dead space left behind where drainage could be advantageous.
- In women, meticulous fascial closure and subcutaneous tissue adaptation is performed, to prevent saddlebag deformity.
The safe zone to perform osteochondroplasty is anterior and anterolateral. If the resection must be extended more laterally, it is necessary to stay proximal to the retinacular vessels to avoid avascular necrosis of the femoral head.

The risk of avascular necrosis of the femoral head is high if the osteotomy is too medial and extends into the base of the neck. Therefore, the posterosuperior edge of the greater trochanter should be identified before the trochanteric osteotomy is performed, and it is of paramount importance that the osteotomy exit anterior to the posterosuperior edge of the greater trochanter.

To reduce the risk of avascular lesions of the femoral head cartilage or acetabular labrum, the straight lateral incision is preferred in obese or female patients to avoid development of a saddlebag deformity. A longer incision may facilitate surgical exposure of the hip, helps to protect the muscle fibers, and allows for easy dislocation of the femoral head with unlimited view.

The Kocher-Langenbeck approach has one advantage over the Gibson approach: it allows better inspection of the posterior aspect of the femoral head and neck, especially in obese patients.

Aiming for short incisions might be dangerous, because they may cause soft tissue damage to the skin and musculature due to stretching.

Postoperative rehabilitation includes touch-down weight bearing for 6 weeks until solid union of the trochanteric osteotomy is achieved.

During the same period, the patient receives low-molecular-weight heparin to prevent deep venous thrombosis.

Flexion of more than 90 degrees and active abduction or flexion of the hip are restricted to allow proper healing of the trochanteric osteotomy.

Continuous passive motion (CPM) with flexion allowed to 90 degrees is started the day after surgery to prevent articular adhesions between the femoral osteochondroplasty and the capsule. Prolonged use of CPM depends on whether or not microfracturing for acetabular cartilage damage was necessary. In such a case, CPM may be necessary for 6 to 8 weeks.

Appropriate patient selection is the key for a good result.

Hips with osteoarthritis higher than grade I on the Tönnis classification have a high risk of an unsatisfactory to poor result.

In a first study we reported good to excellent outcomes in 75% of patients.

In 5 patients (25%), conversion to total hip replacement was necessary, because four of those hips had advanced stage osteoarthritis or large chondral defects on the femoral head.

In a clinical survey including 277 patients, an overall improvement was achieved in 70% of the patients.

Statistical analysis revealed good outcome in hips without radiographically visible degenerative changes and good pre-operative hip function.

Ectopic ossification

Non-union of the greater trochanter

Infection

Deep vein thrombosis

Ischial nerve palsy (anatomical variants, previous surgery)


DEFINITION
- Anterior femoroacetabular impingement encompasses a category of structural hip disorders that are characterized by abnormal abutment of the anterolateral femoral head–neck junction against the acetabular rim–labral complex.
- Repetitive anterolateral impingement produces acetabular articular cartilage delamination, labral disease, and, eventually, secondary osteoarthritis.

ANATOMY
- Understanding the pathoanatomy of hip impingement disorders is essential to establishing an accurate diagnosis and selecting an optimal surgical treatment strategy.
- Structural impingement disease can be primarily femoral-based (ie, “cam” impingement) or primarily acetabular-based (ie, “pincer” impingement) (FIG 1).²,¹²,¹⁷
  - Combined cam and pincer impingement deformities are common,² and are characterized by abnormal anatomy of both the proximal femur and the acetabulum.
  - Deformities of the proximal femur that produce impingement disease include reduced femoral head–neck offset, an aspherical femoral head, slipped capital femoral epiphysis, Perthes abnormalities, and femoral neck malunion.
  - The common impingement deformities on the acetabular side include acetabular retroversion, coxa profunda, and protrusio acetabulum.

PATHOGENESIS
- Impingement deformities of the proximal femur or acetabulum, or both, produce an abnormal mechanical environment that initiates and sustains hip joint degeneration.¹²,¹⁷,²²
  - Mechanical impingement is most pronounced with hip flexion alone or hip flexion and combined internal rotation.
  - Recurrent impingement of the anterolateral femoral head–neck junction with the acetabular rim–labral complex initiates a detrimental cascade of biologic events.
  - Osseous impingement leads variably to delamination of the articular cartilage of the acetabular rim, labral degeneration, posteroinferior acetabular articular disease (due to levering of the femoral head from anterior impingement), and anterolateral femoral head–neck junction chondral disease.
  - This constellation of intra-articular disease worsens with time and is a common cause of secondary osteoarthritis.¹²,¹⁷,²²

NATURAL HISTORY
- The natural history of anterior femoroacetabular impingement has not been clearly defined.
- Radiographic studies have demonstrated an association between structural impingement deformities and secondary osteoarthritis,¹¹⁵,²² but authentic natural history data are lacking.
- The consensus is that the prognosis of symptomatic impingement disorders is poor, and that these diseases commonly result in secondary osteoarthritis.
- Future natural history studies will add substantially to improved understanding of these disorders.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients with anterior femoroacetabular impingement commonly present with activity-related anterior inguinal (groin) pain. Associated lateral and posterior hip pain are common.
- Symptoms are variable and may include a combination of aching pain with intermittent episodes of sharp or stabbing pain.
**Part 3** ADULT RECONSTRUCTION • Section II HIP PRESERVATION

- Mechanical symptoms of locking and catching also may be problematic, presumably from labral disease or unstable articular cartilage flaps.
- Difficulty with daily activities, including prolonged walking, prolonged sitting, raising from a seated position, and pivoting, is common.
- High-demand athletic activities, including running, cutting, pivoting, and repetitive hip flexion (eg, soccer), often exacerbate symptoms.
- Any history of hip trauma, childhood hip disease, previous surgeries, and previous treatments should be determined.
- The patient’s age, activity level, and overall health, and the impact of hip dysfunction on his or her quality of life are obtained.
- Physical examination should include assessment of overall health, conditioning, and body habitus.
- Previous surgical scars are inspected to clarify the nature of previous procedures and to facilitate preoperative planning.
- Observation of sitting posture, gait, palpation of the hip, abductor strength testing, careful hip range of motion assessment, and specific provocative tests are performed.
- Anterior femoroacetabular impingement commonly elicits discomfort in an erect sitting position.
- A level pelvis in the single-legged stance is normal. Dropping of the contralateral hemipelvis indicates abductor weakness of the symptomatic hip. Abductor weakness is common in patients with early intra-articular hip disease and impingement.
- Hip flexion commonly is restricted to 100 degrees or less in impingement disorders. Internal rotation in flexion is frequently restricted to 0 to 10 degrees.
- The gait pattern over short distances and abductor strength usually are normal in early stages of disease.
- A limp and mild abductor weakness may develop as labral disease and joint degeneration progress.
- Hip range-of-motion testing should be performed carefully with stabilization of the pelvis to accurately define motion endpoints. Passive hip flexion motion and internal rotation at 90 degrees of flexion are restricted. Hip discomfort often is reproduced at the endpoints of passive motion.
- The anterior impingement test and Patrick’s test are sensitive maneuvers to detect intrinsic hip disease and usually reproduce hip symptoms in patients with anterior femoroacetabular impingement.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs include a supine anteroposterior (AP) view of the pelvis, cross-table lateral view with the extremity in 15 degrees of internal rotation, and a frog-leg lateral view.
- The structural parameters of the hip are assessed on all radiographic views.
- The acetabular inclination, femoral head coverage, and acetabular version are determined from the AP view of the pelvis. Joint space narrowing, periarticular cysts, and labral ossification also are noted.
- The lateral views are examined to assess femoral head sphericity and femoral head–neck offset.
- These projections best visualize the anterior and anterolateral femoral head–neck deformity that characterizes cam impingement disease.

---

**FIG 2** Radiographic assessment of acetabular version. A. Drawing of an AP view of the hemipelvis showing a hip with normal version. Note the near parallel orientation of the anterior and posterior (dashed line) acetabular walls. There is no crossover, and the lines converge at the superolateral aspect of the acetabulum. B. Drawing of a hip with acetabular retroversion. The “crossover” sign, which has been previously described as an indicator of acetabular retroversion, is present. The anterior aspect of the acetabular rim projects lateral to the posterior aspect of the rim (dashed line) at the most proximal aspect of the acetabulum. C–E. Preoperative radiographs from a 19-year-old football player with left hip pain and cam impingement. C. In this case, the patient has relatively normal acetabular version, femoral head coverage, and acetabular inclination on AP view. D. On the frog-leg lateral view, an anterolateral prominence is noted at the femoral head–neck junction (arrow). E. On the cross-table lateral view, there is a mild decreased offset from the anterior aspect of the femoral head to the anterior aspect of the femoral neck (arrow). (A,B: Adapted from Espinosa N, et al. Treatment of femoro-acetabular impingement: preliminary results of labral fixation. J Bone Joint Surg Am 2006;88A:925–935.)
An MR arthrogram (MRA) of the hip is obtained on all patients with suspected impingement and associated intra-articular disease.
- The contour of the femoral head-neck junction, labral disease, and associated articular cartilage disease are all inspected.
- The MRI also facilitates exclusion of other uncommon disorders, including stress fracture, osteonecrosis of the femoral head, neoplasm, and infection.
- CT scanning of the hip can be useful in identifying and characterizing the extent of osseous impingement lesions.
- The contour of the femoral head-neck junction and the extent of femoral-sided disease can be appreciated in detail.
- Version of the acetabulum and associated osseous abnormalities of the acetabular rim also can be assessed in detail.
- The CT scan complements other imaging modalities and can impact surgical decision making.

DIFFERENTIAL DIAGNOSIS
- Isolated intra-articular hip disease (eg, synovitis, labral tear, chondral disease, loose body) in the absence of an impingement disorder
- Mild hip dysplasia (joint instability)
- Extra-articular disorders (eg, lumbar spine disease, bursitis, inguinal hernia)

NONOPERATIVE MANAGEMENT
- Nonoperative management for the treatment of anterior femoroacetabular impingement has not been rigorously investigated or documented in the literature.
- Consensus is developing that hip impingement disease is common, and that definitive treatment should address the underlying pathomechanics of the joint.
- The benefit of nonoperative treatment has not been established for joints that are relatively healthy with no or mild degenerative changes.
- Activity restrictions, physical therapy, anti-inflammatory medicines, and intra-articular cortisone injections can be considered as potential nonoperative treatment options. Nevertheless, the efficacy of these treatment modalities over time has not been proven.
- Physical therapy should not emphasize improving hip range of motion and should avoid aggressive maneuvers to gain hip flexion and internal rotation motion, because these will irritate the hip.
- Anti-inflammatory medicines may reduce discomfort derived from labral disease and structural impingement.
- Activity restriction may alleviate symptoms in some patients. Athletes involved in repetitive hip flexion activities may experience significant relief of discomfort if they refrain from their sport.
- Patients with symptomatic femoroacetabular impingement who desire to maintain high activity levels often fail nonoperative management and desire surgical intervention.
- For patients with moderate to advanced degenerative disease, the nonoperative modalities listed can be considered as temporizing therapies before joint arthroplasty.

SURGICAL MANAGEMENT
- Surgical management of hip impingement disease continues to evolve, and various surgical techniques are now available for joint reconstruction, including surgical dislocation of the hip, combined hip arthroscopy and limited open decompression, and purely arthroscopic decompression techniques. The fundamental goal of surgery, independent of the technique selected, is to address the structural impingement lesions and the associated intra-articular disease elements (eg, labrum, articular cartilage).
- We prefer surgical dislocation of the hip for cases with nonfocal impingement problems or severe deformities and for those cases requiring acetabular rim trimming with labral repair, eg, hips with a nonfocal femoral head deformity or circumferential pincer impingement.
- For hips with focal, cam-type anterior femoroacetabular impingement, the less-invasive surgical techniques may have distinct advantages. In such cases, we use hip arthroscopy to precisely address the intra-articular disease (eg, labrum, articular cartilage), followed by a limited open osteochondroplasty to correct the femoral-sided impingement deformity.

Preoperative Planning
- The patient history and physical examination findings are reviewed.
- All preoperative radiographs plus the MRA and CT scan (if obtained) are evaluated. The size and location of the impingement lesion or lesions is determined. The status of the acetabular labrum and articular cartilage should be assessed on the MRA.
- Restriction of hip flexion motion and internal rotation in flexion is noted, because these clinical parameters should be improved with recontouring of the anterolateral femoral head-neck junction.
- It is very important that the surgeon determine whether the impingement lesion is a cam, pincer, or a combined cam-pincer deformity, because the characteristics of the specific deformity will impact the surgical planning and treatment.
- In our practice, hip arthroscopy and limited open osteochondroplasty of the femoral head-neck junction are used primarily for the treatment of cam-type impingement and associated intra-articular disease.

Positioning
- Spinal or general anesthesia with muscle relaxation is preferred.
- The patient is positioned supine on a radiolucent fracture table with lower-extremity traction attachments (FIG 3). The feet and ankles are well padded and firmly stabilized within the traction boots. The perineal post is heavily padded to prevent pudendal nerve palsy.

FIG 3 • Surgical positioning and operating room set-up. The patient is positioned supine on a radiolucent fracture table. The hip arthroscopy is performed first followed by the limited open osteochondroplasty of the femoral head-neck junction.
The operative hip initially is positioned in neutral flexion-extension and slight (0 to 10 degrees) abduction. The operative lower extremity is internally rotated 15 to 20 degrees.

The contralateral hip is flexed about 15 degrees and abductd 10 to 20 degrees, and minor traction is applied to stabilize the pelvis.

The ipsilateral upper extremity is positioned over the chest.

Traction is applied to the operative hip to achieve 8 to 10 mm of joint distraction, which is confirmed with fluoroscopy. Traction is released during preparation and draping of the hip.

**HIP ARTHROSCOPY PORTALS**

- Hip arthroscopy is performed via the anterior, anterolateral, and posterolateral portals with the patient in the supine position ([TECH FIG 1A](#)). The limited open osteochondroplasty of the femoral head-neck junction also is performed in the supine position. This surgical incision uses the Smith-Peterson interval to access the anterior hip joint.[19]

- The open incision is 8 to 10 cm long and extends from the anterosuperior iliac spine distally to incorporate the anterior arthroscopic portal ([TECH FIG 1B](#)).

- A cannulated hip arthroscopy system is used for portal placement.

- The anterolateral portal is established first with fluoroscopic guidance.

- The joint is entered distal to the labrum and superior to the femoral head. A 70-degree arthroscopic lens is inserted and used to directly visualize placement of the anterior and posterolateral portals ([TECH FIG 1C,D](#)).

- The anterior portal should be established with specific care to avoid injury to the lateral femoral cutaneous nerve.

- A superficial skin incision is made, and the soft tissues are then spread with a hemostat down to the hip capsule.

- The cannula sheath is advanced through the subcutaneous tissue to the hip capsule, and the trocar is advanced into the joint.

- Diagnostic evaluation of the central compartment is performed with both a 70- and 30-degree arthroscope. This enables excellent visualization of the femoral head and acetabulum.

- Most arthroscopy is done with the arthroscope in the anterolateral portal, but the anterior and posterolateral portals are used for comprehensive joint inspection.

**HIP ARTHROSCOPY FOR LABRAL AND CHONDRAL DISEASE**

- The anterior and superolateral labrum is carefully inspected and probed ([TECH FIG 2A](#)).

- If a labral tear is identified, the labrum is débrided back to the stable labral remnant.

- The débridement is performed with a combination of an arthroscopic shaver and radio-frequency chisel.

- Care is taken to be conservative in not resecting excessive labral tissue.

- In most cases, the capsular attachment of the labrum remains stable and should not be excised.

- Labral repair is an option in selected cases, but our initial experience has focused on partial labral resection ([TECH FIG 2B](#)).

- The articular cartilage is assessed, specifically along the anterior and superolateral rim of the acetabulum.

- Unstable flaps of articular cartilage should be removed with a mechanical shaver.

- If full-thickness delaminated flaps are present, they are débrided back to a stable articular cartilage remnant ([TECH FIG 2C](#)). Care is taken to avoid
Central propagation of the delaminated articular flaps.

- When subchondral bone is exposed, microfracture treatment is performed (TECH FIG 2D,E).
- Associated synovitis is ablated.
- When arthroscopic evaluation and treatment of intra-articular disease is completed, the instruments are removed and the traction is released.

**LIMITED OPEN OSTEOCHONDROPLASTY**

**Surgical Approach**

- The patient is maintained in a supine position and an 8- to 10-cm incision is made extending from the lateral aspect of the anterior superior iliac spine distally to incorporate the anterior arthroscopic portal incision (TECH FIG 3A).
- The dissection is carried through the subcutaneous tissue to the fascia of the tensor fascia lata muscle (TECH FIG 3B). Care is taken to bring the subcutaneous dissection slightly lateral to avoid the lateral femoral cutaneous nerve.
- The fascia of the tensor muscle is incised over the muscle belly, and the tensor fascia muscle is reflected laterally. The medial soft tissue flap, including the sartorius, is reflected medially. The underlying rectus tendon is identified.
- The direct and indirect heads of the rectus are released and reflected distally to allow wide access to the hip and wide exposure of the femoral head-neck junction (TECH FIG 3C,D).

**TECH FIG 2** Arthroscopic treatment of intra-articular disease. A. The anterior and superolateral labrum are inspected and probed. Labral disease commonly involves this region of the acetabular rim and often includes a degenerative, intra-articular tear with an intact capsular attachment. B. Partial labral resection is performed, and the adjacent articular cartilage is examined. C–E. Unstable articular cartilage flaps are débrided (C), and exposed subchondral bone is treated with a microfracture technique (D,E).

**TECH FIG 3** Osteochondroplasty surgical approach. A. The anterior incision (8–10 cm) is started at the lateral aspect of the anterosuperior spine and extended distally to incorporate the anterior arthroscopic portal incision. B. The dissection is carried through the subcutaneous tissue to the underlying fascia of the tensor fascia lata (TFL) muscle. The fascia is incised, and the tensor muscle belly is reflected laterally. The sartorius is reflected medially. C. This enables exposure of the direct (pictured) and indirect heads of the rectus femoris tendon. D. Both heads of the rectus tendon are released, exposing the underlying iliocapsularis muscle over the anterior hip joint capsule. The iliocapsularis is reflected distally and medially. The plane between the hip capsule and overlying iliopsoas muscle is developed medially. (continued)
After release of the rectus, the soft tissue and iliocapsularis muscle fibers are stripped from the anterior hip capsule. A cobra retractor is placed medially between the psoas muscle and the anterior hip capsule, and a right angle narrow-deep retractor is placed laterally.

A capital "I"-shaped arthrotomy is made, and the retractors are moved intra-articularly to displace the medial and lateral capsular flaps and provide access to the femoral head and neck (TECH FIG 3E,F).

The foot is then removed from traction and positioned on the radiolucent table to allow unrestricted motion of the lower extremity and wide access to the femoral head–neck junction.

The joint is inspected with specific attention to the femoral head–neck junction.

**Femoral Head–Neck Recontouring**

The lower extremity is brought up into a figure 4 position, which enables excellent visualization of the anteromedial head–neck junction.

- This region of the proximal femur commonly has normal offset in the face of reduced anterolateral head–neck junction offset. Thus, the anteromedial neck contour may be used as a template for the anterolateral osteochondral resection.

- Articular cartilage discoloration, the presence of chondromalacia, or evidence of an impingement trough (indentation) also is observed at the anterolateral femoral head–neck junction (TECH FIG 4A). The osteochondroplasty is started proximal to the area of suspected impingement.

- A combination of ½- and ¼-inch curved osteotomes is used to perform the recontouring of the femoral head and neck (TECH FIG 4B). The osteochondroplasty is beveled inferiorly to prevent delamination of the preserved femoral head articular cartilage.

- The depth of the osteochondroplasty ranges from 5 to 10 mm, depending on the severity of the deformity. The resection usually involves the majority of the anterolateral femoral head–neck junction, and may expand to cover more than 180 degrees of the femoral head–neck circumference.

- Lower extremity positioning with internal and external rotation greatly enhances the extent of visualization and allows safe recontouring under direct vision.

- Care is taken not to extend into the posterolateral femoral neck, because this area contains the terminal branches of the deep branch of the medial femoral circumflex artery.

- After the femoral head has been recontoured, the resection is assessed by direct visualization and palpation through the arthrotomy. Anterior femoroacetabular impingement is examined dynamically by palpation through the arthrotomy while moving the hip into flexion and combined flexion–internal rotation.

- If palpation identifies residual impingement, then the resection is refined to remove the impinging structures at the femoral head–neck junction or the femoral neck.

**TECH FIG 3 • (continued)**

E. The anterior hip capsule is then identified and a capital I-type arthrotomy made. F. The retractors are placed intra-articularly, and exposure of the anterolateral head–neck junction is obtained.

**TECH FIG 4 •** Femoral head–neck recontouring. The anterolateral femoral head–neck junction is inspected. A. Care is taken to observe any irregularity in the articular cartilage, discoloration of the articular cartilage, and impingement trough or indentation. B. The osteochondroplasty and recontouring of the anterolateral femoral head–neck junction are performed using ½- and ¼-inch curved osteotomes. C. After the osteochondroplasty is completed and inspected by direct physical examination and fluoroscopy, the osteochondroplasty bony bed is treated with bone wax.
Fluoroscopic examination is performed after completion of femoral head recontouring to confirm sphericity and adequate osteochondral resection. The head is visualized in extension with neutral rotation and external rotation. The hip is then examined in a frog-leg lateral position to better visualize the anterolateral head–neck junction. Varying degrees of flexion and internal–external rotation permit excellent assessment of the osteochondroplasty.

The recontouring of the femoral head–neck junction is complete, the osteochondroplasty bed is treated with bone wax (TECH FIG 4C).

TECH FIG 5 • The hip joint capsule and overlying rectus tendons are repaired.

## PEARLS AND PITFALLS

### Indications
- Ideal surgical candidates have symptomatic anterior femoroacetabular impingement, are well-conditioned, are less than 55 years old, and have no or mild secondary osteoarthritis.
- The patient history and physical examination are extremely important to make a definitive diagnosis of anterior femoroacetabular impingement.
- The radiographic and imaging studies are critical in classifying the type of impingement disease.
- Various surgical options are available to treat hip impingement disease.
- The surgical strategy presented here has been used primarily for the treatment of cam-type deformities.

### Labral débridement
- It is extremely important to be technically conservative with the partial labral resection.
- Unstable intra-articular flaps of the labrum should be removed.
- The stable capsular labral remnant should be preserved when possible.
- Full-thickness resection of the labrum should be avoided.

### Articular cartilage
- Articular cartilage delamination along the anterior and superolateral acetabular rim is common.
- Articular flaps should be débrided back to stable articular cartilage.
- Microfracture of the acetabular rim disease can be performed for full-thickness defects.

### Limited open osteochondroplasty
- Wide exposure of the femoral head–neck junction should be obtained to perform the osteochondroplasty safely and precisely.
- Exposure is best achieved by release of the rectus tendon and an I-shaped arthrotomy to enable wide access to the anterolateral head–neck junction.
- A combination of 1/4- and 1/2-inch angled and curved osteotomes facilitates the osteochondroplasty through this surgical approach.
- Dynamic examination of the hip and palpation through the arthrotomy ensures complete decompression of the impinging structures.
- Fluoroscopic examination of the hip after osteochondroplasty assists in judging the adequacy of the femoral head–neck junction recontouring.

### Postoperative rehabilitation
- Emphasis should be on gentle range of motion within the patient's comfort zone and gentle, progressive strengthening as tolerated by the patient.
- A common mistake is excessive therapy within the first 2 months after surgery. This can impede the rehabilitation process.
POSTOPERATIVE CARE

- Postoperative radiographs are obtained to verify the contouring of the femoral head–neck junction and to document the integrity of the proximal femur (FIG 4).
- Patients are treated with one aspirin two times a day for 6 weeks for deep venous thrombosis prophylaxis, and with indomethacin, 75 mg per day for 6 weeks, to prevent heterotopic ossification.
- Patients are toe-touch weight bearing for 4 weeks and then progress to full weight bearing. Gentle physical therapy is started the day after surgery. Therapy focuses on gentle range of motion and progressive strengthening within the patient’s comfort zone.
- Continuous passive motion is used for 4 to 6 hours per day for 2 to 4 weeks.
- The patient may return to normal daily activities as tolerated 4 weeks after surgery and may return to contact sports or running 6 months after surgery.

OUTCOMES

- Documentation of clinical outcomes for surgical treatment of hip impingement disease is limited.3,8,10,14,21
- Early to mid-term results are now available for treatment with surgical dislocation of the hip and are encouraging for most patients.3,10,21
- Reported clinical outcomes with less invasive impingement techniques are limited.8,14
- Our experience with hip arthroscopy and combined limited open osteochondroplasty has been encouraging. Analysis of our first 23 consecutive cases demonstrated good or excellent clinical results in 22 of the 23 hips at a mean 18 months of follow-up.8

COMPLICATIONS

- Femoral neck fracture
- Infection
- Articular cartilage scuffing
- Arthroscopic instrument breakage

REFERENCES

DEFINITION
- The knee classically has been divided into three compartments. Unicondylar knee arthroplasty (UKA) is performed for medial or lateral compartment arthritis.
- Historically, patient selection, surgical technique, and component designs have been less than ideal. The key to a successful outcome for UKA is a successful marriage between these three variables.

ANATOMY
- The three compartments of the knee are the lateral compartment, consisting of the lateral tibial plateau and lateral femoral condyle; the medial compartment, made up of the medial tibial plateau and medial femoral condyle; and the patellofemoral joint.
- In the normal knee, most of the ligaments are at their resting, unstretched lengths in extension.
  - At about 20 to 30 degrees of flexion, the posterior capsule and lateral collateral ligament (LCL) slacken, allowing for a gap under tension.
  - Further gapping is resisted by the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), and medial collateral ligament (MCL).
  - At 90 degrees of flexion, the lateral compartment will distract 7 mm while the medial compartment maintains a constant 2-mm gap.
  - The cruciate ligaments and the MCL exert an isometric effect on the medial compartment throughout the range of motion.
  - In a single-leg stance, the load across the medial compartment is approximately 70%. This increases to 90% when there is a varus deformity of 4 to 6 degrees.

PATHOGENESIS
- Medial unicompartmental osteoarthritis (OA) with intact cruciate ligaments and a functionally normal MCL results in a recognizable pattern of wear.
  - Cartilage and bone erosions are found on the anteromedial tibial plateau and distal surface of the femur, representing a pattern of extension disease.
  - Erosions rarely extend to the posterior quarter and never to the posterior joint margin of the tibial plateau.
  - Cartilage is preserved on the flexion surface of the femur and posterior tibia.
  - The intact ligaments maintain normal femoral “rollback,” resulting in this typical pattern of wear.
  - With a varus deformity, the posterior capsule shortens. However, when the capsule is relaxed at 20 degrees of flexion, the knee can be corrected manually to its prediseased alignment.
  - At 90 degrees of flexion, the knee corrects spontaneously as the cartilage on the flexion surface of the femur comes in contact with the posterior tibia.
- The MCL subsequently is tensioned to its normal length in flexion.
- Unlike tricompartmental disease, unicompartmental disease should not require any ligamentous release during arthroplasty.
- To expose bone on both the tibia and femur, almost 5 mm of cartilage is lost. This typically causes 5 degrees of varus deformity.
- Each additional millimeter of bone lost will result in increasing varus deformity of 1 degree.

NATURAL HISTORY
- Degenerative failure of the ACL may be the event that causes anteromedial OA to make the transition to posteromedial OA, resulting in posterior subluxation and structural shortening of the MCL.
- Varus deformity also will be maintained in flexion as the posterior cartilage is worn.
- The ACL progresses through these stages of failure: normal, loss of synovial covering (usually distal), longitudinal splits in the exposed tendon, stretching and loss of strength, and, finally, rupture, with eventual disappearance of the ligament.
- Chronic synovitis causes nutritional insufficiency and will place the ACL at risk.
- Intercondylar osteophytes from arthritis also will put the ACL at risk of degenerative changes and failure.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Pain is the most common symptom of OA.
  - Pain usually is recognized along the medial joint line, but its localization is unreliable.
  - Pain is felt on standing and walking but usually is absent with sitting or lying down.
  - Varus deformity of 5 to 15 degrees while standing is seen. The deformity corrects with 90 degrees of flexion and upon valgus stress at 20 degrees of flexion.
  - Flexion contracture often is present, as are a joint effusion and synovial swelling.
  - The Lachman’s, pivot shift, and drawer tests often are difficult to interpret in assessing the cruciate ligaments in an arthritic knee, but ligamentous stability should be present.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs, including a weight-bearing anteroposterior (AP) and lateral (Fig 1A,B), stress, and patellar views, are critical in determining whether the patient is an appropriate candidate for UKA.
- If only medial compartment arthritis (ie, joint space narrowing, sclerosis, cysts, osteophytes) is appreciated on the AP view, a valgus stress view (Fig 1C) is needed.
This will demonstrate the normal thickness of the cartilage in the lateral compartment and show whether the varus deformity is correctable.

- The lateral compartment should not measure less than 5 mm (the sum of the thickness of the normal cartilage), and the medial compartment should gap at least 5 mm (the sum of the articular cartilage lost).
- Incomplete loss of medial joint space must be investigated further with a varus stress view to show complete joint space loss.
- If the joint space loss is not full-thickness, UKA should be avoided and other causes for the pain should be sought.
- Lateral radiographs reveal the extent of posterior wear and are, therefore, a reliable indicator of the functional integrity of the ACL.
- The femoral condyles and tibial plateau should appear superimposed.
- If a concave erosion is present on the anterior two thirds of the plateau, the ACL is intact (95% probability).

**DIFFERENTIAL DIAGNOSIS**

- Tricompartmental OA
- Meniscal tear
- Saphenous neuritis
- Osteochondral injury
- Pes anserine bursitis
- Septic arthritis

**NONOPERATIVE MANAGEMENT**

- Nonoperative management consists of nonsteroidal anti-inflammatory drugs, glucosamine and chondroitin, physical therapy, assistive devices, viscosupplementation, bracing, or intra-articular corticosteroid injections.

**SURGICAL MANAGEMENT**

- The patient’s suitability for UKA ultimately is decided in the operating room. The patient must have been prepared in advance for a possible conversion to a total knee arthroplasty if not all the criteria are met.
- We use the Oxford criteria, as follows:
  - Physical signs must include pain severe enough to justify joint replacement and flexion deformity less than 15 degrees.
  - Radiographic signs include full-thickness cartilage loss with eburnated bone-on-bone contact in the medial compartment; full-thickness cartilage preservation in the lateral compartment; intact articular surface at the back of the tibial plateau; and manually correctable varus deformity.
  - Intraoperative signs include the presence of an intact ACL and satisfactory appearance of the central articular cartilage of the lateral compartment.
  - Traditional contraindications for UKA include:
    - Inflammatory arthritis
    - A flexion contracture of 5 or more degrees
    - A preoperative arc of motion of less than 90 degrees
    - Angular deformity of more than 15 degrees
    - Significant cartilaginous damage in the opposite compartment
    - ACL deficiency
    - Body mass index higher than 32
    - Exposed subchondral bone beneath the patella
  - Criteria that are not considered contraindications are age, activity level, weight, patellofemoral arthritis, degenerative lateral meniscus, and chondrocalcinosis.

**Preoperative Planning**

- Preoperative templating for the appropriately sized components is performed using the lateral radiograph.
Examination is performed under anesthesia to assess the stability and motion of the knee.

**Positioning**
- A thigh tourniquet is applied and the leg is placed in a hanging leg holder (**FIG 2**).
- The hip is flexed to about 30 degrees, and the leg is abducted.
- The knee must be free to flex to at least 135 degrees.

**Approach**
- An abbreviated medial parapatellar approach is used for a medial UKA (**FIG 3**).

---

**EXPOSURE**

- With the knee flexed to 90 degrees, a medial parapatellar skin incision is made from the medial margin of the patella to a point 3 cm distal to the joint line. The capsular incision is extended obliquely and medially for 1 to 2 cm into the vastus medialis.
- Part of the retropatellar fat pad is excised, and the anterior cruciate ligament is inspected to ascertain that it is intact (**TECH FIG 1A**).
- All osteophytes must be removed from the medial margin of the medial femoral condyle and from both margins of the intercondylar notch (**TECH FIG 1B**).

**TIBIAL RESECTION**

- The front of the tibia is exposed in the lower part of the wound from the tibial tubercle to the rim of the plateau.
- As much of the medial meniscus is excised as possible.
- None of the fibers of the medial collateral ligament are released.
- The tibial saw guide is applied with its shaft parallel with the long axis of the tibia in both planes (**TECH FIG 2A**).
- The level of resection is estimated—this level varies according to the depth of tibial erosion.
- A minimum of 6 mm of intact posterior cartilage and bone should be removed.
- The saw cut should pass 2 or 3 mm below the deepest part of the erosion.
- It is better to be conservative with the first cut, because the tibia can easily be re-cut if too little bone has been removed (**TECH FIG 2B**).
TECHNIQUES

- A reciprocating saw with a stiff narrow blade is used to make the vertical tibial cut.
  - The blade is pushed into the intercondylar notch close to the lateral margin of the medial femoral condyle.
  - The blade is pointed toward the head of the femur (TECH FIG 2C).
- Before the horizontal cut is made, a retractor is inserted to protect the medial collateral ligament.
- A 12-mm-wide oscillating saw blade is used to excise the tibial plateau (TECH FIG 2D).
- The blade must go right to the back of the joint.
- When the plateau is loose, it is levered up with a broad osteotome and removed.
- The posterior horn of the medial meniscus can now be removed.
- The excised plateau will demonstrate the classic lesion of anteromedial OA and preserved cartilage posteriorly.
- The excised plateau together with the tibial templates is used to choose the size of the tibial implant.
- Sufficient thickness of bone must be removed from the tibia to accommodate the tibial template and a bearing at least 4 mm thick (TECH FIG 3A–C).
  - Whenever a feeler gauge is used to measure a gap, the retractors are removed.
  - If the retractors are left in, they have the effect of tightening the soft tissues, artificially diminishing the gap.
  - If the 4-mm gauge cannot be inserted or feels tight, then more bone needs to be excised from the tibia.
  - With the knee in about 45 degrees of flexion, a hole is made into the intramedullary canal of the femur with the awl. The hole must be situated 1 cm anterior to the anteromedial corner of the intercondylar notch.
- The knee is then flexed to 90 degrees. This must be done with care, because the medial border of the patella abuts against the rod.
  - The tibial template is replaced, the femoral drill guide is inserted, and a feeler gauge is placed that is 1 mm thinner than the flexion space between them.
  - If the gauge is too loose, a thicker gauge is inserted.
  - The femoral drill guide is now manipulated until it is in the middle of the condyle and its handle is aligned parallel with the long axis of the tibia.
- The knee is then flexed to 90 degrees. This must be done with care, because the medial border of the patella abuts against the rod.
  - The tibial template is replaced, the femoral drill guide is inserted, and a feeler gauge is placed that is 1 mm thinner than the flexion space between them.
  - If the gauge is too loose, a thicker gauge is inserted.
  - The femoral drill guide is now manipulated until it is in the middle of the condyle and its handle is aligned parallel with the long axis of the tibia.
  - By adjusting the degree of flexion of the knee, the upper surface of the drill guide is made to lie parallel with the intramedullary rod when viewed from the side.

TECH FIG 2 • A. The tibial alignment guide is placed parallel to the tibia in both the AP and lateral planes. B. With the tibial alignment guide in place, it is possible to observe the depth of tibial bone to be resected. C. A reciprocating saw is used to make the vertical tibial cut. D. A 12-mm-wide oscillating saw is used to excise the tibial plateau.
TECH FIG 3 • A. The resected fragment of tibial bone demonstrates anteromedial osteoarthritis and intact posterior cartilage. B. Tibial sizing templates are aligned on the resected tibial fragment to determine appropriate component size. C. Retractors are removed and a no. 4 feeler gauge is inserted to measure the gap between femur and tibia. D–F. With the tibial template and a feeler gauge 1 mm thinner than the flexion gap in place, the femoral drill guide is inserted and positioned to determine femoral alignment. When all alignment requirements are fulfilled, holes are drilled.

- By internally and externally rotating the tibia, the lateral surface of the fin is made to lie parallel with the intramedullary rod when viewed from above (TECH FIG 3D).
- When all of these five requirements are fulfilled, the drill is passed through the upper hole to its stop and left in place.
- The other hole is then drilled, and both drills and all instruments are removed from the joint.
- The intramedullary rod also may be removed (TECH FIG 3E,F).

POSTERIOR CONDYLE RESECTION AND MILLING

- The femoral saw block is inserted into the drilled holes.
- Using the 12-mm broad sagittal saw, the posterior facet of the femoral condyle is excised (TECH FIG 4A).
- The saw block is removed, and the 0 spigot is inserted into the large drill hole (TECH FIG 4B).
- The spherical cutter is then used to mill the distal femur until the cutter will not advance further (TECH FIG 4C).
- With the leg in 90 degrees of flexion, the tibial template is inserted and the femoral trial component is applied to the milled condyle (TECH FIG 4D).
The extension gap is measured with the knee in 20 degrees of flexion using metal feeler gauges.

**BALANCING THE FLEXION AND EXTENSION GAPS**

- The flexion gap is now carefully measured with feeler gauges. The feeler gauge will slide in and out easily but will not tilt.
- The gauge is removed. It is important to remove the gauge before extending the knee because, at this stage, the extension gap is always narrower than the flexion gap.
  - If the gauge is left in place, it may stretch or rupture the ligaments as the knee extends.
  - Next, the extension gap is measured in 20 degrees of flexion with the metal feeler gauges (**TECH FIG 5**).
  - In full extension, the posterior capsule is tight, and its influence gives a false under-measurement.
• The formula for balancing the flexion and extension gaps is as follows:
  - Flexion gap (mm) – extension gap (mm) = thickness of bone to be milled from femur (mm) = spigot number to be used.
  - For instance, if the flexion gap measures 5 mm and the extension gap 2 mm, the amount of bone to be milled is 3 mm. To achieve this, a number 3 spigot is inserted and the bone is milled until the cutter will advance no further.
• With the tibial template and the femoral trial component in place, the flexion and extension gaps are re-measured.

**TRIAL COMPONENT AND TRIAL BEARING**

• The tibial trial component is inserted and tapped home with the tibial impactor.
  - The trial component must be flush to the bone, and its posterior margin must extend to the back of the tibia.
  - Only a light hammer should be used, to avoid the risk of plateau fracture.
• Final preparation of the femur requires trimming of the condyle anteriorly and posteriorly to reduce the risk of impingement of bone against the bearing in full extension and full flexion (TECH FIG 6A).
• The femoral posterior trimming guide is applied to the condyle, and the osteophyte chisel is used to remove any posterior osteophytes.
• A trial meniscal bearing of the chosen thickness is inserted.
  - It is only at this stage that a trial bearing is used (TECH FIG 6B–D).
• Previously, feeler gauges have been used to measure the gaps, because they do not stretch the ligaments.
• With the bearing in place, the knee is manipulated through a full range of motion to demonstrate stability of the joint, security of the bearing, and absence of impingement.
• The thickness of the bearing should be such as to restore the ligaments to their natural tension so that when a valgus force is applied to the knee, the artificial joint surfaces distract a millimeter or two.
  - This test should be done with the knee in 20 degrees of flexion.
• In full extension, the bearing will be gripped firmly because of the tight posterior capsule.
INSERTING AND CEMENTING THE FINAL COMPONENT

- The femoral and tibial surfaces are roughened by multiple small drill holes made with the cement key drill (TECH FIG 7A).
- The tibial component is inserted and pressed down, first posteriorly and then anteriorly, so that excess cement is squeezed out at the front (TECH FIG 7B).
- Excess cement is removed from the margins of the component with a small curette (TECH FIG 7C).
- The femoral component is applied to the condyle and impacted with the punch held at 30 degrees to the long axis of the femur.
- Again, excess cement is removed from the margins with a small curette.
- During cement setting, the leg is held in 45 degrees of flexion (TECH FIG 7D).
- The leg should not be fully extended, because pressure in this position may tilt the tibial component anteriorly.
- The reconstruction is completed by snapping the chosen bearing into place.
- Routine closure of the wound follows.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Pearls</th>
<th>Pitfalls</th>
</tr>
</thead>
<tbody>
<tr>
<td>There is a tendency to place too tight a bearing. Leave the bearing relatively loose.</td>
<td>Tibial plateau fracture must be avoided. Care should be taken not to damage the posterior cortex or cut too deep a slot for the keel. Gentle blows with a light mallet are used.</td>
</tr>
<tr>
<td>Anterior bone (4–5 mm) is removed from proximal to the femoral component to prevent bearing impingement.</td>
<td>All retractors must be removed during any trial or balance step of the procedure. Retractors will falsely tighten the gaps.</td>
</tr>
<tr>
<td>The tibial feeler gauge must be flush against the lateral rail of the tibial tray during femoral guide placement and femoral drill hole placement.</td>
<td>There is a tendency to cut too much posterior slope. The posterior slope should be about 7 degrees.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Intraoperative local anesthetic (60 mL of 0.5% ropivacaine with 30 mg ketorolac and 0.5 mL of 1:1000 epinephrine) is injected into the damaged soft tissues.
- A drain is used; it is pulled on the first postoperative day.
- Patients typically are discharged from the hospital less than 24 hours after admission.
- Patients usually have a rapid initial recovery (FIG 4). Some patients may experience mild medial pain for 2 to 3 months after surgery.

OUTCOMES

- UKA is a predictable surgical option for appropriate candidates with anteromedial OA. Survival rate of UKA at 10 years is 90% or better (Table 1).
We performed 316 medial Oxford UKA between 2004 and 2005. Classic contraindications to UKA, such as obesity, young age, patellofemoral degenerative joint disease (DJD), and anterior knee pain, were specifically reviewed.

- Twenty-five percent of patients were obese, with BMI greater than 35.
- Fifty-four percent of patients were younger than 60 years of age.
- The incidence of radiographic patellofemoral degenerative disease was 43% preoperatively.
- Only 68% of patients reported isolated medial-sided knee pain preoperatively. Twenty-one percent described global knee pain and 6% reported anterior knee pain.
- There were no differences in failure rates or Knee Society scores between patients with preoperative anterior knee pain and those without anterior knee pain before UKA. No differences in outcomes were noted between those with and those without radiographic evidence of patellar DJD.
- No differences in outcomes were noted between obese and non-obese patients. Additionally, no differences in outcomes were seen between patients younger or older than 60 years of age.
- Our experience with the Oxford UKA now spans 2.5 years. To date, our patients have experienced five implant failures: two for tibial loosening with collapse, one for tibial plateau fracture, one for infection, and one for unexplained pain.
- There have been no dislocations of the mobile bearing.

FIG 4 • Patients typically enjoy rapid recovery, achieving high flexion with normal kinematics.

COMPLICATIONS

- Multiple series (Table 1; see also references 9 and 10) provide an overview of the potential complications and outcomes of the Oxford Mobile Bearing UKA.
- Infection has been observed in up to 0.6% of cases.
- Medial tibial plateau fracture occurs in 0.3% of cases. Care must be taken not to damage the posterior cortex.
- Retrieval studies of the Oxford UKA show wear to be 0.026 to 0.043 mm per year.
- Historically, dislocation of the mobile bearing occurs in 0.5% of cases. Primary dislocations occur for two main reasons: impingement and femoral component malposition. The bearing can impinge on posterior osteophytes or cement, causing the bearing to “spit out” anteriorly. If the femoral component is not positioned correctly, the mobile bearing can “spin out.” The newer bearing with “wings” will help resolve some spin-out issues (FIG 5). However, specific attention to placement of the femoral component is crucial.
- Progression of lateral compartment arthritis requiring revision occurred in 1.4% of patients with UKAs. Most authors believe that progression of lateral compartment OA is due to overcorrection of a varus deformity to valgus due to MCL release or damage.

Table 1

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Prosthesis</th>
<th>N</th>
<th>Survival Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>Berger et al</td>
<td>Miller-Galante (Zimmer, Warsaw, IN)</td>
<td>62</td>
<td>98% at 10 years, 95.7% at 13 years, 82% at 11 years</td>
</tr>
<tr>
<td>2004</td>
<td>Keblish and Briard</td>
<td>Low Contact Stress (LCS) (Johnson &amp; Johnson/DePuy, Warsaw, IN)</td>
<td>177</td>
<td>94% at 5 years, 90% at 10 years, 84% at 20 years, 72% at 25 years</td>
</tr>
<tr>
<td>2004</td>
<td>Naudie et al</td>
<td>Miller-Galante (Zimmer, Warsaw, IN)</td>
<td>113</td>
<td>96.73% at 5 years, 94.04% at 10 years, 93% at 15 years</td>
</tr>
<tr>
<td>2005</td>
<td>O’Rourke et al</td>
<td>Marmor (Richards, Memphis, TN)</td>
<td>136</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>Rajasekhar et al</td>
<td>Oxford (Biomet, Warsaw, IN)</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>Price et al</td>
<td>Oxford (Biomet, Warsaw, IN)</td>
<td>439</td>
<td></td>
</tr>
</tbody>
</table>

FIG 5 • Although the meniscal bearing trial is universal, the actual bearing is anatomic, with longer lateral wings to enhance stability.
As many as 2% of patients may have persistent unexplained pain, possibly caused by tibial condyle overload, overhang of the tibial component, overstretching of the MCL, and pes anserine bursitis by 1 year post-surgery; most medial pain resolves spontaneously by 2 years.

REFERENCES


DEFINITION
- Upper tibial osteotomy (high tibial osteotomy [HTO]) has evolved from a procedure used strictly for treating medial compartment arthrosis of the knee to one that has implications in combination surgeries to address the entire spectrum of knee pathology.
- HTO is now used to alter the mechanical alignment of the lower extremity to offload forces through the medial compartment in arthritic knees.
- It also can be used to offload forces in cartilage restoration procedures (eg, autologous chondrocyte implantation, meniscal transplants, and osteochondral auto- and allografts).
- The subtleties of the HTO can be combined with changes in the sagittal slope of the knee to help correct or aid in treatment of anterior cruciate or posterior cruciate ligament injuries.
- Therefore, the indications for an HTO include:
  - Malalignment plus arthrosis
  - Malalignment plus instability
  - Malalignment plus instability plus arthrosis
  - Malalignment plus cartilage restoration techniques

ANATOMY
- The upper tibial location of the osteotomy has certain key anatomic points to consider for a successful result and to avoid injury to the extremity.
  - On the medial side of the knee, the pes anserine tendons insert on the anteromedial aspect of the tibia. The gracilis and semitendinosus, found on the undersurface of the sartorius fascia, must be preserved. Deep to the tendons, but composing a completely different layer, is the medial collateral ligament (MCL) (deep and superficial layers).
  - The patellar tendon insertion on the tibial tubercle and its relation to the level of the osteotomy. The osteotomy should be made proximal to the tubercle.
  - On the lateral side, the common peroneal nerve and its relation to the fibular head. The proximal tibiofibular joint also can be violated in lateral closing wedge osteotomies, leading to arthritic changes in the future.
  - The posterior neurovascular structures, including the popliteal artery and tibial nerve, must be protected during creation of the posterior aspect of the osteotomy.
  - The cross-section of the proximal tibia at the location of the osteotomy is not a cylinder, but a triangle. Therefore, the most medial location of the osteotomy is different for the posterior and anterior aspects of the tibia. Because of this, to avoid an inadvertent increase in tibial slope when opening up the osteotomy, the anterior portion of the osteotomy should be opened to one third of the posterior height (FIG 1).

PATHOGENESIS
- The biologic basis for performing an HTO can be thought of in regard to its indications.
- Arthrosis
  - Regardless of the cause of the arthritis, whether posttraumatic or primary, medial compartment arthritis continues to be exacerbated when there is mechanical overload of the medial compartment of the knee.
  - If the mechanical axis of the lower extremity from the hip-knee-ankle films shows that the weight-bearing line falls within the medial compartment, the medial cartilage is overloaded and placed at a risk for further degenerative change.
- Instability
  - Because the osteotomy can alter the orientation of the proximal tibia in two planes (coronal and sagittal), altering the slope of the tibia can aid deficient cruciate ligaments in controlling knee instability.
  - When the tibial slope is decreased, the tibia is less likely to translate posteriorly, and, therefore, the HTO can aid the patient with an anterior cruciate ligament (ACL) deficiency. When the tibial slope is increased, the tibia is less inclined to translate posteriorly, and thus the HTO can aid the patient with posterior cruciate ligament (PCL) deficiency.
  - If the status of the ACL is unknown and the tibial slope is unknowingly increased in an ACL-deficient patient, residual instability may worsen due to the biomechanical changes in knee motion.
- Cartilage restoration procedures
  - Because cartilage degeneration necessitating restorative procedures has an associated component of malalignment, placing restored or regenerated cartilage in the knee makes it necessary to off-load the involved compartment to give the new cartilage the best mechanical environment for growth and success.

NATURAL HISTORY
- The natural history of medial arthrosis with varus alignment is one of progression and further cartilage degeneration over time. The end result is a spectrum of arthritic change in the knee, from uni- to tricompartmental arthritis.
- Performing ACL reconstructions for instability on double- or triple-varus knees has been shown to have detrimental effects on the ACL graft and higher rates of failure.
- Noyes et al17 have recommended addressing both the ligament deficiency and the varus alignment of the extremity, to allow the most biomechanically secure construct and avoid excessive tension on the reconstructed graft.
- Cartilage regenerative or restorative procedures (eg, microfracture, autologous chondrocyte implantation, osteochondral auto- and allograft transplantation, meniscal transplantation) have a higher rate of failure in the setting of malalignment, because it subjects the newly implanted tissue to mechanical overload.
- Studies have shown that limb malalignment is a contraindication to these procedures if not addressed concomitantly in either a staged or concurrent fashion.1-3
PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history should be taken to determine whether the patient’s complaints correlate with the ultimate diagnosis. This is especially important when making distinctions regarding pain from arthritis versus pain from instability and when formulating combined treatment options.
- The exact location of the pain is determined by asking the patient to point with one finger to its location.
- Medial-sided knee pain without radiation and subsequent radiographs showing medial compartment arthritis or narrowing make it possible to form a more definitive conclusion regarding surgical intervention.
- Knee pain anteriorly or laterally, for example, does not correlate with varus deformity and medial compartment arthritis, and a different diagnosis must be sought for the patient’s pain.
- Medial-sided knee pain with radiation from the hip can signify hip arthritis as the cause of the lower extremity pain.
- Radiation of the pain distal to the knee and into the foot can signify radiculopathy and a spinal cause of the lower extremity pain.
- Further classification of the pain is important, including duration and frequency of symptoms, what aggravates or alleviates the symptoms, and previous injuries to the knee in question.
- Does the patient complain of pain only, instability only, or pain plus instability? This distinction is important in the multiply injured knee with chronic ligamentous deficiency and arthritic change.
- Pain without instability and radiographs consistent with medial compartment arthritic change can be treated with an osteotomy only.
Instability only with a varus-aligned limb can be treated with a ligamentous reconstruction only when the varus is mild and there is no varus thrust. In the setting of a large varus thrust and significant varus deformity, the ligament reconstruction will fail.

Pain with instability may signify the need to include both a ligamentous reconstruction and an osteotomy, in either a staged or concurrent fashion.

Other conservative treatments have been attempted.

Medial-sided knee pain with varus alignment can respond favorably to heel wedges with lateral posts, which help to offload the medial compartment of the knee by altering the gait mechanics.

Other treatment options include medial unloader braces, which also help to alter the biomechanics of the knee by offloading the medial compartment. Heavy laborers who cannot afford to take time off of work due to job constraints often can get through the work week with the unloader braces and postpone surgical intervention.

Corticosteroid injections or viscosupplementation are other conservative treatment options for early arthritic change in the knee that can be used as temporizing measures to help relieve acute pain attacks from arthritis.

The physical examination of the varus knee should include:

- Investigation of varus thrust when assessing gait
- Collateral ligament stability as an indicator of the residual laxity of the knee in the coronal plane
- Palpation or ballottement of the patella for effusion, which indicates intra-articular cause of the symptoms
- Systematic palpation of various areas of the knee to localize pain
- Assessment of knee range of motion (ROM) to determine goals of surgery: significantly limited ROM may not be caused only by lower extremity varus alignment and may indicate advanced arthrosis.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Radiographic evaluation in planning for an HTO is of paramount importance. Routine radiographs to obtain include bilateral anteroposterior (AP) standing, bilateral posteroanterior (PA) 45-degree flexed (ie, skier’s view), lateral view of affected knee, and bilateral Merchant views.
- The AP standing and PA 45-degree flexed views allow the determination and initial grading of medial or lateral joint space narrowing. Joint space narrowing often can be found at the posterior condylar area and, therefore, may be missed on a routine AP standing knee radiograph.
  - Flexing the knee to 45 degrees allows a different area of the femoral condyle to be evaluated tangentially by the x-ray beam and may reveal significant arthritic change (FIG 2A, B).
- The lateral view allows initial assessment of the patellofemoral joint and the determination of tibial slope.
- The Merchant views complete the patellofemoral joint evaluation and assess the patellofemoral joint for arthritic changes.
- Further radiographic evaluation includes a mechanical axis view (hip-knee-ankle). This view makes it possible to determine initial varus and valgus alignment of the bilateral lower extremities and the overall mechanical axis, and to template correction angles for the opening wedge HTO (FIG 2C).
- MRI can be useful in younger patients to assess cartilage surfaces and ligament deficiency (eg, the chronic ACL-deficient knee with varus alignment and relatively preserved joint space on radiograph). The extent of cartilage surface damage can be assessed, and meniscal injuries also can be documented.
- MRI also can be useful in assessing bone marrow edema and helping to correlate the source of the patient’s pain. For example, in the varus knee with medial joint line pain, meniscal symptoms, and 4 mm of medial joint space left, it is difficult to predict whether the patient’s pain is coming directly from the meniscal tear or from early arthritic change.
- An MRI scan that shows significant bone marrow edema in the medial femoral condyle or tibial plateau indicates that a routine medial meniscectomy should be performed with caution, because the patient’s pain actually may be caused by the early arthritic changes and cartilage overload, and symptoms may increase or remain the same.
- Bone scanning can also be useful in determining the source of elusive pain in the knee (FIG 2D).

**DIFFERENTIAL DIAGNOSIS**

- Meniscal tear
- Osteochondral injury
- Bi- or tricompartmental arthritis
- ACL, PCL, posterolateral ligament instability
- Hip osteoarthritis
- Spinal pathology (eg, stenosis, disc herniation)

**NONOPERATIVE MANAGEMENT**

Nonoperative management for unicompartmental knee arthritis before an osteotomy is needed includes:

- Physical therapy and weight loss
- Medications (eg, acetaminophen, nonsteroidal anti-inflammatory drugs, glucosamine/chondroitin sulfate)
- Intra-articular knee injections: eg, corticosteroids, viscosupplementation
- Mechanical offloading devices or orthoses (eg, heel wedges with lateral posts, unloader braces). We recommend that a patient fail or find unacceptable all of these nonsurgical modalities before proceeding with an osteotomy procedure. Especially with the unloader braces, a patient may get excellent relief and can either continue the conservative treatment or decide that a formal unloading procedure, such as the HTO, would reliably relieve their pain.
- Nonoperative management for instability plus malalignment includes all of the modalities that have been discussed. However, an attempt should be made to distinguish between the patient’s complaints of pain, which may signify an underlying arthritic cause of pain, and instability, which, depending on the final alignment values, may need only a ligament reconstruction.

**SURGICAL MANAGEMENT**

Indications

- Varus malalignment with medial compartment arthritis
  - The ideal patient is physiologically young (less than 55 years old) with an active lifestyle.
  - Patients should not be excluded solely based on age. Treatment plans may focus on the current and desired
Tegner Activity Scores. No study has shown a Tegner Activity Score greater than 4 with total knee arthroplasty or unicompartmental knee arthroplasty.\textsuperscript{22}

- Varus malalignment with instability
- Posterolateral instability\textsuperscript{4,6,17}
- ACL instability

Varus malalignment with arthritis and instability

The HTO can purposely decrease tibial slope in the sagittal plane and decrease anterior translation in an ACL-deficient knee.

Conversely, the tibial slope in a PCL-deficient knee can be increased to aid in decreasing posterior tibial translation.

Varus malalignment with associated cartilage or meniscal procedures

A favorable mechanical environment for newly transplanted cartilage cells or meniscal transplantation must be created. This includes decreasing the mechanical overload in that compartment via osteotomy.\textsuperscript{7,11,14,15}

- Valgus malalignment with lateral compartment arthritis
- A distal femoral varus-producing osteotomy usually is performed to avoid producing obliquity of the tibiofemoral joint line with the varus HTO.
- Adult osteochondritis dissecans\textsuperscript{19}
- Osteonecrosis of the medial femoral condyle in physiologically young individuals

Contraindications

- Elderly patients (>60 years old) with low functional demands are better suited for a total knee replacement.
- Degeneration of the contralateral knee compartment or loss of lateral compartment meniscus
- Loss of knee motion >70 degrees
- Patellofemoral degenerative disease that is symptomatic
- Pain not consistent with clinical examination (eg, patellofemoral pain with medial compartment osteoarthritis)
- Any of the inflammatory arthritides (eg, rheumatoid arthritis)
Preoperative Planning

- All imaging studies are reviewed, especially the mechanical axis view, to determine the amount of correction needed for the osteotomy.
- The patient and surgeon should discuss the use of auto- or allograft material for bone grafting of the osteotomy site.
  - If the osteotomy is smaller than 7 degrees, typically no bone graft is needed.
  - If the osteotomy is larger than 7 degrees, bone graft is needed to fill the defect in opening wedge techniques.
    - Autograft typically is taken from the iliac crest (ie, tricortical iliac crest graft)
    - Allograft combines tricortical iliac crest with croutons for medullary packing. Concerns in regard to placing “dead bone” into the osteotomy site have led to recommendations to include osteoconductive or osteoinductive additives (eg, OP-1, DBM) as well.
- Intraoperative C-arm fluoroscopy should be available.
- Examinations under anesthesia should include assessment of ROM and of varus/valgus stress at 30 degrees and 0 degrees.

Positioning

- The patient is placed supine on the operating table (FIG 3).
- A lateral post is used during the arthroscopy portion of the procedure and can be lowered during the open osteotomy portion.

ARTHROSCOPY

- A routine diagnostic arthroscopy is performed.
- The status of the lateral compartment is confirmed.
  - If unexpected lateral compartment osteoarthritis or chondral defects are found, off-loading the knee into that compartment may be detrimental to the long-term results of the surgery (TECH FIG 1).
- The status of the patellofemoral compartment also is confirmed.
  - Significant patellofemoral arthritis (especially of the lateral patellar facet and lateral trochlea) can be exacerbated with an HTO. Such arthritis also can be detrimental to the long-term results of the surgery.
  - Meniscal tears are débrided back to a stable base.
  - Chondroplasty or marrow stimulation is now performed.
    - If the osteotomy is being performed together with a cartilage restorative procedure (eg, autologous chondrocyte implantation), the osteotomy is performed first and then the restorative cartilage procedures are performed, to minimize any trauma to the newly implanted periosteal covering or injected cartilage cells.

Approach

- The main approach for the opening wedge HTO is through an anteromedial incision, just distal to the medial joint line and 3 cm medial to the tibial tubercle.
- Approaches for the lateral closing wedge are from the anterolateral aspect of the tibia, just anterior to the fibula.
INITIAL DISSECTION

- Proper bony anatomic landmarks are located.
  - The tibial tubercle, posteromedial tibia, and joint line are clearly identified with a skin marker.
  - The incision lies 2 to 3 cm posterior to the tibial tubercle and 1 cm distal to the joint line, and extends distally for 5 to 6 cm (TECH FIG 2A).
  - The incision is taken down through the skin and subcutaneous tissues, revealing the sartorius fascia (TECH FIG 2B).
  - The superior border of the gracilis hamstring tendon is palpated, and the sartorius fascia is opened along the superior border of the gracilis tendon.
  - Medially, the pes bursa is released from the medial tibial tubercle in an inverted L fashion.
  - The pes bursa is carefully elevated distally, taking great care to develop the plane between the bursa and the underlying medial collateral ligament.
  - Proximally, the retinaculum and layer 1 of the knee are incised to the approximate level of the joint line (TECH FIG 2C).

- Anteriorly, the patellar tendon is identified, and a plane posterior to the tendon is identified. A Z-retractor is placed under the tendon to protect it.
  - Occasionally, the most superior fibers of the patellar tendon attachment to the tibial tubercle must be elevated to avoid inadvertent creation of the osteotomy through the patellar tendon.
  - Posteriorly, the MCL is dissected subperiosteally using a Cobb elevator, which is taken back toward the posteromedial border of the tibia.
  - The Cobb elevator is then used to dissect the muscles and tissues from the posterior tibia along the line of the osteotomy. Care must be taken to stay directly on the posterior tibial bone to avoid neurovascular injury.
  - After adequate posterior dissection, it should be possible to pass a finger bluntly across the posterior tibia. For further protection of the posterior neurovascular structures, a laparotomy sponge is placed across the back of the knee.
  - Finally, another Z-retractor is placed posteriorly to retract the pes bursa, MCL, and posterior neurovascular structures (TECH FIG 2D,E).

**TECH FIG 2 • A.** View of the anteromedial knee showing the proper bony landmarks. PMT, posteromedial tibial border; TT, tibial tubercle; arrowhead, joint line; *, level of hamstring tendons. **B-E.** Dissection from an anteromedial view. **B.** Overall orientation of incision through subcutaneous fat, down to sartorius fascia. **C.** Close-up of incision. The sartorius fascia is opened just superior to the gracilis tendon, and the pes bursa is elevated off in an L-type fashion. An incision also is made proximally in the retinaculum. **D.** This incision reveals the fibers of the medial collateral ligament (MCL), which are then dissected subperiosteally with a Cobb elevator. **E.** Retractors are placed under the patellar tendon and at the posteromedial tibia.
PLACING GUIDE PINS

- Commercially available osteotomy systems provide the necessary instrumentation needed to carry out the procedure. We use the Arthrex instrumentation (Arthrex, Inc., Naples, FL).
- Before the osteotomy is performed, an intraoperative mechanical axis view should be obtained, using either the Bovie cord or the alignment rod found in the osteotomy set.

Using fluoroscopy, the alignment rod is placed at the center of the femoral head (TECH FIG 3A) and then at the center of the ankle joint (TECH FIG 3B).

TECH FIG 3 • A. Fluoroscopic image of alignment rod through femoral head. B. Fluoroscopic image of the alignment rod in the center of the ankle. C. The subsequent location of the alignment rod in the knee. This initial mechanical axis must be corrected. It should match with the preoperative planning. D. Initial guide pin from medial to lateral and parallel to the joint line. The pin is placed approximately 1 cm distal to the joint line. E. Osteotomy guide pin assembly over the initial guide pin. The angle of the guide pin assembly is changed so that the guide pins are just superior to the tibial tubercle. Two pins are drilled from medial to lateral along the osteotomy line to intersect the initial guide pin 1 cm from the lateral cortex. F. Fluoroscopic image verifying the two guide pins placed from medial to lateral using the osteotomy guide pin assembly. Note how in this view, which is parallel to the joint surface, the two pins are superimposed on one another, thus verifying that they, too, are parallel to the joint surface. White arrow, guide pin assembly; black arrow, osteotomy guide pins; black arrowhead, initial guide pin.
■ The subsequent location of the alignment rod in the coronal view of the knee is the intraoperative location of the mechanical axis (TECH FIG 3C).
■ These radiographs are saved for later comparison.
■ A guide pin is placed from medial to lateral across the proximal tibia, 1 cm distal to the joint, and parallel to the joint surface.
■ The tip of the guide pin should be just proximal to the level of the fibula. The location of this guide pin should be verified with fluoroscopy (TECH FIG 3D).
■ The osteotomy guide pin assembly is then inserted onto the guide pin (TECH FIG 3E). The guide pin assembly acts on the same concept as an ACL tibial aiming guide, placing the subsequent guide pins at the proper angle and oriented to the tip of the previous guide pin placed parallel to the joint line.
■ A parallel guide sleeve is then inserted onto the osteotomy guide pin assembly.
■ Not only can the osteotomy guide pin assembly determine the angle of the cut in the coronal plane, but it also has the ability to rotate in the sagittal plane to reproduce the anterior-to-posterior tibial plateau slope accurately. This can be helpful in special situations (eg, PCL or ACL deficiency) in which further alterations in the tibial slope may be necessary (eg, a biplane osteotomy).
■ The angle of the guide pin assembly in the coronal plane is set so that the guide pins will enter the proximal tibia above the tibial tubercle.
■ When acceptable, two further guide pins are drilled from medial to lateral along the orientation of the osteotomy cut. Their position is verified with fluoroscopy (TECH FIG 3F).
■ The parallel guide sleeve, guide pin assembly, and initial guidewire parallel to the joint line are now removed.

### CUTTING AND OPENING THE OSTEOTOMY

- An optional cutting guide is available for positioning over the guide pins. Either with or without the cutting guide, an oscillating saw is used to make the osteotomy cut.
- The saw is always positioned on the inferior surface of the guide pins to avoid inadvertent maltracking of the saw toward the joint surface. The oscillating saw is used to cut the tibial osteotomy to within 1 cm of the lateral cortex.
- Fluoroscopy should be used frequently to verify the depth and angle of the osteotomy cut.
- Careful attention should be paid when making the posterior and anterior tibial cortex cuts to avoid injury to the posterior neurovascular structures and patellar tendon, respectively.
- Thin osteotomes are then used to complete the osteotomy cut to within 1 cm of the lateral cortex (TECH FIG 4A).
- To assess whether the osteotomy is ready for distraction, a “valgus bounce test” is performed.
- As when assessing a valgus stress to the knee, a gentle valgus stress is applied to the osteotomy. The osteotomy should easily open 4 to 5 mm and “bounce back” to the closed position.
- This ensures that adequate posterior and anterior cortical cuts have been made.
- An osteotomy wedge is now inserted into the osteotomy cut to gently open the osteotomy to the desired correction.
- If it initially is difficult to open the osteotomy and get the wedge in place, three stacked osteotomes can be placed in the osteotomy cut to gently open the osteotomy and provide the initial plastic deformation of the lateral cortex (TECH FIG 4B).
- Once the wedge can be inserted into the osteotomy cut, it is gently driven across the osteotomy to the desired correction.
- The wedge has laser lines that mark the desired osteotomy opening angle. This angle should be taken from the preoperative templating, and we assume that 1 mm of opening equals 1 degree of correction. Therefore, if your preoperative templating needed an 11-degree correction, the osteotomy guide should be driven to the 11-mm opening laser line. The wedge should be inserted only a few millimeters at a time to allow plastic deformation of the lateral cortex (TECH FIG 4C,D).
- Fluoroscopy should be used to assess the status of the lateral cortex and osteotomy progression (TECH FIG 4E).
- One should be wary of propagation of the osteotomy to the lateral cortex with disruption of the lateral hinge or propagation of the osteotomy intra-articularly. This can be usually felt by a sudden “give” of the osteotomy wedge on insertion.
- The posterior tine of the wedge should be as posterior as possible to avoid an inadvertent increase in tibial slope (TECH FIG 4F).
- The proximal tibia is a triangle in cross-section, so the medial starting point of the posterior tine will be more medial to the anterior tine of the wedge.
- Because of the triangular shape of the proximal tibia, the millimeter reading of the posterior tine will be greater than that of the anterior tine if the osteotomy is in the proper sagittal plane alignment.
- The opening of the anterior half of the osteotomy should be one third the height of the posterior half. This will verify that the tibial slope has not been significantly altered.
Chapter 18  
UPPER TIBIAL OSTEOTOMY

**TECH FIG 4**  
A. Fluoroscopic image showing the thin osteotomes completing the osteotomy cut to within 1 cm of the lateral cortex. *Single black arrow*, osteotomy guide pins; *double black arrows*, osteotome; *, posterior retractor protecting the neurovascular structures.  
B. Stacking the osteotomes in the osteotomy cut to help provide the initial plastic deformation of the lateral cortex.  
C. An osteotomy wedge impacted into the osteotomy cut. The anterior tine reads 10 mm and the posterior tine reads 11 mm, because the proximal tibia is a triangle, as explained in Figure 1A. The laser lines correspond with the desired osteotomy opening angle.  
D. Another view of the osteotomy wedge inserted into the osteotomy site.  
E. Fluoroscopic image showing the osteotomy wedge in place with the guide pins just superior to it. The guide pins are left in place during the opening of the osteotomy to avoid inadvertently propagating the osteotomy. The alignment rod is relied upon to verify the amount of opening of the osteotomy and the change in the mechanical axis. *, osteotomy wedge; *black arrow*, guide pins; *arrowhead*, alignment rod.  
F. The osteotomy wedge handle has been removed, and the posterior tine is seen almost at the level of the posteromedial cortex to avoid the inadvertent increase in tibial slope.

**TECHNIQUES**

- The handle of the osteotomy wedge can be removed *(TECH FIG 5A)*, leaving the anterior and posterior tines in place.  
- The proper-sized osteotomy plate is then inserted into the osteotomy site *(TECH FIG 5B)*. To respect the geometry of the tibial slope, it is recommended that the wedge in the plate be sloped from posterior to anterior.  
- The use of second-generation locking plates is recommended.  
- Before fixation of the plate, the tines are removed from the osteotomy wedge *(TECH FIG 5C)*.  
- The plate is secured with two 6.5-mm fully threaded cancellous screws in the proximal fragment. (It is not necessary to use bicortical screws.) The distal fragment is secured with two 4.5-mm bicortical screws.

**PLATE FIXATION**

- The handle of the osteotomy wedge is removed, and the wedge trial is placed between the tines to confirm the size of the osteotomy plate to be used. *(continued)*
BONE GRAFTING

- Depending on the preference of the surgeon and patient, the osteotomy must be packed with bone graft and the medial cortical margins reinforced with tricortical iliac crest graft.
  - The graft can be auto- or allograft, but this must be determined in discussion with the patient before the operation.

Autograft Iliac Crest and Bone Grafting

- The benefit of autograft iliac crest and bone grafting is that not only are the medial cortical margins of the osteotomy reinforced, but all of the bone graft contains hematopoietic elements and the entire bone formation cascade (TECH FIG 6A).
  - The difficulty with this technique is that it is necessary to prep out the iliac crest, and some morbidity results from taking the iliac crest. Although the morbidity is minimal, there is the possibility of postoperative infection, seroma, and pain.

Allograft Iliac Crest and Autograft Cancellous Bone Graft

- The allograft iliac crest is fashioned into wedges that sit anterior and posterior to the plate.
- The tricortical iliac crest helps to restore the medial cortical margins (TECH FIG 6B).
- The autologous cancellous bone graft can either be obtained from the iliac crest in the standard fashion, or a harvester from the osteochondral autograft transplantation system (OATS; Arthrex, Inc., Naples, FL) can be used to take two plugs of bone from the distal medial femur to pack into the osteotomy site.

Allograft Iliac Crest and Allograft Cancellous Bone Graft

- In this case, we worry about the risk of nonunion with larger osteotomy openings and the amount of bone graft that must be incorporated. Obviously, the larger the correction, the longer it will take for bone graft incorporation.
- If the osteotomy is larger than 11 mm, we routinely use either demineralized bone matrix or OP-1 for added osteoinductive benefits.

CLOSURE

- The pes bursa is reapproximated over the distal portion of the osteotomy plate to its anatomic location with no. 1 Vicryl (TECH FIG 7A).
  - The horizontal incision in the sartorius fascia also is closed with no. 1 Vicryl, as is the proximal split into the medial retinaculum.
  - As much coverage of soft tissue over the plate as possible is attempted. In most cases, with careful initial dissection, the plate can be covered completely.
- A medium Hemovac drain is then placed in the subcutaneous tissue, and the wound is closed in the standard fashion. A sterile dressing is applied and a CryoCuff device (Aircast, Austin, TX) is used (TECH FIG 7B–D).
- The leg is placed into a hinged knee immobilizer, locked in extension.
PEARLS AND PITFALLS

Dissection
- Be sure to dissect the tissues off of the posterior tibia, in line with the proposed osteotomy cut. It should be easy to place the surgeon’s finger across the posterior tibia from medial to lateral. Place a laparotomy sponge along the posterior tibia to further protect the neurovascular structures.

Osteotomy cut
- Pay attention to the sagittal slope of the osteotomy cut to avoid the inadvertent increase in posterior tibial slope. After the osteotomy wedge is in place and the osteotomy is opened, the anterior half of the osteotomy should be one third the height of the posterior osteotomy.
- Before inserting the osteotomy wedge for opening the osteotomy, the cut should have an easy “bounce” to it. If the osteotomy cannot be opened with a slight valgus stress, the anterior or posterior tibial cortex might have been missed with the osteotomes or saw.
- Make the osteotomy cut inferior to the guide pins.
- Use fluoroscopy often to assess whether the osteotomy has propagated intra-articularly or through the lateral cortex. If an intra-articular extension is noticed, it must be addressed like a tibial plateau fracture. If the lateral cortex has been breached, then either a staple or a 2- or 3-hole plate must be placed at the lateral cortex to restore stability to the lateral hinge.

Plate fixation
- Make sure the osteotomy wedge tines have been removed before fixation of the plate so that the osteotomy can compress onto the wedge of the plate and not be fixed in a distracted position.

POSTOPERATIVE CARE
- Immediate postoperative care
  - We admit all of our patients with osteotomies for a one day hospital observation.
  - A patient-controlled morphine drip is used for the first night; the patient is weaned to medication by mouth the next morning.
  - The drain is removed the next morning, before the patient is discharged.
  - Patients are instructed in the immediate use of ankle pumps, straight leg raises, and quadriceps isometric exercises.
- Patients are made non-weight bearing with crutches and the hinged knee immobilizer locked in extension at all times, except for knee ROM exercises.
- Full knee extension is emphasized. Active ROM is allowed to 90 degrees immediately, with or without the brace. No passive ROM is allowed, to avoid any inadvertent stress on the osteotomy site.
- Sequential compression devices are used while in the hospital. Kendall TED anti-embolism knee high stockings (Covidien, Mansfield, MA) and aspirin (650 mg every day) are used for 1 month postoperatively to minimize the risk of deep venous thrombosis.
OUTCOMES

- High tibial osteotomy done with proper indications and meticulous technique can lead to consistent, effective reduction of pain and prolongation of knee arthroplasty for up to 7 to 10 years. Factors associated with poor outcomes include undercorrection of the deformity and obesity.
- Many articles have been written about HTO outcomes (Table 1).

COMPLICATIONS

- Although the HTO can provide many years of pain relief in the physiologically young, arthritic knee, it is not without complications.
  - As with many surgeries, the learning curve is high, and the surgeon should be prepared for the consequences.

<table>
<thead>
<tr>
<th>STUDY</th>
<th>NO. OSTEOTOMIES</th>
<th>FOLLOW-UP (yr)</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yasuda et al²⁵</td>
<td>56</td>
<td>6–15</td>
<td>88% satisfactory results at 6 yr, 63% at 10 yr</td>
</tr>
<tr>
<td>Ritter and Fechtman¹⁸</td>
<td>78</td>
<td>2–12</td>
<td>60% survivorship at 12 yr</td>
</tr>
<tr>
<td>Cass and Bryan³</td>
<td>86</td>
<td>Mean, 9</td>
<td>51% good results; 31 converted to TKA</td>
</tr>
<tr>
<td>Insall et al⁹</td>
<td>95</td>
<td>5–15</td>
<td>85% good to excellent at 5 yr, 63% good to excellent at 9 yr</td>
</tr>
<tr>
<td>Tjornstrand et al²⁴</td>
<td>107</td>
<td>7</td>
<td>42% good results at 7 yr</td>
</tr>
<tr>
<td>Sprenger and Doerzbacher²¹</td>
<td>76</td>
<td>10.8</td>
<td>86% survivorship at 5 yr, 74% at 10 yr, 56% at 15 yr</td>
</tr>
<tr>
<td>Marti et al¹²</td>
<td>34</td>
<td>11</td>
<td>26% excellent, 62% good, 12% fair/poor</td>
</tr>
<tr>
<td>Naudie et al¹⁶</td>
<td>106</td>
<td>10–22 (mean, 14)</td>
<td>51% survivorship at 10 yr, 30% at 20 yr</td>
</tr>
<tr>
<td>Coventry et al⁷</td>
<td>87</td>
<td>3–14 (mean, 10)</td>
<td>87% survivorship at 5 yr, 66% at 10 yr</td>
</tr>
<tr>
<td>Ivarsson et al¹⁰</td>
<td>99</td>
<td>5.7 and 11.9, mean</td>
<td>&gt;50% good results at 5.7 yr, 43% good at 11.9 yr</td>
</tr>
<tr>
<td>Hermigou et al⁶</td>
<td>93</td>
<td>11.5, mean</td>
<td>90% good to excellent results at 10 yr</td>
</tr>
<tr>
<td>Matthews et al¹³</td>
<td>40</td>
<td>1–9</td>
<td>50% function at 5 yr, 28% function at 9 yr (16 converted to TKA)</td>
</tr>
<tr>
<td>Stukenborg-Colsman et al²³</td>
<td>32</td>
<td>7–10</td>
<td>71% good to excellent results</td>
</tr>
<tr>
<td>Billings et al²</td>
<td>64</td>
<td>8.5, average</td>
<td>85% survivorship at 5 yr, 53% at 10 yr (21 converted to TKA)</td>
</tr>
<tr>
<td>Aglietti et al¹</td>
<td>61</td>
<td>10–21 (average, 15)</td>
<td>96% survivorship at 5 yr, 88% at 7 yr, 78% at 10 yr, 57% at 15 yr</td>
</tr>
</tbody>
</table>

Table 1: Results with High Tibial Osteotomy

- Sprenger and Doerzbacher²¹ reported a 21% closing wedge HTO complication rate, and Spahn²⁰ reported a 43.6% opening wedge HTO complication rate.
- Intraoperative complications
  - Fracture of the medial or lateral cortex (FIG 4A)
  - Intra-articular extension of the osteotomy (FIG 4B)
  - Intra-articular screw placement
  - Peroneal nerve palsy
- Immediate postoperative
  - Hematoma
  - Infection
  - Compartment syndrome
  - Thromboembolism
- Delayed postoperative
  - Patella baja
  - Nonunion or delayed union
  - Hardware failure (FIG 4C)
  - Collapse with loss of osteotomy correction (FIG 4D–F)

FIG 4 • A. Lateral cortical breach stabilized with a three-hole 1/3 tubular plate. This was placed after the osteotomy had propagated through the lateral wall of the tibia. B. Intra-articular extension of the osteotomy that was not repaired intraoperatively, with subsequent osteotomy collapse and hardware breakage. C. Hardware failure. There is no collapse of the osteotomy, but the distal screws failed secondary to micromotion. (continued)
REFERENCES

Total knee arthroplasty (TKA) is a successful surgical procedure that provides excellent and durable relief of pain and improvement in functional status for patients with osteoarthritic knees. Cement fixation currently is the preferred method of fixation for TKA.

The knee is a synovial hinge joint with little rotational motion. The stability of the joint is provided by congruity of the joint as well as by the collateral and cruciate ligaments. The mechanical axis is a line drawn from the center of the femoral head, to the center of the tibial articular joint, forming a straight line, and the anatomic axis is the femorotibial axis, created by the intersection of the long axes of the femur and tibia. The intersection of these two axes creates about a 6-degree angle of valgus. The 6-degree valgus angle of the knee is determined by the bony anatomy of the distal femur and the proximal tibia.

The proximal articular surface of the tibia usually is oriented in slight varus—3 degrees, on average. This varus position, combined with the offset of the hip center of rotation, results in the weight-bearing surface of the tibia being parallel to the ground during a single-leg stance. As a result of the slight varus in the tibia, the distal femur actually is in 9 degrees of valgus, resulting in a combined femorotibial alignment of 6 degrees when the knee is in extension.

The asymmetry of the distal femoral condyles is also carried over to their posterior surfaces. When the normal knee is flexed, the joint remains parallel to the floor. For this relationship to be maintained on the varus tibial surface, there must be an asymmetry of the posterior dimensions of the femoral condyles. When observed in flexion, the medial femoral condyle extends more posterior than the lateral femoral condyle.

The sagittal alignment of the tibial articular surface also is important. In the sagittal plane, the tibia is sloped posteriorly about 5 to 7 degrees. In the normal knee, the asymmetry of the bony anatomy maintains the alignment of the joint and ligamentous tension.

Knee osteoarthritis (OA), also known as degenerative joint disease (DJD), is usually the result of wear and tear of the articular cartilage and is seen mostly in elderly women and men. Knee OA can be divided into two types:

- Primary OA: articular degeneration without any apparent underlying reason
- Secondary OA: a consequence of either an abnormal concentration of force across the joint, eg, post-traumatic arthritis (FIG 2), or abnormal articular cartilage, eg, rheumatoid arthritis.

The initial evaluation should focus on identifying the extent to which knee pain is attributable to knee OA. Occasionally pain is referred from the hip joint or lumbar spine to the knee. Although the distinction usually can be made on the basis of physical examination, selective anesthetic injection occasionally is necessary to elucidate the relative contributions of overlapping pathologies to a patient’s symptoms.

With the patient standing, look for periarticular erythema and swelling, quadiceps muscle atrophy, and varus or valgus deformities. Observe the patient’s gait for signs of pain or abnormal hip motion.

If surgery is being considered, systematically assess the surrounding skin for mobility and for the presence and location of scars from any previous surgical procedures (previous scars may influence surgical approach).

Palpate along the joint line, medial and lateral collateral ligaments, iliotibial band, and pes anserine to identify any tenderness suggestive of focal injury.

Active and passive range of motion (ROM) should be assessed. Normal ROM should be from full extension (0 degrees) to full flexion (135 degrees). Any deviation from this normal range should be documented.

The strength of the quadiceps and hamstring muscles should be assessed and documented using a five-point scale.

Palpate and document popliteal, dorsalis pedis, and posterior tibial pulses. Evaluate the patient’s legs for shiny, hairless skin or venous stasis ulcers, which raise concern for vascular problems.

Other methods for examining the osteoarthritic knee before arthroplasty include the following:

- A Q angle of more than 15 degrees often is the cause of patellar subluxation/dislocation or patellofemoral pain and arthritis.
- Anterior drawer test: Increased anterior translation of the tibia compared to the other side plus a mushy endpoint indicates anterior cruciate ligament (ACL) deficiency.
Posterior drawer test: Translation of the tibia more than 10 mm posterior to the femoral condyle is highly suggestive of multiligamentous knee injury and deficiency of the posterior cruciate ligament (PCL).

Varus and valgus stress test: Instability at 30 degrees of flexion suggests isolated collateral ligament injury. Instability at both 0 and 30 degrees is suggestive of a multiligamentous injury.

Patellar apprehension test: A patient with a history of patellar instability may report a sensation that his or her patella feels as if it is about to dislocate.

Patellar tilt test: More than 15 degrees of lateral tilt is suggestive of laxity. Lack of patellar tilt is suggestive of a tight lateral constraint.

The patellar grind test reveals pain or crepitus.

Quadriceps active test: Forward translation of the tibia after attempted knee extension is positive for PCL insufficiency (reduction of posterior tibial sag).

IMAGING AND OTHER DIAGNOSTIC STUDIES

The standing anteroposterior (AP) radiograph best reveals joint space narrowing and any potential dynamic instability. It also shows any marginal osteophytes, tibial and patellar spurs, subchondral sclerosis, joint space narrowing, flattening, squaring of the condyles, and joint line angulation.

Standing lateral in extension

Skyline view of the patella

Occasionally, specialized views of the knee such as the 45-degree posteroanterior (PA) view of the knee (Rosenberg view) or a long-leg view may be required to determine the degree of deformity, and also to obtain information about the status of the femur and tibia in patients with a history of previous trauma or fracture.

DIFFERENTIAL DIAGNOSIS

Any potential cause of local or diffuse knee pain should be considered in the differential diagnosis of knee osteoarthritis, including:

- Hip arthritis
- Low back pain / spinal stenosis
- Patellofemoral syndrome
- Meniscal tear
- Bursitis
- Infectious arthritis
- Gout, pseudogout
- Iliotibial band syndrome
- Collateral or cruciate ligament injury
NONOPERATIVE MANAGEMENT

- A wide range of nonoperative modalities are available for treatment of knee OA. These interventions do not alter the underlying disease process, but they may substantially diminish pain and disability.
- Health and behavior modifications, including patient education, physical therapy, weight loss, and knee braces, can result in improvement of knee pain and function. In all stages of knee OA, weight loss (if the patient is overweight) is valuable. An unloader-type knee brace shifts load away from the involved knee compartment, whereas a support-type brace supports the entire knee load.
- Drug therapy includes acetaminophen, nonsteroidal anti-inflammatory drugs (NSAIDs), COX-2 inhibitors, and glucosamine and/or chondroitin sulfate.
- Intra-articular injections
  - Corticosteroid injections in knees with considerable inflammatory component (eg, swelling) are useful.
  - Hyaluronic acid (viscosupplementation)

SURGICAL MANAGEMENT

- Osteotomy may be indicated for unicompartmental knee OA associated with malalignment, or for correction of symptomatic posttraumatic malunions about the knee.
- Arthroscopic débridement and lavage has a minimal role in the treatment of knee OA.
- Arthroplasty: total or partial knee replacement

Indications

- TKA is regarded as a valuable intervention for patients who have severe daily pain along with radiographic evidence of arthritis. The discrepancy between the severity of radiographic changes and symptoms poses a problem. A painful knee without associated radiographic findings dictates a systematic search to exclude other possible sources of knee and leg pain (ie, referral pains from hip or nerve root compression in the spine). The need for correction of significant or progressive deformities sometimes may be considered an indication for knee replacement in patients with moderate arthritis.

Contraindications

- Absolute
  - Active or latent (<1 year) knee sepsis
  - Presence of active infection elsewhere in the body
  - Incompetent quadriceps muscle or extensor mechanism
- Relative
  - Neuropathic arthropathy (eg, Charcot arthropathy)
  - Poor soft tissue coverage or skin conditions such as uncontrolled psoriatic lesions in the vicinity of the incision
  - Well-functioning and painless knee ankylosed in a good position
  - Morbid obesity
  - Noncompliance due to major psychiatric disorders, including dementia, hostile personality, or alcohol or drug abuse
  - Insufficient bone stock for reconstruction
  - Poor health or presence of comorbidities that make the patient an unsuitable candidate for major surgery and anesthesia
  - Patient’s poor motivation or unrealistic expectations
  - Severe peripheral vascular disease

Preoperative Planning

- A comprehensive medical and drug history is mandatory to confirm that the patient is an appropriate candidate for a major surgery and anesthesia, because an overlooked detail may lead to a serious or life-threatening complication.
- Good-quality radiographs must be obtained, as described earlier. Radiographs are position-sensitive, and care must be taken to obtain the films in neutral rotation. A full-length radiograph from the hip to the ankle is helpful in determining the mechanical axis of the limb and noting unusual shaft bowing or deformities in some cases.
- Template overlay is used to estimate component size and bone defects.
- The patient is required to complete an informed consent regarding the possible risks.

Positioning

- The skin around the knee is shaved using clippers shortly before the procedure in a holding area outside the room where the procedure will be performed. Shaving should be performed in such a manner that skin integrity is preserved.
- The patient is positioned supine on the operating table in an operating room equipped with laminar airflow. The upper torso is secured with a protective belt to allow tilting of the table as needed. A bump is taped to the table in such a position that it supports the heel when the patient’s knee is flexed and frees the assistant’s hands (FIG 3A).
  - A tourniquet is applied snugly and as far proximally as feasible to the upper thigh on soft Webril (Medco, Tonawanda, NY) padding. In obese or short-limbed patients, it may be necessary to use a sterile tourniquet to ensure adequate access to the surgical field.
  - The heel is suspended in a leg holder (FIG 3B).
  - An adhesive drape is put in place distal to the tourniquet to prevent antimicrobial solutions from dripping under the tourniquet.
  - Surgical skin preparation is begun using a broad-spectrum germicidal agent, eg, combined povidone-iodine and isopropyl alcohol solution. Chlorhexidine may be used if the patient is hypersensitive to iodine.
  - Meticulous and secure draping technique is important to reduce the risk of infection. Bulky drapes obscure the palpable bony landmarks, such as malleoli or metatarsal bones, that are routinely used for accurate bone cuts, rotation, and alignment in knee arthroplasty.
  - The limb is exsanguinated by applying an elastic wrap. The incision is marked on the front of the knee along with several horizontal lines that will be used to align the skin properly during closure (FIG 3C). An adhesive plastic surgical drape is placed around the leg without covering the incisional site.
  - A single dose of cefazolin or cefuroxime is administered 30 to 60 minutes before the skin incision is made and 10 minutes before the tourniquet is inflated. If the patient has a β-lactam allergy, alternatives such as vancomycin or clindamycin can be used.

Approach

- Classically, an anterior longitudinal midline incision is used for TKA. This incision may sacrifice the infrapatellar branch of the saphenous nerve, causing an area of lateral numbness; the patient should be warned about this possibility before the surgery.
  - Blood is primarily supplied to the skin of the anterior aspect of the knee from the medial side, so before the skin incision is made, the exact site and size of any previous scars should be taken into consideration; otherwise the viability of
the lateral flap is endangered. In most cases, the preexisting anterior longitudinal scar on the knee is incorporated into the incision, provided that it gives adequate exposure without placing any undue tension on the skin during the operation.

- When parallel anterior longitudinal scars are present, the most lateral one should be used if possible. If this is not possible, a wide bridge of intact skin (8 cm) should be allowed between the new incision and the previous scar. The horizontal scars can be crossed at right angles, and the short oblique ones may be ignored. Acute angles of intersection must be avoided.

- Arthrotomy can be performed by the medial parapatellar approach, the subvastus (Southern) approach, or the midvastus approach.

- The medial patellar approach provides excellent exposure and is associated with a very low incidence of tibial or femoral complications.

**EXPOSURE**

- With the knee in 90 degrees of flexion, the incision (TECH FIG 1) is made from the superior edge of the quadriceps tendon proximally (one hand-breadth above the superior pole of the patella) to the inferomedial aspect of the tibial tuberosity. Flexion tenses the skin and retracts the skin margins as the incision is made.

- The skin, fat, and fascia are incised directly down to the extensor mechanism, and the medial and lateral flaps are reflected only as far as necessary to have adequate exposure while preserving their blood supply.

- Once the deep fascia is opened, the prepatellar bursa is incised and retracted medially and laterally. The paratenon of the patellar tendon should be exposed and protected.

**ARTHROTOMY**

- Bring the knee into extension and perform the arthrotomy.

- Several approaches are described in the following sections, these differ mainly in the proximal part of the incision (TECH FIG 2).

**Medial Parapatellar Approach**

- The quadriceps tendon is cut longitudinally from proximal to distal along its medial border, leaving a cuff of tendon approximately 5 to 10 mm wide. Then the incision is carried further, skirting along the medial border of the patella and patellar tendon.

- The arthrotomy incision is made through the medial retinaculum, capsule, and synovium, leaving a 5-mm cuff of retinaculum attached to the patella to facilitate repair at the end of the procedure. Distally, the incision should stop at the inferior aspect of the patellar tendon insertion, proximal to the inser-
**KNEE RECONSTRUCTION**

**TECH FIG 2** • Planes of dissection for the medial parapatellar approach, the midvastus approach, and the subvastus approach.

**KNEE JOINT EXPOSURE**

- The soft tissue sleeve is dissected from the proximal medial tibial metaphysis (TECH FIG 3) by taking the amount of varus or valgus deformity into account.
  - More extensive dissection is performed for knees with varus deformity, and limited or no dissection for knees with valgus deformity.
  - With sharp dissection or cautery, a subperiosteal layer that includes the deep medial collateral ligament (MCL) is raised carefully from the medial tibial flare to the sagittal midline of the tibia. The dissection must not be extended more than 2 to 3 cm distal to the medial joint line.

**Subvastus (Southern) Approach**

- Blunt dissection is carried from the medial intermuscular septum. Care should be taken to avoid damaging the intermuscular septal branch or the articular branch of the descending genicular artery. This should be avoided by limiting proximal dissection to 10 cm or less.
  - A transverse incision is made at the mid-patella through the medial retinaculum and inferior to the vastus medialis.
  - This incision is stopped once the patellar tendon is reached, and a second incision is made along the medial border of the patellar tendon approximately 1 cm along the medial border to the tibial tubercle.

**Midvastus Approach**

- Blunt finger dissection is begun at the superomedial pole of the patella in the midsubstance and through the full thickness of the vastus medialis muscle, and is extended parallel to its fiber, to a maximum of 4 cm proximomedial to this starting point. By doing this, the incision does not extend far enough medially to violate the saphenous nerve to the vastus medialis obliquus. The medial superior geniculate artery and the muscular branches of the descending geniculate artery are similarly preserved.

**Patellar Eversion**

- The patella is everted, and the knee is flexed (TECH FIG 4A). The medial flap of the quadriceps must be reflected medially off the face of the femur. There should be no undue tension at the patellar tendon insertion. Placing one smooth pin in the tibial tuberosity may provide some protection against tendon avulsion.
  - A 90-degree angled Hohmann retractor is inserted laterally to the lateral meniscus (TECH FIG 4B).
  - The synovial layer surrounding the patella is excised to expose the insertion of the quadriceps and patella tendons. Osteophytes are trimmed with a rongeur to establish the true size and thickness of the patella.
  - To permit full eversion of the patella, the capsular folds of the suprapatellar pouch proximal to the patella are released.
  - If the patella will not evert, the dissection across the lateral tibial plateau is revisited, and the incision in the proximal quadriceps is examined to see whether it has been opened proximally enough. Division of the lateral patellofemoral ligament makes it easier to evert the patella.
  - Release of a portion of the medial portion of the patellar tendon and elevation of a small cuff of periosteum immediately adjacent to the patellar tendon insertion can be helpful.
■ With the tibia completely subluxed anteriorly, the medial and lateral menisci are excised and the PCL exposed, released, or excised, as the surgeon prefers. The popliteus tendon is protected during all soft tissue and bone resection.

■ If adequate exposure cannot be obtained, the femoral cuts should be made first, allowing access to the back of the joint.

■ An anterior synovectomy is performed to expose the supracondylar region of the femur. This is essential to allow for proper and precise sizing of the femoral implant and to prevent notching.

**PREPARATION OF THE TIBIA**

■ The ACL is excised, allowing further anterior translation of the tibia.

■ When combined with external rotation as the knee is flexed, complete anterior subluxation of the tibia from beneath the femur can be accomplished, providing complete exposure of the tibial plateau, femoral condyles, and posterior horn attachments of the menisci.

■ Rarely, this maneuver may be blocked by osteophytes, which should be removed. If the posteromedial corner and posterior capsular structures are not released adequately, anterior translation and external rotation cannot be accomplished.

■ A retractor is applied to gently retract the tibia forward so that exposure of the posterior tibial plateau is achieved.

**BONE CUTS**

■ The five standard bone cuts for any TKA are as follows:
  ■ Transverse upper tibial cut
  ■ Distal femoral condyles resection
  ■ Anterior and posterior condylar resections
  ■ Anterior and posterior chamfer cuts from the distal femur
  ■ Retropatellar cut

■ The sixth step of the intercondylar box cut is performed only for posterior stabilized designs.

■ The surgeon performs either the femoral or the tibial cut first. Generally, when the tibia can be easily shifted anteriorly, the tibia is cut first, but if the knee is tight or good exposure is difficult to obtain on the tibial plateau, the femoral condyles are the first to be cut.

■ Bone cuts can be made using open or slotted cutting guides (**TECH FIG 5**). The cutting slots are more accurate and reduce human error. In practice, however, they obscure the saw blade tip, potentially increasing the risk of injury to important structures such as the MCL. Most newer femoral cutting blocks provide slots for performing distal, anterior, posterior, and chamfer cuts by using a single block, thereby reducing the time.

■ Clinical success of TKA is correlated with correct orientation of the components and the resultant lower extremity alignment. Accuracy of component posi-
tioning relies on alignment guides for making precise and accurate bone cuts.

**Upper Tibial Cut**

- An intramedullary (IM) rod can be used provided that there is no deformity, bowing, offset to the tibial shaft, or blockage in the medulla. By and large, the extramedullary (EM) alignment guide is preferable, because it can bypass any potential deformity of the tibial shaft.
  - In obese patients those bony landmarks are masked, however, and an EM guide may cause more error.
- Tibial cut using an extramedullary guide
  - Attach the strap of the distal end of the alignment guide above the ankle, and pin the proximal end to the upper tibial metaphysis (TECH FIG 6A). Necessary adjustments must be made to make the guide align with the center of the interspinous eminence of the plateau, the tibial shaft, and the middle of the ankle mortis, which is, in fact, 3 to 5 mm medial to the intermalleolar axis.
  - By sliding the distal end of the guide mediolaterally at the ankle, a final adjustment can be made to centralize it over the center of the talus and to minimize the risk of varus inclination of the cut.
  - Set the proximal part to obtain 3 to 5 degrees of posterior slope in the sagittal plane.
- Bear in mind that jig systems fitted to the anterior surface of the proximal tibia will have a tendency to align in excessive internal rotation due to the everted patellar tendon. To avoid this error, center the jig on the medial third of the tibial tuberosity.
- Fit the proximal cutting block snugly up against the tibial cortex to improve the accuracy of the resection.
  - This cut should be made at right angles to the anatomic axis of the tibia in the coronal plane.
- Remove 10 mm of cartilage and bone from the least involved plateau. The bone resected should have approximately the same thickness as the final tibial component, including the metal base plate and polyethylene liner.
- Make the tibial cut using an intramedullary guide.
  - If you opt to use an IM guide, accurately choose the pilot hole that is at the junction of the tibial insertion of the ACL and the anterior horn of the lateral meniscus (TECH FIG 6B). By irrigation and aspiration of the canal, insertion of a fluted, hollow rod, and drilling a hole slightly larger than the size of the IM rod, the risk of fat embolization can be reduced.
  - Insert the IM rod and fix the cutting block in the desired position, then remove the rod together with its outrigger.
  - Use an oscillating saw to cut the bone. To protect the posterior neurovascular bundle, stop cutting the last few millimeters of bone by saw and crack the rest afterward by levering or using an osteotome.
  - Carefully protect the MCL and LCL by proper insertion of retractors.
  - Remove the osteotomized bone along with the remnants of menisci. Establish the anatomic boundary of the tibial metaphysis by removing the osteophytes.

**Distal Femur Cuts**

- Because of a lack of reliable palpable external landmarks, the IM alignment guide is superior to the EM guide for preparation of the femur, except in cases of excessive femoral bowing, previous fracture, Paget disease, or an ipsilateral long-stemmed total hip replacement.
- Drill an entry hole 1 cm anterior to the origin of the PCL, slightly medial to the midportion of the intercondylar
notch (TECH FIG 7A). Touching the anterior surface of the femoral shaft with the other hand can be a good guide to the direction of drilling.

- Simple measures such as slight overdrilling, using a fluted IM guide, and aspiration of the marrow contents before insertion of the guide are recommended to decompress the femoral canal and to subsequently reduce the risk of fat emboli.
- Insert the IM guide and pass it directly in the center of the canal without making any contact with the femoral cortices—otherwise, the angle of resection will be changed. Attach the cutting block to the IM rod, adjust it at 5 to 6 degrees of valgus, and then fix it in place.
- Cut valgus knees in no more than 5 degrees of femoral valgus. Check to be sure that there is no soft tissue in the area below the guide.
- Remove the IM rod and cut the bone. It is crucial to prevent the saw blade from bending or going forward in an undesired direction while proceeding through the osteotomy line, particularly during resection of hard and sclerotic bone.
- The amount of bone to be resected should be precisely equivalent to the thickness of the final femoral component. In the sagittal plane, the distal femur should be cut at 90 degrees to the femoral mechanical axis and, after soft tissue balancing, should be parallel to the resected surface of the proximal tibia (TECH FIG 7B,C).

Anterior and Posterior Femoral Condyle Cuts

- Making accurate cuts is essential to obtain proper size and rotation of the final femoral component.
- Use the AP sizing guide to aid in setting 3 degrees of external rotation of the femoral component in relation to the posterior condylar axis. External rotation means counterclockwise rotation for the right knee and clockwise rotation for the left knee. In knees without deformity, external rotation usually results in removal of more bone from the medial posterior condyle. Erosion of the posterior femoral condyles can distort this posterior condylar axis.
- Appreciating that the posterior cut should be parallel to the transepicondylar line, perpendicular to the Whiteside line (AP axis of the femoral sulcus), and parallel to the upper tibial cut can help the surgeon reduce any error in the rotation of the femoral component (TECH FIG 8A).
- Maximally flex the knee to reduce the chance of injury to the posterior neurovascular bundle during posterior sawing. Adjust the stylus that indicates where the anterior cut exits the femur. Pass the anterior cut tangential to the anterior femoral cortex to avoid notchting and subsequent stress rising for a fracture (TECH FIG 8B–D).
- Conversely, a cut that is too high causes an oversized femoral component and overstuffing of the patellofemoral articulation, which can subsequently cause patellar maltracking or limit range of flexion.

Anterior and Posterior Chamfer Cuts

- Anterior and posterior chamfer cuts are essential for the prosthesis to fit over the distal femur.
- A chamfer guide is placed on the distal femur. In some systems this step is integrated into the same block as that used for the anterior and posterior femoral cuts (TECH FIG 9A,B).
- When the sawing is complete, use a lamina spreader to open the space between the femur and the tibia, and then use an osteotome to free small remnant portions of uncut bone (TECH FIG 9C).

Patellar Preparation

- Remove the osteophytes, synovial insertions, and fat to demarcate the anatomic margins of the patella.
- Use a caliper (TECH FIG 10A) to assess the patellar thickness before the cut and after the patella is resurfaced to ensure that the patellar thickness is equal to the original thickness and that at least 12 mm of bone stock remains.
- To obtain an exact measurement of the patellar thickness, the prepatellar bursa should be dissected to completely expose the anterior surface of the patella.
- Use a patellar cutting jig or a freehand technique. Pass the patellar cut parallel to the anterior surface of the patella through the chondro-osseous junction, completely resecting both facets (TECH FIG 10B).
the cut passes just superficial to the quadriceps insertion; distally, it passes through the nose of the patella.

- Make a flat cut removing any remnants of cartilage.
- Center and firmly hold the appropriate drill guide and drill three lug holes in a triangular arrangement (TECH FIG 10C,D).

To accommodate the post-cam mechanism in the posterior stabilized prosthesis, place the finishing guide onto the distal femur to make the intercondylar box cut (TECH FIG 10E). Center the guide mediolaterally and secure it firmly by pin or screw.

- Use a reciprocating saw to resect the bone from the notch. Complete the resection with a chisel or osteotome.
Chapter 19  CEMENTED TOTAL KNEE ARTHROPLASTY

TECHNIQUES

Soft tissue and ligament balancing is a vital portion of the surgical procedure. In knees with minimal deformity, balancing is not challenging, and it often can be achieved by performing a minimal soft tissue release, making the bone cuts, and then checking the knee by insertion of trial components. In knees with complex or severe deformity, however, cautious stepwise release is necessary. Insert the trial components and check the balance of the knee after each step of the procedure. If no release is necessary, proceed to the next step. When the deformity is severe and leads to loss of the integrity of the ligaments, be ready for application of a constrained prosthesis.

To achieve a proper soft tissue balance, initially remove the offending osteophytes until the anatomic margins of the bone are determined.

Correction of Flexion Contracture
- Use a curved osteotome to release osteophytes in the back of the femur and then extract them with a rongeur.
- Strip the adherent capsule from the posterior aspect of the femur to reestablish the original recess.
- In knees with preoperative moderate to severe flexion contracture, it also is necessary to cut the posterior capsule transversely and to release the tendinous origins of the gastrocnemius.
- Perform recession or resection of the PCL if it is still preserved.
- Resect additional bone from the distal femur.

Correction of Varus Deformity
- The medial capsulotomy, along with subperiosteal medial release, which is included in the initial approach and exposure, can correct minimal varus deformities.
- Extend the medial subperiosteal release for an additional 2 to 3 cm.
- If the medial knee is tight in flexion only, release the anterior portion of the superficial MCL.
- If the medial knee is tight in extension only, release the posterior oblique fibers of the superficial MCL.
- If the medial knee is tight in both flexion and extension, release elements of the superficial MCL.

Correction of Valgus Deformity
- If the lateral knee is tight in extension, release the iliobial band. Some surgeons prefer the “pie-crusting” technique.
- If the lateral knee is tight in flexion, release first the popliteal tendon and then the LCL subperiostealetly from the femoral condyle.
- If the lateral knee is tight in both flexion and extension, sequentially release the iliobial band, the poplitea tendon, the LCL, and finally the posterior capsule.
- Release the biceps femoris tendon only when absolutely necessary.

Correction of Valgus Knee With Incompetent Medial Collateral Ligament
- A valgus knee with an incompetent medial collateral ligament occurs in knees with severe, longstanding valgus deformity.
- Treatment strategies include the use of a varus–valgus constrained articulation, MCL advancement, or MCL reconstruction.
COMPONENT INSERTION AND TRIAL REDUCTION

- Insert provisional femoral and patellar components of the correct size (TECH FIG 11A).
- Next, insert a tibial sizing tray that matches the surface area of the tibial cut. This sizing tray is a jig for drilling final fixation holes for the tibial component and determines its ultimate mediolateral, anteroposterior, and rotational position.
  - Some rotational change is still possible at this point. Internal rotation of the component must be avoided.
  - Check all around the tray to ensure that there is no overhang, especially on the medial side, where overhang may be easily overlooked.
- Insert a spacer of the proper height and reduce the joint. Check the ROM and ligament stability. Apply varus and valgus stresses in both flexion and extension to determine the stability of the knee and the appropriate thickness of the tibial insert.
- At this stage it is particularly important to do meticulous ligament balancing for PCL-retaining designs by using different thicknesses of tibial trial components.
- Align the center of the tibial tray over the medial third of the tibial tubercle and pin it in place (TECH FIG 11B).
- Assemble the proper size of tibial broach on the broach impactor. Seat the impactor on the tray and impact the broach to the proper depth (TECH FIG 11D).
- Check the patellar tracking during ROM.
- Once trial reduction is complete, extract all components.

COMPONENT FIXATION

- Polymethylmethacrylate is used for fixation of the components in knee arthroplasty. The setup of all components and basic instruments for component insertion should be done before the cement is prepared (TECH FIG 12A,B).
- Drill the tibial plateau in the sclerotic parts (1 to 2 mm deep) to achieve adequate anchorage of the tibial component.
- Plug the IM hole of the distal femur with small pieces of cancellous bone (TECH FIG 12C).
- Use pulsatile lavage to thoroughly irrigate the cut surfaces with normal saline in order to remove all debris and increase the depth of cement penetration into the trabecular bone. When done, be sure to dry the bone completely.
- Put some gauze sponges on the cut surfaces and use a hand to press down on the sponges to keep the bones dry until the cement has been prepared by vacuum mixing.
- When the cement is in a doughy state, apply it to the tibial plateau (TECH FIG 12D). Add a thin layer of cement,
then impact the tibial component and polyethylene liner into place (TECH FIG 12E).
- Trim and remove the excess cement as it extrudes from under the plateau.
- Apply cement to the femoral cut surfaces (TECH FIG 12F), especially the posterior condyles, which tend to be undercemented.
- Impact the femoral component into position, and remove the excess cement from around the prosthesis (TECH FIG 12G).
- In areas that are clearly visible, trim the cement by scalpel and then remove it by curette; in areas that are not easily seen, do not use a scalpel to trim the cement.
- Reduce the knee and bring it to full extension.
- With the knee extended, apply cement to the patella (TECH FIG 12H). Insert the patellar component and clamp it firmly in place (TECH FIG 12I). Trim and remove the excess cement.
- Keep the knee in full extension until the cement is fully cured. Inspect all the corners of the joint, especially the posterior parts, to make certain that no extra cement remains, because extra pieces could block knee ROM or act as loose bodies in the knee, producing third-body wear.
- Irrigate the knee thoroughly. For the last time before closing the joint, check the ROM, knee stability, and patella tracking.

**TECH FIG 12** • All components (A) and basic instruments for component insertion (B) are set up in advance of cement preparation. C. The intramedullary hole of the distal femur is plugged with small fragments of cancellous bone. D. Cement is applied to the tibial plateau. E. A thin layer of cement is added to the tibial tray, and the tibial component and polyethylene liner are impacted into place. F. Cement is applied to the femoral cut surfaces and the femoral component. G. The femoral component is impacted into position. H. Cement is applied to the patella. I. The patellar component is inserted and clamped firmly.
**PEARLS AND PITFALLS**

**Distal position of extramedullary tibial guide**
- If not shifted 3 to 5 mm medially from the intermalleolar axis, varus orientation of the tibial guide will result.

**Orientation of the tibial guide when cutting the tibia to be sloped posteriorly**
- If the cutting guide is internally or externally rotated, the posterior slope will translate into valgus or varus inclination, respectively.

**Coronal position of tibial component**
- A medially located tibial component increases both the Q angle and medial overhang.

**Starting point for femoral IM rod insertion**
- A starting point that is too lateral or too medial will increase valgus and varus angulation, respectively.

**Size of femoral component**
- Undersizing introduces the risk of anterior notching or overresextion of the posterior femoral condyle.
- Oversizing can cause overstuffing of the flexion gap or patellofemoral joint, depending on the position in the sagittal plane.

**Position of femoral component in sagittal plane**
- In neutral alignment, neither flexed nor extended.

**Distal femoral cut**
- This cut should never exceed 7 degrees. Otherwise the Q angle will increase, leading to patellar subluxation or dislocation.

**Using only the posterior condylar line as the reference**
- In the presence of lateral or medial condyle erosion or hypoplasia, this results in excessive internal or external rotation of the femoral component, respectively.

**Medial–lateral femoral component positioning**
- Center the femoral component on the end of the femur or slightly laterally, to aid with patellofemoral kinematics.
- Avoid medial or lateral overhang, because this can result in soft tissue irritation.

**Coronal position of the femoral component**
- Medialization of the femoral component must be avoided, because this increases the Q angle.

**Size of femoral component**
- When it is between two sizes, select the smaller size because mild notching (not more than 1–2 mm) is more palatable than overstuffing the patellofemoral joint.

---

**PATELLA TRACKING**

- With the trial components in place and after the insertion of the final components, evaluate patella tracking throughout a full ROM. The patella should track centrally in the trochlear groove without lateral subluxation or lateral tilt in full flexion.
- Perform the no-thumbs test by reducing the patella and taking the knee through the full flexion arc without closing the medial arthrotomy and without applying any medial force with the thumb to keep the patella in position.
- Extensor mechanism balance has been achieved if the patella does not tilt, subluxate, or dislocate during flexion.4

- If there is patellar tilting or slight subluxation with the no-thumbs test, reapproximate the medial retinaculum at the superior pole of the patella with a single no. 0 suture. If the suture does not break through full flexion of the knee, a lateral release is not necessary. Doing this eliminates slight tilting or subluxation that occurs with the no-thumbs test and avoids an unnecessary lateral release.
- To improve the accuracy of these evaluations of extensor mechanism balance, these tests can be performed with the tourniquet deflated, because an inflated tourniquet can alter patellar tracking by binding the extensor mechanism, resulting in perceived patellofemoral maltracking.4

---

**CLOSURE**

- Copiously irrigate the knee to ensure that no bone or cement particles remain.
- Identify the formerly placed markings. Close the arthrotomy (quadriceps and medial retinaculum) in extension by interrupted suture, in order to produce a watertight seal.
- Place the knee through a full ROM to make sure that the closure is strong enough not to disrupt during physical therapy, and to confirm that the patella is tracking normally.

- Try to cover the prosthesis fully. Close subcutaneous tissue and superficial fascia with interrupted No. 2 Vicryl stitches or its equivalent in a single layer. (Use a double layer if the patient is obese.)
- Close the skin with staples. Sutures that are either too taut or too loose can lead to wound healing problems or wound dehiscence.
POSTOPERATIVE CARE

- At the conclusion of the operation, apply a compression bandage from toes to mid-thigh with 50% overlap of each turn to achieve a uniform double layer, then release the tourniquet. Compression dressings are removed after 24 hours.
- Adequate analgesia via application of improved pain management modalities (eg, intravenous patient-controlled analgesia or patient-controlled epidural analgesia), should be a priority during rehabilitation to hasten early convalescence.
- Administer antibiotics for 24 hours. Start the proper thromboprophylaxis.
- The staples usually are removed after 2 weeks in the first postoperative follow-up visit.
- The aim of rehabilitation is to restore the highest possible range of mobility in and full muscular control of the operated knee. Adequate rehabilitation is an important requirement for successful TKA; in fact, this starts preoperatively (1 to 2 weeks before surgery) by education on the surgical process and outcomes, instruction on a postoperative exercise program, and assessment of the patient’s home and social circumstances. At the hospital and at home, physical therapists play an important role in the rehabilitation process.
- The specific rehabilitation program after TKA is somewhat controversial. As a general rule, patients are encouraged to work on the ROM of the prosthetic knee and to progressively increase their activities as tolerated, but excess activity and stresses should be avoided. Overzealous physical therapy (PT) in the immediate postoperative period may lead to swollen stiff knees and damage.
- Although the continuous passive motion (CPM) machine supposedly does not alter the ultimate amount of knee flexion and overall functional outcome, and CPM protocols vary considerably among institutions, a high degree of flexion in the immediate postoperative period produces quicker restoration of ROM, and CPM in conjunction with physical therapy may offer beneficial results compared to physical therapy alone in short-term rehabilitation. The patient should be informed that final ROM after surgery is directly related to preoperative ROM—in other words, if the preoperative ROM is limited the patient is less likely to achieve knee flexion more than 100 degrees postoperatively.
- On the first postoperative day, bed mobility and transfer training (ie, from bed to chair and from chair to bed) and bedside exercises (eg, ankle pumps, quadriceps sets, and gluteal sets) begin.
  - With a cemented knee, full weight bearing under the supervision of a therapist is allowed on the first or second postoperative day.
  - Ambulation initially is done with a walker until the patient has achieved adequate balance to use canes.
  - A knee immobilizer sometimes may be worn by the patient until he or she can do straight leg raising without difficulty.
- Ambulating with weak quadriceps muscles can lead to instability or giving way of the knee, which can be painful and may lead to unnecessary stress on the prosthesis.
- On the second postoperative day, active ROM, active-assisted ROM, terminal knee extension, straight leg raises, and muscle strengthening exercises start. Gait training with an assistive device, moving from a sitting to standing position and vice versa, and toilet transfers continues.
- On the third to fifth postoperative days, progression of ROM, strengthening exercises to the patient’s tolerance, and ambulation on level surfaces and stairs (if applicable) with the least restrictive device possible are done.
- During the hospital stay, the physical therapist teaches the patient stair climbing with a walker or crutch.
- Patients usually are discharged 3 to 5 days after surgery, to home, inpatient rehabilitation, or a skilled nursing facility, based on individual need in consultation with social work and home health services. Discharge directly to home is preferred.
- From day 5 to 6 weeks, the patient increases ambulation distance and independence in activities of daily living as tolerated.
- Patients can start driving when they are able to operate the pedals safely and rapidly, which usually takes 4 to 6 weeks. Return to work usually takes 4 to 10 weeks, depending on work obligations. Laborers should bear in mind that they may not be able to return to their previous activity level.
- Patients are followed up routinely at 6 weeks, 3 months, and 1 year after surgery. Once strength, mobility, and balance are regained, patients can resume low-impact sport activities (eg, cycling, swimming, gentle aerobic-style exercises, walking, hiking, golf, bowling). High-impact activities such as football, soccer, hockey, and baseball are discouraged.

OUTCOMES

- TKA is a reliable and predictable surgery, with reported survival rates above 85% with 10 to 23 years of follow-up. Favorable gains for pain and functionality following TKA are well reported and recognized.
- For most patients, overall satisfaction with the outcome of the surgery is good to excellent.

COMPLICATIONS

- The overall mortality rate following TKA is very low, and this procedure does not considerably reduce the life expectancy in patients with OA.

Infection

- Because pain is a strong associated symptom, infection should be considered in any persistently painful TKA or with the acute onset of pain in a previously well-functioning TKA.8

- Underresection can result in overstuffing of the patellofemoral joint, leading to excessive lateral soft tissue tension, patella maltracking, anterior knee pain, and limited flexion.
- Overresection may result in patellar fracture or osteonecrosis. Decreasing the overall thickness of the patella can result in extensor mechanism weakness.

<table>
<thead>
<tr>
<th>Resection of the patella</th>
<th>Overresection may result in patellar fracture or osteonecrosis. Decreasing the overall thickness of the patella can result in extensor mechanism weakness.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patellar component position</td>
<td>Medial or central positioning of the patellar component is acceptable. Lateral positioning increases the Q angle.</td>
</tr>
<tr>
<td>Thickness of resurfaced patella</td>
<td>Should be equal to or slightly less than the thickness of the native patella.</td>
</tr>
</tbody>
</table>
Radiographs must be carefully studied for signs of probable infection. Progressive prosthetic loosening is the most consistent radiographic sign. In the presence of infection, erythrocyte sedimentation rates and C-reactive protein levels are elevated. The white blood cell count is not a reliable indicator of infection. Aspirate from the knee joint should be evaluated by synovial fluid analysis, Gram stain, culture, and antibiotics sensitivity. Cultures of superficial wounds or sinus tracts are unreliable and misleading. The preferred specimens are joint aspirate, deep wound biopsy, or bone biopsy.  

Superficial incisional infection, characterized by erythema, dry wound, nonpurulence, and neither loculation nor induration, may be treated with systemic antibiotics with the understanding that once antibiotic therapy is initiated, the opportunity to diagnose a deep infection accurately may be lost. Despite understandable concern about inoculating an uninfected arthroplasty, arthrocentesis before antibiotic therapy usually is a sound practice, even if done adjacent to erythematous tissue. By contrast, a wound with either drainage or skin necrosis usually benefits from prompt surgical debridement, at which time reliable culture material may be obtained if antibiotic therapy has not been initiated.  

In the setting of early postoperative drainage without evidence of deep infection, and without erythema, purulence, or pain, where the surgeon does not otherwise suspect superficial or deep infection, immobilization and local wound care are warranted for a short period. If drainage does not stop or significantly decrease after a few days, operative debridement and closure should be considered. Observation times of 3 to 5 days and even up to 1 week have been advocated.  

Surgeons generally agree that a draining hemarthrosis should be evacuated. A nondraining hematoma in and of itself does not necessarily warrant evacuation. However, if the hematoma delays physical therapy, increases tension on the skin edges or closure, and exacerbates pain, surgical evacuation is defensible.  

Anterior knee pain has been significantly reduced since the introduction of patellofemoral resurfacing.  

Instability  

Instability after TKA is a cause of failure and the reason for 10% to 22% of revisions. Successful outcomes are obtained in many of these cases, but without identifying the cause of instability, the surgeon risks repeating the mistakes that led to the instability after the initial TKA.  

Three types of instability may occur after a TKA: extension instability, flexion instability, and genu recurvatum. It is important to understand the causes and treatments of each type of instability. Surgical treatment is largely aimed at restoring balanced flexion and extension gaps at the time of revision TKA. Selective use of constrained and rotating-hinge TKA designs is appropriate for subgroups of patients with instability.  

Osteolysis  

The most significant cause for late revision TKA is osteolysis, which occurs as the result of a foreign body response to particulate wear debris from the prosthetic joint. The ultimate result is loosening of the components. The incidence and extent of osteolysis after TKA are less than that after total hip arthroplasty. This complication has been noted with both cemented and cementless prostheses.  

Clinical symptoms, plain radiographs, and CT scanning have been used to study the extent and the natural history of osteolysis. Early in the disease process, patients may be asymptomatic. Most patients, however, present with symptoms of pain, swelling, and acute synovitis, with or without osteolysis on radiographs. Serial radiographs are then necessary to evaluate its progression.  

Vascular Injury  

Popliteal artery injury during TKA is rare but is potentially catastrophic. The injury may have acute or delayed presentation. Arterial thrombosis due to tourniquet application, arterial kinking during knee manipulation, and direct, sharp injury to the artery have been described. Direct, sharp arterial injury is believed to have a better prognosis than arterial thrombosis. Both hyperflexion and hyperextension of the knee during TKA can put the popliteal artery in danger. Prompt recognition of injury by the orthopedic surgeon and treatment by an experienced vascular surgeon are necessary to achieve a good outcome.  

Nerve Injury  

Both tibial and peroneal nerves may be injured during TKA. Preoperative flexion contracture or valgus deformity, and postoperative hematoma increase the risk of peroneal nerve injury. Conservative treatment is the first line of therapy, aimed primarily at preventing further injury. The knee and hip are flexed to 20° to 45°, and constrictive dressings are removed or loosened. Surgical exploration of the non-neurolytic nerve can be employed if no functional recovery is noted after 3 months from the onset of the injury.  

REFERENCES  

DEFINITION

- Accurate component positioning and limb alignment is one of the most critical steps in total knee arthroplasty (TKA). It has been shown that errors as small as 3 degrees can significantly affect the rate of loosening and the outcome of the TKA. The surgeon’s ability to determine component positioning accurately may be influenced by a number of factors, including patient positioning, obesity, variable anatomy, deformity, bone loss, and ligamentous anatomy.

- The main aim of computer-assisted TKA is to improve component positioning and limb alignment. Such improvement has been shown to increase longevity of the implant and decrease the need for revision surgery.

- The main function of navigation is to give the surgeon accurate information about the knee anatomy, limb alignment, and knee range of motion during the operation. The navigation system also gives real-time information as the operation proceeds. This dynamic intraoperative feedback regarding the orientation of bone cuts, soft tissue balancing, component positioning, limb alignment, and knee range of motion with the trial component in place should help the surgeon make the appropriate adjustments when needed.

- The navigation system makes more accurate information available for the surgeon, providing data that may help in making better decisions. It is still the surgeon, however, not the computer software, that decides how and where to make the cuts or release soft tissues to achieve the best implant position for the individual patient.

ANATOMY

- The success of TKA depends on proper alignment of the prosthesis in the coronal, sagittal, and horizontal planes. The surgical principle for proper alignment in the coronal plane is to restore the mechanical axis to neutral by placing the femoral and tibial components vertical to the mechanical axis of the limb.

- The mechanical axis is defined as a line connecting the center of the femoral head to the center of the ankle joint. The anatomic axis of the knee is described as the intersection of the lines drawn parallel to the long axis of the femur and tibia in the coronal plane and typically is between 5 and 7 degrees.

- In the standard intramedullary techniques, the anatomic axes are used as guides to estimate the mechanical axis; in navigation-assisted technique, however, the mechanical axes are determined and cuts are made perpendicular to those axes.

- When performing a TKA, the sagittal plane is kinematically important because most of the range of motion in the knee occurs in the sagittal plane. The degree of posterior slope of the proximal tibia has been used as the main indicator of proper sagittal alignment.

- The mechanical axis of the tibia on the sagittal plane can be determined in different ways. In one method, the midpoint of the tibial plateau is connected to the midpoint of the talus. In another, the midpoints of medial tibial plateau and the tibial plafond are connected in the sagittal plane. Either line can be used as the reference for measuring the tibial plateau slope.

- Rotational alignment of the implanted components is of the utmost importance in TKA. When a prosthesis is implanted with the incorrect amount of rotation, poor patellar tracking and anterior knee pain can result.

- The reference axis for rotational alignment of the femur remains controversial: the transepicondylar axis, the anteroposterior axis of Whiteside, and the posterior condylar axis have all been suggested. Each of these axes has flaws, however. For the rotational axis of the tibia, the medial third of the tibial tuberosity, as advocated by Insall, is approved by most surgeons.

- In navigation-assisted TKA, the reference for femoral rotation is the average rotational axis calculated by digitized transepicondylar and Whiteside lines, and the reference for tibial rotation is the digitized tibial anteroposterior axis.

- In navigation-assisted TKA with registration, the positions of anatomic landmarks and axes are digitized as references for instrument, bone cuts, and leg alignment. If a mistake in digitization occurs, the computer software usually will not progress. If a mistake is identified, the appropriate landmark should be re-registered.

SURGICAL MANAGEMENT

Preoperative Planning

- The most important step in preoperative evaluation is determining that the patient definitely does need the TKA.

- Preoperative knee radiographs should include a standing anteroposterior (AP) view, a lateral view, and a skyline view of the patella. A long-leg standing AP radiograph usually is unnecessary, because the navigation system can accurately determine the mechanical axis of the limb intraoperatively, even in the presence of previous deformity secondary to trauma or previous surgical procedures.

- In the standard technique, templates can be used to anticipate approximate component size and bone defects that would have to be treated intraoperatively. In the navigation technique, intraoperative templating is performed by digitization of different anatomic areas.

- The preoperative range of motion also is assessed by the navigation system, which is more accurate and helps the surgeon plan different cuts, including femoral flexion and tibial slope.

- Anesthesia, venous thromboembolism prophylaxis, and cardiovascular and internal medicine clearance are the same as that for standard TKA techniques.

Positioning

- The patient is placed supine on the operating table.

- A tourniquet is applied snugly to the upper thigh as far proximally as practical. In very obese patients, fat may be pulled distally from beneath the tourniquet, causing it to bulge.
from the distal edge of the tourniquet. This prevents it from migrating and ensures that the tourniquet is placed as proximal as possible.

- A transverse bar is placed on the table at a level just distal to the joint line. When the knee is fully flexed, the foot engages the bar and can, therefore, be maintained in the flexed position without the use of an assistant.
- The navigation system should be placed opposite the surgeon. Before starting with patient registration (ie, landmark digitization), it is recommended that the camera be brought in line with the knee joint so that all instruments can communicate easily with each other during the surgery (FIG 1).
- The system must be set up before the operation begins. All trackers and pointing tools should be initialized and validated, and the pointer tip should be calibrated.

**Approach**

- All standard and minimally invasive approaches for exposure of the knee joint can be applied and supported with the navigation system. The standard median parapatellar approach is described here.
- The most commonly used skin incision for primary TKA is an anterior midline incision.

---

**EXPOSURE**

- The incision is made with the knee in flexion to allow the subcutaneous tissue to fall sideways, which eases exposure.
- The skin incision should be long enough to avoid excessive skin tension during retraction, because that can lead to areas of skin necrosis.
- The medial skin flap should be kept as thick as possible by keeping the dissection just superficial to the extensor mechanism.
- The retinacular incision is extended proximally to the length of the quadriceps tendon, leaving a 3- to 4-mm cuff of tendon on the vastus medialis for later closure. The incision then is continued around the medial side of the patella, extending 3 to 4 cm onto the anteromedial surface of the tibia along the medial border of the patellar tendon.
- The medial side of the knee is exposed by elevating the anteromedial capsule subperiosteally and elevating the deep medial collateral ligament off the tibia to the posteromedial corner of the knee.
- The patella initially is everted to facilitate fat pad removal, but the remainder of the surgery is performed with the patella subluxated but not everted.
- The knee is flexed, and the anterior and posterior cruciate ligaments are removed.

---

**PLACEMENT OF TRACKER PINS**

- All anchoring pins are placed within the incision. Although this requires a slightly longer incision, it greatly simplifies pin insertion and minimizes damage to muscle. It also eliminates the potential for fractures around the pins, because they are not placed in diaphyseal bone.
- On the femur, the anchoring pin is positioned medially on the anterior surface just at the proximal aspect of the metaphysis (TECH FIG 1A). The tracker pin must be proximal enough to avoid interfering with the femoral cutting jigs and trial components. Medial placement allows

---

**FIG 1** The system should be placed opposite the surgeon to ensure instrument visibility.
The anchoring pin should be angled 30 degrees away from the mid-sagittal plane to avoid interfering with tibial cutting guides.

- On the tibia, the anchoring pin should be inserted across the medial tibial plateau parallel to the joint line in the sagittal plane to avoid collision with the tibial cutting guide and the keel of the implant. Placement in this location with the knee flexed also minimizes the risk of injury to the posterior vascular structures.

- For fixation, a pilot hole is predrilled with a 3.2-Amp drill. The pins should be driven bicortically using the insertion tool, and accurately measured for depth (TECH FIG 1B).

- Two trackers are used, one green and one blue. The green one is affixed to the femoral anchoring pin and the blue to the tibial anchoring pin. All femoral points are referenced off the green tracker and all tibial points off the blue tracker.

### DETERMINATION OF FEMORAL HEAD CENTER

- The center of the hip joint is identified by rotating the hip with both the hip and knee flexed. The software geometrically produces the center of femoral head within 1 mm of accuracy (TECH FIG 2). This is the most accurate way of identifying the center of rotation of the femoral head.

- During hip rotation, pelvic movement should be minimized. If the pelvis moves, an assistant should stabilize the pelvis and digitization should be repeated for location of the femoral head center.

### DISTAL FEMUR MAPPING

- The medial and lateral epicondyles and the knee center are digitized by placing the tip of the pointer at each point and pressing the Select button to record that point (TECH FIG 3A,B).

- For the femoral AP axis (Whiteside’s line), the axis of the pointer should be aligned with the most anterior point of the intercondylar groove (TECH FIG 3C,D). The Select button then is pressed for recording. The computer
software also averages the digitalized AP axis and transepicondylar axis, which can be used as an alternative reference for rotational alignment of the femoral component.

- Surface mapping of the distal femur is determined by digitization of the anterior cortex, the distal and posterior surfaces of the medial condyle, and the distal and posterior surfaces of the lateral condyle.
  - For each surface, the tip of the pointer is located on that surface and digitizing is begun by pressing the Select button. The pointer’s tip should be moved on the surface in a painting fashion.
  - The computer automatically progresses to the next reference point when the number of selected points is enough for mapping.
  - In anterior surface mapping, the least prominent anterior region, which usually is located along the lateral border of the femur, should be included in the mapping (TECH FIG 3E,F) to minimize oversizing of the femoral component.
  - When mapping the distal surface, the most distal aspect of the femoral condyle should be included (TECH FIG 3G,H).
  - During digitization, the pointer should never leave the surface.

PROXIMAL TIBIA MAPPING

- The surfaces of medial and lateral compartments of the tibia are mapped and registered in the computer (TECH FIG 4A,B). The lowest point on each condyle must be digitized.
  - The center of the tibial plateau and the anteroposterior axis also are digitized (TECH FIG 4C,D). The center of the insertion of the anterior cruciate ligament seems to be the most accurate landmark to use.
TECH FIG 4 • (continued) C. The AP axis of the tibia is identified. D. Corresponding navigation system screenshot.

DETERMINATION OF THE CENTER OF THE ANKLE

- The medial and lateral malleoli are digitized, and the computer determines the center of the ankle as a reference for the anatomic axis of the tibia and the mechanical axis of the limb (TECH FIG 5).

TECH FIG 5 • A. Digitizing the medial and lateral malleoli. B. Corresponding navigation system screenshot.

ASSESSMENT OF INITIAL ALIGNMENT AND DEFORMITY

- The trackers are attached to the anchoring pins, and the initial alignment, deformity, and range of motion are recorded. This information is extremely helpful in determining soft tissue releases that must be performed, bone cuts, and actual component selection.

MAKING THE BONE CUTS

- In this section we describe an anterior referencing system. Posterior referencing software also is available. The technique described here involves cutting the femur first, before the tibia, but the software is flexible and also allows tibia-first approaches.

- For all bone cuts, the green tracker will be located proximal to the blue tracker. For example, during all femoral cuts, the green tracker will be on the femoral anchoring pin and the blue tracker on the cutting jig. For all tibial cuts, the blue tracker will be on the anchoring pin and the green tracker on the cutting jig.

Making the Distal Femoral Cut

- The reference for the distal femoral cut resection level is the most distal point of the digitized condyles. The system calculates the length of perpendicular distance, from the most distal point to the resection plane, thereby establishing the depth of cut (TECH FIG 6A).

- The freehand horseshoe guide is put on the distal femoral surface and is fixed with two pins (TECH FIG 6B). Then the distal femoral cutting guide is assembled on the horseshoe guide while the tracker is attached to the tracker interface (TECH FIG 6C).

- In the reactive workflow, the software automatically opens the Resect Distal Femur dialog box (TECH FIG 6D). On the screen, the yellow disc visualizes the actual cutting block position. At the same time, flexion–extension alignment and medial and lateral resection depth are numerically displayed.

- The distal and lateral screws on the cutting device are adjusted until the cutting guide corresponds exactly to what the surgeon thinks is the most appropriate distal femoral resection for that patient (TECH FIG 6E).

- After fixation and position verification, the distal femur can be resected (TECH FIG 6F,G). For cut verification and documentation, a plane probe is held flush.
The system calculates the perpendicular distance, from the most distal point to the resection plane (depth of cut). The freehand horseshoe guide is fixed on the distal femoral surface. The distal femoral cutting guide is assembled on the horseshoe guide. In the Resect Distal Femur dialog box, the yellow disc is visualizing the actual cutting block position. The amount of femoral resection, flexion–extension, and varus–valgus orientation can be set up by the surgeon. Resection and verification of distal femoral cut. The femoral rotation guide and the blue tracker are placed on the distal femoral cut. Corresponding navigation system screenshot.

against the cut surface while the tracker is attached to it. Adjustments to this cut can be made as deemed necessary by the surgeon.

Making the Femoral Rotational Cut

- The blue tracker is attached to the rotation guide and placed on the distal femoral cut, and the Align Femoral Rotation menu is selected in reactive workflow. The yellow lines represent femoral rotation. Rotation is displayed numerically with respect to the average rotational axis, as well as the digitized AP and transepicondylar axes. The surgeon decides which rotational reference to use.
- The stylus is then attached to the rotational guide to prevent anterior notching (anterior referencing).
- Once proper alignment is obtained, the anterior cut is made. Again, the surgeon must determine the actual rotation.

The 4:1 cutting block is adjusted by the anterior cut surface and remaining femoral bone resections.
depth of this cut with respect to the anterior cortex. The plane probe can be used to check the rotational accuracy of this cut.

**Finishing Cuts on the Femur**
- The 4:1 cutting block is adjusted with the anterior cut surface, and the remaining femoral bone resections are completed (TECH FIG 8).
- Computer digitization has suggested a femoral size based on points chosen by the surgeon, but the size of the actual component chosen depends on many other factors that the surgeon must take into account when choosing the appropriate 4:1 cutting block.
  - If it is not clear which size to choose, it is best to err initially on a larger size.

**Making the Proximal Tibial Cut**
- The horseshoe guide is fixed on the proximal tibia using two pins (TECH FIG 9A–C). The tibial cutting guide is then assembled on the horseshoe guide while the green tracker is attached.
- The Resect Proximal Tibia interface is selected on the workflow. The yellow line on the screen is the actual cutting block position. The varus-valgus alignment, slope, and mediolateral resection depth are displayed numerically.
- The depth of resection, slope, and alignment are adjusted using adjusting screws, and then the cutting block is fixed to the tibial bone with two pins (TECH FIG 9D,E). Again, the surgeon decides on the depth, angle, and slope of the cut. The navigation system merely gives accurate numerical information to assist with this decision.
- The proximal tibia is cut, and the cutting surface is verified and documented using Resection Plane Probe with the tracker on it (TECH FIG 9F,G).

**Tibial Rotation**
- Tibial rotation is set using the appropriate tibial template assembled to the alignment handle and tracker. On the reactive workflow, the Tibial Rotation screen is selected. The yellow cross shows the rotational alignment of the handle, which also is shown numerically (TECH FIG 10).
- The tibial template should be aligned in the proper position, as determined by the surgeon, and pinned into the tibia.
Tibial Component Insertion

- At this stage, osteophytes along the medial or lateral margins of the knee can be removed to anatomic contours. The space for the tibial component keel is prepared using a power burr and impactor (TECH FIG 11A).

- If a PCL-substituting design is chosen, the intercondylar box is removed to accommodate the housing for the post and cam mechanism (TECH FIG 11B–F).

**TECH FIG 10** • The space for the tibial component keel is prepared using a power burr (A) and impactor (B).

**TECH FIG 11** • A. Preparation of the intercondylar box for PCL-substituting prosthesis. B. The overall limb alignment and knee motion are assessed while trackers are attached. C–F. Corresponding navigation system screenshots.

**LIMB ALIGNMENT AND SOFT TISSUE BALANCE**

- Trial components are placed, and the trackers are attached to the anchoring pins. Overall limb alignment and knee motion are assessed.

- Soft tissue then is selectively released according to the residual deformity present. (Specific details of how to balance the limb are beyond the scope of this chapter.)

**PATELLA**

- The patella is cut and balanced according to standard techniques.

**IMPLANTATION OF COMPONENTS AND CLOSURE**

- The technique described in this section uses standard techniques for final implantation of components and closure.

- We remove the anchoring pins before implanting the components. However, if the surgeon prefers, the anchoring pins can be left in place during implantation of components to check for accuracy of final component position and limb alignment.
**PEARLS AND PITFALLS**

| Tracker pins | - Loosening of the tracker pins at any point during the surgery indicates that the operation should be stopped. The loosened tracker pin is reinserted in a secure position, and registration and anatomic survey are performed again. |
| Hip center determination | - During hip movement to find the center of the hip, the pelvis should be stabilized; otherwise, the computer cannot locate the exact hip center. |
| Digitization | - During digitization, the pointer should never leave the surface. |
| Mid-range instability | - Mid-range instability often occurs in patients with severe valgus deformity. It can be avoided by releasing the posterior capsule if it is contracted, minimizing resection of the distal femur, and re-approximating the anatomic joint line. |
| Position of the femoral and tibial components in the sagittal plane must be adjusted based on existing deformity. | - In patients with hyperextension deformity: |
| | - Reduce bone cut off distal femur |
| | - Place the femoral component in slight flexion |
| | - In patients with flexion deformity |
| | - Increase bone cut off distal femur: |
| | - Avoid flexion of femoral component |
| Tibial slope | - To achieve more flexion in a particular patient, the tibial slope may be increased slightly. However, this may lead to anterior tibial translation and early posterior wear. Decrease in the tibial slope will lead to a decreased posterior joint space and decreased flexion. |

**POSTOPERATIVE CARE**

- Postoperative care after navigation TKA is the same as that after the standard techniques.
- Important perioperative interventions including prophylactic antibiotic, and deep vein thrombosis prophylaxis should be administered according to standard protocol. The limb is put in a compression bandage at the conclusion of the operation. Pain is controlled according to the selected pain management protocol.
- On the day of surgery, both passive and active range of motion is begun, and the patient sits on the side of the bed, stands with assistance, and walks if able. The importance of active and passive extension is emphasized to the patient.
- The expected length of stay in the hospital is 3 or 4 days.
  - On the second and third postoperative days, the patient transfers to and from the bed and chair, sits up in a chair, and ambulates with weight bearing as tolerated using a walker or crutches.
  - At the same time, the physical therapist starts daily rehabilitation programs to increase knee range of motion and to strengthen the operated leg.
  - On the third or fourth postoperative day, the patient should achieve flexion of at least 70 degrees and can be discharged with a walker or crutches.
  - In the first 2 weeks, a patient should be visited at home by a nurse and physical therapist to check the wound and continue rehabilitation.
  - At 2 weeks, sutures or staples are removed, and the patient should be sent to an outpatient physical therapy facility if needed.
  - The patient is then seen at the office at 6 weeks and 6 months after surgery and then routinely followed every 3 years.

**OUTCOMES**

- Total knee arthroplasty has shown results that are both durable and consistent, with over 90% survivorship into the second decade. This long-term success has been related to patient characteristics and the accuracy with which the prosthesis is implanted.
- The navigation system, unlike standard technique, makes it possible to significantly improve the mechanical alignment of the limb, sagittal and frontal alignment of the femoral and tibial components, and knee range of motion without increased short-term complications. This more accurate and precise positioning and alignment of the components should reduce the rate of long-term complications and revisions.

**REFERENCES**

DEFINITION
- The number of revision TKA procedures performed is projected to increase at an annual rate of 19.3%.8
- Femoral bone defects are uncommon in primary TKA but are very common in revision knee surgery.
- Modular femoral augments are useful for moderate-sized bony defects, allowing the surgeon to maximize bone–prosthesis contact while restoring the joint line or posterior condylar offset.
- Improvements in prosthesis design and biomaterials have increased the usefulness and versatility of metal augments in addressing larger bone defects.
- A systematic approach to preoperative planning, intraoperative evaluation, and reconstruction is essential in addressing femoral defects using augments.

ANATOMY
- The most common form of bone defect encountered at the time of revision surgery is bone loss from the distal and posterior femur (Table 1).
- Aside from “filling the defect,” it is important to restore the femorotibial joint line and the posterior condylar offset. Significant alterations in either or both will be detrimental to the function of the prosthesis.
- The joint line typically lies 25 mm distal to the femoral epicondyles, and the posterior femoral condyles are offset an average of 25.8 mm from the posterior cortex of the femur.2

PATHOGENESIS
- In unoperated knees, bone loss on the femoral side can be caused by previous osteochondral defects, avascular necrosis,
severe valgus or varus deformity, posttraumatic arthritis, and Charcot arthropathy (FIG 1A).

- During revision surgery, osteolysis secondary to wear debris and bone loss secondary to removal of well-fixed components or a cement mantle are the most common causes of femoral bone defects (FIG 1B).
- Rarely, earlier trauma resulting in severe angular deformity may require the use of augments for joint reconstruction and restoration of limb alignment.

NATURAL HISTORY

- Untreated bone defects in the native knee can lead to progressive joint collapse, ligamentous laxity, and progressive bone loss.
- Osteolytic lesions caused by wear debris can progress and lead to loss of implant support and eventual component loosening.
- Intraoperative mismanagement of defects can lead to suboptimal fixation, significant alterations in knee kinematics, instability, and early implant failure.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A complete history and physical examination must be performed before any revision knee surgery is undertaken. The details of the index arthroplasty with regard to pain relief and the interval to failure should be recorded. In addition, problems during the postoperative period such as falls or operative wound complications should be probed.
- Patients with loose femoral components often present with painful TKAs. Pain often occurs at start-up, arising from the seated position, and with stair climbing. These patients often may complain of swelling and effusions within the knees.
- An AP radiograph of the pelvis and a careful back and hip examination should be performed to rule out coexistent spinal or hip disorder as the cause of the patient’s knee pain.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs of the knee, including standing AP, lateral, and Merchant views of the affected knee, should be reviewed. For patients with deformity, the entire length of the affected bone should be visualized.

- In revision cases, serial radiographs may help assess the progression of osteolysis, radiolucent lines, and implant migration.
- CT scans of the knee permit assessment of component rotation and can assess the size and location of osteolysis more accurately.4 Recently, MRI also has been shown to be effective in quantifying osteolytic defects.9
- Blood studies, including a complete blood count with differential, sedimentation rate, and C-reactive protein, should be obtained to rule out infection.
- Nuclear medicine studies including bone scan (to detect a loose prosthesis) and indium and sulfur colloid scans (to detect the presence of infection) also can be helpful in the preoperative workup.
- Aspiration should be done when there is any suspicion of infection. The synovial fluid should be evaluated and cultured for the presence of microorganisms.

DIFFERENTIAL DIAGNOSIS

- Infection
- Arthritis of the hip and spine
- Flexion instability
- Patellar maltracking and extensor mechanism dysfunction
- Tibial component loosening
- Periprosthetic fractures

NONOPERATIVE MANAGEMENT

- Unless the patient has obvious signs of component malpositioning, loosening, fracture, or infection, a trial of conservative treatment aimed at strengthening the quadriceps musculature with emphasis on the vastus medialis oblique muscle should be the cornerstone of nonoperative treatment.
- Patients who have evidence of early osteolysis on plain radiographs but have no clinical symptoms or pain should be encouraged to obtain serial radiographs annually to check for progression of the lesion(s).
- No consensus has been reached regarding when it is appropriate to revise or perform bone grafting in an asymptomatic knee with radiographic evidence of osteolysis.
PART 3  ADULT RECONSTRUCTION • SECTION III  KNEE RECONSTRUCTION

SURGICAL MANAGEMENT

- A systematic approach is required to reconstruct bone defects successfully during revision surgery.

Preoperative Planning

- Thorough preoperative planning is the key to a successful reconstruction.
- Review of radiographs and CT scans and careful templating allow anticipation of problems that could be encountered during surgery (Fig 2A,B).
- Most bone loss can be addressed by the use of metal augments and a long-stem prosthesis (Fig 2C).
- For larger osteolytic lesions, special wedges, femoral heads, and allografts must be ordered in advance so they are available during reconstruction.
- In all cases of revision, stemmed and constrained implants (or sometimes a hinged prosthesis) must be considered and must be available.

Positioning

- The standard position for patients undergoing revision TKA is supine.

- Care is taken to drape out a wide surgical field in case a more extensile approach is necessary. A sterile tourniquet applied on the surgical field may be helpful.

Approach

- The knee is approached via the standard medial parapatellar approach.
- Protection of the patellar tendon during this phase of the operation is crucial.
- An extensive synovectomy and debridement of the medial and lateral gutters are critical for decompression of the joint.
- The patella usually is not everted during revision TKA.
- In knees with severe ankylosis, techniques such as the quadriceps snip, lateral release, and tibial tubercle osteotomy are helpful for exposure. The surgeon must know the implications of each of these releases and repair or reconstruct them properly at the end of the procedure.
- The bone defect is addressed by the use of cement (smaller lesions), metal augments, or structural grafts. The critical issues are to restore joint line, achieve appropriate alignment, and attain ligamentous balancing. Reconstruction also aims at restoring a stable platform for positioning and fixation of the components.

Positioning

- The standard position for patients undergoing revision TKA is supine.

Metal Augments

- Modular metal augments allow for restoration of distal, posterior, and even metaphyseal femoral defects.
- For most systems, the largest femoral augments allow for restoration of 8 to 10 mm of bone defect. The use of cemented stacked augments for filling defects up to 30 mm has been reported.
- Most revision systems have intramedullary systems that allow bone cuts to be made relative to a press-fit intramedullary rod.
- The distal femoral cut is freshened to provide a stable platform for the new prosthesis.
- Next, the size of the femoral component is selected. Preoperative templating can give clues to the proper component size. Traditionally, the femoral component is upsized to better fill the flexion gap (Tech Fig 1A).
- Determining proper femoral component rotation is critical to a successful reconstruction. The femoral component should be set parallel to the transepicondylar axis of the femur (Tech Fig 1B). Other secondary guides include the proximal tibia and the femoral intercondylar line.
- Malrotation of the femoral component also can exaggerate the severity of bone loss.
- The rest of the reconstruction varies according to the revision knee system being used, but should follow a systematic approach. In some systems, the trial components

FIG 2 • A, B. AP and lateral radiographs of the knee before revision surgery. Large osteolytic defects involving both the femur and the tibia are visible. Careful preoperative planning is required to be able to address bone loss encountered at the time of arthroplasty. C. Most cases of knee revision with bone loss can be addressed with the use of a long-stem prosthesis and metal augments.
Chapter 21  REVISION TKA WITH FEMORAL BONE LOSS: METAL AUGMENTS

TECH FIG 1 • A. Sizing the femoral component is an important part of the revision process. B. Assessing the appropriate rotation using transepicondylar axis and Whiteside’s line. Note the distortion of the posterior condylar line as a result of bone loss. C. Some implants have trials with slots, which allows for more precise sizing and preparation for modular augments. D. Femoral trial with augments and stem in place.

have slots that allow cuts to be made for more precise fitting of the modular augment (TECH FIG 1C).
- A stemmed trial femoral component with the necessary augments is assembled and inserted. Trialing should focus on the overall stability of the knee in extension and flexion, and also on patellofemoral tracking (TECH FIG 1D).
- The definitive prosthesis is assembled and cemented into place in the standard fashion.

BONE CEMENT
- Indicated for use in small, preferably contained, bony defects up to 5 mm in depth
- Limitations: cannot be used for uncontained defects, and does not restore bone stock
- Following removal of the existing prosthesis, all surfaces are thoroughly débrided. There is a membrane that often forms between the old bone–cement interface. Areas of bony sclerosis should be débrided to punctate bleeding with the aid of a high-speed burr.
- The femur is prepared with the revision instrumentation specific to the implant system, paying attention to joint line restoration, rotation, and restoration of the posterior condylar offset. The use of stemmed implants allows for distribution of joint stresses and almost always is required in cases of revision surgery with bone loss.
- The new femoral component is cemented into place separately, and the cement is allowed to harden under direct vision.

MORSELIZED AUTOGRRAFT OR ALLOGRAFT
- Indicated for use in larger contained defects, especially in younger patients. The main advantage of this technique is that it allows for restoration of bone stock.
- Limitations: cannot be used for uncontained defects, and does not restore a stable platform capable of supporting the prosthesis
- Using a curette or a high-speed burr, the host bone is débrided to create a favorable environment for graft incorporation.
  - Visible defects are packed with morselized auto- or allograft.
  - A bone tamp may be used to pack the bone chips tightly.
- Prepare the femur using the revision instrumentation particular to the system being used.
- Once the femur is prepared, insert a stemmed trial femoral component, with or without wedges, onto the femur.
- Before final impaction of the trial component, tightly pack the bone chips around the stems and the posterior condyles. Impacting the trial prosthesis into place will effectively shape the new distal femur.
- The new stemmed femoral component is cemented separately to minimize the chance of component malposition.
### Structural Allografts (Femoral Hemicondyle)

- Structural allografts are indicated for large, uncontained defects involving one femoral condyle. The attachments of the collateral ligaments are preserved by a thin shell of bone following removal of the femoral implant.
- The host bone–allograft interface is prepared as previously described.
- Gently, using a hemispherical acetabular reamer, the bony defect is reamed to accept a femoral head (TECH FIG 2A).
- Using the corresponding female resurfacing reamer, a femoral head allograft is reamed to remove all cartilaginous debris (TECH FIG 2B).
- The femoral head is coupled to the bony defect and secured using two threaded Steinmann pins inserted from proximal to distal (TECH FIG 2C).
- The distal femur then is prepared using the instrumentation particular to the system being used.
- The femoral head allograft is fixed to the host bone using 4.5-mm short-thread cancellous screws inserted from proximal to distal (TECH FIG 2D).
- Finally, a stemmed femoral component is cemented into place.

### Distal Femoral Allograft

- Indicated for massive osteolytic defects involving both distal condyles and distal femoral metaphysis. It allows for restoration of bone stock while preserving the collateral ligament insertions.
- In cases in which a distal femoral allograft may be required, preoperative sizing of the host femur and the allograft is crucial.
- Comparing radiographs of the allograft to the host femur (may size against an unoperated side if available) improves fit and decreases the chances of mismatch.
- The native femur is prepared to accept the allograft by carefully preserving the collateral ligament attachments (TECH FIG 3A).
- The allograft is then shaped to allow for intussusception (bone within bone) into the native femur. It is important to obtain a secure fit of the allograft during this step (TECH FIG 3B).
- Using traditional distal femoral cutting guides, the femur is prepared to accept a stemmed prosthesis (TECH FIG 3C–E).
- Demineralized bone matrix is used to line the host–allograft interface. This allows the filling of gaps and also provides a barrier against cement intrusion (TECH FIG 3F).
- A stemmed femoral implant is cemented into place (TECH FIG 3G,H).
**TECH FIG 3** • A. Severe bone loss encountered during surgery. Because the collateral ligaments were still intact, use of structural allograft to reconstitute bone was deemed appropriate. B. The allograft is cut to the approximate size needed to fit the defect. C–E. The rest of the cuts are performed using standard instruments to obtain a well-shaped structural graft. The prepared graft is produced to fit the defect exactly. F. Demineralized bone matrix can be used in the interface between allograft and host. G,H. The long stem implant is then cemented over the allograft.

---

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Preoperative planning</th>
<th>■ Comprehensive preoperative evaluation including workup for infection and other causes of knee pain (hip and spine) should be performed in all patients undergoing revision TKA.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>■ CT scans of the knee are helpful in assessing component rotation and quantify the degree of bone loss.</td>
</tr>
<tr>
<td></td>
<td>■ Preoperative templating is critical for successful reconstruction. Be prepared.</td>
</tr>
<tr>
<td>Exposure</td>
<td>■ Removal of preexisting components is a common cause of bone loss during revision TKA.</td>
</tr>
<tr>
<td></td>
<td>■ Careful exposure of the implants with attention to the interface between the posterior phalanges of the prosthesis and the host bone will prevent unnecessary bone loss.</td>
</tr>
<tr>
<td>Bone loss</td>
<td>■ Small contained bony defects can be addressed with either cement or morselized bone graft.</td>
</tr>
<tr>
<td></td>
<td>■ Metal augments are useful for augmenting distal and posterior femoral defects measuring less than 1 cm and with good structural support.</td>
</tr>
<tr>
<td></td>
<td>■ Proper sizing of the femoral component, the use of offset stems, and correct component rotation can minimize smaller defects.</td>
</tr>
<tr>
<td></td>
<td>■ Large structural and uncontained femoral defects involving one or both femoral condyles require augmentation with allografts.</td>
</tr>
</tbody>
</table>
The host bone should be thoroughly débrided to optimize the interface between the native bone and the allograft bone or cement. Restoration of the joint line and the posterior condylar offset is crucial to the overall success of the revision process. Failure to restore posterior offset can lead to motion loss.\(^6\) When using metallic augments, the decision to use distal femoral augments is made early in the procedure. Revision instrumentation will key off these augments for subsequent bone cuts. When using distal femoral allografts, prepare the allograft by first removing the epicondyles and making a provisional cut on the anterior cortex of the allograft. This will allow the allograft to be impacted into the host bone.

Each component should be cemented separately to prevent inadvertent changes in component position. During final impaction of the definitive prosthesis, pay attention to its position in relation to the posterior condylar offset. Restoration of the joint line and the posterior condylar offset is crucial to the overall success of the revision. An intraoperative radiograph can help assess the overall alignment of the implants and their position in relation to the tibiofemoral joint. Using a marking pen, trace out the anterior phalange of the revision femoral component once a satisfactory trial of all the components. This tracing will provide a guide to the depth of seating for the definitive prosthesis.

Early motion is instituted for most patients using a continuous passive motion (CPM) machine set from 0 to 60 degrees immediately following surgery. For patients who have had extensive procedures, a well-padded Robert Jones dressing is applied following the operation. Immobilization is maintained for 24 to 48 hours. Following revision TKA, patients usually are allowed to bear weight as tolerated on the prosthesis. Alterations of weight-bearing status and limitations on knee flexion generally result from other procedures performed at the time of arthroplasty, such as tibial tubercle osteotomy, quadriceps snip, or V-Y turn-down.

Overall, the survivorship of revision femoral components using metal wedges with or without structural augments is 79.4% at 8 years.\(^1\) For knees with small, contained cavitary defects requiring only cement or morselized graft, the 10-year survivorship approaches that of primary knee arthroplasty.\(^7\) Modular femoral augments used for reconstruction of type II defects have an 11-year survival rate of 92%. It is not uncommon to see nonprogressive radiolucent lines surrounding metallic augments.\(^8\) Femoral revisions augmented with structural allografts have a 10-year survival rate of 75%.\(^3\)

**COMPLICATIONS**

- Traditional complications following revision TKA include infection, wound complications, and loosening.
- Patellar maltracking and extensor mechanism dysfunction also can occur, especially if there is component malrotation.
- Knee instability can result from an imbalance in the flexion and extension gaps.
- Resorption of large structural allografts leading to subsequent implant loosening has been described.

**REFERENCES**

Bone loss and indications for the use of metallic augments in revision total knee arthroplasty (TKA) usually are guided by classification of the bony defect.

Several classification systems have been developed and introduced that describe and quantify proximal tibial bone loss with the intent of guiding preoperative planning and intraoperative treatment and aid in forming a prognosis postoperatively.

Classification systems assess the bony defect in terms of size, location, presence or loss of cortical containment, and symmetry or disparity across the tibial plateau. One of the most widely used systems is the Anderson Orthopaedic Research Institute (AORI) bone defect classification system.

The AORI bone defect classification system divides bone loss of the distal femur or the proximal tibia into three types, based on the radiographic status of the metaphyseal bone.

- Distal femoral metaphyseal defects are graded as FI, FII, or FIII.
- Proximal tibial metaphyseal defects are graded as TI, TII, or TIII.
- The metaphyseal region of the proximal tibia is defined as the bone cephalad to the tibial tubercle.

Type I defects of the proximal tibia have intact metaphyseal bone with no component subsidence or loss of the primarily reconstructed joint line.

- Minor defects may be present that will not compromise the stability of the tibial component at the time of revision surgery; in such cases, primary type reconstruction components may potentially be used.
- Type II defects of the proximal tibia have damaged metaphyseal bone with component subsidence or joint line alteration due to loss of metaphyseal bone.

- Bone loss in type II defects can involve either the lateral or, more commonly, the medial tibial plateau as well as the entire proximal tibia.
- Defect reconstruction with cement, augments, or, possibly, bone grafting is required to reestablish the joint line at an appropriate level, and revision stemmed components usually are required.

Type III defects of the proximal tibia have deficiency of the proximal metaphyseal bone that involves a major segment of the proximal tibia.

- This type of defect may involve the tibial tubercle, with resulting patellar tendon detachment and loss of extensor mechanism function.
- The medial collateral ligament also may be detached or functionally incompetent (ie, pseudo-laxity) as a result of bony deficiency.
- The broad insertion of the medial collateral ligament on the proximal medial metaphysis of the tibia renders incompetence or frank loss of attachment due to tibial bone loss less likely as compared to femoral condylar bone loss, where the origin of the medial collateral has a much smaller footprint or area of attachment to the medial epicondyle.
- Defect reconstruction with augments and structural bone graft is required to fill the bony deficiency. Long-stemmed revision implants are required, including hinged modular revision components.

- A custom component rarely is required because of the availability of modular oncology or limb-preserving systems.

In summary, proximal tibial bone defects are classified as intact, or type I (TI); damaged, or type II (TII); and deficient, or type III (TIII).

- By definition, the use of metallic augments is restricted to type TII or TIII defects. TIII defects with frank bony deficiency often require bulk structural allograft, either alone or in combination with metallic augmentation.
- The major indication for isolated metallic augmentation is a type II tibial bone defect.

The native tibial plateau has a 3-degree varus slope in the coronal plane relative to the mechanical and anatomic axes of the tibia, to match the 3-degree valgus slope of the femoral condyles.

- The distal femur has a 3-degree valgus slope relative to its mechanical axis and a 9-degree valgus slope relative to its anatomic axis in the coronal plane.
- In the sagittal plane, the proximal tibia has a posterior slope of 9 to 10 degrees on average, with a range of 4 to 12 degrees. The medial tibial plateau is mildly concave, and the lateral tibial plateau is mildly convex.

About 60% of ground reaction forces are transmitted through the medial tibial plateau; the remaining 40% are transmitted through the lateral plateau.

- The trabecular bone of the proximal tibia is densest in its most proximal 1 cm and is responsible for load transmission.
- The strength and stiffness of the proximal tibial bone are dictated by trabecular architecture and bone density, with the most dense area being central in each plateau.

- The bone also is more dense between the plateaus under the tibial spine and decreases in density toward the periphery of the plateau.
- The subchondral, epiphyseal, and metaphyseal bone is relatively denser in the medial tibial plateau due to higher load transmission compared to the lateral tibial plateau.
- The tip of the fibular head is approximately 1 cm below the surface of the lateral tibial plateau.
The tibial tubercle is 25 to 40 mm below the joint surface, and the average insertion point of the patellar tendon is 29 mm distal to the tibial plateau.

The patella tendon averages 44 mm in length and ranges from 33 to 53 mm in length. Therefore, the distal pole of the patella averages 15 mm above the joint surface and ranges from 12 to 16 mm.

The fibular head is the most commonly used bony reference for joint line restoration in the revision TKA setting.

Improved outcomes are noted if the joint line is elevated less than 8 to 10 mm. Pre- and postoperative radiographs of the primary procedure allow the most accurate determination of the postarthroplasty joint line.

Blood supply to the proximal tibia is both endosteal and periosteal (FIG 1A). The endosteal blood is supplied via a nutrient artery branching from the posterior tibial artery that enters the tibia posteriorly and distal to the soleal line. The proximal tibial periosteal blood is supplied by the medial and lateral inferior genicular arteries as well as the anterior tibial recurrent artery. The medial and lateral inferior genicular arteries arise from the popliteal artery and pass deep to the collateral ligaments to supply the medial and posterolateral periosteum of the proximal tibia.

The anterior recurrent tibial artery is an ascending branch that arises from the anterior tibial artery just after it passes through the proximal tibiofibular interosseous membrane and supplies the anterolateral periosteum of the proximal tibia. All of these vessels also contribute to the anterior anastomotic peripatellar ring.

Neurovascular injury during primary and revision TKA is rare. The popliteal neurovascular bundle is at greatest risk during proximal tibial resection.

These vessels are 3 to 12 mm posterior to the articular surface of the tibia when the leg is extended and 6 to 15 mm posterior when the knee is flexed to 90 degrees. At the level of the tibial resection the distance is approximately 2 cm posterior to the cut surface.

The popliteal artery and vein are anterior to the tibial nerve at this level.

Most revisions do not put the tibial artery trifurcation at risk unless more than 30 mm of proximal tibia is resected, which occurs when a tumor prosthesis is utilized for proximal tibia replacement.

Most neurovascular injuries during primary and revision TKA result from tourniquet use in the patient with peripheral vascular disease. The proximal tibial anatomy of the TKA requiring revision total knee arthroplasty is highly variable (FIG 1B,C).

Component subsidence, osteolysis, fracture, and infection can alter the usual post-arthroplasty anatomy of the proximal tibia.

Pre- and postoperative radiographs of the primary procedure can be invaluable during preoperative planning of the revision surgery to determine actual bone loss and true change in component position.

The type of component noted on the postoperative primary radiographs can be helpful in determining the amount of bone that was originally resected from the proximal tibia.

Cruciate-retaining implants typically are cut with 3 to 7 degrees of posterior slope in the proximal tibial resection, whereas cruciate-sacrificing and cruciate-substituting or posterior stabilized implants typically have 0 degrees of posterior slope.

Consequently, in the revision setting where posterior stabilized or “super stabilized” or “total stabilized” type components are used, additional anterior resection of the tibial plateau may be required to restore neutral slope.

Some revision systems call for a slight amount of slope to match the design of the stemmed tray, and the proximal tibial should be resected accordingly.

Bone defect classification schemes as outlined earlier for damaged or deficient metaphyseal tibial bone can greatly aid in understanding the pre-revision anatomy.

PATHOGENESIS

Multiple causes may lead to failure of the primary TKA, including aseptic loosening, deep infection, flexion instability, complex regional pain syndrome, malalignment, postoperative stiffness, and extensor mechanism complications.

Proximal tibial bone loss in primary total knee failure can be attributed to the following factors: implant malalignment
Septic loosening is the result of bacterial infection of the knee.

- Bone insufficiency or osteopenia from stress shielding, osteolysis, or osteonecrosis can be underlying factors contributing to pre- or intraoperative bone loss.
- The quantity of osteolysis is affected by implant design and the quality of polyethylene, as well as host response to particulate debris.
- Disuse osteopenia may contribute to massive proximal tibial bone loss in the presence of periprosthetic fracture.
- Component loosening and resultant implant failure occur primarily via two common routes: aseptic, due to osteolysis; and septic, due to bacterial infection.
- Osteolysis of the proximal tibial bone is a result of polyethylene particulate debris from wear at the bearing interface as well as “backside” wear.
- Backside wear results from micromotion between the polyethylene insert and the modular tibial tray.
- Somewhere on the order of billions of submicron polyethylene particles per year can be generated at the bearing surface.
- These particles generate histiocytic and macrophage response, where intercellular signaling pathways are activated that promote osteoclast activity and bone resorption.
- Osteolytic lesions are either focal or expansile, depending on the submicron particle burden as well as the host response to the particles.
- The process begins in areas of soft or exposed bone that are subject to intra-articular synovial fluid pressure.
- Debris-filled synovial fluid and resultant areas of osteolysis follow the paths of least resistance around tibial component of the implant.
- Susceptible areas include uncovered bone of the tibial plateau, ie, areas covered by neither the component nor cement.
- Screw holes and areas on the undersurface of the tibial tray that lack the bony ongrowth surface of a press-fit tibial component also offer pathways to the metaphyseal bone.
- As mentioned previously, the metaphyseal bone is stronger centrally and more resistant to significant osteolysis; however, the periphery is weaker and more prone to osteolysis.
- As osteolysis progresses, the tibial component loses its bony support, and a radiolucent line forms between the component itself or the component cement mantle and the underlying metaphyseal bone.
- The tibial component is aseptically loose when the radiolucent line is circumferential and no direct bony support remains.
- Both expansile osteolysis and component loosening can lead to component subsidence, usually into a varus position.
- The medial tibial plateau is dimensionally larger than the lateral tibial plateau and potentially has more exposed cancellous bone when symmetrical tibial components are utilized.
- Septic loosening is the result of bacterial infection of the knee.
- Classically, the organism most commonly isolated from the knee was *Staphylococcus aureus*; however, more recent studies suggest that *Staphylococcus epidermidis* may be equally common, although less virulent. Bacterial infection occurs through one of several routes.
- The knee may be contaminated at the time of implantation, although this happens in less than 0.5% of cases.

Hematogenous inoculation of the joint with bacteria also may occur in the face of a previously well-functioning prosthesis.

Dental work causes bacteremia 100% of the time, and other procedures such as gastroesophageal endoscopy and colonoscopy all introduce potential for bacteremia and late hematogenous spread to the implanted knee.

All surgical procedures put a prosthesis at increased risk for infection.

Less virulent organisms may not lead to significant bone loss intrinsically, but more virulent organisms often result in a loose component.

A third route of infection is direct contamination of the knee by trauma, ie, traumatic arthrotomy.

Most prosthetic infections are treated with two-stage revision arthroplasty of the knee, in which either a static antibiotic spacer or a dynamic articulated type of spacer is used for the first stage of the revision.

Preformed antibiotic-loaded polymethylmethacrylate spacers are commercially available, but the concentration of antibiotic in the cement is predetermined by the manufacturer.

In some instances, the concentration in a preformed spacer may not be sufficient to overcome a virulent organism or to meet the preference of the surgeon.

Articulated spacer molds allow the surgeon to select the quantity and type of antibiotic to be loaded into the cement spacer.

The second stage of the revision takes place once serum inflammatory markers have returned to within normal limits and the patient has responded clinically to both the antibiotics in the spacer and those given intravenously.

The time between the first and second stage of the revision TKA for infection is typically 8 to 12 weeks.

Implantation of a well-fixed primary component leads to potentially significant bone loss when it is removed from an osteopenic tibial metaphysis.

Occasionally a static antibiotic spacer may subside or displace in the joint between the revision stages, further contributing to bone loss.

A comparison study of static and articulated spacers showed greater bone loss with static spacers than with articulated spacers.

Maximizing bone coverage with either type of spacer appears to preserve bone stock.

The AORI classification also applies to bone loss, either present or anticipated, at the second stage of the staged revision knee arthroplasty.

**NATURAL HISTORY**

- The osteolytic process is clinically silent until the prosthesis loosens.
- A loose prosthesis causes startup pain as well as cyclic pain with loading, provided that fracture or gross displacement of the component has not occurred.
- The pain may decrease with weight bearing as the component reseats itself and motion at the bone implant interface decreases.
- Expansile osteolysis and component subsidence or proximal metaphyseal fracture may result in gross lower extremity deformity, usually varus, and occasionally may also present with hyperextension if the component subsides into an anteriorly sloped position.
Radiographic examinations of the implanted knee should be performed at regular intervals to detect the presence or progression of osteolysis.

The presence of osteolysis and its rate of progression depend on the polyethylene type and processing of the implant as well as the host response to particulate debris.

Many modular systems that use polyethylene inserts gamma-irradiated in air demonstrate accelerated wear patterns with high particle production.

Many of these implants demonstrated osteolysis within 36 months of implantation.17

Specific timeframes for aseptic component loosening are difficult to predict globally, because there are many contributing host and implant variables.

Septic failure of TKA is noted in the perioperative period in 0.5% of patients.

Delayed hematogenous infection occurs in 1% to 2% of TKAs over the lifetime of the implant.20

Infection must be ruled out in all painful TKAs.

Differentiation between septic and aseptic loosening of the tibial component is of paramount importance, because the management of each type is different, and a misdiagnosis can result in loss of limb.

PATIENT HISTORY AND PHYSICAL FINDINGS

The patient history and physical findings are centered around differentiating between septic and aseptic loosening, the amount of bony destruction and the ligamentous insufficiency present, and the resultant instability of the knee.

Patients with symptomatic osteolysis or loosening of the tibial component usually describe gradual onset of pain that is worse with startup type of activities such as arising from the bed or getting out of a chair or a vehicle.

They also commonly describe increased pain with the first steps of ambulation, which may decrease as the component settles into the remaining bony mantle of the proximal tibia.

There is less or no pain with rest.

The infected TKA will cause pain at rest, and patients who have deep infection may describe a temporal pain pattern with increasing or steady pain from the day of surgery to the day of clinical evaluation with no remittance.

Late hematogenous infection presents with sudden onset of pain in a previously well-functioning prosthesis.

An acute knee effusion and loss of range of motion and stiffness also may present in this setting.

Complete neurovascular examination of the affected extremity should be carried out, along with focal examination of the knee.

Visual inspection for edema and erythema is pertinent in the face of infection.

Range of motion and patellar tracking should be evaluated along with ligamentous stability and overall limb alignment. A difference between active and passive extension demonstrates extension lag versus flexion–contracture.

Specific attention should be directed toward evaluating the functional status of the medial collateral and posterior cruciate ligaments in a knee with cruciate-retaining implants.

A quadriceps active test and posterior sag signs are useful to evaluate the functional status of the posterior cruciate ligament (PCL).

Varus and valgus stress tests in extension, in midflexion, and at 90 degrees of flexion are useful to evaluate the collateral ligaments for instability. If present, instability may be graded according to laxity.

Anterior and posterior drawer tests evaluate status of the PCL, conformity of the bearing surface, and proper function of cam–post mechanism as well as flexion gap.

If significant posterior subluxation is seen on posterior sag testing, it suggests a nonfunctioning PCL in a cruciate-retaining TKA.

The quadriceps active test also demonstrates failure of the PCL or of the cam–post mechanism in a posterior stabilized implant.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Plain film radiographic views of the affected knee are required (FIG 2).

Multiple orthogonal views, including oblique views, may illustrate areas of bone loss more fully.

The skyline view, while part of a complete radiographic analysis, does not allow visualization of the tibial component.

Weight-bearing anteroposterior and lateral views can be helpful to load the knee and show the component position of maximum subsidence as well as resultant limb.

It is important to obtain tangential views to properly align the bone implant interface with the beam of the radiograph.

If plain radiographs are thought to underrepresent the true volume of osteolysis, consideration may be given to CT with metal suppression.25

Conversely, if there is doubt regarding actual loosening of the component, technetium-99m bone scanning can illustrate areas of increased bone turnover that may indicate possible looseness of the tibial component.

In cases in which infection is suspected, the bone scan can be compared to an indium-111–tagged white blood cell scan.

Aspiration of the knee joint with culture of a definitive organism is the ideal confirmation of an infected TKA.
DIFFERENTIAL DIAGNOSIS
- Osteolysis
- Infection
- Tibial component loosening
- Tibial component subsidence
- Periprosthetic proximal tibial fracture

NONOPERATIVE MANAGEMENT
- Nonoperative management of a loose tibial component due to osteolysis with or without subsidence and fracture should be considered only if the revision procedure will place the patient’s survival in jeopardy or make their quality of life worse than it was at presentation.
- The same caution applies to patients with indolent infections. Virulent organisms can cause bacteremia and sepsis. Emergent surgical explantation of the components may be required to prevent septic shock and death.

SURGICAL MANAGEMENT
- Ideally, the patient is medically optimized for revision knee surgery and all medical comorbidities have been addressed before the surgery.
  - Risk stratification should be performed by medical subspecialists based on the patient’s medical history and on the recommendations of a general medical doctor.
  - The patient should be fully informed of the risks compared to the benefits of the revision total knee surgery and of the bone loss management plan.
- Intraoperatively, the need for metallic augmentation is confirmed by segmental defects, defects that involve more than a quarter of the cortical rim, or defects that will result in less than 60% direct bony support of the revision component confirm.17

Preoperative Planning
- Evaluating the component position and classifying the present bone loss on plain films is the cornerstone of preoperative planning.
  - Metaphyseal bone quality should be evaluated and intraoperative bone loss anticipated.
  - Templating should be carried out with the focus on restoring the joint line and filling the bony defect. The broad insertion of the medial collateral ligament presents an issue only for severe bone defect unless it is found to be incompetent on the preoperative physical examination. Close attention should be given to the planned level of resection and its relation to the insertion of the extensor mechanism. Wedge augments should be avoided if possible, but are indicated if needed to spare bone around the tibial tubercle.
  - The condition of the patient’s skin should be carefully evaluated in the physical examination.
- All previous skin incision and their age should be noted.
- An anterior midline incision is preferred, but it may be necessary to use the most lateral incision to protect the patient from skin necrosis in areas between incisions. A 7-cm skin bridge should be maintained between all incisions if at all possible.
- Patients with significant potential for necrosis may need to undergo a “sham” procedure to ensure the skin is viable.28 This involves an incision just through the skin without involving the extensor mechanism to verify healing potential.
- The existing implant in the knee should be identified, and the operative reports of the previous surgery should be obtained prior to surgery.

Positioning
- The patient is positioned supine on the operating room table.
- A well-padded, non-sterile tourniquet is placed as proximally as possible on the operative lower extremity. All bony prominences are well padded.
- A bump may be placed under the hip and pelvis on the operative extremity side, depending on the surgeon’s preference.
- The nonoperative extremity is secured to the table.
- A bean bag, horizontal post, or leg-holding device such as an Alvarado leg positioner may be used to hold the leg in a flexed position during the procedure.

APPROACH
- A standard midline incision with a medial parapatellar arthrotomy is ideal. The skin is incised from 5 cm (or more, if necessary) proximal to the patella. The incision is centered over the patella and patellar tendon to the tibial tubercle (TECH FIG 1A).
  - Some surgeons prefer to bring the distal half of the incision slightly medially so that it terminates at the medial edge of the tibial tubercle. Preference is always given to the previous skin incision.
  - The anterior midline incision is carried down to the extensor mechanism, and full-thickness flaps are elevated both medially and laterally (TECH FIG 1B).
- The medial flap usually must only be carried medially to the distal aspect of the vastus medialis obliquus muscle.
- Laterally, the flap is raised sufficiently to allow for possible eversion of the patella after the arthrotomy is performed.
  - An anterior medial parapatellar arthrotomy is then performed (TECH FIG 1C). The previous arthrotomy location is again preferred.
  - Care should be taken to preserve a cuff of tissue on the medial aspect of the patella to facilitate closure of the arthrotomy.
### COMPONENT EXPLANTATION

- Once the joint is opened, scar tissue is resected as necessary for adequate exposure. Specifically, the medial and lateral gutters should be restored with care to avoid injuring the collateral ligament origins. The suprapatellar pouch also should be restored via resection of scar tissue under the quadriceps tendon and from the anterior aspect of the distal femur just proximal to the femoral component.
- The subperiosteal flap is elevated off the proximal and anteromedial aspect of the tibia to allow exposure to the entire tibial component and proximal tibial bone.
- The tibial insert is removed from the tray to allow adequate visualization.
- The tibial tray is then explanted. In cases of a loose tibial component, intraoperative bone loss usually is minimal, and special techniques for tibial component removal are not required.
- In the septic knee with a well-fixed tibial component, bone-sparing techniques are used to remove the component.
- Stemmed tibial revision components are recommended when using augments to provide additional bony stabilization of the implant, thereby shifting some of the load from the damaged or deficient metaphyseal tibia to the diaphysis.

### MEDIAL OR LATERAL HEMIWEDGE AUGMENT

- The explanted proximal tibia is evaluated intraoperatively, and bone loss is compared to the preoperative radiographs. The appropriate preoperative plan is followed with anticipated changes verified by intraoperative findings.
- Intramedullary reaming is followed by placement of an intramedullary alignment guide, and a minimal transverse proximal tibial “skim” resection is taken after the tibial resection block is pinned in place (TECH FIG 2A,B).
- The appropriate wedge augment cutting guide is then selected and positioned over the previously placed cutting guide pins, and medial or lateral wedge cuts are performed (TECH FIG 2C).
- Once the proximal tibial surface is adequately prepared, a stemmed trial component that reflects the intramedullary stem to be used with attached augments is put in place (TECH FIG 2D).
- When adequate bony support is achieved, the joint surface is restored, and flexion and extension gaps are balanced, then the component to be implanted is constructed to match the trial and appropriately cemented into place (TECH FIG 2E).
- The goal is to place the tibial component directly onto a viable cortical rim of bone by converting noncontained defects into contained defects and to have a rigid press-fit intramedullary stem to support the tibial tray.
- This process applies to all of the wedge and block techniques.
Chapter 22  REVISION TKA WITH TIBIAL BONE LOSS: METAL AUGMENTS

TECHNIQUES

A. Intramedullary reaming should be carried to the depth of the stem available in the revision system in use.
B. The block is pinned into place after the guide is placed over the intramedullary reamer or trial stem extension, and a “clean up” or skim cut is made.
C. The pins from the previously used cutting block are maintained, the hemiwaedge block is slid over the pins, and the hemiwaedge cut is performed.
D. The trial tibial component is assembled and placed on the tibia, and if appropriate fit and stability are obtained, the final components are assembled.
E. The final component is cemented into place after tibial preparation is complete, and excess cement is removed after the assembled tibial component is impacted into place. (Courtesy of DePuy Orthopaedics, Inc., Warsaw, IN.)
FULL-WIDTH WEDGE AUGMENT

- Intramedullary reaming is followed by placement of an intramedullary alignment guide, and a minimal transverse proximal tibial “skim” resection is taken after the tibial resection guide is pinned in place.
- An appropriately angled full-width wedge augment cutting guide is then selected and positioned over the previously placed cutting guide pins, and the oblique full-width wedge cut is performed (TECH FIG 3).
- Once the proximal tibial surface is adequately prepared, a trial stemmed component that reflects the intramedullary stem to be utilized with the attached augment is trialed.
- When adequate bony support is achieved, the joint surface restored, and flexion and extension gaps balanced then the component to be implanted is constructed to match the trial and appropriately cemented into place.

TECH FIG 3 • Full-width wedge augment. Reaming is carried out as illustrated for the hemi-wedge technique, and a skim cut is performed if necessary. Then the full-width wedge block is pinned into place according to the technique for the system being used. The system in this illustration allows the block to be rotated, and an oblique skim cut can be made. Trialing and component assembly and insertion are carried out as in Tech Fig 2. (Courtesy of DePuy Orthopaedics, Inc., Warsaw, IN.)

MEDIAL OR LATERAL BLOCK OR STEP AUGMENT

- The explanted proximal tibia is evaluated intraoperatively, and bone loss is compared to the preoperative radiographs. The appropriate preoperative plan is followed, with anticipated changes verified by intraoperative findings.
- Intramedullary reaming is followed by placement of an intramedullary alignment guide, and a minimal transverse proximal tibial “skim” resection is taken after the tibial resection guide is pinned in place (TECH FIG 4A).
- The appropriate block augment cutting guide is then selected and positioned over the previously placed cutting guide pins, and medial or lateral step cuts are performed.
- Once the proximal tibial surface is adequately prepared, a trial stemmed component that reflects the intramedullary stem to be used with attached augment is trialed (TECH FIG 4B).
- When adequate bony support is achieved, the joint surface is restored and flexion and extension gaps balanced. The component to be implanted then is constructed to match the trial and appropriately cemented into place (TECH FIG 4C).

TECH FIG 4 • Medial or lateral block augmentation. A. Reaming and skim cutting are carried out as previously illustrated. Then the step cut is performed with the cutting block attached to either the intramedullary guide or a trial. B. The trial is assembled, and fit is evaluated. Additional freehand cleanup may be carried out to improve bone-to-component apposition in all of the illustrated techniques. C. The assembled revision component with attached block augment is cemented into the now-prepared tibia. (Courtesy of DePuy Orthopaedics, Inc., Warsaw, IN.)
Chapter 22 REVISION TKA WITH TIBIAL BONE LOSS: METAL AUGMENTS

**METAPHYSEAL CONE AUGMENTATION**

- The explanted proximal tibia is evaluated intraoperatively and bone loss is compared to the preoperative radiographs. The appropriate preoperative plan is followed, with anticipated changes verified by intraoperative findings.

- Intramedullary reaming should be carried to the depth of the stem available in the revision system in use (see Tech Fig 2A). Careful attention to tibial alignment while reaming is important. It may be necessary to ream slightly out of line with the tibial shaft to allow adequate space for the metaphyseal cone.

- Intramedullary reaming is followed by placement of an intramedullary alignment guide to evaluate for stem-to-tray mismatch. Some metaphyseal cone augmentation systems do not allow for offset stems.

- Once the appropriate-sized diaphyseal engaging stem is selected, the proximal tibia is sequentially broached with the appropriate-sized trial stem attached to the broach to provide proper alignment (TECH FIG 5A).

- The option for rotational disparity between the tibial tray and the cone is available in some systems. This allows the surgeon to rotate the broach if necessary to improve filling of a proximal metaphyseal defect.

- Broaching is carried out until rotational stability is obtained.

- Some systems then use the proximal surface of the broach as the cutting guide. This necessitates placing the broach at the level determined by preoperative planning and intraoperative assessment. Ideally, this position resects 2 mm or less of the proximal tibial metaphysis (TECH FIG 5B).

- Once the proximal tibia is resected and broached, a trial cone is placed and rotation is marked on the anterior tibia, a properly sized trial tibial tray and stem are assembled and placed through the cone, lack of excessive rotational disparity between the two is verified, and tibial tray rotation is marked (TECH FIG 5C).

- Both the tray with stem and the cone are removed, and the trial cone is assembled to the stemmed trial tibial tray. The assembled trial is placed back onto the proximal tibia, and trialing is completed as previously described.

- The selected trial is removed from the tibia and left assembled as a model for assembly of the final components.

- Final assembly of the tibial components is done to match the trial, and the tibial cone is impacted onto the Morse taper of the revision tibial base plate, with care taken to match the trial model cone rotation on the trial stem.

---

**TECH FIG 5** - Metaphyseal cone augmentation. **A.** After intramedullary reaming, a trial stem of the appropriate length is attached to the metaphyseal broach. Sequential broaching is carried out until good metaphyseal fill is obtained and the top of the broach is at the level of the planned skim cut. The handle is removed, and the broach is left in place. **B.** A skim cut is taken off the top of the broach. Careful attention should have been taken during broaching to ensure that the proximal surface of the broach rests at the planned level of the “clean up” cut. **C.** The trial tibial component is assembled and placed on the tibia. Careful attention should be given to tibial tray versus metaphyseal cone rotation. They may not be aligned with each other, depending on how the cone broach was rotated during broaching to gain maximal metaphyseal fill. The trial component assembly should be referenced during final component assembly. **D.** The final component is cemented into place after tibial preparation is complete. Care should be taken to keep the metaphyseal cone bone ingrowth surfaces free of cement during component insertion and impaction.
Cement is applied to the assembled component selectively, as most cones allow for bony ingrowth with a porous surface coating (TECH FIG 5D). If a diaphyseal press-fit stem is selected, cement is applied only to the proximal tibia and tibial base plate. Selection of a cemented-type metaphyseal stem may require step-cementing of the stem and tibial base plate, with no cement applied to the ongrowth surfaced metaphysical cone. This allows direct bony contact between the cone and the bone, allowing for ingrowth if cement is applied sparingly to the stem to prevent extrusion with tibial component impaction. If care is not taken, cement could potentially cover the cone and prevent bony ingrowth.

FREE TRABECULAR METAL AUGMENTATION

The explanted proximal tibia is evaluated intraoperatively, and bone loss is compared to the preoperative radiographs. The appropriate preoperative plan is followed, with anticipated changes verified by intraoperative findings.

Intramedullary reaming to obtain good diaphyseal fill is followed by placement of an intramedullary alignment guide to evaluate for stem-to-tray mismatch.

If coronal mismatch is found, consideration should be given to an offset stem.

Intramedullary reaming is followed by placement of an intramedullary alignment guide, and a minimal transverse proximal tibial “skim” resection is taken after the tibial resection guide is pinned in place.

The cavitory defect of the proximal tibia is curetted clean, and all membrane is removed.

The trabecular metal augment that most closely fits the defect is selected, and a high-speed burr is used to remove minimal amounts of bone to allow for a tight press-fit of the augment (TECH FIG 6A,B).

The augment is impacted into place. In cases in which the augment does not fully contact the surrounding bone, crushed cancellous allograft croutons can be combined with demineralized bone matrix to fill the peripheral void (TECH FIG 6C-E).

If an offset stem is selected to allow for good tibial coverage, or if the augment is placed off-center of the diaphysis to allow for best void fill, then a high-speed metal cutting burr can be used to trim the augment centrally.

Once clearance is obtained for the augment, the trial tibial stem with baseplate is inserted into the tibial diaphysis through the trabecular metal augment to verify fit.

When adequate bony support is achieved, the joint surface restored, and flexion and extension gaps balanced, the component to be implanted is constructed to match the trial and appropriately cemented into place.

The proximal portion of the tibial stem is cemented to the trabecular metal augment, and the stem is either press-fit in the tibial diaphysis or cemented per the preoperative plan (TECH FIG 6F).

TECH FIG 6 • Free trabecular metal augmentation. A. Trabecular metal augment sizing. The tibia is reamed as previously described, and a skim cut is taken off of the proximal tibia. The proximal metaphyseal defect is then sized by placing various-sized trials over the reamer on the tibial bone in an inverted position. B. Metaphyseal bone preparation. A tibial trial is constructed to determine the quantity and direction of any offset if required. A high-speed burr is then used to remove small amounts of bone, to allow full seating of the selected trabecular metal augment trial. Sufficient bone should have been removed to allow non-forceful seating of the trial, but full “fill” of the metaphyseal defect is not required. C. The trabecular metal augment trial and the tibial component trial are placed in the tibia simultaneously to verify lack of impingement between the two. If impingement is present, the augment may be either repositioned or directly trimmed with a burr to allow clearance of the tibial stem. (continued)
TECH FIG 6 • (continued) D,E. Once the trials have been inserted and appropriate fit has been achieved, the final augment is gently impacted into place. Excessive force may fracture the proximal tibia. Any defect that remains between the metaphyseal bone and the augment is one grafted to fill the void. Impaction grafting techniques may be used. F. Once the tibial augment is inserted and grafted, re-trialing of the tibial component is carried out. Additional removal of a small amount of the augment may be required to prevent impingement. The final component is impacted into the tibia with an adequate amount of cement to fill the void.

PEARLS AND PITFALLS

Block or wedge augment overhang  • An augment that overhangs the underlying tibial metaphyseal bone may irritate the medial collateral ligament or soft tissue envelope, particularly about the anterior and medial aspects of the knee. Downsizing of the tibial component or an offset stem may be required.

Joint line elevation  • Use of medial and lateral augments simultaneously should be an indication to carefully evaluate possible elevation of the joint line. If the joint line is restored, it may be preferable to use medial and lateral augments with a shorter insert to decrease the varus/valgus moment arm on the polyethylene.

Tibial stem to tibial tray mismatch  • The tibial tray that provides appropriate coverage of the proximal tibial with augmentation may not be centered over the tibial diaphysis. In this case, a central stem will move the tibial tray into an overhanging position or require downsizing that does not allow for adequate coverage of the proximal tibial. Offset stems are required to reconcile this mismatch.

Internal rotation of the tibial component  • Careful attention must be given to the rotational position of the cutting guide as it is pinned to the tibia. The second, or augment, cutting guide will be placed over the same pins as the first, or skim cut, guide was placed. Unlike some primary total knee techniques, rotation cannot be adjusted after the bone cut for the augment is made. All efforts should be made to verify appropriate rotation by anatomic landmarks, including the tibial tubercle and the insertion of the PCL.

Extensor mechanism/tibial tubercle  • In the face of significant bone loss in the proximal tibia, the extensor mechanism and its bony attachment should be handled with great care. Exposure of the knee should be accomplished without placing excessive tension on the patellar tendon. When step or slope cuts are made to accommodate wedges and block, careful attention should be paid to ensure preservation of bone about the tibial tubercle. Prevention of extensor mechanism disruption is of paramount importance.
POSTOPERATIVE CARE

- Postoperative care is directed by the intraoperative findings and the stability of the newly implanted component.
- If a proximally cemented stemmed component is seated on cortical bone with all defects contained after use of an augment, then immediate full weight bearing may be allowed.
- Range-of-motion exercises also may begin immediately if the skin over the anterior knee is in good condition postoperatively and the incision has been closed with no tension.
- In situations where the skin is under tension or the wound appears tenuous immediately postoperatively, then range-of-motion exercises are delayed, with the leg held in extension for the first 48 hours.
- The incision and skin are then reevaluated, and if there is no evidence of erythema or wound drainage, gradual range-of-motion exercises are started. The incision is watched carefully for drainage after range-of-motion exercises are initiated.
- When the tibial component is not fully supported directly by native metaphyseal bone, then toe-touch weight bearing should be initiated until incorporation of any allograft that was used in conjunction with augmentation.
- When bony ongrowth cones or free trabecular metal augmentation is used with less than full bony support, consideration should be given to delaying full weight bearing until bony ingrowth occurs.
- In cases in which partial weight bearing is initiated postoperatively, progression to full weight bearing can take place at 6 weeks postoperatively.
- As with primary TKA, deep vein thrombosis prophylaxis is mandatory and should follow usual protocols.
- We use 6 weeks of coumadin prophylaxis in the patient with no history of thrombosis or pulmonary embolism.
- We also use fractionated low-molecular-weight heparin starting 18 to 24 hours after the completion of surgery to protect the patient in the interval after surgery where the international normalized ratio has not yet reached our target of 1.8 to 2.2.

OUTCOMES

- Modular tibial augmentation systems were developed in the mid- to late-1980s and became broadly available by the early to mid-1990s; consequently, no long-term studies are available on the survivorship of this type of tibial component augmentation. A handful of midterm studies are available.
- In an early report on the use of tibial tray augmentation, Brand et al1 reported no failures in 22 knees with an average follow-up time of 37 months. The average age of the patients at the time of surgery was 70 years. There were no failures requiring revision and no loosening of the tibial component at the time of surgery. There were 79% excellent and 21% good results. There were no complications or reparations. Radiolucent lines beneath the metal wedge were present in 13 knees, but none were progressive.
- Haas et al11 used tibial augments combined with press-fit diaphyseal engaging stems to manage bone loss in revision TKA for aseptic failure. The average duration of follow-up was 3 years and 6 months (range, 2 to 9 years). Only patients who had had revision of the femoral component or the tibial component, or both, because of aseptic failure were included. The average preoperative Hospital for Special Surgery knee score was 49. Postoperatively, the knee score improved to an average of 76 points (range, 0 to 97 points). Eighty-four percent of patients had an excellent or good result.
- Hockman et al12 reported midterm results with one modular revision prosthesis. Fifty-four consecutive Coordinate (Deputy, Warsaw, IN) revision total knee arthroplasties were eligible for minimum 5-year follow-up. Nine knees failed and required either revision or component removal. Eight additional knees were considered clinical failures. Metallic augmentation was used in 89% of the knees, and large structural allografts were required in 48% of the knees. Revisions with bone loss that required bulk allograft failed less often (19.2%) than revisions managed without bulk allografts (42.9%). Modular augments did not effectively address the bone loss and instability encountered in many instances at revision surgery. Survivorship of the implant was 79% at 8 years in their study.
- Pagnano et al16 reported on early and midterm results using tibial wedge augmentation. Their mid-term report was a follow-up of their short-term study of 28 knees in 25 patients. The patients were originally reviewed 2.3 years after surgery, at which time 79% had excellent results and 21% had good results. Their midterm report was of 24 knees in 21 patients with metal wedge augmentation for tibial bone deficiency. The patients were reviewed 5.6 years clinically and 4.8 years radiographically after surgery. Clinical results were excellent in 67% and good in 29%. Radiolucent lines at the cement bone interface beneath the metal wedge were present in 13 knees. Eleven of the radiolucencies were <1 mm in width, and 2 were 1 to 3 mm in width. The authors stated that metal wedge augmentation for tibial bone deficiency is a useful option. No deterioration of the wedge-prosthesis or wedge-cement-bone interface was noted at midterm follow-up.
- Radnay and Scuderi18 reported a novel approach to tibial augmentation. They describe the use of free trabecular metal augments (see Techniquest). Ten tantalum tibial cones were press-fit into the prepared cavities with a series of revision TKAs. The stemmed tibial component was cemented into the implanted tibial cone and stems were press-fit in four knees and cemented in six knees. Offset stems were used in three tibias. At follow-up (average 10 months), radiographic evaluation revealed no evidence of loosening or change in position. Strength, range of motion, and stability were comparable to previously reported series of revision arthroplasties. The authors state that trabecular metal cones may eliminate the need for extensive bone grafting or structural allografts in revision knee arthroplasties.

COMPLICATIONS

- Complications of revision TKA with metallic tibial augmentation can be divided into two categories: early and delayed.
Perioperative or early complications can include intraoperative damage to neurovascular structures, extensor mechanism and collateral ligamentous disruption, and early postoperative infection.

Delayed complications most commonly include osteolysis, aseptic loosening, and late septic prosthetic arthropathy.

REFERENCES

DEFINITION
- During revision of the femoral component in total knee arthroplasty (TKA), bone loss from the distal femur is nearly inevitable.
- Deficient bone in the distal femur can be replaced by bone cement (polymethylmethacrylate), metal augments fixed to the revision femoral component, particulate bone graft or substitutes, bulk allograft to augment one or both femoral condyles, and complete replacement of the distal femur with allograft or metal.

ANATOMY
- The anatomy relevant to bone loss during revision total knee surgery consists of the metaphyseal femur, the medial and lateral epicondyles, and the medial and lateral femoral condyles.
- The femoral condyles represent the structural columns that support the revision femoral component. Accordingly, one goal of distal femoral reconstruction in revision TKA is to restore the condylar anatomy such that it can support a new component.

PATHOGENESIS
- The pathogenesis of distal femoral bone loss in revision TKA is related to removal of the previous implant and bone cement. Previous implants fixed to bone with cement or by porous ingrowth require dissection for mobilization and extraction; this process incurs a finite amount of bone loss.
- Even fine osteotomes and saws used to develop a plane between the implant and bone are space-occupying and cause bone loss from the distal femur. Aggressive extraction of well-fixed femoral components without first developing a plane between exposed metal and bone can result in avulsion of one or both femoral condyles.
- Correction of internal rotation of the previous femoral component will result in bone loss both anteriorly and posteriorly as the new component is oriented in the proper rotation.
- Osteopenia from stress-shielding of the periprosthetic femur, as well as osteolysis related to wear debris particles, can result in cavitary lesions in the distal femur that lead to significant bone loss.

NATURAL HISTORY
- Distal femoral bone loss, if severe, can result in the loss of structural integrity of the femur. When this occurs, the existing femoral component can migrate into varus or valgus relative to the femoral shaft.
- Surgical treatment is directed at augmenting this bone loss following removal of the previous loose, unstable femoral component.
- If left untreated, continued particulate debris and motion between loose components and bone can lead to continued symptoms and further bone loss in the distal femur of a failed TKA.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The diagnosis of a failed TKA with loss of bone in the distal femur is best made by plain radiographs.
- The patient history is helpful in that findings in any of the following categories can alert the surgeon to the possibility that significant bone loss may be encountered during revision surgery: the time elapsed since the index arthroplasty; the type of implant and fixation used; any history of diseases such as osteoporosis; advanced age; corticosteroid use; use of cytotoxic drugs; irradiation; rheumatoid arthritis; and periprosthetic femoral fracture.
- Loose femoral components with associated bone loss will present with knee pain, swelling, and instability that is usually worsened by activity.
- Failed TKA femoral components with bone loss will have tenderness to palpation over the distal femur.
- An effusion may also be evident on physical examination.
- A grossly unstable component may result in ligamentous instability of the knee that is elicited on careful examination.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- High-quality radiographs of the knee can help in identifying and classifying a bone defect in the distal femur. The true lateral view of the knee joint can demonstrate the location and extent of osteolysis and bone loss in the distal femur. Oblique views of the knee often result in obscuring of bony detail by the metal implants. Therefore, a true lateral view of the knee should be obtained in 90 degrees of knee flexion, by placing the entire leg, including the knee and ankle joints, flat on the radiograph table.
- Other imaging modalities such as CT scans and metal-subtraction MRI scans may prove useful in defining the extent of bone loss in the distal femur, although the efficacy of these imaging studies in routine revision TKA is yet unproven.
- Intraoperative observation of bone loss after previous component removal and thorough débridement of osteolytic lesions and inflammatory membrane is the best determinant of the nature and extent of bone loss.
- The surgeon should be prepared for the worst-case scenario, because preoperative radiographs can underestimate the extent of bone loss adjacent to the existing femoral component.
- Accordingly, allograft bone, a wide range of revision implants, metal augments, and revision equipment should be available.
The diagnostic workup of femoral bone loss in revision TKA should include a thorough evaluation to exclude the possibility of knee sepsis.

- Preoperative nuclear medicine imaging, laboratory data, knee aspiration, and intraoperative frozen sections of periprosthetic tissues can assist in excluding sepsis.

**DIFFERENTIAL DIAGNOSIS**

- Deep knee sepsis can result in periprosthetic bone loss and is a relative contraindication to distal femoral reconstruction. Infection must be ruled out before reconstructing the distal femur in anticipation of implanting a revision femoral component.
- Stress-shielding of bone adjacent to the femoral component can result in bone loss from the distal femur. When the existing femoral component is extracted, severe loss of bone may be discovered in such cases.
- Osteopenia of the distal femur from osteoporosis, lytic lesions of bone such as benign bone cysts, neuropathic changes, and malignancy can also result in distal femoral bone loss, thereby complicating femoral reconstruction in TKA.

**NONOPERATIVE MANAGEMENT**

- Nonoperative management of severe distal femoral bone loss in a failed TKA should be reserved for debilitated patients in whom surgery is otherwise contraindicated.
- Severe medical comorbidities, integrity of the extensor mechanism, poor condition of the soft tissue, radiation necrosis of adjacent bone, immunosuppression, and metabolic bone disorders should be evaluated carefully to determine whether reconstruction of the distal femur is a reasonable option.
- Where major knee surgery is contraindicated, nonoperative measures such as analgesics, limited ambulation, assistive devices such as a walker or wheelchair, and knee bracing are alternative considerations.
- Chronic suppressive antibiotics may be an option in patients with bone loss from severe deep sepsis, in whom operative treatment is otherwise contraindicated.

**SURGICAL MANAGEMENT**

- Distal femoral bone loss can be managed surgically using bone cement, morselized bone graft, metal augments on the new prosthesis, bulk allograft reconstruction of noncontained defects of the medial or lateral condyles, and bulk allograft replacement of the distal femur with allograft or a special customized prosthesis.

**Preoperative Planning**

- Preoperative planning includes making sure the patient is medically optimized for major elective surgery, and excluding the possibility of deep sepsis in the knee. The surgeon should carefully assess existing scars, leg vascularity, nerve function, and the patient’s overall medical condition.
- Pre- and intraoperative assessment of collateral ligament integrity will help in choosing the appropriate implants.
- In grossly unstable knees, constrained implants or even rotating-hinge revision TKA implants may be indicated.
- If the surgeon prepares for the worst-case scenario, the correct equipment, implants, and personnel will be available to address any scenario. Practically, other than straightforward TKA revision cases with minimal femoral bone deficiency, the specialized resources needed to address severe distal femoral bone loss in TKA effectively limit such procedures to hospitals with the necessary equipment and expertise.
- A preoperative planning session with key personnel (ie, surgeon, assistants, implant representative) is invaluable in discussing the problem and considering all possible solutions. Efficient execution of the procedure requires planning and communication with the bone bank, implant representative, and operating room personnel.
- Structural allografts to rebuild deficient distal femoral condyles should include several allograft femoral heads.
- Fresh-frozen prepared specimens usually are favored because of their superior mechanical strength.
- Preoperative radiography and sizing of allograft tissue is desirable, but may not be practical or feasible.
- Instead, intraoperative preparation of the grafts with special equipment such as the Allogrip system (DePuy, Warsaw, IN) can shape the graft to proper dimensions so that wound closure is not a problem from an oversized graft.
- A full set of revision TKA instruments is essential, consisting of fine osteotomes to develop the plane between metal and bone, curettes, punches, reamers, Gigli saws, and instruments to clean out the intramedullary femoral canal.
- High-speed burrs attached to a pneumatic power driver can assist in loosening up well-fixed implants while preserving bone.
- A typical revision TKA instrument set from any major implant manufacturer has such instruments conveniently packaged in a single set.
- Porous tantalum metal augments are available for proximal tibia reconstruction in revision TKA, and soon may be available for distal femoral reconstruction as well. The advantage of this type of augments is that they heal rapidly to living host bone. These augments offer a custom reconstruction option that permits load-bearing and supports cement fixation.

**Positioning**

- The patient is placed supine, with a small pad under the ipsilateral buttock to ensure neutral position of the flexed knee. A Stulberg footrest or equivalent device is used to control knee flexion during surgery.
- The leg is scrubbed circumferentially and as far proximal as feasible to allow access to the thigh.
- In our practice, we do not use a tourniquet during any total knee procedure, but most surgeons exsanguinate the extremity with gravity or an Esmarch bandage before inflating a well-padded tourniquet applied to the proximal thigh.
- The surgeon must remain vigilant of the duration of tourniquet time, particularly if a long and complex reconstruction is anticipated.

**Approach**

- If several previous scars are present, the one chosen is the one closest to the midline that will allow extensile exposure proximally or distally. The most laterally based incision is the wisest as it preserves blood supply to the overlying skin. For most revision TKA surgery that involves distal femoral reconstruction, a standard medial parapatellar arthrotenomy will adequately expose the distal femur.
- Exposure can be facilitated by avoiding patella eversion in knee flexion. After the patella component is addressed in knee flexion, a medial parapatellar approach is used.
extension, the patella can be pushed into the lateral gutter and retracted safely.

- In our experience, exposure of the distal femur is improved if patella eversion is avoided.
- To understand the extent of bone loss, inflammatory membranous tissue overlying the femoral bone after removal of the previous component must be dissected away. The electrocautery knife works well for this purpose. Previous membrane and granulomas must be débrided thoroughly to appreciate the amount of distal femur available for reconstruction.
- Anteriorly, a proximal quadricepsplasty,\textsuperscript{3,9} tibial tubercle osteotomy,\textsuperscript{2} or other specialized dissection may be needed to mobilize the extensor mechanism safely, and expose the distal femoral cortex.
- The exposure chosen depends on the difficulty in exposing the distal femur and the extent of débridement and preparation for bone reconstruction required.

---

**MORSELIZED ALLOGRAFT OR BONE CEMENT**

- Small, contained defects in the femoral condyles can be filled with bone cement or morselized autograft or allograft.\textsuperscript{10} These grafts are not load-bearing and are suitable only for focal, cystic lesions that are surrounded by intact, structural bone (**TECH FIG 1**).
  - A burr or curette is effective in cleaning out in preparing such defects.
  - Optimize allograft–host bone contact by excising the inflammatory membrane, removing previous metal and cement particles, and creating a viable and healthy host bone bed.
  - Morselize an allograft femoral head using small acetabular reamers. Pack graft into the defects, and cement the revision implant in place.
  - Alternatively, bone cement or a synthetic bone graft substitute filler can be used to pack small, contained defects between the revision implant and host bone.

**TECH FIG 1** - Cavitary, contained defects that do not affect the structural integrity of the distal femur can be packed with cement, morselized autograft or allograft, or synthetic bone fillers.

---

**METAL AUGMENTS ON REVISION FEMORAL COMPONENT**

- After excision of previous cement and inflammatory granulomas, remove the minimum amount of bone from the distal and posterior femoral condyles to expose viable host bone (**TECH FIG 2A,C**).
  - Small defects in the distal and posterior femoral condyles can be reconstructed by using metal augments on the revision femoral component\textsuperscript{8} (**TECH FIG 2B,D**).
  - Determine the joint line by examining the position of the epicondyles, the existing femoral component, position of the patella relative to the femur, contralateral knee radiographs, and the contour of the posterior femoral condyles projected laterally.
  - A combination of these variables makes it possible to estimate the joint line accurately and recreate it.
  - Removal of additional bone from the distal femur will move the joint line more proximally.
  - Impact the trial femoral component on the distal femur, and measure the defects between metal and host bone distally, anteriorly, and posteriorly after determining proper external rotation of the component.
  - Reinsert the trial implant after installing trial augments of the appropriate thickness and check the fit.
  - Augments in revision TKA systems come in a variety of thicknesses to accommodate femoral bone loss from the anterior cortex, posterior condyles, and distal femoral condyles.
  - The goal of revision component augmentation is stable contact between metal and host bone without resorting to a custom implant.
  - If metal augments are used on the revision femoral component, an intramedullary rod extension should be attached to the revision femoral component to achieve initial implant stability.\textsuperscript{8}
TECH FIG 3 • A, B. Severe and complete loss of structural bone in the condyle of the distal femur can be addressed with bulk femoral head allograft to rebuild the deficient bone. C. Acetabular reamers are used to prepare the host condyle for a matching allograft. (continued)

BULK FEMORAL HEAD RECONSTRUCTION OF CONDYLAR DEFECTS

- If one or both femoral condyles are not amenable to reconstruction with metal augments, structural deficiencies can be addressed with allograft tissue (TECH FIG 3A, B).
- The condylar defect is reamed with small-diameter male acetabular reamers from the Allogrip system (DePuy, Warsaw, IN; TECH FIG 3C).
- Matched-diameter female reamers are used to prepare the convex surface of the allograft femoral head (TECH FIG 3D).
- The allograft femoral head is then placed in the reamed defect. Either a whole or a half femoral head allograft will fill the cavitary defect, where it is attached to host bone with cancellous screws (TECH FIG 3E).

- Then, the allograft-host bone composite is cut to match the size of the revision femoral component.
- Metal augments may be needed for residual bone defects remaining after femoral head allograft reconstruction of the femoral condyles, or to recreate the joint line.
- The technique of using metal augments on the revision femoral component is described above.
- Attention must be maintained throughout to ensure recreation of the joint line and of the appropriate external rotation of the femoral component needed for patella stability.

TECH FIG 2 • Bone loss that affects a limited part of the distal femoral condyle can be addressed with metal augments attached to the revision femoral component. Reconstruction of the femur shown in A will require a posterior metal augment (B); that shown in C will need both posterior and distal metal augments (D).
D. The Allogrip system is illustrated, with a femoral head allograft held tightly in the vise while female acetabular reamers expose cancellous bone and size the graft to match the condylar defect. E. The cavitory defect in the femur is filled with a bisected femoral head allograft, which is flush against host bone and stabilized with two compression screws.

TECH FIG 3 • (continued) D. The Allogrip system is illustrated, with a femoral head allograft held tightly in the vise while female acetabular reamers expose cancellous bone and size the graft to match the condylar defect. E. The cavitory defect in the femur is filled with a bisected femoral head allograft, which is flush against host bone and stabilized with two compression screws.

BULK ALLOGRAFT REPLACEMENT OF THE DISTAL FEMUR

- For extensive loss of the distal femur, reconstruction with bulk allograft replacement of deficient bone is a proven option.¹
- If extensive bone loss leaves only an intact cortical shell in the distal femur, an undersized distal femur bulk allograft matched to the operative side can be stabilized within the host cortical shell (TECH FIG 4A).
- The proximal end of the graft should rest against viable host bone, with mechanical stability and maximum host bone–allograft contact to promote healing.
- Conservative resection of the distal femur to match the end of the allograft will accomplish contact between host bone and allograft.
- Once stabilized, the allograft distal femur within the host cortex is sized and cut to match the revision femoral component.

TECH FIG 4 • A. Severe deficiency of both femoral condyles can be addressed by pressing an undersized distal femoral allograft into this void, while retaining the host cortical bone around it. After stabilization to surrounding host bone with screws, the allograft–host composite is shaped to receive the revision femoral component. B. To replace the distal femur, existing epicondyles are osteotomized, and the deficient distal femur is cut to expose viable, stable host bone. In this case, a bulk distal femoral allograft will be used to rebuild the femur. C. The allograft femur is in place, with host epicondyles and distal femur shown. (continued)
Chapter 23  REVISION TKA WITH FEMORAL BONE LOSS: DISTAL FEMORAL REPLACEMENT 967

TECHNIQUES

PEARLS AND PITFALLS

Preparations
- Preparation is the key, with a team conference to review radiographs and assess the availability of equipment, resources, and personnel required for the femoral reconstruction. Anticipate more bone loss than that seen on radiographs and prepare for the worst-case scenario.

Implants
- Have a wide selection of implants available, with metal augments, intramedullary rod extensions, offsets, and implants with increasing amounts of constraint.

Grafts
- Several allograft femoral heads and equipment for milling, grinding, and shaping these heads should be available. Fixation of grafts to host bone requires interfragmentary screws and small plates, which should be readily available. Two or more graft specimens must be available for distal femoral allograft replacement so that the closest size can be chosen.

- After implantation of the revision component (TECH FIG 4D), the epicondyles should be attached to the allograft with cancellous screws augmented with washers. To accomplish this step, the epicondyles on the bulk allograft must be cut off and removed.

- Before final implantation, check the soft tissue envelope to make sure inadvertent over-sizing has not occurred.

TECH FIG 4 • (continued) D. The revision implant is positioned in the bulk allograft that was cut to accept the implant. An intramedullary rod provides additional fixation in the distal host femur. The medial and lateral epicondyles have been screwed into their corresponding anatomic locations on the bulk allograft.

REPLACEMENT OF DISTAL FEMUR WITH A TUMOR RECONSTRUCTION PROSTHESIS

- For severe loss of the metaphyseal and diaphyseal femur (such as in tumor resection), modular implants designed for limb salvage may be the only option for reconstruction.5
  - This option is reserved for cases in which the extent of bone loss precludes reconstruction with bulk allograft.
  - Template radiographs and have appropriate reconstruction systems available, with varying modular lengths to rebuild the deficient femur.
  - Perform an osteotomy of the femur to expose viable bone that is suitable for weight bearing.
  - Prepare the femur retrograde for cementing, using techniques similar to those for cementing a femoral implant in total hip replacement surgery.
  - Use trial and error to reproduce the appropriate limb length, soft tissue tension, and implant rotation. This is most easily accomplished by reconstructing the tibial side first, so that all trial reductions can be assessed by changing the femoral side only, thereby simplifying the procedure.

- When correct rotation and length are determined, mark the host bone and implant to reproduce this rotation, and cement the implant into the distal femur to the appropriate depth, and in the desired rotation.
  - Uncemented fixation into the distal femur may be an option with some reconstruction systems.
  - Assemble the knee articulation (these designs usually rely on a rotating hinge articulation with multidirectional constraint built into the articulation).

  - In severe cases, or if the proximal femur is unsuitable for mechanical fixation with an intramedullary rod, the entire femur can be bypassed with metal.
  - In such cases of complete femoral replacement, a rotating hinge knee reconstruction is done at the distal end, and a constrained hip replacement at the proximal end.
Graft sizing can be judged by preoperative radiographs of the graft superimposed on the patient’s knee, or by intraoperative assessment. Oversized grafts will present problems with wound closure; check soft tissue tension before final fixation of the graft to host bone.

Experience and resources
Be realistic about surgeon experience, support, equipment, and resources available to perform complex distal femoral reconstruction. Specialized training and intense equipment and personnel demands effectively preclude smaller community institutions from doing such surgery.

Operative time
Either avoid using a tourniquet, or be wary of the tourniquet time in lengthy total knee reconstructions. If necessary, the tourniquet can be let down for selected parts of the procedure to minimize limb ischemia time.

POSTOPERATIVE CARE
The goal of distal femoral reconstruction is to achieve initial mechanical stability. Accordingly, the surgeon should aim for weight bearing as soon as possible after surgery.

If allograft reconstruction of the femur is necessary, healing to host bone occurs over a prolonged time. Therefore, protected weight bearing will be required for an extended period of time in such cases.

Assistive devices such as a cane, walker, or crutches should be prescribed in all revision TKA with distal femoral reconstruction to protect the patient against accidental falls or twists on the reconstructed knee, and to allow healing of graft tissue.

Range of motion should be assessed intraoperatively following distal femur reconstruction. Usually, the range of motion will depend on the quality of the soft tissues and integrity of the extensor mechanism, assuming mechanical stability of the reconstruction has been achieved. If knee range of movement must be limited for a period of time, a knee brace that allows movement only through a prescribed arc of motion may be necessary.

Straight leg raises, isometric exercises, and ankle and calf rehabilitation should be possible soon after all distal femoral reconstructions.

A multimodal deep venous thrombosis prevention regimen should be instituted after surgery, and the patient monitored as appropriate.

OUTCOMES
Radiographs at regular intervals and patient interviews will allow assessment of outcomes. Radiographs should be assessed for stability of the reconstruction, and for healing of bone at the allograft–host bone junction.

Bulk allografts heal to living host bone, and allograft bone away from this healed junction remains non-viable over the long term. In load-sharing configurations, where the allograft is supported by host bone or by metal implants, the long-term outcomes are excellent.

If allograft bone is used in load-bearing configurations, late failure of the non-viable bone from repetitive loading is predictable.

Allograft bone cannot remodel in response to stress; therefore, intramedullary stems that bypass the graft completely and transfer loads to living host bone are essential during the reconstruction.

In some complex reconstructions involving distal femur replacements with bulk allograft or limb salvage implants, the patient should be counseled to use protected weight bearing for a prolonged time, such as 6 months or longer.

COMPLICATIONS
A postoperative infection is a devastating complication following complex distal femoral reconstruction with allograft bone. Early diagnosis and aggressive wound débridement may salvage the situation in some instances, but removal of all allograft, cement, and implants in preparation for a staged reconstruction usually is necessary.

Late deep infections with a virulent organism in a knee with massive bone loss and allograft reconstruction of deficient host bone may necessitate a limb amputation.

Mechanical failure of distal femoral reconstructions usually occurs if the surgeon fails to achieve initial mechanical stability. Repeat surgery is necessary to rebuild the femur and achieve rotational and axial stability to permit protected weight bearing after the procedure.

Because anticoagulation for prophylaxis against deep venous thrombosis is necessary after distal femoral reconstruction in revision TKA, the surgeon should monitor the patient for a postoperative bleed.

If a tense hematoma develops, or new wound drainage is encountered, aggressive surgical debridement should be considered early, to avoid the risk of infection.

REFERENCES
DEFINITION
- Substantial bone loss and bone defects are among the most challenging problems faced by surgeons performing revision knee arthroplasty. Tibial bone loss in failed total knee arthroplasty (TKA) is a complex and difficult problem.
- Awareness and proper management of bone loss, through cement fill, metal augments, or bone grafting, are crucial for achieving stability and longevity of the newly implanted revision components.

ANATOMY
- Tibial bone loss during revision TKA is common. The most common areas of deficiency involve the posterolateral and medial tibial plateau.
- Smaller contained defects can often be addressed with morselized bone graft or cement alone. Larger, uncontained defects may require the use of metallic wedges or structural allografts.

PATHOGENESIS
- The etiology of bone loss after TKA is multifactorial. Bone stock deficiency may result from any of the following causes:
  - Stress shielding of the proximal tibia and distal femur can cause clinically significant osteopenia surrounding the knee following TKA.
  - Osteolysis is a biologic response to wear debris following TKA that can result in bony destruction.
  - Aseptic implant loosening can result in pathologic micromotion at the implant–bone interface, resulting in increased wear debris and formation of a biologically active membrane.
  - Removal of well-fixed implants, even using proper technique, can result in some degree of bone loss, particularly from the subchondral region.

NATURAL HISTORY
- Regardless of the mechanism of bone loss, once significant bony destruction is visible on plain radiographs, it is likely that continuing progression leading to failure of the knee arthroplasty will occur.
- In this spiral toward implant failure, patients may be asymptomatic initially, but pain, swelling, and instability, including hyperextension due to loss of tibial height, can be expected and are likely sequelae of the failing TKA with significant tibial bone loss.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patient history and physical findings can range from completely asymptomatic to debilitating pain and instability with normal gait walking.
  - A full history and physical examination are essential, and should include an assessment of type, quality, location, and duration of pain. Any new, severe pain or progressive pain in a previously well-functioning implant, particularly during weight bearing, is of particular concern. The presence of start up pain is also important to elicit in the history.
  - Additional questions should focus on the stability of the knee. A new onset of slowly progressive symptoms “giving out” or weakness of the knee can be an indication of problems.
  - Local tenderness along the interface between the tibial implant and the tibia can be seen in tibial component loosening. This should be distinguished from local tenderness over the pes anserine bursa.
  - Finally, as with all patients undergoing revision knee replacement, infection must be ruled out.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- A thorough clinical and radiographic evaluation is a prerequisite for revision TKA. The extent and location of bone loss, the quality of the remaining bone, the degree of cortical continuity, and the absence of infection must be determined.
- Standing anteroposterior, lateral, and patellar radiographs usually are sufficient for assessment of tibial bone loss, but CT scans can be more accurate in estimating the degree of bone loss and may be helpful when there is massive bone loss or abnormal anatomy.
- All patients should have the appropriate infection laboratory studies (ie, complete blood count, C-reactive protein, erythrocyte sedimentation rate) as well as an attempt at knee aspiration and synovial fluid sent for Gram stain, cell count, and culture. Serial knee aspirations with repeat laboratory studies often are performed on patients with a high index of suspicion for infection.

DIFFERENTIAL DIAGNOSIS
- Bone loss in TKA may result from the following factors, singly or in combination:
  - Stress shielding
  - Osteolysis
  - Instability
  - Implant failure (malalignment)
  - Infection (must be evaluated and ruled out before reconstruction begins).
- In addition, extremity pain in a patient with a TKA can have several possible nonsurgical diagnoses, including:
  - Referred pain from hip, thigh, or calf
  - Complex regional pain syndrome
  - Pes anserine bursitis
  - Patellar or hamstring tendinitis
  - Crystalline deposition disease (ie, gout or pseudogout)
  - Neurovascular problems: neuropathy, radiculopathy, spinal stenosis
- Tumor (needs to be considered)
- Vascular claudication
- Thrombophlebitis or deep vein thrombosis
- Fibromyalgia

**NONOPERATIVE MANAGEMENT**

- Nonoperative management of a painful TKA with tibial bone loss is not often indicated. However, if revision is not deemed a safe option for medical, psychosocial, or other reasons, management is similar to that for a patient with end-stage knee arthritis.
- Treatment options are symptom based and can include activity modification, walking aids, nonsteroidal pain medications, and bracing.

**SURGICAL MANAGEMENT**

- Various joint reconstruction techniques have been described for dealing with bone loss. The choice of reconstruction depends largely on the type of bone loss (ie, contained or uncontained) and the location and size of the defect (Table 1).

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Preoperative Radiographic Appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Intact metaphyseal bone</td>
<td>Metaphyseal bone intact above the tibial tubercle No component subsidence</td>
</tr>
<tr>
<td>II</td>
<td>Damaged metaphyseal bone</td>
<td>Component subsidence or position up to or below the tip of the fibular head</td>
</tr>
<tr>
<td>III</td>
<td>Deficient metaphyseal bone</td>
<td>Bone damage or component subsidence to the tibial tubercle</td>
</tr>
</tbody>
</table>

**Preoperative Planning**

- Bone loss around a knee implant should be assessed systematically, including both femoral condyles, both tibial plateaus, and the patellofemoral joint.
- Location of the joint line is marked. Reference points include the fibular head and the epicondyles of the femur. The joint line typically sits 20 to 25 mm distal to the lateral epicondyle.
- The magnitude of bone loss has significant implications for decisions regarding the use of bone graft or prosthesis augmentation, choice of prosthesis sizing, selection of articular constraint, and need for supplemental stem fixation.

**Positioning**

- Revision TKA usually is performed with the patient in the supine position.

**Approach**

- A standard medial parapatellar approach to the knee is used. The medial collateral ligament is circumferentially released from the proximal tibial metaphysis as a single sleeve.
- Additional exposure often is required if metal wire mesh is used for uncontained defects. The proximal portion of the tibia must be well exposed to ensure fixation of the wire mesh onto the bone. External rotation of the tibia and elevation of the medial sleeve often help with exposure of the cortical margins.
- The patellar tendon should be protected throughout the entire procedure, and the patella should not be everted, to minimize the risk of avulsion. In cases with severe joint ankylosis, the surgeon should be prepared to convert to more extensive revision approaches if necessary to obtain visualization (eg, quadriceps snip, tibial tubercle osteotomy, or V-Y quadricepsplasty).
Chapter 24  REVISION TKA WITH TIBIAL BONE LOSS: BONE GRAFTING

**IMPACTION GRAFTING**

- Full exposure of the knee joint is accomplished using a standard medial parapatellar arthrotomy, as described earlier.
- A formal synovectomy with sharp dissection is performed for removal of polyethylene wear particles and improved exposure.
- Following removal of the components, a high-speed burr is used to define bony lesions, clean multiloculated defects from cavitary defects, and decorticate sclerotic areas.

**Contained Defects**

- Contained defects require impaction of bone directly into the defect (TECH FIG 1).
- Cancellous allograft is introduced into the tibial canal.
- A trial stem is inserted into the tibial canal in proper alignment, bone graft is impacted around the stem, and the stem is removed when the bone graft has filled the defect.

**Uncontained Defects**

- Uncontained defects call for wire mesh to reproduce the cortical anatomy (TECH FIG 2).
- Wire mesh is molded to estimate normal contours of the proximal tibia and is held in place with small cortical screws.
- A central intramedullary guide rod with cement restrictor is inserted to allow a gap of 2 cm from the anticipated end of the final tibial stem component.
- A trial tibial stem is inserted into the tibial canal in neutral alignment. The final chosen stem should be smaller to allow for a 2-mm circumferential cement mantle.
- Thawed fresh-frozen morselized cancellous allograft is introduced into the tibial canal and impacted tightly around the stem using either cannulated or standard tamps and a mallet.
- The trial stem is removed, leaving a restored mantle of cancellous bone.
- The stemmed tibial prosthesis is cemented in standard fashion.

**TECH FIG 1**  Contained tibial defect in the same patient shown in Figure 1A,B.  A. Primary components have been removed, and the lesion has been found to have intact cortices.  B. Cancellous allograft is introduced into the tibial canal.  C,D. A trial stem is inserted into the tibial canal in proper alignment, bone graft is impacted around the stem, and when the bone graft has filled the defect, the stem is removed.  E,F. Postoperative AP and lateral radiographs after completion of the tibial impaction grafting and cementing of the final components.
TECH FIG 2 • Uncontained tibial defect in the same patient shown in Figure 1C. A. Intraoperative photograph showing a wire mesh cage contoured to reestablish approximate proximal tibial anatomy and held in place with small cortical screws. B. The trial tibial stem is inserted in proper alignment, and bone graft is impacted surrounding the stem. (The trial used is larger than the actual stem to allow for several millimeters of cement mantle.) C. The trial tibial stem is removed. D,E. Cement is introduced in the impaction grafting site, the real component is inserted, and excess cement is removed. F. Intraoperative photograph showing the final components. G,H. Postoperative AP and lateral radiographs show reconstruction of the tibial plateau with wire mesh and impaction grafting.

STRATEGIC FEMORAL HEAD ALLOGRAFT

- Preoperatively, estimate the size of the defect and order appropriate-sized femoral head allografts.
- Thaw the allograft material in warm saline for 15 to 20 minutes and mount in a grip device.
- Preparation of the allograft requires the use of a male and female acetabular reamer system (DePuy, Warsaw, IN).
  - Female-type acetabular reamers are used to remove retained cartilage and bone (TECH FIG 3A).
  - Flush the structural allograft with saline to remove marrow elements.
  - The tibial defect is denuded of all nonviable tissue.
  - If sclerotic bone is encountered, the reamer may wander. In these cases, a high-speed burr may be used to remove sclerotic bone.
- A male-type reamer no larger than prepared allograft is used to prepare host bone (TECH FIG 3B). The host bone is reamed to expose healthy, bleeding cancellous bone, including removal of all fibrous tissue and cement.
- The allograft is placed into the defect and provisionally secured with K-wires or Steinmann pins. These should be placed so that they do not interfere with the stemmed prosthesis insertion (TECH FIG 3C,D).
- Revision cutting guides are used to trim allograft for component implantation. Tibial component preparation should follow standard revision principles.
- The K-wires are replaced with partially threaded 4.0- or 4.5-mm cancellous screws, and the tibial component is press-fit or cemented in the standard fashion (TECH FIG 3E-G).
### TECH FIG 3  •  Femoral head allografting.

A. The femoral head allograft is secured into a grip device and a female-type cheese grate reamer is used to denude the allograft of cartilage and subchondral bone. B. A male-type reamer of appropriate size is used to create a socket for the allograft. C,D. The allograft is impacted into place and secured with K-wires. E. The allograft is cut to the appropriate height and fixed with cancellous bone screws. F,G. Final AP and lateral radiographs of the medial tibial plateau reconstruction with femoral head allograft secured with screw fixation. (From Hanssen A. Managing severe bone loss in revision knee arthroplasty. In: Lotke PA, Lonner JH, eds. Knee Arthroplasty, 2nd ed. Philadelphia: Lippincott Williams & Wilkins, 2003:321–344.)

### PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Preoperative planning</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Attempt to define cause of tibial bone loss</td>
<td></td>
</tr>
<tr>
<td>Rule out infection</td>
<td></td>
</tr>
<tr>
<td>Serial radiographs and CT scans can help evaluate and quantify the degree of bone loss.</td>
<td></td>
</tr>
<tr>
<td>Contained bony defects can be managed with morselized bone graft and cement. Large uncontained defects (&gt;2 cm) require the use of structural allografts.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Débridement</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>All defects must be thoroughly débrided. Use of a high-speed burr often is helpful in removing old cement, bony sclerosis, and fibrous membranes.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mechanical contouring</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>The goal should be to restore the normal contour and anatomy of the proximal tibia to provide a stable platform for the revision tibial component.</td>
<td></td>
</tr>
<tr>
<td>Structural allografts and mesh wires should be sized and contoured to match the patient’s anatomy and secured with screws.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impaction grafting</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Use a larger trial stem during canal preparation to allow for a circumferential 2 mm of cement mantle.</td>
<td></td>
</tr>
<tr>
<td>The morselized bone graft should be impacted as tightly as possible.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structural allograft</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Attempt to match the size of the uncontained defect with the allograft bone.</td>
<td></td>
</tr>
<tr>
<td>Avoid oversizing the allograft to prevent overhang and soft tissue irritation.</td>
<td></td>
</tr>
<tr>
<td>Provisionally fix the allograft in place using K-wires during tibial preparation. Replace wires with cancellous screws following insertion of the definitive implant.</td>
<td></td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- Unless a tibial tubercle osteotomy is performed, standard postoperative care, including use of continuous passive motion machine, weight bearing as tolerated, and status with physical therapy is indicated.
- However, the priority should be wound healing and incorporation of the graft. Therefore, the aggressiveness of the postoperative course depends on the type of reconstruction and the security of component or graft fixation.

OUTCOMES

- Lotke et al.\(^2\) recently reported prospectively on 48 consecutive patients treated with impaction allograft for substantial bone loss in revision TKA. They found no mechanical failures, and all radiographs showed incorporation and remodeling of the bone graft. They also found an improvement in Knee Society score from 52.3 to 80.3. Six complications (14%) were reported, including two infections and two periprosthetic fractures.

COMPLICATIONS

- Bone graft resorption
- Graft collapse
- Infection
- Patellar clunk
- Instability
- Joint line elevation
- Stiffness
- Periprosthetic fracture

REFERENCES

DEFINITION

- Estimates indicate that by the year 2030 the volume of primary total knee arthroplasty cases will have increased to 3,480,000, and the number of revision procedures is expected to rise accordingly, to 268,200.¹
- Indications for removing well-fixed total knee components include infection, malalignment, malpositioning, instability, periprosthetic fracture, stiffness, or aseptic loosening of the other part(s).
- Achieving the goal of safe removal of well-fixed components during revision total knee arthroplasty (TKA) depends on meticulous surgical technique and availability of the appropriate instruments. In many ways, these are the most important portions of the revision TKA procedure, because careless technique may lead to damage of the remaining bone stock, iatrogenic fracture, and disruption of soft tissues, ultimately compromising the quality of the revision construct and the outcome for the patient.

ANATOMY

- Removal of well-fixed TKA components necessitates adequate exposure.
- Proper management of the extensor mechanism is essential. A medial parapatellar arthrotomy may not provide the exposure required for component removal and subsequent reconstruction. Extensile exposure techniques using a tibial tubercle osteotomy, quadriceps snip, or V-Y quadricepsplasty, are described in Chapters AR-26 and AR-27.

PATHOGENESIS

- Indications for removal of well-fixed TKA components include infection, malalignment, malpositioning, instability, periprosthetic fracture, stiffness, or aseptic loosening of the other component(s).

PATIENT HISTORY AND PHYSICAL FINDINGS

- The history and physical examination should be directed to determine whether the patient’s pain is extrinsic or intrinsic to the TKA.
- Extrinsic sources of pain (eg, lumbar radiculopathy, referred hip pain) should be considered in the differential diagnosis.
- Pain that is determined to be intrinsic to the TKA should be correlated with the history, physical examination, and radiographic findings to confirm that the cause of the pain can be corrected with revision TKA.
- Failure to identify a cause for the patient’s pain before performing the revision TKA portends a poor prognosis.
- Physical examination includes the following:
  - Visual inspection of the previous incision and the surrounding skin. The most appropriate, lateral-most incision is selected to avoid wound necrosis and maximize healing potential.
  - Passive and active range of motion (ROM) are assessed. ROM postoperatively predominantly depends on their preoperative ROM. Normal ROM after TKA ranges from full extension to 120 to 135 degrees. It is important to inform patients that revision TKA may not improve their ROM. Stiff knees may require extensile exposure techniques or capsular releases. Extensor lag may indicate a deficient extensor mechanism.
  - The medial and lateral collateral ligaments are tested in full extension and at 30 degrees of flexion. Coronal plane instability may make it necessary to remove well-fixed components and implant components with more constraint.
  - The anterior and posterior stability of the knee is assessed. Sagittal plane instability may make it necessary to remove components to improve flexion-extension gap balancing or to compensate for a deficient posterior cruciate ligament in patients with a cruciate-retaining design.
  - The coronal plane alignment is assessed with the patient standing. The femorotibial angle is measured; it usually is 5 to 7 degrees of valgus. It may be necessary to remove well-fixed components to correct malalignment.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Standing anteroposterior (AP), lateral, and patellofemoral radiographic views are essential.
- Full-length standing AP radiographs are useful to determine the overall mechanical alignment of the lower limb.
- The radiographs must show the diaphysis well above the femoral prosthesis and well below the tibial prosthesis.
- The radiographs are assessed for alignment, component positioning and size, joint line position, loosening, and bone stock and osteolysis.
- CT scans may be useful to assess for osteolytic lesions or to assess for femoral and tibial component rotation.
- Inflammatory markers, erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP), are obtained to screen for the presence of infection.
- Aspiration of the knee is indicated if either the ESR or CRP is elevated or if there is clinical suspicion of infection.

DIFFERENTIAL DIAGNOSIS

- Lumbar radiculopathy
- Hip pathology
- Neuropathy
- Complex regional pain syndrome
- Vascular claudication
- Primary bone tumors
- Metastatic disease
- Trauma

NONOPERATIVE MANAGEMENT

- Nonoperative management of the failed TKA may consist of activity modification, physical therapy, bracing, and consultation with pain management specialists.
SURGICAL MANAGEMENT
- Surgical management begins with preoperative planning.
- The patient’s history, physical examination, radiographs, and laboratory studies are reviewed well in advance of the surgery, to allow for adequate preparation time.
- The cause for failure of the TKA is determined.
- The surgical plan is delineated, with a primary plan formulated and contingency plans developed.
- The appropriate instrumentation, implants, and bone graft (if necessary) are ordered.
- The knee is exposed, with extensile approaches if necessary.
- The components are removed carefully, with meticulous attention paid to preservation of bone stock and the soft tissues.
- The knee is subsequently reconstructed.
- Layered closure is performed carefully.

Preoperative Planning
- The key to any successful revision TKA is preoperative planning. The reason for failure of the original TKA is determined from study of the preoperative history, physical examination, imaging studies, and laboratory results.
- It is decided whether removal of all femoral, tibial, and patella components is necessary or if an individual component can be left in situ.
- The previous operative reports are reviewed, with particular attention paid to the surgical approach, releases performed, and implants that were used.
- The operative report or implant stickers should be reviewed carefully. One should determine whether the tibial polyethylene component is modular and what sterilization method was used for it. If some of the index TKA components are to remain in situ, the surgeon must determine whether compatible parts are available.
- Radiographs are reviewed for bone stock quality and quantity.
- Particular attention is paid to the fixation method of the components. Stems that were cemented may require the use of ultrasonic tools for removal of the remaining cement.

Positioning
- The patient is positioned supine on the operating room table.
- A bump is placed so that the foot can be supported with the knee in flexion (FIG 1).
- The knee is draped to allow for an extensile surgical exposure.

Approach
- The preferred surgical approach is a standard medial parapatellar approach, although an extensile approach may be necessary (see Chaps. AR-27 and AR-28).
- Adequate exposure of the components to ease implant removal and subsequent reconstruction is crucial.
- A variety of instruments can be used to remove the well-fixed TKA implant: osteotomes, Gigli saws, punches, saws, burrs, metal-cutting discs or burrs, and ultrasonic tools.
- Implant removal proceeds in the following order (if all components are being removed): tibial polyethylene, tibial tray, femoral component, patella component.
- We prefer to remove the tibial tray before we remove the femoral component to protect the femoral bone from the retractors. However, if it is difficult to remove the tibial tray with the femoral component still in place, it may be necessary to remove the femoral component first. If this is the case, the femoral bone can be protected with sponges.

EXPOSURE
- The extensor mechanism must be subluxated laterally, with careful attention to avoid detaching the insertion of the patella tendon.
- A thorough synovectomy is performed, and the medial and lateral gutters are recreated.
- The collateral ligaments must be identified and protected.
- The interface of the femoral, tibial, and patellar components with bone must be visualized.

TIBIAL COMPONENT POLYETHYLENE REMOVAL
- The tibial polyethylene is removed first to increase the space within which the surgeon can work to remove the components.
- If a modular implant was used, it is removed by inserting an osteotome at the interface of the polyethylene and the tray and levering the polyethylene out. This can even be accomplished with a nonmodular design (TECH FIG 1).
- Certain posterior-stabilized designs have a reinforcing metal pin in the post that may need to be removed before the insert can be levered out. A saw can be used to divide the post, and the pin can be removed with a rongeur.
- Some inserts also are secured to the tray with a clip or screws. Therefore, it may be necessary to order special instruments from the implant manufacturer to facilitate removal.
Chapter 25  REVISION TKA WITH REMOVAL OF WELL-FIXED COMPONENTS

**TIBIAL COMPONENT REMOVAL**

- The prosthesis–cement interface is targeted in cemented components.
- The prosthesis–bone interface is targeted in uncemented components.
- The target interface is disrupted with a thin sawblade, with careful protection of the soft tissues (TECH FIG 2A).
- The area under the tray that is not accessible to the saw is disrupted with osteotomes (TECH FIG 2B). The tibia can be externally rotated to provide access to the posterior aspect of the component. Care must be taken to protect the neurovascular structures posteriorly.
- A clear path for egress of the tibial component must be achieved. The posterolateral aspect of the tibial component must clear the posterolateral femoral condyle. To achieve this, hyperflexion and anterior dislocation of the knee is necessary. Care must be taken to avoid avulsion of the patella tendon.
- It may be necessary to remove the femoral component first if it blocks a clear trajectory for tibial component removal.
- The tray can be gently disimpacted with a punch (TECH FIG 2C). If the component does not separate readily from the cement mantle–bone portion, then further work with the osteotomes is necessary. Excessive force will lead to unnecessary bone loss or fracture.
- The implant can be separated from the cement or bone by stacking broad osteotomes. One should avoid trying to lever the implant out with the osteotomes, because this may lead to fracture. Once the implant is separated from the cement or bone, it can be removed by hand or with a punch.
- The remaining cement is then removed with curettes, osteotomes, saws, and burrs. Reverse curettes, commonly used in hip revision surgery, can be useful in removing cement from the canal.

**FEMORAL COMPONENT REMOVAL**

- The prosthesis–cement interface is targeted in cemented components.
- The prosthesis–bone interface is targeted in uncemented components.
- The target interface is disrupted with a thin osteotome or saw with careful protection of the soft tissues (TECH FIG 3A).
TECH FIG 3 • A. The femoral component–cement interface is disrupted with an osteotome. The osteotome should be inserted parallel to the component. Smaller-width osteotomes can be used at the interface of the chamfer cuts and around distal pegs. Curved or angled osteotomes are helpful to work the interface of the posterior condyles. B. It should be possible to remove the femoral component easily by hand or with light taps from a punch. If the component is not extracted with gentle force, then further work with the osteotomes is needed.

- In general, use of Gigli saws results in the removal of more bone than is seen with the meticulous use of osteotomes.
- The interfaces should be worked from the medial and lateral sides rather than attempting to traverse the entire prosthesis with the instruments. This allows a more controlled division of the interface and minimizes iatrogenic bone loss.
- Care is taken to direct the instruments parallel to the component to avoid removing additional bone unnecessarily.
- Narrow osteotomes are used for the chamfer cuts and for prostheses where there are pegs at the distal aspect of the component.
- The posterior condylar interface can be disrupted with a curved or angled osteotome.
- It should then be possible to remove the implant easily by hand or with light taps from a punch set on the anterior flange (TECH FIG 3B). Alternatively, an extraction device that grasps the distal aspect of the femoral component can be used. The key point is gentle removal of the implant. Excessive force may result in unnecessary bone loss or fracture.
- The remaining cement is then removed with curettes, osteotomes, saws, and burrs.

PATELLA COMPONENT REMOVAL

- The removal of a well-fixed polyethylene component should be done only after thoughtful consideration. The remaining patella bone stock often is thin and osteopenic with one or several stress-risers from previous fixation pegs.
- The prosthesis–cement interface is targeted in cemented components.
- The prosthesis–bone interface is targeted in uncemented components.
- The target interface is disrupted with a thin sawblade (TECH FIG 4A).
- All polyethylene components can be removed with a sawblade, and the pegs subsequently burred (TECH FIG 4B). Cementless components may require the use of a metal cutting disc to sever the pegs from the plate. A pencil-tip burr can then be used to remove the pegs.
- Any remaining cement is removed with curettes, saws, and burrs.

TECH FIG 4 • A. The patella button is removed with a thin sawblade. The pegs remain embedded in the cement. B. A pencil-tip burr is used to lever the polyethylene pegs out of the cement mantle. The burr is advanced into the polyethylene and stopped; the polyethylene is then easily levered out of the cement mantle. A larger burr is then used to remove the remaining cement mantle.
STEMMED IMPLANT REMOVAL

- Stemmed implants usually can be removed once the fixation between the condylar portion of the femoral component and the tray portion of the tibial component has been separated from the bone.
- Preoperative planning should take into consideration the use of stemmed implants, which may complicate extraction of the component.
- Some designs allow for disassembly of the stem from the remainder of the implant.
- Metal cutting burrs and discs may be necessary to separate the condylar portion of the femoral implant or the keel portion of the tibial implant from the stem. The stem can then be removed with trephine reamers, burrs, or ultrasonic tools. Some companies may make special extraction devices available to assist in removal of the stem.
- Rarely, it may be necessary to perform an osteotomy to extract particularly difficult stems.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Preoperative planning</th>
<th>Thorough preoperative planning makes it possible for the surgeon to have the appropriate instrumentation, implants, bone graft, staff, and assistants available.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preoperative workup</td>
<td>Infection must be excluded.</td>
</tr>
<tr>
<td></td>
<td>The patient’s medical status must be optimized.</td>
</tr>
<tr>
<td></td>
<td>The patient must be compliant.</td>
</tr>
<tr>
<td></td>
<td>Information regarding previous surgical procedures and implants must be obtained.</td>
</tr>
<tr>
<td>Intraoperative technique</td>
<td>Excellent exposure must be achieved to avoid iatrogenic bone and soft tissue damage.</td>
</tr>
<tr>
<td></td>
<td>The extensor mechanism should be treated with care to avoid avulsion of the patella tendon insertion.</td>
</tr>
<tr>
<td></td>
<td>The tibial polyethylene is removed first.</td>
</tr>
<tr>
<td></td>
<td>The tibial tray or femoral component is removed next.</td>
</tr>
<tr>
<td></td>
<td>The patella component is removed, if necessary, last.</td>
</tr>
<tr>
<td></td>
<td>Stemmed implants may require special instrumentation, metal-cutting burrs or discs, or ultrasonic tools to remove.</td>
</tr>
</tbody>
</table>

COMPLICATIONS

- Bone loss
- Fracture
- Ligament disruption
- Tendon disruption

REFERENCE

DEFINITION
- Obtaining adequate anterior exposure of the knee can be difficult using standard approaches during revision total knee arthroplasty (TKA).
- The options available for dealing with difficult exposure include extensor mechanism snip (done 5 to 8 cm proximal to the superior pole of the patella), V-Y quadriceps turndown, and tibial tubercle osteotomy.
- Tibial tubercle osteotomy is performed to obtain an extensile exposure of the knee during difficult revision TKA.
- An osteoperiosteal segment—which includes the tibial tubercle and upper tibial crest—is elevated to relax the extensor mechanism and allow safe eversion of the patella.
- The technique was first described by Dolin in 1983, but subsequently was modified and popularized for exposure in revision TKA by Whiteside.

ANATOMY
- The extensor mechanism consists of the quadriceps muscles (ie, rectus femoris, vastus lateralis, vastus medialis, and vastus lateralis), quadriceps tendon, patella, and patellar tendon.
- The quadriceps muscle inserts into the patella via the quadriceps tendon and then into the tibial tuberosity via the patellar tendon.
- Tendinous fibers of the vastus medialis and vastus lateralis form the medial and lateral patellar retinaculae, respectively, which together reinforce the capsule of the knee joint anteriorly (FIG 1A).

PATHOGENESIS
- Adequate anterior exposure of the distal femur and tibial plateau during revision TKA is crucial for gentle soft tissue handling, safe implant removal, recognition of bone defects, and correct placement of revision components.
- During revision TKA, adhesions and fibrosis within the extensor mechanism restrict eversion of the patella and limit exposure.
- A medial parapatellar arthrotomy, combined with intra-articular excision of the fibrous pseudocapsule, allows eversion of the patella in most cases.
- Inadequate exposure with continued forceful retraction of the extensor mechanism risks avulsion of the patellar ligament from the tibial tubercle.

NATURAL HISTORY
- Avulsion of the patellar ligament is a serious complication during revision TKA, because it results in prolonged immobilization, extensor lag, and a poor functional outcome.
- To avoid this complication, an extensile exposure is required to relax the extensor mechanism and allow safe eversion of the patella.

FIG 1 • A. The extensor mechanism of the knee. Note that the medial and lateral patellar retinaculae originate proximally from the tendinous fibers of the vastus medialis and lateralis muscles, respectively. B. The tibial tuberosity. The distal “rough” area is subcutaneous and palpable. The patellar ligament is attached to the proximal “smooth” area.
Three options for obtaining such an extensile exposure during revision TKA are quadriceps snip, V-Y quadriceps turn-down, and tibial tubercle osteotomy.

Tibial tubercle osteotomy is preferred because it has a lower incidence of extensor lag and quadriceps weakness compared to a V-Y quadriceps turn-down.1,5

PATIENT HISTORY AND PHYSICAL FINDINGS

A history of joint stiffness and complications after primary TKA (eg, arthrofibrosis, infection, hematoma) should alert the surgeon regarding potential difficulties with exposure during revision TKA.

Physical findings indicating possible difficulty with exposure during revision TKA include multiple scars, reduced active and passive knee range of movement, a tight posterior cruciate ligament, and patella baja.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Standing anteroposterior and lateral radiographs of the knee usually are adequate in planning for extensile exposures during revision TKA.

The radiographs are specifically inspected for tibial osteopenia and osteolysis, both of which are relative contraindications for tibial tubercle osteotomy.

SURGICAL MANAGEMENT

A tibial tubercle osteotomy is indicated when there is any concern regarding patellar tendon avulsion despite adequate initial soft tissue release, as discussed later in this chapter.

Preoperative Planning

Exposure is considered preoperatively: the history and physical findings should alert the surgeon regarding the potential need for extensile exposures during revision TKA.

Previous operative records and radiographs are studied to identify the initial approach during primary TKA, design of the implanted components to be removed, and potential problems during implant removal.

The quality of skin overlying the tibial tubercle should be assessed. In patients with multiple scars, the most recent, appropriate, healed scar is used, but in many situations where tibial tubercle osteotomy is indicated, it may be necessary to consult with a plastic surgical team to plan soft tissue coverage (FIG 2).

Positioning

- The patient is positioned supine on the operating table.
- A tourniquet is sited around the upper thigh, and the leg is exsanguinated before inflation.
- A clamp is positioned laterally to stabilize the lower leg when the knee is flexed.
- A sandbag is positioned distal to the foot to prevent the lower leg from sliding during surgery.

Approach

A medial parapatellar approach is used whenever possible, because extensile exposures are most easily incorporated proximally (V-Y quadriceps turn-down) and distally (tibial tubercle osteotomy).

If the patella cannot be everted following medial parapatellar arthrotomy, the following soft tissue releases are performed sequentially before considering a tibial tubercle osteotomy.

- **Medial release:** The dissection is carried medially around the proximal tibia with subperiosteal elevation of the medial retinaculum and deep medial collateral ligament around to the semimembranosus insertion (TECH FIG 1A, B). This allows external rotation of the tibia and relaxes the extensor mechanism (TECH FIG 1C, D).
- **Lateral gutter release and pseudocapsule excision.**
  - **Superior to the patella,** the suprapatellar pouch is freed by dividing the underlying adhesions tethering the extensor mechanism to the anterior femur (TECH FIG 1E).
  - **Lateral to the patella,** adhesions in the lateral gutter tethering the extensor mechanism are divided (TECH FIG 1F).
  - ** Inferior to the patella,** the interval between the patellar tendon anteriorly and fat pad posteriorly is identified and the intervening pseudocapsule excised distally to the insertion of the patellar tendon (TECH FIG 1G, H).
- If the patella still cannot be everted, a tibial tubercle osteotomy is performed to reduce the risk of patellar tendon avulsion from forceful retraction of the extensor mechanism.

![Skin incisions. A. Previous skin incisions marked. B. Midline incision through most recent, healed scar.](image-url)
TECH FIG 1 • Initial soft tissue release to relax extensor mechanism and allow eversion of the patella. A. Subperiosteal elevation of medial retinaculum. B. Subperiosteal medial release to semimembranosus insertion. C,D. The pseudocapsule is completely excised medially to free the medial gutter. E,F. First the suprapatellar pouch, with the lateral gutter, is freed from underlying adhesions. G,H. Next, the pseudocapsule inferior to the patella is excised.
TIBIAL TUBERCLE OSTEOTOMY

- The skin incision is extended 8 to 10 cm below the tibial tubercle.
- The periosteum is vertically incised 1 cm medial to the tibial tubercle.
- An osteotomy site measuring 6 cm long, 2 cm wide, and 1 cm thick, which includes the tibial tubercle and anterior tibial crest, is marked with electrocautery (TECH FIG 2A,B).
- The 6-cm medial, vertical limb of the osteotomy is tapered distally to prevent a stress riser.
- The 2-cm horizontal limb proximal to the insertion of the patellar tendon resists proximal migration of the osteotomized segment.
- The proposed medial, lateral, and proximal osteotomy cuts are perforated using a drill (TECH FIG 2C).
- Sequential osteotomes are used to transect the medial tibial crest and separate the osteotomized segment from the tibia.
- The lateral cortex is transected through the osteotomy, but the lateral periosteum and soft tissues are left attached to the elevated segment to act as a “hinge,” allowing eversion of the extensor mechanism.

TECH FIG 2 • Tibial tubercle osteotomy. A. The distal cut is tapered to prevent a stress riser. Proximally, the step-cut reduces the risk of proximal migration. B. The medial, vertical limb should be at least 6 cm long. C. The medial cortex is perforated with a drill, and the drill is passed through the lateral cortex to create corresponding perforations in the lateral cortex that will allow the osteoperiosteal segment to be “hinged” around the lateral soft tissue attachments. The proximal osteotomy cut is perforated, and sequential osteotomes are used to elevate the osteotomy.

REATTACHMENT OF OSTEOTOMY WITH WIRES

- In our preferred technique, three 18-gauge stainless steel wires are inserted and left untied before the final components are implanted.
- The most proximal wire is passed through the osteotomized segment and through a drilled hole in the medial tibial cortex.
- The two distal wires are passed around the osteotomized segment and through drilled holes in the medial and lateral tibial cortices (TECH FIG 3).
- The wires are twisted until tight, cut, and angled 45 degrees posteromedially to prevent soft tissue irritation.

TECH FIG 3 • Reattachment of osteotomy with wires. The most proximal wire is passed through the osteotomized segment to prevent proximal migration; the two distal wires are passed around the osteotomy segment. Wires are cut and angled posteromedially to prevent soft tissue irritation.
**PEARLS AND PITFALLS**

**Indications**
- Anticipate need for extensile exposure preoperatively.
- Anticipate need for soft tissue coverage with plastic surgery.

**Initial exposure**
- Medial parapatellar approach.
- Medial release, meticulous lateral gutter release, and excision of pseudocapsule before tibial tubercle osteotomy.

**Tibial tubercle osteotomy**
- Use a long (6–8 cm) osteoperiosteal segment.
- Use a proximal step-cut to prevent proximal migration.
- Taper distally to avoid stress risers.
- Use sequential osteotomes, not an oscillating saw.

**Reattachment of osteotomy**
- Anatomic fixation of the osteotomized segment is critical to ensure union of the osteotomy.
- At least one wire is passed through the osteotomy fragment to prevent proximal migration.

**POSTOPERATIVE CARE**
- If fixation of the tibial tubercle osteotomy is adequate, weight bearing is permitted as tolerated with unrestricted range of movement in a hinged knee brace.
- If fixation is not adequate, the patient can bear weight as tolerated with the knee locked in full extension in a brace until there is radiologic evidence of union.

**OUTCOMES**
- Whiteside\(^8\) reported good results using a tibial tubercle osteotomy to gain extensile exposure during 136 TKAs, of which 110 were revision procedures. At 2-year follow-up, the mean postoperative range of movement was 94 degrees, with a 1.5% incidence of extensor lag. Three tibial shaft fractures and two avulsions of the tibial tubercle were reported in this series, but no non-unions.
- Mendes\(^6\) reported 87% good-to-excellent results (based on the Knee Society Score) in 64 patients in whom a tibial tubercle osteotomy was used for extensile exposure during revision TKA. At an average follow-up of 30 months, the mean postoperative range of movement was 107 degrees, with a 4.5% incidence of extensor lag. One fracture of the tibia, no tibial avulsions, and two non-unions of the osteotomy were reported in this series.
- Barrack\(^1\) reported a significantly lower incidence of extensor lag following tibial tubercle osteotomy when compared to V-Y quadriceps turndown, although outcome scores were similar for both groups at the 4-year follow-up.
- Biomechanical studies show that although reattachment of an osteotomy with screws has greater fixation strength than cerclage wires, placement of screws around revision tibial component stems is difficult.\(^2\) Cerclage wires are easier to place and still provide solid fixation, especially when combined with a proximal step-cut osteotomy.
- High rates of fixation failure with tibial tubercle osteotomy most likely are due to the use of small (<3 cm) osteoperiosteal fragments and failure to maintain lateral soft tissue attachments in continuity with the osteotomized segment.\(^9\)

**COMPLICATIONS**
- Extensor lag\(^1,6,8\)
- Tibial fracture\(^6,8\)
- Tibial tuberosity avulsion\(^7,8\)
- Non-union of osteotomy\(^6\)
- Metalwork removal\(^7,8\)
REFERENCES

DEFINITION

- Gaining exposure during revision total knee arthroplasty (TKA) and primary TKA for the ankylosed knee can be challenging.
- Although over 90% of revision TKA procedures can be performed through a standard surgical approach, the surgeon should be familiar with more extensile techniques in case one of those must be used to avoid extensor mechanism disruption.4
- If adequate exposure is not obtained, a graduated approach is necessary.
- Quadriceps snip is used most commonly, followed by tibial tubercle osteotomy or V-Y quadriceps turndown.
- Although it may be possible to perform a prosthetic implantation without using an extensile exposure in the ankylosed knee, quadriceps contracture can limit extensor mechanism excursion, leading to poor postoperative flexion.
- V-Y quadricepsplasty may be performed after prosthetic insertion to improve flexion.6

STANDARD APPROACH

- Any skin incisions from previous procedures are clearly marked before skin preparation begins.
- Although a straight, midline anterior incision is preferred, because the vascular supply to this skin is primarily from the medial side, the most lateral useable incision is chosen. Previous skin incisions are intersected at an angle of no less than 60 degrees.
- Thick flaps are developed that include the superficial fascia.
- A medial parapatellar arthrotomy is then made at the junction of the medial and central thirds of the quadriceps tendon.
- Subperiosteal dissection of the tibia is then extended from the tibial tubercle to the posteromedial corner, including release to the semimembranosus insertion.
- A suprapatellar pouch, as well as the medial and lateral gutters, is then reestablished, all adhesions are released, and a thorough synovectomy is performed.
- All peripatellar scar tissue is removed.
- The knee is then gently flexed. The tibia is externally rotated and subluxed anteriorly, thereby reducing tension on the extensor mechanism.
- If the extensor mechanism is still under too much tension, dissection is carried distally and the superficial medial collateral ligament is released, followed by lateral retinacular release, making sure to preserve the lateral superior geniculate.
- If adequate exposure still is not possible, a quadriceps snip is performed, as described in Chapter AR-27.
- In most revision TKAs, adequate exposure can be obtained with these maneuvers.4

TIBIAL TUBERCLE OSTEOTOMY

- Tibial tubercle osteotomy (see Chap. AR-26) is chosen in cases with difficult stem or cement extraction or patients with patella baja.3

QUADRICEPS TURNDOWN

- The quadriceps tendon is exposed proximally to the insertion of the vastus lateralis and medialis muscles.
- The medial parapatellar arthrotomy is extended proximally to the insertion of the vasti.
- The quadriceps is then incised distally and laterally at an angle of about 45 degrees along the insertion of the vastus lateralis (TECH FIG 1).
- This inverted V creates a distally based flap that includes the patella. Essentially, the medial incision is connected to the lateral release.
- Care should be taken to preserve the lateral superior geniculate artery.
- The patella is now “turned down” anterolaterally, providing excellent exposure to the joint.
V-Y QUADROPLASTY

- The quadriceps is repaired in situ with multiple interrupted no. 2 nonabsorbable sutures, and ROM is assessed.
- If ROM is acceptable, closure is completed, leaving the lateral retinacular release open.
- If increased passive ROM is desired, the V is converted to an inverted Y.
- From 1% to 2% of advancement can be performed.
- The knee is flexed, and sutures or clamps are placed along the apex of the Y.
- Once appropriate lengthening is established, no. 2 nonabsorbable sutures are used to close the medial side of the quadriceps mechanism.
- The lateral retinacular release is left open.
- The lateral limb of the quadricepsplasty is covered by closing the quadriceps mechanism to the superficial fascia of the vastus lateralis (TECH FIG 2).
- The maximum flexion of the knee that will not put undue tension on the repair is recorded prior to routine skin closure.

PEARLS AND PITFALLS

- The patient and family members should be counseled preoperatively regarding the possibility that this approach may be required and prepared for the subsequent need for bracing.
- Intraoperatively, a graduated approach is necessary, starting with a medial parapatellar approach with lateral release, advancing to quadriceps snip, and lastly to osteotomy or V-Y turndown as needed.
- Preserve the superior lateral geniculate.
- Do not be aggressive with range of motion (ROM), particularly during the first 2 weeks.

POSTOPERATIVE CARE

- One disadvantage of V-Y quadricepsplasty is that it is necessary to modify postoperative rehabilitation.
- Maximum passive flexion to avoid tension on the repair is determined intraoperatively, after capsular closure. This is not exceeded in the first 2 weeks.
- The patient is placed in an immobilizer immediately postoperatively.
- A hinged brace is fitted after the first dressing change. A flexion stop is used for the first 2 weeks.
- Passive knee extension and active knee flexion are done for 6 weeks.
- Partial weight bearing is required for 6 weeks.
- The brace is locked in extension at night and with ambulation until the extensor lag is less than 15 degrees.

**OUTCOMES**
- Knee scores are similar to those of patients who have had revision TKA and reflect the difficulty of knees that need this procedure.
- In one study⁴ that compared patients who had had quadriceps turndown and tibial tubercle osteotomy to patients whose revision TKAs were performed with routine exposure, patients in the quadriceps turndown and tibial tubercle osteotomy groups had equivalent postoperative scores, which were significantly lower than those of patients in the routine exposure revision group. The turndown group had a higher increase in arc of motion than the osteotomy group, but they also had a higher degree of extension lag. The turndown group also had a lower percentage of patients who considered their surgery unsuccessful in relieving pain and return of function, and a lower percentage of patients who had difficulty with kneeling and stooping.⁵
- In a mixed population of primary and revision TKA, Cybex testing revealed that the quadriceps was weaker on the VY quadricepsplasty side, but this did not reach statistical significance. Only 5 of 14 patients had extensor lag greater than 5 degrees, with active extension lag averaging 4 degrees (range 0 to 20 degrees).⁷

**COMPLICATIONS**
- Patellar osteonecrosis was observed in 8 of 29 patients with quadriceps turndown in one study.⁵ It is critical to preserve the superior lateral geniculate artery.
- One case of minor wound dehiscence also was reported in a hemophiliac patient during manipulation under anesthesia after TKA using VY quadricepsplasty.

**REFERENCES**
DEFINITION
- Patellar tendon rupture following total knee arthroplasty (TKA) is a devastating complication with a prevalence of 0.17% to 2.5%.\(^1,2\)
- The patellar tendon is involved more commonly (0.22%) than the quadriceps tendon (0.1%).
- Despite reports of encouraging results following direct repair in native knees, attempts at primary repair following TKA rarely are successful in restoring extensor function.

ANATOMY
- The patellar tendon connects the tibia and the patella. It originates at the inferior pole of the patella and inserts onto the tibial tuberosity. It is about 5 to 6 cm long and 3 cm wide.
- The extensor mechanism of the knee begins proximally as the quadriceps femoris muscle.
- Anteriorly, the fibers of the rectus femoris tendon traverse the patella and insert on the tibial tubercle inferior to the patella as the patellar tendon.
- The fibers of the vastus lateralis muscle expand to the superolateral border of the patella and proximal tibia to form the lateral retinaculum.
- The fibers of the vastus medialis muscle insert into the superomedial border of the patella and tibia to form the medial retinaculum.

PATHOGENESIS
- The etiology of extensor mechanism disruption is multifactorial.
- Factors associated with patellar tendon rupture include:
  - Difficult exposure in a stiff knee
  - Extensive release of the patellar tendon at the time of surgical exposure
  - Manipulation for the treatment of limited motion
  - Revision TKA
  - Malrotation of the components
  - Overly aggressive postoperative physical therapy
  - Distal realignment procedures
- Some comorbid conditions may predispose patients to extensor mechanism rupture:
  - Systemic corticosteroid use
  - Diabetes mellitus
  - Chronic renal insufficiency
  - Parkinson disease
  - Gout
  - Morbid obesity
  - Multiple intra-articular corticosteroid injections

NATURAL HISTORY
- Patellar tendon ruptures are difficult to treat.
- Despite encouraging results reported following direct repair in native knees, attempts at primary repair following TKA rarely are successful in restoring extensor function.
- Augmentation with autograft or allograft tissue often is required.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients with rupture of the patellar tendon present with localized pain, palpable loss of patellar tendon tension during active knee extension, extensor lag, and hemarthrosis.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Anteroposterior (AP) and lateral radiographs of the knee should be obtained.
- Comparison with either immediate postoperative or preoperative films is helpful to establish the diagnosis of a complete rupture of the patellar tendon.
- Patella alta will be present and can be evaluated by comparison with earlier radiographs (FIG 1).

DIFFERENTIAL DIAGNOSIS
- Patellar fracture
- Quadriceps rupture
- Patella contusion
- Patellar tendinitis
- Prepatellar bursitis

NONOPERATIVE MANAGEMENT
- There is very little role for nonsurgical treatment of patellar tendon ruptures.
- For the rare person with a partial patellar tendon tear with maintenance of patellar height, cast or brace immobilization in
full extension for 6 weeks followed by physical therapy to regain motion and strength may be appropriate. Progress must be slow to allow for tendon-to-bone healing. Strengthening exercises should be delayed for at least 3 months.

- **Contraindications for surgical reconstruction include:**
  - Infection
  - Inability to comply with postoperative immobilization and the physical therapy program
  - For these rare instances, cast or brace immobilization in full extension for 6 to 8 weeks followed by a physical therapy program to regain motion and strength may be appropriate.
  - Progress must be slow, and strengthening exercises should be delayed for at least 3 months.

### SURGICAL MANAGEMENT

- A deficient extensor mechanism in association with a TKA poses a very challenging problem.
- Direct suture or staple repair alone is often unsuccessful.
- Options for management of patellar tendon rupture after TKA include direct repair, with augmentation with an autogenous semitendinosus tendon graft; an Achilles or whole patellar tendon allograft; or a synthetic ligament.
- In this chapter, we describe the technique that we use in our institution, consisting of reconstruction with Achilles tendon allograft with or without augmentation with an autogenous semitendinosus tendon graft.

#### Preoperative Planning

- Initial evaluation of the patient
  - History
  - Physical examination of the knee
  - Radiographs
- Previous operative reports should be obtained. The surgeon should be ready to perform revision surgery of any of the components if there is evidence of malrotation or malalignment.
- Order the Achilles tendon allograft.
  - Fresh-frozen allografts are preferable to freeze-dried allografts
  - Before anesthesia induction, the allograft is inspected visually to ensure that the specimen is adequate. A distal calcaneus bone allograft measuring at least 3 cm must be attached to the Achilles tendon.

### Positioning

- We use a laminar-flow operating room.
- The patient is placed supine on a radiolucent table.
- A regular pneumatic tourniquet around the thigh is used.
  - Alternatively, if the incision extends too proximally, a sterile tourniquet can be used.
- The leg is prepared and draped in the standard sterile fashion for joint replacement surgery.
- Fluoroscopic equipment is in the room with a technician available in case it becomes necessary to use it: eg, for judgment of the joint line, preparation of the tibial box, or placement of the screws to avoid the tibial component.
- Previous incisions are marked (FIG 2).
- The pneumatic tourniquet is inflated (usually to 250 mm Hg) after the leg has been exsanguinated with an Esmarch bandage.

#### APPROACH

- Because the patient already has had a total knee replacement in the past, the previous incision should be used.
- The dissection is carried down in the midline with conservative elevation of skin and subcutaneous flaps.
- The retinaculum and extensor mechanism are exposed.
- The tendon rupture is evaluated.
- A midline incision is performed through the patellar tendon.
- Medial and lateral flaps of retinaculum are created.
- The joint is drained of any hematoma and irrigated using pulsatile lavage (TECH FIG 1).
**PRIMARY REPAIR**

- Create two parallel tunnels through the patellar bone (TECH FIG 2A).
- Use heavy no. 2 nonabsorbable suture in a running, locked fashion (TECH FIG 2B,C).
- The repair is augmented with the use of no. 1 Vicryl in an interrupted figure 8 technique (TECH FIG 2D).

**TECH FIG 2 • A.** Two parallel tunnels are made through the patellar bone. B,C. A heavy no. 2 nonabsorbable suture is used to perform the primary repair in a running, locked fashion. D. The repair is augmented with the use of no. 1 Vicryl in an interrupted figure 8 technique.

**PREPARATION OF THE TIBIA AND ALLOGRAFT**

- A small saw is used to make a rectangular cavity 2.5 cm × 1.5 cm × 1 cm in the proximal part of the tibia slightly distal and medial to the original insertion site of the patellar tendon (TECH FIG 3).
- The Achilles tendon allograft is then prepared.

**TECH FIG 3 • A.** A rectangular cavity is made in the proximal part of the tibia.

**PREPARATION AND INSERTION OF THE CALCANEAL BONE BLOCK**

- The calcaneal bone block is cut to match the created rectangular space in the proximal tibia (TECH FIG 4A,B).
- The bone block is gently impacted into the proximal tibia (TECH FIG 4C).
- Two 4.5-mm screws, angled to avoid the tibial component, are used to secure the bone block to the tibia (TECH FIG 4D,E).
TECH FIG 4 • A,B. The calcaneal bone is cut to match the created rectangular space in the proximal tibia. C. The calcaneal bone block is gently impacted into the proximal tibia. D,E. The calcaneal bone block is fixed to the proximal tibia with the use of two 4.5-mm screws.

TECH FIG 5 • A. The Achilles tendon allograft is cut to obtain a rectangular patch. B. The rectangular patch is used to augment the attempted primary repair. C,D. The Achilles graft is attached to the underlying extensor mechanism.

**PLACEMENT OF THE ALLOGRAFT**

- The Achilles tendon is draped over the anterior tibia and patella while the knee is positioned in full extension.
- Apply enough tension to the allograft to keep it taut and unwrinkled.
- The most proximal part of the Achilles tendon allograft is cut to obtain a rectangular patch (TECH FIG 5A).
- The rectangular patch is used to augment the attempted primary repair, and is sutured in place with no. 1 Vicryl, in an interrupted fashion (TECH FIG 5B).
- The Achilles graft is attached to the underlying extensor mechanism with no. 2 nonabsorbable sutures, in an interrupted fashion (TECH FIG 5C,D).
WOUND CLOSURE
- Subcutaneous tissues are closed in routine fashion.
- The skin is closed with staples and a compression dressing applied. The tourniquet is deflated.
- A knee immobilizer is applied with the knee in extension.
- Postoperative anteroposterior and lateral radiographs of the knee are obtained in the postoperative care unit (TECH FIG 6).

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Graft</th>
<th>Revision of total knee components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary repair of patellar tendon ruptures following TKA rarely is successful, and in most cases augmentation with autograft or allograft tissue is required.</td>
<td>A fresh-frozen, nonirradiated Achilles allograft with calcaneal bone is required.</td>
<td>Be ready to perform revision surgery of the total knee components if malrotation or loosening is present.</td>
</tr>
<tr>
<td>Before anesthesia induction, visually inspect the allograft to ensure that it is adequate, with at least 3 cm distal calcaneus bone allograft attached to the Achilles tendon.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE
- The knee is immobilized in full extension for 4 weeks, using a hinged knee brace locked in 0 degrees of extension.
- Staples are removed 3 weeks after surgery.
- A brace is used to allow 30 degrees of flexion for 4 weeks.
- Then a brace is used to allow 60 degrees of flexion for 4 more weeks.
- A progressive controlled increase in flexion and strengthening exercises is allowed after 12 weeks.

OUTCOMES
- Short-term results are encouraging, but residual extensor lags of 5 to 20 degrees or more are common.3,4
- Longer-term follow-up of patients with Achilles allograft reconstruction of patellar tendon ruptures is required.

COMPLICATIONS
- Graft failure
- Infection

REFERENCES
DEFINITION

At less than 90 degrees of active knee flexion, a total knee arthroplasty (TKA) has inadequate range of motion (ROM) for performing many activities of daily living. The required ranges of motion for daily activities are as follows:

- 67 degrees of flexion for normal gait on level ground
- 83 degrees of flexion to climb stairs
- 90 to 100 degrees of flexion to descend stairs
- 93 degrees of flexion to stand from a standard-height chair
- 105 degrees of flexion to tie a shoe

Flexion contractures can be equally disabling: a flexion contracture of more than 15 degrees usually is considered pathologic, because it greatly inhibits normal gait.

ANATOMY

The primary impediments to exposure of the revision TKA, particularly a stiff TKA, are the extensor mechanism and the patella. The exposure can be thought of as a progressive release or “unleashing” of the extensor mechanism.

The four tethers of the extensor mechanism (FIG 1) are:

- Proximal: quadriceps tendon and musculature
- Medial: medial joint capsule and retinaculum with the insertion of the vastus medialis
- Lateral: lateral joint capsule and retinaculum with the insertion of the vastus lateralis
- Distal: patellar tendon

The blood supply to the patella is provided by an anastomotic ring of vessels supplied by the geniculate arteries. It is important to try to avoid complete devascularization of the patella, because avascular necrosis can occur.

The blood supply to the skin overlying the knee travels from the deeper tissues up through the superficial fascia and does not run superficially. If skin flaps are required at the time of surgery, they must be full-thickness, therefore, to avoid skin necrosis.

PATHOGENESIS

Many potential causes for stiffness following TKA exist, and multiple mechanisms may act in concert in a given patient, resulting in suboptimal ROM.

- Poor perioperative pain control or suboptimal physical therapy. In rare cases, a chronic regional pain syndrome develops, characterized by severe pain, cutaneous hypersensitivity, vaso-motor disturbance, and stiffness.
- Technical issues related to the original surgical procedure may play a role.

![FIG 1](image-url) • Anterior view of the knee showing the patella, patellar tendon, quadriceps tendon, vastus medialis oblique muscle, and vastus lateralis.
Femoral component
- Oversized: leads to tightness in flexion
- Internally rotated: leads to patellar maltracking or an asymmetric flexion gap
- Inadequate distal femoral resection: leads to tightness in extension and a potential flexion contracture
- Over-resection of the distal femur: requires a thicker polyethylene insert to obtain stability, thereby leading to tightness in flexion
- Inadequate removal of posterior femoral osteophytes: leads to tenting of the posterior capsule and flexion contracture or osteophytes that can impinge on the tibial polyethylene insert, limiting flexion
- Anterior placement of the femoral component: leads to "over-stuffing" of the patellofemoral joint

Tibial component
- Most commonly, inadequate or reverse slope of the tibial cut, which leads to tightness in flexion; internal rotation, which leads to patellar maltracking; oversized component, which leads to soft tissue impingement and pain
- Elevation of the joint line (particularly if >1 cm): leads to poor ROM secondary to altered patellofemoral joint mechanics
- Inadequate resection of the tibia: leads to tightness in both flexion and extension

Patellar component
- Under-resection of the patella: leads to overstuffing of the patellofemoral articulation. The native patella–prosthetic composite should be equivalent in thickness to the patella before resection.
- Excessive patellar resection: leads to weakness of the extensor mechanism with initial extensor lag and eventual flexion contracture
- Inadequate medialization of the component: leads to patellar maltracking
- Inadequate removal of lateral patellar osteophytes: leads to impingement and pain
- Ligamentous imbalance: flexion-extension mismatch (typically too tight in flexion, particularly with a cruciate-sparing design) or varus-valgus instability
- Poor component fixation: failed ingrowth of cementless components or inadequate cement mantle around cemented components, resulting in persistent pain that inhibits physiotherapy

Patient-related factors
- Poor preoperative ROM (the best predictor of postoperative ROM is preoperative ROM)
- Genetic predisposition to scarring and stiffness
- A history of previous surgery on the knee that has led to stiffness or a patella baja (shortening of the patellar tendon)
- Noncompliance with physical therapy
- Obesity (soft tissue envelope of the posterior thigh and leg limits flexion)
- Stiffness or arthritis of the ipsilateral hip
- Deep infection
- Heterotopic ossification

NATURAL HISTORY
- The natural history of the stiff TKA is poor. Even with time, patients’ ROM rarely improves enough to positively impact their gait pattern, and chronic pain develops.
- Flexion contractures are equally poorly tolerated, as is inadequate flexion. Flexion contractures greater than 15 degrees limit the ability to stand up straight and cause substantial fatigue when walking.
- Patients with only mild stiffness (ie, ROM near 90 degrees) may improve slightly (5 to 10 degrees) in the first 2 years after surgery, reaching a level of flexion that is tolerable for most activities of daily living.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The history is a critical part of the evaluation to determine which of the factors listed under Pathogenesis have led to stiffness; in most cases, more than one factor is at work.
- Direct questions should be asked to determine whether pain control was adequate in the postoperative period.
- Did the patient have severe pain postoperatively that limited his or her ability to perform physical therapy?
- For how long postoperatively did the patient require narcotics? Is the patient still taking narcotics and still in severe pain?
- Does the patient have hypersensitivity of the skin overlying the incision or other complaints that suggest neurogenic pain or a chronic regional pain syndrome?
- How was the patient’s stiffness addressed postoperatively?
- Did he or she undergo a manipulation under anesthesia (MUA) postoperatively?
- Has he or she undergone any other operative procedures (eg, open or arthroscopic release) in an attempt to improve ROM?
- Does any element of the history suggest infection?
- Wound drainage that persisted for more than a few days after surgery
- The use of antibiotics for more than 24 hours postoperatively
- Persistent pain that is of a different character than the pain the patient had before the surgery

Inspect the skin for the presence of a past or present sinus, indicating infection. Densely adherent skin is much harder to close and may represent a higher risk for necrosis.
- Evaluate the patient’s ROM. Flexion of less than 90 degrees and a flexion contracture of more than 15 degrees are considered pathologic. Loss of ROM affects gait and ability to perform activities of daily living.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standing anteroposterior (AP), lateral, and patellar radiographs should be obtained to identify component loosening, malposition, or improper sizing (FIG 2A).
- Patella baja and joint line position also should be noted (FIG 2B). Severe ligamentous imbalance may be readily apparent on the plain radiographs. Patellar maltracking also can be identified (FIG 2C), as can an unresurfaced patella, which may be causing pain that leads to stiffness.
- Serial radiographs often are helpful in confirming component loosening.
- A CT scan to determine femoral and tibial component rotation often is performed (FIG 2D–F). If component malposition is identified (eg, internal rotation), the components are revised.
Erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) level are obtained before every revision TKA. If either is elevated, an aspiration of the knee joint is obtained and sent for a cell count with differential and cultures, including aerobic, anaerobic, and acid-fast bacilli, and fungi. A white blood cell count above 3000 is considered consistent with infection. Patients must have been off antibiotics for at least 2 weeks before the knee aspiration. At the time of revision, additional cultures are taken from within the joint, and an intraoperative frozen section is taken from the synovial tissues. An average of more than 10 polymorphonuclear cells identified within tissue (and not fibrin) is consistent with infection.

Nuclear medicine studies, such as a triple-phase bone scan, occasionally are helpful in identifying subtle loosening but are not routinely obtained.

**DIFFERENTIAL DIAGNOSIS**
- Deep infection
- Component malposition (eg, internal rotation of the femur or tibia)
- Patellar maltracking or overstuffing of the patellofemoral joint
- Improper component sizing
- Ligamentous imbalance (eg, tightness in flexion)
- Component loosening
- Chronic regional pain syndrome

**NONOPERATIVE MANAGEMENT**
If the patient is seen early in the postoperative period (less than 6–12 weeks postoperatively), he or she can be managed with a combination of the approaches discussed in this section.

**SURGICAL MANAGEMENT**
- The decision to proceed with revision TKA for stiffness should be considered carefully and only after a full investigation as to the cause or causes of stiffness. The patient must be fully
informed of the risks of the procedure and educated that the ROM may not improve, even with further surgery. It is crucial to work with a pain management specialist and a physical therapist to ensure that stiffness does not recur postoperatively.

- Options for surgical management include:
  - Arthroscopic débridement with manipulation$^2,5,7,15$
    - This can be performed in highly selected patients with well-fixed, appropriately aligned components. The procedure is technically demanding, and the results reported in the literature are variable, with most studies showing mild improvements in ROM (15 to 30 degrees, on average).
    - The technique includes release of the posterior cruciate ligament (if present), clearing of scar from the suprapatellar region, and, typically, MUA once the scar has been cleared.
    - Flexion contractures are harder to address arthroscopically, but a posterior release can be performed using small, open, medial and lateral incisions.
  - Open arthrolysis with exchange of the modular polyethylene liner$^1,9,10,13$
    - This procedure also can be performed in selected patients with well-fixed, appropriately aligned components. It often is difficult to fully release the posterior capsule to treat flexion contractures, however, and it is unclear whether this technique has any benefit over arthroscopic release.
  - Revision TKA$^6,8,10,11,14$
    - Revision TKA is the most appropriate treatment for most patients. It allows for optimization of component alignment, size, and rotation, while providing the opportunity to restore the joint line.
    - It affords complete access to the posterior capsule to perform a capsulectomy and remove any retained osteophytes from the previous surgical procedure.
    - An additional benefit is the option of using a more constrained polyethylene insert, if desired, to optimize stability if extensive releases are performed.
    - If a large flexion contracture is being addressed, a flexion-extension mismatch often is present (ie, extension space smaller than the flexion space), and constrained and even hinged implants may be required.

Preoperative Planning

- The history, physical examination, plain radiographs, and CT scan (if obtained) are reviewed before a definite decision is made whether the components are to be removed or retained.
- The ESR, CRP, complete blood cell count, and culture results are reviewed to determine whether a deep infection is present.
- If any of the prosthetic components are to be retained, the operative note from the previous procedure must be reviewed to definitely identify manufacturer, model, and size so that appropriate, matching replacement implants and trials are available on the day of surgery.
- An examination under anesthesia confirms the limits of motion.

Positioning

- The operative extremity is draped free from the hip to the ankle, and a tourniquet is placed on the upper thigh.
- A bump placed underneath the ipsilateral hip assists in keeping the leg upright.
- A leg holder keeps the leg in the desired position for surgery.
- An elastic bandage placed on the lower leg defines the malleoli, which are used as a reference for tibial cut alignment (FIG 3).

Approach

- The workhorse approach for exposure in revision TKA is the medial parapatellar approach with complete excision of intra-articular scar tissue. This approach is useful for most revision TKAs.
  - In the stiff knee, however, a more extensile approach may be required.
  - If additional exposure is needed, a quadriceps snip can be performed.
  - This maneuver assists in freeing the proximal tether of the extensor mechanism, thereby improving exposure.
  - Benefits include relative simplicity of performance and repair, no need to alter postoperative rehabilitation protocols, and clinical results that have been shown to be equivalent to those in patients who have undergone a revision TKA without a snip.
  - If a more extensile exposure is needed, the extensor mechanism can be completely released proximally with a V-Y quadricepsplasty (see Chap. AR-27) or distally with a tibial tubercle osteotomy (see Chap. AR-26).

MEDIAL PARAPATELLAR ARTHROTOMY WITH COMPLETE INTRA-ARTICULAR RELEASE

- Skin incision
  - Previous skin incisions are used whenever possible.
  - Avoid parallel incisions. If choosing among multiple previous incisions, the most lateral one is selected, because the blood supply is derived predominantly from the medial side.
  - Full-thickness flaps are raised, if required.

- The arthrotomy extends from the apex of the quadriceps tendon, around the medial aspect of the patella and just medial to the tibial tubercle (TECH FIG 1A).
- On entering the joint, large amounts of scar typically are encountered (TECH FIG 1B); these prevent proper exposure and contribute to stiffness.
A medial release is performed with electrocautery by subperiosteally releasing a continuous soft tissue sleeve all the way to the posteromedial corner of the tibia and the semimembranosus insertion (TECH FIG 1C).

This allows for external rotation of the tibia, which relaxes the extensor mechanism and improves exposure.

The junction between scar and the extensor mechanism is identified (TECH FIG 1D). The scar is meticulously removed from underneath the extensor mechanism laterally (TECH FIG 1E) and from underneath the joint capsule medially until the medial and lateral gutters have been re-established (TECH FIG 1F).

A thin layer of soft tissue is left on the distal femur to prevent excessive bleeding and also to prevent the extensor mechanism from becoming readherent in this area.

The scar tissue is carefully cleared from behind the patellar tendon by identifying the interval between the patellar tendon and the scar behind it to release the patellar tendon from the proximal tibia.

At this point, the modular polyethylene liner is removed to allow for patellar eversion or subluxation. In most cases, patellar subluxation is preferred, because it places less tension on the extensor mechanism and provides adequate exposure in most cases.

If difficulty is encountered, soft tissue can be peeled off the lateral border of the patella to make it more mobile, and any osteophytes that are present can be removed.

If exposure still cannot be accomplished, a formal lateral retinacular release may be required.

This release involves a full-thickness division of the capsule along the lateral border of the patella from the proximal tibia (just lateral to the patella tendon) to the vastus lateralis.

A lateral release performed from the inside out eliminates the need to raise additional skin flaps.

**QUADRICEPS SNIP**

If inadequate exposure has been afforded by the medial parapatellar arthrotomy and a complete intra-articular release, a quadriceps snip often provides enough additional exposure to complete the procedure safely.

The snip is made at the apex of the arthrotomy, obliquely across the quadriceps tendon at a 45-degree angle in line with the fibers of the vastus lateralis (TECH FIG 2).

At the end of the procedure, the snip is closed side-to-side using nonabsorbable suture.

The postoperative therapy protocol is not altered if a quadriceps snip has been performed.
COMPONENT REMOVAL

- The femoral and tibial components are then carefully removed as described in Chapter AR-26.
- The patella then is assessed. Its thickness is determined (TECH FIG 3), and if the composite is considered to be too thick (i.e., >25 mm for women and >30 mm for men) or in an otherwise suboptimal position (e.g., lateralized), the component is removed.
- If the component is to be retained, any osteophytes or unresurfaced sections of the native patella are removed.

RECUTTING THE UPPER END OF THE TIBIA AND PERFORMING A POSTERIOR RELEASE

- The proximal tibia is recut perpendicular to its mechanical axis with neutral slope. Either an intra- or extramedullary guide may be used. A neutral slope is recommended, so rotation of the cut is not important at this point. The revision component often has an appropriate amount of slope built in (5–7 degrees) so that rotation in the optimal position can be set later.
- A laminar spreader then is inserted both medially and laterally, and the scar tissue in the posterior aspect of the knee along with any remnant of the posterior cruciate ligament, if present, is removed completely to re-establish the flexion space and restore full extension (TECH FIG 4A).
- At this point, ligamentous balance is assessed and appropriate releases are performed until the flexion gap is of equivalent size medially and laterally.
- A curved osteotome then is used to release any remaining capsule from the posterior aspect of the femur and to clear any residual osteophytes retained at the time of the original TKA (TECH FIG 4B).
- Given the tendency to elevate the joint line in revision TKA, a complete posterior capsular release is performed in all cases.
CREATING THE TIBIAL PLATFORM

- The tibia is prepared first, because tibial height affects both the flexion and extension gaps.
- The tibial component is then sized to maximize coverage of the upper end of the tibia.
- A stem typically is used to provide support for the revision component. Stems also assist with component alignment. It is necessary to remember that the tibial shaft is offset posteromedially in relation to the center of the upper end of the tibia, and a stem that allows for offset often is required to optimize coverage of the upper end of the tibia (the stem is used to bring the component anterior and lateral in most cases).
- The tibial trial component is then placed in the appropriate amount of external rotation; typically, the center of the component is aligned with the junction of the medial and middle thirds of the tibial tubercle (TECH FIG 5).
- See Chapters AR-23 and AR-25 for additional details.

CHOOSING THE FEMORAL TRIAL SIZE AND AUGMENTS

- Sizing of the femoral component can be difficult but is a critical portion of the procedure. If the original component is thought to have been too large, a smaller trial component is selected.
- The surgeon must keep in mind that, although it is desirable to leave the patient’s knee “somewhat loose in flexion” in cases of stiffness, this does risk flexion instability. Consideration should be given to using a more constrained insert in cases of revision TKA for stiffness.
Chapter 29  REVISION TKA TO CORRECT STIFFNESS

The knee initially is trialed with a long intramedullary stem to assist with determining appropriate valgus alignment; a shorter stem can be substituted later if desired. Stems are used routinely, both to support the revision component and to assist with alignment.

The initial augments typically used include a small posterolateral augment, to encourage appropriate external rotation of the revision component, and small distal augments placed both medially and laterally, to distalize the femoral component in response to the tendency of revision TKA to elevate the joint line.

Appropriate external rotation of the femoral component is checked using the epicondylar axis of the femur (TECH FIG 6A). The surgeon also can check to make sure that a “piano” or “boot” sign is present when the cut surface of the femur is viewed from above (TECH FIG 6B). This sign indicates that the cut on the lateral side is deeper than that on the medial side, confirming appropriate external rotation of the femoral cut.

**TECH FIG 6**  •  A. The epicondylar axis is used to ensure appropriate external rotation of the femur. B. View of the distal femur from above showing the “piano” or “boot” sign, confirming appropriate external rotation of the femoral component.

**TRIALING AND CLOSURE**

The knee is now trialed with varying thicknesses of polyethylene liners to ensure:

- Full extension of the knee (TECH FIG 7A)
- Adequate flexion of the knee (TECH FIG 7B). A good predictor of postoperative flexion is that achieved at the time of surgery with the knee flexed against gravity.
- Adequate varus-valgus stability
- Good patellar tracking. If patellar tracking is not acceptable, the rotation of the femoral and tibial components must be carefully assessed and changed if necessary until the patella tracks well.
- Restoration of the joint line to within 1 cm of its normal position. The easiest way to assess the joint line is to compare the superior pole of the patella to the superior flange of the revision femoral component.

Various combinations of augments and polyethylene liners should be tried until the optimal combination is found; this may take a considerable amount of time to achieve.

The revision components are now assembled on the field. The stems can be either firmly press-fit into the canal, with cement placed only around the metaphyseal segment of the component (see TECH FIG 4C), or fully cemented, depending on the surgeon’s preference. Antibiotic-loaded cement is recommended, given the higher risk of infection in the setting of revision TKA.

The knee is closed in at least 90 degrees of flexion, because this has been shown to increase final flexion. Following closure of the arthrotomy, ROM and patellar tracking are carefully assessed once again.
**PEARLS AND PITFALLS**

| Indications                                                                 | ■ Patients must be assessed carefully before surgery and must have realistic expectations from the procedure.  
| ■ Patients must be willing to be active participants in their postoperative therapy. |
| Pain management                                                            | ■ The assistance of a specialist in pain management is essential to ensure that patients can participate in their physical therapy.  
| ■ An indwelling epidural catheter is a useful adjunct to this goal. |
| Preoperative planning                                                      | ■ Ensure that operative notes from previous procedures have been reviewed and that replacement parts and trials are available if necessary. |
| Perioperative evaluation for sepsis                                         | ■ All patients should have a thorough perioperative evaluation for deep infection. |
| Retention of components                                                    | ■ An arthroscopic or open arthrolysis should be attempted only after the surgeon is sure that the components are well fixed, appropriately sized, and aligned.  
| ■ If not, a full revision should be performed. |
| Patellar tendon avulsion                                                   | ■ Great care should be taken to protect the insertion of the patellar tendon at the time of surgery.  
| ■ More extensile approaches, such as the quadriceps snip or tibial tubercle osteotomy, should be used if deemed necessary. |

**POSTOPERATIVE CARE**

- Perioperative care must be monitored closely in conjunction with a pain management specialist and a physical therapist.
- Patients are placed on a continuous passive motion (CPM) machine starting at 0 to 90 degrees in the recovery room, with the setting advanced as tolerated. CPM is used for 4 to 6 hours per day, and patients must understand that it is an adjunct to, not a substitute for, active and passive ROM exercises.
- The indwelling epidural catheter is continued for up to 6 weeks. The patient is seen by the surgeon and the pain management specialist weekly for the first 6 weeks to monitor progress.
- Patients are engaged in an aggressive physical therapy program emphasizing ROM, gait training, and strengthening.
- If the patient has not achieved 90 degrees of flexion by 6 weeks, MUA is performed.

**OUTCOMES**

- Include functional and prosthetic survivorship data, as applicable.
- Table 1 summarizes the results of arthroscopic release with manipulation, open arthrolysis, and revision TKA for the treatment of stiffness.
- Most of the literature suggests that reoperations for stiffness are associated with improvements in ROM, pain, and function, but that these gains are modest and in a certain percentage of patients, stiffness will recur.
- An arthroscopic release seems most appropriate for select patients with well-fixed, appropriately positioned and rotated components.
- Flexion contractures are particularly difficult to correct.
Chapter 29 REVISION TKA TO CORRECT STIFFNESS

COMPLICATIONS

- Recurrent stiffness
- Extensor mechanism disruption (particularly patellar tendon avulsion)
- Infection
- Instability
- Neurovascular injury
- Deep venous thrombosis

REFERENCES


<table>
<thead>
<tr>
<th>Procedure/Author</th>
<th>Year</th>
<th>No. Knees</th>
<th>Mean Length of Follow-Up (mo)</th>
<th>Mean Increase in ROM (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arthroscopy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bae, et al¹</td>
<td>1995</td>
<td>13</td>
<td>12</td>
<td>42</td>
</tr>
<tr>
<td>Campbell²</td>
<td>1987</td>
<td>8</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>Diduch, et al⁷</td>
<td>1997</td>
<td>8</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>Williams, et al¹⁵</td>
<td>1996</td>
<td>10</td>
<td>20</td>
<td>31</td>
</tr>
<tr>
<td>Lysis and liner change</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Babis, et al¹</td>
<td>2001</td>
<td>7</td>
<td>51</td>
<td>19</td>
</tr>
<tr>
<td>Hutchinson, et al⁹</td>
<td>2005</td>
<td>13</td>
<td>87</td>
<td>36</td>
</tr>
<tr>
<td>Keeney, et al¹⁰</td>
<td>2005</td>
<td>12</td>
<td>37</td>
<td>26</td>
</tr>
<tr>
<td>Mont, et al¹³</td>
<td>2006</td>
<td>18</td>
<td>30</td>
<td>31</td>
</tr>
<tr>
<td>Femoral component revision</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ries and Badalamente¹⁴</td>
<td>2000</td>
<td>6</td>
<td>33</td>
<td>50</td>
</tr>
<tr>
<td>Revision TKA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Christensen, et al⁶</td>
<td>2002</td>
<td>11</td>
<td>38</td>
<td>56</td>
</tr>
<tr>
<td>Haidukewych, et al⁸</td>
<td>2005</td>
<td>16</td>
<td>42</td>
<td>33</td>
</tr>
<tr>
<td>Keeney, et al¹⁰</td>
<td>2005</td>
<td>11</td>
<td>37</td>
<td>18</td>
</tr>
<tr>
<td>Kim, et al¹¹</td>
<td>2004</td>
<td>56</td>
<td>43</td>
<td>28</td>
</tr>
</tbody>
</table>

Table 1 Results of Arthroscopic Release with Manipulation, Open Arthrolysis, and Revision TKA for the Treatment of Stiffness
DEFINITION
- Knee arthrodesis is an excellent salvage option for infected total knee arthroplasty (TKA) and for severe trauma about the knee. It is a durable solution that lasts a lifetime and allows for a stable, painless extremity for ambulation.
- The energy expenditure for walking with a knee fusion is less than the energy expenditure needed to walk with an above-the-knee amputation. This is important for elderly patients with associated comorbidities who often are unable to walk with such an amputation.9
- In the younger, posttraumatic population, the knee fusion is a durable option that allows for the most physically demanding activities as opposed to above-the-knee amputation or TKA.
- Ipsilateral hip arthritis or significant back pain and arthritis are relative contraindications to knee fusion, although for some patients, knee fusion is the best option despite relative contraindications.

ANATOMY
- The approach for knee arthrodesis is anterior.
- The relevant anatomy depends on the previous surgical procedures that the patient has undergone. In the case of the infected TKA, the extensor mechanism often is no longer present and a soft tissue defect occurs anteriorly.
- The best bone contact for knee arthrodesis is achieved by elevating the posterior capsule off the distal femur and proximal tibia.
- Directly posterior to the posterior capsule are the popliteal artery, popliteal vein, and sciatic nerve as it branches into the posterior tibial and peroneal nerve. Great care must be taken in the area of these vessels (FIG 1).
- When using a long intramedullary rod for knee fusion, the piriformis fossa is an important landmark for the entry of the nail.
- At present, trochanteric-starting intramedullary knee fusion rods are not available.

PATHOGENESIS
- The conditions necessitating knee arthrodesis include infected TKA and severe trauma about the knee destroying the joint.
- Trauma, destruction, or débridement as a result of infection leads to extensive bone loss.
- The most common way to fill this bone defect is by acutely shortening the limb.
- The average shortening associated with knee arthrodesis after infected TKA is 4 cm, which necessitates a shoe lift to equalize the limb lengths.8
- In cases with substantial bone loss (7 to 10 cm) and with soft tissues and vessels that do not allow acute compression, gradual compression of 2 mm/day with an external fixator is an option for knee arthrodesis, although this still leaves the limb significantly shortened.
- My preference in such situations is for bone transport—either double or single level—in which the overall length of the limb is maintained and the large bone gap at the knee is filled with the transported bone. This strategy works well in the young, traumatized patient and in the elderly patient with infected TKA.

NATURAL HISTORY
- The natural history of these severe traumatic and infectious processes occurring about the knee is poor. Without a stable lower limb, the patients are unable to bear weight.
- The alternative to knee fusion is above-the-knee amputation, which allows the young, healthy posttraumatic population to walk with an above-the-knee prosthesis.
- Above-the-knee amputation in the elderly population with infected TKA usually results in the patient’s becoming nonambulatory.9
- The natural history of a knee arthrodesis is extremely durable, lasting the patient’s lifetime.3
- As the patient ages, however, contralateral hip arthritis (secondary to the longer length of the contralateral limb) and arthritis of the spine (secondary to the increased motion across the spine) can develop. These problems can be addressed separately, if and when they occur.

FIG 1 • Proximity of the posterior neurovascular bundle to the posterior aspects of the femur and tibia at the level of the residual knee joint. Also, the bones are very subcutaneous anteriorly and do not have good blood supply secondary to the relatively avascular quadriceps and patellar tendons and lack of good muscle with good blood flow to the bones anteriorly.
PATIENT HISTORY AND PHYSICAL FINDINGS

The history pertinent to preoperative assessment for knee arthrodesis is a list of all surgical and traumatic occurrences about the knee.

- This includes previous flap surgeries for coverage of the anterior knee and integrity of the extensor mechanism.
- Other important issues regarding the history include comorbidities, such as peripheral vascular disease, smoking, diabetes, ambulatory status, social resources, and steroid use.
  - These comorbidities will affect the patient’s ability to heal a fusion.
  - The surgeon’s choice of technique should take into account these comorbidities to maximize the patient’s chance for a successful outcome.
- Physical examination of the hips and ankles is important to assess the integrity of the remaining joints that will be compensating for the resultant lack of knee motion.
  - Any equinus contracture can easily be addressed at the time of surgery with Achilles tendon lengthening or gastrosoleus recession.
  - The examiner should palpate the dorsalis pedis and posterior tibialis pulses. If they are poor, a vascular evaluation is obtained.
  - The skin of the anterior knee is assessed for scars, previous flaps, defects, and integrity. If the skin condition is poor, the surgeon should consider alternative wound-closure techniques postoperatively, such as a wound vacuum or preoperative plastic surgical consultation.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- The most important imaging studies are long standing anteroposterior (AP) view erect lower limbs radiographs and long lateral view radiographs (FIG 2).
  - These radiographs allow the surgeon to assess the present and predicted limb-length discrepancy after knee fusion.
  - With defects in the knee region greater than 5 or 6 cm, acute compression intraoperatively might lead to vascular compromise from vessel kinking. Therefore, these radiographs are essential for determining the method of fusion.
  - Any residual bone cement in the medullary canals can also be visualized on these views, allowing the surgeon to plan for the proper tools to remove it at the time of surgery.
- Magnetic resonance imaging can be helpful in determining the extent of any infection in the distal femur or proximal tibia. Care must be taken with interpreting the images, however, because bone edema can be misinterpreted as osteomyelitis and result in too aggressive a resection.

DIFFERENTIAL DIAGNOSIS

- Indications for knee fusion:
  - Infected revision TKA
  - Severe trauma about the knee preventing reconstruction
  - Reconstruction after tumor resection

NONOPERATIVE MANAGEMENT

- Nonoperative management of a knee with a significant bone defect after trauma or joint infection is very difficult. These patients typically have an unstable limb for weight bearing and need a cast or brace for support.
- This resection arthroplasty option usually is reserved for nonambulators and patients who are too medically ill to undergo a substantial surgical procedure that involves significant blood loss.

SURGICAL MANAGEMENT

- Surgical intervention is the most effective way to obtain a knee arthrodesis.
  - It requires a patient who is medically stable enough to undergo a 2- to 3-hour procedure with 500 to 800 mL of blood loss.²
Preoperative Planning

- Proper preoperative planning begins with the critical points outlined in the Patient History and Physical Findings and Imaging and Other Diagnostic Studies sections.
- Essential to preoperative planning is determination of the resultant gap that will be present at the site of the knee fusion (Table 1).
- Acute compression of the gap with intramedullary rod fusion should be reserved for gaps no more than 5 to 6 cm. Acute compression greater than that can cause vessel kinking and ischemia to the lower limb.
- Gaps greater than 5 to 6 cm can be managed with gradual compression or bone transport to fill in the defect. Bone transport with a fixator allows the limb to remain at a desired length (1 cm shorter than the contralateral limb) and fills the gap with healthy bone from the proximal tibia or femur.
- In cases with large gaps, gradual compression without lengthening, achieved by using an external fixator, will eliminate vessel kinking, but the resultant limb-length discrepancy might be undesirable for the patient and require him or her to wear a 2- to 3-inch shoe lift, which can be cumbersome for ambulation.
- It is vital to discuss the goals of knee arthrodesis with the patient before surgery. The surgeon must be sure that the patient is willing to accept a large shoe lift; if not, the patient must be willing to undergo additional steps to ensure that the limb is of acceptable length.
- The strategy for knee fusion is patient dependent, and the lengthening can be performed at a second surgical setting or during the same surgical setting. It is important to realize that with concomitant lengthening, the rate-limiting step in the complete healing process is the fusion site, not the regenerate bone formation.
- All knee fusions after infected TKA are bone grafted. This is done when there is no evidence of infection.
- For patients undergoing two-stage procedures (infection eradication and spacer plus clean fusion with intramedullary rod or plates), the bone grafting is performed at the time of the fusion.
- In patients who have external fixation and for whom fusion is initiated at the time of the infection eradication surgery, bone grafting is performed at a second surgical setting.
- Regardless of the method of fusion, fusion after infection requires two surgical procedures.

<table>
<thead>
<tr>
<th>Size of Gap</th>
<th>Treatment Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5 cm</td>
<td>Intramedullary rod, external fixator, lengthening optional</td>
</tr>
<tr>
<td>5–10 cm</td>
<td>External fixator with bone transport of one segment (femur or tibia)</td>
</tr>
<tr>
<td></td>
<td>Transport over nail; gradual compression and fusion with lengthening at second surgical setting</td>
</tr>
<tr>
<td>&gt;11 cm</td>
<td>Double-level transport over rod; double-level transport with circular frame</td>
</tr>
<tr>
<td></td>
<td>Bone graft to all docking/knee fusion sites when infection eradicated</td>
</tr>
</tbody>
</table>

- My preferred method for obtaining a large volume of bone with minimal donor site morbidity is to use the Reamer-Irrigator-Aspirator System (Synthes, Inc., Paoli, PA). The reamer is used to obtain a large volume of bone from the contralateral femoral canal through a small (2-cm) incision.

Hardware Considerations

Long Knee Arthrodesis Rods

- The long intramedullary rod is an excellent method of fixation for knee arthrodesis. It is well tolerated by patients and provides good neutralization of the forces generated by the muscles around the knee.
- Biomet, Inc.: Biomet Trauma (Warsaw, IN), Smith & Nephew (Memphis, TN), and Stryker Orthopaedics (Mahwah, NJ) are three companies that currently offer long knee fusion rods.
- The Stryker intramedullary rod is the only one with 5 degrees of valgus to counteract the mild varus mechanical axis of the limb with insertion of a straight rod.
- The Stryker rod also has the ability to compress the fusion site after rod insertion and locking.
- This is done by a proximal compression bolt end cap inserted in the proximal rod. The compression bolt end cap sinks into the rod and engages the proximal interlocking screw in the dynamic slot. This allows for an additional 1 cm of compression at the fusion site, which can be helpful after rod insertion.

Short Intramedullary Fusion Rods

- Short intramedullary fusion rods are rods that couple at the knee arthrodesis site.
- The one that is commercially available is called the Wichita Fusion Nail (Stryker).
- The device (FIG 3) has two separate segments of different diameters for the femur and tibia. Each segment is fixed with interlocking screws, and a coupling device is then used to engage and compress the bone ends.
- The device works very well for the primary knee arthrodesis that has good metaphyseal bone.1
- Without good metaphyseal bone and tight-fitting rods in the femoral and tibial canal, the Wichita Fusion Nail does not provide enough stability to neutralize the long lever arms across the knee.
- Preoperative planning is essential to ensure that the tibial and femoral rods will have good fit in the bone. The femoral rod is 14 cm long, and the tibial rod is 16 cm long.
- If the distal femur and proximal tibia appear as “cortical shells” without good bone, another method should be chosen.

External Fixation

- Many systems are available for external fixation, but my preferred method is a biplanar Orthofix LRS external fixator (Verona, Italy; FIG 4).
- This system has two long smooth rails (65 and 80 cm) that are mounted anteriorly and laterally from the hip to the ankle to adequately neutralize the long lever arms across the knee. It also allows for purchase of the bone in an area not violated by any long revision TKA stems.
- The advantages to external fixation are that at the completion of the fusion, no hardware remains as a nidus for recurrent infection and the external fixator can be applied at the same surgical setting as the removal of infected TKA components or débridement of osteomyelitis. This allows for immediate initiation of bone contact and knee fusion.
It is not recommended to perform bone grafting at this setting but to wait until the soft tissue envelope is stable and no fear of infection at the knee fusion site remains. This often is done 6 to 8 weeks after the application of external fixation.

Also, with a circular or biplanar system, external fixation can be set up so that as the fusion is uniting, the resultant limb-length discrepancy can be diminished by performing an osteotomy of the proximal femur or distal tibia at the same surgical setting.

Circular fixation, with the rings sitting at the medial aspect of the thigh, can be cumbersome for large or elderly patients—hence the description of the biplanar Orthofix external fixator.

Any monolateral system can be set up in a biplanar fashion. The system used must span the length of the femur and tibia to achieve rigid fixation.

**Plates**

Plates are not commonly chosen implants for knee fusion because of the bulkiness of the plates and the lack of soft tissue envelope in the anterior aspect of the knee. However, plates might be preferred for patients with total hip arthroplasty above the desired fusion site.

The ideal construct for plates should be a 90-90 construct in which an anterior plate is used to counteract the flexion–extension forces and a medial or lateral plate is used to counteract the varus–valgus forces.

The plates should initially be used in compression mode, and the remaining screw holes should be inserted in a locking fashion into a locked plate.
Many plating systems are commercially available with locking capability (Synthes, Smith & Nephew).

**Positioning**
- The positioning for knee fusion is the same for each surgical approach.
- A bump is placed under the buttock to allow for visualization of the femoral neck and head on the lateral view radiograph.
- The entire limb, including the foot, needs to be visualized to ensure proper rotation of the limb during surgery and also to assess the pulse during the procedure (**FIG 5**).

**Approach**
- The basic approach to knee fusion is anterior.
- Without any soft tissue compromise, the best incision for knee fusion is a transverse one that will be easily approximated once the limb is acutely shortened.
- A longitudinal incision becomes difficult to close once the bone ends are shortened (**FIG 6A,B**).
- The transverse incision allows for removal of a TKA without difficulty.
- If knee fusion is performed as a solution for infection (post-traumatic or infected TKA), the fusion often can be initiated at the same surgical setting as the débridement.
- The preferred technique is to use a Mayo stand for the débridement (**FIG 6C**).
- The scrub technician places the required instruments onto the Mayo stand, and the surgeon retrieves them as needed. When débridement is completed, the “dirty” Mayo stand is moved away and the limb is reprepared, additional clean drapes are placed, and new gowns are used.
- New Bovie, suction, and light handles are used for the clean procedure.
- A high-speed burr with continuous cooling irrigation is used for débridement of clean, healthy, bleeding bone and to obtain good bone surfaces for maximum bone contact during compression.
- A Versajet hydroscalpel (Smith & Nephew) is used to achieve thorough débridement of the soft tissue and especially the posterior capsule. Use of the Versajet is a very safe way to achieve maximum soft tissue débridement.
- The back of the capsule is always freed from the posterior aspect of the bone to allow good bone contact without compromising the vessels behind the capsule. This usually is done very carefully with the Cobb.
- Once the bone ends are prepared, any of the methods described below can be used to stabilize the fusion.

**FIG 5** - Intraoperative patient positioning used for all knee fusion cases. The entire limb is prepared, with a bump under the ipsilateral buttock. The bump allows for access to the proximal femur for intramedullary rodding or placement of external fixator pins.

**FIG 6** - Transverse anterior knee incision during the surgical procedure (**A**) and postoperatively (**B**). Note the excellent exposure and the excellent wound healing postoperatively. **C.** A separate Mayo stand is used only for the “dirty” or débridement portion of the surgical procedure.
LONG INTRAMEDULLARY ROD INSERTION

Incision and Exposure

- This technique begins with a transverse incision at the knee, centered between the tibia and the femur as determined using fluoroscopy.
- A transverse incision is designed to heal when the bone ends are compressed.
- After the initial exposure, cutting transversely through any remaining patellar tendon or quadriceps tendon, the bone ends are exposed.
- All soft tissue that is tethering the bone ends’ ability to compress must be released without jeopardizing the blood supply to the fusion site.
  - This includes, as mentioned above, freeing the capsule from the posterior aspects of the femur and tibia in a very careful fashion with the Cobb to get direct contact of the bone ends.
- Bone is resected in a careful fashion to minimize the resultant shortening of the limb and to achieve the maximum bone contact possible. Any necrotic bone must be resected.

Reaming the Tibia and Femur

- Once the bone ends are prepared, the tibia is reamed first.
- The femur must be reamed to the same diameter that the tibia was reamed so that maximum stability of the fusion can be achieved with the nail.
  - Overreaming the femur will disallow the best tight fit of the nail into the femoral canal.
  - This is secondary to the fact that the nail diameter is the same from the proximal femur to the distal tibia.
- Previous knee fusion rods had different diameters for the femur and tibia but are no longer commercially available. If this type of rod were available, the femur would be reamed to 1 mm more than the available diameter for the femur (TECH FIG 1).
- The tibia and femur are reamed separately over a guide rod.
  - The tibia is reamed in an antegrade fashion, whereas the femur is reamed in a retrograde fashion.
  - The guide rod is tapped out of the proximal femur through the piriformis fossa. This is an extremely easy way to find the nail insertion site at the proximal femur.
  - Care must be taken, however, to ensure that this does not place the starting point too medial. If this seems to be the case, the proximal starting point is found with a Steinmann pin proximally to ensure that the dreaded complication of femoral neck fracture will not occur from too medial a starting point.

Inserting the Rod

- Rod insertion is the most important part of the case in two respects.
  - The first is to ensure that the bone ends are lined up and there is compression at the fusion site with insertion. It is critical that the bone ends are lined up evenly with the guide rod inserted the entire distance from the femur to the ankle because the rod can still deviate in the soft bone with insertion and violate the cortical wall. Holding the bone ends compressed will also ensure maximum contact at the fusion site after the nail is completely inserted.
  - Second, ensuring the proper rotational alignment of the limb at this stage is critical. The initial position of the limb when prepared was on a bump to internally rotate the limb. When inserting the rod, the limb is adducted. Because of the internal rotation from the bump, my final position for the foot once the limb is adducted is perpendicular to the floor. This ensures some external rotation of the limb once the bump is removed (TECH FIG 2).
Do not count on fixing rotation once the nail has engaged the tibia. Because of the tight fit of the nail in the tibial canal and the anterior bow of 5 to 7 degrees—and, if a Stryker knee arthrodesis rod is used, an additional 5 degrees of valgus that is in the nail—rotating the tibia once the rod is fully engaged in the tibia can lead to tibial fracture.

Once the rod is inserted and locked proximally with a guide arm, additional compression can be achieved at the knee fusion site by holding the foot and driving the rod in more with three or four more mallet slaps to the insertion handle.

The limb is then taken out of adduction and locked distally with the use of a fluoroscopy-guided “perfect circle” freehand technique.

Make sure that adequate compression is maintained until the locking screws are inserted.

The Stryker knee arthrodesis rod has the added feature of a compression screw that can be inserted proximally and allows up to 1 cm of additional compression after the distal interlocking screws are inserted.

**Wound Closure**

- After nail insertion, the incisions are closed with absorbable monofilament suture.
- If nail insertion was performed in a clean fashion, bone graft, bone morphogenic protein, or both can be added to the fusion site before closure. This is especially helpful if minor gapping is present at the fusion site.

**SHORT INTRAMEDULLARY ROD INSERTION**

- The surgical approach can be a standard medial parapatellar approach or through the transverse incision mentioned above.
- Once the bone ends are exposed, an intramedullary guide is used to align the distal femoral and proximal tibial cuts in about 5 degrees of flexion and neutral varus-valgus alignment.
- A trial reduction of the bone ends is performed after the bone cuts to check the bone apposition and alignment. Great care should be taken to obtain good bone contact at the fusion site.
- Another factor to keep in mind is the resultant limb shortening. The average knee arthrodesis is 4 cm short. Too aggressive a resection will result in more shortening and the patient will need to wear a large, bulky, and awkward shoe lift.
- Another way to ensure some flexion in the system is to ream the femur from distal-posterior to proximal-anterior. Because the tibial canal is smaller, it is more difficult to ream the tibia in an eccentric fashion like the femur.
- Once the femur is reamed, the femoral rod is inserted and locked with the targeting arm. Two screws are placed in a lateral-to-medial fashion.
- A slot is then cut into the tibia to allow for the coupling mechanism between the two rods and the tibial guide arm for the interlocking screws.
- The bone plug is saved for grafting at the end of the case.
- There are two options for the tibial screws. Use the ones that will capture the best bone.
- The tibia is then inserted and locked in a medial-to-lateral fashion.
- When inserting the screws, placing a bump underneath the knee will ensure that the femur and tibia are locked with the rods in some flexion, ideally 5 degrees.
- Once the rods are placed and locked, an additional femoral slot can be removed to allow further visualization of the coupling mechanism. This bone plug is also saved for grafting at the end of the case.
- Make sure that the rotational alignment is in neutral to 5 degrees external before completely engaging the tibial rod in the femoral rod and screwing down the compression mechanism. Tighten the screw to get good compression at the bone ends. Take care not to overtighten, or the bone ends might fracture.
- Once the fusion site is compressed, the bone plugs are replaced as bone graft and the incision is closed.
- Full weight bearing is allowed after this procedure if the surgeon is satisfied with the amount of bone contact at the fusion site.

**EXTERNAL FIXATION**

**Application of the Lateral Rail**

- The first step after adequate exposure of the bone ends and débridement of any residual infection is the application of the lateral rail.
- The lateral rail is set up with four clamps: two for the tibia and two for the femur.
- The most proximal clamp is placed at the level of the lesser trochanter, perpendicular to the femoral shaft on the AP view and in the midshaft of the femur.

- It is very important when placing the proximal femoral pins to ensure that they are not positioned too anteriorly in the femoral shaft. This is a major stress riser and can cause a femoral fracture.
- Once one proximal pin is inserted, the most distal tibial pin is then inserted perpendicular to the shaft of the tibia in the AP view.
- Rotation of the limb is set with this pin insertion.
- I prefer to have the toes perpendicular to the floor because when the proximal bump is removed from...
under the buttock, the foot will be about 10 degrees externally rotated.

- After the pin insertions, the middle clamps are positioned (TECH FIG 3).
  - Positioning of the clamps is variable and based on the bone quality at the proximal tibia and distal femur.
  - Ideally, the greater the span of the clamps, the better fixation of the bone.
- A lateral view radiograph is obtained to check the middle clamps.
  - The clamps often are too posterior to hit the bone and need to be moved proximally or distally accordingly.
  - The clamps can also be adjusted by adding a half or full “sandwich” to the clamps to raise the pin insertion site more anteriorly. It is preferable to use the sandwiches to raise the pin insertion sites as opposed to moving the clamps further away from the knee joint.
  - It is at this stage that the flexion of the knee can be “set” into the system.
  - More flexion will necessitate raising the middle lateral two clamps more anteriorly to hit the bone.
  - My usual position is 5 degrees of flexion. This minimizes any additional limb shortening from excessive flexion.
  - In this position, the two middle clamps need one full sandwich to hit the bone.
  - After the insertion of one pin in each clamp, the remaining pins are inserted for a total of eight half-pins (two pins per clamp).
  - The preferred half-pins are hydroxyapatite-coated and are inserted so that the thread distance is the same as the diameter of the bone.

- If the threads remain outside the bone, the pin is weaker than if the threads were buried to the shank.

### Checking Alignment and Mechanical Axis

- Once all the pins are inserted, a Bovie cord is used to check the mechanical axis of the limb. The limb is first placed in the “patella forward” position. Under fluoroscopic guidance, the Bovie cord is used as a straight line from the center of the femoral head to the center of the ankle. After confirming these points, fluoroscopy is used to check where this line or mechanical axis lies at the knee. It should be in the center of the knee or slightly medial. If it is not, the tibial pins can be translated in the clamps more medial or more lateral until the mechanical axis is acceptable.
  - Once this is the case, the pins are secured in the clamps and the tibial clamps are linked with a compression–distraction device. The proximal femoral clamps are secured to the rails.
  - A second compression–distraction device is then placed between the tibial and femoral clamps and compressed.
  - The knee fusion site is visualized during the compression to ensure good bone contact and to make sure there is no soft tissue interposition at the bone ends.

### Wound Closure

- Once the bone ends are opposed and compressed, the anterior knee wound is closed, usually over a drain.
- Once the lateral rail is applied and the wound is closed, it is very easy to apply the anterior fixator. The long rail is placed anteriorly with four clamps set up in the same
fashion as the lateral rail. The clamps are placed so as not to hit the other pins upon insertion of the anterior pins (TECH FIG 4).

- Additional compression can be obtained at the knee fusion site in the office by using the compression-distraction device between the femoral and tibial clamps.

**TECH FIG 4** • The mounted Orthofix LRS after the lateral fixator is applied.

---

**PLATING**

**Plate Size**

- The number of holes in the plates chosen depends on the bone available for fusion in the tibia and femur.
  - If a total hip arthroplasty is present, stopping the plate immediately distal to this can be a stress riser. In such cases, sliding the plate a few holes past the total hip arthroplasty stem and using unicortical screws in the region is helpful.
- The ideal number of holes is 11: 5 for femoral fixation, 4 for tibial fixation, and 2 left empty at the fusion site.

**Exposure**

- The surgical technique begins with the same exposure as previously mentioned.
- A transverse incision can be used, and the plates can be inserted percutaneously in both the anterior and mediolateral plane.
- Fluoroscopy is used to ensure that the plates are flush and securely fastened to the bone.
- The important step is preparation of the bone ends and good bone contact.
- When using plates, the area must first be “sterilized” with the two-stage approach of using an antibiotic-coated cement spacer and then 6 weeks of antibiotics.
- Once this stage is completed, the plates are inserted as a “clean procedure.” This allows autogenous bone graft to be inserted at the fusion site with bone morphogenic protein.
- After preparation of the bone, the alignment is assessed using the Bovie cord test.
- A four-pin temporary lateral fixator can be helpful to achieve alignment and to hold the alignment while the anterior plate is applied. A good assistant can be as helpful as a temporary fixator.
- Once the alignment is good and the plate is applied with the provisional pins, the next pins to be inserted are close to the fusion site—one on the femoral side and one on the tibial side—placed in compression mode.
  - This does two things: compresses the fusion site and pulls the plate down to the bone.
- Once the two screws are inserted, the remaining screws can be placed in a locked mode.
  - This allows for maximum rigidity of the construct so that some weight bearing can be initiated immediately postoperatively.

**Medial or Lateral Plate**

- After anterior plate insertion, the medial or lateral plate can be applied. This is the easier of the two plates to be inserted because the alignment is now rigid.
- Medial or lateral is best determined by the amount of soft tissue coverage, with the plate being applied where there is the best chance for the best soft tissue envelope.
- Occasionally, a posterior plate can be applied on the lateral side of the knee when the anterior soft tissue is too deficient to cover the plate (TECH FIG 5).
  - This requires repositioning the patient in a prone position to apply the plate.

**Anterior Plate**

- When good bone contact and good alignment are achieved, the plates are applied. The anterior plate is easier to apply first.
- The first step is ensuring that the proximal and distal ends will be well approximated to the bone. This is done with a provisional fixation pin at both ends.
  - Great care must be taken to ensure that the rotational, sagittal, and coronal alignments are maintained while the plate is applied.

**TECH FIG 5** • The mounted Orthofix LRS with the completed frame.
For bone loss of more than 5 cm and noncompressible soft tissue defects at the knee secondary to extensive scarring, bone transport is the best option to fill the defect.

The technique begins with determining the extent of the gap. If the gap at the knee will be more than 10 cm, a double-level transport can be performed.

The first step for transport over a nail is to insert the long intramedullary rod as described earlier.

When inserting the rod, make sure that the limb does not inadvertently lose any length. This can best be accomplished by determining the rod length to be used preoperatively from an erect lower limbs radiograph. The length of the normal side can be used as a reference as long as significant shortening of the affected limb is not also present. The affected limb cannot be acutely lengthened because the soft tissues about the knee are not compliant.

Ideally, the affected limb should be 1 cm short to allow clearance of the foot when ambulating. The average knee fusion shortening is 4 cm, and anything up to this amount is tolerable. Any limb shortening more than this can be addressed with the lengthening over a nail technique at the completion of the transport.

The rod diameter chosen for the transport is 10 mm. This allows the transport segment to slide over the rod when the canal is reamed to 12 mm.

Determine the segment to be transported.

The femur is the preferred segment because of the need to perform only one osteotomy and because of the detrimental effects that proximal tibial transport can have on the ankle (equinus).

If, because of the large segmental defect, tibial transport proximally is necessary, the fibula should also be osteotomized at the midshaft and a distal syndesmotic screw should be placed to prevent any proximal fibular migration.

Mark out the osteotomy site of the transported segment.

Once the guide rod is inserted into the femur and tibia, the rod is backed out past the level of the osteotomy and the osteotomy is predrilled with multiple drill holes before reaming.

This allows the reamings to exit out the osteotomy site and to “bone graft” the regenerate site.

The first step is reaming the intramedullary canal of the tibia and femur to 12 mm.

This can be done through the knee, reaming the tibia and femur separately, or from the hip using long 80-cm reamers (Biomet Trauma, Stryker).

Once the rod is inserted and locked at the desired length, the monolateral external fixator is applied.

Applying the monolateral frame to move the transported segment over the nail requires inserting the pins so that there is no contact between the rod and the pins.

With this technique, because the rod and pins are so close, there is a 5% chance for infection of the rod.6

My preference for the femur is to use a lateral Orthofix LRS frame with two pin clamps. Three half-pins are inserted into the proximal clamp, and three half-pins are inserted into the distal clamp. The pins are inserted by using a cannulated wire technique.

The cannulated wire technique starts with a 1.8-mm wire inserted perpendicular to the rod on the AP view fluoroscopic projection but away from the rod by a few millimeters on the lateral view projection.

The most common location in the femur for these pins is proximally and posteriorly at the level of the lesser trochanter (TECH FIG 6).

Once the wire is inserted, it is confirmed using fluoroscopy. The fluoroscopic view must show the wire “on end.”

This is to confirm that when the pin is drilled and placed, it will not be touching the rod. This technique can be very time-consuming.

Fluoroscopy must be used frequently to confirm that the pins are placed away from the rod.

**TECH FIG 6**  • Steps involved in the transport over a nail technique. Bone graft and a plate are applied to the docking site and the fixator is removed at the final surgical setting.
Once the wire is in a satisfactory position on the AP and lateral view projections, a 4.8-mm cannulated drill bit is used to drill the near cortex. This drill bit and the wire are then removed, and a solid 4.8-mm drill bit is used to complete the tract for the pin.

- Drilling with the cannulated drill bit and then the solid drill bit is important because the cannulated drill bit is not end-cutting and sharp enough to go through the cortical bone of the far cortex. Often, these pins are placed entirely in the cortical bone.

- When using the drill, it is imperative that the drill bit not heat up and cause osteonecrosis of the bone.

- If this happens, the pin will become infected and aseptic bone sequestrum will develop. Also, an infected pin places the intramedullary rod at risk for contamination.

- To prevent this, the drill bit is removed at regular intervals while drilling to be cooled and cleaned with a wet, cool laparotomy sponge.

- Once the bone is drilled, a 6-mm hydroxyapatite-coated pin is inserted.

- After insertion of the pins with use of the Orthofix clamp as a guide, the frame is removed and the bone is cut with an osteotome.

- A small incision is used laterally at the level of the femur.

- Often, the bone cannot be completely cut through one incision around the rod. A second incision is then placed anteriorly to complete the osteotomy along the medial femur.

- If the tibia is chosen, the incisions are placed anteriorly and medially to obtain access to the lateral cortex and posteromedial cortex, respectively.

- Once the bone is cut, the pins are used to carefully rotate the bone and determine that the osteotomy is complete.

- When the osteotomy is complete, the fixator is reapplied and the osteotomy site is distracted to ensure that the bone ends will separate.

- This is confirmed by using fluoroscopy, and the osteotomy site is then reapproximated.

- This completes the procedure after the wound closures and dressings.

- Postoperatively, the pins are cleaned daily with saline and redressed with a Kerlix dressing wrapped tightly around each set of pins.

- The dressing prevents skin pistoning around the pins and limits the soft tissue trauma that leads to pin tract infections.

- Touch-down weight bearing for balance only is permitted postoperatively.

- Full weight bearing is permitted once two cortices are present at the regenerate site on the radiographs, once the consolidation phase of bone healing has begun.

- Distraction is begun at postoperative day 5 and is continued until the gap is closed at the knee region.

- When the gap has closed, the patient is brought back to the operating room for insertion of bone graft at the docking site and percutaneous locked plating at the docking site. The locked plating is essential to prevent the transported bone end from migrating.

- Custom rods with predrilled holes to lock the transported segment significantly weaken the rod and are not recommended.

- Once the bone graft and locked plate are inserted, the external fixator is removed.

- If the limb is still significantly short after the docking of the transported segment, the distal interlocking screws are removed from the rod and the external fixator is left in place to continue lengthening.

- Once the desired length is achieved, the patient is returned to the operating room for the insertion of the locking screws and removal of the external fixator.

- The patient is allowed full weight bearing once two of the four cortices are present on the radiographs.

### PEARLS AND PITFALLS

**Poor bone approximation on one side of the fusion or anteriorly**

- This is common anteriorly with good approximation of the medial, lateral, and posterior bone ends. As long as 50% of the diameter of the bone is approximated at the time of fusion, with those bone ends being viable and healthy, the fusion will be successful. Secondary bone grafting can be performed at the defect site. More bone contact is preferred, but not at the expense of massive limb-length discrepancy. If massive limb-length discrepancy is to occur, a different strategy for fusion should be used.

**Difficulty holding the position of the knee fusion with rod insertion**

- Temporary use of an external fixator (one or two pins proximally and one or two pins distally) with the pins placed out of the path of the nail will hold the fusion in a compressed and properly rotated position when inserting the rod. This application is very helpful but not frequently needed for the straightforward fusion.

**Femoral neck fracture**

- Too medial a starting point for the insertion of the antegrade long knee fusion rod can result in a femoral neck fracture. This is very difficult to treat and is best treated with exchange rodding to a long custom knee fusion cephalomedullary nail with screws into the femoral neck and head.

### POSTOPERATIVE CARE

- Postoperatively, regardless of the technique, the patient is encouraged to strengthen the hip and ankle.

- For patients with external fixators, pin tract infections are likely to occur and are initially treated with orally administered antibiotics.

- All patients are given a prescription for an antibiotic to be taken orally, most commonly cephalixin, before discharge and are instructed to start the antibiotic at the first sign of redness, increased tenderness at the pin site, or drainage.

- Follow-up office visits are every 2 weeks for patients who are undergoing bone transport or lengthening. Once the
consolidation phase starts, only monthly follow-up visits are required.
- For patients with external fixation, once the bone has consolidated, the frame is then dynamized in the office 1 month before removal.
  - Dynamization of the frame usually is performed by taking the tension off the compression–distraction devices. This allows the bone to accommodate more load and become stronger before the frame is completely removed.
  - If the bone is strong enough, no pain should occur with dynamization in the office setting.
- For patients with external fixation, if bone graft was not performed at the time of fusion, a second-stage bone grafting procedure can be performed once there is no longer any evidence of infection, approximately 6 to 8 weeks after the index procedure.
- Most patients will need shoe lifts added to the outside of the shoe during the postoperative period.

OUTCOMES
- Harris et al\(^5\) compared the function of knee arthrodesis with that of constrained TKA and found that the knee arthrodesis patients had better stability and performed more physically demanding activities.
- Rud and Jensen\(^11\) examined 23 knee arthrodesis patients and found that 18 had returned to work.
- Most patients should expect to have difficulty with stairs, rugs, and ladders,\(^12\) and patients who performed strenuous work before the arthrodesis rarely resume that strenuous work postoperatively.
- Rand et al\(^10\) reported that seven patients with knee arthrodeses could walk one to three blocks and nine successful knee arthrodesis patients were able to walk more than six blocks.
- Compared with the alternative—above-the-knee amputation—knee fusion offers a stable, painless, and uninjured limb for weight bearing. Most knee arthrodesis patients are ambulators, whereas, according to Pring et al\(^9\), of 23 patients who underwent an above-the-knee amputation for infected TKA, only 7 were ambulators.
- The best way to achieve the best outcomes for these patients with difficult problems is to be thorough in the preoperative discussions regarding what knee arthrodesis can achieve for them.
- Realistic patient expectations are critical in achieving successful outcomes.
- Although revision TKA might be the more attractive alternative, many patients are not proper candidates for that procedure secondary to a poor soft tissue envelope, bone loss, and recurrent infection.
- Hanssen et al\(^4\) documented that 50% of patients with infected revision TKA eventually went on to knee arthrodesis.

COMPLICATIONS
- The complications associated with knee arthrodesis are related to the increased stress placed on the hip, back, and ankle. Osteoarthritis can occur in those areas.
- Takedown of the knee fusion in these circumstances is not recommended, secondary to the extensive complications reported in the literature.\(^7\)
- Other complications that occur include recurrent infection and nonunion.
- These complications can be very difficult to treat, considering the many medical comorbidities in the older population.

REFERENCES
Part 4

Chapter 1
Intramedullary Fixation of Forearm Shaft Fractures 1026

Chapter 2
Open Reduction and Internal Fixation of Displaced Lateral Condyle Fractures of the Humerus 1035

Chapter 3
Open Reduction and Internal Fixation of Fractures of the Medial Epicondyle 1042

Chapter 4
Open Reduction of Supracondylar Fractures of the Humerus 1046

Chapter 5
Closed Reduction and Percutaneous Pinning of Supracondylar Fractures of the Humerus 1050

Chapter 6
Closed, Percutaneous, and Open Reduction of Radial Head and Neck Fractures 1058

Chapter 7
Percutaneous Joystick and Intramedullary Reduction (Metaizeau) Techniques for Radial Neck Fractures 1066

Chapter 8
Supracondylar Humeral Osteotomy forCorrection of Cubitus Varus 1075

Chapter 9
Pediatric Shoulder Fractures 1080
Chapter 10
**Pediatric Hip Fractures** 1088

Chapter 11
**Closed Reduction and Spica Casting of Femur Fractures** 1095

Chapter 12
**Closed Reduction and External Fixation of Femoral Shaft Fractures** 1099

Chapter 13
**Flexible Intramedullary Nailing of Femoral Shaft Fractures** 1106

Chapter 14
**Submuscular Plating of Femoral Shaft Fractures** 1111

Chapter 15
**Distal Femoral Physeal Fractures** 1116

Chapter 16
**Pediatric Tibial Fractures** 1122

Chapter 17
**Open Reduction and Internal Fixation of Tibial Tuberosity Fractures** 1130

Chapter 18
**Operative Management of Pediatric Ankle Fractures** 1134

Chapter 19
**Elbow Arthroscopy for Panner’s Disease and Osteochondritis Dissecans** 1144
Chapter 20  
**Patellar Instability** 1149

Chapter 21  
**Proximal Patellar Realignment** 1156

Chapter 22  
**Arthroscopy-Assisted Management or Open Reduction and Internal Fixation of Tibial Spine Fractures** 1161

Chapter 23  
**Anterior Cruciate Ligament Reconstruction in the Skeletally Immature Patient** 1168

Chapter 24  
**Arthroscopic Drilling of Osteochondritis Dissecans** 1177

Chapter 25  
**Meniscoplasty for Discoid Lateral Meniscus** 1183

Chapter 26  
**Proximal Femoral Rotational Osteotomy** 1187

Chapter 27  
**Proximal Femoral Varus Osteotomy Using a 90-Degree Blade Plate** 1196

Chapter 28  
**Treatment of Congenital Femoral Deficiency** 1202

Chapter 29  
**Surgical Repair of Irreducible Congenital Dislocation of the Knee** 1224
<table>
<thead>
<tr>
<th>Chapter 30</th>
<th>Surgical Management of Blount’s Disease 1230</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 31</td>
<td>Percutaneous Distal Femoral or Proximal Tibial Epiphysiodesis 1238</td>
</tr>
<tr>
<td>Chapter 32</td>
<td>Excision of Physeal Bar 1244</td>
</tr>
<tr>
<td>Chapter 33</td>
<td>Repair of Congenital Pseudarthrosis of the Tibia With the Williams Rod 1251</td>
</tr>
<tr>
<td>Chapter 34</td>
<td>Limb Lengthening Using the Ilizarov Method or a Monoplanar Fixator 1258</td>
</tr>
<tr>
<td>Chapter 35</td>
<td>Guided Growth to Correct Limb Deformity 1270</td>
</tr>
<tr>
<td>Chapter 36</td>
<td>Distal Tibial Osteotomy 1276</td>
</tr>
<tr>
<td>Chapter 37</td>
<td>Multiple Percutaneous Osteotomies and Fassier-Duval Telescoping Nailing of Long Bones in Osteogenesis Imperfecta 1284</td>
</tr>
<tr>
<td>Chapter 38</td>
<td>Syme and Boyd Amputations for Fibular Deficiency 1295</td>
</tr>
<tr>
<td>Chapter 39</td>
<td>Hemi-Epiphysiodesis for Ankle Valgus 1304</td>
</tr>
</tbody>
</table>
Chapter 40
Adductor and Iliopsoas Release 1310

Chapter 41
Rectus Femoris Transfer 1316

Chapter 42
Proximal Hamstring and Adductor Lengthening 1322

Chapter 43
Distal Hamstring Lengthening 1326

Chapter 44
Gastrocnemius Fascia Lengthening 1334

Chapter 45
Distal Femoral Osteotomy for Crouch Gait 1339

Chapter 46
Benign Bone Cysts 1345

Chapter 47
Release of Simple Syndactyly 1351

Chapter 48
Correction of Thumb-in-Palm Deformity in Cerebral Palsy 1358

Chapter 49
Release of the A1 Pulley to Correct Congenital Trigger Thumb 1366

Chapter 50
Transfer of Flexor Carpi Ulnaris for Wrist Flexion Deformity 1371
Chapter 51
Radial Dysplasia Reconstruction 1376

Chapter 52
Forearm Osteotomy for Multiple Hereditary Exostoses 1380

Chapter 53
Modified Woodward Repair of Sprengel Deformity 1387

Chapter 54
Release of the Sternocleidomastoid Muscle 1392

Chapter 55
Posterior Cervical Arthrodeses: Occiput–C2 and C1–C2 1399

Chapter 56
Posterior Exposure of the Thoracic and Lumbar Spine 1408

Chapter 57
Segmental Hook and Pedicle Screw Instrumentation for Scoliosis 1414

Chapter 58
Kyphectomy in Spina Bifida 1424

Chapter 59
Anterior Interbody Arthrodesis With Instrumentation for Scoliosis 1431

Chapter 60
Thoracoscopic Release and Fusion for Scoliosis 1442

Chapter 61
Unit Rod Instrumentation for Neuromuscular Scoliosis 1448
Chapter 73
Triple Innominate Osteotomy 1540

Chapter 74
Chiari Medial Displacement Osteotomy of the Pelvis 1552

Chapter 75
Bernese Periacetabular Osteotomy 1559

Chapter 76
Surgical Dislocation of the Hip 1569

Chapter 77
Valgus Osteotomy for Developmental Coxa Vara 1577

Chapter 78
Valgus Osteotomy for Perthes Disease 1583

Chapter 79
Percutaneous In Situ Cannulated Screw Fixation of the Slipped Capital Femoral Epiphysis 1589

Chapter 80
Flexion Intertrochanteric Osteotomy for Severe Slipped Capital Femoral Epiphysis 1595

Chapter 81
Triple Arthrodesis 1600

Chapter 82
Calcaneal Lengthening Osteotomy for the Treatment of Hindfoot Valgus Deformity 1608
Chapter 83
Open Lengthening of the Achilles Tendon 1619

Chapter 84
Split Posterior Tibial Tendon Transfer 1626

Chapter 85
Surgical Correction of Juvenile Bunion 1633

Chapter 86
Butler Procedure for Overlapping Fifth Toe 1637

Chapter 87
Surgical Treatment of Cavus Foot 1639

Chapter 88
Resection of Calcaneonavicular Coalition 1650

Chapter 89
Excision of Talocalcaneal Coalition 1655

Chapter 90
Ponseti Casting 1661

Chapter 91
Posteromedial and Posterolateral Release for the Treatment of Resistant Clubfoot 1674

Chapter 92
Anterior Tibialis Transfer for Residual Clubfoot Deformity 1682
DEFINITION
- Forearm shaft fractures represent the third most common fracture encountered in the pediatric population.¹
- Closed fracture care is successful in the large majority of children who sustain forearm shaft fractures (especially the common greenstick fracture pattern).
- For children who are 8 to 10 years of age and older with complete fracture patterns, the limits of acceptable displacement (angulation, rotation, and translation) become more strict and the likelihood of surgical intervention increases.⁵

ANATOMY
- The forearm represents a largely nonsynovial two-bone joint with a high-amplitude range of motion (roughly 180 degrees).
- In the fully supinated anteroposterior (AP) plane the radius bows naturally out and away from the relatively straight ulna, while both bones are predominantly straight in the lateral plane.
- Anatomically the shaft of the radius extends from the most proximal aspect of the tubercle of Lister (which approximates the distal metaphyseal-diaphyseal junction) to the proximal base of the bicipital tuberosity. The shaft of the ulna corresponds to these same points on the radius (FIG 1).⁵,⁶
- In unfractured bones the normal orientation of the radial styloid and bicipital tuberosity is slightly less than 180 degrees from one another, while the ulnar styloid and coronoid process come closer to a true 180-degree relationship.
- Classically, forearm shaft fractures are divided into distal third (pronator quadratus region), central third (pronator teres region), and proximal third (biceps and supinator region). These anatomic relationships offer insight into the deforming forces acting on the fractured forearm (FIG 2).

PATHOGENESIS
- Forearm shaft fractures most commonly occur secondary to a fall on an outstretched arm and usually involve both bones. Forward falls tend to involve a pronated forearm and backward falls a supinated forearm.
- Single-bone forearm shaft fractures should raise significant suspicion regarding the presence of a Galeazzi or Monteggia-type injury (see Chap. PE-52).
- Mechanisms of injury that involve little rotational force result in forearm fractures at nearly the same levels, while greater rotational force results in fractures at rather different levels.

NATURAL HISTORY
- The remodeling potential of the pediatric forearm shaft has been well documented and is considered to be most predictable in children less than about 8 to 10 years of age.
- Spontaneous correction and improvement of malaligned shaft fractures are considered to occur in young children via three mechanisms:
  - Adjacent physis produce “straight bone” via normal growth.
  - Physeal orientation tends to “right its horizon” via the Hueter-Volkmann law.
  - True shaft remodeling occurs via Wolff’s law.⁹

PATIENT HISTORY AND PHYSICAL FINDINGS
- The clinician should gather as much pertinent information as possible regarding the mechanism of injury (eg, a fall from the bottom step of the playground sliding board may be much different from a fall from the top step of the same sliding board).
- The clinician should determine whether the patient has any other complaints of pain beyond the forearm shaft region (eg, wrist or elbow tenderness). Any perceived deformity or pain to palpation should trigger dedicated radiographs of the problematic region.
- The clinician should elicit any past history of fracture or bone disease in the patient or the patient’s family.
- Physical examination of the skin of the child’s forearm should be performed to rule out the presence of an open fracture. Any wound, no matter how small or seemingly superficial, should be carefully evaluated. Persistent bleeding or oozing from a small suspicious wound should be considered an open fracture until proven otherwise.
- The environment of the injury has special significance for open fracture management. For instance, farm-related injuries may alter the treatment regimen for the patient.
- Multiple trauma or high-energy trauma scenarios dictate that a screening orthopaedic examination be performed to help rule out injuries to the other extremities as well as the spine.
- Brachial, radial, and ulnar pulses should be palpated and distal capillary refill should be assessed.
- Sensory examination should include, at minimum, light touch sensation testing (or pin prick testing if necessary) of the autonomous zones of the radial, ulnar, and median nerves. Older children may be able to comply with formal two-point discrimination testing.

![FIG 1](image-url) - The radial diaphysis extends from the most proximal aspect of the tubercle of Lister to the proximal base of the bicipital tuberosity. The ulnar diaphysis corresponds to these same points on the radius.
• It has been said that you need only a thumb to test the motor function of all three major nerves: radial nerve = extensor pollicis longus, ulnar nerve = adductor pollicis, median nerve = opponens pollicis.
• Peripheral nerves in the fractured extremity are assessed with the "rock-paper-scissors" method.
  • The radial nerve (really the posterior interosseous nerve in the forearm) is tested with "paper"—extension of the fingers and wrist well above a zero-degree wrist position. The autonomous zone is the dorsal web space between the thumb and index finger. There is a risk of iatrogenic injury during surgical exposure of the proximal radial shaft.
  • The ulnar nerve is tested with "scissors"—adducted thumb, abducted fingers, and flexor digitorum profundus function to ring and pinky. The autonomous zone is palmar tip pinky finger. This is the most common iatrogenic nerve injury after internal fixation of forearm shaft fractures.
  • The median nerve is tested with "rock." The autonomous zone is palmar tip index finger. The median is the most commonly injured nerve after closed or open forearm shaft fractures.
  • The anterior interosseous nerve is tested with the "okay" sign. Flexion of the distal interphalangeal of the index finger and the interphalangeal of the thumb herald flexor digitorum profundus and flexor pollicis longus function of these digits. This is a motor branch only (it has no cutaneous innervation, only articular). Isolated palsy has been reported secondary to constrictive dressings and after proximal ulna fracture.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

• AP and lateral radiographs (two orthogonal views) that include the entire radius and ulna are essential for proper diagnosis of forearm shaft fractures in children (FIG 3). If suspicion exists for compromise of the distal or proximal radioulnar joints (Galeazzi or Monteggia injuries), dedicated wrist and elbow radiographs are also indicated.
• If fracture angulation is noted on both orthogonal forearm views, the true fracture angulation exceeds that measured on either individual view (FIG 4).
The radiographs should be used to classify the forearm fracture in a practical fashion with respect to “2 bones, 3 levels, 4 fracture patterns” (Table 1). This is akin to describing bone tumors in terms of matrix, margins, and so forth.

**DIFFERENTIAL DIAGNOSIS**

- Galeazzi injury (concomitant distal radioulnar joint disruption)
- Monteggia injury (concomitant proximal radioulnar joint disruption)
- Coexisting distal humeral fracture (eg, supracondylar humeral fracture, also known as floating elbow)
- Open fracture (the clinician must be aware of small, innocuous-appearing wounds)
- Compartment syndrome (more common in setting of floating elbow and extended efforts at indirect reduction of difficult-to-reduce fractures)

**NONOPERATIVE MANAGEMENT**

- Nonoperative (closed) fracture management is used in the vast majority of pediatric forearm shaft fractures.
- Successful nonoperative treatment requires an eclectic mix of anatomic knowledge, skillful application of reduction techniques, appreciation for remodeling potential, and respect for the character of the soft tissue envelope.
- Greenstick fracture patterns retain a degree of inherent stability; intentional completion of these fractures is not recommended. Davis and Green reported a 10% loss of reduction rate with greenstick fractures and a 25% rate with complete fractures.2
- Greenstick fracture patterns often involve variable amounts of rotational deformity such that when the forearm is appropriately derotated, reduction of angulation occurs simultaneously.
- Apex volar greenstick fractures are considered to represent supination injuries that require a relative degree of pronation to effect reduction.
- Apex dorsal greenstick fractures are considered to be pronation injuries that require supination to aid reduction.
- Classic finger-trap and traction reduction techniques are probably best reserved for complete both-bone fracture patterns. When dealing with complete both-bone shaft fractures, respect should be paid to the level of the fractures when choosing a relatively neutral, pronated, or supinated forearm position.
- Price has suggested that estimated rotational malalignment should not exceed 45 degrees.3 The related concepts of maintenance of an appropriate amount of radial bow and interosseous space on the AP radiograph must also not be forgotten, but precise criteria do not exist at this time.
- Initial above-elbow cast immobilization is the rule for all forearm shaft fractures, as this appropriately controls pronation–supination as well as obviating the orthopaedic maxim of immobilizing the joints above and below the fracture. An extra benefit of above-elbow immobilization relates to the activity limitation it imposes; in some instances this may increase the chances of maintaining a satisfactory reduction in an otherwise very active customer.

**SURGICAL MANAGEMENT**

- Flexible intramedullary nail treatment of pediatric forearm shaft fractures focuses predominantly on displaced complete fractures, many of which may have minor comminution (butterfly fragments usually less than 25% of a shaft diameter).
- When efforts at closed fracture management do not achieve and maintain fracture reduction within accepted guidelines, surgical treatment is indicated.
- When complete fractures occur in children younger than about 8 to 10 years of age with angulation of at least 20 degrees in the distal third, 15 degrees in the central third, or 10 degrees in the proximal third, risk–benefit discussions are appropriate regarding further efforts at fracture reduction and possible internal fixation.3,10
- Lesser measured angulation associated with significant forearm deformity (as defined in a discussion between the orthopaedic surgeon and the parents) may also prompt intervention in selected children.
- Complete forearm shaft fractures in children older than 8 to 10 years of age should be evaluated very critically with the intention to accept no more than 10 degrees of angulation at any level.3,10 Compromise (loss) of interosseous space should also be considered, as well as rotational malalignment (difficult to assess precisely) when debating the merits of continued cast treatment versus flexible intramedullary nail fixation.

**Preoperative Planning**

- Rotational alignment of the radius and ulna should be assessed and estimated using the guidelines mentioned in the Anatomy section. Concern is increased if greater than 45 degrees of rotational malalignment is judged to be present.
- Measurement of the narrowest canal diameter of the radius (usually midshaft) and ulna (usually distal third) will aid in the selection of appropriately sized intramedullary nails. Implants 2 mm in diameter or smaller are commonly used, and the same-sized nail is used in each bone. It is far worse to select implants that are too big rather than too small.
- Assessment of existing or impending comminution is prudent. Significant comminution may lead the surgeon to choose plate fixation over intramedullary fixation for one or both bones.
- Assessment of the soft tissue envelope of the forearm is important. Tense swelling of the forearm certainly increases suspicion for compartment syndrome, and the surgeon should be prepared to measure compartment pressures accordingly.
Positioning

- The patient is placed in a supine position on the operating room table with the involved extremity positioned on a sturdy hand table to allow easy, unobstructed radiographic visualization of the entire forearm (FIG 5).
- In general, the monitor for the portable fluoroscopy unit should be positioned near the end of the operating table, opposite the imaging unit (C-arm).
- A nonsterile tourniquet may be applied about the upper arm (near the axilla) before preparation and draping, but it is not routinely inflated.
- The limb is appropriately prepared and draped, with care being taken to ensure that the first layer is a sterile impervious one (eg, blue plastic U-drape). The C-arm is also appropriately protected with a C-arm sterile plastic drape and an additional sterile skirt (usually a sterile paper half-sheet). Without this sterile skirt certain limb positions and certain surgical maneuvers occur far too close to nonsterile territory.

Approach

- Physeal-sparing distal radial entry is routinely obtained via the floor of the first dorsal compartment (alternately, the interval between the second and third dorsal compartments near the proximal base of the tubercle of Lister may be used).
- Physeal-sparing proximal ulnar entry is typically achieved via an anconeus starting point just off the posterolateral ridge of the olecranon. The true tip of the olecranon is avoided as an entry point because it needlessly violates an apophyseal growth plate, and a subcutaneous nail in this region often leads to painful olecranon bursitis.
- In complete both-bone fractures the radius is routinely approached first as it is considered to be the more difficult bone to reduce.
- No power instruments are required for completion of the procedure. Key instruments are a stout sharp-tipped awl and T-handled chucks that achieve a firm grip on the flexible nail such that it can be rotated as needed (FIG 6).

DISTAL RADIAL ENTRY POINT (PHYSEAL-SPARING)

- Using fluoroscopy (C-arm), a physeal-sparing distal radial incision is fashioned overlying the first dorsal compartment (TECH FIG 1A).
- Care is taken to protect branches of the superficial radial nerve. A short portion of the first dorsal compartment is opened.
- The tendons within the first dorsal compartment are retracted and protected before the awl engages the distal radius (TECH FIG 1B).
- After fluoroscopic confirmation of starting awl position, partial right and left rotations (not full turns) are used to

TECH FIG 1 • Repair of forearm fracture of the patient in Figure 3. A. Physeal-sparing incision fashioned with fluoroscopic assistance. B. The surgeon must identify and protect the abductor pollicis longus and extensor pollicis brevis. (continued)
gain satisfactory distal radial entry. A two-handed awl technique is used.

- Satisfactory intramedullary awl position is confirmed by a gentle “bounce” against the far cortex as well as fluoroscopic AP and lateral projections (TECH FIG 1C–E).
- The awl is temporarily left in its intraosseous position before insertion of the radial flexible intramedullary nail. Thus, the surgeon’s ability to judge both the portal location and the angle of nail entry will be facilitated by immediate sequential awl removal and nail tip insertion.

**Reduction and Nail Passage Within the Radius**

- The flexible nail for the radius is contoured such that it will re-establish appropriate radial bow. Nail contouring is gradual, smooth, and substantial. Acute bends in the nail should not be apparent (TECH FIG 2A–C).
- Entry into the distal radius entry site should be directly visualized, and the feel of the nail within the intramedullary canal offers distinct tactile feedback called “scrape.” Entry is further confirmed fluoroscopically (TECH FIG 2D).
- The radial nail is gently advanced up to the level of the fracture. Reduction is achieved via a combination of longitudinal traction and judicious use of AP compression with a radiolucent tool such as a vinyl Meyerding mallet (TECH FIG 2E).
- The nail is rotated to optimize nail passage across the fracture site (TECH FIG 2F–H), and then it is advanced to an appropriate depth within the proximal fragment (TECH FIG 2I).
TECH FIG 2 • (continued) D. Under direct visualization, the contoured radial nail is manually inserted into the previously prepared entry point. Distinctive intramedullary tactile feedback (“scrape”) should be detected and the implant advanced as far as possible using only the surgeon’s hands. Note the trajectory of the nail (tip points radially), as this nail orientation should be maintained during most of the procedure. E. Appropriate longitudinal traction needs to be applied by an assistant, as well as supplemental reduction forces such as that provided by the broad flat surface of a vinyl Meyerding mallet. F. The bent tip of the nail (the “fang”) approaches the fracture site after being advanced as far as possible without using a hammer. “Manual forces only” should be used as much as possible to advance the nail within the canal using a properly tightened T-handle or similar chuck. G. As the fang crosses the fracture site, proximal fragment intramedullary canal entry is often facilitated by nail rotation. At this point finesse is much, much more important than brute strength. H. Once the nail properly enters the proximal fragment, the position is radiographically confirmed and the nail is rotated back toward its “entry trajectory.” I. The nail is advanced to an appropriate level in the region of the radial neck and rotated so as to properly recreate radial bow. Restoration of radial bow can be quite striking when visualized under live C-arm imaging. When radial nail contouring is preserved during the insertion process, the nail should be rotated 180 degrees such that the fang points in an ulnar direction. If this position does not optimize radial bow, then live C-arm imaging will allow the surgeon to choose the nail rotation that does.
An entry point is selected on the lateral edge of the subcutaneous border of the proximal ulna. The skin is touched but not pierced by the awl (TECH FIG 3A).

Once correct position is confirmed fluoroscopically, the awl is used to gain percutaneous entry to the intramedullary canal of the proximal ulna (TECH FIG 3B).

A mildly contoured (i.e., nearly straight) flexible nail is inserted into the proximal ulna intramedullary canal (TECH FIG 3C).

Proper position within the proximal ulna is confirmed fluoroscopically (TECH FIG 3D).

The ulnar nail is cut such that it is subcutaneous yet easily palpable.

The ulna is reduced and the nail is passed across the fracture site in a manner similar to the radius. If open reduction becomes necessary, a simple Mueller (AO-type) approach to the ulna is used (exploiting the interval between the extensor carpi ulnaris and the flexor carpi ulnaris).

The ulnar nail is cut such that it is subcutaneous yet easily palpable.

PROXIMAL ULNA ENTRY POINT (PHYSEAL-SPARING)

The precontoured radial nail is rotated so as to optimize and normalize the anatomic bow of the radial shaft. This step is most dramatic when performed under several seconds of live fluoroscopic imaging.

Appropriate full-length forearm imaging must be performed at the end of the case to ensure an acceptable rotational relationship between the radial styloid and the bicipital tuberosity, as well as the ulnar styloid and the coronoid process.

Care must be taken when cutting the radial nail. If the nail is too short, removal will be difficult and dorsal compartment tendons adjacent to a sharp nail edge will be at risk. Thus, the nail should be cut to protrude beyond the tendons while still remaining subcutaneous.

Closure of the radial entry site is performed with absorbable subcutaneous and subcuticular suture and Steri-Strips. Care is taken to protect branches of the superficial branch of the radial nerve (TECH FIG 4A, B).

Light Xeroform, sterile gauze, and Tegaderm dressings are applied to the surgical sites (TECH FIG 4C–E).

A removable forearm fracture brace may also be applied to increase patient comfort (TECH FIG 4F).
TECH FIG 4 • My preferred closure, dressing, and splinting technique. A. Several interrupted absorbable sutures (typically 3-0 Vicryl) are used for closure of the subcutaneous and subcuticular portion of the radial wound. Steri-Strips are added for final wound closure (B), followed by Xeroform and sterile gauze (C), and a Tegaderm dressing (D). E. A similar dressing consisting of Xeroform, sterile gauze, and Tegaderm is applied to the proximal ulnar wound. F. A removable Velcro forearm fracture brace is applied at the end of the procedure.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which bone to reduce and fix first?</td>
<td>Once one bone is successfully reduced and stabilized via indirect techniques, achieving the same for the second bone will be more difficult. Thus, the radius should be stabilized first, as it is “deeper.” Then, if required, exposure of the nearly subcutaneous ulna is relatively easy.</td>
</tr>
<tr>
<td>How much flexible nail should be left extruding from the bone?</td>
<td>If it is too long, soft tissue adjacent to sharp nail edges is at risk. If it is too short, nail removal will be needlessly difficult.</td>
</tr>
<tr>
<td>At what point should efforts at closed reduction be abandoned in favor of a limited open reduction?</td>
<td>I use the “three strikes and you’re out” rule (three low-amplitude shots at crossing the fracture site) or the “11-minute rule.” Once either or both are violated, I convert the case to open reduction. Remember, cases of forearm compartment syndrome have been attributed to extended efforts at indirect reduction.</td>
</tr>
<tr>
<td>What if an intramedullary nail seems to become incarcerated after crossing the fracture site?</td>
<td>The surgeon should remove the nail and convert to one of a smaller diameter before creating new comminution or distracting the fracture site. Distracted fracture fragments may lead to nonunion.</td>
</tr>
<tr>
<td>What if sterile intraoperative radiographs suggest malrotation of one or both of the forearm bones?</td>
<td>The surgeon should back the offending nail up a bit and see if improved rotational alignment of the fracture fragments can be obtained via forearm rotation and T-handle chuck manipulation. The surgeon then re-advances the nail to hold position. If this does not work, the surgeon should consider switching to a smaller-diameter nail as intramedullary interference fit may be excessive.</td>
</tr>
<tr>
<td>When should the flexible nails be removed?</td>
<td>The originators of this technique suggest nail removal by about the sixth postoperative month. Forearm shaft fractures have the highest refracture rate (about 12%) of all pediatric fractures.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Other than patients with open fracture, flexible nailing of the forearm can be performed as a outpatient procedure so long as there are absolutely no concerns about swelling or compartment syndrome.
- Oral prophylactic antibiotics may be continued for several doses postoperatively if desired, but usually an appropriately administered preoperative intravenous antibiotic (within 2 hours of the surgical incision) is all that is required.
- The patient is allowed immediate active elbow and hand motion. Concerns about rotational stability after flexible nail stabilization seem to have been vastly overstated, and above-elbow immobilization is not required.
- As there are no sutures to remove, outpatient follow-up may occur in 4 to 6 weeks (FIG 7A,B).
- The originators of this procedure have suggested that the nails be removed by about the sixth postoperative month (FIG 7C,D).
OUTCOMES

- At this time no randomized trials comparing flexible intramedullary nailing of forearm shaft fractures versus cast treatment have been conducted.
- A systematic review of English-language reports comparing flexible nailing to cast treatment found a significantly lower risk of forearm stiffness with nailing (25% stiffness with casting versus 5% with flexible nailing). This comes at the price of a higher rate of minor complications (21%) with surgery versus casting (6%).

COMPlications

- Sensory neurapraxia (usually the superficial branch of the radial nerve) occurs at a rate of at least 2% after flexible intramedullary nailing. These deficits are almost always temporary, resolving over weeks to months.
- The deep infection rate (osteomyelitis) after flexible intramedullary nailing of pediatric forearm shaft fractures is less than 0.5%; this can be compared to the reported 5% rate of osteomyelitis after plate fixation of similar fractures.
- Extensor tendon injury (especially the extensor pollicis longus) has been reported by multiple authors and may occur during nail insertion or nail removal as well as when tendons repetitively glide past a sharp nail tip (slowly sawing the tendon in two). Radial entry through the floor of the first compartment may minimize this complication (versus entry between the second and third compartments).
- In the clinical setting of forearm shaft fractures coexisting with ipsilateral humeral fracture (floating elbow), the incidence of compartment syndrome may be as high as 33%. When longer operative times are required (about 2 hours), a 7.5% rate of compartment syndrome has also been reported.
- Delayed union and nonunion are decidedly rare after flexible intramedullary nailing of pediatric forearm fractures. If either delayed union or nonunion occurs, there is usually some explanation, such as a technical error (eg, too large an intramedullary implant distracting the ulnar fracture site), infection, or neurofibromatosis.
- There should be a 5% or less chance of long-term forearm stiffness after flexible intramedullary forearm shaft fixation.

REFERENCES

DEFINITION
- Lateral condyle fractures refer to fractures of the lateral aspect of the distal humerus and may involve any or all of the following: metaphysis, physis, epiphysis, and articular surface.
- Fractures of the lateral condyle of the distal humerus account for 10% to 15% of all pediatric elbow fractures, second in frequency only to supracondylar distal humerus fractures.
- Nondisplaced fractures may hinge on the articular cartilage, making them more stable than their unstable, displaced counterparts.

ANATOMY
- Proximally, lateral condyle fractures almost always include some portion of the posterolateral metaphysis and then propagate along the physis before exiting through or around the ossification center of the capitellum.
- The articular cartilage may or may not be violated.
- The extensor carpi radialis longus and brevis muscles and lateral collateral ligament typically remain attached to the distal fragment.
- Anterior and posterior portions of the elbow joint capsule may be torn if there is significant displacement.
- Milch classified lateral condyle fractures based on the distal portion of the fracture line (FIG 1).
  - Milch type I fractures (the less common) traverse the metaphysis and physis as well as extend across the ossification center of the lateral condyle.
  - Milch type II fractures (the more common) extend from the metaphysis, through the physis, and exit in the unossified trochlea, medial to the capitellum ossification center. Displacement of the trochlear crista allows lateral translation of the forearm and increases the instability of this pattern.
- It is difficult to apply the Salter-Harris classification system to lateral condyle fractures since portions of the distal humeral epiphysis may not yet be ossified.
  - A fracture propagating from the metaphysis through the physis and then through the capitellum ossification center (Milch I) is analogous to a Salter-Harris type IV fracture.
  - A fracture that extends from the metaphysis through the physis and exits through the unossified trochlea medial to the capitellum ossification center (Milch II) may appear radiographically analogous to a Salter-Harris type II fracture, but its involvement of the articular cartilage is analogous to Salter-Harris types III and IV.
- A numeric classification system identifies fractures based on displacement.
  - Stage I fractures involve the metaphysis and physis but do not violate the articular cartilage, thus limiting their ability to displace.
  - Stage II fractures cross the articular surface but are minimally displaced.
- Stage III fractures are displaced fractures that cross the metaphysis, physis, and articular surface, frequently resulting in rotation of the distal fragment (FIG 2).

PATHOGENESIS
- The typical mechanism for a lateral condyle fracture is a fall on an outstretched hand.
- Adduction of a supinated forearm with the elbow extended can result in avulsion of the lateral condyle.
- Axial load of the forearm combined with valgus force can also propagate a fracture through the lateral condyle.
- Lateral condyle fractures usually occur as isolated injuries, although elbow joint subluxation and radial head or olecranon fractures may be associated.

NATURAL HISTORY
- The natural history of lateral condyle fractures depends on the initial fracture displacement as well as the long-term viability of the growing physis.
- Completely nondisplaced lateral condyle fractures may heal regardless of treatment.
- Nondisplaced fractures can displace over time if the articular cartilage is violated or if there is significant associated soft tissue injury.
- Delayed union can occur even in nondisplaced fractures and may be due to poor metaphyseal circulation, bathing of the fracture in synovial fluid, or tension on the condylar fragment by attached muscles.
- Fractures that heal in near-anatomic alignment can yield excellent functional and cosmetic outcomes.

FIG 1 • Milch classification of lateral condyle fractures is based on location. A. Type I fracture line passes through the ossific nucleus of the capitellum. B. Type II fracture line passes medial to the capitellar ossific nucleus into the trochlear groove.
Lateral condyle fractures associated with lateral physeal arrest can result in valgus deformity and tardy ulnar nerve palsy.

Lateral condyle fractures associated with central physeal arrest can result in a “fishtail” deformity due to continued growth medially and laterally but limited growth in between.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Most patients report a fall, either on an outstretched hand or from some height, resulting in pain and inability to fully move the elbow.
- It may be difficult to obtain a history from a young child; therefore, parents or caregivers may need to be questioned.
- The clinician should be patient during the physical examination. Young children may be very fearful. The clinician should ask the child to point to what hurts most, and this part should be examined last. This allows the clinician to establish the patient’s trust and rule out other associated injuries.
- The clinician should look for obvious deformity, swelling, ecchymosis, and open wounds about the elbow.
- The clinician should assess for pulses and capillary refill.
- Sensation is assessed by comparison with the uninvolved side. Rather than stroking a finger and asking a young child, “Do you feel this?” the clinician can rub the same site on both hands and ask, “Does it feel the same or different?”
- Motor function is assessed by observing for spontaneous movement during the entire encounter. A scared child may refuse to move when asked by a physician but may demonstrate voluntary movement when asked by a parent or sibling. Being playful during the examination can help. For example, when testing for ulnar nerve function, asking a 5-year-old to show you how old he or she is may be more rewarding than asking the child to spread his or her fingers.
- The wrist and shoulder are palpated before touching the elbow.
- A single finger is used to gently palpate the olecranon, medial epicondyle, posterior humerus, lateral condyle, and radial head to try to localize the site of injury. Crepitus suggests displacement and instability of the fracture fragment.
- Increased motion during varus stress testing suggests instability of the fracture. Due to pain, however, this test can rarely be done on an awake child. It is often reserved for intraoperative assessment rather than preoperative diagnosis.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Radiographs of a suspected lateral condyle fracture should include anteroposterior (AP), lateral, and internal oblique views (FIG 3A–C).
- Valgus and varus stress radiographs can provide information about the stability of the fracture. Since such films are poorly tolerated in an awake child, they are rarely obtained outside of the operating room.
- For nondisplaced or minimally displaced fractures, magnetic resonance imaging (MRI) can be used to determine whether the articular surface is violated (FIG 3D).
- Arthrograms can provide detail about the articular congruity of lateral condyle fractures but are typically reserved for intraoperative assessment (FIG 3E).

**DIFFERENTIAL DIAGNOSIS**

- Contusion
- Lateral collateral ligament strain or sprain
- Radial head or neck fracture
- Supracondylar distal humerus fracture
- Transphyseal fractures
- Medial condyle fractures
- Proximal ulna or Monteggia fractures
- Elbow dislocation
- Child abuse

**NONOPERATIVE MANAGEMENT**

- Nonoperative management of lateral condyle fractures is typically reserved for nondisplaced or minimally displaced (less than 2 mm) fractures.
- The upper extremity is immobilized in a long-arm splint or cast with the elbow flexed 90 degrees and the forearm in neutral.
- Casts that are excessively heavy or short on the upper arm tend to slide down, thus increasing the risk of later displacement.
Follow-up radiographs should be obtained in 3 to 5 days to assess for further displacement. If displacement occurs, operative treatment is indicated. If the fracture remains nondisplaced, long-arm casting is continued for another week and then repeat radiographs are obtained. If still nondisplaced, the fracture is maintained in a long-arm cast for 3 to 4 weeks or until there is radiographic evidence of fracture union. Delayed union may occur, requiring up to 12 weeks of immobilization. Poor vascularization of the fracture fragment and bathing of the fragment in articular fluid may contribute to this phenomenon.

**SURGICAL MANAGEMENT**

- Surgery is recommended for lateral condyle fractures with more than 2 mm of displacement or rotational deformity that occurs acutely or during the early follow-up period of nonoperative treatment.
- Closed techniques with percutaneous pinning are reserved for minimally displaced fractures with a congruous articular surface confirmed by arthrography.
- Open surgery is required for displaced fractures.

**Preoperative Planning**

- Preoperatively, a careful neurovascular examination should be performed and documented. Fortunately, unlike supracondylar fractures, isolated lateral condyle fractures rarely have any associated neurovascular injury.
- Plain radiographs, including AP, lateral, and internal oblique views, should be adequate to make the decision to operate.
- Displacement of more than 2 mm indicates the need for surgical intervention.
- Displacement on two or more views suggests the need for open treatment.
- Displacement on only one view suggests that the fracture may be hinging on intact articular cartilage and may be treatable by percutaneous techniques.
- Fractures with borderline displacement (2 to 3 mm) may be better assessed under anesthesia, where stress radiographs or an arthrogram can guide treatment.

**Positioning**

- The patient is placed in the supine position on the operating table and general anesthesia is induced.
- The child should be brought to the edge of the operating table to facilitate fluoroscopic imaging of the operative limb (**FIG 4**).

**FIG 4 • Positioning the patient on the edge of the table allows easy access for fluoroscopy. The base of the unit may be used as an arm table.**
- Care must be taken to prevent the patient’s head from rolling off the table’s edge. Placing a foam doughnut under the head can provide stability.
- The receiving end of a standard fluoroscopy unit can be used as the operative table for the involved limb. Bringing the fluoroscopy unit up from the foot of the bed allows room for the surgeon and assistant to access the lateral side of the elbow.
- Alternatively, a hand table may be used and the fluoroscopy unit can be brought in after draping.
- A sterile tourniquet is recommended to allow full access to the elbow after draping.

**CLOSED REDUCTION AND PERCUTANEOUS PINNING**

- This technique is reserved for minimally displaced (2 to 4 mm) fractures.
- Fracture stability should be assessed under anesthesia with varus stress radiographs and arthrography.
- Two divergent smooth pins are recommended. Although 0.062-inch Kirschner wires are usually adequate, 5/64-inch Steinmann pins may be used in larger children.
- The first wire is placed through the skin into the lateral condyle to engage the metaphyseal fragment distally.
  - The wire should be directed from distal lateral to proximal medial, penetrating the cortex medially.
  - A second wire is then placed in a similar manner, diverging at the fracture site.
  - Increasing the distance between the wires at the fracture site increases stability (**TECH FIG 1A**).
- Wires may cross the ossification center of the capitellum to improve divergence (**TECH FIG 1B,C**).
- Occasionally, a third wire is needed. This wire is added if, after placing the first two wires, there is still motion at the fracture site when the elbow is varus stressed under fluoroscopy.
- The wires can be cut and bent 90 degrees outside of the skin.
- Sterile felt can be placed between the skin and the cut end of the wire. This helps prevent the cut end of the wire from digging into the skin during the postoperative swelling phase.

**TECH FIG 1** - **A.** Intraoperative fluoroscopic image showing two percutaneously placed Kirschner wires stabilizing a lateral condyle fracture. **B,C.** AP and lateral views of fracture treated with two divergent Kirschner wires.
OPEN REDUCTION AND INTERNAL FIXATION

- Unstable fractures require open treatment. This includes acutely displaced fractures as well as originally nondisplaced fractures that displace during early follow-up.

Exposure

- The lateral Kocher approach is used, although the dissection is typically facilitated by the rent in the brachioradialis that leads directly to the lateral condyle.
- A 5- to 6-cm curvilinear incision is used, with two thirds of the incision proximal and one third distal to the elbow joint (TECH FIG 2A).
- The interval is between the brachioradialis and the triceps down to the lateral humeral condyle. The anterior articular surface of the elbow joint is exposed by working from proximal to distal and retracting the soft tissues of the antecubital fossa anteriorly.
  - Although the fracture hematoma can obscure distinct muscular planes, a tear in the aponeurosis of the brachioradialis may lead directly to the fracture site.
- Dissection is kept anterior. Care should be taken to avoid stripping any of the soft tissues from the posterior aspect of the fracture fragment while the soft tissues are elevated off the anterior distal humerus, since this contains the blood supply to the lateral condyle epiphysis (TECH FIG 2B).
- Exposure is complete when the trochlear or medial extent of the fracture can be assessed anteriorly.

Fracture Reduction

- The goal of reduction is to achieve a congruent articular surface without any step-off.
- Lifting the anterior soft tissues with a Zenker retractor or similar instrument can allow direct visualization and inspection of the articular surface.
  - A Zenker retractor is narrow and angled, which makes it useful for lifting and retracting the anterior soft tissues without unnecessary stretch (TECH FIG 3A).
  - A small finger or elevator can be placed into the anterior elbow joint to palpate the trochlear–capitellar junction.
  - A common kitchen fork can be a useful instrument in this case.
  - Bending the outer tines back decreases the width of the fork and allows the central tines to fit into a small wound.
  - The central tines can be used to engage the distal fragment, which is then rotated and pushed into position.
  - Gaps between the tines allow room for placement of Kirschner wires (TECH FIG 3B).
- Alternatively, a Kirschner wire can be placed into the distal fragment and used as a joystick to help control the reduction.

**Fixation**

- Once the fragment is reduced, a smooth Kirschner wire is advanced from the metaphyseal portion of the distal fragment, across the fracture site, and into the medial cortex proximal to the fracture.
- A second Kirschner wire (or the original joystick wire) can now be advanced across the fracture site into the medial cortex.
- The wires can be cut and bent 90 degrees outside the skin to facilitate easy removal in the office in about 4 to 6 weeks.
- Alternatively, they can be cut very short and bent under the skin. This may decrease the risk of pin tract infection, but it requires a return to the operating room for pin removal (TECH FIG 4).
- If the wires are to be cut and bent outside the skin, the wires enter the skin through a separate stab site posterior to the incision.
- If a wire needs to be placed through the incision, it can be cut and the posterior skin can be pulled up and over the sharp cut end before closure.
- Increasing the gap between the wires at the fracture site increases rotational control.

- In older children with a larger metaphyseal fragment, a compression screw can be used rather than wires.
- The prominent screw head may be symptomatic after healing, however, thus requiring a return to the operating room for removal.
- Compressive threads across immature cartilage can impede growth in younger children.
- This technique, therefore, is usually reserved for delayed unions or nonunions.
- In many cases, closure of the lateral periosteum may be possible with sutures. Such closure may lessen the chance of lateral spur formation, add stability, and speed healing.

**TECH FIG 4** - After reduction and pinning, Kirschner wires may be cut and bent. Here they are to be buried under the skin.

---

### PEARLS AND PITFALLS

**Nonoperative management**

- Follow-up radiographs should be obtained within 3 to 5 days.
- Any loss of reduction suggests instability and prompts the need for operative intervention.

**Postoperative bone spur**

- A posterior or posterolateral metaphyseal bone spur frequently forms postoperatively. This is best seen on lateral radiographs. The bony prominence may give the clinical appearance of cubitus varus. Fortunately, this tends to improve over time and rarely requires intervention. Warning the parents initially of the probability of the occurrence can reduce anxiety later.

**Postoperative swelling**

- Placing felt over the cut, bend ends of the wires onto the skin decreases the risk of skin swelling over or pressing into their sharp tips while in the cast.
- Bivalving the cast decreases the risk of postoperative compartment syndrome.

**Delayed union and nonunion**

- This occurs more commonly in fractures treated nonoperatively.
- Prolonged casting of up to 12 weeks may be needed.
- If the fracture does not heal, open reduction with bone grafting may be necessary.

**Cubitus valgus and tardy ulnar nerve palsy**

- Premature closure of the lateral physis may lead to gradual deformity as the medial side continues to grow.
- Anatomic reduction decreases the risk.
- Follow-up radiographs can reveal the deformity.
- Nerve symptoms can take years to develop; therefore, patients should be counseled about signs and symptoms of ulnar nerve stretch.

**Cubitus varus**

- Unstable fractures treated nonoperatively can displace proximally and laterally, allowing the elbow to drift into a varus position.
- Doing careful early follow-up and fixing unstable fractures should prevent this.
POSTOPERATIVE CARE
- The arm is placed in a long-arm cast with the elbow flexed 90 degrees and the forearm in neutral to slight pronation.
- If there is significant swelling, the cast can be bivalved in the operating room and overwrapped the following week.
- Radiographs are obtained in 1 week to look for any loss of reduction.
- Wires can usually be pulled in 4 to 6 weeks.
- Authors have debated the exact timing. Although some have shown adequate healing by 3 weeks, a period of 4 to 6 weeks is generally required; the decision should be based on radiographic evidence of early callus.
- Gentle early active range of motion is encouraged after wire removal.
- A removable posterior splint can be made for children who will not comply with activity modifications.
- Physical or occupational therapy is rarely needed in children but may be recommended for those who fail to show improved range of motion.

OUTCOMES
- Patients who are treated quickly and whose fractures heal in an anatomic position with no subsequent growth arrest can expect excellent (90%) function and range of motion. Approximately 10% have minor loss of extension (10 to 15 degrees) at 1 to 2 years.
- Outcome studies following patients into adulthood are lacking.
- Patients who are treated with open reduction at 3 or more weeks after fracture are at greater risk for loss of range of motion (about 34 degrees), premature physeal closure, valgus deformity, tardy ulnar nerve palsy, and avascular necrosis, thus emphasizing the need for early treatment.

COMPLICATIONS
- Pin tract infections can occur but usually resolve after wire removal and oral antibiotics.
- Posterior or posterolateral metaphyseal bone spurs frequently form postoperatively and are best seen on lateral radiographs (FIG 5). Fortunately, these tend to smooth over time and are rarely symptomatic; thus, they usually require no treatment.
- Delayed union and nonunion are more common with nonoperative treatment than with surgical treatment.
- Malunion may occur in unstable fractures treated nonoperatively or in those with premature growth arrest.
- Avascular necrosis is more common after operative treatment than nonoperative management and is likely due to excessive posterior stripping that disrupts the epiphyseal blood supply.

REFERENCES

FIG 5 • Lateral radiograph showing postoperative bone spur projecting from posterior metaphysis.

- Tardy ulnar nerve palsy can develop slowly with progressive valgus deformity following premature growth arrest or nonunion.
DEFINITION
- Trauma to the medial aspect of the elbow may cause a medial epicondyle fracture, which is an injury to the apophysis of the medial epicondyle.

ANATOMY
- Medial epicondylar fractures involve the medial epicondylar apophysis on the posteromedial aspect of the elbow.
- The flexor-pronator muscle mass arises from this apophysis, including the palmaris longus, the flexor carpi ulnaris and radialis, the flexor digitorum superficialis, and one part of the pronator teres and the ulnar collateral ligament (FIG 1).³

PATHOGENESIS
- A direct blow to the medial aspect of the elbow may cause a fracture to the medial epicondyle, but this is rare.
- More commonly, a fall on an outstretched arm causes an avulsion of the medical epicondyle via tension generated by stretch of the muscles attaching to it. Elbow dislocation is frequently associated with a medial epicondyle fracture and may occur with spontaneous reduction at the time of the injury (FIG 2).
- Considerable force applied to the arm may cause elbow dislocation and associated disruption of the ulnar collateral ligament. This ligament, the principal stabilizing ligament of the elbow, can avulse the medial epicondyle, and the apophyseal fragment may sometimes become lodged in the elbow joint.³
- Overuse may cause a chronic stress-type injury or an apophysitis, an example of which would be Little League elbow.

NATURAL HISTORY
- The outcome of medial epicondyle fractures is related to the amount of fracture displacement and also the demands placed on the elbow by the patient.
- Minimally displaced fractures treated nonoperatively generally do well, especially if the patient is not an athlete or if the fracture involves the patient’s nondominant arm.
- Untreated displaced fractures may lead to chronic medial elbow instability and even recurrent elbow dislocations.
- Throwing athletes may have significant impairment in their sports activities.⁵

PATIENT HISTORY AND PHYSICAL FINDINGS
- For any elbow injury, the mechanism of injury should be sought, with particular attention to the details of a fall. In children this may be difficult to elicit, but often a witness may be available. Medial epicondyle fractures frequently arise from a fall.
- The two most important issues in the physical examination are to document neurovascular status and to assess for elbow stability. Determination of stability includes determination of whether the elbow is dislocated, which can be assessed clinically and confirmed radiographically.
- Assessment of medial elbow stability is often important in determining treatment.
A positive valgus stress test confirms medial elbow instability. Persistence of medial elbow stability may cause significant elbow disability in athletes or those doing heavy labor. Radiographs may confirm increased displacement of the medial epicondylar fragment.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Standard anteroposterior (AP) and lateral radiographs of the elbow are required, but oblique views are often helpful to visualize the medial epicondyle, which is on the posteromedial aspect of the distal humerus.
- Widening of the apophysis may be the only sign of injury, so comparison views of the unaffected elbow are often helpful to assess for amount of displacement.
- If there is radiographic absence of the medial epicondyle and suspected joint incarceration, an arthrogram, CT scan, or MRI may be needed rarely.

**DIFFERENTIAL DIAGNOSIS**
- Medial condylar fractures
- Supracondylar fractures
- Elbow dislocation

**NONOPERATIVE MANAGEMENT**
- Smith in 1950 became a strong advocate of nonoperative management of this injury, pointing out that the fracture involved an apophysis rather than a physis, and thus future growth was not compromised. He also documented that imperfect reduction or even nonunion was not automatically associated with a poor outcome in terms of elbow function and strength.1
- A recent study from Sweden where all patients were treated nonoperatively showed 96% good to excellent results. Over 60% of the patients had a fibrous union or nonunion.3
- Two studies have compared nonoperative and operative treatment. Bede and associates1 found that nonoperative treatment had better outcomes than operative treatment.
  - Farsetti and coworkers4 demonstrated similar results in displaced fractures of nonoperative treatment and open reduction and internal fixation (ORIF) with Kirschner wires.
- Indications for nonoperative management of medial epicondyle fractures include patients who do not place high physical demands on their elbows, and most nondominant elbows.
- Nonoperative treatment encompasses splinting for 5 to 7 days or until acute soft tissue swelling resolves and then early active range of motion starting as soon as possible after the injury.
- Physical therapy may be required if range of motion is slow to return, but passive stretch may cause more injury and should be avoided.

**SURGICAL MANAGEMENT**
- Absolute indications
  - Incarceration of the medical epicondylar fragment in the joint
  - Associated elbow dislocation with ulnar nerve dysfunction
OPEN REDUCTION AND INTERNAL FIXATION WITH CANNULATED SCREW

- A skin incision about 4 cm long is made centered over the medial epicondyle after inflation of a tourniquet on the upper arm (TECH FIG 1A). Often with displaced injuries, the fractured fragment is just subcutaneous and little dissection is required.
- The ulnar nerve should be identified and carefully protected. Most experts do not recommend routine mobilization or transposition of the nerve.
- The fracture is identified and any organized hematoma is removed (TECH FIG 1B).
- The fracture is reduced with a towel clip. Elbow flexion and forearm pronation aid in reducing the fracture.
- Some surgeons suggest curettage of the apophyseal cartilage to expedite healing of the fracture, which may persist as a healed apophysis if this is not done. This tip may be especially advantageous in the throwing athlete who is eager to return to sports as soon as possible.
- The fracture is stabilized with one or two guide pins from the 4.0 cannulated screw set.

- Radiographs are checked to assess reduction and pin placement.
- The pin selected for overdrilling should not be in the olecranon fossa. The second pin provides rotational stability of the fragment during drilling and screw placement.
- An appropriate-length screw is selected and inserted over the guide pin, stabilizing the fracture.
- A washer may be used to provide a wide surface area of fixation and prevent screw head migration.
- AP and lateral intraoperative radiographs should confirm reduction and screw placement position (TECH FIG 1C–G).
- Elbow stability should be checked and full range of motion confirmed before closure.
- Standard skin closure is carried out, and the arm is splinted or casted at 90 degrees of elbow flexion.

TECH FIG 1 • A. Incision with ulnar nerve identified. B. The fracture fragment is mobilized. C. Fluoroscopic image showing two pins spanning the fracture fragment for rotational stability. D,E. Cannulated screw fixation shown fluoroscopically. F,G. Radiographs showing healed fracture. Heterotopic bone formation anteriorly can be seen on the lateral radiograph.
Chapter 3 ORIF OF FRACTURES OF THE MEDIAL EPICONDYLE

**SUTURE FIXATION**
- Should the fracture cause comminution of the medial epicondyle, repair with sutures may be warranted in a high-demand patient or one with medial instability.
- This would involve sutures placed directly in the tendinous tissue and secured to the periosteum adjacent to the bed from which the epicondyle was avulsed.

**EXTRACTION OF MEDIAL EPICONDYLE FROM ELBOW JOINT: ROBERTS TECHNIQUE**
- A valgus stress is applied to the elbow with the forearm supinated.
- The wrist and fingers are dorsiflexed.
- As the position is reached, the fragment should be dislodged from the joint.
- This technique is most effective in the first 24 hours after the injury, before much muscle spasm occurs.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Medial epicondyle fracture fragment should be fixed with a cannulated screw if possible rather than pins to have rigid fixation permitting early motion.</th>
<th>The surgeon must beware of a medial epicondyle that is absent on radiography: it may be trapped in the joint.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow motion is encouraged as soon as possible after surgery to minimize postoperative stiffness.</td>
<td>The surgeon must document radiographically that the internal fixation is not in the olecranon fossa, where it may block elbow extension.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**
- Postoperative management after open reduction of medial epicondyle fractures depends on the type and stability of the fixation of the epicondylar fragment.
- For ORIF with screws, initial splinting for 3 to 5 days in about 50 to 60 degrees of flexion is recommended, followed by early active range of motion.
- Some authors recommend a removable brace preventing valgus stress but permitting full flexion and extension for 4 weeks.
- In one recent series on young athletes with this injury repaired with screw fixation, active range of motion out of the brace continued from weeks 5 to 8 postoperatively. At 8 weeks noncontact sports were allowed, and return to full activity was possible at 12 weeks after surgery.

**OUTCOMES**
- Eight adolescent athletes undergoing ORIF with screw fixation for this fracture had excellent results with no residual valgus instability and full return to all sports. One patient had a loss of 5 degrees of hyperextension, but all other patients had recovery of full range of motion.
- In another series, 21 of 23 patients treated operatively had recovery of full movement, whereas only 14 of 20 patients treated nonoperatively had full range of motion.
- A recent series of operative treatment and early motion in 25 patients with displaced fractures showed good to excellent results in all patients.

**COMPLICATIONS**
- Failure to diagnose joint entrapment of the medial epicondyle fracture
- Ulnar nerve dysfunction
- Loss of range of motion
- Nonunion
- Myositis ossificans

**REFERENCES**
DEFINITION
- A supracondylar fracture that requires open reduction is one that cannot be treated with closed reduction and percutaneous pinning.

ANATOMY
- A very thin area of bone connects the medial and lateral columns of the distal humerus. This makes the area prone to fracture. The coronoid fossa is located anteriorly and the olecranon fossa is located posteriorly.
- The neurovascular anatomy to consider for an open reduction includes:
  - The ulnar nerve passes behind the medial epicondyle.
  - The radial nerve courses from posterior to anterior just above the olecranon fossa.
  - The brachial artery and median nerve pass through the antecubital fossa.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The patient history is the same for supracondylar fractures being treated by closed methods.
- Tenting of the skin may indicate an open reduction is needed. This may represent buttonholing of the proximal fragment through the periosteum and brachialis muscle, making closed reduction difficult.
- A careful neurovascular examination must also be performed.

SURGICAL MANAGEMENT
- Indications for open treatment of a supracondylar fracture include an open fracture, an irreducible fracture, and a compromised vascular supply to the hand that does not reconstitute with reduction by closed means.
- The timing for surgical intervention has been a matter of debate. Many surgeons believe that prompt pinning or open reduction is optimal. Some newer articles have been published finding no significant increase in complication rates with delayed treatment.2,3

Preoperative Planning
- During preoperative planning, the surgeon must consider the reasons why an open procedure is necessary. This will help guide the approach.
- Other factors for consideration include the pin size for maintaining the reduction once the fracture is reduced. In general, 0.062-mm wires are used for all but the oldest children. More importantly, at least three pins should be used for type III fractures if they are going to be pinned with lateral entry pinning.

Positioning
- The patient is placed supine on the operating table. A hand table attachment is valuable. A sterile tourniquet is placed on the child’s arm after preparation and draping. The surgeon should make sure that the fluoroscope can be moved easily into and out of the operative field to assist with pinning of the fracture.

Approach
- The first factor to consider in determining the approach is the direction of displacement of the distal fragment. This helps guide placement of the incision.
  - In general, a transverse anterior incision through the antecubital fossa is the most useful and cosmetic.
  - If more visualization is needed, this incision can be extended medially or laterally based on displacement, but this is rarely necessary.
  - Extension of the incision on the opposite side of the displacement of the distal fragment allows for removal of soft tissue obstacles to reduction.
  - If there is a suspicion of neurovascular compromise, the anterior approach provides the best exposure.
  - An inability to reduce the fracture may indicate that the proximal fragment has buttonholed through the brachialis muscle. Again, an anterior approach is the most useful exposure to reduce this deformity.
  - Some surgeons have advocated a posterior approach for severely comminuted fractures.4 However, other surgeons strongly believe that a posterior approach risks compromising the blood supply to the distal fragment and should be avoided.5
OPEN REDUCTION THROUGH AN ANTERIOR APPROACH

Incision and Dissection

- Once the patient has been prepared and draped, the tourniquet is inflated.
- A transverse incision is made across the antecubital fossa (TECH FIG 1A).
- Blunt dissection continues through the subcutaneous and fatty tissue. Care must be taken in dissecting as the neurovascular bundle may be located in a nonanatomic place; it may be immediately in the subcutaneous tissue and at risk for damage during initial dissection (TECH FIG 1B).
- Dissection proceeds until the metaphyseal spike is encountered. It is covered by a small amount of tissue and parts of the brachialis muscle that may be torn (TECH FIG 1C).
- It is at this point that the neurovascular bundle should be located, if it has not yet been identified. This usually involves dissecting across the anterior aspect of the metaphyseal spike. This step should not be omitted even if there is no vascular compromise. Once the vessels are identified, they should be retracted out of the field.

Fracture Reduction

- Defining the outline of the distal fragment can be the most challenging aspect of the procedure. It is posterior and lateral and the periosteum is folded over its surface (TECH FIG 2).
- Reduction is obtained by reaching into the fracture site with a hemostat and getting hold of the cut edge of the periosteum. This cut edge is extended with scissors to increase the size of the buttonhole and helps to free up the distal fragment. The distal fragment is then brought anteriorly and reduced to the shaft fragment, which is maneuvered back through the buttonhole into its resting position posterior to the brachialis muscle.
- Alternatively, the surgeon can hold his or her thumb on the proximal fragment and push downward while an assistant applies traction to the forearm with the elbow flexed at 90 degrees. A periosteal elevator can be used as a lever to assist the reduction.

Pinning

- Once a reduction has been obtained, the fracture is fixed with smooth Kirschner wires. This is accomplished in the
POSTOPERATIVE CARE

- Sterile dressings are applied over the incision.
- A strip of Xeroform dressing can be wrapped around the pins, followed by fluff dressings.
- The elbow is splinted in 60 to 90 degrees of flexion with a neutral forearm.
- The patient is admitted overnight for observation. Often a long-arm cast can be placed safely the next day, with the arm flexed about 80 degrees. This cast can be maintained until the pins are removed 3 or 4 weeks after surgery.
- The patient can then be placed back into a sling and started on gentle range-of-motion exercises out of the sling for another 2 weeks.
- The child can then start to use the arm normally.
- Formal physical therapy is usually not necessary.

OUTCOMES

- It is generally agreed that prompt attention to reduction and stabilization of supracondylar fractures results in better outcomes and fewer complications.
- Postoperative loss of reduction is uncommon. However, children with supracondylar fractures that have been treated with open reduction generally take longer to regain their elbow motion than children treated with closed pinning. Families should be advised about this longer period of elbow stiffness in the immediate postoperative period.
- A 2001 study of 862 supracondylar fractures treated with open reduction found 55% excellent results, 24% good results, 9% fair results, and 12% poor results 5.8 months after injury.

PEARLS AND PITFALLS

| Indications | The surgeon should have a good understanding of why an open procedure is necessary. The primary indications for an open reduction are interposed tissue in the fracture site and vascular compromise that does not improve with closed reduction and percutaneous pinning. |
| Neurovascular structures | The neurovascular bundle can be located anywhere within the operative field and must be identified even if there is no suspicion of compromise. |
| Reduction of the fracture | The distal fragment often can be palpated but not seen as it is hidden by the overlying periosteum. The surgeon should expand the buttonhole through the periosteum for better visualization. |
| Fracture pinning | Pins should be maximally separated at the fracture site if three lateral pins are used. Convergent pins are not stable. If medial and lateral pins are used, the surgeon should engage the medial and lateral columns of the distal fragment. |
COMPLICATIONS

- Complications can result from the injury itself or from surgery.
- The risk of infection is decreased with the use of perioperative antibiotics.
- Iatrogenic neurovascular injury
  - Identification of neurovascular structures is crucial.
  - The ulnar nerve is susceptible to injury if a medial pin is used.
- Compartment syndrome
  - The child should be kept overnight for observation and the surgeon should make sure that serial neurovascular examinations are performed.
  - The first sign of compartment syndrome in a child is usually increased pain, or increased pain medication requirements.
  - The children most at risk are those who had compromised blood flow to the hand immediately after injury.
  - Children who have a median nerve injury often do not complain of the pain because of the sensory deficit.
- Loss of motion
  - Although rare, some loss of full extension has been reported.
  - If there is excessive posterior angulation at the time of healing, some loss of full flexion can occur.
  - Cubitus valgus and cubitus varus
  - Varus angulation is mostly cosmetic.
  - Valgus deformity can cause loss of full elbow extension and can result in tardy ulnar nerve palsy.
  - Myositis ossificans is rare and should resolve in 1 to 2 years.

REFERENCES

DEFINITION
- Supracondylar fractures of the humerus are common injuries in children. As many as 67% of children hospitalized with elbow injuries have supracondylar fractures; supracondylar fractures of the humerus represent 17% of all childhood fractures.\(^4,5\)
- The peak age at fracture is 5 to 7 years.
- The cause of injury is most commonly a fall from height (70%).
- The vast majority of supracondylar fractures of the humerus are of the extension type (97%).\(^3\) Flexion-type injuries also occur.
- Open injuries occur in 1% of cases. Concurrent fractures, most commonly involving the distal radius, scaphoid, and proximal humerus, occur in 1% of cases. Associated neurovascular injuries can occur, with preoperative nerve injury existing in 8% of cases and vascular insufficiency present in 1% to 2% of cases.\(^2\)

ANATOMY
- The periosteum most commonly fails anteriorly with extension-type supracondylar fractures of the humerus. With posteromedial displacement, the periosteum also fails laterally. Therefore, with posteromedially displaced fractures, forearm pronation can aid in the reduction (FIG 1).
- With posterolateral displacement, the periosteum also fails medially. Forearm supination usually aids in the reduction of these posterolaterally displaced fractures.
- The direction of displacement has implications for which neurovascular structures are at risk from the penetrating injury of the proximal metaphyseal fragment (FIG 2).
  - Medial displacement of the distal fragment places the radial nerve at risk.
  - Lateral displacement of the distal fragment places the median nerve and brachial artery at risk.
  - The ulnar nerve courses through the cubital tunnel posterior to the medial epicondyle. It is at particular risk with flexion-type fractures or when a medial pin is placed for fracture fixation.
  - The ulnar nerve subluxates anteriorly as the elbow is flexed. Therefore, the elbow should be relatively extended if a medial pin is placed for fracture fixation.

PATHOGENESIS
- Supracondylar fractures of the humerus generally occur as a result of a fall onto an outstretched hand with the elbow in full extension.
  - The distal humerus is very thin at the supracondylar region, a critical factor in producing a consistent injury pattern and failure in the supracondylar humeral region.
  - During a fall with the elbow in full extension, the olecranon in its fossa acts as a fulcrum.
  - The capsule, as it inserts distal to the olecranon fossa and proximal to the physis, transmits an extension force to this region, resulting in failure and fracture.
  - With the elbow in full extension and the elbow becoming tightly interlocked, bending forces are concentrated in the distal humeral region.
  - Increased ligamentous laxity, leading to hyperextension of the elbow, may be a contributing factor to this injury pattern.

NATURAL HISTORY
- The physis of the distal humerus contributes little to the overall growth of the humerus (20% of the humerus); therefore, the remodeling capacity of supracondylar fractures of the humerus is limited. Near-anatomic reduction of these fractures is important.
- The majority of supracondylar fractures of the humerus (other than extension type I fractures) are unstable; therefore, stabilization in the form of cast immobilization or preferably operative fixation is usually necessary.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Evaluation of the child with an elbow injury must include an overall assessment to look for associated trauma (especially in the proximal humerus and distal radius regions) as well as associated neurovascular injury.
- The physical examination may reveal swelling, tenderness, ecchymosis, and deformity. The pucker sign, which occurs as a result of the proximal fracture fragment spike penetrating through the brachialis and anterior fascia into the subcutaneous tissue, may be present.
- Thorough neurovascular examination of the involved extremity is critical. Physical examinations to perform include:
  - Assessing for potential associated injury to the ulnar nerve. Finger abduction and adduction (interossei) strength is tested. Sensation in the palmar little finger is tested.
  - Assessing for potential associated injury to the radial nerve. Finger, wrist, and thumb extension (extensor digitorum communis, extensor indicis proprius, extensor carpi radialis longus and brevis, extensor carpi ulnaris, extensor pollicis longus) is tested. Sensation in the dorsal first web space is tested.
  - Assessing for potential associated injury to the median nerve. Thenar strength (abductor pollicis brevis, flexor
DIFFERENTIAL DIAGNOSIS

- Fracture of elbow (other than involving the supracondylar humeral region)
- Salter-Harris fractures involving the elbow
- Nursemaid’s elbow
- Infection

NONOPERATIVE MANAGEMENT

- The indications for nonoperative management of supracondylar fractures of the humerus are limited to nondisplaced fractures (type I).
- The anterior humeral line transects the capitellum on the lateral radiograph.
- The Baumann angle is >10 degrees or equal to the other side.
- The olecranon fossa and medial and lateral cortices are intact.
- Nonoperative management consists of immobilization of the elbow in no more than 90 degrees of flexion in a splint or cast.
- As the brachial artery becomes compressed with increasing flexion of the elbow, the clinician must ensure that the distal radial pulse is intact and that there is adequate perfusion distally.
- Historically, some supracondylar fractures of the humerus were managed with traction (overhead versus side). With the relative safety of percutaneous pinning techniques, however, the use of traction has been limited.

SURGICAL MANAGEMENT

- The two main options for percutaneous pin fixation are the lateral-entry pin and crossed-pin techniques.
- Most fractures can be stabilized successfully by the lateral-entry pin technique.6
- Two pins are usually adequate for type II fractures; three pins are recommended for type III fractures.
- Biomechanical studies have revealed comparable stability in the lateral-entry and crossed-pin techniques.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Initial imaging studies should include plain radiographs of the elbow—anteroposterior (AP), lateral, and sometimes oblique views.
- Comparison views of the contralateral elbow are sometimes helpful.
- The fat-pad sign, particularly posterior, represents an intra-articular effusion and can be associated with a supracondylar fracture of the humerus (53% of the time) (FIG 3A).7
- On the AP view, the Baumann angle correlates with the carrying angle and should be 70 to 78 degrees or symmetric with the contralateral elbow (FIG 3B).
- On the lateral view, the anterior humeral line (line drawn along the anterior aspect of the humerus) should intersect the capitellum (FIG 3C).
- The most commonly used classification system, the Gartland classification, is based on plain radiographic appearance:
  - Extension type I: nondisplaced
  - Extension type II: capitellum displaced posterior to anterior humeral line with variable amount of extension and angulation; posterior cortex of the humerus is intact
  - Extension type III: completely displaced with no cortex intact
  - Flexion type

FIG 1 • Reduction of a posteromedially displaced supracondylar fracture of the humerus. Pronation of the forearm closes the hinge and aids in reduction.

FIG 2 • Relationship to neurovascular structures. The proximal metaphyseal spike penetrates laterally with posteromedially displaced fractures and places the radial nerve at risk. With posterolaterally displaced fractures, the spike penetrates medially and places the median nerve and brachial artery at risk.

FIG 3A • Fat-pad sign. Excess fat in the olecranon fossa may cause the olecranon process to appear higher than normal, representing an intra-articular effusion or a type II fracture. The olecranon process should align with the capitellum on the AP view, bilaterally.

FIG 3B • Baumann angle. The angle between the capitellum and radial head on the lateral radiograph of the elbow should be 70 to 78 degrees. The Baumann angle is symmetric on the normal side and is equal or greater than 10 degrees on the injured side.

FIG 3C • Anterior humeral line. The anterior humeral line intersects the capitellum on the lateral radiograph of the elbow.
An advantage of the lateral-entry pin technique is the significantly lower risk of iatrogenic nerve injury. The ulnar nerve is at risk when pins are inserted medially (5% to 6% risk).

The crossed-pin technique may be indicated if persistent instability is noted intraoperatively after placement of three lateral-entry pins.

Preoperative Planning
- Displaced supracondylar fractures of the humerus (including Gartland type II and III) require reduction. Usually, reduction can be achieved by closed means. The preferred method for fixation is percutaneous pinning.
- Indications for open reduction of supracondylar fractures of the humerus are limited but include open injuries, fractures irreducible by closed means, and fractures associated with persistent vascular compromise even after adequate closed reduction.
- All imaging studies are reviewed. A high index of suspicion for associated fractures, especially of the forearm, is important; if present, there is an increased risk of compartment syndrome.
- Complete preoperative neurologic and vascular examination is performed and documented.
- The contralateral arm should be examined, and the carrying angle of the contralateral arm should be noted.
- The timing of surgery remains controversial. Recent retrospective studies suggest that a delay in treatment of the majority of supracondylar fractures is acceptable.¹
- Fractures with “red flags” (eg, significant swelling and signs of neurologic and especially vascular compromise or an associated forearm fracture) usually require urgent treatment.

Positioning
- The patient is positioned supine on the operating room table.
- The fractured elbow is placed on a radiolucent armboard (FIG 4A). The arm should be far enough onto the armboard to allow for complete visualization of the elbow and distal...
humerus. In smaller children, the child’s shoulder and head may need to rest on the armboard as well.

- The wide end of a fluoroscopy unit is sometimes used as a table.
- In cases of severe instability of the fracture, use of the fluoroscopy unit as an armboard is suboptimal because reduction of the fracture is frequently lost with rotation of the arm, which is needed for AP and lateral views of the elbow.
- The fluoroscopy monitor is placed opposite to the surgeon for ease of viewing (FIG 4B).

**CLOSED REDUCTION**

- Traction is applied with the elbow in 20 to 30 degrees of flexion (TECH FIG 1A) to prevent tethering of the neurovascular structures over the anteriorly displaced proximal fragment.
- For severely displaced fractures, where the proximal fragment is entrapped in the brachialis muscle, the “milking maneuver” is performed (TECH FIG 1B).
  - The soft tissue overlying the fracture is manipulated in a proximal to distal direction.
- Once length is restored, the medial and lateral columns are realigned on the AP image.
  - Varus and valgus angular alignment is restored.
  - Medial and lateral translation is also corrected.
- For the majority of fractures (ie, extension type), the flexion reduction maneuver is performed next (TECH FIG 1C).
  - The elbow is gradually flexed while applying anterior pressure on the olecranon (and distal condyles of the humerus) with the thumbs.
- The elbow is held in hyperflexion as the reduction is assessed by fluoroscopy.
- Reduction is adequate if the following criteria are fulfilled:
  - The anterior humeral line crosses the capitellum.
  - The Baumann angle is >10 degrees or comparable to the contralateral side.
  - Oblique views show intact medial and lateral columns.
- The forearm is held in pronation for posteromedial fractures.
- The forearm is held in supination for posterolateral fractures.
- For unstable fractures, the fluoroscopy machine instead of the arm is rotated to obtain lateral views of the elbow (TECH FIG 1D).
**LATERAL-ENTRY PIN TECHNIQUE**

- Once satisfactory reduction is obtained, K-wires can be inserted percutaneously for fracture stabilization.
  - 0.062-inch smooth K-wires are commonly used.
  - Smaller or larger sizes may be used depending on the size of the child.
- The goals of the lateral-entry pin technique are to maximally separate the pins at the fracture site and to engage both the medial and lateral columns (TECH FIG 2A–C).
  - The pins can be divergent or parallel.
  - Sufficient bone must be engaged in the proximal and distal fragments.
  - Pins may cross the olecranon fossa.
- As a general rule, two pins are adequate for type II fractures; three pins are recommended for type III fractures.
- The K-wire is positioned against the lateral condyle without piercing the skin (TECH FIG 2D).
  - The starting point is assessed under AP fluoroscopic guidance.
  - The K-wire is held freehand to allow maximum control.
- Once a satisfactory starting point and trajectory are confirmed, the K-wire is pushed through the skin and into the cartilage.
  - The cartilage of the distal lateral condyle functions as a pincushion.
- The starting point and trajectory are assessed by AP and lateral fluoroscopic guidance.
- When satisfactory starting point and trajectory are confirmed, the pin is advanced with a drill until at least two cortices are engaged.
  - At this point, the reduction is again assessed.
  - The reduction must appear satisfactory on AP, lateral, and two oblique views.
  - The elbow is rotated to allow for oblique views of the medial and lateral columns.
- Additional pins are inserted (TECH FIG 2E–H).
  - The elbow is stressed under live fluoroscopy in both the AP and lateral planes.
- Once satisfactory reduction and stability are confirmed, the vascular status is again assessed.
  - Upon completion, the pins can be bent and cut approximately 1 to 2 cm off the skin.
TECH FIG 2 • A–C. Lateral-entry pin technique: optimal pin configuration. The pins are separated at the fracture site to engage the medial and lateral columns. A. Optimal pin configuration for two pins (AP view). B. Optimal pin configuration for three pins (AP view). C. Optimal pin configuration (lateral view). D. The pin is held freehand. Once starting point and trajectory are confirmed under fluoroscopic guidance, the pin is pushed through the skin and into the cartilage. E,F. Assessment of coronal alignment on AP and lateral views. G. Externally and internally rotated oblique views are used to assess the medial and lateral columns. H. Stress fracture. The elbow should be stressed under live fluoroscopy to confirm adequate stability.
CROSSED-PIN TECHNIQUE

- If satisfactory stability cannot be achieved by lateral-entry pins or if the surgeon is more comfortable with lateral- and medial-entry pins, the crossed-pin technique can be performed.
- The lateral-entry pins are inserted first: this will allow the elbow to extend when placing the medial-entry pins.
  - The ulnar nerve subluxates anteriorly with increasing flexion of the elbow; therefore, the ulnar nerve may be at risk when medial-entry pins are placed with the elbow in 90 degrees or more of flexion.
  - After insertion of the lateral-entry pins, the elbow is extended to 20 to 30 degrees of flexion (TECH FIG 3A).
  - A small incision is made over the medial epicondyle.
  - Blunt dissection is performed down to the level of the medial epicondyle.
  - A pin is positioned on the medial epicondyle (TECH FIG 3B).
  - The starting position and trajectory are assessed under fluoroscopic guidance.
  - When a satisfactory starting point and trajectory are confirmed, the pin is advanced with a drill until at least two cortices are engaged (TECH FIG 3C,D). The medial column should be engaged.
  - Ideally, the pin should be separated from the other pins maximally at the fracture site.
  - The reduction and stability of the fracture are assessed just as with the lateral-entry pin technique. The vascular status is similarly evaluated.

TECH FIG 3 • Crossed-pin technique. A. To minimize risk of iatrogenic injury to the ulnar nerve, the elbow is extended to 20 to 30 degrees of flexion before the pins are inserted medially. B. The starting point is on the medial epicondyle. C,D. The medial pin should engage the medial column and at least two cortices.
CLOSED REDUCTION AND PERCUTANEOUS PINNING OF SUPRACONDYLAR FRACTURES OF THE HUMERUS

Chapter 5

POSTOPERATIVE CARE

The arm is immobilized, preferably in a cast (sometimes a splint), with the elbow in 45 to 60 degrees of flexion.

- Flexing the elbow to 90 degrees, as is used for most other casting, will increase the risk of compartment syndrome because the fracture reduction is stabilized by the pins, not the cast.
- Sterile foam may be directly applied to the skin before cast application to allow for postoperative swelling.
- The arm is immobilized for 3 to 4 weeks, with follow-up evaluations at 1 and 3 (or 4) weeks. Postoperative radiographs (AP and lateral views) are obtained.
- Pins are usually discontinued at 3 to 4 weeks postoperatively.
- Range-of-motion exercises are initiated shortly after pins and immobilization are discontinued.
- Return to full activity typically occurs by 6 to 8 weeks postoperatively.

OUTCOMES

Studies have suggested that treatment of supracondylar fractures can be delayed without significant added risk in appropriately selected patients.

- Multiple studies have reported on the efficacy and high safety profile of the lateral-entry pin technique.
- A consecutive series of 124 patients with type II and type III supracondylar fractures of the humerus were evaluated. A Fractures were stabilized by the lateral-entry pin technique.
- There were no cases of malunion or iatrogenic nerve injury.
- One patient had a pin-track infection.

COMPLICATIONS

- Elbow stiffness
- Infection
- Vascular injury
- Neurologic injury
- Malunion
- Nonunion
- Avascular necrosis
- Myositis ossificans

REFERENCES

DEFINITION
- Radial neck fractures are extra-articular fractures of the radius proximal to the bicipital tuberosity.
- Radial neck fractures are most common in children 9 to 12 years old and represent 14% of elbow fractures in children. The physis is typically involved as a Salter-Harris I or II pattern, yet Salter-Harris III and IV patterns also occur. Alternatively, the fracture often is extraphyseal, through the metaphysis.
- Intra-articular radial head fractures are less common elbow injuries in patients with open physes than in skeletally mature patients (7% vs. 52%). The Wilkins classification of radial head and neck fractures is based on the mechanism of injury and the pattern of the fracture, specifically whether there is physeal or articular involvement:
  - Type I: Valgus injury
    - A: Physeal injury—Salter-Harris I or II
    - B: Intra-articular—Salter-Harris III or IV
    - C: Metaphyseal fracture
  - Type II: Elbow dislocation
    - D: Fracture occurred during dislocation
    - E: Fracture occurred during reduction
- The O’Brien and Judet classifications of radial neck fractures are based on degree of angulation.
  - O’Brien classification
    - Type I: Less than 30 degrees
    - Type II: 30 to 60 degrees
    - Type III: More than 60 degrees
  - Judet classification
    - Type I: Undisplaced
    - Type II: Less than 30 degrees
    - Type III: 30 to 60 degrees
    - Type IVa: 60 to 80 degrees
    - Type IVb: More than 80 degrees

PATHOGENESIS
- The most common mechanism of radial neck fractures is a valgus and axial force to the elbow caused by a fall on an outstretched hand. This mechanism results in a lateral compression and a medial traction injury. The actual plane of maximal radial head angulation depends on the forearm position of supination or pronation at the time of impact.
- The other mechanism of injury is an elbow dislocation, where the fracture occurs either during the dislocation (radial head anterior) or during the elbow reduction (radial head posterior).
- Associated injuries, such as medial collateral ligament rupture or occult elbow dislocation, occur in 30% to 50% of radial neck fractures.
- Chronic stress fractures of the radial head and neck can occur with repetitive valgus loading, such as overhead throwing.

NATURAL HISTORY
- The prognosis for radial neck fractures depends on the energy of injury, the amount of displacement, and the presence of any associated injuries.
- Patients with minimal fracture displacement and a congruent joint generally have a favorable prognosis, while more severe alterations of normal joint anatomy can severely impede elbow range of motion unless reduced.

ANATOMY
- The radial head articulates with the capitellum and the radial notch of the ulna. The radial neck is extra-articular and has a normal 15 degrees of angulation on anteroposterior (AP) and 5 degrees on lateral radiographic views. The radial head ossific nucleus appears at about 4 years of age.
- The proximal radioulnar joint is stabilized by the annular ligament and the accessory collateral ligament.
- There are no muscular attachments to the radial neck. The blood supply is derived from the adjacent periosteum.
- The radial nerve gives rise to the superficial radial nerve and the posterior interosseous nerve at the level of the lateral condyle. The posterior interosseous nerve travels distally anterior to the radial head and neck, enters the arcade of Frohse 2.6 cm distal to the radial head (FIG 1), and submerges between the superficial and deep fibers of the supinator 6.7 cm distal to the radial head. The radial recurrent artery originates from the radial artery and travels toward the lateral epicondyle in the opposite direction along the path of the radial nerve, on the anteromedial surface of the supinator.

FIG 1 • The posterior interosseous nerve courses volar to the radial head and neck and enters the arcade of Frohse about 2.6 cm distal to the articular surface of the radial head.
PATIENT HISTORY AND PHYSICAL FINDINGS

- Elucidating the mechanism of injury is important to truly understand the personality of the fracture, which can help in directing treatment. Higher-energy mechanisms are more likely to be associated with concomitant injuries. Elbow dislocations that have reduced before presentation are not uncommon, so it is helpful to ask the patient and family whether a marked deformity was noted at the time of injury.
- Carefully palpating each anatomic area in the elbow to find the points of maximal tenderness helps diagnose the fracture as well as additional injuries. Associated injuries include medial collateral ligament tears, medial epicondyle fractures, ulna fractures, and supracondylar humerus fractures. A neurologic evaluation assesses distal radial, medial, and ulnar nerve motor and sensory function.
- Assessing elbow stability and range of motion can help determine the need for treatment.
  - Valgus instability indicates a medial elbow injury in addition to an unstable radial neck fracture.
  - Blocks in forearm rotation, in particular pronation, are typically due to loss of congruity of the radioulnar joint and indicate a need for reduction.
  - Stability and range-of-motion assessment may necessitate either an intra-articular anesthetic injection or an examination under anesthesia.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- AP, lateral, and oblique radiographs often show radial neck fractures well (FIG 2A,B). However, the true extent of fracture angulation can be underestimated on plain radiographs, as orthogonal views may fail to capture the true plane of angulation.
- Radial neck fractures can occur before the ossification of the radial head, without clear evidence of fracture on plain radiographs. Ultrasound, MRI (FIG 2C), and arthrography (FIG 2D,E) are useful for diagnosing and evaluating radial neck fractures in young patients with nonossified radial heads. In the operating room, arthrography is useful in outlining the nonossified radial head when monitoring and verifying reduction.

DIFFERENTIAL DIAGNOSIS

- The diagnosis of a radial neck fracture is usually easily made with appropriate imaging. However, the presence or absence of the following associated injuries should be ascertained:
  - Medial collateral ligament rupture
  - Medial epicondyle fracture
  - Olecranon fracture
  - Monteggia-equivalent type IV fracture

NONOPERATIVE MANAGEMENT

- Ultimately, the objective is to obtain and maintain a congruent joint with restored elbow range of motion in all planes. Most consider 30 degrees of angulation and 3 mm of translation an acceptable reduction. Controversy exists regarding the exact numbers, however, with reported acceptable angulation ranging from 20 to 60 degrees.\(^1,3,8,12,16,18,19,21,22\)
  - Two things partially account for the controversy:
    - The accuracy of the radiographic measurement is variable and depends on whether the radiographic beam is perpendicular to the true plane of the fracture.

FIG 2 • A,B. AP and lateral radiographs demonstrate an ulna fracture and radial neck fracture in a 3-year-old with a nonossified radial head. However, it is difficult to discern the degree of angulation on plain radiographs. MRI is useful when evaluating radial neck fractures in children with nonossified radial heads. C. The MRI from the same patient clearly shows the 60-degree radial neck angulation not defined on plain films. D,E. Arthrography demonstrates a 90-degree displaced radial neck fracture not seen on plain films. It is also useful to monitor and verify reduction intraoperatively.
Twenty-five degrees of fracture angulation can have variable effects on the congruity of the radioulnar joint, depending on the direction of angulation.

It is therefore important to base the decision of treatment on the functional effects of the angulation, rather than a specific number. Any block of pronation or supination warrants a reduction of the fracture, no matter what the radiographic angulation is.

As remodeling potential decreases with advancing skeletal maturity, less residual angulation is acceptable (15 to 20 degrees).\(^5,21\)

Closed reduction is recommended if there is more than 30 degrees of angulation or 3 mm of translation, or if there is any block to range of motion. Reduction can be done either with sedation in the emergency room or in the operating room. The advantage of the latter is the immediate ability to proceed to a percutaneous reduction technique should the closed techniques fail, which is more likely in cases with severe displacement.

The nature and duration of immobilization depend on the fracture pattern, the presumed stability, and the maturity of the patient. For example, a 17-year-old reliable patient with a nondisplaced stable radial neck fracture can be treated with a sling and early range of motion. Physeal fractures, fractures needing reduction, and fractures in young patients usually need immobilization in a cast for 3 weeks, however.

When clinical and radiographic signs of healing are lacking, the cast may remain for an additional 2 weeks, followed by a re-evaluation of the healing progress.

**SURGICAL MANAGEMENT**

If closed reduction fails, the next step is to proceed to a percutaneous reduction technique. Techniques using a Steinmann pin to push or lever are described in detail in the Techniques section.

Every attempt to achieve a closed or percutaneous reduction is made, as the rates of complications, including avascular necrosis, heterotopic ossification, and nonunion, are higher with an open approach.\(^3,12\)

The markedly displaced floating fragments associated with elbow dislocations often require an open approach, while most angulated radial head fractures can be reduced by a combination of closed and percutaneous techniques.

**Preoperative Planning**

It is essential to obtain proper elbow and forearm radiographs and diagnose all injuries before proceeding to the operating room.

Familiarity with all of the closed and percutaneous reduction techniques described in the Techniques section is useful, as each fracture behaves and responds differently to different techniques.

It is prudent to advise both the parents and the operating room staff that a range of techniques from closed to open may be employed to obtain reduction. Doing so eliminates any element of surprise. The surgeon should ensure the availability of elastic titanium nails, Kirschner wires, and Steinmann pins if needed.

Elbow range of motion and stability are assessed under anesthesia. The elbow is then pronated and supinated under fluoroscopy to find the maximum plane of angulation before reduction (FIG 3).

Several different techniques of closed and percutaneous reduction make up the “reduction ladder” covered in the Techniques section, much like the plastic surgeon’s reconstructive ladder. These tools may be used in stepwise progression or in conjunction as needed.

**Positioning**

The patient is positioned supine on the operating room table, with the elbow on the fluoroscopy C-arm and the arm positioned on the collimator of the C-arm (FIG 4).

The imaging monitor is placed at the opposite side of the bed for easy visualization.

**Approach**

The posterolateral Kocher approach is used for open reduction of severely displaced floating fragments. The approach is further described in the Techniques section.

---

**FIG 3** The maximal angle of displacement is found with fluoroscopy imaging through the ranges of full supination (A) to pronation (B). In this case, maximal angulation is noted with 50 degrees of pronation.
CLOSED REDUCTION

Israeli or Kaufman Technique

- Kaufman described a closed reduction technique with the elbow flexed 90 degrees.8
- Fluoroscopy is used to establish the forearm position demonstrating maximal angulation (see Fig 3).

One hand is used to control forearm rotation, and the other hand is used to provide lateral pressure to the displaced radial head with the thumb (TECH FIG 1A–C).
- After reduction, fracture stability and range of motion are assessed (TECH FIG 1D–G).

**TECH FIG 1 • A–C.** Kaufman (Israeli) technique. One hand grips the forearm distally to control supination and pronation (A), while the thumb of the other hand reduces the fragment in the plane of maximal reduction (B), milking the head from distal to proximal (C). D–G. After reduction has been obtained, the stability and range of motion (pronation–supination) are assessed in extension and 90 degrees of flexion.
Patterson Technique

- With the elbow extended and forearm supinated, varus stress is applied to the elbow by an assistant. The surgeon reduces the fragment with lateral digital pressure (TECH FIG 2).

- If closed reduction fails, a Kirschner wire or a Steinmann pin can be used to directly push or lever the radial head into anatomic position.

- The surgeon must beware of the posterior interosseous nerve coursing volar and distally over the radial head. The radial head can be protected by pronating the forearm and by using a posterolateral pin approach (TECH FIG 3).

- The forearm is rotated during fluoroscopic guidance so that the plane of maximal angulation is visualized.

- The blunt end of a larger Kirschner wire, 0.062 inch or larger, is percutaneously inserted through the skin distal to the fracture and just off the lateral border of the ulna (TECH FIG 4A,B) through a 2-mm incision.

- With fluoroscopic guidance, the pin is placed against the posterolateral aspect of the proximal fragment and the radial head is pushed into place (TECH FIG 4C,D).

- Axial traction and rotation of the forearm can dislodge an impacted fracture and assist in the reduction.

- Alternatively, the pin (or a Freer elevator) can be used as a lever. When doing so, the skin entry site of the pin must be placed more proximally, however, at the level of the fracture site (TECH FIG 5A).

- With the pin just through the skin, the pin is pulled distally (applying tension to the skin) to allow a retrograde approach to the fracture.

PERCUTANEOUS REDUCTION WITH A KIRSCHNER WIRE OR STEINMANN PIN

- Drawbacks of this technique include the need for an understanding assistant providing countertraction and varus stress, and the potential difficulty in palpating the radial head in this position.

TECH FIG 2 • Patterson technique. A. The assistant helps with positioning the elbow in extension, applying a varus force, while holding the forearm in supination. B,C. Digital pressure from the thumb is applied to the radial head to achieve reduction.

TECH FIG 3 • The posterior interosseous nerve moves volar and medial with pronation, moving it away from the working area during percutaneous or open treatment of radial head and neck fractures.
The deeper soft tissues are then pierced, the fracture site is entered (TECH FIG 5B), and the proximal fragment is levered proximally to correct the angulation while translation is corrected with simultaneous lateral digital pressure. During the levering maneuver, the tensioned skin relaxes, thus making the reduction easier (TECH FIG 5C).

If the skin instead were entered distally for the lever maneuver, however, the skin tension during the reduction maneuver would make the reduction substantially more difficult.

After percutaneous reduction, fracture stability in all planes is assessed. If unstable, pin fixation of the fragment is recommended.

Kocher’s posterolateral approach to the radial head is used. Pronating the forearm brings the posterior interosseous nerve further anteromedially, away from the surgical field.

A skin incision about 5 cm long is made, centered over the posterolateral aspect of the radial head (TECH FIG 6A). The interval between the anconeus (radial nerve) and the extensor carpi ulnaris (posterior interosseous nerve) is developed (TECH FIG 6B).

A longitudinal incision is made along the capsule, unless the capsule has not already been torn open by the injury causing trauma (TECH FIG 6C).

The proximal fragment is identified and reduced under direct visualization and fluoroscopic guidance. If the annular ligament has been injured it should be repaired.

Occasionally, the fracture is widely displaced anteromedially, necessitating further exposure before identification. In such a case, a more extensile approach is recommended, as well as a formal proximal identification of the radial nerve and posterior interosseous nerve.

If the fracture requires open reduction, internal fixation is recommended.

A recent retrospective review of radial neck nonunions noted that they were commonly associated with an early loss of fixation, related to either displacement or premature removal of pins.20

Options for internal fixation include pins placed obliquely though the radial head in an “ice-cream cone” pattern throughout the safe zone. Absorbable pins can also be used. Radial head fixation can be
achieved with epiphyseal–metaphyseal interrupted, circumferentially placed absorbable sutures. For skeletally mature children, headless screws or a T-plate in the safe zone can be used.

- Although seldom indicated, Leung and Tse described a lateral mini-plate buttress technique for the open physis. The plate is anchored distally in the radial neck with 2-mm screws and left unattached proximally, providing a buttress preventing lateral dislocation of the radial head.

- Transcapitellar pin fixation has been described, but it provides poor distal fixation and is associated with pin breakage at the radiocapitellar joint.

## PEARLS AND PITFALLS

### Indications
- The surgeon should have a discussion with the family and alert the operating room staff regarding the “reduction ladder” and the various techniques that may be employed.

### Operative technique
- Although percutaneous reduction can be a tedious and time-consuming procedure, open reduction should be avoided if at all possible.
- A mini-open approach using a Freer elevator as a shoehorn can sometimes reduce the fragment when percutaneous Steinmann pin reduction is unsuccessful.
- If an open reduction is necessary, fixation is necessary.
- Transarticular pins should be avoided as they break at the joint.
- Radial head excision is contraindicated in children because of valgus elbow deformity, longitudinal forearm instability, and high incidence of overgrowth.

### Imaging
- After achieving reduction, the surgeon should verify improved range of motion and make sure that the reduction is a true change in alignment and not simply a radiograph taken out of the plane with maximal angulation.
- The surgeon should beware of reversal of radial head position during radial head reductions and should make sure on plain radiographs that the radial head is properly reduced and not flipped 180 degrees.

### Follow-up
- Clinical or radiographic signs of fracture healing should be present before removing pin fixation. The period of pin fixation or immobilization should be longer for unstable, high-energy injuries.

## POSTOPERATIVE CARE
- After reduction, the elbow is immobilized in 90 degrees of flexion in the position of supination–pronation that is most stable for 3 weeks.
- If a splint is used postoperatively because of swelling, it is changed to a cast at 1 week.
- At follow-up, the cast is removed for radiographic and clinical examination. If healing is inadequate (which is more likely in higher-energy injuries in older children), the cast (and the pins if used) is continued for 2 more weeks, after which patient is re-evaluated for healing.

- If pin fixation is used, no elbow motion is allowed until pins are removed.
- Graduated range-of-motion exercises begin when the cast is removed.

## OUTCOMES
- Many series have shown a good to excellent outcome in 76% to 94% of children with radial neck fractures.
- Indicators for a favorable prognosis include younger age (less than 10 years), isolated low-energy injury, closed reduction, early treatment, less than 30 degrees of initial ang-
gulation, less than 3 mm of initial translation, and reduction within parameters discussed above.3,12,17

- Poor outcomes, such as limitations in range of motion, have been reported in 6% to 30% of patients, usually after a severely displaced radial neck fracture.

- Risk factors for a poor outcome include severe displacement, associated injuries, delayed treatment, poor reductions, old age, fractures needing open treatment and internal fixation, and intra-articular fractures in patients with an open physis.10,12,16,17,20

- Poor outcomes that have been noted with open procedures are partially due to a selection bias, where patients needing open procedures are more likely to have had high-energy injuries with additional vascular and soft tissue trauma.

**COMPLICATIONS**

- Loss of joint congruity, fibrous adhesions, and radial head overgrowth result in a loss of elbow motion. In order of decreasing frequency, pronation, supination, extension, and flexion are affected.15

- Radial head overgrowth is observed in 20% to 40% of cases due to presumed increased vascularity stimulating the physis. Premature physeal closure can occur and is seldom symptomatic, but it can accentuate a valgus deformity. Delayed appearance of the ossific nucleus is possible after a fracture occurring before ossification.

- Avascular necrosis of the radial head occurs in 10% to 20% of patients.3,12 Seventy percent of cases occur in cases of open reduction.3

- Radial neck nonunions are rare but have been reported and are often associated with premature loss of fixation.20

- Posttraumatic radioulnar synostosis occurs in 0% to 10% of cases,3,12,16 typically in association with open reductions, extensive dissection, residual displacement, and concurrent ulna fracture. Exostectomy of synostosis is a technically demanding procedure with a variable success rate.

- Heterotopic ossification (6% to 25% of cases)3,12 can occur as myositis ossificans in the supinator or as ossification within the capsule. Surgical treatment is rarely indicated.

**REFERENCES**


DEFINITION
- Radial neck fractures in children are typically transphyseal injuries and seldom involve the epiphysis (radial head).
- The majority of these fractures are Salter-Harris type II injuries. Salter-Harris type I fractures are also common. In older children some fractures may be entirely metaphyseal (FIG 1).
- Radial neck fractures represent about 14% of all elbow fractures in children.8

ANATOMY
- Ossification of the proximal radial epiphysis (radial head) occurs by 4 years of age, at which time the radial head and neck have assumed their adult shape. The proximal radial physis closes at 14 years in girls and 17 years in boys.
- At the level of the radiocapitellar joint, the radial nerve divides into its terminal branches, including the posterior interosseous nerve, which enters the substance of the supinator muscle at the arcade of Frohse and winds around the anterolateral aspect of the radial neck. Pronation of the forearm moves the posterior interosseous nerve more medially and away from the anterolateral side of the radial neck (FIG 2).

PATHOGENESIS
- The most common mechanism of injury is due to a fall on the outstretched hand with the elbow extended and the forearm supinated.
- The resultant valgus force compresses the capitellum against the radial head.

PATHOGENESIS
- Radial neck fractures may occur in association with a posterior dislocation of the elbow that displaces the radial head anteriorly.12
- A posteriorly displaced radial neck fracture can occur during the spontaneous reduction of a posterior elbow dislocation.4
- Alternatively, an unrecognized (undisplaced) radial neck fracture can be displaced posteriorly during the manipulative reduction of a posterior elbow dislocation. During the reduction maneuver, if the elbow is flexed, the distal humerus (lateral condyle) strikes the radial head, knocking it posteriorly off the metaphysis (FIG 3).

NATURAL HISTORY
- Most radial neck fractures are minimally displaced or undisplaced. These heal uneventfully.
- The greater the degree of angulation or translation, the greater the disruption in the relationship of the radiocapitellar joint, which may be associated with a decrease in the range of pronation and supination.2
- The upper limit of acceptable angulation (0 to 60 degrees) is unclear and may be age-dependent.16 Most believe that angulation less than 30 degrees is unlikely to cause a clinically (functionally) significant loss of motion.
Other reported consequences include avascular necrosis of the radial head, heterotopic ossification, radioulnar synostosis, and premature physeal closure, which may result in pain, crepitus, and valgus deformity and stiffness.\(^2,5,16,18,19\)

- These outcomes may be associated with age, severity of displacement, presence of associated injuries, or delay in treatment.
- Some of these might be a complication of the treatment (poor reduction, open treatment, or internal fixation) rather than the natural history.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- History of a fall on the outstretched hand
- Swelling of the elbow with limited range of motion associated with pain. Occasionally lateral ecchymosis may be evident.
- Tenderness and crepitus may be localizable to the radial head, provoked by gentle pronation and supination.
- The clinician should rule out an elbow dislocation and look for other areas of tenderness that might point to associated injuries.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Anteroposterior (AP) and lateral radiographs of the elbow. Oblique views can be helpful but are not routinely necessary.
- Amount of displacement: angulation and translation of the radial neck are noted.
- There are numerous classification systems of the severity of initial displacement. Most categorize the fractures based on amount of angulation,\(^2\) usually in 30-degree increments, while some also include translation.\(^6,9,16,18,19\)
  - The Judet classification is a simple descriptive system (FIG 4; Table 1).\(^6\)
  - The clinician should carefully rule out associated injuries such as fractures of the olecranon (intra-articular) (FIG 5), proximal ulna, medial epicondyle, or lateral condyle or elbow dislocation.
  - In posterior elbow dislocations, the clinician should carefully examine the radial neck for an occult fracture that is at risk for displacement during the reduction maneuver.
Differential Diagnosis

- Radial neck fractures
- Radial head fractures
- Monteggia variant: the clinician should look for any olecranon fractures or proximal ulna fractures
- Elbow dislocations

Nonoperative Management

- The Patterson reduction technique involves longitudinal traction applied to the extended arm with countertraction provided proximally.
  - The forearm is rotated (supinated) until the maximum tilt of the radial head is directed laterally.
  - A varus force is then applied to the elbow, while the radial head fragment is reduced by direct pressure.13
- Kaufman and associates’ describe a closed reduction maneuver with the elbow in 90 degrees of flexion and in maximum supination (the Israeli technique).
  - Thumb pressure is applied to the lateral aspect of the displaced radial head while the forearm is rotated gradually into full pronation.

Surgical Management

- Many displaced radial neck fractures can be satisfactorily reduced to an acceptable position with one of the above closed reduction techniques.
  - Failure to obtain or maintain an adequate closed reduction of Judet type 3 or 4 fractures (more than 30 degrees) is an indication for closed operative techniques.
  - Percutaneous leverage of the radial neck fracture using a Kirschner wire or Steinmann pin is one option.
  - Alternatively, reduction of the radial head can be accomplished by intramedullary manipulation of the radial head using a flexible or elastic nail or a Kirschner wire, with the nail or wire retained to stabilize the fracture if necessary.
  - Intramedullary reduction may be facilitated by the percutaneous leverage technique.
  - Open reduction with internal fixation is reserved for fractures that cannot be successfully managed by the above closed means.

Preoperative Planning

- Careful examination of the radiographs is necessary to rule out intra-articular involvement of the radial head as well as associated injuries of the proximal ulna and distal humerus (FIG 5).
  - The orientation of the displaced radial head must be confirmed to ensure that the articular surface of the fragment is not flipped 180 degrees.
  - A set of Kirschner wires or Steinmann pins should be available if percutaneous pin-assisted reduction using the joystick or leverage technique is considered necessary.
  - If flexible intramedullary nail-assisted reduction is being considered, the narrowest diameter of the intramedullary canal of the radius must be measured to select the appropriate diameter of the intramedullary nail or device (Kirschner wire or elastic titanium nail).
  - Under general anesthesia, closed reduction of the fracture is attempted under fluoroscopic guidance before the decision is made to proceed.

Positioning

- The patient is supine with the injured arm positioned over a radiolucent armboard.
- The image intensifier may be positioned parallel to the operating table to allow the C-arm to be moved freely from the AP to lateral position.

Approach

- For the percutaneous pin-assisted reduction technique, the pin or Kirschner wire is inserted from the posterolateral aspect of the radial neck with the forearm pronated to avoid injury to the posterior interosseous nerve.
  - For the centromedullary technique, the preferred entry point for the elastic nail is at the distal radius proximal to the growth plate through a 1.5-cm incision.
  - If the entry point is on the radial side, care is taken to avoid injury to the branches of the superficial radial nerve. The entry site is placed away from the tendons of the first extensor compartment.
  - An alternative entry point is the dorsal approach, just proximal to the tubercle of Lister, between the third and fourth extensor compartments.
  - If the elastic nail is being retained for fixation of the fracture, the radial approach is favored to prevent late rupture to the extensor pollicis longus tendon, which has been reported with the dorsal approach.
  - This complication can be avoided if the end of the retained nail is trimmed above the dorsal aspect of the extensor tendons so as not to abrade its volar surface.

**FIG 5**  A. Radial neck fracture with associated intra-articular fracture of the olecranon. Olecranon fracture appears minimally displaced on lateral view. B. Significant displacement is seen on AP view.
PERCUTANEOUS PIN (JOYSTICK) REDUCTION TECHNIQUE\textsuperscript{1,14,18}

Insertion and Manipulation of the Kirschner Wire

- Using the image intensifier, the Kirschner wire is inserted from the posterolateral aspect of the radial neck (TECH FIG 1A).
- During the insertion of the pin the forearm is best pronated to avoid injury to the posterior interosseous nerve. The surgeon should observe the thumb and index finger for any signs of metacarpophalangeal extension.
- Once the tip of the Kirschner wire has reached the fracture site, the forearm may be rotated until the maximum displacement of the radial head is visualized (TECH FIG 1B).
- The Kirschner wire is then advanced into the fracture site between the radial head (epiphysis) and the metaphysis and the fracture is disimpacted (TECH FIG 1C,D).
- The Kirschner wire is then swung cephalad to lever the radial head back into position (TECH FIG 1E–G).

TECH FIG 1 • A. Position of pin for percutaneous pin-assisted reduction of a displaced radial neck fracture. B–G. When the Kirschner wire has been introduced into the fracture site, it is used to lever the radial head fragment into position by swinging it cephalad.
**Use of Second Kirschner Wire**

- Occasionally the radial head remains translated even though the angulation has been corrected. With the first Kirschner wire in place, a second Kirschner wire may be introduced percutaneously to push the laterally translated fragment medially back into position (TECH FIG 2A–C).
- The Kirschner wire is removed and the stability of the reduction assessed.

- If the reduction is stable, as is usually the case, no internal fixation is required. The elbow is immobilized in 90 degrees of flexion with a posterior splint for 2 or 3 weeks.
- If the reduction is unstable, the Kirschner wire may be used to repeat the leverage technique and then advanced with a power driver obliquely through the metaphysis to act as a buttress to prevent the radial head from redisplacing.
- The Kirschner wire does not need to pass through the substance of the proximal fragment (TECH FIG 2D,E).

**CLOSED INTRAMEDULLARY REDUCTION AND FIXATION (METAIZEAU TECHNIQUE³)**

**Metaizeau Technique**

- Metaizeau described an intramedullary reduction and fixation technique for the treatment of displaced radial neck fractures⁹ that has been widely adopted.³,¹⁵,¹⁷
- The intramedullary manipulation of the radial head may be accomplished by an elastic titanium nail or a Kirschner wire of sufficient length, the tip of which is bent about 30 degrees.
- The diameter of the elastic nail or Kirschner wire is usually 2 mm. A 2.5-mm nail may be suitable in some children older than 10 years. The curved nail tip can be bent additionally.
- The preferred entry point for the nail is on the lateral cortex of the distal radius 1.5 to 2 cm proximal to the physis. It is created with a sharp awl or drill through a 1.5-cm incision, taking care to avoid injury to the sensory branch of the radial nerve (TECH FIG 3).
Chapter 7 PERCUTANEOUS JOYSTICK AND INTRAMEDULLARY REDUCTION (METAIZEAU) TECHNIQUES

Engaging the Fragment
- The elastic nail is attached to a T-handle and advanced proximally through the medullary canal under fluoroscopic guidance (TECH FIG 4A–C).
  - The forearm is rotated until the plane of maximum deformity is visualized.
  - The curved tip of the nail or the Kirschner wire is directed toward the displaced proximal fragment and gently advanced across the fracture until the tip engages the epiphyseal fragment without penetrating the articular surface (TECH FIG 4D–F).
  - AP and lateral radiographs are obtained to confirm the position of the nail tip in the epiphyseal fragment.

Rotating the Fragment into Place
- The nail tip is used to elevate the fragment to reduce the tilt anchoring the proximal fragment against the lateral condyle.
  - The T-handle is then used to rotate the nail or Kirschner wire typically anteriorly and medially, thereby reducing the lateral or posterolaterally displaced radial head back to its normal location (TECH FIG 5).
  - If the epiphysis is displaced anterolaterally, the nail is rotated posteriorly and medially.
  - The intact periosteum prevents overcorrection of the fragment medially.

Completing the Procedure
- The reduction maneuver may be facilitated with a prior or concurrent closed reduction. In severely displaced radial neck fractures, the percutaneous technique described above may be performed concurrently to facilitate the intramedullary reduction (TECH FIG 6A).
  - With the nail tip engaged in the epiphysis and the reduction complete, the stability of the fracture is assessed and the nail is left in situ.
  - The nail is trimmed 1 cm proud of the bone at the entry site (TECH FIG 6B).
  - If the dorsal approach is used, the nail can be bent 90 degrees dorsally and trimmed just above the plane of the extensor pollicis longus tendon to ensure that the end of the nail does not abrade the tendon (TECH FIG 6C).
**TECH FIG 4** • Closed intramedullary reduction and fixation technique of Metaizeau with an elastic nail. **A–C.** Proximal advancement of elastic nail through the medullary canal. **D–F.** The curved tip is directed toward and advanced into the displaced epiphyseal fragment.

**TECH FIG 5** • The elastic nail is rotated anteriorly and medially to reduce the radial head.
**POSTOPERATIVE CARE**
- A short period of immobilization may be necessary, but usually active range of motion can be started after 2 to 3 weeks. If the fracture is stable or stabilized by the elastic nail, the arm can be placed in a sling and gentle active range of motion encouraged as soon as tolerated.
- Early passive range of motion is not recommended because of the risk of heterotopic ossification.
- The elastic nail or Kirschner wire is removed after 6 to 8 weeks, when the fracture has healed clinically and radiographically.

**OUTCOMES**
- A good outcome, defined as a functional painless range of motion without complications, can be expected in 78% to 93% of Judet grade 3 or 4 fractures treated by elastic stable intramedullary nailing.\(^5,15,17\)

**COMPlications**
- Posterior interosseous nerve injury\(^15\)
- Injury to sensory branch of radial nerve
- Late extensor pollicis longus rupture
- Penetration of the articular surface of the epiphysis, requiring early removal (FIG 6A)
- Malreduction of the radial head flipped 180 degrees\(^11\) (FIG 6B–E)
- Loss of reduction can be avoided by checking stability intraoperatively or retaining the Kirschner wire or elastic nail for fixation.
- Minor limitation of motion
- Avascular necrosis
- Radial head overgrowth
- Premature physeal closure is common as a consequence of the injury, treatment, or both. The clinical significance of this is unknown but it is unlikely to be problematic.
- Nonunion\(^21\)
- Radioulnar synostosis
- Periarticular heterotopic ossification

### TECH FIG 6
- A. Intramedullary reduction can be facilitated by concurrent percutaneous pin reduction technique.
- B. The end of the nail is left proud off the entry site to facilitate removal. C. If a dorsal entry point is used, the end of the nail is trimmed above the level of the tendons to prevent rupture.
TRAUMA

FIG 6 • A. Penetration of the articular surface of the epiphysis may irritate the joint. B–E. Malreduction of radial head flipped 180 degrees. B. Salter-Harris type II Judet 4 fracture. C. Pin-assisted reduction. D. Apparent anatomic reduction. E. AP view reveals radial head fragment is flipped over 180 degrees.

REFERENCES

DEFINITION
- Cubitus varus is a deformity of the distal humerus that results in a change in the carrying angle from physiologic valgus alignment between the upper arm and forearm.
- Historically, cubitus varus was the most common complication following supracondylar humerus fracture, with a frequency as high as 30%.
- The appearance of the deformity is the major concern for the parents and patient, as there is little functional deficit.

ANATOMY
- Bone
  - The distal humerus consists of two structural columns of bone medially and laterally.
  - The olecranon and coronoid fossae separate the two structural columns.
  - The cortices of the distal humerus are thinner in the child than the adult, and the anteroposterior (AP) diameter of the distal humerus is decreased in children.
- Neurovascular
  - The median nerve and brachial artery run along the medial border of the biceps brachii muscle in the upper arm and come to lie anterior and slightly medial in the cubital fossa.
  - The radial nerve enters the anterior compartment of the arm in the distal third of the upper arm and travels between the brachialis and brachioradialis over the anterolateral distal humerus before it enters the supinator muscle in the proximal forearm.

PATHOGENESIS
- Cubitus varus occurs because of a malunited supracondylar humerus fracture and is not due to a growth disturbance of the distal humerus epiphysis.
- The primary cause is coronal varus angulation of the distal humeral metaphysis.
- Varus angulation can be caused by medial column comminution, causing the fracture to collapse into varus. Varus angulation can rarely be caused by lateral gaping at the fracture site.
- Other coexisting deformities can exist with cubitus varus, including extension and internal rotation of the distal fragment.

NATURAL HISTORY
- The deformity is static and does not evolve with time.
- The deformity is often not appreciated until several months after the fracture heals and the elbow flexion contracture that results from casting resolves.
- Tardy ulnar nerve palsy may occur owing to compression by chronic malpositioning of the triceps muscle due to a shift of the olecranon in the olecranon fossa.
- There may be a slight increased risk of subsequent lateral condyle fractures in children with cubitus varus.

PATIENT HISTORY AND PHYSICAL FINDINGS
- A detailed history is essential to understand parental and patient expectations of treatment in cubitus varus.
- Physical findings include a varus change in the carrying angle when compared to the opposite, unaffected side.
- Elbow and forearm range of motion should be documented.
- A thorough examination of nerve function to the forearm and hand should be performed.
- Hyperextension of the elbow indicates coexisting extension deformity at the malunion site.
- A loss of external rotation can be due to shoulder pathology or due to an internal rotation malunion at the distal humerus.
- The difference in carrying angle between the affected and unaffected side is the amount of cubitus varus.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain AP and lateral radiographs of the affected elbow should be obtained (FIG 1).
- Additionally, an AP radiograph of the affected and unaffected elbow in full extension and supination that includes the distal humerus, forearm, and wrist should be obtained. This is used to plan the amount of surgical correction desired.
- Advanced imaging (MRI of the elbow) may be of value in young children where distal humeral growth disturbance is suspected.

DIFFERENTIAL DIAGNOSIS
- Medial humeral condylar or trochlear growth disturbance
- Malunited lateral humeral condyle fracture
- Congenital dislocation of the radial head
- Malunited fracture/separation of the distal humeral physe

NONOPERATIVE MANAGEMENT
- Nonoperative management does not affect the appearance of cubitus varus.
- If correction is contemplated, surgery should be undertaken at least 1 year after injury to ensure that there is no evidence of distal humeral avascular necrosis.

SURGICAL MANAGEMENT
- Surgical indications
  - Skeletally immature child with posttraumatic cubitus varus
  - Full elbow extension and flexion to at least 130 degrees
  - Child and family unaccepting of the appearance of the elbow
  - At least 1 year after initial injury
- Surgical goals
  - Correction of the carrying angle to equal the contralateral side
In our experience, rotational deformity is well compensated for by shoulder and forearm rotation and does not need to be addressed surgically.

Preoperative Planning

- Preoperative AP radiographs of both elbows should be taken in full extension and supination.
- The angle of Bauman and the humeral-elbow-wrist angle should be determined for both sides.
- A tracing of the normal arm on tracing paper is reversed and superimposed on the radiograph of the operative arm (FIG 2A–C).
- By adding the humeral-elbow-wrist angles, the amount of planned correction can be estimated (FIG 2D). Alternatively, attempting to match the Bauman’s angle of the contralateral side can help estimate the amount of correction needed.
- The distal osteotomy cut is just proximal to the olecranon fossa.
- The osteotomy is planned with equal lengths of the proximal and distal limbs; this diminishes the tendency for a lateral condylar prominence.
- The angle of the wedge to be removed is the same as the angle of desired correction.
- Because the osteotomy is performed proximal to the deformity apex and hinges medially, there is a lateral shift of the forearm axis that will make the lateral condyle more prominent than in the normal arm, even with equal osteotomy limbs.
  - This appearance is more accentuated in patients with neutral humeral-elbow-wrist angles.
  - In these cases, a complete osteotomy with medial translation of the distal fragment should be planned.

Positioning

- The patient is placed supine with the arm on a radiolucent extremity table. A sterile upper arm tourniquet is used; this facilitates complete intraoperative visualization of the upper arm.
The lateral approach to the distal humerus is used, between the lateral head of the triceps muscle and the extensor carpi radialis longus muscles (TECH FIG 1A). A posterior approach can be used as well, if cosmesis is of paramount importance; however, the lateral approach is technically simpler. The distal humerus is subperiosteally exposed both anteriorly and posteriorly, and small Hohmann retractors are placed (TECH FIG 1B).

EXPOSURE

- The proximal and distal osteotomy cuts are made with a small oscillating saw as per the preoperative template. Kirschner wires inserted under image intensification can be used to mark the osteotomy sites.
- The distal osteotomy is performed proximal to the olecranon fossa. The proximal osteotomy meets the distal osteotomy at the medial cortex, leaving it intact.
- With the elbow extended, a valgus force is placed on the elbow, closing the osteotomy by creating a greenstick fracture at the medial cortex.
- A single distal lateral-to-proximal medial Kirschner wire is placed percutaneously (not through the incision) to hold the osteotomy apposed.
- The osteotomy site is tested for stability with real-time fluoroscopy. If the osteotomy is unstable, a second distal medial-to-proximal lateral Kirschner wire is used to supplement fixation (TECH FIG 2).
- If there is a lateral condylar prominence after performing the greenstick osteotomy, the Kirschner wire is removed, the medial cortex is cut, and the distal fragment is translated medially to remove the prominence. In this situation, routine medial and lateral Kirschner wire fixation is used.
- The medial Kirschner wire is inserted with the elbow relatively extended.
- The thumb is used to hold the ulnar nerve posterior to the medial epicondyle within the cubital tunnel.
- A small skin incision is made over the medial epicondyle, and a hemostat is used to spread the subcutaneous tissue to the underlying bone.
- Care is taken to prevent the wires from crossing at the osteotomy site.
- Fixation is evaluated with biplanar fluoroscopy to ensure proper pin placement before wound closure.
POSTOPERATIVE CARE
- With the technique described, patients are immobilized in a long-arm cast for 4 to 6 weeks. When radiographs show callus formation at the osteotomy site, the percutaneous Kirschner pins can be removed (FIG 3).

- The patient is then given a sling and active range-of-motion exercises are initiated.
- Once radiographic union is achieved, the sling is discontinued, and the patient can begin full activities once range of motion is restored.

WOUND CLOSURE
- The wound is irrigated and closed in layers in the standard fashion.
- The Kirschner wires are left protruding from the skin and are bent to prevent migration of the pins underneath the skin.
- A long-arm cast or splint is applied with the elbow in 90 degrees of flexion and the forearm in slight pronation. The patient should be closely monitored in the early postoperative period for swelling.
- If a splint is used, it is converted to a long-arm cast after swelling has subsided.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Patient selection</th>
<th>Parents and patients should understand the goal of the surgery, which is to improve the appearance of the elbow.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnosis</td>
<td>Patients with other conditions, such as growth disturbance of the distal humerus, should be identified preoperatively. Patients often have a progressive deformity and are better treated at skeletal maturity using other fixation methods.</td>
</tr>
<tr>
<td>Preoperative planning</td>
<td>Before operating, the surgeon must know the normal humeral-elbow-wrist angle for each particular patient as well as the amount of deformity.</td>
</tr>
<tr>
<td>Performing the osteotomy</td>
<td>Subperiosteal exposure in the distal humerus is essential. An intact medial cortex greatly enhances osteotomy stability.</td>
</tr>
<tr>
<td>Lateral condylar prominence</td>
<td>The osteotomy should be assessed with the elbow extended after closing the osteotomy. Patients with a neutral contralateral carrying angle should have complete osteotomy with translation of the distal fragment.</td>
</tr>
<tr>
<td>Fixation problems</td>
<td>Stability of fixation should be tested intraoperatively with fluoroscopy, and additional fixation is added as necessary.</td>
</tr>
</tbody>
</table>
OUTCOMES
- Patient outcomes after supracondylar humeral osteotomy are good to excellent in most cases, with retention of range of motion and improved appearance of the elbow as the major outcome measures.
- Loss of fixation, persistent lateral condyle prominence or undercorrection, and hypertrophic scar negatively impact outcome.6

COMPLICATIONS
- Persistent lateral condylar prominence6
- Nonunion
- Refracture6
- Hypertrophic lateral scar6
- Loss of fixation2
- Recurrent deformity
- Radial or ulnar nerve palsy
- Infection

REFERENCES
DEFINITION
- Commonly seen fractures include proximal humerus fractures (physseal and metaphyseal) and clavicle fractures and dislocations, as well as less commonly seen fractures of the scapula.
- Most of these injuries can be treated nonoperatively because of the significant remodeling potential.
- Certain fractures will require operative treatment, however, due to decreased remodeling capacity in the older child (proximal humerus), risk to surrounding structures (sternoclavicular dislocations), and open or threatened skin (clavicle fractures).
- Acromioclavicular joint injuries are often physeal fractures in the growing child and are almost exclusively so in children younger than 16 years old. The ligaments usually remain attached to the thick clavicular periosteum, and are thus usually intact.
- Opinion varies on the need for surgical repair, although most do well treated nonoperatively.\(^1,6\)
- Aggressive surgical treatment for some of these injuries (clavicle fractures, scapular fractures) is rarely indicated for most children. Operative treatment in these cases is the same as for the adult patient and will be covered in other chapters in this book.

ANATOMY
- The proximal humeral physis is responsible for 80% of humeral growth. It remains open usually until age 14 to 17 in girls, age 18 in boys.
  - A major portion of the physis is extracapsular and vulnerable to injury.
  - The anterior periosteum is usually thinner than the posterior, often leading to hinging of the fragments posteriorly and possible entrapment of the periosteum anteriorly.
  - The proximal humerus lies in close proximity to the brachial plexus and axillary vessels. Care should be taken to document function of the innervated musculature before initiating treatment (FIG 1).
  - The medial clavicular epiphysis is the last in the body to appear (age 18 to 20 years) and the physis is the last to close (age 23 to 25 years).
  - This is why most of these injuries are physeal fractures rather than true dislocations.\(^2\)
  - Immediately posterior to the sternoclavicular joint lie the trachea, esophagus, and great vessels.

PATHOGENESIS
- Injuries to the proximal humerus occur from either a direct blow to the region or indirect trauma, such as a fall onto the outstretched hand.
  - In cases of pathologic fractures through bone cysts, throwing a ball or reaching overhead can precipitate an injury.
  - Sternoclavicular injuries are usually caused by a direct blow to the clavicle, or by a blow to the lateral shoulder girdle that dislocates the clavicle anteriorly or posteriorly.
  - Scapular fractures are high-energy injuries, requiring comprehensive evaluation as per Advanced Trauma Life Support protocols.

NATURAL HISTORY
- Because of the significant remodeling potential in young children, most patients will heal without sequelae from fractures of the proximal humerus or clavicle.
- Intra-articular fractures of the glenoid should be treated as in the adult.
- Morbidity from associated injuries, however, may be significant, and thus a thorough evaluation is of paramount importance. Posterior sternoclavicular dislocations in particular threaten the great vessels, trachea, and esophagus.
- Debate exists as to the natural history of distal clavicle fractures with significant displacement, but most agree that conservative treatment is effective.\(^2\)
- General guidelines are available to define acceptable healing alignment for proximal humeral fractures (Table 1).

<table>
<thead>
<tr>
<th>Patient Age (years)</th>
<th>Maximum Acceptable Degrees of Angulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;7</td>
<td>70</td>
</tr>
<tr>
<td>8 to 12</td>
<td>60</td>
</tr>
<tr>
<td>&gt;12</td>
<td>45</td>
</tr>
</tbody>
</table>

Examples of complete or near-complete remodeling are readily found in the literature for even completely displaced fractures in children less than 15 years old, however, so a clear understanding of the goals of the procedure and its associated risks is crucial.1,5

PATIENT HISTORY AND PHYSICAL FINDINGS

- History should include mechanism of injury, antecedent pain, and neurologic symptoms in the hand and arm.
- A high-energy injury should also prompt a full trauma workup using standard Advanced Trauma Life Support protocols.
- Physical examination begins with a thorough assessment of the skin for areas of compromise, particularly in clavicle fractures.
- Swelling from a sternoclavicular dislocation may mask initial displacement, so this area should be palpated for pain or crepitance. Stridor in the setting of a sternoclavicular injury is particularly worrisome.
- A neurologic examination to include the brachial plexus distribution, as well as a vascular examination of the arm, is necessary.
- Neurologic injury in conjunction with fracture may signify ongoing compression (ie, sternoclavicular dislocation) and may affect prognosis.
- A high suspicion for vascular injury is important in preventing late sequelae.

The clinician should palpate the medial and lateral clavicles and the proximal humerus to differentiate fracture from soft tissue injury.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Standard initial views of the shoulder should include a true anteroposterior (AP) view, a “shoot-through” lateral, and an axillary lateral view (FIG 2A,B).
- The “serendipity view” is helpful in cases of medial clavicle fracture or dislocation. This is taken by obtaining an AP radiograph of both clavicles with the beam angled 40 degrees cephalad (FIG 2C).
- Computed tomography can be helpful to assess cases of suspected sternoclavicular dislocation, as a contrast study will provide information about potential vascular injury (FIG 2D), as well as detail the relationship of the clavicle to the trachea and esophagus (FIG 2E).
- CT is the standard, although some have recommended MRI.4

DIFFERENTIAL DIAGNOSIS

- Proximal humerus metaphyseal fracture
- Proximal humerus physeal injury
- Shoulder dislocation
- Acromioclavicular fracture-dislocation
- Sternoclavicular fracture-dislocation
- Child abuse

FIG 2 • A,B. Preoperative AP and lateral radiographs of a Salter-Harris type II fracture of the proximal humerus in a 15-year-old girl show mild valgus angulation and complete displacement with 90 degrees of angulation on the lateral view. C. In a different patient, apical oblique radiograph taken with fluoroscopy before reduction of a posterior sternoclavicular dislocation. Note the asymmetric heights of the inferior clavicles (*). D. In another patient, three-dimensional contrast-enhanced computed tomography image of left posterior sternoclavicular dislocation. Note the relationship to the great vessels. E. Axial view of the same patient as in D, demonstrating the injury to be a physeal fracture. The epiphysis (arrow) remains in place, while the metaphysis (*) is posteriorly displaced, immediately anterior to the vasculature.
NONOPERATIVE MANAGEMENT
- Most of these injuries can be treated nonoperatively.
- For proximal humeral fractures with acceptable alignment, treatment consists of sling management for comfort for several weeks, followed by a home range-of-motion program and return to activities in 6 to 8 weeks.
- Treatment of clavicle fractures consists of a sling for initial comfort, followed by a figure 8 bandage or sling, depending on the patient’s preference.
  - Immobilization can usually be discontinued after 3 weeks, with return to sports by 6 to 8 weeks.
  - While surgical management of distal clavicular physeal injuries has been advocated by some, the majority of patients do well with treatment similar to clavicular shaft fractures.
  - Older children can be treated as adults, and the surgical treatment of these injuries is discussed elsewhere.

SURGICAL MANAGEMENT
- The operative management of clavicle fractures and dislocations is well covered elsewhere in this text. Operative treatment of proximal humeral fractures will subsequently be discussed, as well as reduction of posteriorly displaced fracture-dislocations of the sternoclavicular joint.
- For physeal or metaphyseal fractures of the proximal humerus, operative treatment should be considered for fractures with unacceptable residual displacement.
- Closed reduction is often unstable and fixation is desirable.
- Because of open growth plates, standard plate-fixation techniques are rarely indicated.
- Threaded-wire fixation provides sufficient temporary fixation to allow healing.
- Failure to obtain a satisfactory closed reduction may require an open reduction, and surgeons should be familiar with this technique as well.
- Interposition of the biceps tendon has been noted to be the most common cause of a failed closed reduction,³ but other authors disagree.⁵

Preoperative Planning
- Good-quality radiographs of the shoulder should be available.
- It is important to rule out concomitant glenoid fracture or dislocation before surgery.

Positioning

Proximal Humerus Fractures
- For proximal humeral fractures, the patient is positioned in a modified beach-chair position, with the back elevated roughly 30 degrees.
- The imaging machine is then brought in from the head of the table. It can be tilted “over the top” to get an AP view and rotated to get an axillary lateral view (FIG 3).
  - If the table is too upright, the AP view may be difficult to obtain because of limited excursion of the C-arm past neutral.
- A vacuum positioning device (beanbag) is positioned under the patient’s head, neck, and upper torso. This allows the patient to be slid slightly over the edge of the table to allow full access to the shoulder girdle.
- A chest pad attached to the table prevents the patient from being pulled off the table inadvertently when traction is applied to the arm.
  - Alternately, a sheet can be wrapped around the torso and secured by an assistant on the opposite side of the table.

Sternoclavicular Dislocation
- Patients with posterior sternoclavicular dislocations should be positioned supine with a roll between their shoulders to allow hyperextension of the shoulder girdle. It is helpful to position the patient with the operative side near the edge of the table.

FIG 3 • Intraoperative positioning for reduction. A. The patient is over the edge of the table with the entire arm exposed. The imaging machine is brought in from the head of the table. It is tilted into the “over-the-top” position to obtain a true AP view of the shoulder. Note the surgeon’s hands; traction is applied with the left hand, while the right helps to correct the adduction of the distal shaft fragment. B. Without moving the arm, the image can be rotated to obtain an axillary lateral view. In this simulated figure, the fluoroscopy unit is not draped for clarity; in practice, it is brought up beneath the drapes to maintain the sterile field. The surgeon is applying pressure to reduce the apex anterior angulation, while maintaining traction with the left hand. Under the drapes, a chest pad prevents the patient from being pulled off the table with traction; a sheet wrapped around the torso and held by an assistant would accomplish the same purpose.
Approach

Proximal Humeral Fractures
- Reduction of proximal humeral fractures is, generally speaking, a closed procedure.
- Interposed tissue may require an open approach, which is through the deltopectoral interval (FIG 4).

Sternoclavicular Joint
- Reduction of sternoclavicular dislocations can also be performed in a closed fashion and treated without surgical repair of the ligaments.
- While I have treated these injuries with closed reduction followed by a figure 8 splint, close follow-up and postreduction CT are required to detect loss of reduction.

Because of this, others have recommended primary repair of all of these injuries.8
- Open reduction of these injuries is performed using a transverse incision overlying the sternoclavicular joint. A pediatric thoracic–vascular surgeon should be on standby, preferably in the room, because of the proximity of several vital structures in this region.
- The incision is carried through the platysma muscle down to the clavicular periosteum, which is elevated to expose the clavicle.
- Dissection is limited to within the periosteum to avoid injury to surrounding structures.
PROXIMAL HUMERUS FRACTURE

Closed Reduction

- To reduce the fracture, the forces acting on the humerus need to be understood. The proximal fragment tends to be abducted and externally rotated due to the pull of the rotator cuff musculature, while the shaft is adducted from the pull of the pectoralis major muscle. To correct this, the first step is usually abduction and external rotation of the arm.
- Traction is then applied to disengage the fragments. It is helpful to have an assistant stabilize the torso.
- Usually, the shaft can be manipulated in line with the head at this point.
  - The typical angulation to be corrected is varus and apex anterior angulation.
  - It is often helpful to think about pushing down on the proximal end of the shaft to correct the angulation while maintaining abduction to correct the varus.
- In smaller, thin patients it is possible to grasp the head through the axilla to assist with the reduction.
- Once reduced, stabilization ensues (see below).

Open Reduction

- In rare cases, a closed reduction cannot be successfully achieved. A common cause is entrapment of periosteum or biceps tendon.
- In these cases, a small deltopectoral incision can be made.
  - This is a limited approach, not the wide extensile exposure needed for open reduction and internal fixation.
  - A finger can usually be inserted through a small opening to allow clearance of obstructing soft tissue.
- Fixation then ensues (see below).

Percutaneous Pin Fixation

- Once reduced, the fracture is then stabilized.
- Threaded-tip pins, such as the 2.5-mm guide pins found in most cannulated hip screw systems, are ideal for pediatric use and are my first choice, although they are potentially unsuitable for use in osteoporotic adult bone. Fully threaded pins can also be used.
- It is important to understand the relationship of the important neurologic structures to the proximal humerus.
  - The axillary nerve lies in the deltoid muscle 5 cm (in an adult, less in a child) from the tip of the acromion laterally.
  - More anteriorly, the musculocutaneous nerve is at risk.
- Pins are placed through small stab incisions using a tissue protection sleeve after a hemostat has been used to spread the tissue down to the bone.
- Often the reduction is stable enough to allow the arm to be placed down at the patient’s side and internally rotated, which is the position of postoperative immobilization.
  - If not, the pin can be inserted in the abducted position, but on moving the arm down, the skin will then be tented by the pin.
- A relaxing incision can be made, or the first pin put in provisionally, the arm moved to the patient’s side, and the first pin removed after additional fixation has been obtained.
- The easiest pin to place first is usually from distal lateral to proximal medial (TECH FIG 1A).
- The pin is started perpendicular to the shaft, and the surgeon’s hand is then dropped to the correct angle.

**TECH FIG 1** Pinning of a proximal humeral fracture in the patient in Figure 2A,B with a Salter-Harris type II humeral fracture. A. After reduction, the first pin is placed. B. A second pin is then placed, starting more anteriorly and proximally. C. The pins are placed in a divergent fashion. The stab incisions (not shown) should be well distal to the pin–bone interface to prevent soft tissue tension. D. An “advance–withdrawal” test is performed under live fluoroscopy to confirm stability as well as the extra-articular nature of the pins.
It is important to make the initial approach down to the bone along the final angle of pin insertion to avoid skin tension problems later.

The pin is advanced into the head, stopping several millimeters below the subchondral bone.

A second pin is then added (TECH FIG 1B).

I usually prefer to place this pin starting more proximally and anteriorly to the first pin.

If the first pin is aimed at the inferior portion of the head, the second can be aimed more superiorly for greater pin divergence across the fracture (TECH FIG 1C).

If needed, a third pin can be added from the greater tuberosity downward into the shaft.

This is helpful in small patients for better purchase in the head, but I usually avoid this pin because of a higher rate of soft tissue complications.

After fixation is complete, an “advance–withdrawal” test is performed (TECH FIG 1D), similar to that done for a slipped capital femoral epiphysis.

The shoulder is rotated and the tips of the pins should appear to approach the joint surface and then withdraw with continued rotation.

Pins that appear too long should be pulled back.

In larger patients near or at skeletal maturity with sufficient bone stock, cannulated screws can be inserted over a wire in the same fashion as described for threaded pins.

I have found this technique rarely necessary, but it does avoid the issue of pin management (see below).

### POSTERIOR STERNOCLEAVICULAR FRACTURE-DISLOCATIONS

#### Closed Reduction

- My preferred initial technique is to attempt a closed reduction of these injuries. This is usually successful only if performed within 48 hours of injury.
- With a sandbag or towel roll placed between the shoulder blades, the patient is placed supine with the involved side close to the edge of the operating table.
- Intravenous anesthesia or conscious sedation may be used, but I prefer to perform the reduction under general anesthesia, both for patient comfort and so I can proceed to open reduction if required.
- Longitudinal traction on the ipsilateral arm is applied by an assistant.
  - The shoulder is then gradually extended.
  - This often will reduce the dislocation.
- If unsuccessful, the clavicle can be grasped and pulled upward, especially in thin patients.
- Finally, the region can be prepared and draped and a towel clip used percutaneously to grasp the clavicle and reduce it.
- The reduction is usually marked by a satisfying clunk and is often stable. This is not always the case, however, and the stability should be carefully confirmed.
- Gentle posterior pressure on the clavicle confirms the stability of the reduction.
- The shoulder is taken through a range of motion and the reduction checked as well.
- Finally, intraoperative fluoroscopy is used to confirm symmetry of the sternoclavicular joints.
- If confidence in a stable reduction exists, the patient is awakened and a postoperative CT scan obtained to assess the reduction (TECH FIG 2).
- Reductions of questionable stability require an open reduction.

#### Open Reduction

- The first step in this procedure is ensuring the presence of a pediatric vascular-thoracic surgeon in proximity to the operating room, preferably in the room.
- The medial clavicle is approached through a transverse incision centered on the sternoclavicular joint (TECH FIG 3A).
- The platysma muscle is divided and the clavicle periosteum exposed.
- It is helpful to come down on the clavicle laterally away from the injury. The periosteum can then be elevated medially, toward the injury.
- This allows careful exposure of the medial fracture (in the case of a true dislocation) or the physeal fracture site (in the case of a fracture-dislocation).
- The epiphysis lies laterally to the intra-articular disc ligament. Care should be taken when exposing this area so that dissection does not inadvertently excise the epiphysis.
- The medial clavicle is grasped with a pointed tenaculum and reduced (TECH FIG 3B).
- Although descriptions exist of temporary plating or pinning, the risks of these fixation techniques (migration of Kirschner wires, need for plate removal) do not justify
their use. Suture fixation can be performed simply with good results.4,8

- For true dislocations, 1- to 2-mm holes are made in the medial clavicle and the sternum (TECH FIG 3C).
- I use a burr for better control.
- There should be a generous bone bridge between the holes.
- An absorbable, braided no. 1 suture (as opposed to wire often used in adults) is passed through the drill holes in a figure 8 fashion and tied securely.
- For fracture-dislocations, the same technique is applied, but the medial holes are placed in the metaphyseal fragment (TECH FIG 3D).

> It is occasionally easier to pass two separate sutures in these cases.
> The needle is passed through one drill hole, out across the fracture site, and up through the hole in the corresponding fragment.
> This is repeated, and both sutures are subsequently tied.
> The periosteum is then repaired.
> After fixation, the reduction is tested for stability, and after confirmation of such, the wound is closed using standard technique.

**TECH FIG 3** • Approach for open reduction of a posterior sternoclavicular injury. A. The incision is centered on the joint, in line with the clavicle. Under the subcutaneous tissue lies the platysma muscle, which is also split in line with the incision. B. The clavicle is exposed subperiosteally, beginning laterally and working medially toward the joint. It can then be grasped with a towel clip and reduced. It is crucial to remain subperiosteal with the clip to avoid inadvertent injury to the vessels lying immediately posteriorly. After reduction, fixation is achieved with sutures. C. For a pure dislocation, a figure 8 pattern through burr holes will secure the joint. D. For a fracture-dislocation, it is often easier to use two separate sutures perpendicular to the fracture line.

### PEARLS AND PITFALLS

**Proximal humerus**

**Reduction**
- The arm should be fully abducted to allow reduction of the shaft onto the head. Gapping at the fracture may signify interposed tissue, and the preparation should allow open exposure if required.

**Pinning**
- The surgeon should avoid placing the pins in the region of the axillary and musculocutaneous nerve. The skin should be handled carefully and multiple punctures avoided to minimize soft tissue complications.

**Indications**
- A large remodeling potential exists. The surgeon should carefully consider patient age and remodeling capacity before proceeding with surgery. The surgeon should accept less-than-perfect reduction in lieu of open reduction if possible to avoid the complications associated with an open approach.

**Sternoclavicular joint**

**Closed reduction**
- The surgeon should consider open reduction and stabilization if doubt exists about stability.

**Open reduction**
- Preoperative imaging can identify potential associated injuries. A vascular surgeon should be available.
regardless of the treatment method chosen. Most patients with proximal humeral fractures will do well regardless of the treatment method chosen.

POSTOPERATIVE CARE

Proximal Humeral Fractures

- Aftercare of the pins is controversial. I prefer to leave the pins out of the skin for removal in the office.
  - This is usually easily accomplished at 3 to 4 weeks, when the fracture has gained sufficient stability from healing (FIG 5).
  - A battery-powered hand drill is helpful for securely grasping the pins and backing them out, as the tips are threaded.
  - The pins are wrapped in iodine-soaked gauze and covered.
  - They can be checked and redressed if concern exists, and pin care with half-strength peroxide is helpful.
- In obese patients, or in young patients who may have difficulty with activity restriction in the sling, soft tissue movement around the pins may lead to infection.
  - In these patients, the pins should be cut beneath the skin.
  - Removal then requires an additional trip to the operating room, usually at 4 to 6 weeks after surgery.
- After pin removal, the patients are instructed to begin gentle active-assisted shoulder range of motion.
  - Once healing is complete radiographically, formal physical therapy can be initiated to gain any additional mobility and strength.
  - Most children do well, however, by gradually resuming activities at their own pace.

Sternoclavicular Joint Injuries

- After postreduction CT confirms reduction, the patient is followed at weekly intervals for the first 3 weeks with apical oblique radiographs.
  - Immobilization in a figure 8 harness is continued for 6 weeks.
  - Return to sports is allowed at 3 months.
  - Open reductions are protected for 4 to 6 weeks in sling and swathe.
  - Gentle range of motion is begun at 4 weeks.
  - Again, sports participation is restricted for 3 months.

COMPICATIONS

- Proximal humerus fractures
  - Nerve injury
  - Pin tract infection or osteomyelitis
  - Persistent stiffness
  - Growth disturbance
  - Fracture through pin hole in cortex
- Sternoclavicular injury
  - Infection
  - Neurovascular injury
  - Persistent subluxation

OUTCOMES

Proximal Humerus

- Most patients with proximal humeral fractures will do well regardless of the treatment method chosen.

Younger patients, particularly less than 15 years of age, will do well with closed treatment in the absence of neurovascular injury or open fracture.

Operative treatment usually results in satisfactory healing, although several reports note a high rate of complications from operative treatment, including late fracture through a pin hole and late osteomyelitis.1

Sternoclavicular Joint

- Patients who undergo closed reduction of posterior sternoclavicular joint fracture-dislocations can be expected to do well.
  - Some authors recommend accepting residual displacement unless the patient has symptoms of mediastinal compression, as remodeling of the fracture can be expected; however, that view is not universal.10
  - Some authors believe that closed reduction is not sufficiently stable and report excellent functional outcomes from open reduction.5
  - Anterior sternoclavicular joint injuries, after reduction, are usually unstable.
  - The outcome in these injuries is usually quite good, as remodeling will occur and there is no risk to mediastinal structures.2

REFERENCES


FIG 5 • Radiograph taken 4 weeks after surgery of the patient in Techniques Figure 1, before pin removal. Medial sclerosis indicates healing.
DEFINITION
- Hip fractures in children may be intra-articular, involving the physis or femoral neck, or extra-articular, involving the intertrochanteric or subtrochanteric regions.

ANATOMY
- The femoral head is composed of the capital femoral epiphysis, the subcapital physis, and the most proximal portion of the femoral neck (FIG 1A,B).
- The femoral neck forms an angle of about 135 degrees with the femoral shaft. The medial two thirds of the neck is intracapsular; the lateral third is not.
  - The important retinacular vessels that supply the capital femoral epiphysis course along the femoral neck.
  - The intra-articular femoral neck has little if any periosteum.
- The lesser trochanter is an apophysis in the child and forms the insertion for the iliopsoas.
- Much of the greater trochanter is apophyseal and forms the insertion for the hip abductors.
- Fractures may occur through the growth plate (transphyseal), in the intracapsular femoral neck, or in the region distal to the capsule (extracapsular neck), intertrochanteric, and subtrochanteric regions (FIG 1C).

PATHOGENESIS
- The hip may be fractured by means of a direct blow to the hip area or an indirect force applied to the limb.
- While simple falls are a frequent cause of hip fractures in the elderly, they are less common in children.
- An axial load to the femur as in a fall from height or a motor vehicle accident may result in hip fracture.
- A direct blow from the side may result in hip fracture.
- A violent twisting force to the limb may fracture the hip.

NATURAL HISTORY
- Untreated proximal femoral physeal separations that are completely displaced have a poor prognosis because of the high likelihood of avascular necrosis of the capital femoral epiphysis and poor apposition for healing.
- Minimally displaced proximal femoral physeal separations have a better prognosis, much like those of an acute slipped capital femoral epiphysis. Untreated they are likely to heal, but there is a possibility of avascular necrosis.
- Intra-articular fractures of the femoral neck that are undisplaced may heal but also may displace.
  - Displaced fractures have a poor prognosis for healing because they are intra-articular and therefore will not generate much subperiosteal new bone.
  - Furthermore, there usually is not good bony apposition.
- Extra-articular fractures of the femur (low neck, intertrochanteric, and subtrochanteric fractures) have a good prognosis for healing but tend to result in shortening, external rotation, and sometimes varus if untreated.

PATIENT HISTORY AND PHYSICAL FINDINGS
- A routine history is obtained to elicit the mechanism and energy of injury. Concomitant injury and comorbidities must be recognized.
The patient will be unable to bear weight.
Typically the affected limb appears shortened and externally rotated (FIG 2).

IMAGING AND OTHER DIAGNOSTIC STUDIES
Generally, plain films are adequate to diagnose and plan treatment for hip fractures (FIG 3).
Technetium bone scanning or MRI may indicate if the capital femoral epiphysis is perfused, but the accuracy is questionable early on and the avascularity may not be reversible even if diagnosed. Reductive treatment should not be delayed for these imaging studies.

DIFFERENTIAL DIAGNOSIS
- Pelvic fracture
- Slipped capital femoral epiphysis
- Synovitis
- Traumatic hemorrhrosis of hip

NONOPERATIVE MANAGEMENT
- Nondisplaced or minimally displaced proximal femoral physeal separations and truly undisplaced neck fractures can be immobilized in a spica cast, but followed closely (in a few days) to watch for displacement. Displacement requires reduction and fixation.
- Extra-articular fractures (low neck, intertrochanteric, and subtrochanteric fractures) in children less than 6 years old can be treated by closed manipulation and spica casting. Shortening more than 1.5 cm or varus of more than 15 degrees indicates a need for open reduction and internal fixation (ORIF).

SURGICAL MANAGEMENT
- All displaced proximal femoral physeal separations should be reduced and fixed.
- All displaced intra-articular femoral neck fractures should be reduced and fixed. It may be prudent to fixate undisplaced fractures to prevent displacement.
- Extra-articular hip fractures should be treated by ORIF in children age 6 or older, younger children whose fracture cannot be reduced closed, children with polytrauma, and those with wounds or skin conditions that would preclude casting.

Preoperative Planning
The injured hip should be evaluated under anesthesia using fluoroscopy.
Physeal separations and intra-articular neck fractures that can be reduced anatomically should be treated by percutaneous fixation: pins in infants and toddlers (FIG 4A,B), screws in older children (FIG 4C,D).

FIG 2 • The affected limb appears shortened and externally rotated.
FIG 3 • AP and lateral radiographs of the proximal femur.
FIG 4 • Fixation of an intra-articular femoral neck fracture. A. Displaced fracture. B. Pins are drilled from the lateral femoral cortex retrograde across the fracture. For toddlers, pins are sufficient. Fractures below the physis in older children need screws. (continued)
Extra-articular fractures that are stable after reduction should be immobilized in a spica cast.

Positioning
- Positioning should be supine on a radiolucent table. A fracture table is generally not necessary (FIG 5A).

Closed Reduction and Percutaneous Fixation
- This technique is suitable for proximal femoral physeal separations and intra-articular neck fractures.
- With fluoroscopy engaged, the hip is examined under anesthesia. If displaced, it should be reduced, usually by traction and internal rotation and abduction (TECH FIG 1A).
- If the fracture can be anatomically reduced, the surgeon should proceed with percutaneous fixation; if not, open reduction should be undertaken.
- Percutaneous fixation is inserted from laterally, just below the greater trochanteric apophysis and up the femoral neck as visualized under the C-arm (TECH FIG 1B).
Open reduction and internal fixation with pins or screws

- It is customary to use smooth pins for physeal separations or neck fractures in very young children. In older or larger children, cannulated screws are necessary. Screws should stop short of the physis unless there is so little room between the physis and fracture that adequate fixation is precluded.
- A lateral view, usually by frogging the hip, is necessary to confirm pin placement.
- Two pins are usually sufficient to provide safe fixation. A total of three is even better, but three are often difficult to insert.
- Once reduction and pin placement are confirmed by fluoroscopy, two planes, pins are cut and left protruding from the lateral femoral cortex for later removal, or drilling is performed over pins (TECH FIG 1C) and cannulated screws are placed (TECH FIG 1D).
- Because there may be a tense hemarthrosis that tamponades flow in the retinacular vessels of the neck, it may be wise to aspirate the joint capsule to evacuate or decompress the hip joint.

The anterior hip capsule is exposed (TECH FIG 2C).
- The hip capsule is incised longitudinally and “T”-ed if necessary to visualize within (TECH FIG 2D).
- The hematoma is evacuated.
- The fracture is reduced under direct vision (TECH FIG 2E).
- It is often necessary to pull the neck “up” with a bone hook to get it reduced. Reduction is confirmed by palpation and then fluoroscopy.
- Fixation is then performed from the lateral femur as described above.
OPEN REDUCTION AND INTERNAL FIXATION WITH FIXED-ANGLE PLATE AND SCREWS

Exposure and Fracture Reduction
- It is contemplated that the fracture will be fixed with a pediatric-sized lag-screw side-plate device.
- The hip is approached from laterally. An incision is made from just proximal to the greater trochanter, extending about 4 to 5 inches distally (TECH FIG 3A). The fascia lata is split in line with its fibers (TECH FIG 3B).
- The vastus fascia is cut with a “hockey stick” incision, starting anteriorly just distal to the apophysis of the greater trochanter (TECH FIG 3C). The incision is curved posteriorly and then extends distally in the posterior third of the vastus fascia. The muscle is elevated anteriorly, exposing the lateral femoral cortex.
- The fracture is reduced by direct manipulation.

Fracture Fixation
- A guidewire is then drilled up the center of the femoral neck (TECH FIG 4A). The angle the guidewire makes with the femoral shaft is dictated by the fixation device to be used. Generally a fixed-angle plate–lag screw combination will be used.
- The guidewire should be confirmed to be centered in the neck on anteroposterior (AP) and lateral C-arm views. The guidewire need not cross the capital femoral physe.
- The proper length of lag screw is measured (TECH FIG 4B).
- The channel for the lag screw is reamed (TECH FIG 4C) and tapped (TECH FIG 4D). The lag screw is inserted (TECH FIG 4E).
- A side plate is selected; usually three or four holes is sufficient. It is passed over the lag screw (TECH FIG 4F).
- The plate is secured to the femur with appropriate screws and fixed with a compression screw to the lag screw (TECH FIG 4G).
- Reduction and fixation are checked by fluoroscopy. Closure is routine.
Internal fixation of extra-articular hip fracture. A. After fracture reduction, a guidewire is inserted from the lateral femoral cortex up the femoral neck. The angle the wire makes with the lateral cortex should match the angle of the fixation device (usually 135 degrees). B. The length of the intended lag screw is measured from the protruding guidewire. The lag screw should stop short of the physis. C. Reaming is accomplished over the guidewire to accommodate the lag screw and the barrel of the side plate. D. The channel is tapped because the child’s bone is usually quite hard. E. The lag screw is inserted. F. The side plate is placed. G. The plate is secured to the femur with cortical screws and the compression screw locks the lag screw in the side plate.
**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Blood supply to the capital femoral epiphysis</th>
<th>Retinacular vessels may be torn or stretched after femoral neck fracture.</th>
</tr>
</thead>
<tbody>
<tr>
<td>■</td>
<td>Urgent reduction is important.</td>
</tr>
<tr>
<td>■</td>
<td>The surgeon should consider decompressing the hemarthrosis to lessen the effect of tamponade of the vessels.</td>
</tr>
<tr>
<td>■</td>
<td>Parents are warned in advance of the possibility and implications of avascular necrosis.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fracture healing</th>
<th>Intra-articular neck fractures tend to heal poorly because there is no periosteal new bone formation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>■</td>
<td>Perfect reduction and bony apposition provide the best opportunity for fracture healing.</td>
</tr>
<tr>
<td>■</td>
<td>Persistent varus after fixation is a harbinger of future problems.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- Hip fractures fixed with pins, fractures in small children, and fractures in patients who cannot refrain from weight bearing should be immobilized for 4 to 6 weeks in a spica cast.
- Controlled children can be maintained non-weight bearing with crutches.
- Pins should be removed after fracture healing. Screws and hardware should be removed before they are covered by new bone growth.

**OUTCOMES**

- Satisfactory healing is to be expected in most cases.
- Stiffness after cast removal usually resolves without treatment.
- Avascular necrosis may have a benign course similar to that of Perthes disease or may result in relentless disintegration of the femoral head, for which there is no satisfactory treatment in a child.

**COMPLICATIONS**

- Avascular necrosis
- Varus malunion
- Nonunion
- Leg-length discrepancy

**REFERENCES**

DEFINITION
- Femoral shaft fractures in children occur with an incidence of 20 per 100,000. They constitute 2% of all pediatric fractures.1,7
- In the very young child who presents with a femoral shaft fracture, child abuse must be considered, especially if the child is not yet walking.
- In the child who has a history of multiple fractures, osteogenesis imperfecta might be the underlying cause and is often mistaken for child abuse in the young child.
- In children who sustain multiple traumatic injuries, the nature and severity of each injury must be considered to optimize treatment.

ANATOMY
- The limb bud develops at about 4 weeks of gestation, the femoral shaft serving as the primary ossification center. The proximal ossification center is seen by 6 months and the distal femoral ossification center appears at 7 months.
- The femur is initially composed of weaker woven bone, which is gradually replaced with lamellar bone during childhood.
- Both the endosteal circulation and the periosteal circulation supply the femur. The profunda femoris artery gives rise to four perforating arteries, which enter the femur posteromedially. The majority of the blood is supplied by the endosteal circulation. During fracture healing, however, the majority of the blood is supplied by the periosteal circulation.
- The femoral shaft flares distally, forming the supracondylar area of the femur.

PATHOGENESIS
- Age is an important factor to consider in terms of the pathogenesis of the injury. The degree of trauma required to cause injury increases exponentially as the character of the bone changes and gradually becomes stronger and larger from infancy to adolescence. Low-energy injuries resulting in fractures may point to a pathologic nature of the condition, except in toddlers, in whom low-energy femur fractures are common.
- The radiographic appearance of the fracture usually reflects the mechanism of injury and the force applied. High-velocity injuries usually present with more complex, comminuted patterns.
- The position of the fracture fragments after the injury depends on the level of the fracture and reflects the soft tissue and muscle forces acting on the femur.

PATIENT HISTORY AND PHYSICAL FINDINGS
- In most cases, there is a history of a traumatic event.
- The clinician inspects the lower extremity and looks for open wounds, bruising, or obvious deformity.
- In the setting of an isolated femur fracture, the thigh appears swollen with minor bruises and abrasions. Shortening may also be present.
- Open wounds may change the management of this injury; obvious deformity helps in the initial diagnosis.
- The clinician palpates the length of the lower extremity, feeling for bony deformity and checking compartments carefully for tension. Tense compartments may indicate current or developing compartment syndrome.
- The affected extremity should be checked to ensure that there is no vascular or neurologic injury.
- The clinicians should check carefully for femoral, popliteal, dorsalis pedis, and posterior tibial pulses. Diminished pulses may indicate vascular compromise or compartment syndrome. If diminished, they should be rechecked with Doppler.
- Sensation to light touch is tested along the length of the entire lower extremity. Decreased sensation in the lower extremity may indicate nerve damage.
- Motor examination may be difficult because of injury. Ankle dorsiflexion and plantarflexion are tested. Diminished strength may indicate nerve damage or compartment syndrome or may also be secondary to pain.
- Examining reflexes may also be difficult. The clinician strikes the patellar and Achilles tendons with a reflex hammer and looks for contraction of the quadriceps and gastrocnemius, respectively. Diminished knee or ankle reflexes may indicate femoral or sciatic nerve injury or may also be secondary to guarding.
- In cases of high-energy trauma, concomitant injuries to the skin and soft tissue as well as other organ systems are usually present.
- The knee is examined to ensure that no ligamentous injury is present. This examination may be performed under anesthesia.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standard high-quality anteroposterior (AP) and lateral radiographs of the femur are usually all that is needed to define the extent and severity of the injury (FIG 1).
- Radiographs should include the joints above and below the fracture site to avoid missing any concomitant injuries.
- Rarely, a CT scan may be helpful in assessing more complex injury patterns. It also helps in revealing subtle injuries that may not be apparent on radiographs, such as stress fractures, and aids in characterizing intra-articular injuries.

DIFFERENTIAL DIAGNOSIS
- Soft tissue trauma
- Stress fracture
- Tumor
- Metabolic conditions
NONOPERATIVE MANAGEMENT

- Management of femoral shaft fractures depends on the age of the patient.
- In infants, stable femoral shaft fractures can be treated in a Pavlik harness or a splint.
- In children younger than 6 years, closed reduction and casting is used in the vast majority of cases.

Surgical Management

- In children younger than 6 years, closed reduction and casting is successful for most femoral shaft fractures.
- For older children and adolescents, 3 weeks of skeletal traction followed by spica casting was once common but has been replaced by internal or external fixation in most cases.

Preoperative Planning

- A detailed review of the clinical findings and all appropriate imaging studies is performed before the procedure.
- Shortening should be determined to be less than 2 cm using a lateral radiograph, although some suggest spica casting can be accomplished regardless of shortening.\(^6\)
- If the mechanism of injury is considered low energy, a single-leg “walking spica” can be considered, as it has been shown to be as effective as traditional spica casting and may also decrease the burden of care on the family.\(^4\)
- The presence of concomitant injuries should be considered as well as factors that may hinder or complicate treatment.

Positioning

- The child is taken to the operating room or sedation unit and placed in the supine position on the table.
- The injured extremity is casted first, and then the patient is transferred to a spica table.

TRADITIONAL SPICA CASTING

- A long-leg cast is placed with the knee and ankle flexed at 90 degrees (TECH FIG 1A). Because of recent reports of compartment syndrome of the leg after spica casting for pediatric femur fractures,\(^6,9\) many centers (ours included) have been using less hip and knee flexion and not including the foot for the cast of the injured leg.
- Extra padding in the popliteal fossa is applied. To avoid vascular compromise, care must be taken not to flex the knee once the padding is in place.
- A valgus mold at the fracture site is used to prevent varus deformity (TECH FIG 1B).
- The patient is transferred to a spica table, where the weight of the legs is supported with manual traction.
- The hip is placed at 90 degrees of flexion and 30 degrees of abduction. Fifteen degrees of external rotation at the hip is used to allow alignment of the proximal and distal fragments (TECH FIG 1C,D).
- The remainder of the spica cast is placed while holding the fracture out to length.
- Care should be taken to avoid excessive traction, which increases the risk of compartment syndrome and skin sloughing.
- New AP and lateral radiographs are taken to ensure acceptable anatomic alignment.
- Gore-Tex liners are used at some institutions to prevent diaper rash and superficial infections.
WALKING SPICA CASTING

- A walking spica is becoming a popular choice for low-energy femur fractures.
- The cylinder cast should be applied with about 50 degrees of knee flexion.
- The foot remains uncovered with the cast stopping in the supramalleolar area, which is protected with extra padding.
- Before the remainder of the cast is applied, the hip is flexed to 45 degrees and remains abducted to 30 degrees with 15 degrees of external rotation (TECH FIG 2A,B).
- The pelvic band is applied with multiple layers of stockinette folded on the abdomen to prevent abdominal compression from the casting. These folded layers of stockinette are removed after the pelvic band is placed (TECH FIG 2C).

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Spica casting is best used for children 1 to 6 years old with isolated femoral shaft fractures.</th>
</tr>
</thead>
</table>
| Contraindications | Shortening of more than 2 cm (controversial)  
Massive swelling of the thigh  
Associated injury that precludes cast treatment |
| Walking spica | Effective for low-energy isolated femur fractures  
Toddlers typically pull-to-stand and begin walking in 2 to 3 weeks. |
POSTOPERATIVE CARE

- A significant burden of care is placed on the family of a child with a spica cast, including cast care, travel difficulties, and loss of time at work.
- We counsel the family, immediately after reduction in casting, that wedging of the cast may be necessary at about 10 to 14 days after injury.
- We schedule the family to return 1 week and 2 weeks after injury; at that time true AP and lateral radiographs are obtained of the injured femur in the cast. If there is unsatisfactory alignment or either angulation or shortening, we will wedge the cast at the clinic and repeat radiographs. This frequently avoids unnecessary trips back to the operating room in the postoperative period for loss of reduction.
- Prior to callus formation, if shortening of more than 2 cm occurs, one of three options may be required: cast change, traction, or external fixation.
- Shortening of more than 2 cm once callus has formed may be treated with osteoclasis and lengthening techniques at a pace of 1 mm per day.
- At union, acceptable angulation and shortening varies by age (Table 1).

OUTCOMES

- Typically the spica cast is worn for 4 to 8 weeks, depending on the extent of the injury.
  - Infant fractures heal in 3 to 4 weeks.
  - Toddler fractures heal in 6 weeks.
- On removal of the cast, children are encouraged to stand up and walk as soon as they are comfortable.

REFERENCES


Table 1

<table>
<thead>
<tr>
<th>Age</th>
<th>Varus-Valgus</th>
<th>Anterior-Posterior</th>
<th>Shortening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth to 2 years</td>
<td>30 degrees</td>
<td>30 degrees</td>
<td>15 mm</td>
</tr>
<tr>
<td>2 to 5 years</td>
<td>15 degrees</td>
<td>20 degrees</td>
<td>20 mm</td>
</tr>
<tr>
<td>6 to 10 years</td>
<td>10 degrees</td>
<td>15 degrees</td>
<td>15 mm</td>
</tr>
<tr>
<td>11 years to maturity</td>
<td>5 degrees</td>
<td>10 degrees</td>
<td>10 mm</td>
</tr>
</tbody>
</table>

DEFINITION
- Femoral shaft fractures occur in children with a bimodal age distribution peaking at ages 2 and 12.
- The peak in age distribution at age 2 is due to relative weakness of primarily woven bone at a time when ambulation increases the risk of fall-related trauma.

ANATOMY
- Muscular deforming forces, if severe, increase the need for surgical fixation. In proximal and midshaft femoral shaft fractures, the proximal fragment tends to be forced into abduction and external rotation. This is more significant in proximal fractures than in midshaft fractures.
- Fractures of the distal third of the femoral shaft tend not to deform greatly, while supracondylar femoral fractures are often forced into apex posterior angulation.

PATHOGENESIS
- In toddlers, these injuries tend to be low energy and occur during normal activity. In adolescents, they tend to be higher-energy injuries that may result from motor vehicle, biking, or high-speed sporting accidents.
- Abuse should be considered in the infant or toddler with a femur fracture, especially if the child is nonambulatory.

PATIENT HISTORY AND PHYSICAL FINDINGS
- In an unconscious patient or a patient with an insensate lower extremity, deformity, erythema, crepitance, and swelling might indicate the presence of a femoral fracture.
- If child abuse is suspected, a skeletal survey should be obtained and Child Protective Services should be notified. Infants are more likely than toddlers to be the victims of child abuse in the setting of a femoral fracture.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Anteroposterior (AP) and lateral radiographs of pelvis and femur are obtained. The hip and knee should be visualized on the femur radiograph or separately to evaluate possible associated injuries (FIG 1).
- Radiographs should be evaluated for fracture pattern, location, displacement, angulation, and shortening.

DIFFERENTIAL DIAGNOSIS
- In a child with an insensate extremity, the swelling and erythema caused by a femur fracture may resemble an infection.

NONOPERATIVE MANAGEMENT
- Nonoperative management (casting) is appropriate for an isolated femur fracture in a child younger than 6 years. Most children older than 6 years are now treated with some form of operative fracture stabilization.
- Nonoperative options include Pavlik harness or splints for children younger than 6 months and a spica cast for those older than 6 months.

SURGICAL MANAGEMENT
- Operative management of femoral shaft fractures should be considered in any femur fracture in a child older than 6 years. In younger children, polytrauma, head injury, high-energy trauma, an open fracture, severe comminution, or body habitus incompatible with spica cast care are relative indications for operative management.
- Surgical options include flexible nailing, plating, rigid intramedullary nailing, and external fixation.
- Indications for external fixation include polytrauma, concomitant head injury, open fracture with severe soft tissue damage or contamination, severe comminution, and very proximal subtrochanteric or distal diaphyseal-metaphyseal junction fracture.
- Midshaft transverse fractures are at a higher risk of refracture when treated with external fixation compared to other methods of stabilization.

FIG 1 • Preoperative radiograph of a 12-year-old boy who sustained a distal femoral shaft fracture.
Preoperative Planning
- The surgeon should determine where pins will be placed before surgery.
- In each fragment there must be at least 2 cm of intervening bone between the physis and the outermost pin and at least 2 cm between the fracture and the innermost pin.
- The appropriate pin size varies according to the device. The AO/Synthes device guide recommends 4.0-mm Schanz screws be used, while the EBI device guide recommends screws not larger than one third of the bone diameter.

Positioning
- The patient should be placed on either a radiolucent operating table or a fracture table. The latter is useful if preoperative reduction is desired.

**EBI DFS XS FIXATOR TECHNIQUE**

**Pin and Screw Placement**
- The first pin inserted should be one into the shorter or more difficult bone fragment.
- After making a stab incision over the first pin site, the surgeon dissects bluntly to the near cortex.
- The trocar is inserted into the soft tissue guide and seated onto the femur perpendicular to its long axis. The trocar is removed and the soft tissue guide is impacted gently to prevent slippage.
- The appropriate drill guide (based on the chosen screw size) is inserted into the soft tissue guide.
- After attaching a drill stop onto the appropriate bit, the surgeon drills through the near cortex, using the drill guide to keep the pilot hole perpendicular to the long axis of the bone. Drilling should stop once the near cortex is penetrated.
- The surgeon slides the bit up to the far cortex without drilling. The drill stop is adjusted so that the drill can be advanced no more than 5 mm (**TECH FIG 1A**). The surgeon then drills through the far cortex.
- Any tented skin is released.
- The surgeon slides the telescoping arm of the assembled fixator onto the screw in the appropriate position. The clamp bolt is not tightened.
- The soft tissue guide is inserted into another clamp position on the same telescoping arm. Again, the clamp bolt should be loose enough to allow translation of the soft tissue cover through the arm.
- Once the soft tissue guide has been seated on the near cortex, the clamp bolt is tightened to prevent loss of alignment. Repeating the above steps, a second screw is inserted in the position now occupied by the soft tissue guide (**TECH FIG 1B**).
- Once both screws have been placed in the first fragment, the above steps are repeated on the second fragment (**TECH FIG 1C**).
- The telescoping arm clamp bolts are tightened before final reduction.

**Final Reduction**
- The final reduction is made with a variety of adjustments.
- Length can be adjusted on each telescoping arm by either loosening the telescoping set screw and adjusting length manually or by loosening the compression-distraction screw and using this feature to adjust length (**TECH FIG 2A**).
- Any tented skin is released.
- The locking connector bolts can be loosened for the correction of angular deformity (**TECH FIG 2B**).
Each telescoping arm can also be rotated using the rotational set screw on the central body of the fixator (TECH FIG 2C). These can be loosened simultaneously to rotate the central body of the fixator to bring the central locking joints into the plane of correction (TECH FIG 2D).

Each telescoping arm is able to extend up to 2 cm. If more length is needed, a 4-cm arm may be used. This is especially useful when one arm is occupied by the T-clamp, which has no telescoping feature.

Alternative T-Clamp Technique
- If desired, the T-clamp can be used when the fracture pattern precludes placement of screws longitudinally in one of the bone fragments.
- The T-clamp is applied before the telescoping arm using the screw insertion technique described.
- After the T-clamp is in place, the screws for the telescoping arm are placed in the other fragment as in the standard configuration described above.

AO/SYNTHES TECHNIQUE USING PEDIATRIC FEMORAL SHAFT FRAME WITH COMBINATION CLAMPS

**Construct Application**
- Note: All Schanz screws must be coplanar if double stacking (for increased rigidity) or dynamization is desired.
- The most proximal screw and the most distal screw are inserted before inserting the inner pins. Screws should be placed with at least 2 cm of bone between the screw and the physis.
- The screw is inserted in the following manner.
  - A stab incision is made.
  - The trocar with protective sleeve is seated onto the femur by passing it through the incision.
  - The trocar is removed, the screw is inserted into the protective sleeve, and the surgeon drills until the screw is embedded in the far cortex.
  - If preferred, a power drill is used until the near cortex is penetrated; then the surgeon can drill into the far cortex by hand.
  - After inserting the outermost (most distal and most proximal) Schanz screws, the surgeon attaches a medium combination clamp to each screw.
- The carbon rod is attached to each clamp. The construct should now consist of four screws, two clamps, and one carbon rod.
- The fracture is reduced and the clamp bolts are tightened.
- Two additional clamps are attached to the carbon rod. These will attach the inner screws to the carbon rod.
- The two inner screws are inserted in the same fashion as the outer screws. There should be at least 2 cm of bone between the screw and the fracture. These screws are attached to the inner combination clamps and the bolts are tightened.
- The construct now consists of four screws, four clamps, and one carbon rod (TECH FIG 3A).
- A second carbon rod may be added if additional stiffness is desired and all screws are coplanar. The rod is secured to each screw with a combination clamp.
- If this step is completed, the construct will consist of four screws, eight clamps, and two rods (TECH FIG 3B).
Dynamization

- Dynamization can be accomplished only in a double-stacked construct. To dynamize the fixator, the outer bolts on the proximal pins and the inner bolts on the distal pins will be adjusted as follows. The bolt is loosened, a dynamization clip is inserted between the rod vise plates, and the bolt is retightened. This procedure is repeated for all four appropriate bolts (TECH FIG 4A).
- The dynamization clips can be used in the postoperative setting to increase axial loading across the fracture site or intraoperatively for compression or distraction of the fracture.
- Intraoperative distraction or compression is achieved by dynamizing the fixator, attaching the distractor device adjacent to a dynamized clamp (TECH FIG 4B), turning the distractor adjustment ring to either distract or compress, removing the dynamization clips after dynamization or compression, and retightening the clamps.

Assembly of this fixator requires screw insertion of one bone fragment to be completed before inserting screws in the other fragment. Therefore, Schanz screws will not be inserted in the outside-to-inside fashion used for the combination clamps.

- The first Schanz screw should be an outer screw, inserted with at least 2 cm of bone between the screw and the physis. A multipin clamp is attached to this first screw and the screw is drilled into the femur. The clamp may be held parallel to the femoral shaft to ensure that the screw enters the femur perpendicularly.
- The second Schanz screw is inserted through the opposite end of the clamp, with at least 2 cm of bone between the screw and the fracture site. This screw and all subsequent screws should be inserted as described above, with a stab incision, protective sleeve seating, and screw guidance with the sleeve (TECH FIG 5A).
Up to two additional Schanz screws may be inserted through the multipin clamp if necessary. This completes assembly of the hemifixator.

These steps are repeated for the other bone fragment.

The multipin clamp vise plate bolts are tightened on each hemifixator.

The carbon rod is attached to each multipin clamp.

The fracture is reduced and the rod clamping bolt and rod attachment bolt are tightened (TECH FIG 5B).

A second rod may be added to the construct to increase the stiffness of the fixator. This is accomplished with two rod attachment devices (TECH FIG 5C).

Modular frame constructs may be created if the fracture pattern precludes coplanar insertion of Schanz screws. This is accomplished by sequential assembly of modules that are then connected by a spanning carbon rod.

The first screw, which should be an outer screw, is inserted with at least 2 cm of bone between the screw and the physis.

The second screw, an inner screw, is inserted into the same fragment. There should be at least 2 cm of intervening bone between the screw and the fracture. This screw need not be coplanar with the first screw. This screw and subsequent screws should be inserted as described above, with a stab incision, protective sleeve seating, and screw guidance with the sleeve.

Combination clamps are attached to each screw and the bolts are tightened.

A carbon rod is connected to each combination clamp. This completes the assembly of the first module.

The second module is built in the same fashion as the first: the outer screw is inserted, then the inner screw; combination clamps are attached to the screws; and then the clamps are connected with a carbon rod. Each module should consist of two Schanz screws, two combination clamps, and a carbon rod.

Once each module has been constructed, a combination clamp is attached to each carbon rod. The placement of these clamps should be as follows:

The first clamp is placed on the proximal module distal to the most distal screw and the second clamp is placed proximal to the most proximal screw.

These combination clamps are connected to a third carbon rod.

If the spanning clamps are placed correctly, the fixator will have a Z conformation (TECH FIG 6A). If not, the fixator will have an I formation.

The fracture is reduced before tightening the spanning rod clamps.

The spanning rod combination clamps are tightened once adequate reduction is obtained.

To increase the stiffness of the fixator and add rotational stability, a second spanning rod is added. The placement of the second set of spanning clamps should be as follows:

The first clamp is placed on the proximal module proximal to the most proximal screw and the second clamp is placed on the distal rod distal to the most distal screw.

These combination clamps are connected to a fourth carbon rod.

If this second set of spanning clamps have been placed correctly, the modular rods and the spanning rods will have an hourglass configuration (TECH FIG 6B).
PEARLS AND PITFALLS

**Evaluation**
- Although many pediatric femur fractures are isolated injuries, high-energy fractures are often associated with head, chest, or abdominal trauma.
- The injured extremity must be thoroughly evaluated for associated trauma.
- Femoral shortening across the fracture site is best visualized with a lateral femur radiograph before traction is applied.
- Corner fractures and bucket-handle fractures are more specific than spiral fractures for nonaccidental injury.

**Fixation**
- Remodeling potential declines significantly after age 10.
- Angulation across the fracture site is better tolerated proximally than distally and better in the sagittal plane than in the coronal plane.

**Medicolegal**
- Closed treatment of femoral fractures is a common source of malpractice litigation in the field of pediatric orthopaedics.

---

**TECH FIG 6** • A. Basic modular frame with connected modules. B. Fourth bar is added to frame configuration to increase stiffness and rotational stability. The fourth bar should span the length of the frame, connecting the first and second modules. (Copyright Synthes, Inc., or its affiliates. All rights reserved.)

**FIG 2** • Postoperative radiographs from the patient in Figure 1 on postoperative day 1 (A), before external fixator removal on postoperative day 63 (B), and at last follow-up on postoperative day 217 (C).
POSTOPERATIVE CARE
- Pin care is essential in avoiding pin-track infection. This skill must be taught in the postoperative setting and reviewed at each office visit.
- Antibiotics with adequate coverage of skin flora should be prescribed at the first sign of pin-track infection.
- Some advocate removal of the external fixator as soon as bridging callus is seen, with subsequent casting if necessary. Others believe the fixator should be left in place until three of four cortices are bridged by callus.
- A typical radiographic evolution of this injury when treated with external fixation is shown in FIGURE 2.

OUTCOMES
- In one series of 37 femur fractures treated with external fixation, the average duration of fixation was 3 to 4 months (range 2 to 5 months). In all but one case, union was achieved at the time of fixator removal.4
- Risk of refracture may be as high as 20% after fixator removal.2,4
- Pin-track infections occur in about 65% of cases. These can almost always be managed successfully with oral antibiotics; fixator removal is rarely required.
- While clinically insignificant malunion is often seen, malunion requiring surgical correction is rare.

COMPLICATIONS
- Pin-track infection
- Deep infection
- Knee stiffness
- Unsightly thigh scars
- Delayed union
- Refracture
- Malunion
- Leg-length discrepancy

REFERENCES
DEFINITION

- Femoral shaft fractures in children occur with an incidence of 20 per 100,000. They constitute 2% of all pediatric fractures.
- In the very young child who presents with a femoral shaft fracture, child abuse must be considered, especially if the child is not yet walking. In the child who has a history of multiple fractures, osteogenesis imperfecta might be the underlying cause and is often mistaken for child abuse in the young child.
- In children who sustain multiple traumatic injuries, the nature and severity of each injury must be considered to optimize treatment.

ANATOMY

- The limb bud develops at about 4 weeks of gestation, with the femoral shaft serving as the primary ossification center. The proximal ossification center is seen by 6 months and the distal femoral ossification center appears at 7 months.
- The femur is initially composed of weaker woven bone, which is gradually replaced with lamellar bone during childhood.
- Both the endosteal circulation and the periosteal circulation supply the femur. The profunda femoris artery gives rise to four perforating arteries, which enter the femur posteromedially. The majority of the blood is supplied by the endosteal circulation. During fracture healing, however, the majority of the blood is supplied by the periosteal circulation.
- The femoral shaft flares distally, forming the supracondylar area of the femur. This area serves as the entry point for retrograde nailing with flexible intramedullary nails.

PATHOGENESIS

- Age is an important factor to consider in terms of the pathogenesis of the injury. The degree of trauma required to cause injury increases exponentially as the character of the bone changes and gradually becomes stronger and larger from infancy to adolescence. Low-energy injuries resulting in fractures may point to a pathologic nature of the condition.
- The radiographic appearance of the fracture usually reflects the mechanism of injury and the force applied. High-velocity injuries usually present with more complex, comminuted patterns.
- The position of the fracture fragments after the injury depends on the level of the fracture and reflects the soft tissue and muscle forces acting on the femur.

PATIENT HISTORY AND PHYSICAL FINDINGS

- In most cases, there is a history of a traumatic event.
- In an isolated femur fracture, the thigh appears swollen, with minor bruises and abrasions. Shortening may also be present.
- The affected extremity should be checked to ensure that no vascular or neurologic injury is present.
- In cases of high-energy trauma, concomitant injuries to the skin and soft tissue as well as other organ systems are usually present.
- An examination of the knee is likewise performed to ensure that no ligamentous injury is present. This may be performed under anesthesia.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Standard high-quality anteroposterior (AP) and lateral radiographs of the femur are usually all that is needed to define the extent and severity of the injury (FIG 1).
- Radiographs should include the joints above and below the fracture site to avoid missing any concomitant injuries.
- Rarely, a CT scan may be helpful in assessing more complex injury patterns. It also helps in revealing subtle injuries that may not be apparent on radiographs, such as stress fractures, and aids in characterizing intra-articular injuries.

DIFFERENTIAL DIAGNOSIS

- Soft tissue trauma
- Stress fracture
- Tumor
- Metabolic conditions

FIG 1 • Preoperative radiographs of a 7-year-old boy who sustained a spiral diaphyseal femoral shaft fracture while playing football. This injury was treated with titanium elastic nails.
NONOPERATIVE MANAGEMENT
- Management of femoral shaft fractures depends on the age of the patient.
- In infants, femoral shaft fractures can be treated with a Pavlik harness or a splint.
- In children less than 6 years of age, nonoperative management is the treatment of choice. Nonoperative management usually consists of:
  - Closed reduction under sedation or anesthesia as needed
  - Placement of a hip spica cast to maintain reduction for 6 to 8 weeks
  - Correcting rotational and angular alignment is of the utmost importance in treatment. Shortening of up to 2 cm is acceptable.

SURGICAL MANAGEMENT
- In older children and adolescents, nonoperative management is not well tolerated.
- General recommendations for titanium elastic nails are:
  - Children at least 5 years old (ideal for children 6 to 12 years of age)
  - Fractures of the middle 70% of the diaphysis
  - Length-stable fracture patterns. Some difficulty may be encountered in more complex and comminuted fracture patterns.

Preoperative Planning
- A detailed review of the clinical findings and all appropriate imaging studies is done before the procedure.
- The diameter of the nail is predetermined by measuring the isthmus of the femoral shaft. The nail to be used is usually 40% of the narrowest diameter. For instance, if the isthmus measures 1 cm, a 4-mm nail is used.
- The presence of concomitant injuries should be considered, as well as factors that may hinder or complicate treatment.

Positioning
- The patient is positioned in the supine position. We prefer using a fracture table (FIG 2).
- The groin area is adequately padded before application of the post.
- The affected extremity is abducted 15 to 30 degrees to allow room for nail placement. The uninjured leg can be held by the ankle (the well-foot holder) and “scissored” with extension of the hip so that it does not block the lateral radiographic view.
- We generally avoid the well-leg holder that places the well leg with the hip and knee flexed high above the rest of the patient. Compartment syndrome has been associated with this positioning for femoral shaft fracture treatment.
- A distraction force is applied to the affected extremity through the foot using a foot holder. If there is significant soft tissue injury to the leg, the distraction force may be applied through a guide pin. However, a guide pin is rarely necessary in children.
- The extremity is then prepared and draped.

FIG 2 • The patient is properly positioned in the fracture table, the landmarks are identified fluoroscopically, and the proper incision sites are marked.

RETROGRADE FLEXIBLE INTRAMEDULLARY NAILING

Nail Introduction and Fracture Reduction
- Once the patient is properly positioned in the fracture table, the best possible reduction of the fracture is obtained.
- The patient is draped in the standard manner.
- The nail entry site is identified using an image intensifier.
- The distal femoral physis is identified and this position is marked on the skin to avoid dissection in this area.
- A 2-cm incision is marked out both medially and laterally at the level of the distal femoral physis.
- The incision is made and carried through the fascia and quadriceps muscle, observing meticulous hemostasis.
- A drill is placed (with a soft tissue protector) through the incision site against the distal femoral metaphysis. The starting point is the midpoint of the femoral shaft in the AP plane (TECH FIG 1A).
- The size of the drill bit used is largely dependent on the size of the nail; the drill bit should be slightly larger than the nail (eg, a 4.5-mm drill bit is used when using a 4.0-mm nail).

- The drill is inserted, and once the femoral cortex has been breached, the drill is angled obliquely (TECH FIG 1B).
- The nails are prebent into a gentle C shape before insertion (TECH FIG 1C).
- The first nail is inserted into the entry site and gently tapped into the femur. The position of the nail is checked under fluoroscopy in both the AP and lateral views to ensure proper nail placement (TECH FIG 1D).
- Once the tip of the nail has reached the fracture site, the fracture is reduced before further advancement of the nail. Reduction of the fragments is documented in both the AP and sagittal planes.
- When reduction is obtained, the nail that is more difficult to pass is introduced through the fracture site.
- Once the first nail has crossed the fracture line, the same steps for insertion are followed for introduction of the second nail (TECH FIG 1E).
- Alternatively, the second nail may be inserted immediately after the first nail to the level of the fracture site. Once proper reduction of the fracture is obtained, the nails are then advanced past the fracture site alternately as described in the technique above.
Once the incision has been made, the entry point for the nail is identified 2 cm superior to the growth plate at the midpoint of the femur anteroposteriorly. A 4.5-mm drill bit is used to make the starting point. B. Once the cortex has been entered the drill is angled obliquely to fashion a tract. C. The nail is bent in a gentle C shape before insertion. D. The first nail is inserted until it reaches the fracture line. E. Once the first nail has reached the fracture line, the second nail is inserted in the same fashion.

Final Nail Placement

- When reduction has been confirmed and both nails have sufficiently crossed the fracture line (TECH FIG 2A–C), both nails are advanced a few millimeters and their position is checked with the image intensifier in both the AP and lateral planes (TECH FIG 2D).
- Once the position of both nails has been confirmed, they are gradually advanced to their final proximal point (TECH FIG 2E).
- The lateral nail (nail entering through the lateral cortex of the femur) should end at the apophysis of the greater trochanter. The medial nail should come to rest at the medial end side of the calcar at the level of the hip (TECH FIG 2F,G).
- After the final position of the nails has been confirmed, the nails are backed out a few centimeters, cut to the proper length, and gently tapped back into their final position with the ends of the nail resting flush against the femur. Bending the end of the nails will cause undue irritation of the skin and soft tissue.
- The final fracture configuration is checked (TECH FIG 2H,I). If there is a significant gap between the fracture fragments, the distraction is released and the surgeon gently impacts the fracture fragments together.
- A layered closure is performed.
- Rotational alignment of the extremity is evaluated and any malrotation is corrected before leaving the operating room.
Chapter 13  FLEXIBLE INTRAMEDULLARY NAILING OF FEMORAL SHAFT FRACTURES  

TECH FIG 2 • (continued) E. The lateral nail should end at the apophysis of the greater trochanter, the medial nail at the calcar of the femoral neck. F. The distal ends of the nail should be flush with the femoral metaphysis. G. The final configuration of the nails should provide adequate three-point fixation. H, I. AP and lateral radiographs of the femur of the patient in Figure 1, showing adequate nail placement.

PEARLS AND PITFALLS

Indications
- The flexible nailing technique is most successful for children ages 5 to 12, weighing less than 50 kg, with length-stable fractures. Very proximal, distal, or length-unstable fractures can be treated with flexible nailing, but the complication rate is higher and immobilization in a cast may be necessary as an adjunct to treatment.

Preoperative planning
- Proper selection and preparation of the nails are crucial, as well as proper patient selection. The nail sizes and the entry points should be symmetric.

Fracture fixation
- Proper nail configuration must be achieved to obtain three-point fixation. The nails should be gently curved before insertion to ensure maximum cortical contact. If insertion or nail passage may be difficult or the entry site is complicated by soft tissue injury, an anterograde method of insertion through the greater trochanter may be used for one or both nails.

Difficulty in reduction
- An instrument referred to as the “F tool” is a great aid to reduction.

Skin irritation
- To avoid skin irritation, the nails should be cut so that they lie flush with the metaphysis of the distal femur, with only about 1 to 2 cm of the nail outside the cortical entry site.

POSTOPERATIVE CARE
- We prefer a knee immobilizer in the immediate postoperative period to reduce the incidence of soft tissue irritation of the knee and to increase the child’s comfort.
- Weight bearing is instituted immediately after surgery as tolerated.
- Postoperative analgesics are maintained for continued pain relief and to maximize the rehabilitation period.

OUTCOMES
- Multiple studies have reported good to excellent outcomes in femoral shaft fractures treated with flexible intramedullary nails.3-4,7
- Flynn and coworkers5 in a multicenter trial, reported excellent results in 67% (39) of cases and satisfactory results in 31% (18); there was one poor result due to malrotation.
- Mehlman and associates10 showed in a biomechanical study that if an acceptable starting point is achieved, retrograde nailing is more stable for fractures of the distal third of the femoral diaphysis.
- Flynn and associates6 reviewed their first 50 cases and found that insertion site irritation was the most common problem encountered (18% of cases). Very proximal fractures were more challenging to treat and older, larger children were best managed with additional periods of adjunctive immobilization.
- Moroz and colleagues,11 in a review of 234 femur fractures in 229 children, found excellent results in 150 (65%), satisfactory in 57 (25%), and poor in 23 (10%). The poor outcomes were secondary to length discrepancy in 5 cases, unacceptable angulation in 17, and failure of fixation in 1. They likewise reported a correlation with poor outcome in older children (older than 11 years) and in children who weighed more than 49 kg.
COMPLICATIONS

- Nonunion
- Delayed union
- Malunion (angular and rotational deformity)
- Leg-length discrepancy (shortening and overgrowth)
- Compartment syndrome
- Neurovascular injury
- Implant-related complications

REFERENCES

SURGICAL MANAGEMENT

- Plate osteosynthesis of pediatric femur fractures allows stable fixation with good results.\(^2,3,5,7,12\)
  - This traditionally requires a large exposure with soft tissue disruption.
  - Submuscular bridge plating results in stable fixation while minimizing soft tissue dissection.
  - In unstable fractures, it reliably maintains length and alignment that may be difficult to maintain with either immediate spica casting or elastic intramedullary nails.
  - Minimally invasive plating techniques avoid a large dissection and leave the soft tissues intact, allowing rapid “biologic healing.” This has led to more appeal for plating.
  - The technique of femoral shaft plating has evolved with a better understanding of plate mechanics.\(^9\)
  - The indications for this technique are unstable comminuted or oblique femur fractures in ages 6 to skeletal maturity.

PROVISIONAL REDUCTION

- Patients are positioned on a fracture table, and a provisional reduction is obtained with boot traction.
- The well leg is extended if the fracture table allows. Thus, the legs are scissored in an anteroposterior (AP) direction (TECH FIG 1).
  - The well leg can also be positioned on a well-leg holder.
  - This allows the fluoroscopy to be aimed perpendicular to the fractured leg to get a good lateral image for percutaneous screw placement.
- A radiolucent table can also be used if there is enough assistance for traction.
- The goal of the provisional reduction is to restore length and rotation.

IMPLANT SELECTION AND PREPARATION

- The final reduction, particularly in the AP plane, can be done with the plate and screws.
- A 4.5-mm narrow low-contact dynamic compression plate (LC-DCP) is chosen for most patients.
  - Locking plates may be used in osteopenic patients or in proximal or distal fractures in which the amount of available room for screws is compromised.
  - Given the percutaneous nature of screw placement, self-tapping screws are used to facilitate insertion.
  - The usual plate length is from 10 to 16 holes, depending on the fracture location and patient size.
  - Plate length is determined by placing the plate over the anterior thigh and using imaging to confirm the appropriate length.
- As a general rule, the plate spans from the trochanteric apophysis to the distal femoral metaphysis.
- If possible, length should allow six screw holes proximal and distal to the fracture.
- Some fracture locations may allow for only two or three holes.
- A table plate bender is used to contour the plate.
  - This usually involves a small bend to accommodate both the proximal femur and the distal metaphysis.
  - It is important to contour the plate as close to anatomic as possible, as the femur will reduce to the contour of the plate with screw placement.
After the plate is contoured, it is again placed on the anterior thigh, and imaging is used to “shadow” the lateral aspect of the femur to confirm the contour (TECH FIG 2).

- It is not necessary to contour the plate to fit the normal anterior bow of the femur.
- In our experience, there has been no misalignment secondary to a poorly contoured plate.

**INTERNAL FIXATION**

**Plate Placement**

- A small incision (about 4 to 7 cm) is made over the distal lateral femur and through the tensor fascia to expose the obliquely oriented distal fibers of the vastus lateralis.
- Blunt dissection is performed deep to the distal aspect of the vastus lateralis to enter the plane between the lateral femoral periosteum and vastus lateralis, which is easily defined.
- The plate is then tunneled proximally along the lateral femoral periosteum (TECH FIG 3A–C).
- Slow advancement of the plate allows the surgeon to feel the plate contact against the lateral femur.

Fluoroscopy may assist the surgeon in guiding the plate past the fracture (TECH FIG 3D).
- Once the plate is fully advanced, AP and lateral views are obtained with fluoroscopy to confirm the plate position.
- A Kirschner wire is then placed percutaneously in the most proximal and distal holes using fluoroscopy to secure the plate position (TECH FIG 3E,F).
- Occasionally, adjustments need to be made to the plate position on the lateral view before Kirschner wire placement.
Screw Placement

- The principles of external fixation are used to guide the surgeon in screw placement.
- Three screws are placed proximal and three screws distal to the fracture (rarely there is room for only two screws).
- The screws should be spaced as far apart as possible on each side of the fracture.
- One of the screws should be placed near the proximal and distal margins of the fracture (TECH FIG 4A).
- No lag screws are used as the fracture region is bridged.
- Freehand “perfect circle” technique is used for percutaneous screw placement.
- With fluoroscopy in the lateral position, the holes in the plate are visualized as a “perfect circle” to guide the drill.
- A stab incision is made over the “perfect circle” and the knife blade is directed horizontal to the fluoroscopic beam through the iliobial band and vastus lateralis to the desired hole.
- The 3.2-mm drill bit is then placed into the desired hole and the surgeon drills perpendicular to the plate through both cortices.
- The fluoroscopic image is rotated to the AP view.
- The depth gauge is placed on the anterior thigh, and fluoroscopic imaging is used to obtain the appropriate screw length.
- A Vicryl suture is tied over the screw head so the screw capture into the screwdriver is not lost during percutaneous screw placement (TECH FIG 4B–E).
- The decision as to which percutaneous screw to place first is determined by where the femur is furthest from the plate and closest to the fracture.
- The screw will act as a reduction screw, reducing the femur to the plate contour (TECH FIG 4F,G).
- The second screw is placed on the opposite side of the fracture.
- The remaining screws are then placed, attempting to achieve the greatest screw spread possible to achieve maximal stability.
- Once the plate has been fixed to the femur, final radiographs are obtained to ensure adequate alignment and length (TECH FIG 4H,I).
- The Vicryl ties are cut and the incisions are closed.

**TECH FIG 4** • A. Fluoroscopic image of two screws bridging the fracture. These are commonly the first two screws placed. They are on the proximal and distal margin of the fracture. B–E. Percutaneous screw placement using fluoroscopic guidance and “perfect circle” freehand technique. B. The scalpel localizing the position and forming a percutaneous incision to the desired screw hole. C. Drilling a bicortical screw hole. D. An absorbable suture is tied around the screw head. E. Percutaneous screw placement. F,G. Reduction of the femur to the precontoured plate using the screw for reduction. H,I. Postoperative AP radiographs of the long oblique proximal-third femur fracture managed with the submuscular plate.
PEARLS AND PITFALLS

- A provisional reduction should be obtained with traction to restore fracture length and rotation.
- The surgeon should make sure rotation is correct using fluoroscopy and fracture geometry before plating.
- The correct plate length is one that spans from just below the greater trochanteric apophysis to the distal femoral metaphysis.
- The plate is temporarily secured to the femur with a Kirschner wire placed in the proximal and distal screw holes. Plate position is confirmed with fluoroscopy before screw placement.
- Three screws proximal and three screws distal to the fracture are placed.
- The screws should be kept spaced as far apart as possible.
- The first screw placed is used to reduce the femur to the plate.
- An absorbable suture is tied around the screw to keep it from being lost in the soft tissue with percutaneous placement.

POSTOPERATIVE CARE

- A soft dressing is applied.
- A knee immobilizer can be used for postoperative comfort with mobilization.
- No bracing or casting is required in the postoperative period.
- Patients are then allowed to perform hip and knee range of motion as tolerated.
- Touch-down weight bearing is encouraged until fracture callus is seen (about 6 to 8 weeks).
- Full activity, including sports, is allowed when a bridging callus is present on at least three of the four cortices.
- Plate removal is at the discretion of the surgeon and family.
  - Removal is often recommended in the younger child with the potential for bony overgrowth of the plate.
  - If plate removal is chosen, it is recommended at 6 to 8 months.
  - If the plate is removed at a later date it will be more difficult to remove in a percutaneous manner secondary to tissue overgrowth.
- The plate can be removed through the same percutaneous incisions.
  - A Cobb elevator is advanced proximally along the lateral aspect of the plate to free the soft tissue.
  - The screws are then percutaneously removed using fluoroscopy.
  - A Cobb elevator is then placed between the plate and bone to free the plate to allow removal through the distal incision.

OUTCOMES

- Over the past 30 years, femur fracture plating has evolved in terms of the use of longer plates, indirect reduction techniques, fewer plate screws, and fewer lag screws.
- The best predictor of success is the length of the plate.9
  - In comminuted and long oblique fractures treated with submuscular plating, the longer plate results in less strain on the healing fracture.
- Since the comminuted fracture is spanned with a long plate, the strain on the healing fracture is less.
- With the soft tissues intact around the fracture, the more rapid callus formation results in earlier load-sharing of the bone with the plate.
- This limits the period of the load carried by the plate and the potential for failure.
- The longer plate also requires fewer screws for optimal plate fixation.

- There is a subgroup of pediatric femur fractures in which the options for treatment are complex.
  - This encompasses the comminuted and long oblique length unstable fracture, the larger adolescent, and more proximal and distal fractures.
  - Complications have been reported while treating these complex fractures with other methods of fixation, such as titanium elastic nails or external fixation.3,8,11
  - In comparison, the published results of submuscular plating are very successful, with minimal reported complications.1,6,10
  - Submuscular bridge plating is a reliable and predictable method to stabilize the more complicated pediatric femur fracture.

COMPLICATIONS

- Reported complications are rare, and there are only two currently reported: refracture after early plate removal and a 3.5-mm plate that bent.6
  - These reported complications can be avoided by waiting for complete healing before plate removal and using a 4.5-mm plate in all but the smallest femurs.
- Since the fracture is secured out to length, there is the potential for postfracture femoral overgrowth.
  - In our experience, this potential overgrowth does not become clinically relevant.
  - There is a loss of anterior bow or a few degrees of recurvatum in many fractures after union, but again this has not been proved to be clinically relevant.
- Appropriate plate bending can help prevent malunion.

REFERENCES


DEFINITION
- Distal femoral physeal fractures involve the femoral condyles distal to the physis.
- The fractures may be extra-articular (Salter-Harris types I and II fractures), which are also referred to as distal femoral physeal separations. The fractures may also be intra-articular (Salter-Harris types III and IV) (FIG 1).¹
- The important things to assess are involvement of the distal femoral growth plate and articular congruity.

ANATOMY
- The distal femoral physis is one of the fastest-growing and most important growth plates of the lower extremity (FIG 2). The physis is remarkable for its multiple undulations.
- The medial and lateral collateral ligaments originate from the medial and lateral condyles.
- The anterior and posterior cruciate ligaments originate in the intracondylar notch.
- The peroneal nerve and popliteal artery are close by.

PATHOGENESIS
- A direct blow to the knee from medial or lateral may result in avulsion of the distal femoral epiphysis in whole or in part. The distal femoral condylar unit may displace medially or laterally.
- A hyperextension injury of the knee may result in distal femoral physeal separation with anterior displacement of the femoral condylar unit.
- A direct blow to the flexed knee (dashboard injury) may result in fracturing of the distal femoral epiphysis in a variety of patterns, including the Salter-Harris type IV fracture.

NATURAL HISTORY
- While most physeal separations (Salter-Harris type I and II fractures) have an excellent prognosis for healing without growth derangement, fractures of the distal femur are more prone to result in growth problems.
- This may result from “shaving off” of the undulations of the growth plate or from “scuffing” of the growth plate by the metaphysis during displacement and replacement of the epiphysis.⁴
- Because this growth plate is rapidly growing and makes an important contribution to the total length of the limb, any derangement here is likely to become symptomatic.²,³,⁴
- Parents must be warned of the possibility of growth derangement (shortening or angular deformity) as a result of physeal damage.
- Healing problems and joint stiffness are unlikely.

PATIENT HISTORY AND PHYSICAL FINDINGS
- A history is necessary to reveal the direction and magnitude of the injuring force.
- Pulses and neural function must be routinely assessed.
- Inspection often reveals that the knee is swollen; it may even appear dislocated (FIG 3).
- The degree of displacement correlates with the degree of deformity.
- True knee dislocation is uncommon in the immature patient; distal femoral physeal separation is not.
- The clinician should perform a varus–valgus stress test. Apparent instability suggests that radiographs (with and without stress) should be obtained to differentiate separation from ligament injury.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain film anteroposterior (AP) and lateral radiographs of the distal femur or knee should be obtained (FIG 4A,B).
- Truly undisplaced separations may be visualized on stress radiographs (FIG 4C,D).
- Displaced intra-articular fractures should be visualized by CT scanning (FIG 4E-H).
- If there is suspicion of concomitant intra-articular derangement, MRI should be obtained before the insertion of metallic hardware.
Chapter 15

DISTAL FEMORAL PHYSEAL FRACTURES

FIG 2 • A. AP diagram of knee with physis, collateral ligaments, and cruciate ligaments. B. Lateral diagram of knee with cruciate ligaments.

DIFFERENTIAL DIAGNOSIS
- Dislocation of knee
- Dislocation of patella
- Proximal tibial fracture
- Fracture of distal femoral metaphysis

FIG 3 • Picture of swollen knee.

NONOPERATIVE MANAGEMENT
- Truly undisplaced fractures can be immobilized in a long-leg cast.
- Fractures should be re-evaluated by radiography in a few days to check for displacement.
- Fractures that are easily reducible are rarely stable and are not amenable to simple cast immobilization.3

SURGICAL MANAGEMENT
- Surgical management should be considered for displaced or irreducible distal femoral physeal separations (Salter-Harris type I or II).
- Surgical management should be considered for displaced or unstable intra-articular fractures (Salter-Harris type III or IV).

■ Surgical management should be considered for fractures associated with nerve, vascular, or soft tissue injuries that would preclude standard casting.

Preoperative Planning
■ If manipulative reduction is contemplated, the surgeon should request muscle relaxation from the anesthesia provider after induction.
■ If distal pulses are diminished before fracture reduction, provision should be made for vascular surgical consultation if the normal pulse is not restored after reduction.
■ The distal femur must be visualized in AP and lateral views on fluoroscopy.
■ Intra-articular fractures should be studied by CT scan preoperatively. Fractures that are simply separated may be amenable to percutaneous lag-screw fixation. Fractures that are widely displaced or rotated may require open reduction and internal fixation.

Positioning
■ Generally patients can be positioned supine on a radiolucent table. However, fractures that are displaced into extension may be best fixed with the knee flexed over a bolster (FIG 5).

Approach
■ Distal femoral physeal separations will generally be managed by closed reduction and percutaneous fixation.
■ Fractures that cannot be reduced closed should be managed with open reduction, with the surgical approach on the side (medial or lateral) where the periosteum is torn.
■ Salter-Harris type I and I fractures with a small Thurston Holland fragment should be fixed with smooth pins across the physi.
■ Salter-Harris type II fractures with large Thurston Holland fragments should be fixed with transverse screws that lag the Thurston Holland fragment to the metaphysis.
■ Salter-Harris type III and IV fractures should be anatomically reduced and fixed with lag screws.

CLOSED REDUCTION AND PERCUTANEOUS PINNING

Fracture Reduction
■ Reduction should be done as soon as possible and certainly within a week of injury or the fracture may not be reducible.
■ Optimal anesthetic technique includes maximum muscle relaxation before fracture reduction.
■ Extension injuries are best reduced with the knee in flexion (TECH FIG 1).
■ Separations displaced medially or laterally are reduced by a medial or lateral force opposite to the direction of displacement.

Fixation
■ Smooth Kirschner wires are placed under fluoroscopic control after reduction of the fracture. Stout wires should be used (greater than 2 mm in diameter). Two pins are used.
■ One starts in the medial epiphysis and is advanced across the separation out the medial femoral metaphysis (TECH FIG 2A–C).
The second starts in the lateral epiphysis and is advanced across the separation into the lateral metaphysis (TECH FIG 2D,E).
- Pins left protruding distally may provide a portal to seed the knee joint with bacteria. For this reason, consideration should be given to advancing the pins proximally out the contralateral metaphysis and out the skin of the thigh. The pins are grasped proximally and drilled retrograde until the distal end disappears into the knee joint and the epiphysis of the distal femur. Pins are left protruding proximally (TECH FIG 2F).
- A cast or splint is applied with the knee in a comfortable degree of flexion.

**CLOSED REDUCTION AND PERCUTANEOUS SCREW FIXATION**
- This technique is satisfactory for type II epiphyseal separations with a substantial Thurston Holland fragment or for type III and IV fractures that are not widely displaced or rotated.
- The fracture is reduced by closed manipulation (TECH FIG 3A,B). Guidewires for cannulated screws (usually 4.5 mm) are passed percutaneously using fluoroscopic guidance. The guidewires should be passed perpendicular to the plane of the fracture and parallel to the physis (TECH FIG 3C).
- Fluoroscopy confirms wire placement. Overdrilling precedes placement of lag screws (TECH FIG 3D). Generally two screws are placed (TECH FIG 3E).
- Stability of fixation is tested. Hardware is added if needed.
- A splint or cast is applied.
OPEN REDUCTION AND INTERNAL FIXATION

Extra-articular Fractures
- A tourniquet should be applied to the thigh and inflated after exsanguination.
- Irreducible epiphyseal separations should be approached from the side on which the periosteum is torn (TECH FIG 4A).
- An incision is made medially or laterally over the physis. Interposed soft tissue, usually periosteum, is removed and the fracture is reduced (TECH FIG 4B).

Intra-articular Fractures
- Fixation is then placed as for the above procedures (TECH FIG 4C).

Fixation is then placed as for the above procedures (TECH FIG 4C).

Intra-articular Fractures
- Salter-Harris type III or IV fractures that cannot be reduced closed should be approached by a parapatellar arthrotomy on the same side of the fracture.
- Hematoma is evacuated.
- The fracture is reduced under direct vision and lagged in place with cannulated screws (TECH FIG 5).
- Closure and splinting or casting are routine.
PEAKS AND PITFALLS

| Indications | Fractures that present late (more than 7 to 10 days after injury) may be irreducible. These should be left to heal. Late osteotomy can be performed if necessary. |
| Nerve and vascular injury | Specific examination for distal pulses and peroneal nerve function is necessary before treatment. |
| Pin placement | When drilling pins retrograde, it is important to avoid the nerve and vascular structures in the posterior aspect of the distal thigh. |
| Pin tracts | Tension in skin around pin tracts should be relieved before immobilization to prevent problems with pin tract irritation. |

POSTOPERATIVE CARE

- The splint or cast is left for 1 month.
- Straight-leg raising is encouraged.
- Weight bearing is not allowed.
- Pins are pulled at cast removal.
- Motion is allowed after cast removal.
- Screw removal is optional after complete healing.

OUTCOMES

- Healing is not a problem and can be expected in all cases.
- The knee will be stiff when the cast is removed, but range of motion is usually quick to return.
- Up to one third of patients may develop late growth derangement. Assessment of the physis with plain radiographs and in most cases MRI is important because the rate of growth arrest is so high. An MRI at 4 to 6 months may show the first signs of physeal arrest.

COMPLICATIONS

- Nerve or vessel injury
- Malreduction
- Pin tract infection
- Growth derangement

REFERENCES

DEFINITION
- Fractures of the tibia are common in children.
- Severity ranges from nondisplaced “toddler’s” fracture to high-energy open injury.
- Open growth plates at the ends of the tibia preclude standard adult treatment options such as solid interlocked nails.
- Many cases can be managed nonoperatively, but orthopaedists need to maintain familiarity with operative techniques.

ANATOMY
- Relevant anatomy includes muscle compartments (anterior, posterior, superficial and deep posterior), cross-sectional shape, and growth plates (FIG 1).
- Neurovascular structures are at risk from direct trauma or compartment syndrome.
- Understanding the anatomy of the growth plates is crucial when planning fixation techniques.

PATHOGENESIS
- The most common injury scenarios are either low-energy injuries, such as those sustained during sports (twisting injury), or high-energy ones, such as seen in car-versus-pedestrian accidents (direct blow, comminuted fracture).
- Many injuries fall somewhere along the spectrum.
- High-energy injuries often are seen with concomitant injuries, such as ipsilateral femoral injuries (the so-called floating knee), compartment syndromes, and intra-articular injuries of the proximal or distal tibia.
- Occasionally, the fracture may be pathologic through an underlying bone lesion (eg, nonossifying fibroma, aneurysmal bone cyst, osteomyelitis, osteosarcoma).
- As in all fractures in young children, child abuse must be suspected if the history is unclear or multiple fractures are present.

NATURAL HISTORY
- Because of the significant remodeling potential in young children, most patients heal without sequelae.
- Morbidity from associated injuries, however, may be significant (ie, compartment syndrome), so a thorough evaluation is of paramount importance.
- General guidelines are available to define acceptable healing alignment (Table 1).

PATIENT HISTORY AND PHYSICAL FINDINGS
- The history should include mechanism of injury, antecedent pain, neurologic symptoms, and other areas of pain (eg, femur, abdominal pain, headache).
- A high-energy injury should also prompt a full trauma workup using standard Advanced Trauma Life Support protocols.

FIG 1 • A. Cross-sectional anatomy at the midtibial level. Note the triangular shape of the tibial shaft; this is important when placing external fixator pins. B. Arterial supply of the leg viewed from posteriorly. The anterior tibial artery penetrates the interosseous membrane proximally and is tethered there, putting it at risk for injury in proximal fractures. C. Proximal tibial physis viewed laterally. It is important to appreciate the continuity of the tubercle and proximal tibial growth plates. Injury to the tubercle growth plate will result in a recurvatum deformity.
Fractures of the Tibia

Curso: 

Computed tomography can be helpful to assess these regions.

For complex fractures, dedicated knee and ankle films can be helpful to evaluate for extension into the physeal or articular regions.

Computed tomography can be helpful to assess these regions if radiographs do not provide sufficient clarity.

Contralateral full-length films are helpful for determining length in comminuted fractures.

STUDIES

Compartment pressure measurements should be obtained in cases of concern (Figure 1A). Compartment syndrome is signaled by tense swelling of the compartment, pain with gentle squeezing of the compartment, pain with passive extension–flexion of toes, and paresthesias in involved nerve distributions. Loss of pulse is a late finding.

Patients with any of these signs should be considered at risk. A low threshold should be present for measuring compartment pressures and performing fasciotomy as needed. Vigilance is required to prevent permanent sequelae due to missed compartment syndrome.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acceptable Deformity By Patient Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valgus</td>
<td>5 degrees 5 degrees</td>
</tr>
<tr>
<td>Varus</td>
<td>10 degrees 10 degrees</td>
</tr>
<tr>
<td>Apex anterior/posterior</td>
<td>10 degrees 5 degrees</td>
</tr>
<tr>
<td>Angulation</td>
<td>10 mm 5 mm</td>
</tr>
<tr>
<td>Shortening</td>
<td>5 degrees 5 degrees</td>
</tr>
<tr>
<td>Malrotation</td>
<td>5 degrees 5 degrees</td>
</tr>
</tbody>
</table>


The physical examination should focus on assessing initial displacement and skin condition (ie, open injury), as well as swelling of the compartments.

The limb should be splinted, in the case of gross deformity, before obtaining films using material that permits high-quality radiographs.

A thorough neurovascular examination is needed to assess for vascular injury or compartment syndrome.

Pulses should be palpated or obtained with Doppler assistance.

Sensation in the deep and superficial peroneal nerve and tibial nerve distributions should be assessed, as well as motor function (toe flexors–extensors).

Pain with passive motion of the toes may represent an evolving compartment syndrome. More specifically, increasing pain, or pain out of proportion to the injury, is often the first early warning sign and should be taken seriously. Splitting or removal of casting material should be performed if any question exists.

Compartment pressure measurements should be obtained in cases of concern (Figure 1A).

Compartment syndrome is signaled by tense swelling of the compartment, pain with gentle squeezing of the compartment, pain with passive extension–flexion of toes, and paresthesias in involved nerve distributions. Loss of pulse is a late finding.

Patients with any of these signs should be considered at risk.

A low threshold should be present for measuring compartment pressures and performing fasciotomy as needed. Vigilance is required to prevent permanent sequelae due to missed compartment syndrome.

DIFFERENTIAL DIAGNOSIS

- Isolated tibial fracture
- Floating knee
- Pathologic fracture
- Intra-articular or intraphyseal injury
- Compartment syndrome
- Child abuse

NONOPERATIVE MANAGEMENT

Most tibial fractures can be managed with closed reduction and cast immobilization in an above-the-knee cast.

The cast should be molded to the anatomy of the tibia.

A supracondylar “squeeze” mold above the knee and 15 to 20 degrees of knee flexion can prevent cast slippage.

To truly avoid weight bearing, the cast must be flexed at least 70 to 80 degrees (if appropriate for a specific fracture).

In cases of acute fracture, the cast can be univalved to allow for swelling. It can then be overwrapped before initiating weight bearing.

Weekly radiographs are obtained for the first 3 weeks, with the cast being wedged or changed as needed for loss of alignment.

Weight bearing is dictated by patient comfort.

The cast is changed to a short-leg or patellar-bearing cast after 4 to 6 weeks, and immobilization is continued until healing is complete.

Surgical management is required for inability to maintain satisfactory alignment (Table 1).

SURGICAL MANAGEMENT

Indications for surgical treatment of tibial fractures in children include open injuries, compartment syndrome, multiple injuries, and fractures for which closed treatment fails.

Treatment in mature adolescents is the same as for adults with reamed, locked nails.

Younger children’s open physes require techniques that avoid the proximal and distal tibia, such as external fixation, plate fixation, and elastic intramedullary nailing.

Traditionally, external fixation was used primarily for fractures with significant comminution or soft tissue injury, where intramedullary fixation was considered impractical. However, recent work challenges this paradigm for surgeons experienced with elastic nailing.

Rapid stabilization of the multiply injured child is often accomplished using external fixation as well.

Plate fixation is a helpful technique for fractures not amenable to elastic nail fixation.

It is particularly helpful in patients who present with late loss of reduction and require an open approach to remove callus and realign the fracture.

It is used at our institution primarily for distal-third fractures.

After successful use in the treatment of pediatric femur fractures, the elastic intramedullary nail technique has also been successfully applied to the tibia.

Preoperative Planning

Full-length radiographs of the tibia and fibula should be obtained.

Views of the contralateral side can be helpful to determine proper length in comminuted fractures.

A clinical examination of the well side can guide the surgeon in determining rotational alignment.
The choice of fixation is determined by fracture location, comminution, and soft tissue envelope (FIG 2).

Positioning
- The patient is positioned supine on the operating table (FIG 3).
- The fluoroscopy machine can be brought in from the opposite side of the table so that it is out of the surgeon’s way.
- A small bump placed under the ipsilateral hip is helpful to counter external rotation of the femur, so that the patella is pointed straight vertically.

Approach
- The approach for treatment of tibial fractures depends on the technique used.
- Elastic nails and external fixation pins are placed through stab incisions.
- Open reduction and internal fixation approaches are the same as described for adult injuries elsewhere in this text.

EXTERNAL FIXATION
- In the supine position, traction is used to roughly align the fracture.
- Pins are placed using fluoroscopic guidance to avoid the physis.
  - Particular care is required when placing the most proximal pin.
  - The tibial tubercle physis is not easily seen on the AP radiograph.
  - A lateral view is required to avoid injury to this structure and a late procurvatum deformity.
- An array of pin sizes should be available.
- Full-sized adolescents may require 5-mm pins as in adults, but smaller children require smaller pins to avoid an overly stiff construct.
- Four-millimeter pins should be used for younger children (ie, under 10 years old), and I have found an adult wrist external fixator with 2.5-mm pins useful for treatment of toddlers with open injuries requiring fixation, such as lawnmower injuries.
- Pins are placed on each side of the fracture, one close (within several centimeters of the fracture line) and one far (at least 2 to 3 cm away from the physis).
- Children’s bone is often quite hard. Despite using “self-drilling” pins, I prefer to predrill the anterior cortex before placing the pin.
- Ring sequestra may develop from the heat generated in hard bone if pins are drilled directly in some children.
- The roughly triangular shape of the tibia should be noted (see Fig 1A).
- The pins should be started on the tip of the anterior tibia or just medial and aimed slightly medially.
- Laterally aimed pins may be unicortical, as the lateral cortex of the tibia is vertically oriented.
- The fracture is then manually reduced, using the pins for traction if necessary, and the frame is connected (TECH FIG 1A).
- In cases of soft tissue injury requiring the ankle to be immobilized, extending the frame to the first or fifth metatarsal can allow easier wound management (TECH FIG 1B).
- The pin sites are covered with iodine-soaked gauze.
  - I have caregivers begin cleaning the pin sites with half-strength hydrogen peroxide once or twice daily after the 1-week follow-up visit.
  - A posterior splint is applied to immobilize the ankle and allow soft tissue healing. It is removed after 2 to 3 weeks to begin ankle range of motion.
PLATE FIXATION

- Treatment is essentially the same as for adult injuries, but several points bear emphasis.
- It is helpful to make the incision slightly laterally over the anterior compartment so it will not lie directly over a medially placed plate (TECH FIG 2A).
- The fracture is reduced using standard techniques. Care should be taken to avoid unnecessary stripping of the fracture.
- I prefer to make an incision over the fracture large enough to reduce the fragments but not the entire length of the plate.
  - The plate can be slid under the skin, over the periosteum, and the screws placed through stab incisions, as for percutaneous plating in adults (TECH FIG 2B).
- For larger children, many adult fracture systems include precontoured 3.5-mm plates for the distal tibia.
  - For smaller children, a small fragment plate may be contoured to fit appropriately.
  - It is important to avoid injury to the perichondral ring at the distal extent of the plate.
- If the plate is applied on the medial side of the tibia, as it often is for fractures with valgus angulation, it will usually need to be removed after healing due to prominence.
- If applied laterally, I usually make a longer incision, since percutaneously placed screws will traverse the anterior compartment and potentially injure the neurovascular bundle. I prefer open placement in this case.
- The wound is closed using standard techniques. A posterior splint is applied to protect the soft tissues.

**TECH FIG 1**  • A. External fixation in a patient with a compartment syndrome. Arrows mark the proximal and distal growth plates. The proximal pins start fairly distally to avoid the tubercle physis. B. In this patient, an external fixator was used for a grade 2 open fracture treated with delayed closure. The patient also had a degloving injury requiring a flap and skin graft over the medial ankle. The frame was extended to the first metatarsal to immobilize the foot during healing. Although somewhat bulky, the “double stack” configuration of the frame allows for easy dynamization.

**TECH FIG 2**  • A. Incision for open reduction and internal fixation is made laterally over the anterior compartment, and the skin can then be mobilized to gain access to the fracture site. It is important not to incise the skin directly over the proposed location of the plate. B. Medial view of internally fixed tibia. A lag screw compresses the fragment, and the plate stops short of the physis. The skin incision is centered over the fracture to allow an accurate reduction, but the proximal and distal screws can be placed percutaneously through a medially applied plate. It is helpful to make one stab incision for every two holes, centered between them.
ELASTIC INTRAMEDULLARY NAIL FIXATION

- The surgeon begins by selecting the proper nail size. Usually nails should be 0.4 times the diameter of the tibial isthmus.
- The nails are contoured so that there is a C shape with its apex at the fracture site. This will cause cortical contact at the apex, yielding three-point fixation (proximal, cortical at fracture level, and distal).
- By contouring rods of equal diameter symmetrically, the elasticity of the nails resists deformation of the fracture, as opposed to reamed nailing, where the fracture is statically supported by the strength of the nail.

Preparation for Nail Insertion

- The nails are inserted in the tibial metaphysis.
  - The proper starting point is at least 1 cm distal to the proximal tibial physis and 2 cm posterior to the tibial tubercle physis (TECH FIG 3A,B).
  - The relevant landmarks should be identified fluoroscopically and marked on the skin (physis, tubercle, starting points) before proceeding (TECH FIG 3B).
  - The incision should be 1 to 1.5 cm long, with its most distal extent roughly 1 cm proximal to the physis.
    - This will allow an oblique passage of the nail at the correct proximal-to-distal angle.
  - A small hemostat is used to carefully spread through the tissue down to bone, and a drill sleeve and drill are placed on the bone. The drill should be 1 to 1.5 mm larger than the diameter of the nail.
  - After checking the position of the drill tip with fluoroscopy (TECH FIG 3C), a starting hole is drilled along the proposed path of the nail (TECH FIG 3D).
    - Care is taken not to drill across the tibia out the opposite cortex.

Nail Pattern and Placement

- Multiple nail patterns have been described, but the standard is one medial and one lateral nail (TECH FIG 4A,B).
  - Alternately, if soft tissue compromise precludes the use of an entry site, the first nail is bent into a C, with the second bent into an S. The apex of the more distal curve in the nail should be at the fracture site.
  - The first nail is contoured into a C shape. It should be placed on the tibia and a fluoroscopic image obtained (TECH FIG 4C,D).
    - A gentle bend is placed in the nail, centered at the fracture.
  - The nail is placed up to the fracture site under fluoroscopic guidance. Initially, it is helpful to direct the bend posteriorly, as in the passage of a guidewire for a standard reamed nail, but it is important to rotate the bend into the proper plane to prevent a recurvatum deformity (TECH FIG 4E,F).
  - The second nail is placed in the same fashion.

Fracture Reduction and Fixation

- The fracture is then manually reduced.
  - It is rarely necessary to open the fracture to obtain a reduction, as the fracture can be easily manipulated.
  - The bent tip of the nail can be used to assist in reduction as well.
  - To pass the nails across the fracture, it is helpful to consider the initial deformity of the fracture.
    - For example, if the fracture tends to lie in valgus, it may be helpful to pass the medial nail first to apply a varus force. The second nail is then directed across the fracture site.

TECH FIG 3 • A. The proper starting point for nail insertion lies at least 1 cm distal to the proximal tibial growth plate and 2 cm posterior to the tubercle physis. B. Patient undergoing elastic intramedullary nailing of the tibia. Marked on the skin are the proximal growth plate and proposed entry sites, as well as the fracture. The incision is made proximal to the line of the physis, and an oblique angle matching the final path of the nail is dissected with a hemostat down to the bone. C. After confirming the entry site radiographically, a drill is used through a guide to open the cortex 1 to 2 mm larger than the nail diameter. D. The drill starts perpendicular to the bone and is advanced distally. Care is taken not to drill into a previously placed nail or through the far cortex.
Care should be taken to stop the nails short of the distal physis and to avoid distraction at the fracture site.

When passing the nails, it is often helpful to pass them both to the level of the fracture and sequentially crossing the fracture site.

In oblique fractures, the first nail will deform the fracture and make passing the second nail difficult if the first nail is passed all the way down initially.

In simple fractures, the order of passage is less important.

**CUTTING THE NAILS AND WOUND CLOSURE**

The nails are then cut, pulling them away from the bone without exceeding the elastic modulus of the nail, so they lie against the bone after they are cut, with about 2 cm out of the bone available for removal if required at a later date.

Alternately, the nails can be withdrawn a few centimeters, cut short, and then impacted back down the tibia, again leaving 2 cm of exposed nail beyond the entry site.

This step is important, because if the nails are left too long or are bent out away from the bone, they will become symptomatic before fracture healing. This is especially true medially, where the rod is subcutaneous (TECH FIG 5).

The incisions are closed with subcuticular suture, and a posterior splint is applied to allow tissue healing.

**TECH FIG 4 • A,B.** Potential patterns of nail insertion. The standard pattern (A) entails one medial and one lateral nail. Alternately, both nails are inserted from the same side to avoid compromised skin (B). In the tibia, the former technique is far easier. C. The nail is placed on the skin, with the tip at the proposed final location, as confirmed radiographically. D. The nail is marked at the fracture site and bent to place the apex at that location. E. When starting a nail, it is helpful to rotate the nail so that the tip points anteriorly, bouncing off the posterior cortex. F. The nail is then turned so that the bend in the nail lies in the coronal plane.

**TECH FIG 5 •** Instead of cutting the nail under the skin, it can be withdrawn, cut at skin level (A), and tamped in to prevent irritation (B).
**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Compartment syndrome</th>
<th>A high index of suspicion is required.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The surgeon must maintain vigilance throughout the postoperative period for late development.</td>
</tr>
<tr>
<td></td>
<td>Increasing pain is the first sign of pediatric compartment syndrome.</td>
</tr>
<tr>
<td>External fixation</td>
<td>Rigid frames may lead to delayed union.</td>
</tr>
<tr>
<td></td>
<td>Care should be taken to use appropriately sized pins and to dynamize early.</td>
</tr>
<tr>
<td></td>
<td>Fluoroscopic guidance is used to avoid growth plates.</td>
</tr>
<tr>
<td>Plate fixation</td>
<td>Incisions should be carefully chosen to avoid compromised skin.</td>
</tr>
<tr>
<td></td>
<td>Low-profile plates may help avoid irritation from the plate before fracture healing.</td>
</tr>
<tr>
<td>Elastic intramedullary</td>
<td>Fractures that are very distal or proximal, or highly comminuted, should be treated by other techniques.</td>
</tr>
<tr>
<td></td>
<td>Proper nail contouring and size selection are important to maintain stability of the fracture.</td>
</tr>
<tr>
<td></td>
<td>Ideally, the nails should be the same diameter to provide balanced fixation (FIG 4A).</td>
</tr>
<tr>
<td></td>
<td>Nails should be passed carefully to avoid the “creeping vine” effect.</td>
</tr>
<tr>
<td></td>
<td>If the nails spiral around each other, the elastic recoil, and thus the stability of the technique, will be lost (FIG 4B).</td>
</tr>
<tr>
<td></td>
<td>Care should be taken to avoid physeal injury.</td>
</tr>
<tr>
<td></td>
<td>Nails should be cut short to avoid irritation.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- For patients treated with external fixation, a splint is used for 7 to 10 days to allow the tissues to recover.
- For stable fractures, progressive weight bearing is initiated in reliable patients.
- Unstable or comminuted fractures require waiting until visible callus is present before weight bearing.
- Depending on fracture stability, dynamization of the fixator is initiated early, after sufficient callus is seen. The frame is removed in the office or the operating room after healing is noted radiographically.
- Most patients benefit from short-term support with a bivalved cast after removal.
- Patients treated with plate fixation begin a progressive weight-bearing program, with immobilization discontinued after sufficient radiographic healing is present, usually by 6 weeks.
- Patients treated with elastic intramedullary fixation are usually splinted for 7 to 10 days, followed by progressive weight bearing. The plan is modified based on fracture stability, soft tissue injury, and patient reliability.
- Patients with substantial (over 50%) cortical contact may begin weight bearing as tolerated after soft tissue healing has occurred.
- In general, prolonged stiffness is unusual in pediatric patients.
- It is better to overimmobilize in questionable cases to avoid malalignment and regain motion later with aggressive physiotherapy.
- Removal of symptomatic hardware (ie, nails or plate) should be delayed until fracture healing and remodeling are complete.
- I prefer to remove elastic nails electively in all patients 6 to 9 months after injury, as the nails will become completely intramedullary with significant continued growth, thus making late removal extremely difficult.
- Ideally, plate removal is delayed for a year, after remodeling is complete.

**OUTCOMES**

- Most tibial fractures in children will heal uneventfully, although healing difficulties can occur, especially in older patients.\(^4\)
- Slon\o^13 noted that most complications seen in his series were a result of improperly applied technique, particularly residual distraction at the fracture site, leading to a “pseudarthrosis model” even in children.
- Bar-On and associates\(^2\) noted increased callus formation and shorter time to union in the elastic intramedullary nailing

---

**FIG 4** Potential pitfalls in nail placement. A. The nails are of differing diameter, inducing a valgus moment that needs to be controlled in a cast. Note the incidental nonossifying fibroma. B. “Spiraling nails.” The elasticity afforded by three-point fixation is lost, making the construct less stable.
group versus external fixation (7 weeks compared with 10) in a femur model.

- Myers and coworkers\textsuperscript{10} reported a significant complication rate in high-energy tibial fractures treated with external fixation, including delayed union, malunion, leg-length discrepancies, and pin-tract infections.
- Kubiak and colleagues\textsuperscript{8} reported 2 delayed unions, 2 malunions, and 3 nonunions in a series of 15 patients managed with external fixation, although these appear to have occurred in open injuries.
- They reported higher functional scores in their patients treated with elastic intramedullary nailing compared to external fixation.
- Operative techniques usually require additional procedures for removal of pins or prominent nails or plates.
- Obviously, operative complications do not occur in nonoperatively treated patients. Knowledge of proper indications is crucial to maximize outcomes.

COMPLICATIONS

- Malunion
- Delayed union
- Leg-length discrepancy
- Compartment syndrome
- Symptomatic hardware
- Infection

REFERENCES

DEFINITION
- Tibial tuberosity fractures are relatively rare fractures in adolescents. They commonly occur in the later years of skeletal growth before physeal closure.
- The fracture mainly occurs in boys, but there are a few cases reported in girls.
- The injury occurs while jumping, such as while playing basketball.
- There may be a history of prior tuberosity apophysitis.

ANATOMY
- The tibial tubercle develops in four stages. 5
  - In the first stage the tubercle is completely cartilage before a secondary center of ossification forms.
  - The second, or apophyseal stage, occurs at age 8 to 12 years in girls and 9 to 14 years in boys. The secondary center of ossification forms, but it is not connected to the epiphysis of the proximal tibia.
  - The third, or epiphyseal, stage is when the “tongue” of the apophysis and the epiphyseal bone are continuous. The ages for the third stage are 10 to 15 years for girls and 11 to 17 years for boys.
  - In the final stage the physis is completely fused and becomes bony.
- The patellar ligament inserts into the proximal portion of the apophysis. There is a broad insertion into the periosteum distal to this. The insertion is lateral to the midline; thus, the fracture fragment is centered lateral to the midline.
  - This is important when considering the approach for intra-articular visualization.
- The anterior tibial recurrent artery may tear after a displaced fracture. Bleeding from its proximal branches as it retracts into the anterolateral compartment may lead to compartment syndrome.

PATHOGENESIS
- The injury occurs with a forceful quadriceps contraction while the foot is fixed. There is a significant force that the quadriceps mechanism is able to generate, and this overcomes the strength of the epiphysis and the surrounding periosteum.
- The other mechanism of injury is sudden passive knee flexion while the quadriceps is contracted.
- It has been hypothesized that individuals with this fracture may have quadriceps strength that is greater than their peers. 8 Thus, the conditions for the fracture are present during jumping and in strong individuals.
- Many of the patients have pre-existing Osgood-Schlatter disease. 1,11,12
- The injury usually occurs at a time when the tuberosity is undergoing normal closure.
- There have also been reports of associated injuries such as quadriceps tendon injury, cruciate ligament tears, and meniscal injury. 1,6,7,9

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients are usually very tender, with significant swelling over the anterior proximal tibia.
- In the more displaced fractures (type II and III) there is usually no possibility of active extension against gravity. There may also be patella alta in the more displaced fractures.
- Patients with minimally displaced fractures may extend the knee, but with obvious discomfort.
- A good neurovascular examination should be performed.
- The clinician evaluates for the presence of leg compartment syndrome.
- In the acute fracture there is a sudden onset of pain and it is difficult to ambulate. This is unlike Osgood-Schlatter disease, in which the onset is more chronic and there may be radiographic findings of a chronic condition such as calcification anterior to the secondary center of ossification.

RADIOGRAPHIC FINDINGS
- Good anteroposterior (AP) and lateral radiographs are often able to make the diagnosis.
- The displacement is most obvious on the lateral radiograph. If it is a nondisplaced fracture or the separation is minimal, a contralateral comparison radiograph may help confirm the diagnosis.
- Ogden described three types: 12
  - Type I fractures are through the apophysis.
  - Type II fractures exit between the epiphysis and apophysis.
  - Type III fractures propagate into the anterior knee joint under the anterior meniscus attachments (FIG 1).

NONOPERATIVE MANAGEMENT
- Open reduction and internal fixation (ORIF) is indicated for all patients except those with completely nondisplaced fractures.
- In nondisplaced fractures where patients can perform a straight-leg raise, a long-leg cast may be used for treatment.
  - Immobilization should be for 6 to 8 weeks.
- Close radiographic follow-up is needed for the first 2 weeks to ensure the fracture does not become displaced.
- Even in the nondisplaced fractures, percutaneous screw fixation may allow earlier immobilization and prevent 6 to 8 weeks of casting.

SURGICAL MANAGEMENT
- For fractures with more displacement, open reduction and fixation with screws is recommended.
Positioning
- Patients are positioned supine with the operative leg and knee prepared free.
- The table should allow good anterior and posterior views to be obtained with fluoroscopy.
- The tourniquet can be used to keep the field dry, allowing for good visualization of the fracture fragments and the joint reduction. The tourniquet, however, may prevent the quadriceps from being freely mobilized and may make reduction more challenging.

Approach
- A midline anterior incision is made.
- The proximal extent is the midpatella and the distal aspect is a few centimeters distal to the tibial tubercle fracture bed.
- There is a significant amount of hematoma formation and torn periosteum; thus, the incision length allows the surgeon to define the appropriate anatomy and prepare the fragment for reduction.
- Since the tubercle and the fracture are on the lateral aspect of the proximal tibia, a lateral parapatellar approach will give better visualization of the fracture and intra-articular reduction.
- The lateral approach also limits any damage to the infrapatellar branch of the saphenous nerve.

DISSECTION AND FASCIOTOMY
- The large hematoma should be evacuated.
- There is commonly a long periosteal flap of the proximal tibia seen with the elevated fragment that needs to be extracted from the fracture.
- A prophylactic anterior compartment fasciotomy is performed.
- The distal, medial, and lateral extent of the fracture should be surgically defined with sharp dissection.
- For the type of fracture that exits the anterior part of the knee joint, the surgeon must visualize the knee joint. This can be accomplished by looking into the knee through the fracture or by a parapatellar approach. Specifically, the surgeon must ensure the meniscus is not injured or interposed in the fracture before reduction.

OPEN REDUCTION
- Next, the fracture is reduced; this is aided by leg extension.
- Often the articular surface can be first reduced and the distal aspect then reduced into the base.
- Reduction is confirmed with both visualization and fluoroscopy.
- If the fracture is not reduced anatomically, it is due to soft tissue interposition or meniscal interposition (TECH FIG 1).

TECH FIG 1 • A. A 15-year-old boy with a displaced tibial tuberosity fracture that enters the joint surface. B. Initial postoperative lateral radiograph after open reduction and internal fixation. Despite initial fluoroscopic views indicating an adequate reduction, the radiographs indicate a poor reduction. (continued)
Once the fracture is reduced, screw fixation is recommended. Provisional Kirschner wires may be placed to hold the reduction before screw fixation. The screws are placed from anterior to posterior parallel to the joint surface. Bicortical purchase is not imperative due to the thin posterior cortex in this region. It is important to prevent vascular injury posterior to the knee joint in this region. Cancellous screws in compression are ideal for this location. Cortical screws will achieve fixation as well, especially more distal.

If there is a large bone fragment, two or three 4.5-mm screws are ideal and may lead to less screw head irritation (TECH FIG 2A,B). We often use a washer for the thinner cortical bone at the distal region of the fracture. Alternatively, 6.5- or 7.3-mm screws can be used, although screw head irritation may occur. The surgeon should avoid placing the screws directly under the incision (TECH FIG 2C).
POSTOPERATIVE MANAGEMENT

- Postoperatively, a cylinder cast for 4 weeks is commonly used, followed by progressive range of motion, or a knee immobilizer for 4 weeks, followed by range of motion.
- Postoperative immobilization depends on the fixation. Smaller bone fragments will likely require more immobilization than larger bone fragments, where greater fixation can be achieved.

OUTCOMES

- Most of the published series have a small number of patients, due to the rare nature of this fracture.
- All studies have been consistent in their conclusion that the fractures heal with success and patients return to normal function. Growth abnormality has not been reported.4,9,11,12

COMPLICATIONS

- Reported complications are few for the tibial tuberosity fracture. Screw prominence is the most common complication.14
- Compartment syndrome has been reported.10,13 A prophylactic anterior compartment fasciotomy and close observation and recognition may decrease the possibility of this complication.
- Growth disturbance, such as a recurvatum from tibial tubercle arrest, is not much of a concern as this fracture occurs in adolescents near the end of growth.
- Loss of motion or quadriceps muscle weakness is extremely rare but may occur with a malunion or malreduction.2

REFERENCES

DEFINITION

- Ankle fractures account for about 5% of all pediatric fractures and are second only to distal radius fractures as the most prevalent long-bone physeal fracture comprising approximately 15% of these injuries.1
- As in most pediatric trauma, nonoperative management is the mainstay of treatment; however, surgical indications can be specific to the pediatric population.
  - Surgical treatment is mandated with any significant articular incongruity as in the adult population.
  - It is our experience that physeal fractures of the distal tibia require near-anatomic alignment to prevent the complication of premature physeal closure.1,7
- Classification of pediatric ankle fractures can be a practical tool for both the treatment and prognosis of these fractures.
  - The most common classification scheme for pediatric ankle fractures is the anatomic Salter-Harris method for physeal fractures.
  - We have found the Lauge-Hansen mechanistic classification derived for adults is very useful, as this aids in conceptualizing the reduction technique by reversing the fracture pattern. Also, our data have shown that pronation-type injuries have a higher rate of premature physeal closure than the supination–external rotation type of injuries.7
  - We also find this useful as most orthopaedic surgeons are familiar with this classification.
  - Additional classification systems include the fibular-based Danis-Weber system, as well as a more comprehensive classification suggested by Dias and Tachdjian that uses the Lauge-Hansen guidelines correlated with the Salter-Harris classification.2,4
- Transitional fractures of the ankle occur near skeletal maturity and are due to the asymmetric closure of the distal tibial physis.
  - Triplane fracture is described as a complex Salter-Harris type IV fracture that consists of sagittal, transverse, and coronal components with an epiphyseal and metaphyseal fragment.
  - Tillaux fractures occur most often in adolescents within 1 year of distal tibial physeal closure. They involve an external rotational force that avulses off the anterolateral aspect of the tibial epiphysis, which is attached to the anterior tibiofibular ligament, which is stronger than the residual open physis laterally.
ANATOMY

- The ligaments of the ankle attach to the epiphyses, provide stability to the ankle mortise, can play a role in the pathomechanics of transitional fractures as the growth plate closes (triplane and Tillaux fractures), and are often more stout than the growth plate about the ankle, leading children to sustain physeal fractures more readily than ankle sprains.
  - The anteroinferior tibiofibular ligament attaches strongly to the anterolateral border of the tibial epiphysis, and with an external rotation force on the foot it has the ability to avulse off the anterior lateral fragment of the tibial epiphysis; the strength imbalance between the ligament and weaker physis can create the transitional Tillaux and triplane fractures.
  - The anatomy of the distal tibial physis is relevant to understanding certain ankle fractures and their management and prognosis.
  - The secondary ossific nucleus of the distal epiphysis appears between 6 and 24 months, with the apophysis of the medial malleolus often extending from an elongation from this ossific nucleus or from a separate ossification center, the os subtibiale, which ossifies between 7 and 8 years of age.
  - The distal tibial physis is for the most part transverse; however, there is an anterior medial undulation that consistently appears within the first 2 years of life that has been described by Kump (termed Kump’s bump). This central-medial location is where physiologic physeal closure begins (FIG 1).
  - Physeal closure of the distal tibia occurs around 15 years of age in girls and 17 years of age in boys.
  - Closure progresses from the central-medial location of Kump’s bump medially, then laterally from this location, over about 18 months.
  - The anatomy about the physis also greatly influences ankle fractures in children.
    - The perichondral ring of La Croix is a transitional area between the articular cartilage and the periosteum of the diaphysis, which is perichondrium and retains the potential for producing cartilage and bone.
    - Functionally, the perichondral ring provides stability to the physis and may play a role in certain fractures and growth plate injuries in children.

![FIG 1 • Kump’s bump. The arrow demonstrates the central-medial–located Kump’s bump, which is where physeal closure begins. We believe that damage to this structure may induce premature physeal closure.](image)
Also, this periosteum, rigidly attached to the perichondral ring, can become interposed in the fracture site and obstruct anatomic reduction.

PATHOGENESIS

- The Lauge-Hansen classification system was developed in 1950 to understand the injury mechanism by reproducing the fracture patterns in cadavers.4
- This classification is a two-part classification, with the initial portion describing the position of the foot at the time of injury (e.g., supination, pronation) and the following portion describing the direction of the deforming force; the forces are either rotational (internal or external) or translational (abduction or adduction).
- This system grades the severity of ankle injuries as I to IV in rotational patterns and I to II in translational patterns.
- In our most recent series of 114 classifiable ankle fractures (Salter II) using the Lauge-Hansen system, supination–external rotation (SER) composed 66%, abduction 30%, pronation–external rotation 3%, and axial crush injuries 1%.7
- The activity that resulted in ankle fractures varied in our series, with most occurring during falls and sports.1,7
- SER fractures did not seem to have any specific activity that was more likely to produce premature physeal closure; however, abduction injuries occurring with playing soccer or skateboarding were much more likely to develop premature physeal closure when compared to other activities.
- Specific anatomy and growth plate closure patterns create certain fractures in adolescence.
  - For example, the same external rotation mechanism can produce a Tillaux or a triplane fracture depending on the age and degree of physeal closure of the child.
  - The last portion of the distal tibial physis to close is lateral. This is often an area of weakness in the skeletally maturing child, allowing an anterolateral fragment to be avulsed from the epiphysis, creating Tillaux fractures or the fragments in the triplane fracture.

NATURAL HISTORY

- Premature physeal closure of the distal tibia has been historically described as a rare sequela in physeal fractures, with an incidence as low as 2% to 5%.1
- Our recent data demonstrate an overall 38% incidence of physeal arrest in Salter-Harris I and II fractures; however mechanism and treatment modality has been shown to affect this incidence.7
- SER injuries have a better prognosis for premature physeal closure, with a 38% overall incidence, as compared to abduction-type injuries, with a 52% overall incidence.
- In SER-type injuries the rate of premature physeal closure in patients treated without surgery was 56%; the incidence rate was only 16% in those who were treated with open reduction.
- Abduction injuries had a relatively poor prognosis for premature physeal closure whether the intervention was closed treatment (54.5% closure rate) or open treatment (50% closure rate).
- This difference in prognosis between SER and abduction injuries may be explained by the shearing force of Kump’s bump that may occur in abduction injuries, as opposed to less traumatic rotational force to this anatomic structure that occurs with SER injuries.
- These data have relevance in operative indications in pediatric ankle fractures, as an earlier series demonstrated a 3.5-fold increase in the premature physeal closure rate if a gap of 3 mm or more was present on the postreduction imaging of Salter-Harris type I and II fractures.
- Our experience suggests that periosteum interposed in the physis leads to residual fracture gapping and ultimately premature physeal closure.
- The orthopaedic surgeon should discuss the potential for premature physeal closure with the family at the initial visit, particularly with an abduction type of injury.

PATIENT HISTORY AND PHYSICAL FINDINGS

- As in adult trauma, the initial evaluation of children’s ankle injury consists of eliciting the mechanism and timing of injury.
- Basic examination should consist of evaluating the skin and soft tissues, finding areas of maximal tenderness to palpation, and obtaining an accurate sensory, motor, and vascular examination.
- Particular issues that must be considered in the diagnosis of ankle fractures in children include osteomyelitis and child abuse.
  - Osteomyelitis prevalence is 1 per 5000 children. It generally occurs in the vascular loops of the metaphyseal regions of bone in children and can occur because of hematogenous spread or as a result of trauma, which can further complicate diagnosis.
  - A good history of the proximity of pain onset relative to the inciting trauma will help differentiate trauma from infection.
  - Metaphyseal fractures of the distal tibia in children can be concerning for child abuse, as the mechanism can be attributed to forceful pulling or twisting of the extremity, fracturing the cancellous bone through the metaphysis. Additional concerns are bilateral extremity fractures and fractures at different stages of healing.
  - Visualization of the skin is critical in evaluation for potential open injuries. The quality of skin can also affect the timing of surgical fixation and give insight into the energy and location of injury.
  - Palpation of the ankle can assist in locating the injury and may allow diagnosis of occult physeal fractures or ligamentous injuries not seen on radiographs.
  - Establishing preoperative deficits is critical in their postoperative management and aids in establishing the need to release the extensor retinacular compartment.
  - In ankle injuries preoperative deficits can be due to nerve contusion or laceration, in addition to tendon disruption or mechanical block. This can affect the surgical approach.
  - Vascular status is the key to the ultimate viability of the extremity. If deficits are found, the fracture should be immediately reduced. If a deficit is still present after reduction, a vascular study may be considered versus immediate operative exploration to evaluate for transient spasm or vascular injury.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- If there is any suspicion of an ankle injury, a complete plain radiographic ankle series should be performed. This consists of anteroposterior (AP), lateral, and mortise views (FIG 2A–C).
  - The mortise view is critical and is taken from anterior to posterior with the foot internally rotated 20 degrees to view
the talus with a symmetric clear space seen medially and laterally.

- The importance of the mortise view is seen in Tillaux fractures, where the anterior lateral fragment is often obscured by the overlap of the posterior fibula on the AP view and is not well visualized on the lateral view.
- We do not advocate stress radiographs in children; however, we will use an external rotation stress view intraoperatively to evaluate for syndesmosis injury if suspected in children near skeletal maturity.
- Accessory ossicles can be commonly visualized on plain radiographs and may be confused with ankle fractures.
  - These include the os subtibiale medially (up to 20% of population), the os trigonum posteriorly (about 10% of population), and the os fibulare laterally (about 1% of population).
  - Contralateral comparison films may be helpful to differentiate accessory ossicles from a fracture.
- Computed tomography (CT) is required to fully understand many ankle fractures, and we often advocate three-dimensional postreduction CT scans (FIG 2D–G).
- We advocate CT scans for intra-articular fractures that show any evidence of displacement on plain radiographs, and we routinely obtain three-dimensional CT scans for triflare and many Tillaux fractures after attempted closed reduction.
- For any physeal fracture with apparent displacement in children with greater than 2 years of growth remaining, we advocate CT scanning of the ankle to evaluate for displacement, as we recommend operative treatment for trapped periostem with greater than 2 mm of displacement.
- At time of injury for Salter-Harris type I, II, and triflare fractures of the distal tibia, we also obtain plain radiographs, with an AP view of the left hand to establish bone age and AP and lateral views of the contralateral ankle for a baseline for physeal maturity and physeal comparison.

**DIFFERENTIAL DIAGNOSIS**

- Ankle sprain
- Accessory ossicle
- Osteochondral lesion (osteochondritis dissecans)
- Contusion
- Osteomyelitis

**NONOPERATIVE MANAGEMENT**

- Our clinical pathway for surgery advocates all closed ankle fractures have an attempt of closed reduction under conscious sedation in the emergency department.
- Reductions generally take place in our emergency department with the use of ketamine for conscious sedation and the aid of a portable image intensifier.
- Reduction maneuvers should reverse the established mechanism of injury derived from patient history and fracture pattern, such as the Quigley maneuver for the abduction-external rotation type of fractures.
- All our children are placed in fiberglass casts that are initially univalved with plastic spacers inserted in the cast to accommodate for swelling (FIG 3).
- In children with a high-energy mechanism or with any neurovascular change that has not improved after reduction, admission for serial neurovascular checks to monitor for compartment syndrome is recommended.
- For Salter-Harris type I, II, and triflare fractures, if a near-anatomic reduction is obtained with 2 mm or less of residual displacement, we will proceed to a long-leg cast and non-weight bearing for 4 weeks with periodic radiographs, with the frequency depending on the stability of the fracture pattern.
- To assess residual displacement in both the physis and articular surface, CT scan provides more accurate anatomic assessment, and we routinely perform plain radiographs and CT scans after reduction.
For physeal fractures that do not attain this reduction tolerance, we advocate closed reduction under general anesthesia. If we do not meet our less-than-2-mm-displacement tolerance, we proceed to perform open reduction and internal fixation in children with more than 2 years of growth remaining.

In children close to skeletal maturity, we will accept a less anatomic reduction of the physis, but not the joint.

For children with any residual intra-articular irregularity, we will generally obtain a CT scan, and if we feel we can improve on the anatomic alignment, we will proceed with open reduction and internal fixation.

SURGICAL MANAGEMENT

Preoperative Planning

A repeat attempt at closed reduction may be made in the operating room under general anesthesia in many ankle fractures to see if the fracture would be amenable to closed reduction and casting, or closed reduction and percutaneous pinning.

CT scanning with three-dimensional reconstructions now allows the surgeon to truly understand ankle fracture pathoanatomy beyond our previous abilities. We feel these studies are essential in preoperative planning in many complex ankle fractures, especially triplane fractures.

Evaluation of the CT scan allows understanding of the complex configuration of these fractures and ultimately allows the planning for lag screw placement in relation to the fracture planes.

As mentioned previously, CT scans are also important in assessment of the need for open reduction of the fracture due to gapping of the growth plate.

For the most part, in children with open growth plates, transphyseal fixation should involve only smooth Kirschner wires; screws may be used, positioned parallel to the physis.

Positioning

Almost all ankle fractures can be addressed in the supine position.

If lateral ankle exposure is necessary, a bump can be placed underneath the operative hip to improve lateral visualization.

The image intensifier is positioned with the screen at the foot of the table angled toward the surgeon on the operative side, while the C-arm should come in directly from the opposite side of the operative ankle.

The operative leg can be elevated with blankets or a foam pad to allow a pull-through lateral view unobstructed by the contralateral extremity.

Nonsterile tourniquets are applied as proximal as possible before sterile draping.

Approach

The anterior approach involves an incision of about 8 to 10 cm over the distal tibia.

The superficial peroneal nerve lies over the ankle retinaculum at this level and should be avoided.

The superior extensor retinaculum is incised at the interval between the extensor digitorum longus and the extensor hallucis longus.

Care is taken not to injure the neurovascular bundle consisting of the deep peroneal nerve and anterior tibial artery, which lies in this interval.

The posteromedial approach to the ankle consists of an incision about 8 to 10 cm roughly midway between the medial malleolus on the medial border of the Achilles tendon.

The deep fascial layers are incised longitudinally to expose the flexor tendons posterior to the ankle. At this level the flexor hallucis longus is the only muscle that still has muscle fibers.

Dissection is carried out along the lateral border of the flexor hallucis longus, which will still have identifiable muscle fibers at the level of the ankle, and the ankle is exposed as the flexor hallucis longus is retracted medially.

Care must be taken because the neurovascular bundle is just medial to the flexor hallucis longus; the tibial nerve is relatively large in young children compared to the tendon of the flexor digitorum longus.

The lateral approach involves an incision over the posterior margin of the fibula toward the distal end centered about the fracture site.

The short saphenous vein and the sural nerve run just posterior and inferior to the distal portion of the lateral malleolus.

The medial approach can be centered more anterior or posterior depending on the location of the medial malleolar fracture and the need to visualize the posterior tibia.

The incisions for these approaches should be centered over the malleolus longitudinally but should not be over the most prominent portion of the malleolus to prevent irritation.

Anterior to the medial malleolus run the long saphenous vein and the saphenous nerve, which should be preserved.
SALTER-HARRIS TYPE I AND II DISTAL TIBIA FRACTURES

- A standard anterior approach for the SER fractures is used as described above.
- For a medially gapped Salter Harris type II abduction injury, a medial approach is used (TECH FIG 1).
  - The approach can be made slightly more medial or lateral depending on the location of the fracture.
  - The fracture and growth plate should be identified and defined.
  - The fracture will most always be associated with a fracture hematoma.
  - The growth plate and perichondral ring should be identified and protected.
    - The physis has an identifiable white cartilaginous appearance.
  - Two Hohmann-type retractors can be placed around the distal tibia to allow for exposure.
  - Once exposure is obtained the interposed periosteum can be removed by using a Freer elevator to carefully sweep this periosteum out of the physis.
  - Care should be taken to preserve the periosteum, as it provides blood flow to aid in fracture healing and can be intimately associated with the perichondral ring.
  - The periosteum, however, may be carefully incised and radially cut to obtain adequate reduction.
  - It is our experience in children that if necessary the periosteum can be sacrificed for anatomic reduction, as nonunion and infection are much less of a problem in this population than premature physeal closure.
  - The perichondral ring should be protected as much as possible.
  - At this point, under direct visualization, the reduction is achieved and manually held in place.
  - Once the periosteum is atraumatically removed from the fracture site and physis, the reduction should be obtained without much difficulty and should be relatively stable.
  - Many Salter type II fractures can be successfully stabilized with two 0.062-inch smooth Kirschner wires.
  - The wires are placed from distal to proximal, from the anteromedial malleolus and from the anterolateral corner of the tibial epiphysis (TECH FIG 2).
TECH FIG 2 • (continued) E,F. Open reduction was obtained after failed closed reduction due to interposed periosteum in the physeal fracture. Then the fracture was stabilized with two crossed Kirschner wires placed percutaneously. G,H. At 1 year postoperatively the distal tibial physis appears open. The red arrows mark the Harris growth line, which is parallel with the physis, demonstrating symmetric growth after injury. This further supports that the tibial physis is open.

- The entry point of the percutaneous pins must be placed distally enough through the skin to enter the bone at the appropriate starting point.
- On insertion, the Kirschner wires can be directly visualized through the open incision at their appropriate entry point into bone.
- Occasionally there may be large metaphyseal fragments that may be more appropriately stabilized with one or two lagged cancellous bone screws.
- These screws should be placed proximal to the physis and perpendicular to the fracture site.
- Cannulated screws can be used, based on the surgeon’s preference.

TILLAUX FRACTURES: SALTER-HARRIS TYPE III FRACTURES

- An anterolateral approach to the ankle is used.
- This fracture can be fixed by a distal-to-proximal, and anterior-to-posterior, compressive interfragmentary cancellous screw (TECH FIG 3).
- Again, cannulated screw fixation may be used if the surgeon prefers it to the use of noncannulated screws.
- Crossing the physis is not contraindicated in this fracture pattern because by definition the medial physis is closed and complete physeal closure is imminent.

TECH FIG 3 • Tillaux fracture treatment. A,B. Tillaux fractures are often not seen clearly on plain radiographic views, and it is important to obtain a mortise view to see the fracture fragment that is obstructed by the fibula in standard AP views. C,D. CT scans often aid in fracture characterization and operative planning. E,F. These fractures are fixed with compressive interfragmentary cancellous screws across the fracture site, without concern for transphyseal fixation as these patients are always close to skeletal maturity.
MEDIAL MALLEOLAR FRACTURES: SALTER-HARRIS TYPE III AND IV FRACTURES

- If there is only a small metaphyseal fragment, these fractures may be fixed with 4.0-mm cancellous bone screws or Kirschner wires completely within the epiphysis and parallel to the physis and joint (TECH FIG 4).
  - These fractures can be treated percutaneously if anatomic reduction can be attained by closed treatment; however, a small incision can easily allow direct visualization of the reduction.

- If a larger metaphyseal fragment is present, another metaphyseal screw can be placed parallel to the physis in addition to the epiphyseal screw.
- If the patient is skeletally immature and the fracture is not amenable to intraepiphyseal fixation, Kirschner wires may be placed across the fracture site and physis for stability of the fracture and later removed.
  - This method can also be used if there is a small avulsion fragment off the medial malleolus.
- If a larger metaphyseal fragment is present, another metaphyseal screw can be placed parallel to the physis in addition to the epiphyseal screw.
- If the patient is near skeletal maturity, these fractures can be treated as in adults with two partially threaded cannulated screws placed perpendicular to the fracture site.
  - Alternatively, in this population near maturity, compression across the fracture and apophysis can be obtained with two Kirschner wires compressed by means of a tension band wire loop.
- If the patient is near skeletal maturity, these fractures can be treated as in adults with two partially threaded cannulated screws placed perpendicular to the fracture site.
  - In certain cases it has been advocated to excise and discard the metaphyseal fragment to allow improved visualization of the physis and prevent bony bridging in this area. However, we do not advocate this form of treatment.
  - We do not advocate this approach as our goal is to ultimately restore anatomic alignment.
- If it is necessary to remove this bony fragment, we will subsequently replace it after anatomic alignment is restored and the physis is atraumatically cleared of any mechanical blockages.

![Image of medial malleolar fracture fixation with epiphyseal screw](image)

**TECH FIG 4** • Medial malleolar fracture fixation with an epiphyseal screw. If there is only a small metaphyseal fragment, medial malleolar fractures can be fixed with compressive screws placed within the epiphysis, parallel to the physis. Cannulated screws can be used to help ensure the physis is not compromised.

TRIPLANE FRACTURES: SALTER-HARRIS TYPE IV FRACTURES

- Triplane fractures are typically geometrically complicated fractures that, as mentioned above, are transitional fractures that involve the distal tibial physis at the time of its asymmetric closure during the early teenage years.
- Because these fractures are typically quite complex, we advocate CT scans with three-dimensional reconstruction for visualization and surgical planning (see Fig 2).

The surgical approach depends on the complexity of the fracture: these fractures can be two-, three-, or four-part fractures (TECH FIG 5A–C).
- Growth plate disturbance is not typically a problem owing to the proximity to skeletal maturity in these patients.
- Anatomic alignment of the articular fracture at the joint surface is important in the outcomes of these patients.

![Images of triplane fractures](image)

**TECH FIG 5** • Triplane fractures can be two-part (A), three-part (B), or four-part (C) fractures, but all involve an intra-articular epiphyseal component in addition to a metaphyseal component, making them Salter-Harris type IV fractures. (continued)
Alternative Techniques

- External fixation may be a useful tool in grossly contaminated fractures or fractures with significant soft tissue compromise, such as a lawnmower injury.
  - The goals of the external fixator are to maintain length and to ensure there is no pressure on the soft tissues from bone fragments, while the soft tissues recover.
  - External fixators can be used as temporizing devices or definitive treatment.

- There are no pediatric-specific rules for external fixator application other than to avoid physeal damage by crossing the growth plate.
  - Large, medium, or even small external fixator sets may need to be available depending on the size of the child.
  - Syndesmosis injuries generally occur in the pediatric population only at or near the time of skeletal maturity; thus, these injuries can generally be treated like adult injuries.
### Pearls and Pitfalls

#### Use of CT scans
- We advocate regularly obtaining postreduction CT scans to evaluate physeal gap as well as joint space congruity; many plain radiographs may be misleading in assessing how anatomic a reduction may be.

#### Superior extensor retinaculum syndrome
- Patients presenting with severe ankle pain and swelling, hypoesthesia or anesthesia in the first dorsal web space, weakness of the extensor hallucis longus and extensor digitorum communis, and pain on passive flexion of the great toe (FIG 4) should be evaluated for superior extensor retinaculum syndrome with pressure measurement and should likely have a release of their superior extensor retinaculum to prevent ischemic changes. Untreated, the natural history of this syndrome involves a residual sensory deficit in the first dorsal web space and contracture of the extensor hallucis longus and extensor digitorum brevis.1

#### Premature physeal closure
- To attempt to mitigate this complication we have developed an algorithm:
  - Nondisplaced fractures (less than 2 mm) are casted.
  - Displaced fractures undergo closed reduction under general anesthesia or conscious sedation, then casting for 3 to 6 weeks if displacement is successfully reduced to less than 2 mm.
  - If still displaced more than 4 mm, open reduction and internal fixation is undertaken.
  - If displacement is 2 to 4 mm with less than 2 years of growth remaining, casting is undertaken.
  - If the displacement is 2 to 4 mm and the patient has at least 2 years of growth left (girls under 12 years old and boys under 14), the surgeon’s preference of open reduction and internal fixation or casting is done.
- In addition to prereduction and postreduction ankle radiographs, to direct this algorithm we routinely obtain contralateral ankle radiographs and left-hand bone age films and, if there are any questions about fracture displacement, a postreduction CT scan.
- Additionally, we follow up with patients with growth plate fractures at regular intervals until skeletal maturity.

#### Abduction injuries versus SER-type injuries
- Abduction-type injuries carry a worse prognosis, leading to premature physeal arrest in spite of treatment (open reduction versus closed treatment), whereas the prognosis for SER injuries involving the growth plate can be greatly improved by anatomic reduction. These issues should be discussed with the family preoperatively.

#### Postoperative follow-up
- For follow-up after physeal injuries we routinely obtain baseline radiographs of the contralateral ankle, and an AP view of the left hand for establishing bone age. After initial fracture management follow-up is maintained at 6-month intervals and should include bilateral ankle radiographs.
- Alignment of both the child’s ankles should be assessed while weight bearing, as malalignment can be a sequela of premature physeal closure. If closure is noted, early physeal assessment with CT scans is necessary to prevent ankle deformity and leg-length discrepancy.

---

**FIG 4** • Superior retinaculum syndrome. A. Cross-sectional view of the superior retinaculum tunnel, which may require release with displaced physeal fractures. B. Patients presenting with severe ankle pain and tenderness, hypoesthesia or anesthesia in the first dorsal web space, weakness of the extensor hallucis longus and extensor digitorum communis, and pain on passive stretch of the great toe may require release of the superior extensor retinaculum. (A: Adapted from Mubarak SJ. Extensor retinaculum syndrome of the ankle after injury to the distal tibial physis. J Bone Joint Surg Br 2002;84B:11–14.)
POSTOPERATIVE CARE

- Treatment after surgical fixation generally consists of immobilization with a short-leg cast applied in the operating room, and the patient is kept non-weight bearing for 4 weeks.
- We univalve our fiberglass casts and place plastic spacers taped in with waterproof tape to accommodate for swelling, with the patient returning in 1 week for removal of spacers and cast overwrap and tightening with fiberglass (see Fig 3).
- Four weeks postoperatively the cast is changed to a weight-bearing cast and the child is allowed to be weight bearing as tolerated for 2 or 3 more weeks with a cast shoe.
- With percutaneous pin fixation we use 0.062-inch Kirschner wires left through the skin, which are removed at the 4-week cast change.
- Physical therapy is rarely needed for range of motion in the preadolescent population as daily activity with walking often suffices to restore function. Occasionally adolescents may benefit from physical therapy for range of motion and proprioceptive conditioning.
- We advocate follow-up for at least 1 year, at 3, 6, and 12 months, then every 6 months until skeletal maturity for children with physeal injuries to monitor for premature physeal closure.
- At these follow-up visits plain radiographs should include images of the affected ankle as well as AP and lateral views of the contralateral ankle.

OUTCOMES

- As in most children’s fractures, children with ankle fractures generally fare well.
- Data on long-term follow-up are sparse. However, data for intra-articular triplane fractures have shown the importance of anatomic alignment of less than 2 mm of displacement after treatment.
- Ertl and coworkers demonstrated with a follow-up of 18 to 36 months that “residual displacement of two millimeters or more after reduction was associated with a less than optimum result unless the epiphyseal fracture was outside the primary weight-bearing area of the ankle.”
- Rapariz and colleagues, with a mean follow-up of 5 years, found that “prognosis is surprisingly good” and that “only when adequate reduction (<2 mm displacement) has not been achieved can degenerative changes be seen at long-term follow-up (>5 years).”
- Rapariz and colleagues found good functional results ubiquitously, but as in the study by Ertl and associates, the follow-up was shorter than the time that likely could predict the long-term sequela of posttraumatic arthritis.
- Both these studies stressed the need to obtain CT scans to define and characterize the fracture and the degree of displacement, as well as advocating a trial of closed reduction to obtain adequate reduction.

COMPLICATIONS

- Premature physeal closure, as mentioned above, can lead to limb-length discrepancies and malalignment, which in younger children with continued growth potential can be symptomatic and may need to be addressed surgically.
- Reflex sympathetic dystrophy or complex regional pain syndrome is a chronic pain syndrome that can develop after these ankle injuries.
- It is characterized by pain out of proportion that persists beyond a typical recovery timeframe and may also entail swelling, skin color changes, and limited range of motion.
- Treatment can include medications, therapy, psychological counseling, and sympathetic nerve blocks; in extreme cases sympathectomy or implantation of a dorsal column stimulator has been proposed.
- Arthrosis is a normal sequela from joint injury or prolonged immobilization. Generally, in the pediatric population, interventions such as physical therapy or manipulation under anesthesia are not necessary.
- Superior extensor retinaculum syndrome, as described above, can lead to residual numbness in the great toe web space and persistent pain and weakness in the toe extensors.
- Acute compartment syndrome that is untreated can lead to permanent neuromuscular damage, including weakness or altered sensibilities.
- Malunion of fractures can occur with operative or nonoperative treatment or can be a secondary consequence of premature physeal closure.
- Osteochondral injury in ankle fractures can ultimately lead to symptomatic posttraumatic osteoarthritis, and studies have demonstrated that anatomic reduction is important to prevent this complication.
- If significant chondral injury does occur in the young patient population, drilling for focal posttraumatic osteochondritis dissecans lesions can be successful. In extreme cases with osteochondral damage, osteochondral allografting can be attempted.
- Complications with casts are inherent when they are used to treat fractures.
- These complications include cast ulceration from poorly fitted or padded casts. Casts applied too tightly or not appropriately split can lead to acute compartment syndrome. Removal of casts can lead to cast saw burns, which can permanently scar children’s skin.

REFERENCES

Elbow Arthroscopy for Panner’s Disease and Osteochondritis Dissecans

Theodore J. Ganley, Gilbert Chan, Aaron B. Heath, and J. Todd R. Lawrence

DEFINITION

Panner’s Disease

A term often used synonymously with osteochondritis dissecans (OCD) of the capitellum, Panner’s disease is a condition in which there is diminished blood supply to the developing ossific nucleus within the distal humerus chondral epiphysis in preadolescents. Those affected are typically 6 to 10 years old, and symptoms usually respond to a reduction of the offending repetitive microtrauma.

Osteochondritis Dissecans of the Capitellum

This term is used to describe the condition of compromised subchondral bone in the capitellum of adolescents, which can lead to secondary articular surface separation.

ANATOMY

The three articulations in the elbow are the ulnohumeral joint, the radiocapitellar joint, and the proximal radioulnar joint. The ulnohumeral joint is a hinge joint that allows for flexion and extension of the elbow, while the radiocapitellar and radioulnar joints are trochoid joints that allow for axial rotation and pivoting of the elbow. The capitellum articulates with the rim of the radial head throughout flexion–extension and pronation–supination. Secondary ossification centers are involved in the formation of the distal humerus, proximal radius, and ulna. The ossification center of the capitellum appears at 18 months and completely fuses by age 14. Descending extraosseous branches of the brachial artery supply the capitellum. Chondral vessels supply the osseous nucleus, which in turn supplies the chondroepiphysis.

PATHOGENESIS

It is theorized that both Panner’s disease and OCD of the capitellum result from abnormal valgus forces exerted across the radiocapitellar joint. The result of this abnormal stress on the radiocapitellar joint may depend on the age of the patient, with those exposed to the stress at a younger age (6 to 10 years) developing Panner’s disease and those exposed to the stress at a later age (10 to 17 years) developing OCD of the capitellum. The development of the lesions also depends on the limited blood supply of the capitellum, which allows for limited repair potential.

NATURAL HISTORY

With activity restriction, reossification and resolution of symptoms typically occur in Panner’s disease. The natural history of OCD is articular surface separation for patients who do restrict their activities. Even with activity modification and brief periods of immobilization, elbow OCD lesions will progress in most patients treated nonoperatively. Initially, radiographs show irregularity and fragmentation of the capitellum. Erosion, lysis, and sclerosis may be observed in later stages.

PATIENT HISTORY AND PHYSICAL FINDINGS

Early stages Patients have full motion but complain of vague aching discomfort during throwing and load-bearing activities as well as swelling at the lateral elbow. They typically have full range of motion.

Later stages: Patients complain of mechanical symptoms, including locking and catching and limited flexion and extension; palpable synovial thickening and an effusion may also be found.

IMAGING AND OTHER DIAGNOSTIC STUDIES

High-quality, standard anteroposterior (AP) and lateral radiographs of the elbow are needed to evaluate both conditions. In Panner’s disease the size of the ossific nucleus and the degree of radiolucency can be determined from the radiographs. In OCD lesions, subchondral lysis or cystic changes may be seen on radiographs (FIG 1A). MRI findings in OCD may reveal bone edema, synovitis, and loose bodies, as well as subchondral and cartilage separation (FIG 1B).

DIFFERENTIAL DIAGNOSIS

Familial OCD

Hemophilia and variants

Multiple epiphyseal dysplasia

Autoimmune vasculitis

Steroid-induced avascular necrosis

NONOPERATIVE MANAGEMENT

Treatment for Panner’s disease consists of:

- Sling for several weeks
- Cessation of all offending activity
- Range-of-motion exercises

Nonoperative treatment of OCD is reserved for cases in which the cartilage is intact. Nonoperative treatment consists of:

- Rest until symptoms resolve
Range-of-motion exercises
Follow-up radiographs through resorption and reconstitution phases prior to resumption of sport-specific exercises.

SURGICAL MANAGEMENT
- Surgical management is largely dependent on the character of the lytic lesion and the presence or absence of symptoms.
- Cartilage intact but persistent pain and swelling
  - Arthroscopic evaluation, search for loose bodies
  - Consider drilling of lesion to stimulate subchondral bone healing.

Preoperative Planning
- All imaging studies obtained before surgery should be reviewed. An MRI may be helpful to determine the extent of the lesion and the location and size of chondral or small osteochondral loose bodies in the joint.

ARTHROSCOPIC TREATMENT
- A thorough physical examination should be performed under anesthesia to note range of motion and appropriate or pathologic degrees of laxity.

Positioning
- The patient is adequately padded and placed in the lateral decubitus position.
- The involved elbow is placed over a padded bump that places the elbow in 90 degrees of flexion.
- The extremity is then properly prepared and draped in a standard manner.
- The landmarks over the elbow are marked with a marking pen (FIG 2).

Approach
- Arthroscopy-assisted mini-arthrotomy (Children’s Hospital of Philadelphia approach) is used for large to massive loose bodies and osteochondral defects.
- After the patient is positioned, prepared, and properly draped and the anatomic landmarks are identified, a 3- to 5-cm incision is carried over the capitellum. If during the course of arthroscopy a larger incision is required, then the superior and inferior arthroscopy portals can be incorporated into an incision of 1.5 cm. Deep dissection can be in the plane of the anconeus–extensor carpi ulnaris approach.
- The incision is carried down to the fascia, and the plane between the anconeus and the extensor carpi ulnaris is identified and entered.
- The joint capsule is incised to allow adequate visualization of the lesion.
- A 30-degree arthroscope is then inserted and used to view the joint surface (TECH FIG 3B). The arthroscope is placed on the outer border of the radiocapitellar joint and angled to allow a complete view of the capitellum and radiocapitellar interval.

Preoperative Planning
- All imaging studies obtained before surgery should be reviewed. An MRI may be helpful to determine the extent of the lesion and the location and size of chondral or small osteochondral loose bodies in the joint.

ARTHROSCOPIC TREATMENT
- The patient is positioned, prepared, and draped in a lateral decubitus position as previously described.
- After the landmarks in the elbow are drawn with a marking pen and the tourniquet is inflated, 15 to 25 mL of sterile saline is injected into the joint, depending on the size of the patient.
- A smaller set of instruments (2.9 mm) is used (TECH FIG 1A).
- The arthroscopic portals are identified (TECH FIG 1B).

Preoperative Planning
- All imaging studies obtained before surgery should be reviewed. An MRI may be helpful to determine the extent of the lesion and the location and size of chondral or small osteochondral loose bodies in the joint.

ARTHROSCOPIC TREATMENT
- The patient is positioned, prepared, and draped in a lateral decubitus position as previously described.
- After the landmarks in the elbow are drawn with a marking pen and the tourniquet is inflated, 15 to 25 mL of sterile saline is injected into the joint, depending on the size of the patient.
- A smaller set of instruments (2.9 mm) is used (TECH FIG 1A).
- The arthroscopic portals are identified (TECH FIG 1B).

Positioning
- The patient is adequately padded and placed in the lateral decubitus position.
- The involved elbow is placed over a padded bump that places the elbow in 90 degrees of flexion.
- The extremity is then properly prepared and draped in a standard manner.
- The landmarks over the elbow are marked with a marking pen (FIG 2).

Approach
- Arthroscopy-assisted mini-arthrotomy (Children’s Hospital of Philadelphia approach) is used for large to massive loose bodies and osteochondral defects.
- After the patient is positioned, prepared, and properly draped and the anatomic landmarks are identified, a 3- to 5-cm incision is carried over the capitellum. If during the course of arthroscopy a larger incision is required, then the superior and inferior arthroscopy portals can be incorporated into an incision of 1.5 cm. Deep dissection can be in the plane of the anconeus–extensor carpi ulnaris approach.
- The incision is carried down to the fascia, and the plane between the anconeus and the extensor carpi ulnaris is identified and entered.
- The joint capsule is incised to allow adequate visualization of the lesion.
- A 30-degree arthroscope is then inserted and used to view the joint surface (TECH FIG 3B). The arthroscope is placed on the outer border of the radiocapitellar joint and angled to allow a complete view of the capitellum and radiocapitellar interval.
Definitive management depends on the intraoperative findings.

**Cartilage Intact**
- Drilling of the lesion is performed to stimulate healing.
- A 0.62 or 0.45 Kirschner wire is used to drill into the subchondral bone. Drilling is performed as perpendicular to the capitellum as possible, in a distal-to-proximal direction. The Kirschner wire may be placed through the inferior portal or via an inferior percutaneous approach.

**Cartilage Fractured**
- After thorough inspection of the joint is performed, any loose bodies found within the joint are removed (TECH FIG 2A,B).
- After satisfactory bleeding is obtained, final inspection of the area is performed and the arthroscope is removed and the wounds are closed using no. 4-0 Monocryl subcuticular sutures, followed by Steri-Strips.
- A sterile dressing and a posterior splint are applied.

**Techniques**

**TECH FIG 1**
- A. A smaller set of instrumentation is used.
- B. The arthroscopic portals are identified.
- C,D. The arthroscope is placed through the lateral portal, and a needle can be used as both an outflow portal (arrow in C) and as an instrument to secure loose bodies to prevent them from migrating (arrow in D).
- E. The osteochondral defect of the capitellum (above) is identified along with the radial head (below).

**TECH FIG 2**
- A,B. Loose bodies within the joint are identified and removed.
- C-E. Débridement of the defect is performed until a stable chondral rim is noted.
- F,G. Drilling is performed with a 0.62 Kirschner wire. At times it is helpful to place the wire percutaneously and flex the elbow to ensure that it is always placed perpendicular to the surface of the capitellum. Care is taken to use a posterior starting point to avoid the posterior interosseous nerve.
The defect is identified and curettage of the defect is performed to remove all granulation tissue and to ensure that a stable rim of cartilage exists circumferentially (TECH FIG 2C–E).

The underlying sclerotic bone is exposed.

Drilling of the lesion is performed using a 0.62 or 0.45 Kirschner wire. Drilling is performed as perpendicular to the capitellum as possible, in a distal-to-proximal direction (TECH FIG 2F,G).

Final inspection of the area is performed and the arthroscope is removed and the wounds are closed using no. 4-0 Monocryl subcuticular sutures, followed by Steri-Strips.

A sterile dressing and a posterior splint are applied.

**TECH FIG 3** • A. For massive lesions and loose bodies, a mini-arthrotomy can be performed through the plane of the anconeus and extensor carpi ulnaris. B,C. A 30-degree arthroscope is inserted and the lesion is identified. When a mini-arthrotomy is performed, the arthroscope can be used like a dental mirror to enhance visualization and minimize the need for extensive open dissection. D. Arthroscopic image of the elbow demonstrating an uncontained lesion treated with multiple osteochondral grafts.

**ARTHROSCOPIC-ASSISTED MINI-ARTHROTOMY**

- The patient is properly positioned, prepared, and draped as previously described.
- The mini-arthrotomy approach is carried through the plane of the anconeus and extensor carpi ulnaris. The capsule is incised to access the lesion (TECH FIG 3A).7
- A 30-degree arthroscope is inserted through the arthrotomy site to view and assess the entire lesion (TECH FIG 3B,C).
- The arthroscope can be used to assess the portions of the capitellum not clearly visualized through the arthrotomy site, much like a dental mirror.
- Once the entire lesion is visualized and assessed, removal of any loose bodies is performed with débridement and drilling of the lesion with Kirschner wires as described in the arthroscopic technique. For massive or uncontained lesions, osteochondral grafting can be performed (TECH FIG 3D).
- Final inspection of the area is performed and the arthroscope is removed.
- The capsule is repaired. A layer-by-layer closure is then performed (TECH FIG 3D).
- A sterile dressing is applied and a posterior splint are applied.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Surgical technique</th>
<th>• When performing the mini-arthrotomy, posterior dissection of the capitellum is avoided to prevent devascularizing the capitellum.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling of the lesion</td>
<td>• When drilling the lesion, the Kirschner wires should be maintained as perpendicular to the capitellum as possible. They may be inserted through the inferior portal or through a separate inferior percutaneous portal. Care should be taken to avoid neurovascular injury.</td>
</tr>
<tr>
<td>Arthroscopic technique</td>
<td>• The bony landmarks and the location of the ulnar nerve are drawn carefully before the procedure to avoid inadvertent neurovascular injury. Draping the hand free also allows for more flexibility in the procedure.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- For full-thickness defects, immediate continuous passive motion and physical therapy are started for 6 weeks.
- After 6 weeks, a gradual return to activity is instituted. Strengthening and range of motion are still the main goals of therapy. Axial loading, impact loading, and throwing are prohibited for up to 6 months.

OUTCOMES

- Panner’s disease
  - Full recovery is expected in 12 to 18 months, but long-term noncompliance can result in lesion progression.
- OCD of the capitellum
  - Ruch and coworkers\(^8\) reported on 12 patients treated for OCD of the capitellum by arthroscopic débridement; 11 of them were highly satisfied. The average age was 14.5 years and the average follow-up was 3.2 years. Clinical presentation showed a contracture improvement from 23 degrees to 10 degrees.
  - Byrd and Jones\(^2\) reported on 10 baseball players treated for OCD of the capitellum by arthroscopic débridement; 4 of them were able to resume playing competitively. The average age was 14.5 years and the average follow-up was 3.9 years. However, in this study the outcomes were poorly correlated with the lesion grade.
  - Baumgarten and associates\(^1\) reported on 14 young athletes (gymnastics or throwing sports) whose OCD of the capitellum was treated by arthroscopic débridement. Three were forced to give up their sport. The average age was 13.8 years and the average follow-up was 4 years. In this review contracture was noted to improve by 14 degrees.

COMPLICATIONS

- Angular deformity
- Avascular necrosis of the capitellum
- Detachment and capitellum overgrowth
- Early arthritis

REFERENCES

DEFINITION
- Patellar instability in children and adolescents usually involves an episode of complete dislocation of the patella from the trochlear groove. Occasionally there can be episodes of patella subluxation without gross dislocation.
- There are two types of patella dislocation:
  - Acute traumatic patella dislocation
  - Atraumatic dislocations or subluxation secondary to ligamentous laxity
- First-time patella dislocations tend to occur most commonly in adolescent high-level athletes.\(^2\)
- Pain is often associated with episodes of dislocation, but chronic patellofemoral pain is not usually the primary complaint.
- The incidence of primary patella dislocation in 10- to 17-year-olds is reported at 29 and 43 per 100,000.\(^6\)

ANATOMY
- Traumatic dislocation of the patella occurs almost exclusively in the lateral direction and often results in a tear of the medial patellofemoral ligament (MPFL) off the femur or the patella or in its midsubstance (FIG 1A).
- The MPFL provides 50% to 80% of the restraining force to lateral patella displacement.\(^8\)
  - It is a flat band adjacent to the medial retinaculum that courses between the medial epicondyle of the femur and the medial patella.
  - It inserts into the superior two thirds of the patella on its medial aspect.
- Specifically, the MPFL attaches into the femur just distal to the adductor tubercle and just superoposterior to the medial epicondyle (FIG 1B).\(^12\)
- In a skeletally immature patient, the MPFL appears to attach to the femur between the growth plate and the medial epicondyle.
- Traumatic dislocation can cause a serious fracture of the medial patella facet (FIG 1C) or the lateral femoral condyle (FIG 1D) and can be cartilaginous or osteocartilaginous.
  - Stanitski found a 71% incidence of osteochondral injury at arthroscopy after patella dislocation, most of which was radiographically occult.\(^16\)
  - More frequently there is a less serious nonarticular avulsion fracture of the MPFL off the medial patella.
  - There can be an immediate or delayed appearance of an osseous lesion at the avulsion site off the medial patella (FIG 1E).
  - A shallow trochlea groove, patella alta, patellar tilt, and a lateralized tibial tubercle can increase the risk of dislocation,\(^5\) along with a hypoplastic tibial tubercle and valgus knee alignment.

PATHOGENESIS
- Noncontact patellar dislocation during sports usually involves lower extremity internal rotation combined with knee valgus on a planted foot (a mechanism very similar to anterior cruciate ligament injury).
- Less commonly, patella dislocation is caused by a direct blow that pushes the kneecap laterally.
- Most episodes of traumatic patella dislocation spontaneously reduce in the field.
- The common finding of a lateral femoral condyle bone bruise at the sulcus terminalis suggests that dislocation usually occurs at 70 to 80 degrees of flexion.\textsuperscript{14}
- Multiple anatomic factors are theorized to increase the risk of patella dislocation, such as family history, increased Q angle, femoral intorsion, tibial extorsion, knee valgus, trochlear groove dysplasia, and foot pronation. Only patella alta is a proven risk factor.\textsuperscript{3}

**NATURAL HISTORY**
- After a primary patellar dislocation, there is only a 17% risk of recurrence. The risk of recurrence jumps to 49% if there is a history of prior patellar dislocation or subluxation.
- Young age was also associated with recurrence, as was a positive family history.\textsuperscript{6}
- At 6 months after patellar dislocation, only 69% of patients had returned to sports.\textsuperscript{7}
- At 2 to 5 years of follow-up after patellar dislocation, Fithian and coworkers\textsuperscript{9} showed no radiographic or scintigraphic evidence of degenerative joint disease.
- At 6 to 26 years of follow-up after nonoperative treatment for patellar dislocation, 22% of knees showed arthritic changes compared to 11% of each patient’s opposite uninjured knee.\textsuperscript{9}
- At least 30% to 50% of patients with patella dislocation will have knee pain more than 2 years after injury;\textsuperscript{7} and 69% of athletes will decrease their sports activity.
- Young age and skeletal immaturity, especially in females, is associated with worse prognosis.\textsuperscript{11}
- Overall, the natural history is not improved with the routine operative stabilization of primary dislocations.\textsuperscript{2,4,11}

**PATIENT HISTORY AND PHYSICAL FINDINGS**
- Most episodes of patellar dislocation spontaneously reduce in the field.
- Patients with an acute traumatic patella dislocation often present to the emergency room with a history of a noncontact or contact injury to their knee, and many do not recognize the injury as a patellar dislocation.
- An effusion is usually present after traumatic dislocation but is rarely present after atraumatic dislocations. If the patella is still dislocated, the emergency physician usually performs a reduction by slowly extending the knee from its flexed position.
- Patella dislocation that spontaneously reduces in the field may mimic the history and presentation of an anterior cruciate ligament tear.
- The patella apprehension sign is the best test for patellar instability. With the knee flexed over a bolster at 25 degrees, the patella is translated laterally. If the patient exhibits apprehension, the test is positive.
- Patella glide test: With knee flexed 25 to 30 degrees, the patella is gently translated laterally. Lateral translation of more than two quadrants of the patella may indicate instability.
- Testing for the J sign (patella pulls laterally as knee reaches full extension, in the path of an upside-down J) can identify proximal alignment issues.

**DIFFERENTIAL DIAGNOSIS**
- Knee radiographs should include the anteroposterior (AP), lateral, and sunrise (or Merchant) views.
- The sunrise or Merchant view requires a patient to flex the knee 30 to 45 degrees, which may be impossible owing to pain at the initial time of presentation in the emergency department. The sunrise view can usually be obtained at the first follow-up visit.
- Plain radiographs can miss 40% of arthroscopically documented chondral or osteochondral lesions. Many reparable osteochondral injuries show only a sliver of bone on one view in the plain radiographic series, which can be easily overlooked (FIG 2A).
- Because of the high rate of occult articular or osteoarticular injury, we recommend an MRI scan on patients who present with a large traumatic effusion.
- The site of MPFL ligament disruption can often be identified on MRI. MRI is reported to be 85% sensitive and 70% accurate (FIG 2B).\textsuperscript{15}
- Patellar dislocation produces a signature bone contusion pattern in which the medial patella and the midportion of the lateral femoral condyle show increased signal (FIG 2C). This bone bruise pattern is distinct from that associated with anterior cruciate ligament tears.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Anterior cruciate, medial collateral, lateral collateral, or posterior cruciate ligament tear
- Meniscal tear
- Patellofemoral pain syndrome
- Knee contusion
- Osteoarticular fracture

**NONOPERATIVE MANAGEMENT**
- Initial management of traumatic patellar dislocation after reduction is with a knee immobilizer, analgesia with oral narcotics, and crutch walking (weight bearing as tolerated).
- The risk of redislocation is three times higher in patients treated with immediate mobilization versus immobilization with cast or brace.\textsuperscript{10} The authors use a knee immobilizer for 4 weeks.
- Initial nonoperative management of acute patellar instability in children begins with the management of any residual acute symptoms, such as pain and swelling.
Small metallic or bioabsorbable screws or pins should be available for osteochondral fracture repair.

- MRI can locate the site of MPFL failure with 70% accuracy to help target the site of repair (patella versus femoral side of ligament).
- Examination under anesthesia involves testing lateral patella tracking and checking overall knee stability.

**SURGICAL MANAGEMENT**

- Operative treatment is indicated for first-time patellar dislocation that fails to reduce concentrically, or that involves osteochondral damage necessitating repair or removal of a loose body.
- Osteochondral lesions larger than 1 cm in diameter should be repaired if any bone is attached to the chondral fragment. Fixation devices should be countersunk 1 to 2 mm beneath the cartilage surface.
- The MPFL can be repaired at the time of surgery for osteochondral lesions in acute dislocations, but the recurrence rate is higher with repair versus reconstruction.
- Reconstruction (versus repair) is indicated for recurrent instability, or in patients who are noted to have an attenuated MPFL at the time of surgery.
- MPFL reconstruction is not indicated for malalignment, patellofemoral pain, or arthrosis.
- Lateral release is rarely necessary with repair or reconstruction of the MPFL.
- Recurrent traumatic dislocations and recurrent traumatic dislocations that fail bracing and physical therapy can benefit from surgical patella realignment.
- Tibial tubercle realignment procedures should be avoided in skeletally immature patients with open growth plates because of the risk of creating iatrogenic genu recurvatum from growth arrest.

**Preoperative Planning**

- MRI scans should be reviewed to determine the size and location of osteochondral fractures and their potential for repair versus removal.

- Small metallic or bioabsorbable screws or pins should be available for osteochondral fracture repair.
- MRI can locate the site of MPFL failure with 70% accuracy to help target the site of repair (patella versus femoral side of ligament).
- Examination under anesthesia involves testing lateral patella tracking and checking overall knee stability.

**Positioning**

- The patient is positioned supine on a table that will allow knee imaging (FIG 3).
- An intravenous bag is taped to the table to allow blocking the knee at about 30 to 60 degrees flexion during patella repair and reconstruction tensioning.

**Approach**

- The surgeon uses an approach through the anterior knee midline or a medial parapatellar approach. If needed, the hamstrings semitendinosus graft is harvested through a standard proximal medial tibial approach with a tendon stripper.

**Preoperative Planning**

- MRI scans should be reviewed to determine the size and location of osteochondral fractures and their potential for repair versus removal.

- Small metallic or bioabsorbable screws or pins should be available for osteochondral fracture repair.
- MRI can locate the site of MPFL failure with 70% accuracy to help target the site of repair (patella versus femoral side of ligament).
- Examination under anesthesia involves testing lateral patella tracking and checking overall knee stability.

**Positioning**

- The patient is positioned supine on a table that will allow knee imaging (FIG 3).
- An intravenous bag is taped to the table to allow blocking the knee at about 30 to 60 degrees flexion during patella repair and reconstruction tensioning.

**Approach**

- The surgeon uses an approach through the anterior knee midline or a medial parapatellar approach. If needed, the hamstrings semitendinosus graft is harvested through a standard proximal medial tibial approach with a tendon stripper.
MEDIAL PATELLOFEMORAL LIGAMENT REPAIR

- A 3- to 5-cm longitudinal incision is made centered over the medial border of the patella.
- Sharp dissection is carried to the bony surface of the patella with a subperiosteal incision down to bone in a vertical line about 1.5 cm lateral to the medial patellar border (TECH FIG 1A).
- The periosteum and all overlying soft tissues are collectively elevated off the medial 1 to 1.5 cm of the patella and a tissue plane is developed in the fatty plane between the retinaculum and synovial joint capsule using Metzenbaum or curved tenotomy scissors.
  - This soft tissue tunnel is expanded down toward the medial epicondyle of the femur.
  - It is not necessary to enter the joint space, and this should be avoided.
- A finger is placed in the tunnel that lies just outside the synovium of the knee joint but is deep to the MPFL.
- The MPFL can be digitally palpated on its inner surface down to the medial epicondyle to determine its suitability for repair versus reconstruction.
  - It should feel like a stout band of tissue originating from the medial epicondyle when traction is applied on its patellar end with a Kocher clamp (TECH FIG 1B).
- A rongeur or burr is used for superficial decortication of the exposed anterior medial patella, thus creating a bed for healing of the advanced MPFL.
- Multiple extra-articular drill holes (three or four) are placed in the patella to create transosseous suture tunnels for imbrication.
- Suture anchors can be used as an alternative for fixation to the patella (TECH FIG 1C).
- No. 2 or stronger nonabsorbable sutures are placed through the patella tunnels and woven through the advanced MPFL.
  - The MPFL should be sutured to the anteromedial surface of the patella, not the posteromedial surface (TECH FIG 1D).
  - The tension should be set with the knee at 45 to 60 degrees of flexion to prevent overcorrection or undercorrection.
- The remaining free lateral edge of the MPFL tissue is sewn down to the patellar soft tissue with a running 2-0 suture.
  - The knee should be placed through a range of motion to assess the repair’s ability to prevent dislocation and maltracking in all degrees of knee flexion and extension.
  - The wounds are irrigated and the skin is closed.

MEDIAL PATELLOFEMORAL LIGAMENT RECONSTRUCTION

- A 3- to 5-cm medial patellar longitudinal skin incision is carried down to the medial patella and the initial dissection is similar to the above MPFL repair.
- A thick periosteal flap is elevated off the medial 1 to 1.5 cm of the patella and carried down to the medial fibrofatty layer just outside the knee synovium.
- An extrasynovial tunnel is created deep to the MPFL and medial retinaculum. From inside out, the MPFL is palpated to determine its suitability for repair or the necessity for reconstruction. The MPFL should feel like a stout band originating off the medial epicondyle.
- The semitendinosus tendon (single tendon) is harvested using standard technique with a tendon stripper, and no. 2 Ethibond suture is placed in each end of tendon with a Krackow type of locking stitch (TECH FIG 2A).
  - The doubled tendon is sized usually to 5 to 6 mm in diameter.
- A 2-cm incision is made over the medial epicondyle and an anterior cruciate ligament guide pin is placed just anterior and proximal to the medial epicondyle.
  - Because the medial epicondyle is difficult to palpate, the guide pin’s location should be verified with AP and lateral fluoroscopy.
  - In skeletally immature children, the guide pin should be 4 to 5 mm distal to the growth plate.
- A 4-mm transosseous tunnel is drilled in the medial patella just superior to the equator.
- An umbilical tape is passed through the patella tunnel and under the medial retinaculum and around the guide pin to test isometry. The tape is tightened at 30 to 60 degrees of flexion.
A soft tissue interference screw matched to the tunnel size (same size) is then placed to lock the folded double end of the hamstring graft securely in the tunnel (TECH FIG 2B, C).

- If the patella tracks medially in flexion, the pin is moved distal; if the patella tracks medial in extension, the pin is moved slightly proximally. If the pin is too anterior, the tape will tighten in terminal extension and flexion. If the pin is too posterior, the tape will loosen in terminal extension and flexion.
- The Beath needle guide pin is advanced across the distal femur condyle until it comes out the lateral skin, avoiding the patellofemoral joint anteriorly and the common peroneal nerve posteriorly. A 5 × 25-mm tunnel is drilled over the guide pin.
- The tendon is folded in half and looped over a no. 5 nonabsorbable suture. The no. 5 suture ends are placed into the eyelet of the Beath needle.
- The folded end of the tendon is drawn into the tunnel as the guidewire and no. 5 suture are advanced across the knee condyles to exit laterally.

A soft tissue interference screw is placed in the femoral bone tunnel to lock the hamstring graft into the tunnel after the looped graft is pulled into the tunnel when the guide pin is advanced across the femur.

- The two free ends of the graft are routed under the medial retinaculum up toward the patella.
- One end of the tendon is passed through the patella tunnel and then sewn to the other end of the tendon with the knee flexed to about 45 degrees while the patella is held firmly in the trochlear groove.
- Patella tracking and stability are tested through a full range of motion.
- Standard closure is performed and a knee immobilizer is placed.

**GALEAZZI PROCEDURE (SEMITENDINOSUS TENODESIS)**

- The semitendinosus tendon (posterior and distal to the gracilis) is harvested with an open tendon stripper and the distal tendon is left attached to the proximal tibia.
- The free end of the tendon is secured with a Krakow type of locking stitch of no. 2 nonabsorbable suture.
- Through a midline incision, the patella is exposed to allow an oblique 4- to 5-mm drill hole placed from proximal lateral to distal medial in the coronal plane of the patella.
- A lateral release is performed about 1 cm lateral to the patella, extending from the proximal tibia to 1 cm above the proximal patella.
- The free end of the semitendinosus is passed retrograde up through the oblique tunnel and the free end is folded back across the anterior surface of the patella periosteum and sutured to the anterior patella, or sewn back to itself if its length permits (TECH FIG 3).
- The graft should be tensioned and fixed with the knee at 45 to 60 degrees flexion.
- A knee immobilizer is placed, and the patient may bear weight as tolerated. Early motion is encouraged.

**TECH FIG 2 • A.** Harvest of semitendinosus, showing the fibrous band diverging posteromedially toward the gastrocnemius. These bands must be cut before passing a tendon stripper. **B,C.** A soft tissue interference screw is placed in the femoral bone tunnel to lock the hamstring graft into the tunnel after the looped graft is pulled into the tunnel when the guide pin is advanced across the femur.

**TECH FIG 3 •** Galeazzi procedure. Semitendinosus is harvested and left attached distally. The free end of the graft is fixed into the oblique patellar tunnel.
### Pearls and Pitfalls

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pitfalls</th>
</tr>
</thead>
</table>
| **MPFL repair** |  - Works best for acute traumatic dislocation in which the MPFL has avulsed off the medial patella, or off the adductor tubercle. Repair has a higher recurrence rate than reconstruction. The surgeon must test to make sure the MPFL is sturdy for repair. If it is attenuated, MPFL reconstruction should be used.  
  - Sutures should be tensioned with the knee in 30 to 60 degrees flexion and the patella well seated in the trochlear groove to avoid maltracking.  
  - The MPFL is secured to the anteromedial patella, not the posteromedial patella.  
  - The surgeon should avoid repair into a medial patella osteochondral fracture fragment; the fragment should be excised first.  
  - Suture anchors make repair much easier than multiple suture tunnels. |
| **MPFL reconstruction** |  - The isometry of the guidewire should be checked to avoid patellar maltracking before drilling the medial epicondyle tunnel.  
  - The tendon is passed through the patellar tunnel with a Hewson suture passer or a folded no. 22 steel wire.  
  - The interference screw is placed beside the doubled tendon in the epicondyle tunnel, not between the two limbs, to avoid wrapping up the tendon. |
| **Galeazzi procedure** |  - The hamstring tendon is passed retrograde through the patellar tunnel using a Huysten suture passer or a guide pin with an eyelet.  
  - The transferred hamstring tendon is tensioned with the knee flexed 30 to 60 degrees. |
| **Roux-Goldthwaite procedure** |  - The surgeon should avoid overtensioning the transferred lateral half of the patella tendon to keep adequate tension on the untransferred half. |
POSTOPERATIVE CARE

- MPFL repair and reconstruction patients are placed in a knee immobilizer and are weight bearing as tolerated. Full range of motion starts 1 to 2 weeks postoperatively, and patients are advanced to physiotherapy at 6 weeks postoperatively.
- Galeazzi procedure patients have similar rehabilitation due to solid fixation if the tendon is sewn to itself.
- Roux-Goldthwaite procedure patients are kept toe-touch weight bearing for 6 weeks postoperatively owing to the less secure fixation of the transferred tendon into medial proximal tibia soft tissue.

OUTCOMES

- MPFL reconstruction appears to be more reliable at preventing redislocation than other soft tissue procedures.
- Nomura and associates\textsuperscript{13} reported that only 2 of 22 patients had a repeat subluxation or dislocation episode after MPFL reconstruction, with an average follow-up of 11.9 years.
- Thaunat and Erasmus\textsuperscript{17} found that 3 of 148 MPFL reconstructions redislocated with an anatomically placed double loop of autogenous gracilis tendon. All failures were related to repeat trauma occurring at least 4 years from the index surgery.
- Andrish\textsuperscript{1} suggested that failed MPFL reconstructions associated with trochlear or patellar dysplasia often necessitate a trochleoplasty, tibial tubercle transfer, or both.

COMPLICATIONS

- Recurrence is seen in less than 10\% of patients after MPFL reconstruction.
- Patellofemoral pain is often unchanged from the preoperative condition.
  - Patients with severe patellofemoral arthrosis and patellofemoral pain syndrome may not benefit from these procedures.
  - Skeletally mature patients may benefit from a procedure that moves the tibial tubercle more anterior (Fulkerson osteotomy).
- Overtightening of medial soft tissue can result in medial dislocation. This is especially possible if a medial repair is tensioned in full extension or is combined with an extensive lateral release.
- Care must be taken to avoid patella articular cartilage penetration when drilling patella holes, especially with the Galeazzi procedure.
- With the Roux-Goldthwaite procedure, there are reports of patellar tendon rupture of the untransferred tendon.

REFERENCES

DEFINITION
- Instability of the patellofemoral joint is a significant cause of pain and dysfunction in children and young adults.
- Instability or dislocations may occur in either ligamentously lax individuals or in athletic non-lax individuals.
- Instability or dislocation patients without generalized ligamentous laxity are more likely to sustain an injury to the ligament and to structures about the knee.
- Injuries sustained to the medial aspect of the patellofemoral joint may lead to ligament disruption of the patellofemoral ligament with or without stretching or tearing of the medial retinaculum. This may lead to persistent pain or recurrent instability of the patellofemoral joint.
- The key to treatment is the persistent complaint of instability feelings and examination consistent with instability with or without pain.
- Care must be taken to avoid realignment surgery for pain only.

ANATOMY
- The medial restraints of the patellofemoral joint are made up predominantly of the medial retinaculum and the medial patellofemoral ligament. Forty to 60% of the resistance to lateral translation is supplied by the medial patellofemoral ligament.\(^3\)
- The medial patellofemoral ligament is about 15 mm wide. It extends from the medial aspect of the patella, about 10 to 15 mm distal to the superior pole of the patella, near the widest portion of the patella, to the medial epicondylar area just above the origin of the medial collateral ligament.
- This area can also be located distal to the vastus medialis obliquus (VMO) insertion into the quadriceps tendon and anterior to the medial intermuscular septum.
- The lateral retinaculum may also be tight, characterized by less than 12 mm of medial translation.\(^2\)
- The bony anatomy and alignment of the lower extremities must also be considered. The quadriceps angle may be greater than average, increasing the lateral translational force.
- So-called miserable malalignment syndrome may exist, including excessive femoral anteverision with or without increased external tibial torsion.\(^1,2\)

PATHOGENESIS
- The onset of patellofemoral instability or dislocation can be either traumatic or atraumatic. In young athletes, it can occur during a valgus twisting maneuver such as swinging a baseball bat while twisting out of the way of a pitch. It may also occur with a direct blow on the valgus bent knee.
- Like an anterior cruciate ligament injury, it is common to hear or feel a “pop.” If the patella completely dislocates, the athlete may be found to have a deformity of the knee and may be unable to actively extend the knee.
- It may be associated with significant swelling or little swelling. It is commonly difficult to distinguish between a medial collateral ligament tear, a meniscal tear, or an acute patellofemoral subluxation or dislocation.
- The bony anatomy of the patellofemoral joint may also be abnormal with a deficient lateral femoral slope of the trochlear groove, leading to decreased force needed to laterally translate or dislocate the patella.

NATURAL HISTORY
- Patients with an atraumatic presentation of instability or dislocation of the patellofemoral joint have a higher likelihood of repeat instability episodes despite aggressive physical therapy and bracing.\(^1,2\)
- Patients with a traumatic-onset presentation may have a fracture or loose body created by the subluxation or dislocation. If a loose body exists, as in other conditions, surgical intervention is warranted.
- There is controversy over whether to acutely operate on first-time dislocators who are young athletes without generalized ligamentous laxity.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The clinician must evaluate potential associated or confounding injuries and consider the differential diagnosis, which should include (but not be limited to) meniscal tears, which are characterized by joint-line tenderness, painful popping with provocative maneuvers (full squat, McMurray, or Apley compression test), and with or without loss of full extension.
- A thorough examination will include the following:
  - Examination for effusion
  - Patellar stability testing. Instability of 25% to 50% indicates increased laxity but a still-competent retinaculum and medial patellofemoral ligament. Instability of more than 50% indicates insufficiency of both structures.
  - Femoral rotation: Average rotation is external rotation greater than or equal to internal motion.
  - Tibial alignment: Average axis is 10 to 15 degrees of external tibial torsion.
  - The clinician should observe and palpate the patella for lateral subluxation (J sign) during active range of motion.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Anteroposterior (AP), lateral, and Merchant views are all standard and provide information regarding the acute injury. Each radiograph is evaluated for fracture or loose fragment necessitating more emergent surgical indications.

DIFFERENTIAL DIAGNOSIS
- Meniscal tear
- Medial collateral ligament tear
- Chondral injury or bruise
- Anterior cruciate ligament tear
- Tendinitis
- Sindig-Larsen-Johanssen disease

**NONOPERATIVE MANAGEMENT**
- Over 80% of patients will respond well to nonoperative treatment.
- Nonoperative treatment is appropriate for multiple dislocators or subluxators, especially those who have generalized ligamentous laxity or an atraumatic type of presentation.
- Controversy exists as to the best treatment of first-time dislocators who are ligamentously tight, with or without a traumatic (but usually forceful) event.
- First-time dislocators who are young athletes without ligamentous laxity or a loose body or fracture are the most likely to respond well to nonoperative treatment.
- Some advocate early surgical intervention to repair the medial patellofemoral ligament and medial retinaculum even without fractures or loose body.
- Nonoperative regimen for a dislocation includes:
  - Rest, ice, compression, and elevation, plus anti-inflammatory medications
  - Immobilization for about 6 weeks
  - Immediate physical therapy to strengthen the weakened quadriceps and a patellar protection program
  - Bracing, with a lateral patellar restraint type of brace, for return to activity
- Treatment options for recurrent subluxation should include:
  - Bracing with a lateral patellar restraint type of brace
  - Physical therapy: a patellar protection program emphasizing strengthening of the hip flexors, abductors (which are routinely weak in this patient population), and quadriceps in particular
  - The clinician should emphasize to the patient that therapy requires participation at home as well as at therapy sessions.

**SURGICAL MANAGEMENT**
- Operative intervention should not be considered in chronic subluxators unless they prove that despite good effort in therapy over 6 to 12 months, instability still is problematic.
- The surgeon should be wary of operative treatment for patients with pain without instability.
- Recurrent dislocators who dislocate in a brace during physical activity despite good effort during therapy and training as well as those who dislocate during activities of daily living in a brace after therapy are candidates for surgical intervention.
- Any loose body or patellar avulsion fractures with large displaced fragments are indications for early surgical intervention.

**Preoperative Planning**
- All imaging studies are reviewed for other pathology that also needs to be addressed concurrently.
- Before positioning, an examination of the knee under anesthesia (including ligamentous testing) should be performed.
- The examination should include a Lachman test, pivot shift, varus–valgus stress test, and anterior–posterior drawer as well as medial and lateral patellar stability testing at 45 degrees of knee flexion. Results should be compared with those from the opposite knee.
- Translation of the patella over 50% of the width of the patella laterally indicates an incompetency of the medial patellofemoral ligament and the medial retinaculum, and both should be addressed at surgery (**FIG 1**).

**Positioning**
- The supine position is used with the patient’s operative leg free and with a tourniquet on the proximal leg.
- The foot of the table is flexed about 30 to 45 degrees and a lateral post is used for valgus moment, visualizing the medial compartment.
- The opposite leg can be positioned per the surgeon’s preference, depending on whether the foot of the table is flexed 90 degrees or if the foot is kept flat with a lateral post.

**Approach**
- If an arthroscopic lateral release is being performed, a 4- to 5-cm limited medial approach may be used, centering on the widest portion of the patella (**FIG 2**). Subcutaneous flaps can be elevated to allow great mobility of the prepatellar skin to limit the size of the incision.
- Alternatively, an open subcutaneous lateral release can be performed through a 1-cm incision, along with the medial plication–imbrication, or both may be done through a midline incision.
MEDIAL RETINACULAR Plication (Modified Insall)

- After dissection of the subcutaneous tissues, a medial parapatellar incision is made, leaving about 2 mm of tendon with the VMO (TECH FIG 1A).
- This incision in the tendon and the retinaculum is made from about 3 to 4 cm above the superior pole of the patella distally to 3 to 4 cm distal to the inferior pole of the patella medial to the tendon, leaving enough retinaculum with the tendon to suture to.
- The entire depth of the tendon and retinaculum is incised.
- The knee is then held in 45 degrees of flexion and the patella is held in position in the center of the trochlea (TECH FIG 1B).
- Three nonabsorbable no. 1 or no. 2 sutures are placed but not tied in a horizontal mattress fashion.
- These are typically placed 25% to 40% across the width of the patella from medial to lateral, imbricating the edge of the tendon of the VMO and the retinaculum distally and laterally.
- With the three sutures held tight, the knee is placed through a range of motion, from full extension to 90 degrees of flexion, to check that enough imbrication has been performed.
- The sutures are then tied and a 0 absorbable suture is used above and below the imbrication to reinforce the tension set by these sutures.
- A running 0 absorbable suture then can be sutured over the imbrication to help reinforce the imbrication as well as lower its profile.
- The wound is irrigated and closed in layers.
- Absorbable 3-0 or 4-0 monofilament should be used in the skin.1,2

Medial Patellofemoral Ligament Reconstruction

- The incision in the quadriceps mechanism and retinaculum is kept as extrasynovial as possible, especially directly medial to the patella and distally.
- The retinaculum is dissected from the subcutaneous tissue superficially back to the medial intermuscular septum (TECH FIG 2A).
- It is then dissected from the synovium deep back to the intermuscular septum.
- A puncture hole is made in the retinaculum immediately anterior to the intermuscular septum, superficial to the medial epicondylar insertion of the natural ligament and immediately distal to the VMO.
- The distance from the widest portion of the patella to the planned puncture site is measured.
- The medial 6 to 8 mm of full-thickness quadriceps tendon is taken typically as a 50- to 60-mm-long graft remaining attached to the superior pole of the patella (TECH FIG 2B).
- The graft is subperiosteally reflected distally about 10 to 12 mm from the superior pole of the patella (more distally laterally than medially, to allow it to fold over on itself during fixation and tensioning).
- A nonabsorbable suture is placed in the free end of the graft, with a whipstitch or other graft stitch performed with two ends.
- The graft is then passed deep to the retinaculum through the puncture hole to the superficial side of the retinaculum (TECH FIG 2C).
- The tension is then set via the medial retinacular suture plication as described above before setting the tension of the graft.
- At 45 degrees of knee flexion the graft is then tensioned to allow no more than 25% lateral translation of the patella at 45 degrees of knee flexion (TECH FIG 2D).
- The graft is secured into position with no. 1 or 2 nonabsorbable suture placed through the medial intermuscular septum periosteum of the medial epicondyle and the graft and retinaculum at the puncture hole in the retinaculum.
- It is further secured by 0 absorbable sutures in the graft and retinaculum, catching the graft superficial and deep to the retinaculum as the free end of the graft is directed back toward the patella.
- The suture in the free end of the graft is also used to secure it in position.
- Once the graft is secured and imbrication is complete, the knee is flexed to 90 degrees to ensure that no overtightening of the quadriceps mechanism has occurred and that the sutures stay in place.
- Tracking of the patella is also checked as described above.4
**POSTOPERATIVE CARE**

- Patients are placed in a hinged postoperative knee brace locked in full extension.
- Physical therapy for range of motion (passive and active assisted) should be started in the first few days to combat arthrofibrosis.
- Weight bearing is protected with crutches until the patient is comfortable enough to walk in a locked knee brace in full extension.

- During the initial phase of therapy, patellar mobilization, quadriceps activation, straight-leg raises, pain modalities, and edema control are important.
- Range of motion is restricted to 0 to 90 degrees for the first 3 to 4 weeks postoperatively.
- At 4 weeks, full range of motion is allowed, with progressive quadriceps strengthening, edema control, and pain control, and gait training is initiated.
- Brace use in community settings is continued until adequate quadriceps strength has returned (about 6 weeks).

**PEARLS AND PITFALLS**

**Indications**
- Careful patient selection process is a must.
- Patients with pain without instability should not be operated on unless all else fails.
- A careful examination should be done to determine whether reconstruction of the medial patellofemoral ligament is warranted.

**Tension setting**
- The surgeon should make sure that the patella translates close to 25% of its width laterally.
- The patella should also medially translate 12 to 20 mm.
- This is best done by setting the tension with the knee flexed about 45 degrees.
- If medial patellofemoral ligament reconstruction is being performed at the same time, the tension should be set with the retinacular imbrication before tensioning the graft (this avoids over-tensioning).
- Before closure, the knee is taken through the range of motion from 0 to 90 degrees to ensure good alignment and to make sure that the sutures are not under too much tension.

**Quadriceps graft management**
- Care must be taken not to detach the quadriceps graft from the patella completely.
- Dissecting more distally on the lateral aspect of the patellar attachment allows for the graft to lay down on itself.
- The puncture site is positioned distal to the most inferior aspect of the VMO and immediately anterior to the intermuscular septum.
- When passing the graft through the puncture hole in the retinaculum, a snap or Kocher clamp is used to hold the stitch in the free end. It is pulled through in line with the graft (the surgeon should push anterior to posterior, not pull posterior to anterior).

**Fixation problems**
- The graft is sutured at the patellar attachment as it folds over itself.
From 6 to 12 weeks, there is continued progression of quadriceps strengthening.
Functional return to activities starts at 3 months postoperatively.

COMPlications
- Failure of fixation is typically seen at the time of surgery if knee is tested from 0 to 90 degrees.
- Late fixation failure is uncommon but can happen if flexion beyond 90 degrees is started too soon postoperatively.
- Arthrofibrosis should be treated aggressively with manipulation under anesthesia if greater than 90 degrees of flexion is not obtained by 6 weeks.
- Continued pain may occur, especially if not enough or too aggressive of a lateral release was performed, leading to either increased pressure on the patella or medial pressure and instability.
- Injury to the cutaneous nerves is common, and patients should be warned of this risk. It can be avoided with well-placed small incisions.
- Recurrent instability may occur in patients with rotational or angular malalignments that either are not recognized or cannot be addressed because of skeletal immaturity.

REFERENCES
DEFINITION
- Tibial spine fractures are synonymous with an avulsion of the anterior cruciate ligament (ACL) with its attachment on the anteromedial portion of the tibial eminence.\(^{16,21}\) Some authors consider them to be equivalent to the midsubstance ACL injuries seen in the adult population.
- This injury commonly occurs in the younger age group, particularly in those with open growth plates.
- Tibial spine fractures occur in 3 per 100,000 children each year.\(^{18}\)
- Meyers and McKeever classified this fracture into three types based on the degree of displacement (FIG 1)\(^{14}\):
  - Type I is a nondisplaced fracture.
  - Type II is the hinged, partially displaced type.
  - Type III is a complete displacement of the fragment.
- The classification proposed by Meyers and McKeever was later modified by Zaricznyj to include a fourth type, which would signify a comminuted fragment.\(^{22}\)

ANATOMY
- The tibial eminence is found lying in the intercondylar area of the tibia (FIG 2).
- Two elevations are seen: a medial and a lateral. These elevations are triangular.
  - The medial elevation provides the attachment for the fibers of the ACL.
  - There are no structures that attach to the lateral portion of the eminence.
  - The ligamentous ends of the medial and lateral menisci likewise insert into the intercondylar eminence.
  - The tibial eminence also serves as an insertion for the posterior cruciate ligament (PCL); the fibers of the PCL typically arise from the posterior portion of the intercondylar eminence.\(^{14}\)
- In the younger child the majority of the anterior portion of the eminence is cartilaginous.\(^{14}\)

PATHOGENESIS
- Avulsion of the tibial eminence or tibial spine is usually traumatic in nature. It is more common in children, particularly those with incomplete ossification and open growth plates. The incompletely ossified tibial spine is primarily cartilaginous, which is weaker in resisting tensile forces.
- The injury occurs because of a stretching of the ACL. The ACL is much stronger in resisting tensile forces than the immature osteochondral surface; this often results in failure and avulsion of the osteochondral attachment of the ACL.
- The usual mechanism of injury is a forced valgus moment applied to the knee, which is coupled with external rotation forces. Other mechanisms reported include hyperextension of the knee coupled with rotational moments.
- Different loading mechanisms are likewise implicated in the development of the injury. Experimental models have shown that rapid loading rates result in midsubstance ACL tears, whereas gradual loading results in tibial spine avulsion fractures.\(^{16,21}\)
- The inherent anatomy of the knee has likewise been implicated. Kocher and colleagues\(^{10}\) compared 25 skeletally immature knees with tibial spine fractures against 25 age-matched skeletally immature knees with midsubstance ACL tears and found a narrower notch width (intercondylar notch) in individuals who had sustained the midsubstance ACL tears.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Fractures of the tibial spine are usually precipitated by an acute traumatic event. The clinical presentation usually coincides with the severity of injury.
- Usually a patient with a tibial spine injury will have a history of trauma or sports-related injury; the most common mechanism is usually a fall from a bicycle. Lately, sports-related injuries have been reported with increasing frequency. High-velocity trauma may also cause tibial spine injuries.
- The patient will usually present with a painful swollen knee. Swelling is secondary to hemarthrosis from the intra-articular knee injury.
- Knee joint laxity is present, as well as an inability to bear weight on the affected extremity.
- The knee should also be carefully examined for any concomitant injury.
- Gentle palpation and examination of the knee are undertaken. Most patients have some degree of swelling due to hemarthrosis secondary to the intra-articular fracture. Other superficial injuries are related to the degree and nature of the traumatic event.
In the presence of a deficient ACL complex, during the pivot shift test the femur falls posteriorly in relation to the tibia as the leg is raised and rotated internally. The valgus force applied to the leg along with slight flexion of the knee results in the pivot shift phenomenon. The intact iliotibial band reduces the femur when the knee is brought into 20 to 30 degrees of flexion.

A positive anterior drawer test indicates knee joint laxity. However, this is not as sensitive as the Lachman test in assessing for ACL deficiency.

A positive result on the Lachman test indicates deficiency of the ACL complex. The test has greater sensitivity and specificity for ACL tears.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standard anteroposterior (AP) and lateral views of the knee are usually adequate in making the diagnosis. These views help to define and identify the extent of bony injury.
  - In lesions that are predominantly cartilaginous, these views may sometimes detect a small piece or a fleck of avulsed bone, which may be indicative of the avulsed osteochondral fragment (FIG 3).
  - MRI is a good imaging modality for suspected tibial spine injuries, especially in the immature knee, where the tibial spine is predominantly cartilaginous. It differentiates between a true midsubstance ACL injury and a true avulsion fracture of the tibial spine. It also helps to detect concomitant injuries around the knee joint.8
  - Computed tomography is helpful in the older age group and in cases of severe trauma, where the fracture configuration may be severely comminuted.

**DIFFERENTIAL DIAGNOSIS**

- ACL tear
- Osteochondral lesion
- Meniscal injury
- Other ligamentous injuries about the knee

**NONOPERATIVE MANAGEMENT**

- Nonoperative management is reserved for nondisplaced type I fractures and reducible type II fractures.
- Type II fractures may be reduced by first aspirating the hematoma and injecting a local anesthetic agent into the joint space.
  - The knee is extended in an attempt to reduce the fracture fragment. The mechanism is through direct pressure exerted by the lateral femoral condyle.
  - This maneuver may be effective for lesions that are large enough to include part of the tibial plateau.
  - In small lesions, the maneuver may not afford adequate reduction.
  - The reduction is assessed with radiographs and the knee is immobilized.
  - A long-leg cast is placed to immobilize the leg and maintain reduction.
  - There has been controversy about the optimal position for cast placement.
  - We recommend long-leg casting between 10 and 20 degrees of knee flexion.
  - The reduction should be checked after 1 week and at 2 weeks. Any loss of reduction warrants an operative reduction of the fracture.

**SURGICAL MANAGEMENT**

- The general indications for surgical management of tibial spine fractures include:
  - Completely displaced tibial spine fractures (type III)
  - Type II tibial spine fractures with inadequate closed reduction

**Preoperative Planning**

- Careful preoperative evaluation and preparation are always imperative to the success of treatment.
- All imaging studies obtained before surgery should be reviewed.
If the avulsed fragment has a relatively large osseous component, plain radiographs will usually suffice in determining treatment. In lesions that are primarily cartilaginous, MRI may be required to determine the extent of the lesion. Any other lesion noted on imaging studies should likewise be addressed. A thorough physical examination should be performed under anesthesia. The choice of surgical treatment (open versus arthroscopic reduction) as well as the choice of fixation device largely depends on the preference and experience of the surgeon and the character of the lesion. Larger lesions with an adequate osseous component, for example, may allow for screw fixation, whereas a lesion that is primarily cartilaginous may be better treated with suture fixation. Inevitably, the final decision as to which fixation device is best is made intraoperatively.

The surgeon should be prepared to offer fixation techniques that will provide stable anatomic fixation by open methods or through arthroscopy.

Positioning
- For arthroscopic procedures, the position largely depends on the surgeon’s preference. A variety of positions can be used. The leg can be placed on the operating table with the knee joint past the break in the table. This allows the knee to flex 90 degrees when the lower end of the table is dropped down, allowing the knee to dangle off the table. This position can be done with or without a leg holder (FIG 4A).
- The leg can be placed supine on the operating table, with the hip flexed and the knee flexed 90 degrees. The knee is allowed to angle off the table as needed (FIG 4B, C).
- For open reduction techniques, the patient is placed supine on the operating table, a tourniquet is placed on the thigh, and the knee is draped in a standard fashion. The leg is exsanguinated.

Approach
- The standard arthroscopic portals used for ACL reconstruction are used (FIG 5).
- For open reduction and internal fixation (ORIF), the knee is approached through a limited parapatellar approach.

**FIG 4 • Position of the knee in the leg holder.**

**FIG 5 • The standard portals used for anterior cruciate ligament reconstruction are the same ones commonly used for arthroscopic treatment of tibial spine fractures.**

**ARTHROSCOPY-ASSISTED Tibial Spine Repair**

**Arthroscopic Fixation**
- An anterolateral portal is made for visualization, a superomedial portal is used as an outflow tract, and an anteromedial portal is made for instrumentation.
- The hemarthrosis is removed to allow for direct inspection and evaluation of the knee joint.
- Any concomitant injuries are identified.
- The base of the fracture fragment is débrided using shavers and curettes and the fracture hematoma is carefully removed.
- A posterior force is applied to the leg and an attempt is made to reduce the fracture fragments (TECH FIG 1).
If any interposing structure is found preventing reduction, it should be carefully retracted and sutured or repaired if necessary.

Midpatellar tendon portals may be added to allow the use of accessory probes and instruments.

**Screw Fixation**

- Once anatomic reduction of the fracture has been achieved, a guide pin is passed through the fracture fragment (TECH FIG 2A,B).
  - The position of the guide pin is checked under fluoroscopy to ensure proper placement and to avoid traversing the growth plate.
  - A second pin may be introduced, depending on the stability of the fracture reduction, to maintain the fragments in place.
  - A screw of appropriate size and length is chosen.
    - A 3.5-mm or 4.0-mm cannulated, self-drilling self-tapping screw is used. The screw size is largely dependent on whether the fracture fragments will accommodate the screw.
    - One or two screws may be placed, depending on the size of the fragment.

- With reduction maintained, the screw is gradually advanced under fluoroscopic guidance, making sure that the growth plate is not traversed.
- Once adequate fixation has been obtained, the guide pins are removed.
- The knee is gently flexed and extended while the stability of the reduction is checked under direct vision.
- AP and lateral radiographs of the knee are taken to document appropriate positioning of the screw and to document the fixation before closure (TECH FIG 2C–E).
- Once satisfactory reduction is documented, the instruments are removed and the arthroscopic portals closed.
- The knee is placed in a cylinder cast in 5 to 10 degrees of flexion.

**Suture Fixation**

- Two 1-0 PDS sutures are placed at the base of the ACL proximal to its insertion on the tibial spine (TECH FIG 3).
- An incision is made 1 to 2 cm medial to the tibial tubercle to allow for placement of the ACL tibial guide.
- Two parallel 2-mm transphyseal tunnels are made.
- A suture passer is passed through each tunnel and the suture ends are retrieved.

---

**TECH FIG 2** • Arthroscopic screw fixation.

A. The fracture fragment is maintained using cannulated guidewires. B,C. A cannulated screw is inserted under fluoroscopic guidance. D,E. AP and lateral radiographs showing the tibial spine fracture fixed with a single cannulated screw with washer. Care should be taken to avoid crossing the physis with the screw.

**TECH FIG 3** • Suture fixation. Two 1-0 PDS sutures are passed through the base of the anterior cruciate ligament. A suture passer is used to grab the suture ends through a transphyseal tunnel and the suture ends are tied in the anteromedial border of the tibia.
The tibial spine is reduced in its own bed and the suture ends are tied over a bone bridge in the anteromedial portion of the tibia.

The reduction is checked under direct visualization. If reduction is found to be inadequate, fixation may be augmented with percutaneous Kirschner wires or cannulated screws as needed.

Once adequate reduction had been achieved, gentle flexion and extension of the knee is performed to check for stability of reduction.

When satisfactory reduction of the fracture is obtained and documented, then the instruments are removed and the arthroscopic portals are closed.

The knee is placed in a cylinder cast in 5 to 10 degrees of flexion.

**Kirschner Wire Fixation and Percutaneous Pinning**

After adequate reduction of the fracture is obtained, the fracture fragment is held in reduction.

Two Kirschner wires are inserted percutaneously under fluoroscopic guidance 0.5 cm proximal to the tibial tuberosity on the medial and lateral side of the patellar tendon.

The Kirschner wires are withdrawn gradually in a retrograde manner until the tips are flush with the surface of the tibial spine (TECH FIG 4A).

Proper placement of the Kirschner wires is documented radiographically and arthroscopically.

The stability of reduction is checked with gentle passive flexion and extension of the knee.

The Kirschner wires are bent and cut at the level of the skin.

The instrumentation is removed and the arthroscopic portals are closed.

Adequate padding is applied over and beneath the pins to allow for support before cast immobilization.

A cylinder cast is applied to the knee in 5 to 10 degrees of flexion (TECH FIG 4B, C).

**OPEN REDUCTION AND INTERNAL FIXATION**

**Exposure**

The procedure begins with a standard median parapatellar approach. The skin incision may be parapatellar or midline.

The median parapatellar incision is started at the inferior pole of the patella and follows the medial border of the infrapatellar tendon down to the level of the tibial tubercle. The incision can be extended as needed (TECH FIG 5).

When performing the medial parapatellar skin incision, care should be taken to avoid inadvertent transection of the infrapatellar branch of the saphenous nerve; if a branch is cut it should be buried in fat to decrease the risk of developing a neuroma.

The skin incision is carried down to the fascia. The skin and subcutaneous tissues are retracted and reflected.

![TECH FIG 5 • A. Median parapatellar approach to the knee can be done through a straight midline incision. B. The parapatellar incision is carried through to the knee joint and the patella is reflected laterally.](image-url)
Dissection is carried through the medial border of the patellar retinaculum, making sure to retain at least a 2- to 3-mm cuff of soft tissue to allow for adequate closure, and down along the medial border of the patellar tendon. The patella and patellar tendon are retracted laterally to allow for direct visualization of the ACL and tibial spine fracture.

**Fracture Fixation**

- Once complete exposure of the knee joint is achieved, the fracture fragments as well as any concomitant injuries are identified.
- The leg is held in the posterior drawer position by the assistant to allow for an easier reduction.

Fixation materials used to hold the fragment in place, including sutures, screws, and Kirschner wires, are similar to those described in the arthroscopic technique.
- Once fixation of the fracture has been achieved, stability is tested by gentle flexion and extension of the knee.
- Any concomitant injuries about the knee joint are addressed.
- Copious washing of the knee joint is done before closure to clear the knee joint of any remaining debris.
- Meticulous hemostasis and layer-by-layer closure are performed.
- The knee is placed in a cylinder cast in 5 to 10 degrees of flexion.

### PEARLS AND PITFALLS

#### Indications
- A careful assessment of the injury is done before treatment; any concomitant injuries such as meniscal tears or injuries to the collateral ligaments should be carefully evaluated and incorporated into the surgical plan.

#### Surgical preparation
- Even with proper preoperative planning, the surgeon should be prepared to use a variety of fixation devices and techniques. This is often dictated by the size and character of the fracture fragment. A large fragment may accommodate more than one screw; a smaller fragment, however, may be better treated with suture fixation or percutaneous pinning.

#### Fracture fixation
- The fracture fragment should be assessed and carefully fixed. Multiple attempts at obtaining purchase with the use of fixation devices should be avoided as this may cause comminution of the fragment.
- In skeletally immature individuals, care must be taken to avoid crossing the physis, particularly with the use of screw fixation. Fluoroscopic guidance should be used and the physis identified and avoided during fixation.

#### Fracture reduction
- Difficult reduction is often secondary to soft tissue interposition. The fracture bed should be cleared and any interposing soft tissue should be retracted or removed as deemed necessary. Often the anterior horn of the medial meniscus becomes entrapped; performing an anterior drawer maneuver may allow the entrapped fragment to be liberated. The fragment may then be reduced onto the fracture bed and fixed accordingly.

#### Mobilization
- Early mobilization should be undertaken to avoid postoperative stiffness. Mobilization is allowed depending on the stability of fixation. If prolonged immobilization is needed, immobilizing in extension is preferred, as flexion contractures are a more difficult problem to treat.

### POSTOPERATIVE CARE

- Postoperatively the knee is immobilized in 5 to 10 degrees of flexion. If adequate fixation is obtained, then the extremity may be placed in full extension; hyperextension should always be avoided.
- Radiographs are taken to document adequate reduction of the fracture fragment.
- Early range of motion may be started at 1 to 2 weeks when the swelling has subsided and if good fixation of the fracture fragment is obtained.
- In more severe cases, where stability may be in question, range-of-motion exercises are generally instituted once adequate healing of the fracture can be ascertained; this is usually 4 to 6 weeks after surgery.

### OUTCOMES

- Residual laxity of the knee is commonly seen, even with anatomic reduction of the fracture, and is due to the inherent stretch of the ACL before the tibial spine fails. Excellent functional outcomes have been reported despite the residual laxity with both closed management and operative treatment of tibial spine fractures, as long as reduction is maintained.\(^2,11,19,20\)
- Good to excellent outcomes have been reported with ORIF as well as arthroscopic reduction with suture fixation,\(^1,5,11\) arthroscopic reduction with screw fixation,\(^9,17\) and arthroscopic reduction and percutaneous pin fixation.\(^13\)
- Hunter and Willis’ found similar outcomes with both screw and suture fixation. In 10 cases they found interposition of the intermeniscal ligament that required retraction or resection to allow for adequate reduction.

### COMPLICATIONS

- Nonunion
- Malunion
- Arthrofibrosis\(^4\)
- Residual laxity
- Implant-related complications
- Growth disturbance
- Loss of motion
REFERENCES

Chapter 23

Anterior Cruciate Ligament Reconstruction in the Skeletally Immature Patient

J. Todd R. Lawrence and Mininder S. Kocher

DEFINITION

- Skeletally immature patients have open growth plates, or physes, and thus have growth potential remaining.
- Intrasubstance anterior cruciate ligament (ACL) injuries were once considered rare in this population, with tibial eminence avulsion fractures considered the pediatric ACL injury equivalent. However, intrasubstance ACL injuries in children and adolescents are being seen with increasing frequency and result in an “ACL-deficient knee” as in adult patients.
- ACL deficiency in the skeletally immature patient usually results in an unstable knee at risk for further injury and accelerated degeneration.
- Conventional surgical reconstruction techniques risk potential iatrogenic growth disturbance due to physeal violation, and thus special consideration must be given to this patient population.
- The physiologic age of the patient reflects the amount of remaining growth potential and heavily influences the treatment options.

ANATOMY

- The ACL originates from a semicircular area on the posterior portion of the medial aspect of the lateral femoral condyle and courses obliquely to the anteromedial aspect of the tibial plateau at the anterior tibial eminence (or spine).
- The primary role of the ACL is to resist anterior translation and rotation of the tibia on the femur.
- The ligament is composed of two anatomically and biomechanically distinct bundles, the anteromedial and the posterolateral bundles.
  - The anteromedial bundle is more anterior and vertical in orientation. It largely resists anterior translation and tightens in the last 30 degrees of extension.
  - The posterolateral bundle is more posterior and oblique in orientation. It is more isometric and plays a greater role in rotational control.
- Not all skeletally immature patients are the same. Some have a tremendous amount of growth remaining, while others are essentially done growing.
- Most of the longitudinal growth of the lower extremities comes from the distal femur and the proximal tibia. The tibial physes can be as close as 15 to 20 mm to the tibial spine. The femoral physes comes within millimeters of the femoral attachment of the ACL at the most posterior aspect of its insertion (FIG 1).

PATHOGENESIS

- The etiology of ACL injury in skeletally immature patients is similar to that in the adult population. It is usually due to a noncontact injury involving a cutting, pivoting, or rapid deceleration maneuver.
- Patients often report hearing a “pop” followed by swelling of the knee. ACL injury has been reported in up to 65% of pediatric patients with acute traumatic hemarthroses.
- The “shift” that occurs with the ACL-deficient knee at the time of injury causes an impaction injury on the posterior aspect of the tibial plateau against the distal femur at the sulcus terminalis as the tibia translates anteriorly on the femur. Characteristic bone bruises in this location on MRI are pathognomonic for ACL injury (FIG 2).
- Ligamentous, meniscal, and chondral injuries are commonly associated with ACL injury.
  - The medial collateral ligament is commonly injured with the ACL.
  - The posterolateral corner is less often injured with the ACL but is a common cause of failure of ACL reconstruction if it is not addressed as well.
  - Tears of the lateral meniscus are associated with acute tears of the ACL.
  - The posterior horn of the medial meniscus is a secondary restraint to anterior translation of the tibia. In the chronically ACL-deficient knee the posterior horn of the medial meniscus assumes a greater role in preventing anterior translation and is thus at increased risk of injury.

NATURAL HISTORY

- Partial tears may be successfully managed nonoperatively in some patients.

FIG 1 • Sagittal MRI demonstrating the relationship of the anterior cruciate ligament to the distal femoral and proximal tibial physes. (From Kocher MS, Garg S, Micheli LJ. Physeal sparing reconstruction of the anterior cruciate ligament in skeletally immature prepubescent children and adolescents: surgical technique. J Bone Joint Surg Am 2006;88A[Suppl 1 Pt 2]:283–293.)
PATIENT HISTORY AND PHYSICAL FINDINGS

Adolescents are notoriously bad historians, but every attempt should be made to garner an appreciation for the mechanism of injury, a history of acute or recurrent effusions, and a sense of instability with activities or mechanical symptoms.

Physiologic age should be established informally in the office using the Tanner staging system. This can be confirmed in the operating room after the induction of anesthesia. Skeletal age can be determined via hand and wrist radiographs or the method of Greulich and Pyle.

A complete examination of the knee should be performed. Particular attention should be given to evaluating the knee for associated pathology.

Patella ballotttement and fluid wave test should be done to evaluate for the presence of an effusion.

Range of motion (ROM) is important to assess because regaining full ROM before ACL reconstruction may be critical to prevent postoperative arthrofibrosis. Loss of extension should alert the clinician to the possibility of a displaced bucket-handle tear or preoperative arthrofibrosis. Loss of flexion may be due to pain secondary to a tense effusion.

Tenderness to palpation should be assessed and localized specifically as it can greatly direct the diagnosis of related injuries.

Tenderness to palpation along the joint line, particularly the posterior aspect of the joint line, should alert the clinician to the possibility of a meniscal tear. Pain or palpable popping with provocative maneuvers, such as McMurray, Apley compression, or duck walk, will help to confirm this finding.

Pain along the course of or at the femoral or tibial insertion points for the collateral ligaments should alert the clinician to the possibility of a collateral ligament tear.

Pain at the physis should prompt an investigation for a physeal injury, although in our experience this is not commonly associated with complete ACL injuries.

Tenderness along the medial retinaculum or the course of the medial patellofemoral ligament can indicate an acute patellar dislocation that reduced spontaneously.

Ligamentous evaluation should include the anterior and posterior cruciate ligaments, the medial and lateral collateral ligaments, and the posterolateral corner.

Skeletally immature athletes have a greater degree of physiologic laxity than adult athletes, and as such a comparison should always be made to the uninjured knee.

Evaluation of the ACL is best done with the Lachman test in the cooperative patient. In the patient who voluntarily or involuntarily guards against traditional Lachman testing, the prone Lachman may encourage relaxation and give a more reliable examination.

Pivot shift testing may be performed in the office but is usually not well tolerated by pediatric patients. It should be performed in the operating room as part of the preoperative evaluation of every patient.

The posterior cruciate ligament should be evaluated using the posterior drawer test. The relative starting point should always be assessed first and compared to the contralateral side. The utility of posterior drawer stress radiographs is unclear at this time. Injuries of grade II and above should alert the clinician to the possibility of an associated posterolateral corner injury.

Medial and lateral collateral ligament injuries are assessed through stress opening with valgus and varus stress at 0 and 30 degrees of knee flexion. In the pediatric patient, opening with varus and valgus stress can be due to physeal injuries, and the clinician should always be vigilant for this.

Evaluation of the posterolateral corner is best done with the dial test. The posterolateral drawer and the external rotation recurvatum tests are also useful for evaluating posterolateral corner injuries.

Evaluation for patellar instability with apprehension testing should be performed.

Evaluation of quadriceps bulk and strength is important for postoperative recovery.

IMAGING AND OTHER DIAGNOSTIC STUDIES

All pediatric patients with a complaint of knee pain should receive an initial plain radiographic evaluation including AP, lateral, and patellar views. Special attention should be given to evaluate for physeal injuries as well as other injuries on the differential diagnosis.

AP and frog-lateral plain radiographs of the hip should be considered in the evaluation of all pediatric patients with complaints of knee pain.

Overall varus and valgus malalignment, if present clinically, should be evaluated with full-length, hip-to-ankle radiographs.
MRI is the diagnostic imaging test of choice for further evaluation of ACL tears in the skeletally immature patient. However, it is significantly less sensitive and specific for diagnosing ACL injuries in this population compared with the adult population. Findings on MRI signifying an ACL tear include a discontinuity in the fibers on the ACL and a characteristic bone bruise pattern on the distal femur and the posterior tibial plateau of the lateral hemi-joint.

MRI in the pediatric population also has a high false-positive rate for meniscal tears. This is likely due to the increased vascularity of the meniscus, which is often interpreted as intrasubstance degeneration or a tear of the meniscus.

Differential Diagnosis

- Tibial eminence (spine) fracture
- Other intra-articular or physeal fracture
- Patellar dislocation
- Meniscal tear
- Posterior cruciate ligament tear
- Medial or lateral collateral tear
- Posterolateral corner injury
- Physiologic laxity
- Hip etiology

Nonoperative Management

- Partial or incomplete tears can be successfully managed nonoperatively in some patients if clinical and functional stability is possible. The following criteria have been shown to be associated with successful nonoperative treatment of partial tears:
  - Tears of less than 50% of the ligament
  - Relative preservation of the posterolateral bundle
  - Age less than 14 years
  - Normal or near-normal Lachman or pivot shift test
- Up to a third of patients may require subsequent reconstruction and should be made aware of that risk at the onset of treatment.
- Successful treatment based on the above criteria includes:
  - A hinged knee brace is worn for 12 weeks.
  - Touch-down weight bearing is maintained for 6 to 8 weeks.
  - Passive terminal extension is restricted for the first 6 weeks.
  - Active terminal extension is restricted for 12 weeks.
  - Physical therapy emphasizes hamstring muscle strengthening.
- Return to sports and active play is permitted at 3 months with the use of a functional knee brace for 2 years for cutting and pivoting activities.
- Nonoperative management of complete tears in skeletally immature patients generally has a poor prognosis.
- For prepubescent patients with a complete ACL tear and without concurrent chondral injury requiring stabilization or meniscal injury requiring repair, we favor attempted nonoperative treatment with activity modification, functional bracing, and continued rehabilitation.
- In our experience, compliance with activity modification and brace use and effectiveness limits the success of this treatment.
- Delay in surgical stabilization can lead to further meniscal and chondral injury due to recurrent instability.
- Although results of nonoperative management are generally poor, the risk of further intra-articular injury by waiting until skeletal maturity to undergo reconstruction must be weighed against the risk of growth disturbance with early reconstruction.
- Some patients are able to cope with their ACL insufficiency or modify their activities, allowing for further growth and aging such that an adolescent-type reconstruction can be performed with transphyseal hamstrings tendons in a more anatomic manner.
- For prepubescent patients with recurrent instability despite the above treatment, reconstruction is indicated.
- For adolescent patients with growth remaining who have a complete ACL tear, we do not advocate initial nonoperative treatment since the risk of functional instability with injury to the meniscal and articular cartilage is high, the risk and consequences of growth disturbance from ACL reconstruction are less, and the transphyseal technique is an anatomic reconstruction.

Surgical Management

- Conventional adult ACL reconstruction techniques risk potential iatrogenic growth disturbance due to physeal violation, and cases of growth disturbance have been reported in animal models and clinical series.
- The following principles should be applied when considering any reconstructive strategy:
  - Hard fixation, such as with an interference screw, or any bone crossing the physe, has a high risk of inducing a growth disturbance.
  - A tensioned soft tissue graft in a bone tunnel across the physe can also induce a growth disturbance.
- The approach to ACL reconstruction in the skeletally immature patient should be based on physiologic age.
- A variety of reconstructive techniques have been used, including physeal-sparing, partial transphyseal and transphyseal methods using various grafts.
- In prepubescent patients with large amounts of growth potential remaining, we perform a physeal-sparing, combined intra-articular and extra-articular reconstruction using autogenous iliotibial band.
- Recognizing that the physeal-sparing reconstruction described here is nonanatomic, we counsel patients and families that revision reconstruction may be needed if recurrent instability develops, but that this procedure may temporize for further growth such that the patient may then undergo a more conventional reconstruction with drill holes.
- A variety of other physeal-sparing reconstructions have been described to avoid tunnels across either the distal femoral or proximal tibial physe, but they will not be described here.
- In adolescent patients with significant growth remaining, we perform transphyseal ACL reconstruction with autogenous hamstring tendons with fixation away from the physe.
- In adolescent patients approaching skeletal maturity, we perform conventional adult ACL reconstruction with interference screw fixation using either autogenous central-third patellar tendon or autogenous hamstrings (see Chap. SM-10).
- In skeletally immature patients, as in adult patients, acute ACL reconstruction is not performed within the first 3 weeks after injury to minimize the risk of arthrofibrosis.
- Prereconstructive rehabilitation is performed to regain ROM, decrease swelling, and resolve the reflex inhibition of the quadriceps.
Skeletally immature patients must be emotionally mature enough to actively participate in the extensive rehabilitation required after ACL reconstruction.

Preoperative Planning
- All imaging studies, including plain radiographs and MRI, should be reviewed and associated injuries identified.
- In general, associated injuries, such as meniscal, articular cartilage, or other multiple ligament injuries, should be addressed at the time of ACL reconstruction. However, reconstruction may be staged in some cases, such as nonoperative treatment of a medial collateral ligament injury before ACL reconstruction.
- Consideration should be given to using pediatric anesthesia services, given the age of the patient.
- Tanner staging should be confirmed at the time of surgery after the induction of general anesthesia.
- A complete ligamentous knee examination, including Lachman, pivot shift, varus and valgus stress, posterior drawer, and dial tests, should be performed and the findings compared to the contralateral side to confirm the diagnosis.

Positioning
- For both procedures described here, the physeal-sparing combined intra-articular and extra-articular reconstruction with autogenous iliotibial band and the transphyseal reconstruction with autogenous hamstrings with metaphyseal fixation, positioning and setup are very similar.
- The procedure is performed under general anesthesia with overnight observation. Regional anesthesia can assist with pain relief but is not required. Local anesthesia with sedation may not be reliable in this population and has the potential for a paradoxical effect of sedation.
- The patient is placed supine on the operating room table and moved close to the operative side of the table such that the operative leg easily drapes over the edge of the table.
- A tourniquet is placed high about the upper thigh. It is routinely used during the physeal-sparing procedure but is not routinely used during the transphyseal technique.
- A side post is placed two fingerbreadths above the flexed knee as it drapes over the side of the bed. It is used in the “up” position for the diagnostic arthroscopy and dropped to the “down” position to provide a ledge for supporting the knee during the ACL reconstruction.

Approach
- The approach depends on the technique employed and the choice of graft.
- Autograft is preferred, but soft tissue allograft could be considered based on patient preference. Allograft would negate the need for hamstring harvest in the transphyseal reconstruction.
PHYSEAL-SPARING, COMBINED INTRA-ARTICULAR AND EXTRARTICULAR RECONSTRUCTION WITH AUTOGENOUS ILIOTIBIAL BAND IN PREPUBESCENT PATIENTS

Harvest of Iliotibial Band Graft
- An incision of about 6 cm is made obliquely from the lateral joint line to the superior border of the iliotibial band.
- Proximally, the iliotibial band is separated from subcutaneous tissue using a periosteal elevator under the skin of the lateral thigh.
- The anterior and posterior borders of the iliotibial band are incised and the incisions carried proximally under the skin using curved meniscotomes (TECH FIG 1A).
- The iliotibial band is detached proximally under the skin using a curved meniscotome or an open tendon stripper. Alternatively, a counter-incision can be made at the upper thigh to release the tendon.
- Dissection is performed distally to separate the iliotibial band from the joint capsule and from the lateral patellar retinaculum (TECH FIG 1B).
- The iliotibial band is left attached distally at the tubercle of Gerdy (TECH FIG 1C).
- The free proximal end of the iliotibial band is tubularized with a no. 5 Ethibond whipstitch and wrapped in a moist sponge until needed later.

Arthroscopy
- Diagnostic arthroscopy of the knee is performed through standard anterolateral viewing and anteromedial working portals.
- Management of meniscal injury or chondral injury is performed if present.
- The ACL remnant is excised with the use of biting instruments and the shaver.
- The over-the-top position on the femur and the over-the-front position under the intermeniscal ligament are identified and cleared of excess tissue to allow passage of the graft.
- Minimal notchplasty is performed to avoid iatrogenic injury to the perichondrial ring of the distal femoral physis, which is very close to the over-the-top position.2

Graft Passage
- The free end of the iliotibial band graft is brought through the over-the-top position using a full-length clamp (TECH FIG 2A) or a two-incision rear-entry guide (TECH FIG 2B) and out the anteromedial portal (TECH FIG 2C,D).
- A second incision of about 4.5 cm is made over the proximal medial tibia in the region of the pes anserinus insertion.
- Dissection is carried through the subcutaneous tissue to the periosteum.
- A curved clamp is placed from this incision into the joint under the intermeniscal ligament (TECH FIG 2E).
- A small groove is made in the anteromedial proximal tibial epiphysis under the intermeniscal ligament using a curved rat-tail rasp to bring the tibial graft placement more posterior.
- The free end of the graft is then brought through the joint, under the intermeniscal ligament in the anteromedial epiphyseal groove, and out the medial tibial incision (TECH FIG 2F).

Graft Fixation
- Through the lateral incision, the iliotibial band graft is sutured near the over-the-top position to the intermuscular septum and the periosteum of the posterior lateral femoral condyle with the knee flexed 90 degrees, tension on the graft, and the foot externally rotated 30 degrees (TECH FIG 3A).
- Fluoroscopic imaging is used to assess the location of the proximal tibial physis.
- A longitudinal incision is made in the periosteum distal to the proximal tibial physis.
The edges are gently elevated and a trough is made in the proximal tibial medial metaphyseal cortex.

The knee is flexed 20 degrees and tension applied to the graft.

The graft is sutured to the periosteum at the roughened margins with mattress sutures (TECH FIG 3B).

The knee is checked for stability to Lachman testing and ROM.

### Wound Closure

- The wounds are copiously irrigated.
- The tourniquet is deflated and meticulous hemostasis is achieved.
- The wounds are then closed in layers in a standard fashion.

**TECH FIG 2** • Graft passage for physeal-sparing anterior cruciate ligament reconstruction. A. The graft is brought through the knee in the over-the-top position using a full-length clamp introduced through the anteromedial portal and out the lateral incision. B. Alternatively, a two-incision rear-entry guide can be used. C,D. The lead sutures are used to bring the graft through the notch and out the anteromedial portal. E. After a rasp is used to create a groove in the anterior tibia, under the intermeniscal ligament, a curved clamp is placed under the intermeniscal ligament (F) and the graft is brought to the anterior aspect of the knee. (A,C,E,F: From Kocher MS, Weiss JM. ACL reconstruction in the skeletally immature patient. In Tolo VT, Scaggs DL, eds. Master Techniques in Orthopaedic Surgery: Pediatrics. Philadelphia: Lippincott Williams & Wilkins, 2008:277–287.)

**TECH FIG 3** • Graft fixation for physeal-sparing anterior cruciate ligament reconstruction. A. With the knee flexed 90 degrees, tension on the graft, and the foot externally rotated 30 degrees, the graft is secured to the intermuscular septum and the periosteum of the posterior lateral femoral condyle near the over-the-top position. B. With the knee flexed to 20 degrees, the tensioned graft is secured to the periosteum at the roughened margins of a trough in the proximal tibia. Fluoroscopic imaging is used to ensure that the proximal tibial physis is not disturbed. (A: From Kocher MS, Weiss JM. ACL reconstruction in the skeletally immature patient. In Tolo VT, Scaggs DL, eds. Master techniques in orthopaedic surgery: pediatrics. Philadelphia: Lippincott Williams & Wilkins, 2008:277–287.)
TECHNIQUES

Part 4

Harvest and Preparation of Autogenous Hamstrings Tendon Graft

- Hamstrings are routinely harvested at the start of the case if the diagnosis is not in question. However, if the diagnosis is in doubt, arthroscopy can be performed first to confirm ACL tear.
- The leg is placed in a slightly externally rotated position with the knee slightly bent.
- A 4-cm incision is made over the palpable pes anserinus tendons on the medial side of the upper tibia.
- Dissection is carried through skin to expose the sartorius fascia.
  - The underlying gracilis (superior) and semitendinosus (inferior) tendons are identified by palpation.
  - A longitudinal incision is made in the flat sartorius fascia. The cordlike gracilis and semitendinosus tendons are identified on its deep surface.
  - The tendons are dissected free distally and their free ends whipstitched with no. 2 or no. 5 Ethibond suture.
  - They are dissected proximally using sharp and blunt dissection. Fibrous bands to the medial head of the gastrocnemius should be sought and must be completely released before proceeding with tendon stripping.
  - A closed tendon stripper is used to dissect the tendons free proximally. Firm, steady longitudinal retraction is placed on the tendons individually as the tendon stripper is gently and slowly advanced proximally collinear to the vector of pull of the tendons.
  - Alternatively, the tendons can be left attached distally and an open tendon stripper used to release the tendons proximally.
  - The tendons are taken to the back table and excess muscle is removed by scraping with the side of a no. 15 blade or a Freer.
  - The ends are whipstitched with no. 2 or no. 5 Ethibond suture.
  - The tendons are folded over a closed loop EndoButton.
  - The graft diameter is sized and the graft is placed under tension with wet gauze around it.

Arthroscopy

- Arthroscopy of the knee is then performed through standard anterolateral viewing and anteromedial working portals.

- Management of meniscal injury or chondral injury is performed if present.
- The ACL remnant is excised with the use of biting instruments and the shaver to reveal the anatomic footprint on the tibia and the over-the-top position on the femur.
- Minimal notchplasty is performed to avoid iatrogenic injury to the perichondrial ring of the distal femoral physes, which is very close to the over-the-top position (see Fig 1).

Tibial Tunnel Preparation

- A tibial tunnel guide (set at 50 to 55 degrees) is used through the anteromedial portal.
- The hamstrings harvest incision is used and a guidewire is drilled into the posterior aspect of the ACL tibial footprint.
- The guidewire entry point on the tibia should be kept medial to avoid injury to the tibial tubercle apophysis.
- The guidewire is reamed with the appropriate-diameter reamer based on the size of the graft.
- Excess soft tissue around the tibial tunnel is excised to avoid the formation of a cyclops lesion, which may limit postoperative ROM.
- The posterior rim of the tunnel is smoothed with a rasp to prevent graft abrasion over a sharp tunnel edge.

Femoral Tunnel Preparation

- The transtibial over-the-top guide of the appropriate offset to ensure a 1-mm or 2-mm back wall is passed through the tibial tunnel and hooked around the back wall of the femur in the notch. Rotating the guide and slightly extending the knee help facilitate passage past the posterior cruciate ligament.
- It is rotated to the 10:30 position on a right knee (1:30 on a left knee) and used to pass the femoral guide pin.
- The femoral guide pin is overdrilled with the EndoButton reamer.
- Both are removed and a depth gauge is used to measure the femoral tunnel length.
- The guide pin is replaced and brought through the distal lateral thigh.
- The femur is reamed to the appropriate depth (femoral tunnel length – EndoButton length + 6 to 7 mm to flip the EndoButton).

Graft Passage and Fixation

- The no. 5 Ethibond sutures on the EndoButton are placed in the slot of the guidewire and pulled through the tibial tunnel, through the femoral tunnel, and out the lateral thigh.
- One set of sutures is used to “lead” the EndoButton, while the other set of sutures is used to “follow.” The lead sutures are used to pull the graft through the tibial tunnel and into the femoral tunnel (TECH FIG 4A).
- Once the graft is fully seated in the femoral tunnel, the “follow” sutures are pulled to flip the EndoButton.
(TECH FIG 4B). The flip can be palpated in the thigh, and tension is applied to the graft to ensure that there is no graft slippage.

- The knee is then extended to ensure that there is no graft impingement and cycled about 10 times with tension applied to the graft.
- The knee is flexed to 20 to 30 degrees, tension is applied to the graft, and a posterior force is placed on the tibia.

- On the tibial side, the graft is fixed either with a soft tissue interference screw if there is adequate tunnel distance (at least 30 mm) below the physis to ensure metaphyseal placement of the screw or with a post and spiked washer (TECH FIG 4C,D).
- Fluoroscopy can be used to ensure that the fixation is away from the physis.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>History and physical examination</th>
<th>Because of normal physiologic laxity in adolescents, physical examination findings should always be compared to the opposite side.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic imaging</td>
<td>MRI in skeletally immature knees is less sensitive and specific for evaluating ACL tears than in adult knees.</td>
</tr>
<tr>
<td>Graft preparation</td>
<td>With the physeal-sparing approach, the surgeon should avoid having too short of a graft to adequately secure to the tibia by harvesting a long enough strip of iliotibial band fascia.</td>
</tr>
<tr>
<td></td>
<td>With autograft hamstring harvest, care should be taken to clear all bands attached to the hamstring tendons before performing tendon stripping.</td>
</tr>
<tr>
<td></td>
<td>Grafts should be handled carefully and secured while waiting for insertion.</td>
</tr>
<tr>
<td>Arthroscopy</td>
<td>The surgeon should avoid dissection or notching around the posterolateral aspect of the physis during over-the-top nonphyseal femoral placement to avoid potential injury to the perichondrial ring and subsequent deformity.</td>
</tr>
<tr>
<td>Tunnel preparation</td>
<td>Large tunnels should be avoided as the likelihood of arrest is increased with greater violation of epiphyseal plate cross-sectional area.</td>
</tr>
<tr>
<td>Graft fixation</td>
<td>The surgeon should avoid fixation that crosses the physis, particularly across the lateral distal femoral epiphyseal plate, which seems to have the greatest risk of producing a growth disturbance.$^7,9$</td>
</tr>
<tr>
<td></td>
<td>For tibial fixation while performing the physeal-sparing technique, the surgeon should stay medial to avoid damage to the vulnerable tibial tubercle physis.</td>
</tr>
<tr>
<td>Postoperative care</td>
<td>The patient’s emotional maturity and ability to comply with postoperative rehabilitation protocols should be factored into the clinician’s recommendations. Slower rehabilitation protocols should be used for some patients.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE
- Rehabilitation after ACL reconstruction in skeletally immature patients is essential to ensure a good outcome, allow return to sports, and avoid reinjury.
- Rehabilitation in prepubescent children can be challenging. A therapist who is used to working with children and can make therapy interesting and fun is very helpful.
- Compliance with therapy and restrictions should be carefully monitored.
- Weight bearing is limited to touch-down weight bearing for 6 weeks for the physeal-sparing technique and for 2 weeks for the transphyseal technique in adolescents with growth remaining.
- A protective brace is used for 6 weeks postoperatively.
- ROM is limited from 0 to 90 degrees for the first 2 weeks, followed by progressive full ROM.
- A continuous passive motion (CPM) machine from 0 to 90 degrees and cryotherapy are used for 2 weeks postoperatively.
- Progressive supervised rehabilitation consists of ROM exercises, patellar mobilization, electrical stimulation, pool therapy (if available), proprioception exercises, and closed-chain strengthening during the first 3 months postoperatively. A running program that progresses through straight-line jogging, plyometric exercises, and finally sport-specific exercises follows.
- Return to full activity, including cutting sports, is usually allowed at 6 months if the patient has achieved full ROM, has 90% strength compared to the uninjured leg, and can perform a single-leg hop to 90% of the uninjured leg.
- A functional knee brace is routinely used during cutting and pivoting activities for the first 2 years after return to sports.

OUTCOMES
- Performed properly, physeal-sparing combined intra-articular and extra-articular ACL reconstruction using iliotibial band in preadolescent skeletally immature patients appears to provide an excellent functional outcome, with a low revision rate and a minimal risk of growth disturbance.
- The largest study of outcomes after physeal-sparing reconstruction noted a 4.5% revision rate for graft failure at 4.7 and 8.3 years postoperatively, which is comparable to rates for reconstructive procedures in adults (2.3% to 5.3%).
- No cases of significant angular deformity measured radiographically or leg-length discrepancy measured clinically were noted in this series.

COMPPLICATIONS
- Growth disturbance
- Leg-length discrepancy
- Distal femoral valgus
- Tibial recurvatum with an arrest of the tibial tubercle apophysis
- Arthrofibrosis, particularly loss of extension
- Graft failure
- Recurrent instability despite an intact graft, requiring revision to more anatomic reconstruction at skeletal maturity
- Tunnel widening
- Infection
- Deep venous thrombosis

REFERENCES
DEFINITION

- Osteochondritis dissecans (OCD) is a relatively common cause of knee pain and dysfunction in children, adolescents, and young adults.
- OCD is an acquired potentially reversible idiopathic lesion of subchondral bone resulting in delamination and sequestration with or without articular involvement and instability.

ANATOMY

- Initially, softening of the subchondral bone and overlying articular cartilage is noted with an intact articular surface; this can progress to early articular cartilage separation and later osteochondral separation.

PATHOGENESIS

- Although the exact pathogenesis of OCD is unknown, several factors have been historically implicated, including repetitive trauma, ischemia, inflammation, accessory centers of ossification, and genetic factors.
- Overall it is likely that chronic repetitive microtrauma potentially leads to microfractures causing focal subchondral ischemia or alteration of growth. Some patients are believed to have a genetic, biochemical, or behavioral predisposition toward this condition.
- The name “osteochondritis dissecans” implies that this condition has an inflammatory etiology, but further study has not supported inflammation as a primary cause of OCD.
- Although abnormalities in ossification do not account for most cases of OCD as proposed by Ribbing in 1955,16 some incidentally found lateral femoral condyle lesions in younger children that resolve spontaneously may represent ossification variants.
- Based on their anatomic and histologic findings, Green and Banks8 proposed that ischemia was implicated in OCD, although further studies have failed to find a relative ischemic watershed of the lateral aspect of the medial femoral condyle, suggesting that this is not the primary causative factor.
- Petrie14 found OCD in 1 of 86 first-degree relatives, although Mubarak and Carroll15 reported 12 instances of family members with OCD over the course of four generations. While some familial tendencies exist, it is widely believed that the most common form of OCD is not familial.
- In 1933, Fairbanks6 suggested that OCD might be due to a “violent rotation inwards of the tibia, driving the tibial spine against the inner condyle.” Although isolated acute trauma and anterior tibial spine impingement may not be the etiology of lesions in the most common location of the posterolateral aspect of the medial femoral condyle, the frequent occurrence of OCD in patients who are involved in sports with repetitive impact supports a repetitive microtrauma etiology.

NATURAL HISTORY

- Crawford and associates5 followed 21 patients with undetached lesions left in situ with an average follow-up of 7.5 years.
- Healing was noted in the medial femoral condyle in 3 of 10 patients; healing elsewhere was noted in 10 of 11 patients.5

PATIENT HISTORY AND PHYSICAL FINDINGS

- Physical examination findings are often subtle.
- Children and adolescents with stable OCD lesions may walk with a slight antalgic gait.
- In late presentations in which an osteochondral flap or loose body is present, classic biomechanical symptoms including locking, catching, buckling, and giving way may occur.
- With careful palpation through varying amounts of knee flexion, a point of maximal tenderness often can be located over the anterior medial aspect of the knee. The tender area corresponds to the lesion, usually on the lateral aspect of the distal medial femoral condyle.
- With stable lesions, knee effusion, crepitus, and extreme pain through a normal range of motion are rarely observed.
- The Wilson sign may be helpful but is often not present. The Wilson test is performed by starting with the knee flexed to 90 degrees. The tibia is then internally rotated as the knee is extended from 90 degrees toward full extension.
- In a positive Wilson test, pain is elicited over the anterior aspect of the medial femoral condyle. This pain has been described as resulting from contact of the medial tibial eminence with the OCD lesion.
- The mechanical symptoms are more pronounced in the unusual circumstance in which the child or adolescent presents with an unstable lesion. An antalgic gait is common, and there is usually a knee effusion, possibly associated with crepitus, as the knee is taken through a range of motion.
- In stable and unstable presentations, both knees should be examined to determine whether the condition is bilateral. Ipsilateral quadriiceps atrophy may also be noted if the patient has been having pain for more than an extended period of time.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Imaging protocols have received close attention in the literature as a result of the varied success of nonoperative treatment. The goals of imaging are to characterize the lesion, determine the prognosis of nonoperative management, and monitor the healing of the lesion.
- Imaging workup begins with plain radiographs, including anteroposterior (AP), lateral, and tunnel views (FIG 1A–C).
- The tunnel view is particularly valuable since the typical OCD lesion is located on the flexion surface of the lateral aspect of the medial femoral condyle.
A Merchant view should be included to best reveal any OCD lesions of the patella or trochlea.

Plain radiographs usually characterize and localize the lesion and rule out other bony pathology of the knee region.

MRI is most useful for determining the size of the lesion and the status of the cartilage and subchondral bone (Fig 1D,E).

The extent of bony edema, the presence of a high-signal zone beneath the fragment, and the presence of other loose bodies are also important findings on initial MRI.

While less commonly used, technetium bone scans have been employed to provide information about the biologic capacity of an OCD lesion to heal.

**DIFFERENTIAL DIAGNOSIS**

- Irregular ossification
- Acute osteochondral fractures
- Meniscal injuries

**NONOPERATIVE MANAGEMENT**

An initial course of nonoperative management is the treatment of choice for skeletally immature children with small intact lesions.

Controversy exists regarding the ideal nonoperative management for these patients. Clinicians who adhere to treating the subchondral bone as the primary source of pathology favor a period of immobilization. Those whose focus is on the articular cartilage as a source of pathology tend to favor maintaining mobilization.

The options for immobilization include casting, bracing, and standard knee immobilization.

We recommend a three-phase approach to the nonoperative management of OCD lesions.

- Phase I
  - Weeks 1 to 6
  - Knee immobilization in a hinged brace. The patient may walk with the hinged brace locked in extension. The brace may be unlocked to work on range of motion for 5 minutes 5 times per day.

- Phase II
  - Weeks 6 to 12
  - If the patient is pain-free and radiographs show signs of healing after 6 weeks, he or she is allowed to begin weight bearing without immobilization and to begin a physical therapy protocol to improve knee range of motion and quadriceps and hamstring strength.

- Phase III
  - This phase is instituted if the patient continues to remain pain-free and shows radiographic evidence of healing.

  - This phase begins typically 3 months after treatment. Running, jumping, and cutting sports are permitted under close observation.

  - High-impact activities and activities that might involve shear stress to the knee should be restricted until the child has been pain-free for several months and the radiographs show a healed lesion.

  - The goal of nonoperative intervention is to promote healing in the subchondral bone and potentially prevent chondral collapse, subsequent fracture, and crater formation.

**SURGICAL MANAGEMENT**

It is widely accepted that operative treatment should be considered for patients with unstable or detached lesions, and in patients whose lesions have not resolved with an appropriate period of nonoperative management, especially in those approaching skeletal maturity.
Operative treatment is recommended if one or more of the following conditions are met: persistently symptomatic juvenile lesions, the presence of symptomatic loose bodies, predicted physeal closure within 1 year, or fragment detachment.

The goals of operative treatment are to promote healing of subchondral bone, to maintain joint congruity, to fix rigidly unstable fragments, and to replace osteochondral defects with cells that can replace and grow cartilage.

Optimal surgical treatment provides a stable construct of subchondral bone, calcified tidemark, and repair cartilage with viability and biomechanical properties equivalent to or similar to native hyaline cartilage.

Preoperative Planning

Careful preoperative evaluation and preparation are always imperative to the success of treatment.

All imaging studies obtained before surgery should be reviewed. If the avulsed fragment has a relatively large osseous component, then plain radiographs will usually demonstrate the lesion. However, radiographs do not demonstrate the actual size of the cartilaginous component. To demonstrate the cartilaginous component, MRI may be required to determine the extent of the lesion. Any other lesion noted on imaging studies should likewise be addressed.

Positioning

For arthroscopic procedures, the position largely depends on the surgeon’s preference. A variety of positions can be used.

- The leg can be placed in a leg holder on the operating table with the knee joint past the end of the operating table, thus allowing the knee to flex 90 degrees and the lower leg to hang freely.
- The leg can be placed supine on the operating table, with the hip flexed and the knee flexed 90 degrees. The knee can be flexed and the lower leg can in this case hang freely over the side of the operating table.

Approach

Standard arthroscopic parapatellar portals are initially used (FIG 2A).

- Accessory portals may be created higher or lower to the standard parapatellar portals if the lesion is excessively large or in an atypical location.

Transarticular drilling can be used for intact lesions, but it is particularly valuable when the lesion is detached, partially detached, or unstable (FIG 2B).

Epiphyseal drilling is reserved for cases with intact lesions (FIG 2C).

ARThROSCOPIC DRILLING OF INTACT OCD LESIONS

- The knee is exsanguinated and the tourniquet applied.
- An anterolateral portal is made for visualization and an anteromedial portal is made for instrumentation.
- A complete arthroscopic inspection of the knee is performed. Any other pathologies in the knee are recorded and treated accordingly.

Transarticular Drilling

- The lesion is identified (TECH FIG 1A).
- A 0.62-inch Kirschner wire is positioned perpendicular to the lesion (TECH FIG 1B). The portal used depends on the location of the defect.
- The key is to keep the Kirschner wire as perpendicular as possible. Additional portals as well as varying the degree of knee flexion and extension may be used as needed to achieve adequate position.

Transarticular drilling is performed under arthroscopic visualization.

- Appropriate depth of penetration is confirmed by the efflux of blood or fat from the drilled holes (TECH FIG 1C,D).

The drilling should be performed through the calcified tidemark in immature patients, taking care not to penetrate the physis.
**TECH FIG 1** • **A.** The knee is inspected and the lesion is identified. The *solid arrow* shows the intact cartilage side and the *open arrow* shows the osteochondritis dissecans side. **B.** A Kirschner wire is shown superimposed over a T1-weighted MRI. The arrow shows the direction of drilling. The smooth 0.62-inch Kirschner wire should be kept as perpendicular to the lesion as possible to prevent undermining the defect. **C, D.** The appearance of fat or blood demonstrates that subchondral bone has been penetrated.

**Epiphyseal Drilling**

- Once complete inspection has been performed, a 0.62-inch Kirschner wire is directed toward the lesion in a proximal-to-distal direction with fluoroscopic guidance and a guide (**TECH FIG 2**) to help maintain an appropriate angle.
  - The starting point of the Kirschner wire is immediately distal to the physis to avoid any damage.
  - The Kirschner wire is slowly advanced through the subchondral bone, taking care not to penetrate the articular cartilage.
  - The Kirschner wire is kept as perpendicular to the lesion as possible.
  - The position and depth of the Kirschner wires are confirmed using fluoroscopy.
  - Kirschner wires are inserted through the lesion several millimeters apart as needed.
  - Final inspection of the knee is performed and the Kirschner wires and instrumentation are removed.
  - Closure of the knee is performed and sterile dressing is applied before placing the knee in a knee immobilizer.

**TECH FIG 2** • Appropriate guides can be used for antegrade arthroscopic drilling.

**ARTHROSCOPIC DRILLING OF HINGED OCD LESIONS**

- The entire lesion is assessed and the bed is prepared. A débridement is performed until all granulation tissue and sclerotic bone beneath the flap is removed and subchondral bone is reached.
- In deep lesions, autograft or allograft cancellous bone grafting may be required to ensure that the hinged portion of the lesion is not recessed relative to the remaining unaffected cartilage within the knee.
- The lesion is reduced into its bed and fixed with a variety of implants, such as cannulated screws and Herbert screws. The fixation devices may be made of metal or bioabsorbable materials. The implant used depends on the surgeon’s preference.
- We prefer to use small bioabsorbable double-ended threaded compression screws for hinged lesions in which there is appropriate subchondral support (**TECH FIG 3**).
- Once the lesion is secured, drilling may be performed to augment healing.

**TECH FIG 3** • Small bioabsorbable double-ended threaded compression screws are used for hinged lesions in which there is appropriate subchondral support.
ARTHROSCOPIC DRILLING OF UNSTABLE OCD LESIONS

- The knee joint is inspected and loose fragments are removed from the knee joint as necessary (TECH FIG 4A–C).
- The bed of the lesion is inspected and a débridement is performed to remove any granulation tissue and sclerotic bone (TECH FIG 4D–F).
- In reducible lesions, the fragment is prepared as necessary by trimming the edges and securing the lesion into its bed. A variety of implants may be used to secure the lesion based on the surgeon’s preference.
- The joint is inspected before final closure.
- The arthroscopic instrumentation is removed and the arthroscopic portals are closed.
- The knee is placed in a hinged knee brace.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Surgical technique</th>
<th>Careful review of all prior imaging modalities and a complete clinical evaluation is performed before surgery.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transarticular drilling</td>
<td>The Kirschner wires should be kept as perpendicular to the lesion as possible to prevent detaching or undermining the lesion. This technique is indicated for intact OCD lesions.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- For patients with intact lesions:
  - We use a hinged knee brace in extension or slight flexion for 4 to 6 weeks.
  - Patients are permitted partial (1st week) then complete weight bearing with brace locked in extension.
  - This allows compression to stimulate healing while high-impact running and jumping activities are eliminated.
  - After the hinged brace is removed, patients are sent to physical therapy, where range-of-motion and strengthening exercises are performed.
  - Patients are restricted from running and jumping during weeks 6 through 12.
  - After 3 months repeat imaging (AP, lateral, notch, and tunnel views) is obtained.
  - Healing is typically noted in intact lesions. Occasionally the lesion is not completely healed and another 2 to 3 months of activity restriction are maintained until complete healing.

- For patients with full-thickness lesions:
  - Continuous passive motion (CPM) has been used to enhance the healing of the articular surface in the postoperative period for patients with full-thickness lesions. We prefer 6 weeks of CPM use.
  - CPM was shown to promote articular cartilage healing for moderately small lesions in rabbits (less than 3 mm in diameter). Similar effects were found in humans with predominantly 1- to 2-cm lesions by Rodrigo and colleagues; they reported that CPM for 6 hours per day for 8 weeks produced an improved clinical result.
  - Regardless of the treatment selected, the patient should have a rehabilitation program that combines protection of the compromised articular surface and underlying subchondral bone with maintenance of strength and range of motion.
  - Straight-leg raising and isometric exercises can be performed in the postoperative or immobilization period. In general, the straight-leg raising exercises are performed without resistance initially and advanced by adding 2 to
3 pounds per week, or as tolerated, until 10% of the patient’s body weight is reached.

- A 6- to 8-week home or formal physical therapy program is instituted, incorporating range of motion, stretching, progressive strengthening, and functional or sport-specific training.
- Closed-kinetic-chain exercises are initiated on the sixth week. During this time, the patients are kept out of running and jumping sports but are permitted to perform low-impact activities such as walking, submaximal biking, swimming, and activities of daily living.
- All high-impact activities are limited until 6 months after surgery for those patients treated for full-thickness lesions.
- If patients return to activity before the cartilage has become firm, they will typically complain of pain with maneuvers such as squatting or jumping.

OUTCOMES

- Nonsurgical treatment is often regarded as the treatment of choice for small stable lesions in skeletally immature patients. Typically a period of 3 to 6 months of nonoperative treatment is instituted, with numerous authors reporting a success rate of 50% to 94%.2–4,6–10
- Skeletally immature patients with wide open physes and no signs of instability on MRI are more likely to respond to nonoperative measures.16
- Bradley and Dandy2 reviewed 11 knees in 10 children treated with arthroscopic drilling and found evidence of healing in 9 of 11 knees after 12 months.
- Aglietti and coworkers1 reviewed 14 children (16 knees) treated with transarticular drilling after 1 year of conservative management and found all cases progressed to healing after treatment.
- Kocher and associates10 reviewed 30 knees in 23 patients treated with arthroscopic transarticular drilling after 6 months of conservative therapy. All patients who failed to respond to nonoperative measures were noted to have healed after drilling.

COMPLICATIONS

- Potential failure to heal, especially in older adolescents treated nonsurgically. The prognosis for OCD lesions is worse in those patients who have reached skeletal maturity. Patients who have been treated nonsurgically and have not shown progressive healing and those patients with large lesions that are approaching skeletal maturity are therefore treated surgically to promote healing.

REFERENCES

DEFINITION
- A discoid meniscus is abnormal in both thickness and amount of covering or interposition of the compartment or plateau.
- Over 99% of cases occur on the lateral side of the knee, with an overall incidence of 1% to 15% of the general population.
- Ten percent of children found to have a discoid meniscus will have it bilaterally.

ANATOMY
- Three types of discoid meniscus are described: complete (covering entire compartment), incomplete (on partial compartment covering), and Wrisberg (complete or incomplete compartment covering with no peripheral attachments).5
- Wrisberg type is by definition unstable, allowing displacement, popping, and locking as well.

PATHOGENESIS
- It arises either congenitally or through abnormal development. No cases have been found in autopsies of fetal deaths or stillborns.

NATURAL HISTORY
- Discoid menisci have frequently been found at autopsy in elderly, reportedly asymptomatic people.
- Frequently it is an incidental finding.
- Symptoms typically present in the late first or early second decade of life but may occur at any age.6
- Symptoms are pain with or without loss of motion.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The common presentation is a young child (younger than 10 years) with a catch or popping of the lateral side of the knee with motion, with or without pain.
- Some patients describe true mechanical locking symptoms.
- The patient may present with painful or painless loss of motion.
- The clinical examination may show a hypermobile lateral meniscus with palpable, audible, and frequently visual meniscal instability.
- Effusion is a common finding. Objective signs of swelling with or without activity indicate irritation of the joint and possible tearing.
- Loss of extension and joint line tenderness are also common.4
- A discoid meniscus with a tear or instability will click or pop and may be uncomfortable. The results of the McMurray test will help with diagnosis.
  - Positive: pain and a pop or click
  - Negative: no pain and no pop or click
  - Equivocal: pop or click or pain without the other
  - Significant mobility of the lateral meniscus, while not uncommon, normally may indicate a discoid meniscus.

In children, varus instability may be due to accommodation of the large discoid lateral meniscus. Collateral ligament test results are important.
- Normal: symmetric to the opposite side
- Mild: 1 to 3 mm of increased laxity from the opposite side

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographs may show flattening or sloping of the lateral femoral condyle, with widening of the lateral compartment compared to the medial compartment (FIG 1A).
- MRI will show the discoid meniscus the best (FIG 1B).
  - A discoid meniscus will be thicker and wider than a normal meniscus.
  - Frequently signal change is present in the center of the discoid meniscus; this could represent a tear or degenerative tissue.1
  - There should be no more than three consecutive 3-mm cuts of the body of a meniscus on the sagittal view before it is separated into an anterior and posterior horn. Coronal cuts may also show a wide, thickened meniscus (more than 12 to 15 mm).

FIG 1 • A. Radiographs may show no significant changes, although there may be a widened lateral joint on weight-bearing views, and relative flattening of the lateral femoral condyle may be present. B. MRI shows the discoid meniscus clearly with a thickened, wide meniscus that also has abnormal signal intensity throughout the lateral meniscus.
DIFFERENTIAL DIAGNOSIS
- Meniscal cyst
- Tear in a normal meniscus
- Anterior cruciate ligament tear
- Hypermobile lateral meniscus
- Osteochondritis dissecans
- Patellofemoral instability or dislocation

NONOPERATIVE MANAGEMENT
- If there is no loss of motion or locking, a period of nonoperative management is the first line of defense.
- Nonoperative treatment consists of activity modifications, anti-inflammatory medications, and swelling control (ice, elevation, and compression).
- Patients with intermittent symptoms only that can be controlled with mild doses of nonsteroidal anti-inflammatories are candidates for nonoperative management.

SURGICAL MANAGEMENT
- If locking, loss of motion, or persistent pain and disability exists despite nonoperative management, surgical intervention is indicated.3

Preoperative Planning
- The surgeon should review imaging studies to evaluate the likelihood of a tear or the presence of other pathology.
- The knee examination is repeated under anesthesia, including ligamentous testing, range of motion, and the McMurray test to evaluate whether significant lateral meniscal instability is present.

**ARTHROSCOPIC SAUCERIZATION OF A DISCOID LATERAL MENISCUS**
- After systematic arthroscopic evaluation of the knee is performed, the lateral compartment is opened in the figure 4 position.
- The type of discoid meniscus is determined using a probe sequentially over and under the posterior horn of the meniscus, pulling forward to evaluate displacement.
- Displacement of more than 40% to 50% anteriorly is unstable and requires stabilization with suture fixation.
- Determining peripheral instability may be difficult until the meniscoplasty is at least partly completed.
- Starting in the notch, the free edge of the discoid meniscus is identified (TECH FIG 1A–C).
- May indicate higher likelihood of the Wrisberg type of discoid meniscus.

**Positioning**
- The patient is positioned supine.
- A tourniquet is placed on the proximal thigh of the operative leg over padding.
- A leg holder is placed over the tourniquet.
- The opposite leg is padded and is placed in slight flexion at the hip.
- The foot of the bed is flexed 90 degrees, allowing both legs to flex 90 degrees over the edge of the table.

**Approach**
- Three standard arthroscopic portals are established with a no. 11 blade through stab incisions: inferolateral parapatellar portal for scope visualization, inferomedial parapatellar portal for instruments, and lateral suprapatellar pouch portal for outflow.
- An accessory anterolateral portal may be established for another working portal.
- If the remnant of the discoid meniscus is unstable or torn, requiring fixation or stabilization, a posterolateral approach should be made for inside-out suture fixation.
- A lateral incision is made from the joint line distally by 2 cm, longitudinally in line with the posterior aspect of the fibular head.
- The interval between the biceps femoris and the iliotibial band is entered, as is the space deep to the lateral head of the gastrocnemius.
- A posterior knee retractor is placed in this interval as far medially as possible to protect the neurovascular bundle.
ALTERNATIVE TECHNIQUE FOR MENISCOPLASTY

- The accessory anterolateral portal is made under direct visualization to ensure that there is no inadvertent damage of the peripheral meniscus.
- The free edge of the discoid meniscus is grabbed with an arthroscopic locking grasper through the medial portal.
- A meniscal knife is carefully placed through the accessory lateral portal, ideally with a protective cannula or a sheath.
- Under tension, the discoid meniscus is incised from the anterior notch, leaving about 15 mm of anterior rim, directed toward the junction of the anterior horn and body.
- The surgeon should keep in mind the normal curved architecture of the meniscus.
- At this point the surgeon may need to regrasp the free edge of the discoid meniscus closer to the leading edge of the incised meniscus.
- The knife is then turned to cut along the body of the meniscus.
- The surgeon amputates and removes the flap of the cut discoid, leaving the posterior portion of the discoid left to finish.
- The surgeon piecemeals the remaining excess posterior aspect of the discoid with arthroscopic biters and shaver.
- The remnant is smoothed or thinned with a shaver, biters, or both.

PEARLS AND PITFALLS

| Indications                      |  |
|---------------------------------|  |
| Locking, loss of motion, or persistent pain |  |

| Portal placement                 |  |
|----------------------------------|  |
| Accessory portals are potentially dangerous; they should be placed under direct arthroscopic vision and control. |  |
| A spinal needle is used to identify the level of portal before making the incision. |  |

| Meniscal handling                |  |
|----------------------------------|  |
| The abnormal meniscus is typically difficult to handle arthroscopically owing to its thickness. All the tools at the surgeon's disposal (biters, shaver, meniscal knives) should be used to shape the meniscus. |  |

| Failure to recognize instability |  |
|----------------------------------|  |
| Snapping or pain may be due to a tear of the discoid or an unstable variant. |  |
| It may be difficult to identify some unstable menisci on initial evaluation. |  |
| After saucerization is underway or completed, probing and stability testing are repeated to ensure that an unstable variant or tear is not missed. |  |

| Failure of stabilization         |  |
|----------------------------------|  |
| Stabilization of a congenitally unstable meniscus may fail even with meticulous technique. |  |
| All inside techniques are less successful when used for the lateral meniscus, especially with larger tears. |  |
| Inside-out technique should be used when an unstable or Wrisberg variant is encountered. |  |
| The surgeon should rasp, irritate, or freshen the vascular portion of the meniscus and the synovial lining of the lateral compartment before fixation. |  |

| Leaving the right amount         |  |
|----------------------------------|  |
| The surgeon should aim to leave about 8 mm of meniscus behind. |  |
POSTOPERATIVE CARE

- Weight bearing depends on whether a meniscal repair or stabilization was performed. Immediate weight bearing as tolerated with crutches may be instituted if the discoid meniscus was saucerized only.
- If a stabilization or repair was needed, touch-down weight bearing with crutches, or wheelchair non-weight bearing for young children, is maintained for 4 to 6 weeks.
- Immediate motion (at least 0 to 90 degrees) should be initiated in all children, with full range of motion for saucerization without repair.
- An Ace bandage is used for edema control as needed.
- Bracing is typically not needed. For repairs or stabilizations to limit meniscal stress, a range-of-motion brace (0 to 90 degrees) may be used.
- Physical therapy is useful for obtaining range of motion, as well as initiation of quadriceps activation and strengthening.

COMPLICATIONS

- Infection
- Arthrofibrosis
- Iatrogenic damage
- Subtotal or total meniscectomy
- Nerve or peroneal damage
- Failure of stabilization or repair
- Additional surgery

REFERENCES

DEFINITION
- Femoral anteversion is the angle in the transverse plane by which the neck of the femur is directed (forward) relative to the transcondylar or coronal plane.

ANATOMY
- Femoral anteversion is measured from the projection of the femoral neck axis and the transcondylar axis onto the (transverse) plane perpendicular to the long axis of the femur (FIG 1).
- The terms femoral anteversion and femoral torsion are sometimes used interchangeably, the latter term preferred by those who believe that the orientation of the proximal femur relative to the distal condyles is a consequence of torsion occurring in the shaft of the femur rather than in the neck.6,17,20

PATHOGENESIS
- At birth the femoral anteversion is estimated to be 30 to 50 degrees.
- During normal development, as the child crawls, pulls up to stand, and then walks, hip extension against the anterior iliofemoral ligaments pushes back on the cartilaginous femoral head, gradually decreasing the femoral neck anteversion. The increased anteversion of infancy “unwinds” spontaneously with growth.
- This natural remodeling process may be impaired because of abnormal hip anatomy, developmental delay, abnormal muscle tone, or ligamentous laxity, resulting in the persistence of the increased anteversion of infancy.21
- Increased anteversion has been associated with a number of clinical conditions, including cerebral palsy, developmental hip dysplasia, and Perthes disease.2,7,12,24

NATURAL HISTORY
Physiologic Anteversion
- In some children the increased anteversion of infancy may persist without any other identifiable pathology. This is the most common cause of in-toeing in children. Most of these cases resolve spontaneously with growth by the time of puberty.7
- In a few children, anteversion persists into adolescence. Most children compensate well and only in a small minority does this interfere with their gait or physical function.

Cerebral Palsy
- Cerebral palsy is associated with developmental delay. By the time the child stands or walks, the more ossified femoral head and neck is less likely to remodel in response to increasing hip extension. This may be further compromised because of the presence of hip flexion contractures. Furthermore, spasticity of the muscles that internally rotate the femur, such as the medial hamstrings and anterior gluteals, may contribute to the development of increased anteversion. Consequently, the increased anteversion of infancy may persist or even increase.
- To seat the femoral heads congruously within the acetabulum during walking, the limb is internally rotated and the pelvis tilted anteriorly (increased lumbar lordosis), resulting in significant gait anomalies.8
- In the face of increased femoral anteversion, the greater trochanter and the insertion of the gluteus medius are located more posterior. This effectively reduces the abductor lever arm.1
- In children with severe nonambulatory cerebral palsy, the increased anteversion and coxa valga are features of the hip at risk for dislocation.
- Increased anteversion is a component of “miserable malalignment syndrome,” which has been implicated as a source of patellofemoral pain and instability.5,13
- There is conflicting evidence linking abnormally increased or decreased femoral anteversion with osteoarthritis of the hip and knee.2,6,27
- Slipped capital femoral epiphysis has been associated with decreased anteversion or even retroversion.9

PATIENT HISTORY AND PHYSICAL FINDINGS
- This is a common cause for in-toeing in children.
- Children are more likely to sit in the W position and may not be able to sit cross-legged (FIG 2). This is because their hips can rotate internally more than they can rotate externally.
- Normal foot progression angle during walking is 5 to 10 degrees external. Internal foot progression angle accompanied by medial or internal rotation of the knee is attributable to increased internal rotation at the hip associated with increased femoral anteversion.
- Normal or even abnormal external foot progression angle may be present in the face of increased femoral anteversion when it is accompanied by excessive external tibial torsion.
- Examination of the torsional profile in the prone position indicates the presence of increased femoral anteversion. The
Part 4 PEDIATRICS • Section III RECONSTRUCTION

The magnitude of anteversion can be quantified by physical examination using the palpable prominence of the greater trochanter as a proxy for the femoral neck axis. This method, first described by Netter, was adapted by Ruwe and associates, who also described an intraoperative method to estimate anteversion that could be applied at the time of derotational osteotomy of the proximal femur. The accuracy of the physical examination method has been evaluated by Davids and coworkers.3

IMAGING AND OTHER DIAGNOSTIC STUDIES

A number of imaging techniques have been described to estimate femoral anteversion, including plain radiography, CT, ultrasonography, and MRI (FIG 3).

DIFFERENTIAL DIAGNOSIS

Increased anteversion is encountered in the following situations:

- Physiologic anteversion
- “Miserable malalignment syndrome”
- Cerebral palsy
- Developmental hip dysplasia
- Legg-Calvé-Perthes disease

NONOPERATIVE MANAGEMENT

Attempts to treat increased femoral anteversion with twister cables and other braces have been abandoned as the natural history of spontaneous remodeling came to be understood.22

SURGICAL MANAGEMENT

Indications

- Increased anteversion with severe medial rotation of the lower extremity and increased internal foot progression angle that has failed to resolve by adolescence, and is interfering with gait and function due to tripping
- Increased femoral anteversion associated with increased external tibial torsion and genu valgum, the so-called miserable malalignment syndrome when it is associated with patellar instability or patellofemoral pain refractory to nonoperative methods of treatment
- Increased femoral anteversion in children with ambulatory cerebral palsy, in whom the increased internal rotation of the hip results in significant abductor “lever arm dysfunction,” leading to impaired gait efficiency, instability, and tripping. Increased femoral anteversion may be accompanied by increased external tibial torsion, which must be simultaneously addressed with internal tibial derotational osteotomies to optimize the ultimate foot progression angle while walking.
- Increased anteversion along with coxa valga is a component of the abnormal proximal femoral anatomy in longstanding cases of congenital, developmental, or neurogenically acquired hip dislocations. In these instances, the proximal femoral derotational osteotomy is combined with varusization of the femoral neck. The proximal femoral varus derotational osteotomy is described in Chapter PE-27.

Preoperative Planning

Preoperative planning involves quantifying the extent of the femoral anteversion in order to guide the extent of derotation required.

- Assessment of the torsional profile of the entire limb is critical because any proximal corrections will result in distal consequences if distal torsional malalignments are not taken into consideration and concurrently addressed.
- In most children physical examination by the method described above is adequate to detect the presence of increased anteversion and to quantify it accurately enough to guide surgical correction. Generally, preoperative axial imaging such as CT scan is unnecessary, as the magnitude of intraoperative corrections is also based on the physical examination technique.
- In children with ambulatory cerebral palsy whose femoral anteversion is possibly one of a number of multilevel lower extremity soft tissue and bony abnormalities, there may be great value in conducting a 3-D gait analysis. Gait analysis provides a dynamic assessment that can provide useful transverse plane kinematics and kinetics to help guide the decision regarding the need for and amount of derotation.
- Plane radiographs are important, including an anteroposterior (AP) view of the pelvis to include the proximal femurs and frog-leg lateral views of each proximal femur.

FIG 2 • W-sitting (A) is easier than sitting cross-legged (B) for children with increased femoral anteversion.

FIG 3 • CT method of estimating femoral anteversion involves overlapping images of three slices: the femoral head, the femoral neck at the base, and the distal femur through the femoral condyles.
Positioning
- The supine position is preferred when other operations necessitating this position are necessary, such as intramuscular psoas lengthening, pelvic osteotomies, or rectus femoris transfers (FIG 4A).
- The prone position has the advantage of permitting the same intraoperative assessment of the torsional profile as the preoperative assessment (FIG 4B,C). The exposure is facilitated by the reflected vastus lateralis falling away from the field of surgery owing to gravity.
- The prone position allows other concomitant operations to be performed, such as posterior knee (hamstring lengthening) or posterior calf surgery.
- This position does not permit anterior pelvic or hip surgery.

Approach
- Standard lateral approach to the proximal femur

PROXIMAL FEMORAL DEROTATIONAL OSTEOTOMY WITH 90-DEGREE AO BLADE PLATE: SUPINE TECHNIQUE

Positioning, Incision, and Exposure
- The patient is positioned supine on the radiolucent table.
- The image intensifier is set up perpendicular to the long axis of the table, from the contralateral side, to obtain clear AP and frog-leg lateral images of the proximal femur.
- Both lower extremities are prepared and draped free to permit assessment and comparison of the torsional profile.
- A longitudinal incision is made along the lateral aspect of the proximal thigh starting at the level of the greater trochanteric prominence and extended distally for about 10 to 12 cm in line with the femur.
- The underlying fascia lata is divided in line with the skin incision to expose the vastus lateralis and the overlying bursa at the level of the greater trochanter.
- The vastus lateralis is divided transversely at its origin on the trochanteric ridge, which corresponds to the inferior level of the insertion of the gluteus medius anteriorly (TECH FIG 1A).
- The vastus lateralis separation is continued inferiorly in an L-shaped manner along its posterior margin just anterior to the insertion of the gluteus maximus (TECH FIG 1B).
To minimize injury to the muscle belly, the thin fascia over the vastus lateralis is divided along the posterior margin close to the linea aspera, and the muscle is peeled off the septum with a broad elevator or cautery until the subperiosteal surface of the lateral aspect of the proximal femur is exposed (TECH FIG 1C).

Care is taken to identify and cauterize the perforators as they are encountered.

The vastus lateralis is then elevated subperiosteally until the lateral surface of the femur is adequately exposed for sufficient distance to accommodate the length of the blade plate (TECH FIG 1D).

At the level of the planned osteotomy, at the upper end of the lesser trochanter, the periosteum is elevated circumferentially with a narrow curved elevator.

The transverse osteotomy at this level heals rapidly and permits the use of strong internal fixation (blade plate), obviating the need for casting or any other external immobilization.

Preparation for Osteotomy and Fixation

Using the image intensifier, a guide pin is inserted through the middle of the superior portion of the proximal femoral neck at an angle that is 90 degrees to the long axis of the femur.

An effective way of ensuring that the initial guide pin is in the middle of the femoral neck axis in the transverse plane is to internally rotate the lower extremity and hip until the prominence of the greater trochanter is directly lateral. This usually occurs when the neck axis has been horizontalized.

With the lower extremity held in this position, the guide pin can be inserted parallel to the floor.

Because the greater trochanter is set slightly posterior relative to the neck axis, the starting point is best made in line with the middle of the AP width of the femur just distal to the greater trochanter.

On the AP image the guide pin needs to be sufficiently proximal (superior) to provide enough room to permit the introduction of the seating chisel inferior to the guide pin (TECH FIG 2A).

On the frog-leg lateral view, the guide pin should lie in the middle of the femoral neck in line with the neck axis (TECH FIG 2B).

The seating chisel is then used to create the hole in the bone to accommodate the blade plate.

Depending on the age of the child and the size of the bone, the matching seating chisel corresponding to the appropriately sized blade plate is used (infant, toddler, child, adolescent, or adult).

The seating chisel must be inserted perpendicular to the long axis of the femur if derotation is the only objective (TECH FIG 2C). Any deviation from the perpendicular on the AP view will lead to varus or valgus changes in the neck-shaft axis.

The face of the seating chisel should also be perpendicular to the long axis (in the sagittal plane) to prevent unintended flexion or extension through the osteotomy (TECH FIG 2D).

The direction of the seating chisel for the blade plate can be adjusted if the guide pin is not perfectly aligned.

Alternatively, if a cannulated seating chisel is available, the guide pin must be placed in the correct position for the seating chisel.

The disadvantage of a cannulated system is that there is no room for error in the placement of the guide pin. Furthermore, the blade plate itself is not cannulat-
lated, which necessitates removal of the guide pin (in addition to the seating chisel) at the time of insertion of the blade plate, which removes an important guide for its introduction.

- The seating chisel is advanced up to the depth of the selected blade length. The depth in millimeters of the seating chisel is marked on its inferior surface.
- In older ambulatory children with healthy bone, the seating chisel should be intermittently backed out to prevent its impaction in the strong bone.
- It is prudent to back the chisel out, short of its final resting position, before completion of the osteotomy to facilitate its removal in exchange for the blade plate (TECH FIG 2E).

**Osteotomy**

- The level of the transverse osteotomy is marked on the bone with a marking pen or cautery. This is done about 1 to 1.5 cm below the level of the seating chisel, at the upper end or just proximal to the lesser trochanter (TECH FIG 3A).
- The periosteum is elevated circumferentially at this level to allow placement of protective retractors during the osteotomy.
- Two smooth pins (2.5-mm Kirschner wires) are placed in an anterior-to-posterior direction parallel to each other and perpendicular to the long axis, just proximal and distal to the proposed osteotomy site respectively (TECH FIG 3A).
- These two pins will serve as useful retractors of the vastus lateralis muscle anteriorly, and as joysticks to retain effective control of the proximal and distal segments after the osteotomy.
- At the time of the derotation, the angle between the distal and proximal pins accurately gauges the magnitude of correction obtained and maintained during fixation of the blade plate.
- The transverse osteotomy is completed with an oscillating saw directed perpendicular to the long axis of the femur and parallel to the seating chisel above (TECH FIG 3B, C).

**Derotation and Fixation**

- The seating chisel is removed in exchange for the matching 90-degree blade plate of appropriate blade length (TECH FIG 4A).
- The blade is inserted manually into the seating hole using thumb pressure. The blade plate holder is struck with a mallet to advance the blade until the plate lies adjacent to the lateral surface of the femur (TECH FIG 4B).
- The plate is held against the distal segment of the femur using a plate-holding clamp such as the Verbrugge clamp (TECH FIG 4C).
- Before securing the plate, the lower extremity (along with the distal femoral segment) is externally rotated by the desired angle of derotation that can be estimated by the position of the distal pin relative to the proximal pin (TECH FIG 4D).
- Since the guide pin in the femoral neck has been placed along the middle of the neck axis, it is relatively simple to estimate the new femoral anteversion.
- If the lower extremity is held with the patella positioned anteriorly, then the angle between the femoral neck guide pin and the horizontal plane is the new angle of femoral anteversion.
- Once the desired degree of derotation has been set, the plate is secured to the bone with standard fully threaded...
The plate is held against the femur with a plate-holding (Verbrugge) clamp. The distal fragment is externally rotated by the desired amount using the two AP pins to judge the angle of correction. The plate is secured with cortical screws and the osteotomy is compressed. An impacter is used to advance the blade plate to its full depth. AP view of the proximal femur. Frog-leg lateral view of the proximal femur.

C. After fixation with the first screw, the arc of rotation is estimated (with the hip extended) using the guide pins to quantify the amount of internal and external rotation from the neutral position.
D. At least two of the screws are placed eccentrically to compress the osteotomy site.
E. The impacter is used to advance the blade plate to its full depth.
F. The guide pins are removed and AP and frog-leg lateral images obtained to confirm satisfactory position of the blade plate.
G. Wound Closure
H. 

Wound Closure
- The vastus lateralis is reattached to its origin on the trochanteric ridge with absorbable braided 0 suture so that the entire plate is covered (TECH FIG 5). Two or three tacking sutures are used to reattach the posterior edge of the vastus fascia to the septum.
- The wound is closed in layers, including the fascia lata, the subcutaneous tissue, and the skin. Absorbable running subcuticular suture will obviate the need for suture removal.
- The patient is positioned prone on appropriate (low) bolsters to support the chest and iliac crests, keeping pressure off the abdomen and the genitalia.
- The table mattress padding under the thigh segments can be built up to keep the hips relatively extended.
- The approach and dissection are identical to those described for the supine technique; only the orientation must be remembered with the anterior vastus lateralis now falling away from the operative field (TECH FIG 6A).
- The torsional profile in the prone position is much easier to verify and compare with the contralateral side (TECH FIG 6B, C).
Chapter 26  PROXIMAL FEMORAL ROTATIONAL OSTEOTOMY  1193

TECH FIG 6 • Proximal femoral derotation osteotomy using the prone technique. A. Orientation of the exposure in the prone position. B, C. Intraoperative ability to estimate the torsional profile.

PROXIMAL FEMORAL DEROTATIONAL OSTEOTOMY WITH A REGULAR LOW-CONTACT DYNAMIC COMPRESSION (LCDC) PLATE

- Using the identical approach described above, the derotational osteotomy can be stabilized with a regular LCDC plate.
- For secure fixation, the osteotomy would have to be done lower, in the subtrochanteric region, to allow a sufficient number of screws (at least three) proximal to the osteotomy.
- The fixation is not as strong as that afforded by a blade plate but might be adequate in most children.
- This is not a good technique if derotation of the proximal femur is combined with varusization for hip instability.

DISTAL FEMORAL DEROTATIONAL OSTEOTOMY

- There is controversy about whether a distal or proximal femoral osteotomy is the optimal method to address abnormal femoral torsion or anteversion.
- The distal femoral derotational osteotomy is described elsewhere.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Preoperative planning</th>
<th>Assessment of the complete torsional profile is essential to prevent unintended postoperative consequences.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation of 90-degree blade plate</td>
<td>The seating chisel and the blade plate must be introduced at right angles to the long axis of the femur both in the coronal and sagittal planes, if derotation is the only goal.</td>
</tr>
<tr>
<td></td>
<td>Any significant deviation in the orientation of the blade plate in the coronal plane will result in unintended varus or valgus.</td>
</tr>
<tr>
<td></td>
<td>Any significant deviation in the orientation of the blade plate in the sagittal plane will result in unintended flexion or extension.</td>
</tr>
<tr>
<td>Orientation of osteotomy</td>
<td>The orientation of the transverse osteotomy must also be at right angles to the long axis of the femur both in the coronal and sagittal planes, if derotation is the only goal.</td>
</tr>
<tr>
<td></td>
<td>The osteotomy should be made parallel to the seating chisel.</td>
</tr>
<tr>
<td>Derotation technique</td>
<td>The use of two parallel anteroposterior guide pins placed just proximal and distal to the line of the osteotomy provides an excellent guide to judge the magnitude of derotation, while providing a joystick to fine-control the position of the fragments at the time of fixation. This is particularly useful when using the supine technique, where the femoral anteversion and correction are more difficult to estimate.</td>
</tr>
<tr>
<td></td>
<td>The two pins also provide useful retraction of the overhanging muscle belly of the vastus lateralis when the supine position is used.</td>
</tr>
</tbody>
</table>
**POSTOPERATIVE CARE**

- With secure blade plate fixation, external immobilization is seldom if ever required. External immobilization in the form of a below-knee cast or a knee immobilizer may be indicated for concomitant procedures, but not for the femoral derotational osteotomy per se.
- Touch-down weight bearing (no more than the weight of the lower extremity) is permitted on the affected lower extremity.
- If the procedure is done bilaterally, the child is unable to bear weight safely and a wheelchair is required.
- Depending on the age and ambulatory status of the child, progressively increased weight bearing is permitted from 4 to 6 weeks postoperatively.
- Supported weight bearing in a pool may be possible as early as 3 weeks postoperatively.
- Once there is clinical and radiographic evidence of union and consolidation of the osteotomy, all restrictions can be lifted (FIG 5).

**OUTCOMES**

- Little is known about the long-term outcomes of femoral derotational osteotomies, as these are seldom done in isolation.
- If adequate correction is achieved, ambulatory patients can expect to experience noticeable benefits in the appearance of their gait. Whether there are measurable functional improvements is less clear.
- In conditions like cerebral palsy, the primary pathology in the brain cannot be addressed. Consequently, the abnormal forces that created the increased anteversion in the first place may contribute to its recurrence in the growing child.
- There is no clear indication for routine removal of hardware.

**COMPLICATIONS**

- Undercorrection
- Overcorrection
- Unrecognized or unaddressed abnormal tibial torsion
- Recurrence

**REFERENCES**

Proximal femoral varus osteotomy can be useful for many conditions:
- Coxa valga deformity
- Hip subluxation (nearly all etiologies)
- Containment for Perthes disease
- Degenerative arthritis
- Correction in other planes can be accomplished simultaneously (derotation and extension–flexion). Proximal femoral varus osteotomy can be accomplished at any age as satisfactory implants are available for all bone sizes.
- In some situations (eg, neuromuscular disease), it may be necessary to address the etiology of the proximal femoral deformity and hip disease simultaneously.

ANATOMY
- The normal femoral neck–shaft angle is 135 degrees (range 120 to 150 degrees).
- The true neck–shaft angle cannot be directly assessed from an anteroposterior (AP) pelvis radiograph unless femoral anteversion is compensated for by internally rotating the femur to eliminate it.
- The tip of the greater trochanter is at the level of the center of the femoral head.
- The neck–shaft angle at birth is typically 150 degrees, decreasing to 135 degrees by skeletal maturity.
- Normal anteversion at birth is 45 degrees, decreasing to 10 degrees in boys and 15 degrees in girls by 8 years of age.

PATHOGENESIS
- The development of normal femoral anatomy and resolution of fetal bone alignment requires the attainment of gross motor activities at a typical age and is dependent on normal musculoskeletal forces. Both of these can be affected by neuromuscular conditions such as cerebral palsy or myelomeningocele.
- Patients with Perthes disease may have a subluxated or uncovered femoral head even with proximal femoral anatomy that is normal except for the avascular femoral head segment. Even so, with good neuromuscular function, varusizing the femur can be well tolerated and can improve the containment of the diseased femoral head.
- Contributing factors to the hip joint pathology may include musculotendinous contractures, ligamentous laxity, and coexistent acetabular dysplasia. If present, these may also require direct treatment. Adductor lengthening, psoas lengthening, open reduction of the hip with capsulorrhaphy, and acetabuloplasty may need to be considered.
- Excessive ROM indicates relative ligamentous laxity.
- Shifted ROM (eg, excessive internal ROM) indicates excessive femoral anteversion.
In adolescents and young adults being evaluated for early degenerative arthrosis, pain may be found at the extremes of ROM. Severe ROM restrictions could be a contraindication to consideration of realignment osteotomy in these cases.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- A plain AP pelvis radiograph with anteversion eliminated is diagnostic of coxa valga.
  - If anteversion is normal, no compensation for hip rotation is necessary.
  - If anteversion is excessive, the AP pelvis radiograph should be taken with the hip internally rotated to obtain a true AP view of the proximal femur.
  - Acetabular dysplasia should be ruled out.
  - Hip subluxation or femoral head uncoverage is assessed. Signs of degenerative arthrosis are sought.
- CT scans (including three-dimensional reconstruction) are not useful or needed for primary proximal femoral deformities but can be helpful in evaluating acetabular dysplasia or potentially in revision cases.
- MRI may be useful in evaluating associated problems, including labral tears, hip joint effusions, narrowing of articular cartilage, and femoral head vascularity.

**DIFFERENTIAL DIAGNOSIS**

- Hip joint contracture
- Hip joint subluxation
- Femoral anteversion or retroversion
- Musculotendinous contracture
- Acetabular dysplasia

**NONOPERATIVE MANAGEMENT**

- Nonoperative management may be helpful for one of the associated conditions listed above.
- There is no nonoperative treatment for bone deformity that is clinically significant and adversely affecting hip joint development.

**SURGICAL MANAGEMENT**

**Preoperative Planning**

- The AP pelvis radiograph is reviewed.
- The size of implant is chosen based on radiographic templates.
- The amount of varusization can be determined based on radiographs preoperatively or on intraoperative findings. Other associated problems (musculotendinous contracture, joint instability, and acetabular dysplasia) are addressed concurrently.
- There is no examination under anesthesia to determine the amount of varusization to accomplish. An examination under anesthesia can guide decision making regarding concurrent tendon lengthening.
- Varusization will inevitably shorten the extremity. The effect on leg length can be controlled by altering the amount of varusization and the size of the wedge of bone removed (if any) depending on preoperative leg-length assessment. Varus can be accomplished using a medial closing or lateral opening osteotomy.

**Positioning**

- Although some surgeons prefer to perform proximal femoral varus osteotomy with the patient supine, I prefer the prone position with the leg draped free (FIG 1).
  - This allows ease of exposure posterior to the muscle belly of the vastus lateralis.
  - The prone position also allows accurate control of femoral torsion comparable to the prone physical examination for femoral anteversion by palpation, thereby improving consistency of surgical realignment.

**Approach**

- A direct lateral approach to the proximal femur is routine. The procedure involves placing the chisel for the blade plate in the appropriate position in the femoral neck corresponding to the amount of varus to accomplish (eg, 20-degree varus correction corresponds to 70-degree chisel placement relative to the lateral femoral cortical surface: 90-degree blade plate minus 70 degrees equals 20 degrees varusization), completing the osteotomy, and placing the 90-degree blade plate as detailed in the Techniques section.

**FIG 1** Prone positioning allows easy access to divide the vastus lateralis posteriorly and replicates the position for physical examination for femoral anteversion, allowing improved accuracy and reliability of assessment and correction of femoral torsional alignment.
EXPOSURE

- A longitudinal lateral incision is made over the proximal femur matching the length of the blade plate.
- The fascia lata is divided in line with the skin incision (TECH FIG 1A).
- The vastus lateralis is reflected from its proximal and posterior origins and elevated to expose the proximal femur subperiosteally.
- Circumferential subperiosteal elevators are placed in the intertrochanteric area to protect the soft tissues (TECH FIG 1B).

GUIDEWIRE PLACEMENT

- A fluoroscope is used to guide placement of a guidewire in both the AP and lateral views.
- The entry point is just below the greater trochanteric apophysis if the patient is skeletally immature and through the greater trochanter after maturity.
  - The entry point is chosen to allow insertion of the guidewire and chisel without violating the medial calcar.
- The anterior-to-posterior placement is determined in the view obtained by flexing the hip and knee (with the knee over the edge of the operating table) and internally and externally rotating the hip until the fluoroscopic image shows the femoral neck and femoral shaft colinear with the guidewire placed centrally and parallel to the neck and shaft of the femur (TECH FIG 2A).
- The orientation of the pin on the AP view is controlled with an osteotomy triangle (TECH FIG 2B,C).
- If preoperative planning indicated a 15-degree varusization goal, a 75-degree triangle would be used (see the Approach section above).
- Alternatively, determination can be made based on preoperative and desired postoperative alignment; for example, the preoperative neck-shaft angle (150 degrees) minus the desired postoperative neck-shaft angle (120 degrees) equals 30 degrees of varusization. In this case, the guidewire would be placed at a 60-degree angle to the femoral shaft when using the 90-degree plate.
- The anteversion is determined (transverse plane) by the angle between the pin (placed as described above) and the tibial shaft (perpendicular to the posterior aspect of the femoral condyles when the knee is flexed, provided there is no tibial varus or valgus).
PLACEMENT OF THE BLADE PLATE CHISEL

- The appropriate-size chisel for the blade plate is then placed just below and exactly parallel to the pin to the desired depth (greatest depth possible depending on anatomy and available length of the blade plate; TECH FIG 3).
- The chisel should be dislodged 5 to 10 mm before the osteotomy to allow for ease of later removal.

PERFORMING THE OSTEOTOMY

- The details of the osteotomy are based on preoperative planning.
- To minimize the shortening effect of the osteotomy on leg length in a child, a single transverse osteotomy can be performed in the intertrochanteric area (TECH FIG 4).
- This will result in a lateral opening osteotomy.
- Alternatively, a wedge of bone can be removed to accomplish a medial closing osteotomy.

Wedge Osteotomy

- The first osteotomy is performed parallel to the chisel.
- The entry point for the osteotomy saw blade is determined by the implant (distance between the blade and the subsequent angle in the plate for medialization).
- A second osteotomy is then performed perpendicular to the femoral shaft.
- The starting level for this osteotomy varies depending on the desired amount of shortening of the extremity.
- A beginning point identical to the entry point for the first osteotomy achieves full contact of the osteotomy after fixation.
- A lateral starting level distal to the first removes a portion of the lateral femoral cortex, achieving more shortening, but is limited by the insertion of the psoas tendon on the lesser trochanter (typically should not be violated).
- An entry point proximal (within the cut of the first osteotomy) leads to less shortening, but incomplete final apposition of the osteotomy surfaces.
**PLACEMENT OF THE BLADE PLATE**

- Realignment and fixation of the osteotomy are achieved by placing the blade plate.
- The chisel is removed and the blade plate is placed in the chisel path parallel to the guidewire and impacted to its final position (TECH FIG 5A).
- The femoral shaft is reduced to the plate and held in position with a Verbrugge clamp (TECH FIG 5B).
- Final anteversion alignment is controlled at this point (TECH FIG 5C).

- The first two screws are typically placed in compression to optimize fixation and promote rapid healing (TECH FIG 5D).
- Alignment is checked after placement of the first screw both radiographically and by physical examination.
- If satisfactory, the final screws are placed. If not, alignment is adjusted accordingly.
- Final radiographs are taken in both views (TECH FIG 5E,F).
- The wound is closed in layers.

**TECH FIG 5** • A. The chisel has been replaced with the blade plate (guidewire is still in place). B. Correction of deformity by reducing the plate to the femoral shaft with a Verbrugge clamp. C. Anteversion is assessed before guide pin removal (corrected to 10 degrees). D. Fixation is complete (note well-apposed osteotomy surfaces). E,F. Postoperative AP and lateral views confirming implant placement, proper osteotomy alignment, and appropriate medialization of the femoral shaft to align the piriformis fossa with the intramedullary canal.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Guidewire placement</th>
<th>Accurate placement of the guidewire is crucial to all steps of the procedure.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Care must be taken to ensure its proper placement.</td>
<td></td>
</tr>
<tr>
<td>Indications</td>
<td>Adequate range of motion must be available.</td>
</tr>
<tr>
<td>Hip joint pathology must not preclude repositioning of the femoral head within the acetabulum in a functional position of the leg.</td>
<td></td>
</tr>
</tbody>
</table>

| Accurate realignment | Prone positioning promotes accurate control, correction, or both of femoral torsion. |
| Final alignment depends only on the angle of pin insertion and the choice of blade plate angle (in this case, 90 degrees). |
| Apposition of the osteotomy surfaces themselves also depends on the orientation of the osteotomy cuts. |
POSTOPERATIVE CARE
- Weight-bearing status and immobilization depend on patient age, condition being treated, compliance, bone size, implant size, and bone quality.
  - Weight bearing can vary from toe-touch to non-weight bearing for the first 3 to 6 weeks.
  - With poor bone quality, small bone size, small implant size, or poor compliance, a spica cast should be applied.
  - In intermediate situations, bilateral short-leg casts with a Dennis Brown bar can be applied along with knee immobilizers (Fig 2).
  - Unrestricted range of motion without external immobilization may be allowed (eg, most adults).
  - A range-of-motion and strengthening program often is instituted at 3 to 4 weeks postoperatively.
  - Advancement to full weight bearing can be accomplished within 6 to 8 weeks of the procedure, depending on muscle strength.

OUTCOMES
- Patients over 8 years of age with moderate Perthes disease (lateral pillar B or B/C border) have a better outcome with surgery.2
- The complex spectrum of cerebral palsy hip subluxation, hip dysplasia, and dislocation can be treated successfully in most cases using a treatment algorithm that incorporates femoral varus and derotation osteotomy. While there is a risk of recurrence and complications, McNerney and associates3 reported excellent results with aggressive surgical management with a low rate of complications and repeat acetabuloplasty or varus osteotomy.

COMPLICATIONS
- Excessive varusization leading to hip abductor insufficiency
- Implant failure
- Malunion
- Nonunion
- Deep venous thrombosis in adults
- Infection
- Avascular necrosis
- Implant irritation contributing to Trendelenburg gait
- Overcorrection or undercorrection

REFERENCES
DEFINITION

- The term proximal focal femoral deficiency (PFFD) is used to describe congenital femoral deficiency and deformity of the proximal femur to be distinguished from the congenital short femur.6 However, the more comprehensive term congenital femoral deficiency (CFD)13 better describes the spectrum of deficiency, deformity, and discrepancy ranging from the congenital short femur to the most severe PFFD.
- The severity of the deformity varies widely, and this condition can be diagnosed in the prenatal period using ultrasound examination.11
- In most cases, CFD is not simple coxa vara. Patients with CFD lack integrity, stability, and mobility of the hip and knee, with concurrent joint malorientation, bony deformity, and soft tissue contractures. The affected limb grows at an inhibited rate depending on the severity of the underlying deficiency. The resulting limb-length discrepancy (LLD) can be accurately predicted using the multiplier method.1,2,10

ANATOMY

- Although existing classification systems for PFFD are descriptive, these classification systems are not helpful in determining the final femoral morphology or treatment strategies.13
  - The Paley classification system (FIG 1) is based on factors that reflect the severity of pathology and reconstructability of the congenitally deficient femur. This classification is based on pathologic factors that determine surgical reconstruction strategies.8
  - The abnormal anatomy of CFD consists of coxa vara of the proximal femur with abduction contracture of the hip (ie, tensor fascia lata [TFL], gluteus medius, and gluteus minimus muscles), proximal femoral extension deformity (flexion in some cases) with concurrent hip flexion contracture (ie, rectus femoris, TFL, and psoas muscles), and external femoral torsion–retroversion with concurrent external soft tissue contracture (ie, piriformis muscle).
  - The proximal femur can also present a region of delayed ossification in either the subtrochanteric region or the neck region. Ossification of the cartilaginous proximal femur differentiates Paley type 1a CFD (ie, normal ossification) from Paley type 1b CFD (ie, delayed ossification) (FIG 1).
  - Once treated with realignment of the proximal femur, these regions of delayed ossification in the type 1b hip begin to ossify (the regions do not always fully unite), converting the hip into type 1a. This area of delayed ossification is often mistaken for a pseudarthrosis (it could be referred to as a stiff cartilaginous pseudarthrosis to differentiate it from type 2, in which there is a true mobile, fibrous pseudarthrosis).
  - A more severe form of CFD is classified as Paley type 2; this type has a true mobile pseudarthrosis between the greater trochanter and femoral head or complete absence of the femoral head (FIG 1).

- The most severe proximal deficiencies are classified as Paley type 3 (diaphyseal deficiencies). In these cases, the greater trochanter is absent and the knee joint is affected to a greater extent. Complete absence of the femur is included in this group.
- In very rare cases, there is a distal deficiency of the femur (ie, Paley type 4). Cases of distal deficiency present with very severe knee varus but a well-developed, intact hip joint.
- Acetabular dysplasia is almost always present in patients with CFD. This deformity must be recognized and corrected to prevent subluxation or dislocation of the hip during lengthening.
- Congenital knee abnormalities also exist with CFD. Absent or hypoplastic cruciate ligaments (ie, anterior cruciate ligament [ACL], posterior cruciate ligament [PCL]), hypoplastic lateral femoral condyle resulting in genu valgum, and hypoplastic patella with lateral maltracking, subluxation, or dislocation are common. Rotatory instability of the tibiofemoral joint and knee flexion contractures (ie, biceps femoris muscle, posterior knee joint capsule, iliotibial band) are also common.

PATHOGENESIS

- The cause of an isolated single-limb abnormality is usually unknown. CFD is usually not related to a genetic syndrome. This is in contrast to radial clubhand, tibial hemimelia, or multiple limb deficiencies.
- A patient with CFD presenting for initial evaluation does not require a genetic consultation unless multiple limb deficiencies or other congenital malformations are present.

NATURAL HISTORY

- The natural history of CFD is a progressive LLD in unilateral cases. The deformities and soft tissue contractures described above persist but do not progress.
- The Paley type 1b hip shows eventual ossification of the cartilaginous femoral neck or subtrochanteric region. Although ossification occurs over time, the severe coxa vara deformity persists.
- Progressive LLD can be accurately predicted using the multiplier method.1,2,10 Determining the LLD at maturity and using the Paley classification system allows the surgeon to formulate an overall strategy for deformity correction and limb lengthening.
- The number and timing of surgical procedures can be presented as a general overall plan to the parents during the initial consultation.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A general history and physical examination should be performed.
- The clinician should concentrate on family history or concurrent known congenital abnormalities, which could
Chapter 28 TREATMENT OF CONGENITAL FEMORAL DEFICIENCY

Type 1: Intact Femur with Mobile Hip and Knee

Type 2: Mobile Pseudarthrosis with Mobile Knee

Type 3: Diaphyseal Deficiency of Femur

Type 4: Distal Deficiency of Femur

FIG 1 • Paley classification of congenital femoral deficiency. (Copyright 2006, Sinai Hospital of Baltimore.)
indicate a genetic syndrome that could require further workup and genetic consultation.

- The facies and upper extremities are examined, looking for abnormal appearance or multiple congenital anomalies, which can indicate a genetic syndrome. In such cases, genetic consultation should be obtained.

- **Hip ROM**
  - Abduction–adduction and flexion ROM are examined in the supine position. Thomas test (hip extension) is performed to measure fixed flexion deformity of the hip. Hip internal rotation–external rotation is measured in the prone position, together with the thigh–foot angle. Muscle length tests include popliteal angle (hamstring length) and prone knee bend (rectus femoris muscle).
  - ROM is measured and contractures are identified and quantified in degrees. A popliteal angle of more than 0 degrees and prone knee bend less than supine knee bend indicate tightness of the hamstring and rectus femoris muscles, respectively.
  - Contractures need to be treated in preparation for lengthening. Lengthening of the rectus femoris and hamstring muscles is recommended for positive muscle tightness.

- **Knee ROM**
  - Flexion and extension knee ROM is measured in the supine and prone positions.
  - Greater than 10 degrees of fixed flexion deformity should be corrected during preparatory procedures. A fixed flexion deformity can be present.

- **Knee stability (anteroposterior)**
  - The Lachman test and the anterior and posterior drawer tests are performed. The clinician looks for posterior sag and rotatory instability. The amount of instability is measured:
    - Grade I: mild with endpoint
    - Grade II: moderate with endpoint
    - Grade III: moderate or severe with no endpoint
  - Anteroposterior knee instability is common.

- **Knee stability (rotatory)**
  - The rotatory stability of the knee joint is examined by internally and externally rotating the tibia on the distal femur in flexion and extension. The presence of subluxation with rotation of the tibia on the distal femur is noted.
  - External rotatory instability is a common finding that is secondary to a contracted iliotibial band, which can lead to rotatory subluxation of the knee and patellar dislocation.

- **Patellar stability**
  - The clinician should flex the knee and palpate the alignment of the patella to the notch in flexion. Tracking of the patella is assessed from 0 to 90 degrees. The clinicians should attempt to push a thumb into the intercondylar notch.
  - If the examiner’s thumb is able to palpate the intercondylar notch with the patient’s knee flexed, this denotes lateral subluxation or dislocation of the patella.
  - Patellar instability is common and can be an indication of lateral rotatory instability of the knee and contracture of the iliotibial band.

- **The clinician should look at the overall appearance of the foot and ankle.**
  - Any missing rays or positional abnormalities are noted. Ankle ROM is tested with knee flexed and extended. Inversion and eversion ROM is tested.

- The amount of dorsiflexion, plantarflexion, inversion, and eversion is recorded. Equinovalgus deformity with missing lateral rays indicates concurrent fibular hemimelia. Subtle increase in eversion ROM indicates fibular hypoplasia or a ball-and-socket ankle joint.

### IMAGING AND OTHER DIAGNOSTIC STUDIES

- During the initial evaluation of an infant with CFD, supine long anteroposterior (AP) and lateral radiographs should be obtained that include the pelvis and both lower extremities. Both lower limbs are pulled down to make sure both knees are in maximum extension (FIG 2A).
- The supine long AP view radiograph should be assessed for the overall appearance of the ossific anatomy. This radiograph should allow the physician to classify the type of CFD.
  - The lengths of both femora and both tibiae should be measured. The difference between them is the LLD, not including the foot. The clinicians should measure from the lateral acetabular edge to the midpoint of the knee joint space for the femoral lengths and from the same midpoint of the knee joint space to the end of the tibial ossific nucleus for the tibial lengths. The amount of current LLD can be used with the multiplier method to predict the overall LLD at maturity.\(^1,2,10\)
  - The acetabulum should be assessed for dysplasia using the center–edge (CE) angle (even in infants) and the acetabular index (AI).
  - The long lateral view radiograph of the lower extremity is assessed for underlying fixed flexion deformity of the knee.
  - The anterior cortical line of the distal femur should normally be colinear with the anterior cortical line of the proximal tibia. A flexion angle between these lines represents fixed flexion deformity of the knee.
  - Other imaging studies that are useful include magnetic resonance imaging (MRI) and arthrography of the hips. If the presence of a true pseudarthrosis of the proximal femur is questionable, an evaluation with MRI can be used in an attempt to visualize the presence or absence of a cartilaginous connection between the femoral head and shaft (FIG 2B,C).
  - Arthrography under general anesthesia is the gold standard to determine the presence of pseudarthrosis versus delayed ossification of the proximal femur. While the arthrogram is obtained, the lower extremity is manipulated and the proximal femur is visualized.
    - If the proximal femur and femoral head move as a unit, this denotes a cartilaginous connection in the proximal femur, and the CFD is classified as type 1b. The arthrogram is also useful to differentiate between Paley types 2a and 2b. Both 2a and 2b might have a femoral head present; the difference is whether the femoral head is fused to the acetabulum or not. If dye can be injected into a joint space, the hip can be classified as type 2a.

### DIFFERENTIAL DIAGNOSIS

- If the patient has bilateral CFD, the clinician must consider the following differential diagnoses:
  - Camptomelic syndrome
  - Femoral hypoplasia (unusual facies syndrome)
NONOPERATIVE MANAGEMENT

- Shoe lifts, orthoses, and prostheses are used for the nonoperative management of LLD. All children should receive a shoe or prosthesis with a lift when they begin to cruise the furniture. A simple shoe lift of an amount equal to 1 cm less than the LLD is used in most cases in which LLD is less than 10 cm (FIG 3A).

- It is helpful to supplement the lift with an articulated ankle–foot orthosis (AFO) for ankle support from the long lever arm of the shoe lift. If the lift is more than 10 cm, a prosthetic foot connected to an AFO is preferred both to reduce weight and improve cosmesis.

- The clinician should avoid splinting the foot in equinus because it might cause an equinus contracture.

- In children younger than 6 years, a limb-length radiograph should be obtained every 6 months to assess LLD and prescribe a new lift.

- After age 6 years, annual assessment and prescription is adequate.

- In more severe cases with hip and knee fixed flexion deformity, it might be necessary to extend the orthotic or prosthetic support above the knee (FIG 3B).

SURGICAL MANAGEMENT

- Patients with types 1a, 1b, 2a, and 2b CFD can be managed successfully with lengthening reconstruction surgery as opposed to prosthetic reconstruction surgery.

- Before undergoing lengthening reconstruction surgery, patients with certain knee and hip deformities and deficiencies should undergo preparatory procedures to prevent complications during lengthening and to reconstruct the knee and hip joints. This chapter will present the preparatory surgical procedures of the hip and knee and the external fixation method we prefer for CFD lengthening surgery.

Type 1 CFD

- Type 1 CFD is the most reconstructable.

- Before lengthening, hip stability should be determined radiographically. The best indicator is the CE angle. If the CE angle is less than 20 degrees, a Dega osteotomy should be performed before lengthening. In addition, the AI should be less than 30 degrees. If the CE angle is borderline 20 degrees but the AI is high, it is better to err on the side of caution and perform a Dega osteotomy (FIG 4).

- Coxa vara should be corrected before lengthening if the neck-shaft angle is less than 120 degrees. When coxa vara and hip dysplasia are present and when the coxa vara is severe, the superhip procedure is performed. The pelvic and femoral osteotomies should be performed 6 to 12 months before the first lengthening. The superhip procedure is a comprehensive
surgery to correct the proximal femoral and hip deformities with concurrent soft tissue releases.

- At the conclusion of a successful superhip procedure, the re-orientation of the proximal femur allows for ossification of the proximal femur (type 1b [ie, femoral neck or subtrochanteric region]). This ossification converts type 1b to type 1a and usually occurs within 2 years of the superhip procedure. Lengthening is not performed in type 1b cases until they convert to type 1a (except in special circumstances).

Type 2 and 3 CFD

- The strategies that should be used to treat types 2 and 3 CFD are complex and beyond the scope of this chapter. A summary of the strategies is provided below.

Type 2 CFD

- The presence or absence of a mobile femoral head in the acetabulum determines the treatment strategy. Although MRI and arthrography can be used to examine the femoral head for mobility, opening the hip joint capsule is the only definitive way to determine the presence or absence of a mobile femoral head.
- If the femoral head does not move in the acetabulum, it should not be joined to the femoral shaft. If the femoral head is mobile, it can be connected to the remainder of the femur by a complicated procedure in which the femoral neck is reconstructed.
- We call this procedure superhip 2, and it converts type 2a CFD to type 1a. For type 2b CFD, only the superhip soft tissue release is performed without the osteotomy. The flexion contracture of the hip is released and the fascia lata excised. Serial lengthenings with external fixation to the pelvis, femur, and tibia are performed before skeletal maturity. A pelvic support osteotomy is performed during the final lengthening at skeletal maturity.

Type 3 CFD

- Type 3a can be treated like type 2b. Patients can undergo hip release, serial lengthenings, and pelvic support osteotomy or they can be treated by prosthetic fitting options, including prosthetic reconstruction surgery (ie, Syme amputation or rotationplasty).
- Prosthetic reconstruction surgery is recommended for type 3b CFD, which includes a stiff knee joint (less than 45 degrees of motion). Although type 3a can be converted to type 2b, the treatment would consist of four or more lengthenings. Rotationplasty is recommended for type 3a because it provides a more predictable functional result than does lengthening (FIG 5).

Lengthening

- The number of lengthenings that are required for type 1 CFD is determined by the initial LLD prediction. Patients with type 1a CFD typically undergo their first lengthening at age 3 years. Patients with type 1b typically undergo lengthening closer to age 4 years. Between 5 and 8 cm can be obtained during each lengthening.
- For type 1 CFD, the femur should be lengthened by using a distal femoral osteotomy instead of a proximal femoral osteotomy.
- Distal osteotomies allow for better regenerate bone formation because they have a broader cross-sectional diameter and because the bone is not sclerotic or dysvascular, which often is seen in the proximal femur of patients with CFD. Distal osteotomies can also be used to simultaneously correct the valgus deformity of the distal femur.
- Proximal osteotomies are used to correct the external femoral torsion and proximal varus deformities. Proximal osteotomies are not used for lengthening because of poor regenerate bone formation. A proximal osteotomy can be used for deformity correction with a concurrent distal osteotomy for lengthening.
- Soft tissue releases are performed during lengthening to prevent subluxation and stiffness of the knee and hip. Soft tissue releases that were addressed during a previous superhip or superknee procedure do not need to be repeated.

Lengthening Via External Fixators

- Femoral lengthening with an external fixator can be performed with various devices.
- The essential principle of lengthening with external fixation is to stabilize the knee during lengthening while allowing for knee motion. This is accomplished by using hinges and external fixation of the tibia.
- From 1987 to 2000, only the Ilizarov apparatus was used with fixation across the knee joint with a hinge. This method
has previously been described. We did not use a monolateral external fixator because it could not articulate across the knee joint.

Since 2000 a method was developed that combined the pediatric Limb Reconstruction System (LRS) (Orthofix, Inc., McKinney, TX) with Sheffield Ring Fixation System components (Orthofix) to articulate across the knee with fixation to the tibia. Both Ilizarov and Orthofix parts are used to create this construct.

Preoperative Planning

Preoperative evaluation consists of obtaining radiographs and performing a physical examination as previously described.

The radiographs are assessed as previously described and the CFD is reclassified if progressive ossification has occurred.

During each visit before the first surgical reconstruction, LLD is recalculated to increase accuracy so that the overall strategy can be altered as needed.

Positioning

The patient undergoing the superhip procedure is positioned supine on the operating table with a bump placed under the ipsilateral sacrum to tilt the pelvis about 35 to 40 degrees. The entire lower extremity to include the groin, iliac crest, and gluteal region is prepared to the subcostal margin (FIG 6A).

The patient undergoing the initial femoral lengthening is positioned supine on the operating table with a radiopaque grid placed under the operating table pad. A small bump is placed under the ipsilateral sacrum to allow the extremity to rest in a patella-forward position. The entire lower extremity to include the groin, iliac crest, and gluteal region is prepared (FIG 6B).

Approach

The approach for the superhip and superknee procedure is the same extended lateral approach to the hip, femur, and knee as described in the following section.

The lengthening procedures are performed using percutaneous techniques.
SUPERHIP PROCEDURE

- An anterior incision is made starting two to three fingerbreadths posterior to the anterior superior iliac spine and at the level of the iliac crest. This incision gently curves to the posterolateral border of the femur along the level of the posterolateral intermuscular septum.
- A second S-shaped incision is made from the lateral side of the patellar tendon and is extended proximally in line with the intermuscular septum at the level of the knee joint. A bridge of intact skin is left between the two incisions. A recently developed distal alternative is an anterior midline incision.
- If the extremity is significantly short, these incisions become one extended approach.
- The flap of skin and the subcutaneous tissues are reflected in a full-thickness fashion off the deep fascial layer anteriorly.
- For the proximal incision, the interval between the TFL muscle and the sartorius muscle is dissected.
- For the distal incision, the fascia lata’s anterior and posterior borders are exposed at the level of the superior pole of the patella. The posterior border blends with the posterolateral intermuscular septum (TECH FIG 1A,B).
- At the TFL-sartorius interval, the fascia is split longitudinally. Care is taken to avoid injury to the lateral femoral cutaneous nerve. This is accomplished by releasing the fascia on the tensor fascia lata side of the intermuscular septum.
- This fascial incision is extended distally to join the anterior margin of the fascia lata that was previously exposed.
- The fascia lata is cut distally at the tibia and is reflected proximally if a concurrent superknee procedure with knee ligamentous reconstruction is not required. If ligamentous reconstruction is planned, the fascia lata is cut proximally and reflected distally.
- The TFL muscle is reflected proximally and posteriorly on its posterior pedicle. Its anterior vascular pedicle (ie, lateral femoral circumflex vessels) can be cauterized and cut.
- The TFL muscle is separated from the underlying gluteus medius muscle distally. If the muscles do not separate well, the interval is left alone. The surgeon must remember that any tissue that is inserting onto the greater trochanter is the gluteus medius muscle and must remain intact (TECH FIG 1C).
- The conjoint tendon of the rectus femoris, before it divides into the direct and reflected heads, is transected.
- The psoas tendon is exposed and released at the level of the pelvic brim. The surgeon must realize that the femoral nerve is much closer to both the rectus femoris and psoas tendon in patients with CFD. Therefore, the femoral nerve is identified and protected before the aforementioned releases (TECH FIG 1D).
- If the anterior fascia of the thigh and the fascia of the sartorius muscle are tight, they are released. The lateral femoral cutaneous nerve is identified and protected before releasing the fasciae.
- The femur should now be adducted, internally rotated, and flexed such that the greater trochanter is brought to the level of the center of the femoral head and the posterior border of the greater trochanter is parallel to the floor. If the proximal femur cannot be placed in this position, there is an abduction contracture of the hip joint. In these cases, the glutei muscles should be elevated off the greater trochanter along with the vastus lateralis muscle as a trigastric flap.
- The posterior border of the vastus lateralis at the intermuscular septum is identified and dissected free of the femur subperiosteally. The dissection is continued proximally along the posterior aspect of the greater trochanter. It is important to peel a thin layer of cartilage with the flap because the tendinous covering over the trochanter is thin.
- The dissection of the posterior border of the greater trochanter is continued proximally to sharply reflect the tendinous portions of the gluteus medius and minimus muscles as a continual sling (TECH FIG 1E).
- The flap of the conjoint gluteus–quadriceps tendon is sharply dissected and reflected from posterior to anterior off the trochanter. It is then reflected anteriorly off the intertrochanteric line, leaving the anterior hip capsule intact. The dissection should remain extra-capsular. The capsule should not be incised, and the pelvic trochanteric ligament running superior to the hip joint capsule should never be cut. During the release, the piriformis tendon should be identified and released, which allows the femur to rotate internally. The surgeon should avoid releasing the hip capsule from the greater trochanter because doing so can lead to hip instability, lateral subluxation, and dislocation (TECH FIG 1F).
- An alternative approach for patients with mild abductor contractures is to split the iliac crest apophysis and dissect the gluteal muscles in a subperiosteal fashion. This allows the gluteal muscles to slide distally, resolving the abductor contracture. This exposure is later used for the Dega osteotomy. At the completion of the procedure, the iliac crest is then resected by 1 cm to allow for closure of the apophysis with no tension.
- An arthrogram of the hip is obtained. The femoral head and neck are placed in a neutral orientation to the pelvis by extending and maximally adducting the hip joint.

Plate Fixation of Proximal Femur

The preferred method of fixation is the hip plate method. The preferred implant is the 130-degree pediatric cannulated blade plate (custom ordered from Smith & Nephew, Memphis, TN). If this is unavailable, the pediatric sliding hip screw (Smith & Nephew, Memphis, TN) can be used with a second screw for rotational control.

The first step is to place a guidewire from the tip of the greater trochanter to the center of the femoral head. This creates the proximal femoral joint orientation line (TECH FIG 2A).

A second guidewire is inserted in the center of the femoral neck to the center of the femoral head, at a 45-degree angle with the initial guidewire. The second guidewire is then visualized under a lateral fluoroscopic view to confirm its position in the center of the femoral head ossific nucleus (TECH FIG 2B,C). The correct
Chapter 28  TREATMENT OF CONGENITAL FEMORAL DEFICIENCY

TECHNIQUES

TECH FIG 1 • Superhip procedure. A. Incision. A point 4 to 6 cm posterior to the anterior superior iliac spine is marked on the skin, and the lateral “bump” is marked on the skin. These two points are connected with a curvilinear line that extends distally on the posterior margin of the vastus lateralis muscle belly. The second incision is a distal S incision that begins at the level of the lateral intramuscular septum on the side of the thigh and proximally at the level of the superior pole of the patella and extends to the lateral margin of the patellar tendon to the tibial tubercle. The anterior flap is dissected off the deep fascia to the midline of the thigh.

C. Reflection of fascia lata and TFL muscle. The anterior and posterior margins of the fascia lata are dissected as described, with the fascia lata being released proximally at the musculotendinous junction of the TFL muscle. The fascia lata is reflected distally to its insertion on the tubercle of Gerdy of the proximal tibia. The TFL muscle is dissected off the gluteus minimus and medius and reflected proximally.

D. Hip flexion contracture release. After the TFL muscle is reflected proximally, the dissection is continued medially under the sartorius muscle. The rectus femoris tendon is the first structure identified as it inserts on the anterior inferior iliac spine. This tendon is released, and the psoas muscle and tendon are then identified. Before release of the psoas tendon, the femoral nerve, which is adjacent to the psoas tendon, is identified and decompressed. E,F. Release of abduction and external rotation contracture. The confluent tendinous portions of the hip abductor muscles (gluteus minimus and medius muscles) and the vastus lateralis muscle are sharply dissected off the cartilaginous greater trochanter, creating a continuous musculotendinous sling. This release resolves the abduction contracture and allows access to the piriformis tendon. FL, fascia lata; m, muscle; n, nerve; RF, rectus femoris; TFL, tensor fascia lata; VL, vastus lateralis. (Copyright 2007, Sinai Hospital of Baltimore.)
orientation on the lateral fluoroscopic view is when one can see a “bullseye” created by the concentric circles of the arthrographic outline of the femoral head and femoral neck with the ossific nucleus in the center.

- The appropriate sized cannulated blade plate chisel is driven over the femoral neck guidewire to create a path for the blade plate (TECH FIG 2D). The chisel should be oriented perpendicular to the straight posterior border of the greater trochanter. The chisel is removed, and the appropriately-sized cannulated blade plate is inserted over the femoral neck guidewire (TECH FIG 2E).

- At the intertrochanteric level, two wires are inserted perpendicular and parallel to the side plate. A sagittal saw is used to remove a triangular segment of bone. The first cut is parallel to the plate, and the second cut is perpendicular to the plate. The width of the second cut is equal to the diameter of the femoral diaphysis (TECH FIG 2F).

- A second subtrochanteric osteotomy is performed by cutting obliquely from the lateral starting point of the previous parallel cut. This cut divides the femur into two segments and leaves a medial buttress of bone (TECH FIG 2F).

- The distal femoral segment is extended, abducted, and internally rotated and aligned with the plate allowing the femoral segments to overlap. The bone ends have to overlap because of the constraints of the surrounding soft tissues. The amount of overlap determines the amount of shortening of the distal segment that is required (TECH FIG 2G,H).

- A third osteotomy is performed perpendicular to the distal femoral shaft at the level of overlap (usually 1 to 2 cm distal to the second osteotomy site). The distal femoral segment is reduced to the plate and fixation is completed with three or four screws. The resected bone segment is used in the Dega osteotomy at the end of the procedure (TECH FIG 2I).

- For type 1b cases (delayed femoral neck ossification), an adjunct treatment can be performed by drilling a channel with a diameter of 3.2 to 3.8 mm into the femoral neck and packing bone morphogenetic protein (INFUSE Bone Graft, Medtronic, Inc., Memphis, TN) into the cartilaginous tunnel to induce ossification of the femoral neck (TECH FIG 2I).

Pelvic Osteotomy

- The next step is to perform the Dega osteotomy. To expose the ilium, the iliac crest apophysis is split and detached with the periosteum. The outer table of the ilium is subperiosteally dissected, and the hip abductor muscles are lifted from anterior to posterior. The posterior dissection is continued to the sciatic notch and should not cross the triradiate cartilage (TECH FIG 3A).

- The pelvic osteotomy is curved along the lateral cortex from the anterior inferior iliac spine (AIIS) to the triradiate cartilage posteriorly. At the AIIS, the osteotomy goes through both tables of the ilium. It is important to cut the apophysis and periosteum transversely at this level to allow the osteotomy to separate anteriorly. The osteotomy does not enter the sciatic notch but passes anterior and parallel to the level of the triradiate cartilage. The apex of the osteotomy should start 2 cm above the hip joint and is inclined to the triradiate cartilage medially (TECH FIG 3B).
TECH FIG 2 • (continued) (E) Cannulated 130-degree pediatric blade plate is inserted over the femoral neck guide pin to its final position. The protruding plate is used as a guide for the initial bone cuts. The plate should be parallel to the posterior trochanteric border to ensure correction of the flexion deformity. (F) Sagittal saw is used to remove a triangular segment of bone (first osteotomy). The two bone cuts are parallel and perpendicular to the plate. The width of the perpendicular cut is equal to the femoral diaphysis. The second osteotomy is started at the parallel cut and directed distally in an oblique fashion. This creates a medial buttress on the proximal femoral fragment. (G,H) Distal femoral segment is adducted, extended, internally rotated, and aligned with the side plate. The distal segment overlaps the proximal segment due to the soft tissue constraints. This determines the amount of shortening required and the position of the third osteotomy. The third osteotomy is performed perpendicular to the distal femoral diaphysis. (I) Distal femoral segment is reduced to the side plate and secured with three to four cortical screws. For type 1b cases, an adjunct treatment can be performed by drilling a channel with a diameter of 3.2 to 3.8 mm into the femoral neck and packing bone morphogenetic protein (INFUSE Bone Graft, Medtronic, Inc., Memphis, TN) into the cartilaginous tunnel. (Copyright 2009, Sinai Hospital of Baltimore.)
- The osteotomy is levered distally and laterally to cover the femoral head. The large opening wedge is maintained by inserting the resected femoral segment. The end point of correction is a horizontal sourcil (TECH FIG 3C).
- The stability of the graft is tested by attempting to pull the graft from the osteotomy site with a Kocher clamp. The graft should be fully within the lateral cortical margins of the ilium. Typically, the graft is extremely stable and no further fixation is needed.
- With the abductor sparing approach, the medial apophysis is pried off the crest. The crest is then resected using a saw until the medial and lateral apophysis can be repaired without excessive tension.
- With the trigastric flap approach there is no apophysis to repair, but the trigastric tendon has to be fixed to the cartilaginous trochanter. The hip should be slightly abducted to make sure the abductors are under tension.
- The tensor fascia lata is then sutured to the greater trochanter.
- The femur is placed in neutral abduction, and the conjoint abductor–quadriceps tendon is sutured directly into the cartilaginous greater trochanter with absorbable suture under some tension.
- The TFL is also sutured to the greater trochanter.
- The incision is closed in layers. A suction drain is used and is left in place until the draining stops (less than 10 cc per 24 hours), which can take several days. Prophylactic antibiotics are administered intravenously until the drain is removed.
- A spica cast is applied with the hip in full extension, neutral abduction, and neutral rotation. The knee is splinted in full extension. The cast is removed 6 weeks after surgery. Recently, we have been splitting the cast in surgery and allowing early ROM and bathing between splinting with the cast.

TECH FIG 3 • (A) Dega osteotomy is performed by exposing the outer table of the ilium by splitting the iliac crest apophysis and lifting the abductor muscles. (B) Osteotomy curves from the anterior inferior iliac spine to the triradiate cartilage along the lateral cortex of the ilium. The osteotomy does not enter the sciatic notch or cross the triradiate cartilage. In the coronal plane, the apex of the osteotomy starts 2 cm above the joint and is inclined toward the triradiate cartilage medially. (C) Osteotomy is levered distally to cover the femoral head, and the opening wedge is filled with the resected femoral segment graft. The end point of correction is a horizontal sourcil that is confirmed with the use of fluoroscopy. (D) The iliac crest is now resected to provide both additional bone graft for the Dega osteotomy and to relax the hip abductors to correct the preoperative abduction contracture. (E) Preoperative radiographic example of bilateral congenital femoral deficiency. (F) Postoperative radiograph obtained after superhip procedure. A Dega osteotomy is completed with horizontal sourcil. Note the complete femoral head coverage. (Copyright 2009, Sinai Hospital of Baltimore.)
SUPERKNEE PROCEDURE

Incision and Dissection

- If significant knee instability is present, a superknee procedure should be performed conjointly with the superhip procedure. The superknee procedure can address ACL and PCL insufficiency, patellar subluxation or dislocation, and maltracking. Different parts of the procedure can be used depending on the knee pathology.

- A long, S-shaped incision is made to expose the knee. The anterior and posterior margins of the fascia lata are incised longitudinally. The fascia lata is transected as proximally as possible and reflected distally until its insertion onto the tibia. (TECH FIG 4A,B). The proximal aspect of the incision is developed as described for the superhip procedure.

- The biceps femoris tendon should be Z-lengthened if knee flexion deformity is present or if the tibia is externally rotated on the femur. The peroneal nerve should first be identified as it emerges from behind the biceps femoris muscle and decompressed at the first and second tunnel of compression in the anterior and lateral compartments of the lower leg (TECH FIG 4C).

Patellar Stabilization

- The fascia lata is split into two longitudinal strips to make two ligaments. A Krackow whipstitch is used to run a nonabsorbable suture from the free end of the fascia lata toward the tubercle of Gerdy in a tubular fashion (TECH FIG 5A).

- A lateral release of the capsule leaving the synovium intact is performed in all cases.

- A Grammont procedure is performed to medially transfer the patellar tendon if patellar maltracking is significant.

- This procedure is done by releasing the patellar tendon from proximal to distal and from lateral to medial, leaving intact a long sleeve of periosteum distally. The periosteal extension of the tendon is elevated with the tendon so that the detached tendon remains tethered distally. The patella and patellar tendon are shifted medially and sutured into position with an absorbable suture (TECH FIG 5B).

- A modified Langenskiöld procedure is performed when fixed patellar subluxation or dislocation is present (see TECH FIG 4A).
description below in Alternative Step for Patellar Realignment).

- The lateral capsule is cut to, but not through, the synovium. The vastus lateralis muscle is elevated off the intermuscular septum.
- If the patella is still tethered laterally by the vastus lateralis muscle, its tendon is released from the lateral aspect of the patella and transferred centrally to the quadriceps tendon under minimal tension.
- The lateral release is extended distally to the lateral aspect of the patellar tendon. If a Grammont procedure is to be performed, the incision is extended past the tibial tuberosity along the crest of the tibia so that the proximal periosteum is elevated as described above.

**ACL Reconstruction**

- Next, a MacIntosh intra-articular or extra-articular ACL reconstruction (or both) is performed. The lateral collateral ligament (LCL) is identified. Two tunnels are made. One tunnel is placed under the LCL and does not enter the knee joint (TECH FIG 6A). The other tunnel is made subperiosteally, from anterior and proximal to posterior and distal, over the lateral intramuscular septum of the femur.
- A hole is made in the posterior knee joint capsule by inserting a curved clamp from the “over-the-top” position.

- The posterior limb of the fascia lata is passed under the LCL. An ACL reamer is used over a guidewire to create a bony tunnel in the proximal tibial epiphysis. The wire is inserted from the anteromedial aspect of the tibia and is directed to the center of the tibial epiphysis. The outer diameter of the actual graft is measured, and the hole in the epiphysis is reamed to this diameter (TECH FIG 6B). A suture passer is passed through the tibial epiphyseal tunnel and out the posterior capsule of the knee to exit laterally anterior to the septum. The fascia lata suture is pulled through the knee and the bony tunnel using the suture passer. A bioabsorbable headless screw (Arthrex, Inc., Naples, FL) is used to secure the graft to the tunnel (TECH FIG 6C). The ACL graft is tensioned and sutured with the knee reduced and in full extension to prevent creation of a fixed flexion deformity of the knee.
- If only an extra-articular ACL repair is needed, the fascia lata is looped back after passing under the LCL and the lateral intramuscular septum. The fascia lata is sutured to itself and no tunnel is made (TECH FIG 6D,E). To prevent loosening, the graft can be reinforced and retensioned after fixation by passing a nonabsorbable suture through bone at the point at which the graft loops over the intermuscular septum.
- Extra-articular or intra-articular PCL reconstruction is performed.
**Extra-articular PCL Reconstruction**  
(Reverse MacIntosh Procedure Developed by Paley)\(^8\)

- The anterior skin flap is elevated off the knee and dissected and reflected medially until the entire vastus medialis muscle can be visualized.
- The anterior limb of the fascia lata is not tubularized. It is passed first under the patellar tendon and then through a medial capsular tunnel. The graft is then passed through a subperiosteal tunnel around the adductor magnus tendon. Finally, it is sutured to itself with nonabsorbable suture (TECH FIG 7).
- This extra-articular ligament is tensioned with the knee in 90 degrees of flexion to prevent an extension contracture.
- To expose the medial side, the medial soft tissue flap is reflected to the midline.

**Intra-articular PCL Reconstruction**

- The peroneal nerve is identified, decompressed, and protected.
- The lateral head of the gastrocnemius muscle is then released from the femur. The posterior aspect of the proximal tibial epiphysis is identified to the midline.
- An anterior-to-posterior drill hole is made through the epiphysis, and the anterior limb of the fascia lata is passed from anterior to posterior, exiting near the midline posteriorly.
- Another drill hole that passes through the medial distal femoral epiphysis from anteromedial to posterolateral is made. The ligamentized fascia lata is pulled through the posterior capsule and into the medial femoral epiphyseal tunnel using its leading suture. It is fixed in place with a biotenodesis absorbable screw (Arthrex) after tensioning in flexion.

**Alternative Step for Patellar Realignment: Langenskiöld Reconstruction**

- If the patella has a fixed lateral subluxation or dislocation, a modified Langenskiöld patellar reconstruction is performed before the knee ligamentous reconstruction (intra-articular and extra-articular).
This procedure is performed through the same superknee incision and can be performed as a part of the overall reconstruction.

The retinaculum is released on both the medial and lateral aspect of the patella. This is the same incision used for the lateral release (TECH FIG 8A,B).

The incision is taken down to the synovial layer without violating the synovium. The synovium is then carefully dissected free of the undersurface of the quadriceps muscle proximally and from the patellar tendon distally.

Medially, the capsule is incised proximally in a longitudinal fashion, separating the vastus medialis muscle from the vastus intermedius muscle.

The distal medial capsule is cut transversely at the level of the joint line. The capsule is separated from the synovium as far as the medial gutter.

Once the synovial layer has been separated completely from the overlying tissues, its connection to the patella is incised circumferentially (TECH FIG 8C,D). The quadriceps and patellar tendon are left attached to the patella and the entire extensor mechanism can be shifted medially.

**TECH FIG 8 • A,B.** Initial step in the modified Langenskiöld reconstruction is to perform a medial and lateral capsulotomy. The knee joint capsule is dissected away from the synovium medially and laterally. The synovium also is dissected free from the quadriceps tendon and the patellar tendon. **C,D.** Synovium is released from the patella circumferentially, leaving the quadriceps and patellar insertions intact. **E,F.** The hole in the synovium is closed longitudinally with absorbable suture, leaving the patella with the quadriceps and patellar attachments extra-articular. The Grammont elevation and Grammont medial patellar tendon shift are then performed (see Tech Fig 5). *(continued)*
The synovium is now a free tissue layer with a patella-sized hole in the center.

- The synovial hole is sutured longitudinally with absorbable suture (TECH FIG 8E,F). The patella is left extra-articular at this point.
- The Grammont procedure is performed as described above, and the patellar tendon is shifted medially. The patellar tendon is secured with absorbable suture.
- The patella with the quadriceps muscle is now realigned medially to its new position and a marking pen is used to mark its new location on the synovium (TECH FIG 8G).

The synovium is incised longitudinally with the knee in full extension (TECH FIG 8H). The patella is inserted into this new position and sutured circumferentially to the synovium with a continuous absorbable suture (TECH FIG 8I,J).

- The medial retinacular flap is now advanced over the patella and sutured to the lateral side of the patella (TECH FIG 8K).

Once the modified Langenskiöld reconstruction is completed, the ACL and PCL knee ligamentous reconstruction, as previously described, is performed (TECH FIG 8L,M).

**TECH FIG 8 • (continued)**

G. Knee is positioned in full extension, and the new position for the patella is marked on the synovium. H. A longitudinal incision is created in the synovium. I,J. The synovium is sutured to the patella in a circumferential fashion. K. The medial capsule is advanced and sutured onto the lateral side of the patella. The lateral capsule is not repaired. L,M. If an extra-articular posterior collateral ligament (reverse MacIntosh) procedure is performed, the Langenskiöld reconstruction is completed before the ligamentous reconstruction. Fascia lata graft passes through the advanced medial capsule and is sutured onto itself. BF, biceps femoris muscle; m., muscle; RF, rectus femoris tendon; VM, vastus medialis. (Copyright 2009, Sinai Hospital of Baltimore.)
FEMORAL LENGTHENING OF TYPE 1 CFD: ORTHOFIX FIXATOR TECHNIQUE

Preparatory Surgery
- The preparatory surgery that is required consists of a Dega pelvic osteotomy for underlying hip dysplasia (CE angle less than 20 degrees or AI greater than 30 degrees), rectus femoris tendon release, and iliotibial band release at the level of the superior pole of the patella. If the popliteal angle is greater than 10 degrees, the biceps femoris tendon and medial hamstrings should be released.
- If the patient has undergone a superhip procedure, the preparatory surgery has been completed and repeat releases of the soft tissues are not necessary.
- If the preparatory surgery has not been performed and the Dega osteotomy is needed, it should be combined with excision of the fascia lata, superknee reconstruction, or both. Alternatively, the soft tissue releases can also be performed simultaneously with the lengthening procedure.

Placement of Femoral Fixator
- An arthrogram of the involved knee is obtained under fluoroscopy. In the lateral view, the femoral condyles are rotated until they superimpose each other. This is considered a “true lateral of the knee” (note that this is not the patella-forward position—actually the patella will be externally rotated approximately 10 degrees in this position).
- The center of knee rotation is identified. The center of rotation is the intersection of the posterior cortical line and the distal femoral physis line.
- A 1.8-mm Ilizarov wire is inserted into the distal femoral physis at the center of rotation and parallel to the distal femoral joint line in the frontal plane (TECH FIG 9A,B).
- The pediatric LRS is aligned with the hinge-axis wire through the most distal clamp hole. A commercially available “sandwich” clamp is used in the distal clamp, which provides a second layer of pin holes more anteriorly (TECH FIG 9C,D).
- If these are not available, two pin clamp lids can be joined by 30-mm bolts to create a sandwich clamp.
- The external fixator rail is aligned with the femur in the sagittal view and the most proximal half-pin is inserted at the level of the base of the greater trochanter (this pin should be distal to the apophysis).
- The half-pins are inserted using the cannulated drill technique: a 1.8-mm or 1.5-mm wire is first inserted into the bone and the position is checked with fluoroscopy in both the AP and lateral views.

TECH FIG 9 • A,B. Intraoperative fluoroscopic images show arthrography of the knee. The lateral view is obtained, and the posterior aspects of the femoral condyles are superimposed to create the perfect lateral view. The hinge reference wire is inserted at the intersection of the posterior femoral cortical line and the distal femoral physis. This marks the center of rotation of the knee joint. C,D. Bone model shows LRS sandwich clamp placed distally, with the most distal hole containing the hinge-axis wire. The first distal half-pin is placed on the anterior row one hole proximal to the hinge-axis pin. E. Example of pediatric Orthofix rail with a three-hole cube placed on the distal half-pins to allow a third half-pin to be inserted into the distal fragment. F. Radiograph shows acute valgus correction performed at the osteotomy site for lengthening. (Copyright 2006, Sinai Hospital of Baltimore.)
If the wire is in the center of the bone, a cannulated drill is used to overdrill the wire. The half-pin is then inserted in a perfect position.

- Half-pins placed in the anterior half of the femoral diaphysis can result in a fracture either during the lengthening process or after frame removal.
- The most distal half-pin is placed one hole proximal and anterior to the knee axis reference wire.
- At this point, the position of the hinge axis is a fixed point to the initial distal half-pin. The reference axis wire is removed.
- An LRS without a sandwich clamp is now placed on the two half-pins. The additional half-pins are placed proximal and distal. Three half-pins should be placed in each segment.
- If concurrent distal valgus deformity is being corrected, a swivel clamp should be used at the proximal clamp site when placing the first two half-pins.
- When using the pediatric LRS, the standard clamp offers only three half-pin sites and one site is occupied by the knee axis dummy pin. Therefore, a three-hole Ilizarov cube should be connected to the two half-pins that occupy the pediatric Orthofix clamp and a third half-pin placed through the cube more proximal (TECH FIG 9E).
- After all half-pins are placed, the template LRS with swivel clamp is removed and a distal femoral osteotomy is performed using the multiple drill hole technique.
- The distal femoral valgus deformity is acutely corrected, and the LRS with sandwich clamp attachments is placed on the half-pins, stabilizing the correction (TECH FIG 9F).

Placement of Tibial Fixator

- The distal pins should be in the upper deck of the double-decker sandwich clamp.
- The only pin in the lower deck of the sandwich clamp is a dummy pin (i.e., partial pin that is captured by the clamp and protrudes away from the patient but does not enter the patient’s limb) in the distal lower hole.
- This dummy pin is the hinge-axis pin.
- A Sheffield clamp (Orthofix) is applied to the hinge-axis pin. Conical washers are placed medial and lateral to the Sheffield clamp to reduce friction. A single-hole Ilizarov cube and set screw are placed laterally.
- The hinge-axis pin and Sheffield clamp have now created a mechanical hinge (TECH FIG 10A,B).
- The Sheffield clamp is temporarily tightened and positioned parallel to the LRS rail. A one-third Sheffield arch is then attached to the clamp and arched medially to be anterior to the tibia. The arch should be perpendicular to the tibia in the sagittal plane (TECH FIG 10C–E).
- A single-hole ilizarov cube is placed on the Sheffield arch, and an AP half-pin is placed in the proximal tibia. As the first pin is being secured to the Sheffield arch, the knee must be in full extension and reduced.

Testing and Completion of the External Fixator Construct

- After the first half-pin is inserted into the tibia, the Sheffield clamp is loosened and the hinge tested with gentle ROM of the knee.
If the motion is smooth, a drop-leg test is performed.
- The drop-leg test consists of lifting the lower extremity off the bed and fully extending the knee. The thigh is supported and the lower leg dropped.
- If the knee flexes with no catching or friction, two additional half-pins are placed in the tibia.
- If there is friction during the drop-leg test, the hinge and knee rotation axis needs to be examined and adjusted. Usually, the dummy axis pin can be slightly bent and the hinge axis reoriented to the knee rotational axis. After the axis pin adjustment, the drop-leg test is repeated until knee ROM is smooth, with no friction (TECH FIG 11A,B).

PEARLS AND PITFALLS

Superhip—initial dissection
- Rectus femoris and iliopsoas tendons are located closer to the femoral nerve than expected. The surgeon should first identify the femoral nerve before performing any releases or tenotomies.

Superknee—knee flexion contracture
- Knee flexion contracture should be released with biceps femoris lengthening and posterior capsular release. A concurrent ligamentous reconstruction should not be performed because of postoperative stiffness of the knee joint.

Femoral lengthening
- Positioning the hinge-axis wire is the crucial step when applying the external fixator. Great care should be taken to ensure precise placement of the wire at the center of rotation of the knee (intersection of the posterior femoral cortical line and the distal femoral physis). This must be performed after an arthrogram of the knee is obtained, which allows exact visualization of the overlapped posterior femoral condyles in the lateral fluoroscopic view.

External fixator removal
- At the time of external fixator removal, a Rush pin should be placed prophylactically as described below. Activities, to include physical therapy, should be modified for 4 weeks after removal. A removable long-leg cast should be applied to maintain extension and to protect the tibia.

Femoral lengthening
- If the initial distal femoral half-pin is positioned too far anterior when placed through the sandwich clamp, the initial hinge-axis pin is too far anterior. The surgeon should carefully examine the hinge-axis wire and ensure that it is at the level of the posterior femoral cortical line.

Postoperative therapy and preservation of knee motion
- Knee flexion should be maintained at greater than 45 degrees. If knee flexion is 40 degrees or less, lengthening should be slowed or discontinued and knee rehabilitation increased.
POSTOPERATIVE CARE

- Patients who have undergone the superhip or superknee procedures are placed into a 1-1/2 hip spica cast.
- The involved limb is placed in neutral abduction, neutral rotation, and 0 degrees of extension. The knee is held in full extension, and the foot is included.
- The cast is removed at 6 weeks, and gentle ROM of all joints is performed as well as weight bearing as tolerated.
- Patients undergoing femoral lengthening require close follow-up and intensive rehabilitation. Patients are usually discharged on postoperative day 3 or 4.
- The lengthening begins on day 5 or 7 at a rate of 0.75 to 1.0 mm per day.
- The patient is assessed every 2 weeks in the outpatient clinic with radiographic and clinical examinations.
- Pin-site problems, nerve function, hip and knee ROM, and knee subluxation are assessed.
- The joint location, limb alignment, regenerate bone quality, and length gained are assessed radiographically.
- The rate of distraction is adjusted according to regenerate bone quality and joint ROM.
- Physical therapy is begun on postoperative day 1. During the distraction phase, physical therapy is continued daily, with formal therapy occurring 5 days per week.
- The formal therapy consists of one or two sessions with a therapist each day, with 1 hour of land therapy and 1 hour of hydrotherapy.
- The patient also undergoes two physical therapy sessions at home each day with the parents.
- During therapy, the patient should perform exercises that obtain knee flexion and maintain knee extension.
- Knee flexion should be maintained at greater than 45 degrees but not more than 90 degrees.
- If knee flexion is 40 degrees or less, lengthening should be discontinued or slowed and knee rehabilitation should be increased.
- If there is no improvement, lengthening is discontinued.
- During the distraction phase, passive exercises are most important; during the consolidation phase, passive plus active exercises are important. Hip abduction and extension are two important hip exercises.
- During the consolidation phase, the formal therapy can be reduced to three sessions per week if the patient is doing well. Weight bearing is allowed as tolerated.
- The frame can be removed from the femur and tibia after the regenerate bone has healed.
- A prophylactic Rush pin (Zimmer, Inc., Warsaw, IN) is placed in the femur at the time of external fixation removal (FIG 7). Application of the Rush pin prevents refracture after lengthening.
- The frame is removed under general anesthesia, and radiographs in the AP and lateral views are obtained.
- At this point, the pin sites are cleaned, prepared, and then isolated with Tegaderm dressings (3M Healthcare Ltd, St. Paul, MN). The entire lower extremity to include the hip, iliac crest, and gluteal region is prepared and draped.
- A 1.8-mm Ilizarov wire is inserted into the tip of the greater trochanter and driven into the center of the proximal femur. An intraoperative lateral view radiograph after external fixation removal is used to place the starting point on the greater trochanter. The 1.8-mm wire is drilled or tapped into the femur and then overdrilled with a cannulated 3.2-mm or 4.8-mm drill to create the starting hole for the prophylactic Rush pin insertion, depending on whether a 3.1-mm (1/8 inch) or 4.6-mm (3/16 inch) Rush pin is used.
- If needed, the femur is then sequentially reamed using T-handled hand reamers (ie, Foresight nail reamers [Smith & Nephew]) until the desired pin diameter is obtained. The hand reamer should be slightly bent at the tip to allow for careful guidance down the canal under fluoroscopic control.
- After the reaming is complete, the Rush pin is inserted and should reach just above the distal femoral physis. Its tip might need to be slightly bent to navigate the curves of the femur.
- The small proximal incision is closed, and the pin sites are dressed. The pin sites are not manipulated or released to decrease the risk of concurrent infection.
- Antibiotics are administered intravenously during the procedure, and oral antibiotics are used for 7 days postoperatively.

FIG 7 • A. AP view radiograph of right femur of a patient with Paley type 1a congenital femoral deficiency after initial lengthening of 8 cm. B. Postoperative AP view radiograph of femur after external fixation removal with insertion of Rush pin to protect the newly consolidated regenerate bone. C. Longstanding lateral view radiograph shows the inserted Rush pin after external fixation removal. (Copyright 2007, Sinai Hospital of Baltimore.)
If a significantly problematic pin site or pin-site infection is present at the time of removal, the prophylactic intramedullary rod placement is delayed for 2 weeks and the affected limb is placed into a hip spica cast.

Physical therapy is discontinued for 1 month to avoid fracture through the regenerate bone or a pin hole.

Physical therapy is restarted 1 month after frame removal and Rush pin application. With the Rush pin in place, no cast or brace is needed. The patient is allowed partial weight bearing.

OUTCOMES

Saghieh and associates\textsuperscript{12} studied our first 79 consecutive patients with Paley type 1 CFD. The patients underwent 99 femoral lengthenings between January 1988 and December 2000. Medical charts and radiographs were retrospectively reviewed. Fifty-nine patients (73 lengthenings) had Paley type 1a and 20 patients (26 lengthenings) had Paley type 1b CFD. Forty-six (58\%) were female and 33 (42\%) were male patients. The mean patient age was 12.3 years (age range, 1.5 to 62.3 years). The lengthenings were divided into three age groups: toddler (younger than 6 years), juvenile (between 6 years and skeletal maturity), and adult (skeletally mature). Because 19 patients each underwent more than one lengthening (18 underwent two lengthenings, and 1 underwent three lengthenings), each lengthening was evaluated independently as a separate lengthening and studied for its own results and complications.

- Distraction gap, percent of femur lengthened, external fixation time index, degree of preservation of knee motion, result score, and complications were compared among the groups. The complications and ROM data were routinely recorded, and the data were obtained from a review of the charts. Radiographic measurements were obtained from preoperative lower limb alignment AP view radiographs (tele-oroentgenograms), compensating for magnification, and from lateral view radiographs of the femur and tibia. The CE angle and neck–shaft angle also were measured, preferably by using an AP view radiograph of the pelvis. The average follow-up from the time of removal of the external fixator was 69 months (range, 19 to 132 months).

- The average discrepancy in femoral length was 9.1 cm (range, 1.2 to 22.1 cm) preoperatively and 4.1 cm (range, 14.7 to 2.3 cm) postoperatively. The mean distraction gap was 5.8 cm (range, 2.4 to 12.0 cm). The average duration of treatment with external fixation was 5.9 months (range, 2 to 15.9 months) with an external fixation time index of 1.07 months/cm (range, 0.49 to 2.38 months/cm). The result score was excellent in 61 (61.6\%) lengthenings, good in 29 (29.3\%), fair in 7 (7.1\%), and poor in 2 (2\%).

- Excellent and good results were achieved in 91\% of patients. No significant differences in most of the studied parameters, including result score, were observed among the different groups. The two younger groups experienced a higher incidence of fracture (no prophylactic rodding was used in this group). The adult group experienced a higher incidence of delayed union and joint stiffness. However, the overall complication rates were similar among the three groups. We prefer to begin lengthening at an early age so that additional needed lengthenings can be spaced in time.

- Currently, we are reviewing our experience since 2000. Our outcome study includes more than 250 patients with CFD who have undergone more than 350 lengthening procedures.

COMPlications

- Flexion contracture of the knee
- A significant knee flexion contracture places the knee at risk for posterior subluxation.
- One of the primary goals of physical therapy is to maintain knee extension and to continue to obtain knee flexion. Both the surgeon and therapist need to closely monitor the patient’s ROM and must be in regular communication if difficulties arise.
- To prevent fixed flexion deformity, a knee extension bar is used every night and part-time during the day. If the patient experiences a loss of motion, therapy must be increased and the patient assessed immediately.
- Acute pin-site infections can lead to increased pain and decreased motion and should be immediately treated with oral or intravenous antibiotics.
- If significant soft tissue tightness is present in the quadriceps muscle, the distraction rate should be decreased. However, decreasing the distraction rate should be followed closely with radiographs to prevent premature consolidation. If Botox was not used at the index procedure, the surgeon should consider injecting the quadriceps muscle with 10 units of Botox solution per kilogram of body weight. We perform the Botox injection under anesthesia or sedation for the younger patient.

- Adduction and flexion contractures of the hip

- Hip adduction contractures place the hip joint at risk for subluxation and dislocation during the lengthening process. Hip adduction should be assessed at the time of the lengthening surgery. If a contracture is present, an adductor tenotomy should be performed.

- Hip ROM and stretching is addressed by the therapist on a daily basis. If a contracture is a concern initially, an abduction pillow is used at night. If the patient has subluxated or dislocated the hip in a previous procedure, the external fixator should be extended above the hip with a hinge device similar to that used for the knee. Hip flexion contracture might occur when the patient is positioned in a wheelchair for prolonged periods of time.

- The patient should not only stretch during the therapy sessions, but also should be placed in a prone position on a daily basis. Occasionally, a repeat rectus femoris tendon release along with a release of the anterior thigh fascia is performed at the time of external fixation removal. Iliopsoas contracture does not occur during the lengthening because the distraction site is distal to the psoas insertion.

- Nerve injury

- Nerve injury is unusual with femoral lengthening. Complaints of pain in the foot are usually referred pain from nerve entrapment. Quantitative sensory testing is the best method to identify early nerve entrapment.\textsuperscript{7} The nerve problem can be treated by slowing the distraction or nerve decompression. The peroneal nerve should be decompressed at the neck of the fibula if symptoms continue or pressure-specified sensory device testing is positive.\textsuperscript{9} Premature consolidation

- Premature consolidation usually occurs during the first 2 cm of distraction and is rare after 4 cm of distraction. In a young child, the latency period should not be more than 7 days.
■ Increasing pain with distraction or difficulty while turning the distracting unit are signs of possible preconsolidation. Radiographs should be obtained to assess the regenerate bone. If the fibrous interzone disappears, the turning rate should be increased (ie, five quarter-turns per day) and additional radiographs obtained within 1 week.
■ If one of the cortices has bridged with narrow bone, continued distraction at an increased rate can be performed.
■ The physician must warn the parents that the patient may experience or hear an audible “pop” during distraction. This will be followed by a mild to moderate increase in pain. However, the distraction will become easier and surgery can be avoided.
■ If the regenerate site is consolidated with abundant bone, the pins might bend or become deformed. This type of preconsolidation is addressed with a repeat osteotomy 1 to 2 cm proximal to the original site. The surgeon should not attempt to repeat an osteotomy at the same regenerate site because the patient will have increased bleeding and poor regenerate bone formation. If the fibrous interzone is greater than 5 mm, lengthening should be slowed (ie, two or three turns per day).
■ Regenerate bone failure
  ■ Partial defects in the bone are not uncommon on the lateral cortex. Sequential radiographs obtained during the distraction phase must be closely followed for increasing fibrous interzone distance and poor regenerate bone formation.
  ■ Regenerate bone failure is prevented by slowing the distraction rate when signs of poor regenerate formation are present. During the consolidation phase, a partial defect can be treated with dynamization to increase healing of the regenerate bone.
  ■ If the defect persists and encompasses less than 25% of the bone diameter, a rigid intramedullary rod placed at the time of removal will allow for ossification during a prolonged time period (6 to 12 months).
  ■ If the regenerate bone failure is more severe, open autogenous bone grafting should be performed after first excising the interposing fibrous tissue.

REFERENCES
DEFINITION
- Congenital dislocation of the knee (CDK) is a rare deformity that presents at birth as recurvatum.
- The incidence of CDK is estimated at 1 per 100,000 live births, which is approximately 1% of the incidence of congenital dislocation of the hip.7
- It may be an isolated entity or occur with associated musculoskeletal anomalies such as dislocated hips, clubfoot, and congenital vertical talus. It can also occur with myelodysplasia, Larsen syndrome, and arthrogryposis.
- It varies in severity and has been classified as simple hyperextension, subluxation, and anterior dislocation of the tibia on the femur (FIG 1).3

ANATOMY
- The fundamental pathologic feature in CDK involves the quadriceps muscle. The amount of quadriceps muscle is small, and the muscle as well as the lateral retinaculum adheres to the femur.
- The quadriceps femoris tendon is shortened and fibrosed, which is thought to be secondary to the dislocation rather than its cause.3
- The patella is often laterally displaced.
- There is hypoplasia of the suprapatellar pouch.
- The hamstrings are often deficient, subluxed anteriorly, or both.
- The anterior knee articular capsule is tight.
- The menisci are usually present and normal.
- The pathology in the cruciate ligaments is variable, from absence to elongated.5

PATHOGENESIS
- The exact cause of CDK remains unknown.
- A genetic etiology is supported by the presence of familial occurrence in some cases as well as the association of CDK with developmental hip dysplasia, idiopathic clubfoot, and congenital vertical talus, all three of which have a known or presumed genetic basis.1,11
- Simple hyperextension of the knee in newborns may be caused by aberrations in intrauterine positions, such as frank breech presentation, which slowly stretches the hamstrings and posterior knee soft tissues.7 Chronic knee hyperextension results in anterior subluxation of the hamstrings, allowing them to function as knee extensors.
- Severe CDK often occurs in association with disorders with muscle imbalance, such as myelodysplasia, arthrogryposis, Larsen syndrome, Ehlers-Danlos syndrome, Streeter syndrome, and oligohydramnios.3,11

NATURAL HISTORY
- The natural history of CDK depends on the severity of the disorder on presentation. Simple hyperextension of the knee tends to resolve spontaneously or with splinting.2,6
- In cases of subluxation and dislocation, spontaneous resolution is not common, and most patients require surgical correction.
- Left untreated, these patients have great difficulty with ambulation owing to the inability to flex the knees. These patients often have associated neuromuscular or genetic syndromes.3

PATIENT HISTORY AND PHYSICAL FINDINGS
- The physical findings of CDK are readily apparent at birth but of variable severity (FIG 2).
- The knee is hyperextended, in severe cases to such a degree that the foot rests against the baby’s face.
- In cases of simple hyperextension, the knee can be passively brought into flexion.
- In the more common scenario of subluxation, passive flexion is limited but improves with splinting, casting, or both.
Nonoperative treatment consists of serial manipulations and long-leg plaster castings.2,6,10

With the patient relaxed with a bottle of milk, gentle traction is applied to the tibia to stretch the contracted quadriceps muscle. After several minutes of stretching, a long-leg plaster cast is applied from the toes to the top of the thigh. The cast is applied in one section and is carefully molded to maintain the position achieved with stretching and to avoid skin sores.

The casts are changed on a weekly basis in the clinic. Once the tibia reaches the distal femur with traction, flexion of the knee is begun.

In cases of simple hyperextension, flexion of the knee can often be started quite early (FIG 4).

In cases of subluxation and complete dislocation of the knee, however, flexion of the knee often cannot be started for several weeks until the quadriceps muscle is adequately stretched.

It is very important to obtain a lateral radiograph of the knee once knee flexion reaches 45 degrees and again if 90 degrees of flexion is reached during serial casting. It is possible to create an iatrogenic physeal separation of the distal femur or to deform the proximal tibia plastically.

Closed treatment should be stopped if anatomic reduction of the tibia cannot be confirmed.

If 90 degrees of flexion is obtained and a normal restoration of the femoral–tibial articulation is demonstrated on a lateral radiograph, it is unlikely that any surgical intervention will be necessary.

Historically, nonoperative treatment has been successful in treating simple hyperextension of the knee and some cases of subluxation. Most patients with complete knee dislocation have an extensive surgical release operation after a failed attempt at casting.

**SURGICAL MANAGEMENT**

**Preoperative Planning**

If serial casting fails to obtain a reduction of the anteriorly dislocated tibia on the end of the femur, which is verified on a lateral radiograph of the knee, surgical management should be considered.
Timing of the surgical correction depends on the particular technique that the surgeon chooses, but usually ranges from 1 month of age to 2 years.

**Positioning**
- The patient is positioned supine on a radiolucent table. No tourniquet is used as this interferes with the location of the surgical incision.
- The entire leg is prepared into the field from the hip to the tip of the toes to allow easy manipulation of the knee (FIG 5).

**Approach**
- The approach depends on the surgeon’s preference but varies from minimally invasive approaches to extensile approaches with quadriceps mechanism reconstruction.

---

**PERCUTANEOUS QUADRICEPS RECESSION**

- This procedure is ideally performed at 1 to 2 months of age and is described by Roy and coworkers.\(^1\)
- An assistant holds the affected leg and attempts to flex the knee.
- A small stab incision is made one to two patellar lengths superior to the patella in the midline of the thigh, and the fascia overlying the rectus femoris is released (TECH FIG 1).
- Medial and lateral stab incisions are then made at the superior border of the patella to release the medial and lateral quadriceps tendon and retinaculum.

- After the release is performed, the knee is flexed to 90 degrees.
- Sterile dressings are applied, followed by a long-leg plaster cast with the knee flexed at 90 degrees or greater.
- The cast is worn for 4 to 6 weeks.
- After cast removal the patient is placed in a Pavlik harness to maintain knee flexion for an additional 4 to 6 weeks.

---

**MINI-OPEN QUADRICEPS TENOTOMY**

- This approach is ideally performed between 1 and 6 months of age and has been described by Dobbs and associates (TECH FIG 2).\(^4\)
- A 2-cm vertical midline incision is made just above the superior pole of the patella.
- Dissection is carried down to the patella and the quadriceps tendon.

- The quadriceps tendon is carefully isolated with blunt dissection using a hemostat.
- The quadriceps tendon is transected completely about 1 cm proximal to its insertion on the superior pole of the patella.
- The knee is then gently flexed until at least 90 degrees of flexion is obtained.
If 90 degrees of flexion cannot be obtained after the quadriceps tenotomy, the anterior knee capsule is released as well as the lateral retinaculum until 90 degrees of flexion is obtained.

An intraoperative lateral knee radiograph is obtained to ensure anatomic reduction of the tibia on the distal femur.

After wound closure, a sterile dressing is applied, followed by a long-leg plaster cast with the knee in 90 degrees of flexion.

**EXTENSILE RECONSTRUCTION OF CONGENITAL KNEE DISLOCATION**

- This approach is usually performed between 6 months and 1 year of age.
- A midline longitudinal incision or serpentine incision can be used. The midline incision extends from the tibial tubercle to the middle of the thigh; the serpentine incision extends from the tibial tubercle to the proximal thigh.
- The serpentine incision may facilitate wound closure and result in fewer wound-healing problems than the straight incision.
- The patella, the quadriceps muscle and tendon, the patellar tendon, and the lateral retinaculum are all carefully exposed.
TECH FIG 3 • V-to-Y quadriceps advancement. A. The quadriceps tendon is exposed proximal to the patella, and most of the medial and lateral fibers are detached from the tendon. The medial and lateral retinaculum is divided to the collateral ligaments. The iliotibial band is divided if the tibia is in valgus and externally rotated. B. The posterior borders of the lateralis and the medialis are divided sharply and the flap of muscle created is dissected free of underlying attachments to the femur. This will permit the tibia and collateral ligaments to slide posteriorly and allow sufficient mobilization of the quadriceps. C. With the knee flexed at about 40 degrees, the medialis and lateralis are reattached to the quadriceps tendon, creating the V-to-Y advancement and repair. The retinaculum is not closed.

PEARLS AND PITFALLS

Indications
- A complete history and physical examination should be performed.
- Associated diagnoses must be recognized as this can alter the prognosis and treatment strategy.

Nonoperative treatment
- Care must be taken during manipulation and casting not to create iatrogenic fractures in the distal femur or proximal tibia.
- Use of radiographs can confirm anatomic reduction of the tibia on the distal femur.

Extensile surgical approach
- Reapproximation of the quadriceps mechanism must be done in 30 to 40 degrees of flexion. Flexing the knee less than 30 degrees often results in recurrent subluxation, and flexion greater than 40 degrees is too much to permit reconstruction of the quadriceps tendon.

Postoperative management
- No matter what treatment method is used to correct the deformity, splinting and range-of-motion exercises are essential to maintain flexion and minimize loss of extension. A knee flexion contracture can be more debilitating than a lack of full flexion.

Management of associated musculoskeletal problems
- Associated clubfoot deformity can be treated at the same time as the CKD by incorporating the foot into the long-leg cast using the Ponseti method.
- Management of associated hip dislocation should be done later as a staged procedure.
POSTOPERATIVE CARE

- A lateral radiograph of the knee is essential to ensure anatomic reduction of the tibia on the distal femur.
- Casting is required after each treatment method. The degree of knee flexion in the cast and the duration of casting vary with technique.
  - Percutaneous quadriceps resection
    - A long-leg plaster cast with the knee flexed at least 90 degrees is applied at the end of the procedure and worn for 4 to 6 weeks.
    - After cast removal, the patient is placed in a Pavlik harness to maintain knee flexion for an additional 4 to 6 weeks.
  - Mini-open quadriceps tenotomy
    - The initial long-leg plaster cast with the knee in 90 degrees of flexion is changed in the operating room at 3 weeks postoperatively to assess knee range of motion.
    - Another long-leg cast is applied with the knee in 70 degrees of flexion for 2 weeks. This cast is removed in the clinic and formal physical therapy is begun on an outpatient basis to maintain knee flexion and extension. Splints are also used for 4 to 6 weeks, alternating between a flexed and an extended position at the knee.
  - Extensile reconstruction: spica cast with the knee in about 45 degrees of flexion
    - Once casting is complete, close follow-up is mandatory to ensure maintenance of knee motion.
    - Splinting is also important after each treatment method to maintain maximal flexion and minimize loss of knee extension.
    - Physical therapy is also an essential part of postoperative rehabilitation and is done on an outpatient basis several times a week for up to 3 months.

OUTCOMES

- Patients with a hyperextension deformity that requires only serial manipulation and castings do very well long term both clinically and radiographically.2,5,8,10
- Roy and colleagues11 report good short-term results using the percutaneous quadriceps tenotomy, but there are no long-term data with this technique. This technique was successful only in patients without associated syndromes or neuromuscular deformities.
- Dobbs and coworkers4 report good short-term results using the mini-open quadriceps tenotomy in patients with isolated CDK as well as in some children with associated genetic and neuromuscular conditions. No long-term follow-up is available for this technique.
- Patients with severe dislocation who have undergone an extensive open procedure, but do not have any other associated musculoskeletal problem, generally do well long term if knee flexion is 80 degrees or greater.
- Children with associated neuromuscular disorders or genetic syndromes do not do as well long term.
- Children with bilateral deformities do not do as well as those with unilateral deformity.
- Early correction has a more satisfactory result than late repair.4,7,11

COMPlications

- Wound-healing problems have been reported with extensile approaches.
- Loss of flexion initially gained at surgery can be a late complication.
- Development of a flexion contracture can occur postoperatively and compromise long-term outcome.
- Iatrogenic fractures of the distal femur, proximal tibia, or both can occur with casting and manipulation.

REFERENCES

DEFINITION
■ Blount’s disease, also known as idiopathic tibia vara and osteochondritis deformans tibiae, is characterized by abnormal growth of the proximal tibia physis with progressive varus deformity.
■ Blount’s disease is classified into three types based on age of clinical onset: infantile (0–3 years); juvenile (4–10 years); and adolescent (11 years and older).
■ Infantile tibia vara is most prevalent in African-American females and is associated with obesity, internal tibial torsion, and leg-length discrepancy. Radiographs reveal a prominent medial metaphyseal beak, and the origin of the varus deformity is in the proximal tibia only. About 80% of cases are bilateral, and the potential for deformity is the greatest in this group.
■ Adolescent tibia vara is most prevalent in African American males with marked obesity, minimal internal tibial torsion, mild medial collateral ligament laxity, and mild leg-length discrepancy. The site of the deformity is in the proximal tibia and sometimes in the distal femur as well. About 50% of cases are bilateral, and pain rather than deformity is more commonly the presenting complaint.

ANATOMY
■ When evaluating patients with Blount’s disease, the normal development of the tibiofemoral angle in children must be considered.
■ The normal tibiofemoral angle in newborns is approximately 15 degrees varus. It decreases with growth, so that the tibiofemoral angle approaches 0 degrees around 18 months of age.
■ The tibiofemoral angle progresses to maximum valgus around 3 years of age and then decreases until adult physiologic valgus is achieved between 7 years of age and skeletal maturity.
■ One standard deviation of the anatomic tibiofemoral angle throughout growth is approximately 8 degrees.

PATHOGENESIS
■ Blount’s disease is likely due to a combination of genetic factors and a cycle of increased stress across the medial physis, which leads to decreased medial endochondral ossification, further varus deformity, and, subsequently, further medial physeal stress. The medial physeal stress is aggravated by obesity and progressive genu varum.
■ Histopathologic studies of infantile and late-onset tibia vara are similar to those of patients with slipped capital femoral epiphysis. Findings include fissuring and clefts in the physis, fibrovascular and cartilaginous repair at the physeal-metaphyseal junction, foci of necrotic cartilage, and marked disorganization of the medial degenerative physeal zone.

These findings are consistent with an arrest of the normal endochondral growth mechanism.

NATURAL HISTORY
■ A varus alignment of the lower extremity places excess stress on the medial compartment of the knee. This stress places the knee at increased risk for arthritis.
■ The goal of intervention is to restore the normal anatomic orientation of the knee and ankle joints and to restore the normal mechanical axis of the leg.

PATIENT HISTORY AND PHYSICAL FINDINGS
■ The chief complaint in infantile tibia vara usually is deformity. In late-onset tibia vara, in contrast, knee pain is the primary complaint. The characteristics of the pain should be elicited.
■ Patients may exhibit a limp, with or without a leg-length discrepancy. Observe the patient’s gaiting, noting a limp or lateral thrust.
■ The mechanical axis of the lower leg is in varus. Genu recurvatum and internal tibial torsion may be present as well.
■ Inspect the sagittal profile for the presence of genu recurvatum; if present, it may be necessary to address it at the time of surgery.
■ The Q angle provides a clinical estimate of the anatomic tibiofemoral angle.
■ Range of motion and collateral ligament laxity also should be assessed.

IMAGING AND OTHER DIAGNOSTIC STUDIES
■ AP long-leg radiographs (which include the hips, knees, and ankles) should be obtained. The patella (not the foot) must be pointing forward.

FIG 1 • Orthoradiograph of patient with adolescent Blount’s disease.
Infantile Blount’s disease has several characteristic radiographic findings.
- To help differentiate infantile Blount’s disease from physiologic varus, the metaphyseal-diaphyseal angle is drawn. A metaphyseal-diaphyseal angle less than 10 degrees is consistent with physiologic varus, whereas an angle of more than 16 degrees is consistent with infantile Blount’s disease.
- Acute angulation of the medial proximal tibia, medial beaking, fragmentation of the medial metaphysis, progressive varus, and unilateral involvement are consistent with infantile Blount’s disease.
- Care must be taken that the radiographs are taken with the patella forward.
- If tibial torsion is present, the feet must cross medially so that the patella is forward. The medial and lateral flares of the distal femurs will be equal if the patella is forward.
- The proximal tibia is examined to determine the Langenskiöld stage.
  - Stage I: Age under 3 years. Medial and distal beaking of metaphysis with irregularity of entire metaphysis
  - Stage II: Age 2.5 to 4 years. Sharp anteromedial depression in ossification line of wedge-shaped medial metaphysis
  - Stage III: Age 4 to 6 years. Deepening of metaphyseal beak
  - Stage IV: Age 5 to 10 years. Enlargement of epiphysis
  - Stage V: Age 9 to 11 years. Cleft in epiphysis, appearance of double epiphysis
  - Stage VI: Age 10 to 13 years. Closure of medial proximal tibial physis
- Late-onset Blount’s disease is characterized by less obvious changes in the proximal tibia.
  - These changes include wedging of the medial portion of the epiphysis, a mild postero-medial articular depression, a serpinginous curved physis of variable width, and mild or no fragmentation of the proximal medial metaphysis.
- Radiographic analysis for deformity has been well described by Paley et al.4
  - The magnitude of the overall lower extremity malalignment can be determined by the anatomic tibiofemoral angle or the mechanical axis deviation. The anatomic tibiofemoral angle is the angle between the midshaft lines of the femur and the tibia. The mechanical axis deviation is the distance from the center of the knee to the mechanical axis line of the leg.
  - Analysis of the frontal plane deformity begins with the malalignment test.
    - The mechanical axis line is drawn from the center of the hip to the midpoint of the ankle plafond.
    - To identify whether the source of the deformity is the femur, the tibia, or both, joint orientation angles are measured.
    - The mechanical lateral distal femoral angle (mLDFA, normal value 85 to 90 degrees) and medial proximal tibial angles (mPTA, normal value 85 to 90 degrees) are measured to determine which is/are abnormal.
    - The joint line convergence angle is measured to determine whether the joint line is an additional source of deformity.
    - If the midpoints of the femur and tibia are over 3 mm apart, then frontal plane subluxation is a source of deformity as well.
- Finally, the joint lines are inspected for intra-articular sources of deformity.
- The malalignment test is applied to the ankle and hip to determine whether these joints are oriented normally to the mechanical axis line.
- Abnormal joint orientation angles indicate which joints are contributing to the deformity.
- Sagittal plane radiographs are obtained and analyzed as appropriate.
- Leg lengths are measured in order to identify a leg-length discrepancy.
- The location of the deformity point, or center of rotation of angulation (CORA), is identified during preoperative planning.

DIFFERENTIAL DIAGNOSIS
- Physiologic varus
- Pathologic causes
  - Blount’s disease
  - Rickets
  - Skeletal dysplasias
  - Focal fibrocartilaginous dysplasia
  - Renal osteodystrophy
  - Osteogenesis imperfecta

NONOPERATIVE MANAGEMENT
- Nonoperative treatment with bracing may be indicated in patients with infantile Blount’s disease.
- Bracing should be considered for varus deformity greater than 15 degrees in children over 2 years of age with Langenskiöld stage I or II Blount’s disease.
- Bracing usually is not helpful in obese African-American girls over the age of 3 years.
- Nonoperative treatment with bracing is not successful in adolescent Blount’s disease.

SURGICAL MANAGEMENT
- The surgical treatment of infantile Blount’s disease is distinct from that for adolescent Blount’s disease.
- In patients with infantile Blount’s disease, the proximal tibial physis has several years of growth remaining. A proximal tibial osteotomy should be performed with the goal of correcting the anatomic tibiofemoral angle to within 5 degrees of neutral. In addition to the osteotomy, medial proximal tibial physis should be performed with the goal of improving the alignment of the physis and to allow for proper future growth.
  - Definitive surgery for infantile Blount’s disease should be done before 5 years of age, because recurrence may develop if surgery is performed after this age.
- In patients with adolescent Blount’s disease, treatment options are hemiepiphysiodysis and osteotomy. However, if insufficient growth remains for hemiepiphysiodysis to be effective, osteotomy is the best option for correction of the deformity. Hemiepiphysiodysis of an already short limb may leave the patient with a significant limb-length inequality. If such limb-length inequality will require osteotomy for lengthening, the tibia vara should be corrected by osteotomy for angular and linear correction with external fixation.
The objective of the osteotomy is to obtain a neutral mechanical axis with a horizontal knee joint. Many different types of osteotomies have been described for the treatment of adolescent Blount’s disease, including opening and closing wedge osteotomies, dome osteotomies, and oblique osteotomies.

Following the osteotomy, fixation may be achieved with external or internal fixation. The use of cast immobilization alone has been associated with a loss of correction.

Internal fixation after osteotomy for Blount’s disease has been associated with problems. Loder et al reported poor results in patients treated with internal fixation and noted many were internally fixed in malposition, likely due to difficulty in assessing intraoperative alignment. Crossed K-wires have been associated with a loss of fixation. The use of plates has been associated with stress shielding, delayed and nonunion, and hardware breakage, and requires a second surgical procedure to remove the implant.

External fixation allows for acute or gradual correction and for later adjustments as clinically and radiographically indicated. In addition, external fixation allows for correction of the coexistent leg-length discrepancy. Price et al reported the successful use of dynamic external fixation to stabilize osteotomies for tibia vara without supplemental casting. Monolateral, hybrid, or circular external fixators may be used.

In this chapter, we describe the technique for correction of adolescent Blount’s disease via osteotomy and external fixation. The external fixator used in this technique is the EBI Multi-Axial Correction System (EBI, Parsippany, NJ). This fixator allows gradual or acute correction of deformity in two planes of angulation, two planes of translation, rotation, and lengthening without the disadvantages of a ring fixator.

### Preoperative Planning

Standing lower extremity alignment radiographs are obtained (see Fig 1). The location of the CORA in the tibia in Blount’s disease cannot be determined by simply drawing two shaft lines, because the deformity is metaphyseal or juxta-articular.

If the mechanical axis method of preoperative planning is used, the mechanical axis of the proximal tibia may be estimated by extending the femoral mechanical axis (if mL DFA is normal) or by drawing the MPTA of the contralateral MPTA (if normal) or the population normal value (87 degrees).

The distal tibia mechanical axis of the tibia is represented by a line that begins at the center of the ankle and extends parallel to the shaft. If the distal tibia has insufficient shaft length on which to base the line, the line is drawn using the contralateral lateral distal tibia angle (LDTA) or the population normal value (90 degrees).

The intersection of these lines is the CORA.

If the femur also was found to be a source of deformity during the alignment test, then CORA in the femur is identified as described by Paley et al.

The technique described in this chapter is for adolescent Blount’s disease with deformity located solely in the proximal tibia metaphysis.

The external fixator used in this technique can be applied in three different locations with respect to the CORA: CORA-centric, CORA-perpendicular, and CORA-proximal.

- The CORA-centric method places the fixator hinge directly over the CORA and minimizes unintended translation.
- The CORA-perpendicular application places the fixator hinge on the bisector of the deformity, which, when placed on the convex side of the deformity, produces simultaneous lengthening during angular correction. CORA-perpendicular application is advisable only when lengthening is required.
- The CORA-proximal application places the hinge near the CORA. This application is used when the hinge cannot be placed on the CORA or the bisector and relies on the flexibility of the hinges and translation screws to correct secondary translation.

### Positioning

The patient is placed supine on a radiolucent table. The use of an OSI table with Jackson imaging top (Orthopaedic Systems, Inc, Union City, CA) permits fluoroscopic images to be taken with minimal difficulty. A bump may be placed under the ipsilateral buttock.

A tourniquet typically is not used, because the thigh circumference of patients with Blount’s disease often is too large for a tourniquet to be used effectively.

The entire lower extremity is prepared and draped. The toes are left uncovered so that muscle contraction caused by inadvertent nerve irritation during pin placement is visible.

### Approach

The procedure is divided into fibular osteotomy, external fixator application, proximal tibia osteotomy, and completion of the surgery. Prophylactic fasciotomies are performed during exposure for the fibular and tibial osteotomies.

- The lateral approach to the fibula is used for the fibular osteotomy and lateral compartment fasciectomy. Small medial and lateral incisions are made for the tibial osteotomy, and the anterior compartment is released from the lateral incision.
- The surgeon must have thorough knowledge of the cross-sectional anatomy of the lower leg and the half-pin positions of safety.

### Surgeries

- **Fibula Osteotomy**
  - A longitudinal incision is made just lateral to the fibula at the intersection of the middle and distal thirds of the lower leg. Dissection is carried down to the deep fascia.
  - A prophylactic subcutaneous lateral compartment fasciectomy is then performed. Care is taken to avoid injury to the superficial peroneal nerve and its branches.

- **Tibial Osteotomy**
  - The peroneus longus and peroneus brevis muscles are visualized. These muscles are then retracted either anteriorly or posteriorly (depending upon exposure), and the fibula is visualized. Subperiosteal exposure of the fibula is then developed using a Cobb elevator or right-angle, and retractors are placed around the fibula to protect the soft tissues.
Chapter 30  SURGICAL MANAGEMENT OF BLOUNT’S DISEASE

TECHNIQUES

■ The tibia is corrected in the direction of valgus. Because the fibula is lateral to the tibia, correction will push the fibula proximally.
■ To prevent damage to the peroneal nerve at the proximal fibula, a 1-cm segment of bone is removed from the fibula. Oblique cuts in the fibula are made with the most proximal end aspect of the cut in the posterior edge of the fibula (TECH FIG 1). The cut is made carefully so that the saw is not inadvertently pushed past the posteromedial edge of the fibula with resultant injury to the peroneal artery.
■ Wound closure is performed at this point, because this is easier to do before the external fixator is applied.

External Fixator Application
■ The external fixator can be assembled before the procedure begins or just before application.
■ A rotating arc is selected that will allow for correction of coexisting rotational deformity or rotation inadvertently caused by misplacement of the fixator.
■ The ring size (130, 150, 180, or 220 mm) is based on the leg circumference at the level of the proximal tibia.
■ The arc should match the curvature of the anterior proximal tibia with two fingerbreadths between the ring and the leg.
■ The adult multiaxial correction (MAC) central component is then attached to the center of the rotating ring such that the primary arc on the MAC central component is facing anteriorly.
■ The MAC female adapter is placed at the other end of the MAC central component, and the telescoping arm is attached to the female adapter.
■ The primary hinge of the MAC central component is adjusted so that the fixator matches the angular deformity of the tibia.
■ In the example illustrated in this section, the MAC is applied in the CORA-centric location.
■ The CORA, as identified during preoperative planning, is localized under fluoroscopy, and an appropriately sized guide pin (supplied with the MAC) is placed from anterior to posterior into the CORA (TECH FIG 2A).
■ The guidewire should be perpendicular to the tibial diaphysis. Although placement of the guidewire exactly into the CORA can be difficult, the multiaxial or translation and rotation ability of the MAC device can correct any secondary deformity due to misplacement of the MAC off the CORA.

TECH FIG 1 • An oblique 1-cm wedge is removed from the fibula.

A. The tibia is corrected in the direction of valgus. Because the fibula is lateral to the tibia, correction will push the fibula proximally.
B. Oblique cuts in the fibula are made with the most proximal end aspect of the cut in the posterior edge of the fibula.
C. The cut is made carefully so that the saw is not inadvertently pushed past the posteromedial edge of the fibula with resultant injury to the peroneal artery.
D. Wound closure is performed at this point.

TECH FIG 2 • A. Fluoroscopy is used to localize the CORA (which was identified during preoperative planning). B. Sterile web roll padding is placed over the guidewire to serve as a spacer. C. The MAC external fixator is placed on top of the spacer. D. Two or three bone screws are placed in the proximal tibia. E. The length and angulation of the MAC external fixator are adjusted to match the deformity. F. Three bone screws are placed in the tibia shaft.
Sterile Webrik padding (The Kendall Company, Mansfield, MA) is then placed around the K-wire to serve as a two-fingerbreadth spacer (TECH FIG 2B).

The centering hole of the primary hinge of the MAC fixator is placed over the K-wire so that the fixator rests on top of the spacer (TECH FIG 2C).

Universal screw carriages are locked onto the rotation arc and used as guides for placement of two or three proximal screws.

Three proximal half-pins are then placed in the safe zones of the proximal tibia.

At least one pin is placed from anteromedial to posterolateral and one is placed from anterolateral to posteromedial.

The pins are placed distal to the physis (which may be open).

Holes are predrilled bicortically with the 4.8-mm drill bit, and 6.0-mm pins are placed.

We prefer to use hydroxyapatite-coated pins to reduce the risk of loosening and, therefore, infection. Pin size typically is around 60 mm thread length and 160 to 180 mm overall length (TECH FIG 2D).

The size of the bone screw depends on the size of the patient, the tibia at the level of screw insertion, and the size of the arc chosen.

The carriages are tightened after the pins are placed. The MAC is then adjusted to the tibial deformity, ensuring that the distal bone screw block is parallel to the distal tibial diaphysis at the medial subcutaneous face of the tibia (TECH FIG 2E).

Three distal half-pins are placed through the telescoping arm in the midshaft of the tibia (TECH FIG 2F). Pin size typically is 120 mm overall and 40 mm of thread length.

If the MAC is aligned such that the pins placed through the telescoping arm will not go through the tibia, the CORA pin should be removed and the device rotated so that the pins are aligned. (If this is done, rotation must be corrected first before the remainder of the deformity is corrected).

At this point, all the pins (bone screws) have been inserted.

**Tibia Osteotomy**

Using the MAC external fixator, placing the pin at the CORA allows deformity correction to occur at the CORA. The osteotomy does not have to be made at the CORA. It should be performed just below the insertion of the tibial tubercle, decreasing the risk of damage to the nearby physis and joint line. Placement of the osteotomy below the tibial tubercle will also avoid pulling the patella distally during distraction.

The tibial osteotomy may be performed using one of several different techniques. Our preference is to perform the osteotomy through small transverse anteromedial and anterolateral incisions with a Gigli saw passed subperiosteally.

Fluoroscopy is used to identify the metaphyseal-diaphyseal junction where the osteotomy will be made.

The guide pin is removed.

A 2-cm transverse incision is made on the medial and lateral aspects of the anterior tibia at the level for the osteotomy. The incision is made transversely to avoid skin injury from the Gigli saw.

From the lateral incision, dissection is carried down to the fascia of the anterior compartment.

A prophylactic subcutaneous release of the anterior compartment is then performed through this incision.

A hemostat is used to expose the tibia subperiosteally at the level of the osteotomy (TECH FIG 3A).

Umbilical tape is then held taut by a right-angle and passed, subperiosteally, around the back of the tibia (TECH FIG 3B). A hemostat is placed posterior to the tibia from the opposite side, and the umbilical tape is grasped and pulled out the opposite side of the leg (TECH FIG 3C).
To verify that the saw has not been placed around the anterior or posterior tibial arteries, the ends of the umbilical tape are pulled taut while palpating the pedal pulses for occlusion. Care should be taken to avoid shredding the umbilical tape, which can leave foreign material behind.

The Gigli saw is then tied to the umbilical tape to pass the saw around the back of the tibia.

The osteotomy is then performed with the Gigli saw.

Care is taken to avoid injury to the skin.

Fluoroscopy is used to verify the completion of the osteotomy and alignment of the proximal and distal fragments with the external fixator.

**Completion of Surgery**

The lengthening device is then inserted onto the telescoping arm and turned such that it slides into the telescoping arm (TECH FIG 4A). Both screws of the lengthening device are then tightened.

All screws of the external fixator are then given their final tightening.

All wounds are closed, and a sterile dressing is applied (TECH FIG 4B).

Acute correction typically is not performed if there is risk of stretching neurovascular tissues.

During the first postoperative week, the patient learns to walk with crutches, 10 pounds, partial weight bearing.

On the 8th day, the patient is taught to lengthen through the compression distraction mechanism at a rate of one 90-degree turn of the Allen wrench four times a day. This will cause lengthening of 1 mm per day.

On the 14th day, a radiograph should show that the ends of the osteotomized tibia are separated by a distance of about 7 mm (TECH FIG 4C,D).

Angular correction can now begin. The patient is taught to place the Allen wrench into the primary angulation screw and turn 90 degrees in the direction for angular correction. This 90-degree turn will correct...
Patients must be followed closely during correction so that malalignment does not occur. Pin site infections must be recognized and treated appropriately. Radiographs must be evaluated carefully and systematically so that the location of the CORA and coexistent deformities of the femur or sagittal plane are identified. Careful neurovascular examinations must be performed postoperatively. A correct diagnosis of Blount’s disease must be made before treatment is initiated. Treatment alternatives, including hemiepiphysiodesis (if there is sufficient growth remaining), must be discussed with the patient and family.

### TECHNIQUES

The correction phase begins with lengthening the leg by 7 to 8 mm at a rate of 1 mm per day (0.25 mm four times per day) to separate the bone ends. Angulation is then corrected. The patient is evaluated clinically and radiographically to follow correction of the mechanical axis. Scanograms can then be obtained to determine leg-length inequality, which can be corrected by lengthening with the fixator. The rotational deformity (internal tibial torsion) is corrected last. Placing white adhesive tape with arrows onto the device helps patients remember how to turn the screws appropriately for angular, linear, and rotational correction.

Weight bearing is increased during the consolidation period. The consolidation period is approximately twice the correction period. Most patients treated with this technique for adolescent Blount’s disease will have the external fixator on for 3 to 4 months. They can walk with crutches initially and progress to full weight bearing as the osteotomy heals. They can shower within 3 days of application of the fixator.

When radiographs show that the osteotomy and distraction gap have healed, the external fixator is removed. Removal can be done in the office or in the operating room. Considerable torque is required to remove hydroxyapatite pins, and this must be done in the operating room with adequate sedation and analgesia.

### PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>A correct diagnosis of Blount’s disease must be made before treatment is initiated. Treatment alternatives, including hemiepiphysiodesis (if there is sufficient growth remaining), must be discussed with the patient and family.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deformity planning</td>
<td>Radiographs must be evaluated carefully and systematically so that the location of the CORA and coexistent deformities of the femur or sagittal plane are identified.</td>
</tr>
<tr>
<td>Neurovascular injury</td>
<td>All half-pins must be placed into safe zones of the leg to avoid inadvertent neurovascular injury.</td>
</tr>
<tr>
<td>Postoperative care</td>
<td>Patients must be followed closely during correction so that malalignment does not occur. Pin site infections must be recognized and treated appropriately.</td>
</tr>
</tbody>
</table>

### POSTOPERATIVE CARE

- Patients are admitted to the hospital and monitored closely for signs and symptoms of neurovascular injury and compartment syndrome.
- Patients initially are allowed touch-down weight bearing only. Range-of-motion exercises are begun immediately.
- Pin care is begun on postoperative day 2. Patients are instructed on the signs and symptoms of pin site infections.
- No adjustments or corrections are made to the external fixator for the first 7 days. A 7-day latency allows fracture callus to develop at the site of the osteotomy. Then the correction phase is begun.
- The correction phase begins with lengthening the leg by 7 to 8 mm at a rate of 1 mm per day (0.25 mm four times per day) to separate the bone ends. Angulation is then corrected. The patient is evaluated clinically and radiographically to follow correction of the mechanical axis. Scanograms can then be obtained to determine leg-length inequality, which can be corrected by lengthening with the fixator. The rotational deformity (internal tibial torsion) is corrected last. Placing white adhesive tape with arrows onto the device helps patients remember how to turn the screws appropriately for angular, linear, and rotational correction.
- When radiographs show that the osteotomy and distraction gap have healed, the external fixator is removed. Removal can be done in the office or in the operating room. Considerable torque is required to remove hydroxyapatite pins, and this must be done in the operating room with adequate sedation and analgesia.

### OUTCOMES

- Because adolescent Blount’s disease is relatively uncommon, there are few outcome studies in the literature.
- Price et al7 reported on the treatment of 31 tibiae in 23 patients with dynamic external fixation. All osteotomies healed. There was an average correction of 20 degrees, and no postoperative loss of correction occurred.

### COMPLICATIONS

- High complication rates have been reported for proximal tibial osteotomies.
- Steel et al8 reported a 20% rate of neurologic complications in 46 tibial osteotomies. The neurologic complications are related to the location of the osteotomy, which must be done in the metaphysis to avoid damaging the proximal tibial epiphysis.
- Deformity correction at this level can stretch or compress the anterior tibial artery because of its proximity to the tibia at that level. While arterial stretch or compression is more common than laceration or edema in anterior compartment following correction, prophylactic fasciotomies of the anterior and lateral compartments are still indicated to decrease the risk of neurovascular complications.
- Other complications include delayed union and nonunion.
REFERENCES

DEFINITION

Epiphysiodesis (epiphysio–diaphyseal fusion) is an established method to treat a mild limb-length discrepancy (2 to 5 cm) in children.

With epiphysiodesis, growth of a longer extremity is inhibited by prematurely arresting a selected physis so that the remaining growth of the shorter extremity may approximate or equalize limb lengths at maturity.

The open epiphysiodesis technique was first described by Phemister in 1933 and modified by White in 1944. “Percutaneous epiphysiodesis” was reported first by Bowen and Johnson in 1984.

Subsequently, other variations of percutaneous epiphysiodesis with their outcomes have been reported.

When equalizing limb-length discrepancy by epiphysiodesis, caution should be used in terms of the patient’s age at operation, the physis selected for premature closure, and the number of physis necessary to correct the discrepancy.

Useful data in decision making include:

- Body length from head to foot (to determine percentile of height)
- Length of the bones of the lower extremity (to determine degree and source of discrepancies)
- Skeletal maturation age (to determine potential remaining growth), and the disease course that caused the limb inequality (to determine the predictability of remaining growth)
- Proper patient age for timing of the epiphysiodesis may be determined by several methods, including the Green and Anderson method, the Mosley straight-line method, the “rule of thumb” method, and the multiplier method.
- Physseal stapling is an alternative operative procedure for correcting limb inequality by retarding growth in a longer extremity. The goal of physseal stapling is to retard growth of a physis with staples until the desired correction is obtained, after which the staples can be removed, with physseal growth resuming until maturity.

ANATOMY

An epiphysiodesis can be achieved by ablation of the medial and lateral peripheral margins of the physis. These subsequently form bony bars that restrict growth, and then the central aspect of the physis closes spontaneously, resulting in a total epiphysio–diaphyseal fusion.

Caution is required in the femur distally because the epiphysis is narrow at the central area of the physis.

Posteriorly the neurovascular structures are deeply positioned within the condyles, and anteriorly the patella–femoral joint is close.

Injury to the neurovascular structures may be catastrophic. Therefore, I prefer the peripheral margin ablation technique as described here, in which the central area of the physis remains undisturbed.

The common peroneal nerve at the knee runs obliquely along the lateral side of the popliteal fossa, close to the medial border of the biceps femoris muscle and the lateral head of the gastrocnemius muscle, toward the head of the fibula.

The nerve winds posteriorly around the neck of the proximal fibula and passes deep to the peroneus longus muscle, where it divides into the superficial and deep peroneal nerves.

PATHOGENESIS

The etiology of a limb-length discrepancy may be important in determining the appropriate patient age at which the percutaneous epiphysiodesis is performed.

Shapiro reported different patterns of growth inhibition that may cause shortening of a limb.

Predictable growth of the shorter extremity is required to achieve optimal results with a percutaneous epiphysiodesis.

NATURAL HISTORY

After a percutaneous epiphysiodesis, bony bridges form at the peripheral margins of the physis both medially and laterally. These bony bars prevent further physeal growth.

After peripheral bony bar formation following a percutaneous epiphysiodesis, the central area of the physis (unoperated area) will spontaneously close within 6 to 8 months.

The scientific reason for this spontaneous closure of the central area is unclear. Confusion exists in that staples do not cause physseal closure, whereas peripheral bony bars from an epiphysiodesis result in progressive physseal closure.

I have studied this phenomenon but found no definitive causes.

Reversal of limb-length discrepancy could occur if the shorter limb (contralateral) were to overgrow the epiphysiodesis limb (ipsilateral) before maturity.

I have not had a patient have this complication, but follow-up until skeletal maturity is advised.

By following growth until maturity, this potential problem may be detected and a contralateral epiphysiodesis may prevent a limb-length discrepancy at maturity.

A percutaneous epiphysiodesis can be used in combination with contralateral limb lengthening in patients with severe shortening.

In major limb-length discrepancies, lengthening may not be able to correct the full discrepancy, and remaining small discrepancies of 2 to 5 cm may be more easily corrected by a contralateral percutaneous epiphysiodesis than by a secondary ipsilateral lengthening.

After leg-lengthening procedures, growth of the lengthened limb may be retarded or occasionally stimulated.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient history and physical examination should include the following:
  - Etiology of the limb-length discrepancy
The patient’s height (percentile of height)\(^8,10\)
- The total height and the leg lengths (in centimeters) are measured. The percentile of height is then determined and used to plot limb-length predictive charts.

- The level of maturation, based on the appearance of secondary sexual characteristics and the Tanner scale.\(^11\) Caution should be used if the clinical maturation scale differs significantly from the Greulich and Pyle skeletal developmental age.
- Foot height (foot height is not typically considered in radiographs that measure limb length)
- The patient’s “bone age” (expressed in years) using the Greulich-Pyle method. Caution should be used if the chronological age differs from the “bone age.”
- Radiographs of the limbs are obtained to measure the tibia and femur (expressed in centimeters). These measurements are plotted on growth charts to predict the discrepancy at maturity and to determine the age for epiphysiodesis.
- Blocks of differing thicknesses are placed under the foot of the shorter limb until the pelvis is level to determine the length discrepancy (expressed in centimeters). This method also helps evaluate discrepancies in the foot that are not reported by radiographs.
- After length measurements of both limbs are obtained, the ratio of femur to tibial discrepancy of the normal to abnormal limb is determined.
- A disease diagnosis can be made with Shapiro developmental patterns.\(^22\) However, proportional inhibition of growth is more predictable, while disproportional growth is difficult to predict.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Skeletal age determination by the Greulich and Pyle method\(^11\)
- Green-Anderson method of predicting limb-length discrepancy (my preference)\(^2,3\)
- Mosley graphic method of predicting limb-length discrepancy\(^16\)
- Multiplier method of predicting limb-length discrepancy\(^1,18\)
- Menelaus “rule of thumb” method\(^15\)
- I prefer the Mosley straight-line method because growth inhibition is expressed graphically, multiple data entries can be charted to help predict growth more accurately, and the method is easy to calculate in a brief outpatient visit.
- I perform a proximal fibular epiphysiodesis in addition to the proximal tibial epiphysiodesis if the final discrepancy between the tibia and fibula is anticipated to be more than 1 cm.
- If the discrepancy is anticipated to be less than 1 cm, I do not perform a proximal fibular epiphysiodesis and have not detected a clinical problem with such a mild discrepancy.

**NONOPERATIVE MANAGEMENT**
- No treatment is required if the limb-length discrepancy is less than 2.5 cm at maturity.
- A shoe lift can be used to treat mild limb-length discrepancies of more than 2.5 cm.
- Often a lift is used in children until an appropriate skeletal age is reached to perform an equalization procedure.
- A prosthesis may be necessary if deformities are so severe that adequate length or ambulatory ability cannot be achieved by operative methods.
- Surgery may be necessary to provide an appropriate stump for the prosthesis, and a percutaneous epiphysiodesis is used occasionally to achieve correct stump length.

**SURGICAL MANAGEMENT**
- Epiphysiodesis is most commonly performed at the distal femoral physis or the proximal Tibia–fibula physis.
- Ablation of the peripheral margins both medially and laterally in a physis causes bony bridges to form between the epiphysis and metaphysis that accomplish growth inhibition in that physis (epiphysiodesis).
- This can be accomplished by different techniques and instruments, which include a curette, a drill, a burre, a reamer, and a circular tube saw.
- I prefer a curette because surgeon control is easy and the curette can be passed percutaneously. I have used various instruments, but drills and burrs tend to burn and occasionally grab tissue, and reamers and circular saws require a larger incision (really not percutaneous, almost the size of a typical open epiphysiodesis).
- A bony bridge needs to form only at the peripheral margins of the physis both medially and laterally to accomplish an epiphysiodesis. The central part of the physis does not require treatment because it will close spontaneously.
- The stability of the bone is maintained postoperatively and the patient may continue to ambulate.
- I restrict sports for 6 weeks to reduce the possibility of a fracture.

**Preoperative Planning**
- Anticipated remaining growth is determined by one of the following methods:
  - Green-Anderson method\(^10\)
  - Mosley graphic method\(^16\)
  - Multiplier method\(^18\)
  - Menelaus “rule of thumb” method\(^15\)
- I prefer the Mosley straight-line method because growth inhibition is expressed graphically, multiple data entries can be charted to help predict growth more accurately, and the method is easy to calculate in a brief outpatient visit.
- I perform a proximal fibular epiphysiodesis in addition to the proximal tibial epiphysiodesis if the final discrepancy between the tibia and fibula is anticipated to be more than 1 cm.
- If the discrepancy is anticipated to be less than 1 cm, I do not perform a proximal fibular epiphysiodesis and have not detected a clinical problem with such a mild discrepancy.

**Positioning**
- Image intensification
- Supine position
- The limb is prepared and draped up to the proximal thigh into a sterile field. A tourniquet is placed on the proximal thigh but is not inflated unless bleeding occurs.

**Approach**
- Femoral epiphysiodesis at distal physis
  - Longitudinal incisions of 3 mm (stab incisions) medially and laterally in the skin at the level of the physis at its peripheral area
- Tibial epiphysiodesis at proximal physis
  - Longitudinal incisions of 3 mm
  - Medially the incision is 3 mm at the level of the physis at its peripheral area.
  - Laterally the incision is 3 mm at the level of the physis and at the anterior border of the fibula.
- Fibular epiphysiodesis at the proximal physis
  - The same incision is used for the fibular epiphysiodesis as for the lateral physeal area of the tibia; however, in the epiphysiodesis of the fibula the curette is directed differently to avoid injury to the common peroneal nerve (described below). (See above section on anatomy.)
EPIPHYSIODESIS OF THE FEMORAL PHYYSIS DISTALLY OR THE TIBIAL PHYYSIS PROXIMALLY

Preparation of the Physis
- A metal marker is placed over the skin and under the image intensifier, and the level of the physis is identified at its peripheral area (either medially or laterally) (TECH FIG 1A).
- A 3-mm skin incision is made with a scalpel at the level of the physis plate on the peripheral side (medially or laterally) (TECH FIG 1B).
- Under image intensification control, a 3-mm-wide osteotome is directed through the skin incision to make a longitudinal split in the periosteum–cortex, and the physeal plate is then penetrated to a depth of about 0.5 cm (TECH FIG 1C,D).
- The osteotome is rotated to create a hole in the physis and is then withdrawn.

Physeal Plate Ablation
- A 3-mm oval curette is advanced through the skin into the hole of the physis (TECH FIG 2A).
- Under image intensification control, the curette is rotated and advanced to the level of the inner third of the physis (TECH FIG 2B).
- The curette is then swept cephalad and caudad in the physis to ablate the peripheral third of the physis, leaving the middle third intact (TECH FIG 2C).
- Specific surgical attention is directed toward adequate ablation of the most peripheral aspect of the physeal plate (TECH FIG 2D–F).
- The same operative process is repeated on the opposite side of the physeal plate (medially or laterally), again sparing the middle third of the physeal plate.
- The wound is closed by suture (typically one absorbable suture) (TECH FIG 2G).

(continued)
Epiphysiodesis of the Fibula Proximally

- The same incision is used to perform the epiphysiodesis of the fibula as the proximal physis of the tibia laterally.
- To avoid injury to the common peroneal nerve with a percutaneous epiphysiodesis of the proximal fibula, direct the curette into the anterosuperior area of the proximal epiphysis and then inferiorly into the physis of the proximal fibula (TECH FIG 3A).
  - The most superior extent of the fibular epiphysis proximally is usually at the level of the tibial physis.
  - The curette is used to ablate the entire central area of the physis of the fibula to achieve the epiphysiodesis (TECH FIG 3B).
- The surgeon should not exit the cortex of the fibula as the central area is ablated.
- The 3-mm incisions are each closed with a single suture.
- The incision is covered by an adhesive strip and bandage.
- A knee immobilizer foam brace is applied and maintained postoperatively.
- The elastic of the knee immobilizer adds very mild compression to the incision and helps prevent a hematoma or edema.
- The knee immobilizer brace should not be applied with a force that impedes circulation.
PEARLS AND PITFALLS

| Discrepancy between bone age and chronological age | In such cases, I prefer to use the bone age. Another choice is to use a stapling technique (or figure 8 plate-screw), which preserves the physis, rather than epiphysiodesis. |
| Discrepancy between predictive charts and parental opinion | Use several methods to substantiate the outcome. Also, I prefer to delay the epiphysiodesis for a short period to ensure that the limb lengths do not reverse the discrepancy. Another choice is to use a stapling technique. |
| Neuromuscular weak and short extremity | I prefer to have the weak extremity slightly shorter at maturity; about 1 to 1.5 cm short seems acceptable. |
| Follow-up to maturity | Some diseases tend to produce growth in a manner that is poorly predictable. If the limb lengths correct and remaining growth will cause a problematic (reversal) discrepancy, I would perform a contralateral epiphysiodesis. |

POSTOPERATIVE CARE

- Postoperatively the leg is protected by a knee immobilizer brace, and full weight bearing with crutch support is allowed.
  - The patient may usually be discharged within the same operative day (outpatient surgery).
  - The knee immobilizer is used for 3 to 4 weeks to protect the extremity from fracture.
  - The scars of the percutaneous epiphysiodesis are small and have an acceptable appearance (FIG 1).
  - Radiographs are performed about 4 to 6 months postoperatively to ensure adequate healing.
  - Bony bars at the peripheral margins of the physis are usually observed radiographically by 6 months postoperatively.
  - Total closure of the physis occurs 8 to 12 months postoperatively.
  - Correction of the leg-length discrepancy may be determined by periodic radiographs and clinical examinations.
  - During postoperative evaluations the extremity should be evaluated to ensure appropriate length correction and to watch for an angular deformity.
  - Lack of appropriate closure may result in undercorrection and asymmetric closure causes angulation.

OUTCOMES

- Recently I reviewed the outcome of percutaneous epiphysiodesis as described above in a consecutive series of 97 patients (56 girls and 41 boys) with a mean skeletal age of 12.6 years (range 10 to 16 years) at surgery. All patients were followed until skeletal maturity, a mean of 3.8 years. The mean residual limb-length discrepancy in 88 patients at maturity was 1.3 cm (I consider normal to be a lower-limb discrepancy of less than 2.5 cm). In nine patients, the epiphysiodesis was combined with a femoral lengthening or femoral shortening.
  - The Moseley straight-line method accurately and efficaciously predicted the timing for percutaneous epiphysiodesis in all but one patient, who had unpredictable growth from hemihypertrophy secondary to a hemangiomatosis.
  - Horton and Olney12 reported the results of 42 percutaneous epiphysiodeses in 26 patients. Physeal arrest developed in all cases and no angular deformities occurred. They considered the percutaneous epiphysiodesis to be reliable and safe. Stated advantages include a cosmetic scar, short hospital stay, low incidence of complications, and reliability.
  - Canale and coworkers6 reported on 13 children treated by a percutaneous epiphysiodesis; growth plate fusion occurred in all cases. They used a pneumatic burr under image intensification to perform the procedure.
  - Brax and Gille7 performed a percutaneous epiphysiodesis using a drill and radiographic control in 10 children. They had good results in all but one case and considered the procedure to be minimally traumatic, cosmetically preferable, and safe.
  - Craviari and colleagues7 reported the results of 60 cases followed to skeletal maturity who were treated by a percutaneous epiphysiodesis. They concluded that the procedure was satisfactory and complications were rare. Complications comprised hematoma in 2 cases, need for surgical revision in 10 cases, limb deviation in 4 cases, and inverted discrepancy in 2 cases.
  - Gabriel and associates8 reported the results of 29 patients who underwent 56 physeal procedures with a percutaneous epiphysiodesis. The procedure lasted a mean of 36 minutes, and in all patients a physeal closure developed. No unplanned angular growth, no deep infections, and no cases of joint stiffness were reported.
  - Kemmitz and coworkers13 performed a retrospective review of 57 patients who underwent percutaneous epiphysiodesis. They reported no significant operative problems. A final limb-length discrepancy greater than 2 cm was seen in 17.5% of the cases, and they concluded the timing of the procedure remains the main problem.
  - Macnicol and Gupta14 reported 35 cases of epiphysiodesis in which a cannulated tube saw was used to ablate the physis. The mean anticipated discrepancy was 3.3 cm, and at maturity the discrepancy averaged 0.7 cm. One patient had slight overgrowth of the fibula and another had an unsightly scar; otherwise the results were favorable.
  - Ogilvie and King15 used a low-speed, high-torque drill to create an epiphysiodesis in seven children. This technique required a 1-cm incision. There were no cases of failure of physeal...
fusion, no infections, no angular deformity, and no restriction of joint motion.

- **Porat and coworkers** performed epiphysiodesis in 20 children, with good results in 90% of the patients. They recommended the Moseley straight-line graph and percutaneous epiphysiodesis.

### COMPLICATIONS
- Errors in predicting growth
- Infection
- Angulation
- Lack of physeal closure
- Temporary exostosis formation (believed to develop as bone forms in the elevated periosteum)
- Hematoma
- Neurovascular injury

### REFERENCES
DEFINITION
- A physeal bar, or partial premature physeal arrest, is an osseous connection that forms across a physis and has the potential to affect physeal growth.4
- Partial physeal arrest may result in three clinically significant consequences:
  - Angular deformity
  - Limb-length discrepancy
  - Bone-length discrepancy in a two-bone limb segment such as the forearm or leg.
- When evaluating a patient with a physeal bar, one must critically consider whether there is sufficient growth remaining to cause a clinically significant length discrepancy or angular deformity.
- One should consider the linear magnitude of anticipated growth remaining, as well as the years of remaining growth.

ANATOMY
- The normal physis acts as a physical cartilage barrier separating the trabecular bone of the epiphysis from the metaphysis (FIG 1).
- Blood vessels typically do not traverse the physis, necessitating an independent blood supply for the epiphysis and metaphysis.1

PATHOGENESIS
- Physeal bars form when the cartilage barrier is breached as the result of trauma, infection, or cell death and trabecular bone heals in continuity between the epiphysis and the metaphysis across the physis.6
- Variation in physis anatomy may predispose certain physes to physeal bar formation. For example, the distal radius physis is relatively two-dimensional and uniplanar, while the distal femoral physis has a more complex three-dimensional biconcave configuration.
- Distal radius physeal fractures are quite common, yet subsequent premature physeal bar formation is relatively rare. In contrast, distal femoral physeal fractures are uncommon but distal femoral physeal bar formation is much more prone to occur after injury.
- The three-dimensional configuration of the distal femoral physis contributes to the considerable energy required to fracture through the distal femoral physis, and the complex geometry increases the likelihood for violation of the physeal cartilage barrier between epiphyseal and metaphyseal bone, thereby increasing the risk of partial physeal bar formation after injury.
- Breach of the physeal cartilage barrier is most frequently caused by fracture, followed by infection.
- Less common pathogenesis for partial physeal bar formation may occur when the germinal or proliferating cells on the epiphyseal side of the physis plate are injured by ischemia, infection, heat, laser, electricity, or other insult. As the germinal cells die and cell division in this region of the physis stops, partial physeal bar formation may occur.3

NATURAL HISTORY
- In almost all situations, once a physeal bar has formed, length discrepancy, angular deformity, or both will continue to increase so long as the patient is skeletally immature and the affected physis (or its contralateral counterpart) continues to grow.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Questioning the patient quickly reveals the cause for physeal bar formation in most cases. The most common causes of physeal bar formation, fracture and infection, are typically memorable events that the patient can quickly recall.
- The examiner should ask the patient and family if they have noticed a progressive limb-length discrepancy, limp, angular deformity, or bony prominence; this may confirm the presence of a physeal bar.
- Ideally the orthopaedist is aware of the physeal injury, is anticipating possible physeal bar formation after injury, and is

FIG 1 • The physis acts as a physical barrier separating the trabecular bone of the epiphysis from the trabecular bone of the metaphysis. The physis also acts as a barrier to blood flow, separating the epiphyseal blood supply (a) from the metaphyseal blood supply (b). Magnification of the physis illustrates the four physeal cell layers: the resting cell zone (c), the proliferating cell zone (d), the hypertrophying cell zone (e), and the enchondral ossification zone (f). Insults that breach the physical separation between metaphyseal and epiphyseal trabecular bone, that significantly compromise epiphyseal blood flow, or that critically injure the resting or proliferating cell layers may result in physeal bar formation.
Chapter 32  EXCISION OF PHYSEAL BAR

monitoring the patient at 6-month intervals with clinical examination and radiographs.

- The patient is examined for lower extremity limb-length discrepancy using blocks of known height under the shorter limb until the pelvis is level.
- The patient is also examined for lower extremity angular deformity. The alignment at knee and ankle is assessed and compared to the contralateral limb.
- The patient is also examined for upper extremity limb-length deformity. Length of the affected limb is compared to that of the contralateral limb.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Appropriate imaging is critical for the evaluation of a potential physeal bar. Initial imaging is performed to determine whether the patient has sustained a clinically significant physeal injury and therefore should demonstrate limb-length discrepancy and angular deformity.
- True scanograms use a slit beam that is perpendicular to the patient that scans the length of the limb and therefore has no magnification. The scanogram provides limb length and angular information with a single image (**FIG 2A**).
- A teleoroentgenogram, or full-length, standing, hip-to-ankle radiograph taken at a distance, does result in some magnification of the limb.
  - By placing blocks of known height beneath the shorter limb, a teleoroentgenogram can also provide information about length and angular deformity with a single radiograph.
  - A ruler or magnification markers can also be placed next to the limb to allow more accurate measurement of limb length.
- Orthoroentgenograms (separate exposures of the hip, knee, and ankle on a single film with a ruler) or CT scout images can be used to determine limb length.
  - These must be supplemented by a full-length image of the limb to assess angular deformity.
- If the distal tibial physis is the injured physis in question, standing anteroposterior (AP) and lateral ankle radiographs are indicated to assess angular deformity.
- If limb-length discrepancy or angular deformity is confirmed, additional imaging is indicated to determine the size and location of the physeal bar.
- Either fine-cut CT or MRI may be used, and axial, coronal, and sagittal plane images are obtained.
  - The CT or MRI images are used to create a map that illustrates the location and approximate cross-sectional area of the physeal bar (**FIG 2B,C**).
  - The relative cross-sectional area of the bar is important because physeal bars occupying greater than 50% of the cross-sectional area of the physis have a less favorable result after resection. Excision of bars greater than 50% of the physeal cross-sectional area may still be indicated in young patients, such as a 5-year-old patient with a 65% bar of the distal femoral physis.
- A skeletal age radiograph of the hand and wrist may be helpful in older patients if one is trying to determine if there is sufficient growth remaining for physeal bar resection to be indicated.

**DIFFERENTIAL DIAGNOSIS**

- Physeal injury without growth abnormality
- Idiopathic limb-length discrepancy
- Developmental cause for limb-length discrepancy or angular deformity
- Blount disease
- Madelung deformity of the distal radius

**NONOPERATIVE MANAGEMENT**

- Anticipated lower extremity limb-length discrepancy of less than 1 cm requires no treatment.
- The simplest means of correcting a lower extremity limb-length discrepancy is to place a lift either inside or on the bottom of the shoe on the shorter limb.

---

**FIG 2 • A.** A true scanogram uses a slit beam of radiation that moves or “scans” down the length of the extremity. Because the radiation beam always remains perpendicular to the film, there is no magnification of the radiographic image, and distances can accurately be measured directly on the radiograph. The entire limb is included on the image, so angular deformity can be measured as well as length. Using multiple CT or MRI images (**B**), a map of the physeal bar is created (**C**) and the relative cross-sectional area of the bar is estimated.
Anticipated lower extremity discrepancy of 1 or 2 cm is most easily treated with a shoe lift inside the shoe.

Discrepancy greater than 2 cm treated nonoperatively is typically managed by a lift placed on the shoe sole.

There is no effective nonoperative treatment to correct clinically significant angular deformity caused by a physeal bar.

**SURGICAL MANAGEMENT**

- Lower extremity physeal arrest resection should be considered in patients with an anticipated growth remaining from the affected physis of about 2 years or 2 cm.
- Pure length discrepancy in the upper extremity caused by a physeal bar in the proximal humerus causes little functional problem, and anticipated discrepancy of up to 5 cm may be observed.
- Bone-length discrepancy in a two-bone limb segment such as the forearm or leg is less well tolerated. Anticipated bone-length discrepancy of greater than 1 cm at the wrist may warrant surgical treatment either by physeal bar resection or complete epiphysiodesis of both bones to prevent bone-length discrepancy.
- Surgical treatment for a physeal bar may consist of physeal bar resection, complete epiphysiodesis of the involved physis, epiphysiodesis of the adjacent bone in leg or forearm, epiphysiodesis of the contralateral physis, or an approach combining more than one of these. The surgical technique for physeal bar resection alone will be discussed below.
- If the decision has been made to perform physeal bar excision and an angular deformity is present, one is faced with the question as to whether an osteotomy should be performed at the time of physeal arrest resection to correct angular deformity.
- Our philosophy is to first perform physeal bar resection alone.
- Physeal bar resection is a relatively minor procedure with rapid recovery and the potential to correct (at least partially) the angular deformity. Accurate prediction of angular correction after physeal bar resection is not possible, making it very difficult to know with certainty the degree of osteotomy angular correction to perform.
- We would prefer to perform physeal bar resection alone first, then correct any residual angular deformity when physeal growth is complete.
- At skeletal maturity, the target is no longer moving and any additional adjustment in limb length can be addressed as well.

**Preoperative Planning**

- Imaging studies are reviewed and a map of the size and location of the physeal bar is created.
- A strategy is determined to provide the safest and most direct surgical approach to the physeal bar.

**Positioning**

- The patient is positioned to facilitate a direct approach to the physeal bar. For example, if a lateral approach is determined to be the most direct and safe route to a distal femoral bar, the patient is positioned with a generous bump elevating the hemipelvis and affected limb, with a tourniquet placed on the proximal thigh.
- Fluoroscopy is used to guide physeal bar resection, so the patient must be placed on a radiolucent table in a position to facilitate AP and lateral fluoroscopic images.

**Approach**

- The particular approach for each patient is determined by the location of the physis affected by the physeal bar and the location of the bar within the physis.
- A direct approach to the bone surface at the level of the physis is used for peripheral bars.
- Central physeal bar resection is typically performed by approaching the physis through the metaphysis adjacent to the physeal bar.
- The general strategy for central physeal bar excision in a long bone is to access the bar through a metaphyseal bone tunnel, resect the bar, and place an interposition material that will prevent recurrent bar formation (FIG 3).

![FIG 3](https://example.com/fig3.png)

**FIG 3** • The general strategy for central physeal bar resection (A) is to create a cortical window (B) through which the surgeon can excise the bar (C) and then place interposition material (D) to prevent bar recurrence. (Adapted from Peterson HA. Partial growth plate arrest and its treatment. J Pediatr Orthop 1984;4:246–258.)
With the patient prepared and draped, fluoroscopy is brought into the field and the location of the physis is marked on the skin surface. Next, using a blunt pin or straight instrument, mark on the skin the desired approach trajectory to the physeal bar. Draw the skin incision line on the approach trajectory (TECH FIG 1A).

Exsanguinate the limb and incise the skin longitudinally where an internervous plane can be used. With metaphyseal bone exposed, using AP and lateral fluoroscopic imaging, consider advancing a Kirschner wire or Steinmann pin along the approach trajectory from the metaphysis into the center of the physeal bar. This Kirschner wire will act as a guide to the location and depth of the physeal bar (TECH FIG 1B).

Using multiple drill holes and an osteotome, create an oval cortical window in metaphyseal bone (TECH FIG 1C). Remove and save the cortical window and superficial metaphyseal bone to be used for later closure. As the tip of the reference Kirschner wire is approached, use a motorized burr to carefully remove bone until the center of the physeal bar is reached, as confirmed fluoroscopically. Within the center of the physeal bar, no physis will be seen. Under fluoroscopic guidance, use the motorized burr to carefully expand the area of resection until normal physis is encountered (TECH FIG 1D).

**TECH FIG 1 • A.** Before making a skin incision, fluoroscopy is brought into the surgical field and the surgeon draws on the skin the physis location, the physeal bar location, the surgical approach trajectory, and the skin incision location that will permit the desired approach. **B.** Under fluoroscopic guidance a Kirschner wire is advanced to the level of the physeal bar along the desired surgical approach trajectory. Multiple drill holes are then made that incorporate the Kirschner wire into the periphery of an elliptical cortical window. The Kirschner wire will act as a guide to the location and depth of the physeal bar. **C.** Multiple drill holes are connected with a narrow osteotome to create a cortical window. The window is saved and replaced during closure. (Kirschner wire guide is not shown in this photograph.) **D.** After removing metaphyseal bone with a curette, a burr is guided by fluoroscopy to expand the bar resection cavity until normal physis is visualized within the cavity. (C,D: From Peterson HA. Epiphyseal Growth Plate Fractures. Heidelberg: Springer, 2007. With kind permission of Spring Science and Business Media.)
BAR RESECTION

- Once the physis is identified within the resection cavity, the motorized burr is used to remove bone along the leading edge of the exposed physis until normal-appearing physis is exposed throughout the entire circumference of the resection cavity.
  - The exposed normal physis should appear flat and smooth (TECH FIG 2A).
  - A surgical headlight is helpful to visualize the physis within the resection cavity.
  - If a region of the resection area cannot be seen by direct vision, use a dental mirror or small joint arthroscope to visualize the physis and confirm complete physeal bar excision (TECH FIG 2B).
  - Topical liquid thrombin may be applied to the resection cavity bone surface to reduce hematoma formation, which in theory might promote recurrent bar formation.

MARKER PLACEMENT

- Place titanium markers in the epiphysis and metaphysis to facilitate later measurement of physeal growth (TECH FIG 3A).
  - Marker position in the center of the bone prevents the metaphyseal marker from becoming extraosseous with future remodeling.
  - Our preference is a titanium 0.062 Kirschner wire notched 10 mm from the tip, which can be broken off within bone (TECH FIG 3B).
  - Titanium markers avoid artifact on subsequent MRI or CT scans.

TECH FIG 2 • A. Within the resection cavity the physis should appear smooth, flat, and healthy after bar resection. B. A dental mirror is used to look back at the physis in regions within the cavity where the physis cannot be directly visualized. At the conclusion of bar resection, normal physis should be visualized as a continuous cartilage line around the full circumference of the resection cavity.

TECH FIG 3 • A. The first titanium marker has been placed centrally within the metaphysis proximal to the physis. A second marker is going to be placed within the epiphysis distal to the physis. B. A 0.062 titanium Kirschner wire notched 10 mm from the end makes an ideal radiographic marker that will not interfere with future MRI imaging. (From Peterson HA. Epiphyseal Growth Plate Fractures. Heidelberg: Springer, 2007. With kind permission of Spring Science and Business Media.)
CRANIOPLAST INTERPOSITION

- An interposition material is then placed in the physeal bar defect. Some authors have recommended fat as an interposition material, but we prefer cranioplast polymethylmethacrylate for several reasons:
  - Cranioplast has a slow polymerization rate and does not generate heat, which might be harmful to the physis.
  - Cranioplast confers immediate structural strength to the resection area, allowing full weight-bearing after surgery.
  - No loosening has ever been reported after physeal bar resection.
  - Cranioplast stays securely within the resection bed and cannot “float” out of the resection bed on hematoma.
  - An additional incision to harvest fat interposition material is avoided.
  - Cranioplast can be injected into the resection defect in its liquid state, or it can be allowed to polymerize to the consistency of putty, then gently digitally pressurized into the cancellous bone of the resection bed, preventing displacement.

FAT INTERPOSITION

- If fat is chosen as the interposition material, a donor site must be chosen.
  - Rarely, in a patient with a small physeal bar, local fat may be harvested.
  - Most patients require harvesting fat from a distant site, and the gluteal region is typically used.

- Our current indications for fat interposition material include:
  - Physeal bars caused by infection, where this is a concern for recurrent infection
  - Peripheral physeal bar resection, where cranioplast may become prominent during future growth and remodeling (TECH FIG 4)

CLOSURE

- After placement of the interposition material, cancellous bone saved during exposure is gently packed into the remaining bone cavity.
- The cortical window of bone is replaced and may be sutured in place if desired.
- Periosteum is closed over the cortical bone window.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Detection</th>
<th>Absence or angulation of a Harris growth “resumption” line at the injured physis, especially when present at the contralateral physis, may be an early sign of physeal bar formation (FIG 4).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indications</td>
<td>For older patients with limited growth remaining, the surgeon should consider epiphysiodesis to prevent angular deformity or limb- or bone-length discrepancy from occurring.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- At the conclusion of the operation, local anesthetic is injected into the incision site, ketorolac (Toradol) is administered unless there is a medical contraindication, and the patient is placed in a gentle compressive dressing, which is removed on the first postoperative day.
- Patients are allowed to bear weight as tolerated with crutches as needed for comfort, and early active joint range of motion is encouraged.
- Noncontact sports are typically permitted 3 months after surgery and full-contact sports are allowed 6 months postoperatively in most patients.

OUTCOMES

- One hundred patients treated at the Mayo Clinic with physeal bar resection in the femur or tibia were followed to skeletal maturity.7
  - 13% of the patients required no additional treatment; the physeal bar was definitively treated by a single physeal bar resection procedure.
  - 94% of the patients did experience some growth after physeal arrest resection.
  - Restored physeal growth was, on average, 86% of the contralateral physeal growth rate.
  - 118 additional procedures were performed, for an average of 1.2 additional procedures per patient.
  - In all patients (except the six in whom there was no growth), any subsequent surgery was of lesser magnitude than would have been necessary had physeal bar resection not been performed.

COMPLICATIONS

- In 100 patients treated at the Mayo Clinic with physeal bar resection and cranioplast interposition followed to skeletal maturity, 2 patients had a surgical wound infection and 2 patients had a late fracture at the cranioplast site, for a total complication rate of 4%.7
- Fracture through the resection cavity after using fat as an interposition material has also been reported.2

REFERENCES

DEFINITION
- Congenital pseudarthrosis of the tibia follows pathologic fracture of a tibia.\(^2,4\)
- In most cases, the pseudarthrosis is preceded by increasing anterolateral bowing of the tibia.\(^8\)
- Spontaneous healing does not occur; shortening and angulation with instability are progressive and impair ambulation.
- Surgical treatment with a solid intramedullary rod and bone graft and long-term protection with a total-contact orthosis can provide lasting consolidation and minimize secondary deformity.\(^1,3,5,7,9\)
- Inability to achieve stable union may necessitate amputation.\(^5,7\)

ANATOMY
- The tibia is abnormal from birth; however, this may not become apparent until weight bearing begins. The remainder of the extremity is normal.
- Most patients will have anterolateral bowing that increases to the point of pathologic fracture.
- Shortening is common and tends to increase after fracture.
- As the anterior bowing increases, the foot may assume a dorsiflexed position to maintain contact with the floor.
- Involvement of the fibula is variable and may worsen as the tibial pseudarthrosis progresses.
- Nearly all cases are unilateral.

PATHOGENESIS
- Anterolateral bowing, when present, increases with weight bearing as the mechanical axis falls farther behind the axis of the tibia. Additionally, the calf musculature acts like a bowstring and increases tension within the tibia, leading to failure.
- Most pseudarthroses occur in the middle to distal third of the tibia.
- The pseudarthrosis comprises hamartomatous fibrous tissue, not neurofibroma.
- Fibular bowing or pseudarthrosis compounds the deformity and further compromises stability.\(^7,8\)

NATURAL HISTORY
- Rarely, bowing or sclerosis is present and does not progress to fracture and pseudarthrosis.
- Once established, the pseudarthrosis remains and does not resolve spontaneously. The resultant instability and shortening interferes with normal ambulation.
- Use of a total-contact orthosis may slow the progression and postpone but not eliminate the need for surgical intervention.
- More severe deformities become symptomatic at an earlier age, occasionally presenting in infancy.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The most common presenting complaint is anterolateral bowing of the tibia (FIG 1).\(^2,4\) Shortening of the involved extremity may not be apparent at presentation.
- Pain is absent unless the tibia has fractured acutely.
- Limp or dull aching may precede pathologic fracture.
- Over half of these patients have neurofibromatosis (NF) type 1.\(^4,8\)
- The skin should be closely inspected for café-au-lait spots, axillary or inguinal freckles, or neurofibromas as signs of underlying NF.
- A family history of NF may be present.
- Referral to a geneticist is recommended for confirmation of the diagnosis and genetic counseling.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Anteroposterior (AP) and lateral plane radiographs of the affected tibia are sufficient for diagnosis (FIG 2).
- The radiographic appearance of the tibia is variable; it may be cystic, sclerotic, or atrophic. There may be involvement throughout the tibia.\(^2-4\)

**FIG 1 • Standing AP photo of lower extremities. Anterior and lateral bowing is present in the left tibia of this 4-year-old girl. Shortening is minimal. The foot, knee, and thigh appear normal. Note multiple café-au-lait spots on the thighs and lateral side of the right leg, one of the major criteria of type 1 neurofibromatosis.**
SURGICAL MANAGEMENT

1. The intramedullary rod is designed to provide long-term stabilization of the tibial pseudarthrosis as the child grows. The rod remains in place, anchored by press fit in the medullary canal. The proximal tibia and the distal tibia grow away from the ends of the rod.\textsuperscript{10}

2. Younger children may require exchange with a longer rod if needed to maintain support of the tibia and stabilization of the pseudarthrosis.

Preoperative Planning

1. The dimensions of an appropriate-size rod can be determined from the plain films. The width of the medullary canal adjacent to the pseudarthrosis dictates the diameter of rod to be used. The length of the rod is determined from the lateral film.\textsuperscript{6}

2. The anticipated length of tibia to be resected to healthy bone is also measured; it is usually 1 to 2 cm.

3. In young children (less than 8 years) and in those with a very distal pseudarthrosis, the intramedullary rod should cross the ankle and subtalar joints to provide maximum stabilization because of the short distal tibial segment. The distance from the proximal tibial physis to the bottom of the calcaneus is measured. That length minus the amount to be resected is the length of intramedullary rod to be used.

4. In older children (more than 8 years), the rod can be placed within the tibia and does not need to remain across the ankle or subtalar joints. The distance from the proximal tibial physis to the distal tibial physis minus the amount of tibia to be resected is the length of rod that will be needed.

5. The Williams rod is made up of two sections: the section with the female coupling remains within the tibia and the piece with the male coupling is used as an introducer or pusher rod and is not considered in the selection of rod length (FIG 3). The rod can be cut or trimmed intraoperatively if needed to adjust the length.\textsuperscript{6}

6. If additional angular deformity is present in the tibia, an osteotomy may be needed to allow passage of the straight rod within the medullary canal.

7. If a fibular pseudarthrosis is also present, it should also be stabilized using an intramedullary Kirschner wire. If the fibula is intact, osteotomy may be needed to facilitate preparation of the tibia and introduction of the intramedullary rod.\textsuperscript{7,8}

Positioning

1. The patient is supine for preparation and rodding of the tibia. Before this, an iliac bone graft is obtained.

2. For small children, the graft should be obtained from the posterior iliac crest. In those cases, the child is positioned in the lateral decubitus position and is prepared from the waist to the toes.

3. For larger children, a bump can be placed under the buttock to facilitate positioning for an anterior iliac crest graft. It is removed before proceeding with the tibial exposure.

Approach

1. The tibia is approached directly along the anterior subcutaneous border. The incision is centered over the pseudarthrosis and extends 3 to 4 cm above and below that level.

2. The fibula is approached through a longitudinal incision, centered over the fibular pseudarthrosis, anterior to the peroneal muscles.
Chapter 33  REPAIR OF CONGENITAL PSEUDARTHROSIS OF THE TIBIA WITH THE WILLIAMS ROD

FIG 3  A. This assortment of Williams rods includes the female rod, which will remain within the tibia, and the complementary male rod used for insertion. Ideally, variable lengths and widths should be available. Selection of the appropriate-sized rod is based on the width of the medullary canal on the AP and lateral plane films. The length is estimated using the lateral film, measuring from the proximal tibial physis to the distal physis or bottom of the calcaneus, depending on the need to include the ankle and subtalar joints, and subtracting the length of the pseudarthrosis to be resected. The rod is to be coaxial with the tibia and of maximum length to minimize recurrent bowing above and below the rod as growth continues. B. Close-up view of the ends of the male and female sections. The male rod with the knurled end is the distal section and will be removed. The female flat, threaded end will be left in place. If the rod chosen is too long, it can be shortened using a bolt cutter and the tip of the rod removed, leaving the threaded end intact.

OBTAINING THE ILIAC CREST BONE GRAFT

Posterior Iliac Graft
- A 6-cm incision is made following the contour of the posterior medial corner of the iliac crest.
- The incision is carried down through the subcutaneous tissue, exposing the fascia overlying the iliac crest and abductor musculature.
- The apophyseal cartilage is exposed along the ilium and is split in half, sharply, along the course of the iliac crest.
- The lateral (superficial) half of the apophyseal cartilage and attached periosteum is elevated to expose the outer table of the ilium, subperiosteally.
- An osteotome is used to cut the outer table. Cortical and cancellous strips are obtained.
- The apophysis is reapproximated with interrupted sutures. A drain is used at the surgeon’s discretion. The subcutaneous layer and skin are closed, and the patient is then rolled to the supine position.

Anterior Iliac Crest Graft
- In larger children, the anterior iliac crest can be used.
- The approach is similar except the incision is centered over the anterolateral ilium.

PREPARATION OF THE TIBIA

- A sterile thigh tourniquet is applied and inflated.
- A 6- to 8-cm longitudinal incision is made over the tibial pseudarthrosis, along the subcutaneous border.
- The tibia is exposed subperiosteally and circumferentially around the pseudarthrosis.
  - The plane for subperiosteal dissection is more readily identified proximal and distal to the pseudarthrosis rather than directly over it.
  - The fibrous tissue within the pseudarthrosis is removed to expose the bone. A combination of sharp dissection, rongeur, and curettage is used.
  - The pseudarthrosis must be excised in addition to the abnormal dense, sclerotic bone adjacent to it.
  - The medullary canal can be probed and identified with a small curette.
  - A drill bit, smaller in diameter than the intramedullary rod to be inserted, is used to open and enlarge the medullary canal above and below the pseudarthrosis (TECH FIG 1A).
- The C-arm image is used to ensure that the canal preparation is not eccentric.
- If secondary bowing is present, it may not be possible to remain within the central medullary canal. Osteotomy of the tibia at that level should allow passage of the drill bit, remaining central in the medullary canal.
- Distally, the drill bit is passed through the tibia, stopping at the physis.
- If the rod will be left across the ankle and subtalar joints, a similar-sized smooth Kirschner wire is used to perforate the talus and calcaneus. Care must be taken to hold the foot and ankle in a neutral position during this process.
- Preparation of the tibia is complete when the drill bit can be passed through the proximal fragment up to the physis and distally to the physis.
- The drill bit should be centered within the tibia in both the AP and lateral images (TECH FIG 1B).
A fibular pseudarthrosis is approached through a lateral incision, anterior to the peroneals. The fibula is exposed subperiosteally and the fibrous tissue and adjacent pathologic bone are removed, as in the tibia.

- Care must be taken to avoid injury to the deep motor branches of the peroneal nerve, just medial to the fibula.
- Ideally, the fibula is stabilized with an intramedullary Kirschner wire. This is inserted through the distal fragment, exiting the skin at the tip of the fibula. After insertion of the tibial rod, the wire is then drilled into the proximal fibula. In some cases this cannot be accomplished because the fibula is too atrophic.
- An intact fibula may interfere with preparation of the tibia as it can limit mobilization of the proximal and distal fragments. It can also prevent contact of the tibial fragments. Osteotomy of the fibula will resolve the issue. It may be necessary to resect a portion to allow compression across the tibia.

TECH FIG 1 • Preparation of the tibia. A. A drill bit is used to open the medullary canal proximal and distal to the pseudarthrosis. C-arm image intensification is used to maintain central positioning within the medullary canal on the AP and lateral views. If there is severe bowing of the tibia, an osteotomy may be needed to prevent eccentric reaming, as in this patient. B. Lateral C-arm image of the distal tibia showing central position of the drill bit, stopping just above the distal phys. A similar-size Kirschner wire can be used to cross the physis, talus, and calcaneus if needed prior to rod insertion.

PREPARATION OF THE FIBULA

- The length of the rod is checked before insertion by reducing the tibia, laying the rod next to the leg, and noting the position of the rod proximally and distally.
  - The proximal point should be just below the proximal tibial physis.
  - The flat, distal end (female) should be at the distal tibial physis (if the rod is to remain within the tibia) or within the calcaneus (if the rod will stabilize the ankle and subtalar joints).
  - If the rod is too long, the pointed end can be cut on an angle to the appropriate length.
  - The rod sections are assembled by twisting the two sections together. A power drill is used to insert the pusher section into the distal fragment and it is advanced antegrade, across the ankle and subtalar joints, exiting the bottom of the foot through the heelpad (TECH FIG 2A).
  - The foot must be kept in a neutral position both in plantarflexion and dorsiflexion as well as varus-valgus alignment.
  - A small incision may be needed to relieve the skin tension around the rod (TECH FIG 2B).
  - The drill is detached from the proximal rod section and reattached to the distal rod, exiting the foot. The rod is drawn into the distal fragment (TECH FIG 2C).

STABILIZATION WITH THE WILLIAMS ROD

- The tibia is reduced and the rod advanced retrograde across the pseudarthrosis into the proximal tibia, stopping adjacent to the tibial physis (TECH FIG 2D,E).
- C-arm imaging is used to ensure concentric location of the rod within the tibia (TECH FIG 2F,G).
- The rod is grasped through the pseudarthrosis; with the drill on reverse, the pusher rod will disengage the female section (TECH FIG 2H). Spot C-arm images are used to confirm satisfactory position of the rod before the pusher is completely removed.
- Contact of the tibial fragments is confirmed visually. If the fragments are distracted, the surgeon should osteotomize or remove more fibula to ensure contact is made.
- The fibular Kirschner wire is advanced into the proximal fibula and cut flush with the tip of the fibula.
- The bone graft is placed circumferentially about the tibia (TECH FIG 2I). Cortical strips can be secured with loops of suture placed around the tibia. Cancellous bone is placed within and across the pseudarthrosis.
- The tourniquet is deflated and circulation assessed around the repair and in the foot.
- The periosteum usually cannot be closed over the bone graft. The wound is closed in layers over a drain.
TECH FIG 2 • A. The male section of the Williams rod is inserted antegrade into the distal segment and advanced through the talus and calcaneus. The foot must be held in neutral flexion and mediolateral angulation as the rod is passed. B. The Williams rod is pushed through the heelpad as it exits the foot. A small incision may be needed to relieve the skin tension around the rod. C. The Williams rod is assembled by twisting the male and female sections together. The drill is attached to the exposed tip of the male section and the rod is drawn into the distal fragment. Note the neutral position of the foot relative to the tibia. D,E. The tibial fragments are approximated and the rod is advanced retrograde into the proximal tibia. F. As the rod is advanced, C-arm images are used to confirm satisfactory coaxial positioning of the rod in both planes. This AP view shows satisfactory position. The rod fills the middle of the canal. A fibular shortening osteotomy has also been completed to allow contact of the tibial fragments. This is usually necessary to avoid distraction by an intact fibula after resection of the pseudarthrosis. G. Lateral C-arm image of the advancing rod. The rod is slightly anterior and can be withdrawn and redirected posteriorly to achieve a satisfactory position. In the presence of more severe bowing, an osteotomy would be needed to achieve satisfactory alignment. H. Once the rod is in satisfactory position within the proximal tibia, the male section is partially untwisted from the female section. It may be necessary to grasp the rod through the pseudarthrosis to disengage the two sections. The lateral C-arm image reveals the position of the distal end of the rod before the sections are completely disengaged. The separation of the sections is shown at the arrow. The proximal–distal position of the rod can easily be adjusted if needed. Once contact of the tibial fragments is also confirmed by direct vision and C-arm, the male end is detached and removed. I. The medullary canal is packed with cancellous bone. The corticocancellous strips are placed circumferentially about the pseudarthrosis. These can be secured by loops of suture passed around the tibia.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Patient selection</th>
<th>▪ This procedure should be considered only for patients with an established pseudarthrosis. Infants and young children with anterolateral bowing (prepseudarthrosis) should be observed and treated with a total-contact orthosis.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alignment and centering of the rod</td>
<td>▪ Residual anterior angulation increases the potential for recurrent bowing and refracture. Placement of the rod in a colinear fashion within the tibia—that is, a straight rod within a straight tibia—optimizes protection of the tibia from deformity and fracture. As the tibia grows away from the ends of the rod, bowing may increase through this unprotected segment.</td>
</tr>
<tr>
<td>Foot position</td>
<td>▪ If the ankle and subtalar joints are transfixed by the rod, it is important to maintain neutral alignment and a plantigrade foot. Because of the anterior bow, the foot tends to assume a dorsiflexed position; the lateral bow promotes a valgus deformity at the ankle. A calcaneus foot position further weakens the posterior musculature of the leg. Angular deformity may require treatment by hemiepiphyseodesis or guided growth.</td>
</tr>
<tr>
<td>Distraction</td>
<td>▪ An intact or overly long fibula may distract the tibia and compromise consolidation. Osteotomy with shortening as needed to permit contact of the tibial fragments resolves the issue.</td>
</tr>
<tr>
<td>Rod selection</td>
<td>▪ Ideally the rod spans enough of the tibia to provide long-term mechanical support and protection of the pseudarthrosis. As growth occurs, more of the tibia is exposed to stresses that promote recurrence of bowing. Selection of the longest and greatest-diameter rod is best. Preoperative measurements from plain films provide a reliable guide for the length and width needed. An assortment of rod sizes are available and may need to be modified—that is, cut to an appropriate length—before surgery.</td>
</tr>
<tr>
<td>Orthotic management</td>
<td>▪ Use of a total-contact orthosis is essential throughout growth to reduce stress through the pseudarthrosis and maintain consolidation. A solid AFO is used if the rod transfixes the ankle and subtalar joints. A KAFO is used in young children (less than 5 years).</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- Cast immobilization is used postoperatively until consolidation of the pseudarthrosis occurs, usually at least 12 weeks. A one-and-a-half spica cast is used for infants and young children (less than 6 years) to minimize stress across the pseudarthrosis. A long-leg, non-weight-bearing cast is used in older children.

- A total-contact orthosis is used long term to protect the area of consolidation and reduce mechanical stresses on the lower leg that promote anterior bowing. Initially a nonarticulated KAFO is used in young children and in those with the rod across the ankle and subtalar joints. This is changed to an articulated AFO when the rod is positioned within the tibia, no longer transfixing the ankle.

**FIG 4 • A.** AP view of tibia after rodding in this 5.5-year-old girl shows ideal rod placement centrally within the tibia. The proximal tip of the rod is just below the physis, the fragments are in contact, and the distal rod is central within the tibia and also fills the medullary canal. The ankle is in neutral varus–valgus alignment. The fibula is very atrophic and could not be stabilized even with a small-diameter Kirschner wire. **B.** Lateral view of the same patient. The rod crosses the ankle, which is held in neutral flexion. The rod controls a maximum length of the tibia and centers the proximal tibia over the plafond.
Once the ankle is no longer transfixed, an ankle rehabilitation program is implemented that includes range of motion and calf strengthening.

Periodic follow-up is necessary throughout growth to monitor the quality of healing and maintenance of good rod position (FIG 5).

Ambulation and activities are unrestricted as long as the orthosis is used. Once skeletal maturity is reached, the orthotic use is recommended for sports and high-stress activities.

OUTCOMES

Patients resume independent ambulation with long-term orthotic protection.

Consolidation reliably occurs in 90% of cases with this technique.1,3,5,7-9

Two long-term studies assessed the quality of maintenance of healing, with variable results. Both studies emphasized the importance of paying attention to details regarding the technique of rod insertion, continued orthotic use, and long-term follow-up care.7,8

Anterior bowing may recur and lead to refracture. If the rod is in good position, healing can be obtained by simple cast immobilization. If healing is delayed, the addition of bone graft will generally lead to union.1

Valgus angulation may also occur and may need to be managed by guided growth or hemiepiphysiodisis.8

Limb-length inequality is variable. It is more common with patients with severe deformity, those requiring greater length of pseudarthrosis resection, and those with recurrent fracture.

While most patients realized long-term satisfactory healing and function, some patients ultimately chose amputation after multiple recurrent fractures resulting in loss of function or limb-length inequality.7,8

COMPLICATIONS

Complications include those routinely associated with musculoskeletal procedures, such as swelling, wound healing, and pain, with similar incidence.

The most likely intraoperative complication is neurovascular injury, particularly to the deep motor branches of the peroneal nerve. These are at risk during fibular osteotomy.

None of the studies have reported occurrence of a compartment syndrome, although this could be produced by overzealous use of bone graft, which may compress the tibial vessels. Fasciotomy is usually incidental with the surgical approach to the tibia.

Refracture with progressive shortening and loss of stability may compromise function sufficiently to warrant amputation.

Satisfying the primary goal of a healed pseudarthrosis is easier to accomplish than maintaining union, which serves to emphasize the recalcitrant nature of this pathologic process.

REFERENCES

**DEFINITION**

- Limb lengthening is a surgical procedure performed to lengthen a bone.
- In the Ilizarov method, lengthening is accomplished by gradual bone distraction through a low-energy, atraumatic corticotomy site. The bone fragments are controlled via stable bone fixation using half-pins and tensioned wires through bone that are rigidly fixed to an external ring fixator or arch.\(^1\)\(^1\)
- When a monoplanar fixator is used, lengthening is accomplished by distraction of the atraumatic corticotomy of the bone.\(^9\)\(^,\)\(^18\)

**ANATOMY**

- Using the Ilizarov method, one can lengthen bones of both the upper and lower extremities, including bones of the hand and foot and the surrounding soft tissue.
- The most commonly lengthened bones in the lower extremity include the tibia and fibula, the femur, and the metatarsal. In the upper extremity, the most commonly lengthened bones are the humerus, the radius and ulna, and the metacarpal bones.
- Consideration is given to lengthening of the surrounding soft tissues, which include the muscle tendon unit, neurovascular bundle, and skin.\(^11\)
- During bone lengthening, the tension in the surrounding soft tissue may predispose the lengthened segment to deformity\(^12\),\(^19\):
  - Femur: varus and procurvatum
  - Tibia: valgus and procurvatum
  - Humerus: varus and procurvatum
  - Radius and ulna: has a tendency to collapse in the interosseous space, which may cause synostosis
  - Metatarsal and metacarpal: apex dorsal angulation
- During large lengthening, care is necessary to prevent subluxation or dislocation of the adjacent joint.\(^19\)
- Femoral lengthening, especially in the setting of congenital short femur, may result in hip or knee subluxation or dislocation secondary to associated deficient acetabular coverage at the hip and the high frequency of deficient cruciate ligaments at the knee.
- Tibial lengthening may cause knee or ankle subluxation and progressive equinus deformity of the foot.
- Metatarsal and metacarpal lengthening can cause metatarsophalangeal subluxation.
- All of these issues are considered during any lengthening procedure.

**PATHOGENESIS**

- The term *distraction osteogenesis* implies synthesis of new bone by slow, gradual (no more than 1 mm per 24 hours) controlled distraction of the bone fragments under conditions of rigid fixation.\(^7\)\(^,\)\(^11\)
  - The new bone is formed mostly by intramembranous ossification and, to a lesser extent, through endochondral ossification.\(^9\)\(^,\)\(^11\)
  - To provide maximum construct stability and to minimize soft tissue trauma, it is important to maintain the two fragments well apposed to each other following the corticotomy.
  - Distraction is a good tool for influencing reparative regeneration of both the bone and the soft tissue (“stretching tension,” as described by Ilizarov). However, the new regenerate ossifies and remodels slowly.
  - Gradually removing distraction and applying mild compression increases the rate of remodeling. Therefore, the regenerate becomes more rigid against bending loads.
  - To prevent any shortening of the segment from compression, preliminary over-distraction of up to 0.5 to 1 cm may be performed.
  - Functional load is a strong stimulus for the improvement of blood flow and allows organic remodeling of the regenerated osseous part. The extent of load depends on the stability of fragments and the amount of regenerate.

**NATURAL HISTORY**

- The natural history of the limb-length discrepancy (LLD) depends on the condition causing the LLD.\(^16\),\(^22\) A partial list of causes follows:
  - Congenital shortening: Proximal focal femoral deficiency, coxa vara, congenital short femur, fibula and tibia hemimelias, hemiatrophy
  - Congenital lengthening: Overgrowth syndromes such as hemihypertrophy, Beckwith-Weidemann syndrome, Klippel-Trenaunay-Weber syndrome, and Parke-Weber syndrome
  - Skeletal dysplasia or tumor: Multiple hereditary exostoses may result in limb shortening on the affected side as growth cartilage cells are diverted to the cartilage tumor.\(^18\) Radiation for malignancies adjacent to the physes may result in growth suppression or complete destruction of physese cartilage cells, resulting in limb-length discrepancy or angular deformity.
  - Infection: Physial destruction may result from physial invasion from adjacent metaphyseal or epiphyseal bacterial osteomyelitis, or direct physial involvement in the case of intracapsular joint physis such as at the hip and shoulder.
  - Paralysis: Poliomyelitis and cerebral palsy as well as other nervous system afflictions in children typically result in shortening on the more affected side.
  - Trauma: Direct injury to growth plate, postraumatic bone loss or shortening, and overgrowth following femoral fracture
  - Miscellaneous: Slipped capital femoral epiphysis, Legg-Calvé-Perthes disease
  - Upper extremity discrepancy or shortening usually does not cause major functional problems, but may result in significant cosmetic deformities.
Predicted lower extremity discrepancy of 3 to 5 cm may be dealt with by long-leg epiphysiodesis in children or by leg lengthening using the Ilizarov technique. LLD greater than 5 cm is amenable to leg lengthening.\(^{22}\)

In children, the LLD at maturity can be predicted in a variety of ways:
- The arithmetic method\(^{13}\)
- The growth remaining method\(^{1}\)
- The Moseley straight line method\(^{15}\)
- The Paley multiplier technique\(^{20}\)

Untreated LLD of more than 3 cm may result in pelvic obliquity, visual gait disturbance, short-legged gait, or structural/nonstructural scoliosis.\(^{22}\)

LLD greater than 5.5% of the long leg has been shown to decrease the efficiency of gait, as determined from kinetic data.\(^{21}\)

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The common symptoms at presentation are limp, compensatory gait mechanics, pelvic obliquity, and nonstructural scoliosis.
- Physical findings depend on the etiologic factors.\(^{22}\)
- In hemihyperplasia (both syndromic and nonsyndromic), the affected extremity may be larger in both length and girth. In classic hemihyperplasia, upper extremity hypertrophy as well as hemifacial asymmetry may be present. Vascular overgrowth syndromes may be associated with cutaneous or deep hemangiomas, which may alter surgical approaches to attempted limb equalization.
- Clinically, LLD is best measured by the block test, in which the shorter leg is placed on increasingly larger measured blocks until the posterior iliac crest is level. Discrepancies as small as 2 cm are accurately detected by this method, and detection of discrepancies is largely unaffected by patient size or body mass. Direct measurement of leg length from anterosuperior iliac spine to the tip of medial or lateral malleolus is significantly less accurate.
- Apparent leg length is measured with the patient supine with the legs parallel to each other. The landmarks are the umbilicus to the tip of medial malleolus. Pelvic obliquity and fixed deformities of the hip and knee affect the reading.
- True leg length is measured from the anterior superior iliac spine to the tip of the medial malleolus. It is important to place the legs in identical positions to measure true leg length.
- If the patient has a 20-degree abduction deformity of right hip, the left hip is placed in 20 degrees of abduction to measure true length.\(^{22}\)
- Range of motion is noted for all joints, primarily the hip, knee, ankle, and subtalar joints. The ankle joint range of motion is measured with the knee in extension and flexion.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs are helpful to document the objective measurement of LLD (FIG 1).
- Full-length (hip to ankle) anteroposterior (AP) radiographs are obtained in standing position with both patellae facing directly anteriorly. The appropriate-sized block is placed beneath the shorter leg to level the pelvis. A long x-ray cassette (51-inch) is used with the x-ray beam centered focused on the knee from a distance of 10 feet. A radiolucent ruler often is used to assist in calculation of limb discrepancies.

**DIFFERENTIAL DIAGNOSIS**

- True shortening (eg, femoral or tibial)
- Apparent shortening due to dislocated hip
- Apparent shortening from contractures
- Angular deformity causing apparent shortening
- Overgrowth syndrome with both increased length and limb girth: hemihypertrophy
- Congenital limb deficiency (beware knee joint instability)

**NONOPERATIVE MANAGEMENT**

Nonoperative management is based on the amount of discrepancy:\(^{16}\):
- 0 to 2 cm: no treatment
- 2 to 6 cm: shoe lift (option for epiphysiodesis or lengthening in this range)
- More than 20 cm: extension prosthesis

**SURGICAL MANAGEMENT**

*Preoperative Planning*

**Ilizarov Method**

- Accurate radiographic measurement of current discrepancy and calculation of projected LLD at maturity
- Determination of which bony segment is affected
- Assessment of compensatory mechanics used for walking: equinus gait, circumduction, vaulting, or combination\(^{21}\)
- Assessment of contractures: eg, extra- or intra-articular, bony
- Assessment of associated deformities: eg, angulation, translation, and rotation
- Long-leg standing radiographs in both planes help determine malalignment.
Stability or laxity of joints (hip, knee, ankle) is determined clinically and radiographically.

- Skin condition: eg, open defect, scar tissue
- Planning for corticotomy level, for lengthening as well as for correction of associated deformity with appropriate room for wire or half-pin fixation.
- Determine optimum frame configuration, with or without inclusion of the adjacent joint.
- Details on ring size, half-pin, or K-wire placement
- Single-stage lengthening of 10% to 15% of bone length is associated with fewer complications.

Technical considerations
- The Ilizarov frame may be constructed before surgery. The design of the frame and the number of rings and arches depend on the amount of lengthening planned.
- Separate threaded connecting rods are used between each ring block and the next. A rod spanning two or more rings allows less flexibility if adjustments are needed.
- Adequate skin clearance of at least 2 to 3 cm must be maintained circumferentially under the ring. Small rings are more rigid than large rings, but smaller rings may hinder skin care and may cause soft tissue compression if there is postoperative swelling.
- A template or an actual ring can be used to select the appropriate ring size (Fig 2).
- Due to the changing diameter of each limb segment, different ring sizes may be required for a single limb segment (for example, the diameter of the proximal arch for the femur typically is larger than the distal ring).

Monoplanar Fixation
- True measures of current discrepancy and calculation of projected LLD
- Compensation mechanisms used during walking: equinus gait, circumduction, vaulting
- Assessment of contractures: extra- or intra-articular
- Associated deformity: angulation, translation, and rotation
- Stability or laxity of joints: eg, hip, knee, ankle
- Skin condition: eg, open defect, scar tissue
- Long-leg films showing hip, knee, and ankle for lower extremity; and similar long films for the upper extremity
- Planning for corticotomy level; osteotomy level if needed for correction of associated deformity; and planning for points of fixation
- Choose appropriate size arch, rods, rail, half-pin and/or K-wires.

Choose the appropriate size of the fixator (pediatric or adult)

Positioning
- Lower extremity: Supine position on any radiolucent table (eg, Jackson table)
- Upper extremity: Supine position with arm over a radiolucent table
- Intraoperative fluoroscopy (for both the AP and lateral images)
- For the Ilizarov method:
  - Place rolled sheets (as bumps) beneath the ipsilateral buttock and proximal tibia, leaving the femur free (Fig 3A).
  - Similarly, for the tibia, a rolled sheet is placed beneath distal femur and ankle to create space for the tibial frame (Fig 3B).
  - Place a sandbag beneath the ipsilateral shoulder/scapula and rolled sheets (as bump) beneath the humerus and radius ulna to create a space for the frame.
- For monoplanar fixator use, place rolled sheet (as bumps) beneath the femur and tibia to create working space for application of the frame.

Monoplanar Fixation
- True measures of current discrepancy and calculation of projected LLD
- Compensation mechanisms used during walking: equinus gait, circumduction, vaulting
- Assessment of contractures: extra- or intra-articular
- Associated deformity: angulation, translation, and rotation
- Stability or laxity of joints: eg, hip, knee, ankle
- Skin condition: eg, open defect, scar tissue
- Long-leg films showing hip, knee, and ankle for lower extremity; and similar long films for the upper extremity
- Planning for corticotomy level; osteotomy level if needed for correction of associated deformity; and planning for points of fixation
- Choose appropriate size arch, rods, rail, half-pin and/or K-wires.
**Tibial Lengthening**

**Wire Insertion**
- The wire insertion site is determined by local anatomy and the use of cross-sectional anatomic atlases to protect and avoid damage to blood vessels, nerves, and tendons.
- In small children, 1.5-mm fixation wires are used; in adolescents and adults, 1.8-mm fixation wires are used. The wires usually are tensioned to 100 kg in children and to 130 kg in adults.
- The wire is introduced from the side nearest the neurovascular bundle. This helps prevent inadvertent injury to the neurovascular structures.
- Initially the wire is gently pushed through the soft tissue until it hits bone cortex. The center of the bone is located, and the wire is drilled through the cortex. It is important not to bend the wire while drilling.
- The wire is prevented from bending by a short lever arm on the wire that holds the wire with a wet sponge or by use of a protective soft tissue sleeve (TECH FIG 1).
- After piercing the far cortex, the lowest possible drill speed is used to further insert the wire. After exiting the far skin, the wire is inserted further by tapping with a mallet.
- The wire is fixed to the ring without bending the wire. Bent wires will move the bony fragments on tensioning.
- Any tension or puckering of the skin at wire insertion or exit is corrected by releasing the surrounding skin or fascia with the help of a no. 15 blade on a scalpel.

**Half-Pin Insertion**
- Hydroxyapatite-coated half-pins are recommended, because they achieve better fixation and are associated with lower rates of infection and loosening.\(^3\)
- The size of the half-pin should not exceed one-third the diameter of the bone segment being fixed.
- Freehand technique
  - Identify the optimal site for pin insertion.
- Incise the skin over the insertion site, and then dissect down to the bone using a hemostat.
- Now drill the bone (both cortices) through a protective drill sleeve.
- The half-pin is introduced in the drilled track. The pin traverses only 1 to 2 mm through the far cortex, confirmed with fluoroscope.
- The half-pin is attached to the ring or arch, which is positioned perpendicular to the bone segment.
- If the half-pin insertion is not perpendicular to the bone, a post and half-pin fixation bolt are utilized.
- Ring guide technique
  - First the ring or arch is fixed perpendicular to the bone with a wire.
  - Depending on the optimal site for pin insertion, the half-pin fixation bolt or Rancho cube is attached to the ring.
  - Now the sleeve is introduced through the half-pin fixation bolt or cube, and the skin site is marked.
  - The skin is incised and dissected to the bone using a hemostat.
  - The sleeve is advanced further to contact the bone.
  - The drill is introduced through the sleeve, and the bone is drilled (both cortices).
  - The half-pin is introduced in the drilled track. The pin traverses 1 to 2 mm through the far cortex, and this is confirmed fluoroscopically.
  - The half-pin fixation bolt or the cube is tightened over the pin.

**Fibular Osteotomy and Anterior Compartment Fasciectomy**
- The osteotomy is done at the junction of the proximal and middle thirds of the fibula. Avoid osteotomies of both the tibia and fibula at same level.
- The fibula is approached laterally through the plane between the peroneus longus and the lateral intermus-
cular septum. The periosteum is incised with a sharp knife and is elevated circumferentially with a periostal elevator.

- A Hohmann or Bennett retractor then is placed around the exposed fibula to protect the surrounding soft tissue.
- The fibula is osteotomized, either with an oscillating saw or using an osteotome, after placing several drill holes through both cortices. Irrigation fluid is used to prevent thermal necrosis while using the saw or drill.
- An oblique osteotomy is used to have larger contact area between the two fragments.
- The skin and subcutaneous tissues are closed without closing the underlying fascia.
- Now the skin is incised over the tibial corticotomy site. The corticotomy site usually is the proximal metaphysis.
- Prophylactic fasciotomy of the anterior compartment may be performed by releasing the anterior compartment fascia distally and proximally with a Metzenbaum scissors.
- We recommend fasciotomy before the frame is mounted, because more space is available to work. However it can be done later after mounting the frame.
- Now a temporary suture is placed over the proximal tibial incision, deferring the corticotomy until later in the procedure.

Ilizarov Frame Application

- For simple lengthening (without deformity), three rings (or two rings and one arch) are used.
- Introduce a transverse proximal tibial wire perpendicular to the shaft and below the growth plate in children (TECH FIG 2, #1).
- To avoid penetrating the joint capsule, the transverse wire should be no closer than 14 mm to the subchondral bone of the proximal tibia.
- Attach the proximal ring (previously constructed frame) to this wire, and tension the wire with a wire tensioner. Adequate ring clearance from the soft tissues must be verified circumferentially.
- Another transverse wire is introduced in the distal metaphysis of the tibia proximal to the distal growth plate and fixed to the distal ring (TECH FIG 2, #2).
- The biomechanical and anatomic axis of the tibia is the same in the absence of deformity.
- The lengthening rods are placed parallel to the biomechanical axis. Radiographically, the rods should be parallel to the posterior cortex on the lateral view and parallel to the longitudinal axis of the tibia on the AP view.
- Next a wire is placed proximally, passing from lateral to medial. This wire enters the fibular head (just distal to the proximal fibular growth plate), traversing the tibia and exiting through the anteromedial tibial cortex.
  - Care is necessary to prevent damage to the peroneal nerve, which is in close proximity to the fibular neck.
  - The wire is then fixed and tensioned to the proximal ring.
- Now two half-pins are placed in the most proximal ring. In this configuration, there should ideally be 90 degrees of angulation between the two pins (TECH FIG 2, #3).
- Usually a half-pin fixation bolt is required with one half-pin and a one-hole cube for the other half-pin, so that the pins are placed at slightly different levels.
- It is important not to damage the tibial tubercle and proximal tibial physis while placing the half-pins or wires.
- Next, a wire is placed distally through the fibula and tibia just above the growth plate at the level of the syndesmosis (TECH FIG 2, #4). This wire is attached and tensioned to the distal ring.
- Place the fibula-tibia wire more than 12.2 mm from the distal tibia subchondral surface to avoid capsular penetration and the risk of joint sepsis.
- A half-pin is introduced just proximal to the distal ring in an anteromedial direction. It is then fixed to the distal ring (TECH FIG 2, #5).
- One or two half-pins are similarly introduced just above and below the middle ring and are securely fixed to the middle ring (TECH FIG 2, #6).
- The connecting rods between the proximal and middle rings are then disconnected, and attention is directed to the corticotomy site.
- Extra-periosteal dissection is performed at the proximal tibial metaphyseal osteotomy site.

![TECH FIG 2](image)

**TECH FIG 2** The sequence and placement of K-wires or half-pins in tibial lengthening. 1, Proximal transverse tibial wire perpendicular to the shaft and below the growth plate in children. This wire is placed anterior to the fibula head. 2, Transverse wire in the distal metaphysis of the tibia proximal to the distal growth plate. 3, Two half-pins are inserted proximally, one above and one below the proximal ring at an approximate angle of 90 degrees to one another. 4, Distal wire through the fibula and tibia above the growth plate at level of syndesmosis. 5, Distal tibial half-pin is introduced in the anteromedial direction. 6, One or two half-pins are introduced, just above and below the middle ring.
The periosteum is not elevated circumferentially, in order to preserve the blood supply.

**Corticotomy**

- Multiple drill holes are made in both tibial cortices from anterior to posterior. If necessary, additional drill holes can be made at the same level from another point over the anteromedial cortex (TECH FIG 3A).
- A 5-mm osteotome is advanced through the bone at the level of the drill holes (TECH FIG 3B).
- First the anteromedial cortex is osteotomized, followed by the anterolateral cortex. Each time the osteotome passes through the far cortex, it is twisted with a wrench to cause a controlled fracture in the cortex.
- Finally, a wider osteotome is seated in the posterior cortex and twisted with a 14-mm wrench to break the posterior cortex.
- The corticotomy is confirmed by externally rotating the distal block. Internal rotation is avoided, because it places tension on the common peroneal nerve. The fragments are rotated back to the normal reduced position.
- The rods between the proximal and distal blocks are reconnected as they were before the corticotomy, and the osteotome is reduced.
- The use of square nuts or clickers on the connecting rods allows future distraction.

**Wound Closure**

- The skin is closed without closing the underlying fascia.
- Check that all the nuts and bolts are tight.
- Put a dressing (eg, Xeroform [Covidien, Mansfield, MA], sponges) around the wires and half-pins. Pressure dressing is applied over the fibular and tibial corticotomy sites. Place the dressing material between the frame and the surgical wound.

The foot is placed in a plantigrade position and a footplate is attached. When planning a large lengthening, the foot may be included in the frame to prevent progressive equinus deformity of the ankle.

Similar consideration is given to including the knee in the frame for large lengthening or in the setting of cruciate ligament laxity.

**Taylor Spatial Frame**

- The Taylor Spatial Frame (TSF; Smith & Nephew, Andover, MA) has Web-based spatial software, which helps to calculate correction of deformity or lengthening of the bone.
- Deformities can be corrected using chronic deformity correction, the rings-first method, or the residual deformity method.
- In the TSF, the proximal and distal blocks may or may not be connected preoperatively.
- The number and site of wire/half-pin fixation, the number of rings, and the basic construct of the frame are similar to those described earlier.
- The details of fibular osteotomy and anterior compartment fasciotomy are the same.
- Mount the frame and secure with wires and half-pins.
- The proximal and distal blocks are connected with six connecting struts. The details of the strut lengths are recorded, after which the struts are disconnected and corticotomy is completed as discussed earlier.
- The corticotomy is reduced, and the struts are reconnected the way they were before the corticotomy (TECH FIG 4).
- The deformity, frame, and mounting parameters are entered in the software program, which prescribes a lengthening/corrective program.
- The rate of distraction is determined based on local bone and soft tissue status. Typically, it is 1 mm per day in healthy bone and soft tissue.
Femoral Lengthening

- The usual frame construct for simple femoral lengthening (without deformity) is composed of two rings and one arch.
- Initially, a transverse wire is placed in the distal femur, parallel to the knee joint line and proximal to the growth plate in children (TECH FIG 5A, wire 1). The direction of the wire is from lateral to medial.
- The previously constructed frame is mounted, and the distal ring is attached to this wire. The wire is then tensioned. All the rings, including the arch, should have at least one or two fingerbreadths clearance from the anterior and posterior surface of the thigh.
- The mechanical and anatomic axes of the femur are not identical as in the tibia. The mechanical axis is drawn from the center of the femoral head to the center of the knee joint, whereas the anatomic axis is the central axis of the femoral shaft. The anatomic axis forms a 7-degree angle with the mechanical axis.
- A transverse half-pin is introduced in the lateral proximal femur perpendicular to the mechanical axis, using the ring guide technique (TECH FIG 5A, pin 2). The pin is placed centrally in the lateral cortex and is fixed to the proximal arch.
- The frame rods are placed parallel to the mechanical axis. Radiographically, the rods are parallel to the posterior cortex on the lateral view and parallel to the mechanical axis (marker from center of femoral head to the center of knee joint) on the AP view.
- Next, two half-pins are placed in the distal femur proximal to the growth plate. The direction of these half-pins is from posterolateral to anteromedial and from posteromedial to anterolateral (TECH FIG 5A, pin 3).
- While introducing half-pins, it is necessary to flex the knee to avoid placement across the tendon and muscle (ie, biceps femoris, semitendinosus, semimembranosus). Care is necessary to prevent any damage to the common peroneal nerve, which is in close relationship with the biceps femoris.
- One or two half-pins are introduced in the proximal femur (TECH FIG 5A, pin 4). The half-pins are fixed to the proximal arch using different-size Rancho cubes to avoid pin placement at the same level.
- Next, one or two half-pins are placed adjacent to the middle ring (TECH FIG 5A, pin 5).
- The rods between the middle and distal rings are disconnected for corticotomy of the distal femoral metaphysis.
- A skin incision is made over the anterolateral distal femur close to the distal metaphysis. The deep tissue is incised, and the vastus lateralis is elevated by blunt dissection to expose the lateral femoral cortex without disturbing the underlying periosteum. The osteotomy is performed approximately 1 cm proximal to the most proximal wire or half-pin attached to the distal ring.
- The cortex is drilled at the same level, with multiple drill holes at varying angles. A 5-mm osteotome is advanced through the anterior, lateral, medial, and posterior cortices.
- Each time the osteotome is fully seated through the far cortex it is twisted with a wrench to cause an atraumatic fracture in the cortex. The corticotomy is confirmed by externally rotating the distal ring.
- The fragments are rotated back to the normal reduced position. This will decrease bleeding from the cut bony surfaces.
- The rods are reconnected as before the corticotomy. Square nuts or clickers are used with these connecting rods to allow for controlled distraction.
- The corticotomy site is closed. A check is done to tighten all nuts and bolts (TECH FIG 5B).
During large lengthening and in presence of knee ligament laxity, one should consider extending the frame across the knee joint.

**Taylor Spatial Frame**
- When using the TSF for femoral lengthening, the proximal and distal blocks may or may not be connected preoperatively.
- The number and site of wire/half-pin fixation, number of rings, and basic construct of the frame are similar to those described with the ilizarov technique.
- Mount the frame and secure with wires and half-pins.
- The proximal and distal blocks are connected with six connecting struts. The details of the strut lengths are noted. Then the struts are disconnected and corticotomy is completed as discussed earlier.
- The corticotomy is reduced, and the struts are reconnected at the same lengths as before corticotomy (TECH FIG 6). This results in anatomic reduction at the osteotomy site.
- The deformity, frame, and mounting parameters are entered in the software program, which prescribes a lengthening/deformity correction program. Lengthening proceeds at 1 mm/day under normal circumstances.

**MONOPLANAR FIXATOR ASSEMBLY**

**Technical Considerations**
- Monolateral fixators stabilize bone fragments using percutaneous half-pins to transfix the bone with external fixation of the half-pin to the clamp, rail, rod, or arch.
- Some monoplanar systems use arches or rings to achieve multiplanar fixation.
- Advantages of monoplanar fixators:
  - Greater patient comfort during femur and humerus lengthening
  - Less bulky frame
  - Simple construct

- Disadvantages of monoplanar fixators:
  - Less rigid
  - Less flexible: eg, the MAC frame (EBI, Parsippany, NJ) has a universal hinge that allows correction of angular deformity and a translation device that allows correction of translation in two directions.
  - Not recommended for large lengthening (more than 5 cm)
- The monolateral frame is constructed before the surgery is done. The design of the frame, including the number of clamps and arches, depends on the planned lengthening.
- Rail size depends on the planned lengthening.
- Techniques to increase frame stability include:
  - Increase number of half-pins
  - Increase diameter of the half-pins (pin diameter should not exceed a third of the bone diameter)
  - Greatest possible angle between half-pins (maximum, 90-degree angle)
  - Reduce distance between the bone and the external frame.
  - Increase the distance between half-pins.
  - Fixation as close to the corticotomy as possible.

**Femoral Lengthening**
- For simple lengthening (without deformity), three-point fixation is required in each segment.
- Use guidewire technique to place the first half-pin in the distal femur. A guidewire is introduced parallel to the knee joint line and proximal to the growth plate in children.
- Because the femur has a natural anterior bow, the guidewire is placed slightly anterior (not central) in the lateral femoral cortex (TECH FIG 7A, #1).
- The bone is drilled over the guidewire with a 4.8-mm or 3.2-mm cannulated drill bit (depending on the size of half-pin to be used). Then a self-tapping, hydroxyapatite-coated half-pin is introduced in the drilled track (TECH FIG 7B, #1).
- Attach this half-pin to the clamp, which is connected to the rail (monolateral fixator).
- At least one fingerbreadth of distance is maintained between the external frame and the lateral surface of the proximal thigh.
- A second half-pin is introduced in the proximal femur perpendicular to the biomechanical axis and fixed to the proximal clamp (TECH FIG 7B, #2).
- This half-pin is also placed slightly anterior (not central) in the lateral femoral cortex (TECH FIG 7A, #2).
- With intraoperative fluoroscopy, check the AP and lateral relationships of the frame with the femur. The frame should be located parallel to the biomechanical axis on the AP view (TECH FIG 7B, #3). On the lateral view, all the holes of the proximal and distal clamp should overlie the bone.
- Introduce two or more half-pins through the empty holes of the proximal clamp (TECH FIG 7B, #4).
During femoral lengthening, soft tissue tension predisposes the femur to develop procurvatum deformity. Procurvatum deformity can be prevented by making simple adjustments during frame application. After the proximal half-pins have been placed, the rail is disengaged from the proximal clamp. The distal clamp is then angulated by 10 degrees anteriorly (TECH FIG 7C).

The additional two half-pins are then placed in the distal clamp. This pin placement creates a mild recurvatum deformity (10 degrees), which compensates for the predicted procurvatum deformity.

At this point the frame is removed in preparation for corticotomy. The distance between the clamp and the skin is marked on the half-pins.

Gloves are changed, and the skin at the level of the corticotomy is prepped again.

The femoral corticotomy is completed following the same principles discussed earlier.

After completion of the corticotomy, the frame is reapplied, maintaining the same distance between the clamps and the skin.

Fluoroscopy is used to confirm the slight recurvatum deformity. This recurvatum deformity compensates for the procurvatum tendency during lengthening of femur.

The skin is closed after repair of the tensor fascia.

The distraction device is connected to the clamps, and final tightening is performed.

Half-pins are dressed with Xeroform gauze and sponges.

**Tibial Lengthening**

For simple lengthenings (without deformity), two- or three-point fixation is required in each bony segment.

The tibial frame usually includes a proximal clamp or arch with two or three half-pins and a distal fixation clamp with two or three half-pins.

Fibular osteotomy is performed first (as discussed previously).

A distal tibia-fibula transfixation screw is required to prevent distal tibia-fibula subluxation.

The skin is incised over the tibial corticotomy site, which usually is the proximal metaphysis.

Prophylactic fasciotomy of the anterior compartment is performed under direct vision before frame application.

Now a temporary suture is placed at the corticotomy skin incision, and corticotomy is performed after pin fixation is complete.

Two half-pins are introduced in the proximal tibial metaphysis perpendicular to the shaft and distal to the growth plate (TECH FIG 8, #1). The half-pins are placed
in the anteromedial and anterolateral cortex, with care to avoid the tibial tuberosity.

- The half-pin configuration should aim for pin spread of 90 degrees. The half-pins are introduced at different levels. The first half-pin is placed freehand. The arch is placed parallel to the proximal tibial joint line, and the second half-pin is placed through the clamp.

- The anterior aspect of the arch should be at least a fingerbreadth from the anterior cortex.

- In the absence of deformity, the mechanical and anatomic axis of the tibia are the same. The mounted frame should be parallel to the biomechanical axis in both the AP and lateral views (TECH FIG 8, #2).

- A half-pin is then introduced in the distal tibia through the clamp (TECH FIG 8, #3). Once again, parallel alignment of the frame with the mechanical axis is confirmed.

- Two additional half-pins are placed distally through the distal clamp (TECH FIG 8, #4).

- The distance of the clamps from the skin is marked on the half-pins. The frame is then removed in preparation for the corticotomy.

- Gloves are changed, and the skin at the level of the proximal tibial metaphysis is prepared again.

- The tibial corticotomy is completed following the same principle discussed earlier (TECH FIG 8, #5).

- The frame is reapplied, maintaining the same distance between the clamps and the skin as measured before the corticotomy.

- A properly executed procedure will not have any residual displacement at the corticotomy site.

- The skin is closed, leaving the underlying fascia open.

- The distraction device is connected to the clamps, and final tightening is performed.

- Half-pins are dressed with Xeroform and sponges. A pressure dressing is applied over the corticotomy site.

- The foot is placed in a plantigrade position.

**PEARLS AND PITFALLS**

**Intraoperative**

- Incomplete osteotomy will not allow distraction. Identify this intraoperatively and complete the corticotomy. Confirm complete osteotomy with fluoroscopy by externally rotating the distal fragment.

- Avoid neurovascular injury by placing half-pins and wires through the safe zones. Use cross-sectional atlas in operating room.

- Skeletal muscle relaxants may mask intraoperative nerve injury, and paralyzing agents are avoided.

**Distraction period**

- Prevent joint contracture by reducing or stopping distraction temporarily, increasing physical therapy, and using static or dynamic splinting of the joint.

- To prevent subluxation and dislocation of an adjacent joint during limb lengthening:
  - Correct hip instability before performing femur lengthening.
  - Extend the frame across the knee joint in the setting of cruciate ligament laxity.
  - Maintain full knee extension using nighttime static splinting.
POSTOPERATIVE CARE

- Distraction is started after a latency period of 7 to 10 days (depending on the age of the patient, the level of the corticotomy, and the local blood supply).6,11,18
- The rate of distraction is 1 mm per day, distributed as 0.25 mm four times a day.6,11,18
- Pin care is done with half-strength hydrogen peroxide and normal saline.
- Showering is allowed 1 week after the surgery, with antibacterial soap.
- Full weight bearing is encouraged as tolerated.
- Physical therapy to maintain range of motion and prevent contractures:
  - Minimum: three times a week, and a home program is performed four times a day
  - During active lengthening, the patient is seen once per week.
- Routine perioperative intravenous antibiotic prophylaxis is used.

OUTCOMES

Ilizarov Technique

- In 1995, Stanitski et al23 reported the results of 36 femoral lengthenings in 30 consecutive patients using the Ilizarov technique. The etiology of femoral shortening was congenital in 21 femurs and acquired in 15. The average lengthening was 8.3 cm (range, 3.5 to 12 cm), with a treatment time of 6.4 months (range, 2.5 to 12 months). Complications included premature consolidation in four patients, malunion of more than 10 degrees in two patients, and residual limb length inequality (less than 2 cm) in two patients. Two patients developed knee subluxation. There were no reports of osteomyelitis, ring sequestra, neurologic or vascular compromise, compartment syndrome, hypertension, or hip or knee dislocations in their series. Psychological problems necessitated cessation of lengthening in two patients.
  - These results show a significant improvement over previous reports of earlier techniques of femoral lengthening in terms of greater lengthening, simultaneous deformity correction, and fewer major complications.
- Stanitski et al24 reported tibial lengthening for 62 tibiae in 52 patients using the Ilizarov technique. The average lengthening was 7.5 cm (range, 3.5 to 12 cm). Twenty-eight (22%) patients required unplanned procedures, which included osteotomy for malunion or deformation of the regenerate and Achilles tendon for persistent equinus contracture. The complication rate decreased after the initial learning curve.

Monoplanar Fixator

- Coleman and Noonan4 reported results of distraction osteogenesis in 114 femurs and 147 tibias treated with monoplanar external fixator for a variety of different conditions. Mean femoral lengthening was 11 cm, or 48% of the original femur length. The femora that gained more length (expressed as percentage of original length) had poor healing indices.
  - Interestingly, LLD was more difficult to correct with distraction osteogenesis than short stature. In tibia the mean tibial lengthening was 9 cm or 41% of the original tibial length. The mean healing index was 32 days per centimeter of lengthening. The complication rate was 1.33 per tibia. Seemingly, obstacles or problems were also considered as complications in their study.
  - Overall, good results were obtained. They concluded that larger lengthenings are possible, but the cost is increased time and complications.

COMPLICATIONS

Intraoperative

- Ilizarov method: Compartment syndrome is rare, but may occur early following the surgery. Pain with passive stretch and paresthesia are important clinical signs of compartment syndrome. Measure compartment pressures and decompress the affected compartment as needed. Prophylactic anterior compartment release may be performed at the time of corticotomy.18,19
- Monoplanar fixator
  - Incomplete corticotomy: Confirm complete corticotomy by externally rotating the distal fragment under fluoroscopic imaging.
  - Avoid neurovascular injury by placing half-pins through safe zones.5 Use a cross-sectional atlas.
  - Avoid paralyzing anesthetic agents during surgery, because they may mask nerve injury.5,19

Distraction Period

- Pin tract infection initially is treated with a short course of oral antibiotics (7 to 10 days) and appropriate pin tract care. If infection persists, consider intravenous antibiotics or removal of the wire or half-pin with curettage of the infected site.
- Premature consolidation may be due to incomplete osteotomy, slow distraction rate, or incorrect direction of distraction.
- Neurologic symptoms may arise in the form of altered sensation or weakness of the muscle. The wire or half-pin is removed if direct contact or irritation of the nerve is suspected. Stretching of the nerve with rapid distraction may result in nerve injury, and it may be necessary to decrease the rate of distraction or even stop distraction temporarily.5,19,25
- Surgical nerve decompression occasionally is required to release the nerve from compressing structures.
- Unplanned deformity may develop during bone lengthening. Appropriate frame modifications may be required to correct the deformity.12,19
- Joint contractures may occur during lengthening. Treatment includes increasing the number of physical therapy sessions and use of dynamic splinting, especially to prevent equinus contracture.
- Iatrogenic deformity may develop during lengthening. Frame modifications may be required to correct the deformity and maintain a neutral mechanical axis.7-8
  - Compartment syndrome is rare (the anterior compartment is always released intraoperatively) but may occur following surgery. Paresthesia, pain with passive stretch, and pain out of proportion to the surgical procedure are clinical indicators of compartment syndrome. Compartment pressures should be measured, and compartments should be released as needed.4

Consolidation Period

- Pin tract infection (as described earlier).
- Delayed consolidation of regenerate may respond to electrical or ultrasound bone stimulator. The frame can be dynamized or the regenerate can be compressed by 0.5 cm.
After Frame Removal

- The regenerate bone may deform after premature frame removal (eg, poor regenerate, fewer than three continuous cortices). This can be prevented by frame dynamization prior to frame removal and protected weight bearing.
- Assess the regenerate bone clinically and radiographically at the time of frame removal. Consider use of a cast or brace and protected weight bearing in the setting of questionable bone regenerate.
- Stress fracture can occur either at the site of half-pins, especially when the half-pin size exceeds one third the diameter of the cortex, or through the regenerate bone. Fracture is treated with reapplication of the frame, casting, intramedullary rod fixation, or plate application.5

REFERENCES

DEFINITION
- Physiologic genu varum (before age 2) and genu valgum (before age 6) are ubiquitous in children. These deformities are self-correcting and need no intervention.
- At maturity, limb lengths should be symmetric, or at least within 2 cm of each other.
- However, various pathologic processes may cause progressive and harmful angular deformities of the knee or knees, with or without limb-length discrepancy.
- With the insidious deviation of the mechanical axis, secondary ligamentous laxity, patellofemoral instability, and joint subluxation may ensue, resulting in gait disturbance and functional limitations.
- These findings may be unilateral or bilateral, involving the femur, tibia, or both. The deformities may or may not be symmetric.
- Concomitant torsional deformities and length discrepancy of greater than 2 cm may complicate matters.

ANATOMY
- During standing, the normal knee joint line and physes remain horizontal. The mechanical axis, represented by a line joining the center of the hip and center of the ankle, should bisect the knee at an angle of 87 degrees with respect to the joint line (FIG 1A). Allowing for normal variation, the mechanical axis should at least fall within the inner two quadrants (+1 or −1) of the knee (FIG 1B).
- The distal femur normally has about 6 degrees of anatomic valgus relative to its shaft, expressed as a lateral distal femoral angle (LDFA) of 84 degrees.
- The proximal tibia has 3 degrees of varus relative to its shaft; consequently, the medial proximal tibial angle (MPTA) is 87 degrees.
- Weight-bearing forces are relatively evenly divided between the medial and lateral compartments. This results in physiologic loading of the articular surfaces and physes.
- The patella remains centered in the femoral sulcus, guided by the retinacula.

PATHOGENESIS
- Intrinsic weakness within the femoral or tibial epiphyses or physes may inhibit growth, resulting in deviation of the mechanical axis.
- Progressive deviation invokes the Hueter-Volkmann principle, where excessive and chronic compression further inhibits articular and physeal cartilage growth. Thus, a vicious cycle is established, perpetuating the problem (FIG 2A).
- An arthrogram may help to demonstrate the phenomenon of delayed ossification due to malalignment (FIG 2B).
- Direct or indirect trauma may result in physeal damage, with either restricted growth or occasionally overstimulation of growth.
- Secondary effects on the extensor mechanism and patellofemoral joint may compound issues related to genu valgum, and patellar instability may ensue.
- Length discrepancy that is predicted to exceed 2 cm at maturity may warrant surgical intervention; epiphysiodesis is a good option for the 2- to 5-cm range.

NATURAL HISTORY
- The natural history of physiologic knee deformities is spontaneous resolution, without the need for braces, therapy, or surgery.\(^3\)
- The natural history of pathologic deformities is progressive valgus or varus resulting in knee instability and joint deterioration. As the ground reaction forces are displaced medially or laterally, eccentric compression of the distal femur and proximal tibia exceeds their loading tolerance and inhibits normal growth, not only of the physis but of the epiphysis as well (Hueter-Volkmann effect).
- Gait disturbance and functional limitations will ensue, often accompanied by pain.\(^6\)

FIG 1 • A. The mechanical axis is a line drawn on a full-length standing AP radiograph of the legs, preferably with the pelvis leveled and the patellae facing forward. Connecting the center of the head and ankle, it should bisect a horizontal knee. B. Dividing the knee into quadrants, the axis should pass within medial or lateral zone one, allowing for physiologic variations. Mechanical axis deviation into zone 2 or 3 is an indication for surgical intervention.
PATIENT HISTORY AND PHYSICAL FINDINGS

- Family history may yield important clues regarding the cause and natural history of deformities. The parents and siblings have often been subjected to corrective osteotomies.
- The patient presents with knock knees or bowlegs; the deformity may be unilateral or bilateral. There may be concomitant limb-length discrepancy with both true and apparent foreshortening of the involved limb.
- Knock knees may be accompanied by outward femoral or tibial torsion (or both). Medial collateral laxity may permit medial knee thrust.
- Patellar instability is not uncommon as the deformity progresses. Circumduction gait is inevitable and problematic for walking and running.
- Knock knees are documented by measuring the intermalleolar distance while the patient is standing with the knees touching (patellae neutral) (**FIG 3A**).
- Bowlegs may be accompanied by inward tibial torsion and intoeing. Lateral ligament laxity may permit lateral knee thrust during walking.
- Bowlegs are readily documented by measuring the intercondylar distance while the patient is standing with the feet together (patellae neutral) (**FIG 3B**). This should corroborate the mechanical axis deviation from the center of the knee that is measured on the standing radiograph (**FIG 3C**).
- The spine and feet should be evaluated as well.
- Orthotics may provide knee support but will have no corrective effect upon growth. Whether this is due to suboptimal design or compliance issues is a matter of debate.
- Physical examination should include observation of stance, knee alignment, torsional profile, limb lengths, and gait.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Weight-bearing anteroposterior (AP) and lateral views of the lower extremities are obtained with the patellae facing forward. For limb-length discrepancy, the pelvis is leveled with blocks.
- A patellar view may document patellar tilt or subluxation.
- Estimation of skeletal maturity (hand or elbow film) may be useful. Guided growth requires at least 6 months to produce demonstrable improvement in alignment.
- Computed tomography (CT) scan or magnetic resonance imaging (MRI) is obtained if a physeal bar is suspected. A “gunsight” CT is obtained for “miserable malalignment” (femoral plus tibial torsion) (**FIG 4**).
- The landmarks for femoral measurement are a line that bisects the femoral neck versus a line crossing the back of the femoral condyles (normal, 11 to 15 degrees).
For the tibia, it is a line across the back of the condyles versus the bimalleolar axis (normal, 15 to 20 degrees).

**DIFFERENTIAL DIAGNOSIS**
- Genu valgum
  - Idiopathic genu valgum (see Fig 3A)
  - Hereditary multiple exostoses
  - Cozen fracture (proximal tibial metaphysis)
  - Congenital limb anomalies
  - Postaxial hypoplasia
  - Neuromuscular disorders: cerebral palsy, spina bifida
  - Down syndrome
- Genu varum
- Blount disease
- Rickets
- Osteochondral dysplasia (see Fig 3B,C)
- Ollier disease
- While the underlying diagnosis (see above) has often been established, the cause has little relevance to the treatment. The degree of deformity and the evolution of symptoms dictate the timing and need for intervention.

**NONOPERATIVE MANAGEMENT**
- Activity restriction and nonsteroidal anti-inflammatories are not definitive treatments. Valuable time may be wasted, and there is no logical endpoint to this form of management.
- Physical therapy remedial exercises are of no lasting benefit with respect to the established growth pattern.

- While knee bracing may compensate for muscle weakness or secondary ligamentous laxity, it may not predictably effect growth modulation or improvement in skeletal alignment.
- Furthermore, adequate braces are cumbersome and expensive, so noncompliance may be an issue.

**SURGICAL MANAGEMENT**
- Any child or skeletally immature adolescent being considered for corrective osteotomy may be a candidate for guided growth.
- As long as the physis are open, hemiepiphysiodesis or guided growth offers advantages and has few associated complications compared to more invasive osteotomies.
- The indications for surgery include progressive deformity resulting in gait disturbance, functional limitations, and pain. Many patients have already exhausted other options, including nonsteroidal anti-inflammatories, bracing, activity restriction, and physical therapy or even osteotomy.
- Options for growth modulation include:
  - Phemister bone block: permanent; requires precise timing and close follow-up
  - Percutaneous drilling: permanent; same drawbacks as Phemister technique
  - Epiphyseal stapling (Blount): rigid implant compresses dynamic physis
  - Percutaneous screw (Metaizeau): reversibility unknown; rigid implant violates or compresses the physis; limited applications (adolescence, frontal plane deformities)
  - Guided growth with eight-plate (Stevens): reversible; tension band principle; versatile (any age, diagnosis, or plane)

**Preoperative Planning**
- Both the clinical examination and appropriate radiographs should reveal and document varus or valgus deformities of the knee as well as limb lengths. The torsional profile should be documented.
- When indicated, bilateral or multilevel surgery may be accomplished at one sitting (outpatient).
- Length discrepancies and rotational malalignment may not be directly addressed by guided growth. However, relative
length is gained and there may be subsequent rotational improvement when the mechanical axis is restored to neutral.
- Occasionally an intraoperative arthrogram will demonstrate the true shape of the articular surfaces (see Fig 2B).
- A modular approach may permit angular correction to neutral mechanical axis, followed by length adjustment.

**Positioning**
- The patient is positioned supine on the operating table.
- Fluoroscopy is recommended.

**GUARDED GROWTH: EIGHT-PLATE**
- With the patient in the supine position and (preferably) under tourniquet control, the medial or lateral aspect (or both) of the distal femoral or proximal tibia (or both) are identified fluoroscopically and 2- to 3-cm skin incisions are marked.⁶,⁷
  - It is helpful to inject them with 0.25% Marcaine for postoperative comfort.
- When approaching the medial femur, the fascia of the vastus medialis is incised parallel to its inferior border, and the muscle is retracted. On the lateral femoral approach, the iliobial band is split longitudinally. Over the medial tibia, the medial collateral ligament is split longitudinally; over the lateral tibia, the anterior compartment muscles are left intact and the fibula is undisturbed.
- The dissection is deepened sharply, dividing fascia and retracting muscles as necessary but preserving the periosteum.
- A Keith needle is inserted into the physis (this characteristically feels like pushing a needle into a bar of soap), and the position and direction are confirmed with the image intensifier.
- The 12- or 16-mm plate (surgeon preference) is centered on the Keith needle using the middle hole; it is inserted deep to the soft tissues to rest in an extraperiosteal position.
- The 1.6-mm smooth guide pins are inserted, placing the epiphyseal one first, followed by the metaphyseal pin.
- The cortex is drilled to a depth of 5 mm to permit insertion of the 24- or 36-mm (surgeon preference) fully threaded, cannulated, self-tapping screws (TECH FIG 1).
  - The screws do not have to be parallel or to match in length.
- If the position looks good, the guide pins are removed and the screws are further tightened so that the heads are countersunk in the plate.
- After routine wound closure, a soft compression dressing is applied.

**STAPLING (BLOUNT)**
- The surgical approach is the same, preserving the periosteum.
- A guide needle is inserted.
- Thigh tourniquets are employed for speed and accuracy of hardware placement.

**Approach**
- The surgical approach is minimally invasive, directly over the physis, at the apex of the deformity.
- Hardware should be midsagittal unless correcting an oblique or sagittal-plane deformity. Placement is confirmed with fluoroscopy and the implant position is adjusted as needed.

**Tech FIG 1**
- **A.** The eight-plate instrumentation includes a soft tissue guide with 1.6-mm cannulation for the guide pin and 3.2 mm for the “stubby” drill that permits a 5-mm depth of penetration. **B.** The 4.5-mm screws are cannulated and self-tapping and come in three lengths: 16 mm (shown here), 24 mm, and 32 mm. **C,D.** The plate application is extraphyseal, over a localizing guide pin, while preserving the periosteum. Any open and approachable physis may be instrumented for correction in the frontal, sagittal, or oblique planes as well as for length correction.
- One to three rigid Blount staples (Zimmaloy) are inserted per physis.
- Simple closure is done with a elastic bandage.
Part 4 • PEDIATRICS • Section III  RECONSTRUCTION

TECHNIQUES

PERCUTANEOUS SCREW (METAIZEAU)

- Under fluoroscopic guidance, a single 7.3-mm transphyseal screw is placed either from the medial or lateral side of the bone, crossing the physis near its perimeter.
- The goal is to place the tip of the screw just inside the medial or lateral aspect of a given physis to effect angular growth.
- Upon correction to neutral, the screw is removed.

PHEMISTER

- This approach is mainly of historic interest.
- The same approach is used as for stapling or eight-plate.
- Periosteal flaps are raised to visualize the physis.
- A bone rectangle is removed and inverted to establish a bony bridge.
- This technique is permanent and thus most suitable for teenagers. It requires precise timing and calculations.

PERCUTANEOUS EPIPHYSIODESIS (MODIFIED FROM PHEMISTER)

- Under fluoroscopic guidance the physis is drilled or curetted (or both) to produce a bony physeal bar.
- The requisite depth of penetration has yet to be specified.
- There may be a delay in effect until a bone bridge is established.
- This technique is permanent and thus suitable only for teenagers. It requires precise timing and calculations.

PEARLS AND PITFALLS

Follow-up
- Parents should be educated about the importance of routine periodic follow-up; typically follow-up is done every 3 months (FIG 5A, B).

Staples
- If stapling is part of the procedure, forewarn parents about possible hardware migration or breakage requiring revision surgery (FIG 5C).

Periosteal damage
- Periosteal damage should be avoided during hardware insertion or removal.

FIG 5 • A. This 12-year-old boy, stapled for unilateral genu valgum, failed to return for follow-up for 14 months and overcorrected into varus. The staples were removed and eight-plates inserted laterally. Had he had physeal drilling, the only salvage would have required femoral and tibial osteotomies with lengthening or contralateral epiphysiodesis. B. A 14-year-old boy 1 year after tibial stapling for limb-length inequality due to congenital clubfoot. The lateral staples have loosened, resulting in mechanical axis deviation into medial zone 2. A lateral eight-plate corrected this iatrogenic varus deformity to neutral. C. This 12-year-old girl with neurofibromatosis was stapled for length discrepancy. One year later her staples inexplicably had migrated (medial more than lateral), causing iatrogenic varus and requiring unplanned reoperation. Through bending, these narrow-gauge staples have afforded dramatic correction of fixed knee flexion deformity. It is impossible to tell, however, if or when they might break, and periosteal damage will be unavoidable upon removal.
POSTOPERATIVE CARE
- No immobilization is required.
- Immediate weight bearing is permitted.
- No activity restriction is imposed.
- Follow-up is done at 3-month intervals with weight-bearing AP radiographs of the legs when clinically straight.
- Hardware is removed, avoiding periosteal damage, when the mechanical axis is neutral or limb lengths are equal.
- Continued follow-up is important. Guided growth can be repeated if rebound growth causes recurrence.
- Osteotomy may be reserved for rotational correction or further length equalization.

OUTCOMES
- Initially after hemiepiphysiodesis there is no visible difference, and the family needs to be forewarned of this.
- The correction is gradual and subtle, and therefore routine follow-up is imperative.
- Correction to neutral (eight-plates) will take 12 months on average; staples take somewhat longer.
- The hardware is removed upon correction of the valgus or varus deformity. (The surgeon must preserve the periosteum!)
- Follow-up should continue until maturity to watch for recurrent deformity due to rebound growth. While this is unpredictable, it will be evident within 12 months of hardware removal.
- Premature physeal closure is unlikely, provided the hardware is inserted and removed uneventfully, leaving the periosteum intact.
- Because the plate–screw construct is flexible and serves as a tension band, it is unlikely to break or migrate, making revision surgery less likely.
- Modular adjustment of limb lengths is convenient and simple to accomplish.
- If secured with cannulated screws, eight-plate survivorship is rarely problematic.

COMPLICATIONS
- There is a race between deformity correction and hardware failure. Failure is more likely with a rigid implant.
- The rigid staples are at a disadvantage owing to occasional migration or breakage, necessitating unplanned revision surgery (FIG 6).
- A bent staple may permit excellent correction but is more difficult to monitor and remove.

REFERENCES
DEFINITION
- Angular deformities of the distal tibia can lead to varus or valgus malalignment of the ankle joint.
- Additional sources of ankle malalignment include both bony and ligamentous disorders.

ANATOMY
- Normally, the tibiotalar joint is in neutral alignment. This is assessed by measuring the lateral distal tibial angle (LDTA), which has a normal value of 90 degrees (range, 88 to 95 degrees).
- Sagittal alignment of the ankle joint is normally in slight dorsiflexion and is assessed by measuring the anterior distal tibial angle (ADTA), which has a normal value of 80 degrees (range, 78 to 81 degrees).

PATHOGENESIS
- Coronal plane deformities about the ankle are not uncommon and may occur secondary to congenital or acquired conditions.1–3
- Varus angular malalignment of the ankle is generally due to either a traumatic or infectious insult to the medial aspect of the distal tibial physis, with resultant premature closure of the injured area and relative overgrowth of the lateral distal tibial physis and fibula.2,3,7
- Valgus deformity of the ankle in children is associated with a wide variety of conditions. Relative overgrowth of the medial aspect of the distal tibial physis can occur as a result of fibular shortening or hypoplasia. Longitudinal deficiency of the fibula may be due to premature distal fibular physeal closure, fibular nonunion, malunion, congenital pseudarthrosis of the fibula, or longitudinal deficiency of the fibula, or it may occur after harvest of a portion of the fibula for bone grafting. In addition, progressive ankle valgus with lateral wedging of the distal tibial epiphysis may be seen in patients with myelodysplasia.2,3,7
- Deformities occurring secondary to physeal injuries are progressive.
- Correction of deformities about the ankle is complicated by the fact that deformities are frequently centered about the distal tibial physis, very close to the ankle joint.
- Because the deformity is often centered very close to the joint, opening or closing wedge osteotomies performed proximal enough to allow fixation of the fragments often produce unacceptable translation of the ankle joint.

NATURAL HISTORY
- Angular deformity of the distal tibia leads to abnormal loading of the hindfoot, ankle joint, and knee, and may lead to secondary deformities such as a planovalgus foot or hallux valgus. Long-term malalignment of the ankle joint may lead to the development of premature osteoarthritis of the ankle.8,9
- Initially, the limb may be treated with braces or orthotics without difficulty. However, progression of the deformity with growth leads to increased soft tissue pressure, bursa formation, and risk of skin ulceration over the medial malleolus, lateral malleolus, or talonavicular region.

PATIENT HISTORY AND PHYSICAL FINDINGS
- A detailed history should be obtained, including recent or remote trauma, infection, or congenital conditions. In addition, symptoms related to ankle malalignment or instability should be elicited.
- Physical examination should include gross inspection of both lower extremities with the patient standing, walking, and sitting to determine the location of deformity as well as the alignment of adjacent structures (in particular the hindfoot and knee) that may contribute to perceived deformity as well as affect the surgical outcome.
- The clinician should inspect standing foot and ankle alignment from behind the patient to determine the location of deformity (distal tibia, ankle, hindfoot).
- Standing heel alignment in varus or valgus may indicate the presence of uncompensated distal tibial deformity. Normal alignment in the presence of deformity alerts the surgeon to hindfoot compensation, which may be rigid or supple.
- The clinicians should check hindfoot passive inversion and eversion to evaluate the ability of the hindfoot to accommodate surgical changes.
- Lack of hindfoot motion can alert the surgeon that the patient may not be able to compensate for distal tibial osteotomies. Further procedures may be warranted to realign the hindfoot to correct fixed deformities.
- Single-limb toe rise: With the patient standing, viewed from posterior, the patient lifts one limb, then rises onto the toes of the standing limb. This should result in prompt inversion of the heel, rising of the longitudinal arch, and external rotation of the supporting leg. Lack of hindfoot inversion should draw attention to the subtalar and transverse tarsal joints as possible sites of pathologic alignment.
- To check forefoot–hindfoot alignment, the patient is seated, facing the examiner. The patient’s hindfoot is grasped in one hand and the calcaneus is held in the neutral position, in line with the long axis of the leg. The examiner’s other hand grasps the foot along the fifth metatarsal. The thumb of the hand grasping the heel is placed over the talonavicular joint, and the joint is manipulated by moving the hand holding the fifth metatarsal until the head of the talus is covered by the navicular. The position of the forefoot as projected by a plane parallel to the metatarsals is compared to the orientation of the long axis of the calcaneus. The forefoot will be in one of three positions relative to the hindfoot—neutral, forefoot varus, or...
forefoot valgus. The examiner should determine whether this relation is supple or rigid, especially when considering surgery, since a fixed varus or valgus forefoot deformity will not allow the foot to become plantigrade after realignment of the tibiotalar or subtalar joints.

- Standing lower extremity alignment: If distal tibial deformity is present in conjunction with genu varum or valgum, the patient’s entire deformity should be evaluated and a comprehensive plan developed.
- The patient’s gait may show an antalgic pattern or may reveal limitations of functional motion in the hindfoot.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standing anteroposterior (AP) and mortise views of both ankle joints should be obtained (FIG 1A–C). The LDTA is measured from the intersection of a line drawn parallel to the long axis of the tibia and a second line drawn across the dome of the talus. The normal LDTA is 90 degrees as measured from the lateral side. The amount of deformity is calculated from the number of degrees that differ from 90 degrees.
- Lateral weight-bearing radiographs of both ankles should be obtained to detect any sagittal plane deformity (FIG 1D). The lateral tibiotalar angle is measured from the anterior side. The average ADTA is 80 degrees as measured from the anterior side.
- Foot radiographs, including standing AP, standing lateral, and oblique views, are used to evaluate hindfoot alignment to avoid over- or undercorrection at the time of surgery. The standing lateral view of the foot is used to evaluate talar–first metatarsal alignment; normally, the talus and first metatarsal are parallel. The standing AP view is used to evaluate the talocalcaneal angle; if the talocalcaneal angle exceeds 35 degrees, hindfoot valgus is present.
- A standing AP view of the pelvis is obtained to evaluate for leg-length discrepancy.
- Computed tomography can be useful in assessing the presence and size of physeal bars.

**DIFFERENTIAL DIAGNOSIS**

- In addition to distal tibial angular deformity, varus or valgus malalignment about the ankle joint may be due to other local bony or ligamentous disorders.
- Fixed hindfoot varus or valgus may simulate ankle deformity on clinical examination.
- Apparent ankle valgus may occur secondary to disorders such as angular deformity of the fibula with shortening and associated lateral shift of the talus hindfoot valgus, hindfoot valgus, or fixed forefoot varus.
- Apparent ankle varus may occur secondary to disorders such as hindfoot varus as seen in Charcot-Marie-Tooth disease, residual clubfoot, or fixed forefoot valgus.

**NONOPERATIVE MANAGEMENT**

- Mild distal tibial angular deformity associated with ankle varus or valgus can be managed through the use of custom braces and orthotics or medial or lateral posting of the shoes.
- Surgery is the mainstay of treatment of bony deformity of the distal tibia.

**SURGICAL MANAGEMENT**

- An opening or closing wedge supramalleolar osteotomy (SMO) may be performed for simultaneous correction of frontal- and sagittal-plane deformities of the ankle.
- SMOs allow for immediate correction of the deformity. However, they are considered technically demanding and relatively invasive and require a period of limited weight bearing or non-weight bearing and immobilization.
- The challenge involved in correcting varus or valgus deformities of the ankle is to correct the deformity without introducing new secondary deformities. The mechanical axis of the tibia should pass through the center of the ankle perpendicular to the joint surface.
- Some SMO techniques may lead to the development of secondary deformities. For instance, a transverse closing wedge osteotomy performed 4 cm proximal to the joint surface to correct a valgus deformity causes lateral shift of the ankle and a prominent medial malleolus.

---

**FIG 1**

A. Standing AP view of both ankles in a 14-year-old boy with a left distal tibial valgus deformity due to congenital pseudarthrosis of the tibia. B. Standing AP radiograph of the left ankle in a 16-year-old boy showing a varus deformity after a healed physeal distal tibial fracture with medial physeal arrest. C. Standing lateral radiograph of the left ankle of the same patient. D. Standing mortise radiograph of the left ankle in the same patient showing a varus deformity after a healed physeal distal tibial fracture with medial physeal arrest.
In a child with growth remaining, physeal modulation via a hemiepiphysiodesis with an eight-hole plate, transphyseal screw, or staples can be used to correct distal tibial valgus deformities.

Correction occurs gradually after hemiepiphysiodesis, so it is not ideal for patients requiring acute corrections such as those with skin breakdown or significant pain. Close follow-up after hemiepiphysiodesis is essential to avoid over-correction.

Currently, SMOs are the procedure of choice for correcting ankle valgus in the absence of adequate growth to correct the deformity by hemiepiphysiodesis techniques.

Deciding on the Technique

Several techniques have been used and are described below, including transphyseal SMO, transverse SMO with translation, and the Wiltse SMO.

- Oblique supramalleolar opening or closing wedge osteotomy
  - Lubicky and Altiok\(^3\) described an oblique distal tibial osteotomy to correct varus and valgus deformity of the distal tibia.
  - This technique offers the advantage of placing the hinge of the osteotomy at the level of the deformity and thus performing the correction at the site of the deformity so that maximum correction can be obtained without creating a secondary translational deformity.

- Transverse supramalleolar osteotomy with translation: Concomitant fibular osteotomies are performed to allow for compression at the osteotomy site and translation of the tibial osteotomy.

- Wiltse osteotomy
  - Wiltse\(^6\) noted that a simple wedge resection for correction of distal tibial valgus deformities will lead to malalignment and prominence of the medial malleolus.
  - The author developed and reported the results of resection of a triangular section from the distal tibia with rotation of the distal fragment in order to produce a normal-appearing ankle and improved weight-bearing alignment.

- This procedure is effective because it creates a stable osteotomy and forces the surgeon to lateralize the osteotomy when correcting a valgus deformity, thereby bringing the ankle joint beneath the tibial shaft and preventing medial prominence of the medial malleolus.

- Screw hemiepiphysiodesis is used to address valgus deformities in children with sufficient growth remaining to correct the deformity.

- We have found that the oblique osteotomy allows for correction of the deformity and offers the advantage of improved bone healing as minimal periosteal stripping is necessary and the deformity is corrected by hinging the osteotomy at a point along the bisector of the deformity.

Preoperative Planning

- The principal issues to be addressed in surgical correction of distal tibial deformities are the magnitude and direction of the deformity, any rotational component, and length. The surgeon should address all of these components with a comprehensive plan.

- Length discrepancies in particular are critical because when the limb-length discrepancy is greater than 2 cm, a lengthening or shortening procedure should be performed in conjunction with correction of the distal tibia. Either contralateral epiphysiodesis or shortening should be planned or lengthening of the index limb, which may make the entire procedure preferable to perform with circular external fixation.

- Weight-bearing radiographs of the ankle in the AP and lateral planes are essential to determine the extent of the deformity. In addition, it is important to thoroughly assess the hindfoot and forefoot.

- The magnitude and plane of the deformity to be addressed should be calculated preoperatively and noted in the preoperative plan (FIG 2A).

- After the deformity is assessed using the methods described by Paley and Tetsworth,\(^4,5\) the position of the center of rotation of angulation (CORA) is identified and a bisector is constructed. Most commonly this point is very near the physis and articular surface (FIG 2B).
Although the osteotomy can be performed at a level consistent with the biology of the bone and allowing for adequate fixation, the correction of the deformity should occur along the bisector.

- The goal of surgical correction should be to obtain an LDTA of about 90 degrees with a tibial mechanical axis that passes through the center of the ankle.
- Care should be taken to evaluate the hindfoot motion preoperatively.
- Patients with fixed varus or valgus hindfoot alignment may require additional procedures, such as a calcaneal osteotomy, or the surgeon may elect to compensate for a mild fixed deformity by leaving the ankle in mild varus or valgus alignment, thereby bringing the hindfoot into neutral alignment.

Positioning

- The patient is placed in the supine position on a radiolucent operating table with a bolster placed under the ipsilateral hip. A well-padded nonsterile tourniquet is placed around the ipsilateral proximal thigh.
- Intraoperative fluoroscopy is essential. The C-arm should be placed on the opposite side of the table. The C-arm monitor should be placed with the image intensifier on the opposite side of the table from the limb to be corrected.

Approach

- Distal tibial osteotomy is performed through either a medial incision centered over the medial malleolus or an anteromedial incision made slightly lateral to the anterior tibialis tendon.

MEDIAL APPROACH

- The proximal extent of dissection is determined by the size of the bone wedge to be resected in a closing wedge osteotomy or by the extent of the fixation required in an opening wedge.
- A medial incision is made directly along the medial border of the tibia extending from just proximal to the physeal to as far proximal as needed based on the size of the wedge to be removed for correction of the valgus deformities (TECH FIG 1).
- Care is taken to protect the saphenous vein and nerve. The distal tibia is exposed to a point just proximal to the physis. If the distal tibial physis is closed, the dissection can be extended beyond the physis and to the epiphysis if needed. The periosteum is divided sharply. This area is exposed subperiosteally anteriorly and posteriorly.
- After the tibia is exposed medially, a limited subperiosteal dissection is made anteriorly and posteriorly in an oblique direction down to the lateral aspect of the distal tibial physis. Crego or Chandler retractors are then placed to protect the soft tissues.

TECH FIG 1 • Placement of incision on the anteromedial aspect of the ankle for oblique osteotomy.

ANTERIOR APPROACH

- A longitudinal incision is made over the anterior aspect of the ankle extending distally to the ankle joint and proximally about 5 cm. The dissection should be carried down lateral to the anterior tibial tendon, protecting the anterior tibial artery and deep peroneal nerve laterally.
- Subperiosteal dissection is carried out around the tibia distally to the level of the physis. Crego or Chandler retractors are then placed medially and laterally to protect the soft tissues.
- If necessary, the fibular osteotomy is performed using a separate 2-cm lateral incision that parallels the fibula and is centered over the point of the osteotomy.

OBLIQUE SUPRAMELLLOAR OPENING OR CLOSING WEDGE OSTEOTOMY

- If the osteotomy is performed through a medial approach, the preplanned osteotomy is then performed with an oscillating saw to the physis, leaving the lateral cortex intact.

Valgus Deformities

- For valgus deformities, a second osteotomy is made at an angle to the first corresponding to the amount of deformity.
bone to be resected according to the preoperative plan. This is also done with a power saw, ending at the lateral extent of the first osteotomy, and the wedge is removed (TECH FIG 2A,B).

- The foot and ankle are then rotated into varus, closing the wedge while leaving the lateral hinge intact, and the correction is assessed using the image intensifier and if necessary plain radiographs. Additional bone can be removed from the proximal fragment if the amount of correction is insufficient.

- Once the osteotomy closes, the drill is passed through the medial malleolus in patients with a closed physis, securing the osteotomy. If the patient has an open physis, an oblique interfragmentary screw is passed across the osteotomy site beginning just proximal to the physis. The screw should be centered in the sagittal plane.

- If the fibula is an impediment to correction (it usually is not) an oblique osteotomy of the fibula is made and if necessary fixed with a plate and screws.

**Varus Deformities**

- For varus deformities, an opening wedge is created along the same line. Once the osteotomy is made, the osteotomy site is distracted using a lamina spreader to the preplanned distance to correct the deformity (TECH FIG 3A–C).

- It is then held open by a wedge-shaped tricortical iliac crest graft or simply stabilized with a medial plate and screws (TECH FIG 3D–H), beginning with a screw passed from medial to lateral across the osteotomy site.

- After wound closure, a short-leg non-weight-bearing cast is applied.

---

TECH FIG 2 • A. AP intraoperative view of the ankle showing a Crego elevator in place with a saw blade performing the initial osteotomy. **B.** AP intraoperative view of the ankle with a saw blade placed into the initial cut and the saw completing the second cut.

TECH FIG 3 • A. Position of the two Crego elevators used to protect the soft tissues during the oblique osteotomy. An oscillating saw is used to create the oblique osteotomy. Fluoroscopy is used to confirm the angulation of the cut as well as to ensure that the lateral cortex remains intact. **B.** A large osteotome is placed into the osteotomy site and used to open the osteotomy. **C.** A laminar spreader is used to hold open the osteotomy site. **D.** The amount of medial opening needed for deformity correction is verified by measuring the medial opening in millimeters. **E.** A bicortical 3.5-mm screw (cortical) is inserted from the proximal to distal fragments to hold the osteotomy site open, allowing for removal of the laminar spreader. **F.** A 3.5-mm small fragment dynamic compression plate is contoured to the medial aspect of the distal tibia. (continued)
Chapter 36  DISTAL TIBIAL OSTEOTOMY

**DISTAL TIBIAL OSTEOTOMY**

- The tibiotalar joint should be corrected to neutral at the time of surgery.
- A wedge of bone is resected, apex medial in valgus ankles and apex lateral in varus ankles. The angle of the wedge is based on preoperative radiographs. The wedge of bone is harvested so that continuity of the apex is maintained and acts as a hinge.
- An anteromedial longitudinal incision is made over the distal tibial metaphysis. The periosteum is incised medial to the tibialis anterior tendon. The surgeon should avoid cutting into the physeal perichondral ring distally. The periosteum is elevated and retracted with Crego retractors placed medially and laterally. The level of the distal tibial physis is checked using fluoroscopy.
- When addressing valgus deformities, a closing wedge osteotomy is performed in the metaphyseal bone about 3 cm proximal to the ankle joint. The proximal cut is made first. It is aligned perpendicular to the long axis of the tibia. The second distal osteotomy cut is made obliquely. The triangle formed by the two cuts is medially based. Enough bone is removed to convert the preoperative LDTA to neutral.
- Preoperatively, a sterile template triangle can be prepared with a piece of paper and a goniometer. The paper is placed on the tibia, which is marked with an osteotome and then cut with an oscillating saw.

**TRANSVERSE SUPRAMEALLEOLAR OSTEOTOMY WITH TRANSLATION**

- The tibiotalar joint should be corrected to neutral at the time of surgery.
- A wedge of bone is resected, apex medial in valgus ankles and apex lateral in varus ankles. The angle of the wedge is based on preoperative radiographs. The wedge of bone is harvested so that continuity of the apex is maintained and acts as a hinge.
- An anteromedial longitudinal incision is made over the distal tibial metaphysis. The periosteum is incised medial to the tibialis anterior tendon. The surgeon should avoid cutting into the physeal perichondral ring distally. The periosteum is elevated and retracted with Crego retractors placed medially and laterally. The level of the distal tibial physis is checked using fluoroscopy.
- When addressing valgus deformities, a closing wedge osteotomy is performed in the metaphyseal bone about 3 cm proximal to the ankle joint. The proximal cut is made first. It is aligned perpendicular to the long axis of the tibia. The second distal osteotomy cut is made obliquely. The triangle formed by the two cuts is medially based. Enough bone is removed to convert the preoperative LDTA to neutral.
- Preoperatively, a sterile template triangle can be prepared with a piece of paper and a goniometer. The paper is placed on the tibia, which is marked with an osteotome and then cut with an oscillating saw.

**WILTSE OSTEOTOMY**

- The osteotomy is performed through an anterior approach to the distal tibial metaphysis at the level of the metadiaphyseal junction.
- A triangular piece of bone is removed from the region of the distal tibial metadiaphyseal junction. The apex of the cut is centered on the longitudinal axis of the tibia.
- The magnitude of the angle of the lateral portion of the triangle should be equal in size to the magnitude of the deformity to be corrected.

**TECH FIG 3 • (continued)**

G. The plate is secured to the distal tibia with 3.5-mm cortical bone screws. H. Intraoperative AP radiograph showing opening wedge osteotomy with internal fixation.

- The fibular osteotomy, if necessary, is performed at the same level as the tibial osteotomy. The fibular osteotomy is performed because it allows for sufficient compression at the tibial osteotomy site, and it also allows for centralization of the distal tibial fragment to improve foot alignment.
- The tibial osteotomy may be fixed with a small fragment plate or Kirschner wires.
- The fibular osteotomy is made through a second incision, laterally over the fibula. The osteotomy is shaped in the form of a triangle. The proximal cut is oblique and ends proximal at the medial cortex. The distal cut is perpendicular to the shaft of the fibula.
- The extent of correction is checked with an intraoperative radiograph.
- Care is taken to avoid injury to the distal tibial physis when obtaining fixation of the osteotomy.
- Internal or external rotation deformities can be addressed at the same time.
- Alternatively, an opening wedge osteotomy may be performed about 2 to 3 cm proximal to the physis. An osteotomy is made parallel to the ankle joint, and an opening wedge correction is performed and filled with bone graft.
**POSTOPERATIVE CARE**

- After wound closure, a short-leg non-weight-bearing cast is applied. Non-weight bearing is maintained for 4 to 6 weeks.
- Closing wedge osteotomies are typically stable and patients are allowed full weight bearing at 4 weeks.
- Opening wedge osteotomies are stable based on fixation and grafting, and the patient is kept non-weight bearing for 6 weeks.
- After 4 to 5 weeks, when weight bearing is initiated, the cast is removed and a CAM walker is applied.
- Physical therapy should be instituted to regain motion, strength, and proprioception before resuming activities.
- It is important to follow immature patients closely for the development of a limb-length discrepancy, which can be addressed by performing an epiphysiodesis of the contralateral lower limb.
OUTCOMES
- Lubicky and Altiok\(^3\) reported their experience in 26 limbs with the oblique osteotomy and found rapid healing and few complications, with all patients resuming their preoperative level of activity.
- They noted that patients with preoperative hindfoot valgus had improved alignment with varus overcorrection of the distal tibia and recommended overcorrection by 5 degrees in these patients.
- We have not overcorrected patients with normal hindfoot alignment, particularly those with posttraumatic deformities.

COMPLICATIONS
- Nonunions, wound healing problems, and loss of correction after surgery may be related to a number of factors.
- Historically, the distal tibia is associated with increased difficulty with both soft and hard tissue healing in the traumatized limb. Also, impaired tissue development and growth due to decreased innervation and physiologic stresses can create a barrier to normal healing.
- Leg-length discrepancy can be seen after opening and closing wedge osteotomies in growing children.
- Delayed union may require prolonged immobilization with weight bearing as tolerated. Nonunion can be managed with improved fixation, autologous bone grafting, and further immobilization in a non-weight-bearing cast.
- Malunion can be due to inadequate fixation or slow healing and loss of fixation.
- Recurrence of the deformity can be due to continued growth with partial physeal arrest.
- Premature growth plate closure can occur with the oblique osteotomy. This can occur as a planned portion of the procedure or can be due to periosteal stripping at the level of the physis or fixation crossing the physis.
- Pseudarthrosis of the fibula can occur after fibular osteotomies. These are most often asymptomatic and can be observed. When painful, open reduction, plate fixation, and bone grafting should be considered.

REFERENCES
DEFINITION
- Children with osteogenesis imperfecta (OI) and syndromes with congenital brittle bones sustain recurrent fractures and deformity, which cause chronic pain and limit their function.\(^{19,20}\)
- Multiple percutaneous osteotomies and percutaneous telescoping intramedullary nailing can improve comfort and function with lower morbidity than previously was possible.
- The severity of bone disease, fracture incidence, degree of deformity, and functional level of the patient, as well as the patient’s response to medical treatment, are more important in surgical decision-making than the specific diagnostic type of OI or brittle bone disease.

ANATOMY
- There is broad variation in anatomic findings in the different types of OI and other brittle bone diseases that resemble it.
- Some children have blue sclera, obvious dentinogenesis imperfecta, triangular facies, and ligamentous laxity, but this varies greatly, even within the same family, and many affected children have none of these findings.
- The defining characteristics of children with OI are a varying degree of bone fragility, and recurrent fractures.
- Progressive anterior bowing of the long bones is quite common, especially in children with moderate to severe involvement, even with early treatment with bisphosphonates ([FIG 1]).
- Coxa vara, both apparent and true, can develop.\(^{8}\)

PATHOGENESIS
- OI is caused in the great majority of cases by dominant mutations in type I procollagen genes.
- In the remaining cases, children may have brittle bone disease with a similar presentation and problems that are not caused by mutations in the type I procollagen genes.\(^{1,19}\)
- The flexors, such as the gastrocnemius muscles and hamstrings, contribute to the progressive bowing.
- Secondary joint contractures may be seen as a result of the longstanding deformities.

NATURAL HISTORY
- Historically, children with very severe OI, especially Sillence type II, rarely survived infancy, and children with types III and IV had severe disability secondary to recurrent fractures, bone pain, and deformities.\(^{24,25}\)
- Before bisphosphonate therapy was available, ambulation and even functional, comfortable sitting were difficult if not impossible for many children with severe forms of OI.
- Even children with less severe forms of OI may have many significant fractures, which inhibit comfort, function, and quality of life.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Findings vary greatly depending on the type and severity of OI. In addition, findings on physical examination may change dramatically as children respond to treatment with bisphosphonates.

FIG 1 • A. Radiographs of an infant with moderately severe osteogenesis imperfecta (OI). B. At 16 months of age, bone strength is improved, but deformity does not remodel.
Possible physical findings include blue sclera, triangular face, dentinogenesis imperfecta, joint laxity, bowing of the arms and legs, and flattening of the skull, especially in infants with severe involvement, but these findings vary greatly even within the same family, and many of the children have none of these classic physical findings.

Flexible flat feet and externally rotated lower extremities are quite common.

A variety of presentations are possible, and children with subtle forms of OI may appear totally normal on physical examination, but present with multiple and recurrent fractures.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs are preferred as the initial study to evaluate children who have or may have OI.
- Full-length radiographs of both legs on the same cassette from the hips to the ankles are ideal to assess areas of fractures and degree of deformity.
- Radiographs of the lower extremity should be performed with the patellas directly anterior and also with the legs maximally externally rotated. This helps assess the severity of the disease, can help predict risk of fracture, and is useful in preoperative planning for osteotomies and instrumentation (FIG 2).
- Standardized posteroanterior (PA) and lateral spine radiographs demonstrate spinal fractures, scoliosis and spondylolysis, and spondylolisthesis.
- Bone density (dual x-ray absorptiometry [DEXA]) scans, although not perfect, can be useful in monitoring changes in bone density, using age-matched Z-scores and consistently using the same techniques and machine type. The DEXA scan alone, however, cannot be used for diagnosis, especially in infants, for whom no standardized validated Z-scores have been established.
- The child’s clinical course with regard to incidence of fracture and pain is a much more reliable indicator of successful medical treatment than a specific Z-score.

**DIFFERENTIAL DIAGNOSIS**

- Child abuse
- Metabolic bone disease (eg, hypo- and hyperphosphatasia, rickets)
- Idiopathic juvenile osteoporosis

**NONOPERATIVE MANAGEMENT**

- Early diagnosis and treatment with bisphosphonates has significantly improved the lives of children with OI. This treatment positively alters the mechanical properties of their bones, decreases their fracture rate and pain, and enhances their psychomotor development.
- This improvement in bone density and strength often allows them to function at levels that previously were not possible by decreasing their bone fragility and pain.
- Surgical treatment for these children is now possible, whereas previously in many cases no surgical options existed because of the severity of their bone disease.
- It has been suggested that treatment with pamidronate may be related to delayed healing of osteotomies—but not fractures—in children with OI.
- It remains unclear whether the incidence of delayed healing will decrease with lower doses of pamidronate.
- Casting, splinting, and bracing for many children with OI should be short-term temporizing measures only, because residual deformities will not remodel, and osteoporosis is worsened by prolonged immobilization.

**SURGICAL MANAGEMENT**

- Intramedullary fixation of long bones in children with OI required extensive soft tissue disruption with traditional techniques.
- Insertion of telescoping and nontelescoping rods still requires extensive exposure and arthrotomies for insertion, and the reoperation rate is high.
- Improved surgical treatment has been made possible by the development of percutaneous techniques, as well as modification of existing nails and development of new nails for fixation, both telescoping and nontelescoping.

**Principles of Surgical Treatment**

- Primary indications for surgical treatment include recurrent fractures, pain, and deformity.
  - These approaches should be considered as children begin attempting to stand or crawl.
  - There is no advantage to waiting until the child is older.
  - Surgical treatment should be considered in acute fracture with deformity, even with less severe OI (FIG 3A,B).
- Correct deformity and axial alignment.
  - Residual bowing does not correct with growth and predictably leads to further fracture.
  - As many involved, symptomatic bones should be corrected at one setting as can be safely accomplished.
- Minimize soft tissue dissection and trauma.
  - Percutaneous technique provides more stability, less scarring, and earlier healing.
- Minimize immobilization.
  - Light splints only
  - Early weight bearing and motion as symptoms allow
  - The role of bracing for long bones is not proven, and bracing may inhibit function.
Part 4 PEDIATRICS • Section III RECONSTRUCTION

**FIG 3** A,B. Plating of the proximal femur in a young child with progressive bowing pain and recurrent fractures at the end of the plate. C. An 8-year-old child treated with an adult nail with lateral migration distally, coxa vara, and proximal growth inhibition. D. The same child treated with the Fassier-Duval nail and valgus osteotomy 6 months postoperatively.

- Use telescoping intramedullary devices whenever possible.
- Use relatively small, flexible nails to share stress.
- Rigid nails may lead to disappearing bone (**FIG 3C,D**).
- Do not remove nails electively.
- Plating predictably leads to stress reaction.
- Indications in forearm are more limited.
- Fixation in the forearm is less predictable, and has higher risks and rate of complications.
- Instrumentation and bone quality are not optimal.

- Such fixation should be considered only when comfort, motion, and function are significantly limited by deformity.

**Preoperative Planning**

- The keys to surgical success are careful selection of children with adequate bone strength and density, and availability of an experienced team and appropriate equipment (**FIG 4A**).
- Templates must be used to ensure that every appropriate size and type of device is available (**FIG 4B**).

**FIG 4** A. Fassier-Duval instrumentation tray. B. Templates for Fassier-Duval nail. (B: Courtesy of Pega Medical, Inc, Montreal, Canada.)
Radiographs can be used to estimate length and diameter of nails as well as to determine osteotomy sites (FIG 5).

**Measuring the Fassier-Duval Nail**
- The distance from the greater trochanter to the distal femoral physis can be used to estimate the length of the female nail.
- The female nail should be approximately 1 cm shorter than this distance.
- Digital software and templates to determine length and diameter of the nails are available.
- Angular correction can also be estimated on digital radiographs, but they can be deceiving because of the multiplanar nature of the angulation.
- The female nail can be cut preoperatively, but I prefer to cut the female nail intraoperatively, after the osteotomies are completed.

**Positioning**
- For fractures and deformities of the tibia and femur, the patient is placed in the semilateral position with an axillary roll and a long, padded posterior roll near the edge of the radiolucent table.
- The leg can be gently rotated from the anteroposterior (AP) to the lateral position with the C-arm positioned on the opposite side of the table (FIG 6).
- Only one leg can be prepped at a time especially if both the femur and tibia are being treated at the same surgical setting.
- Bilateral tibial surgery can be done supine, but not femoral surgery.

**Approach**
- For the femur, a 1.5-cm vertical incision is made, starting at the tip of the greater trochanter and extending proximally (FIG 7A).
- The fascia of the abductors is then incised, exposing the white greater trochanter (FIG 7B).
- The tibia is approached through a medial peripatellar incision, bluntly dissecting behind the patellar tendon when possible without disrupting the synovium. If necessary, an arthrotomy can be used to expose the starting point for the tibial nail just anterior to the tibial spines.
- The humerus is approached through a small deltoid-splitting incision to expose the greater tuberosity.
APPROACHES TO OSTEOGENESIS IMPERFECTA

Percutaneous Osteotomy With Intramedullary Telescop ing Fassier-Duval Nail

- The percutaneous technique described in this section is as described by Fassier and Duval\(^7,8,17\) with only minor technical variations.
- The open technique, which is not described in this chapter, is performed the same way, with the following exceptions:
  - A larger incision at the osteotomy or fracture site
  - Retrograde guidewire placement and reaming of the proximal fragment
  - Passing the wire into the distal femur under direct vision

Guidewire Placement and Osteotomies in the Femur

- Short and long guidewires are available, depending on the length of the femur.
- Ideally, the tip of the guidewire is placed just medial to the center of the greater trochanter.
- It may be difficult to visualize the greater trochanter in small children with poor bone density, and the insertion point may be necessarily in the piriformis fossa to avoid overreaming of the lateral cortex and to allow a straight line of advance to the femoral canal.
- Avascular necrosis has not been demonstrated in children in whom this technique has been used.
- The relation between the entrance point and use of the nail and the development of coxa vara is not clearly defined at this point\(^1\) (TECH FIG 1A).
  - The wire is then advanced to the first osteotomy site.
  - In many cases it is necessary to angle the wire markedly, both anteriorly and laterally, at first because of the very common severe anterior and lateral bowing of the femur in the subtrochanteric region.
  - Osteotomy sites are marked on the skin after visualization with the C-arm, based on preoperative templating and intraoperative visualization (TECH FIG 1B).
  - A 1-cm incision is made directly over the anterior lateral apex of the deformity.
  - Blunt dissection then is performed with a hemostat down to the periosteum (TECH FIG 1C).
  - The periosteum is incised longitudinally with a small osteotome, which is then rotated 90 degrees (TECH FIG 1D).
  - An incomplete osteotomy is performed while stability of the leg is maintained manually. The osteotomy is completed with gentle manual pressure, the guidewire is extended to the next osteotomy site, and the process is continued until all deformities are corrected.
  - The guidewire is then passed into the distal femur (TECH FIG 1E).
  - Use of a longer guidewire can help to avoid capturing the guidewire in the reamer.
  - A subtle flexion deformity often is present distally, in both the femur and tibia, that is not always apparent on the preoperative radiographs and that will cause the nail to go too far anteriorly.

TECH FIG 1 • A. Guidewire placed through the greater trochanter to the site of the first osteotomy. B. Localization for osteotomy. Reaming can be done at the site of the osteotomy to stabilize the proximal segment. C. A 1-cm incision is made over the apex of the osteotomy, and the soft tissues are spread to the periosteum. D. The osteotome is rotated and the osteotomy completed. Gentle manual traction and use of a lever such as a padded mallet will help to gently align and complete the osteotomy site. E. Guidewire in the distal femur.
Reaming and Placement of the Male Nail
- The reamers are 0.25 to 0.35 mm larger than the corresponding nails.
- The canal is reamed over the guidewire down to the distal femoral metaphysis, approximately 1 cm proximal to the physis in the center-center position on both AP and lateral radiographs (TECH FIG 2A).
- The guidewire is removed to insert the male nail driver and nail after verifying the distal male nail thread length, while maintaining traction manually.
  - Avoid bending the rod and driver, to prevent impingement and damage to the nail.
  - The nail and driver cannot be used to forcefully manipulate the osteotomy or fracture site.
- The nail and driver are passed to the center-center position in the distal metaphysis (TECH FIG 2B,C).
- If the male nail requires redirection, it should be retracted slowly, while maintaining a gentle counterclockwise screwing motion to prevent dislodgment of the driver from the wing of the nail, which is not locked in the male nail driver (TECH FIG 2D).
- On occasion, it may be necessary to remove the male nail and repeat the process.
- Varus and valgus malalignment can be corrected with a distal osteotomy and correct placement of the nail in the center-center position in the distal femur.
- Correct positioning is checked using AP and lateral views with the C-arm just before passing the male nail across the center-center position of the physis.
- The threads are gently screwed into the epiphysis until the rounded portion of the rod located just proximal to the threads is bridging the physis.
- Multiple transgressions of the physis are to be avoided.
- The rod pusher is then placed into the cannulated portion of the male nail driver, and a sharp backward blow is made on the T handle. The C-arm verifies that the male nail is still engaged in the epiphysis (TECH FIG 2E).

Cutting and Insertion of the Female Nail
- To measure the length of the female rod intraoperatively, it is placed with the threaded portion just at the top of the ossified greater trochanter with C-arm verification using a metal marking device distally approximately 1 cm above the physis (TECH FIG 3A).
- The appropriate length of the female nail is verified with the C-arm, as previously discussed.
- The female nail is covered with K-Y Jelly (Johnson & Johnson, New Brunswick, NJ) then cut with a diamond-tip burr and cooled with sterile saline.
- The cannulated portion must be checked to ensure that no metal will impinge on the male nail to prevent it from lengthening and that any metal shards are rinsed off (TECH FIG 3B,C).
- The male nail driver is then removed, and the female nail is placed over the male nail.
- The female nail is then screwed into the greater trochanter with the T-handle screwdriver until just a few threads are engaging the bony portion of the greater trochanter, and the upper part of the female nail is just palpable above the greater trochanter (TECH FIG 3D).
- If the female nail is too shallow, it will back out, but if it is too deep, it is more likely to become overgrown and ultimately reside in the femoral canal.
The female nail is checked distally to be sure there is some space between its distal end and the wing of the male nail, to ensure that the male nail is not driven distally into the joint either acutely or with impaction of the osteotomy with weight bearing (TECH FIG 3E,F).

The male nail can be cut either with a front-biting heavy wire cutter or with the male nail cutters in the FD set.

Cutting the male nail approximately 1 cm above the top of the female nail rarely causes persistent symptoms and allows for more growth.

The probe is used to ensure that the cut male nail is smooth and not bent, which would prevent telescoping.

Occasionally, the diamond-tipped burr may be necessary to smooth the end of the male nail, but the soft tissues must be protected from debris and injury.

**Coxa Vara**

If true coxa vara is present, it should be corrected at the same sitting by combining this femoral nail technique with the valgus osteotomy described by Fassier and Glorieux® (TECH FIG 4).

**Revision**

When a rod system requires revision after maximal telescoping, it usually can be retrieved through just a proximal incision.

A guidewire is placed in the greater trochanter and into the cannulated portion of the female nail under fluoroscopic control.

Specialized female and male retrievers, as shown, allow for intramedullary retrieval (TECH FIG 5).
Open osteotomy, cutting the rod and removing the segments, may be necessary to retrieve a broken or bent nail or one that has migrated laterally and distally. The male nail also may be retrieved with an arthroscopic alligator clamp after the female nail is removed.

**Tibial Technique**

- Nails from the small-bone set are used. These have a somewhat shorter female-threaded portion to avoid extension of the threads across the proximal tibial epiphysis.
- Injury to the anterior horn of the medial meniscus is avoided with arthrotomy if necessary.
- A 0.62-inch K-wire or awl is placed just lateral to the anterior horn of the medial meniscus, and just anterior to the tibial spine in the non-weight-bearing surface. A soft tissue protector is helpful in directing the guidewire.
- This usually places the wire in the midportion of the tibial epiphysis on the AP view and at the junction of the anterior and middle thirds on the lateral view.
- With the knee kept flexed in excess of 90 degrees, the guidewire is passed into the center position of the proximal metaphysis and shaft.
- Typically, the wire tends to go posteriorly and laterally so that the wire driver must be directed anteriorly and usually slightly medially.
- Alternatively, the wire can be manually pushed into the epiphysis if this provides better control and visualization with the C-arm.
- Avoid repetitive injury to the physis by checking the direction of the wire with the C-arm while it is still in the proximal tibial epiphysis. The guide pin can be advanced either with manual pressure on the pin or using a drill.
- While maintaining hip and knee flexion, the lateral radiograph can be done by simply abducting and externally rotating the leg.
- The guidewire is drilled down to the site of the first osteotomy, which often is the mid- to distal portion of the shaft of the tibia, although bowing of the proximal tibia also may be present.
- To perform the tibial osteotomy, a 1.5-cm incision is made. The periosteum is visualized and partially elevated. Multiple osteotomies may be necessary (TECH FIG 6A).
- A pure closed technique is more hazardous in the tibia.
- When the medullary canal is obliterated by recurrent fracture and bowing, retrograde drilling is required to establish a medullary canal at the osteotomy site.
The guidewire is then passed beyond the osteotomy.
Ideally, the entrance point to the distal tibial epiphysis is slightly posterior on the lateral view and slightly lateral on the AP view. This helps to avoid the tendency to valgus and anterior cut-out.
Closed osteoclysis of the fibula often can be performed with minimal force after the first osteotomy, especially in younger children, but open osteotomy may be necessary.
The reamer is passed down to the distal metaphysis while maintaining the knee in flexion at all times.
Reaming should be done slowly, with frequent stops at the apex of the angular deformity. This bone typically is quite dense in response to recurrent fractures.
Extending the knee while the reamer is in place can impinge and injure the femoral condyles.
The male nail is either cut after determining the length with the C-arm before placement into the tibia, which is my preferred technique, or inserted, removed, and then cut after the appropriate length is determined (TECH FIG 6B,C).
There is a small hole in the distal male nail to allow interlocking with a small wire, which is then bent over into the epiphysis. I have not used this technique and have concerns about migration and retrieval of the wire with growth.
The female nail is cut to length in the same manner as for the femoral technique, and inserted until the threaded portion is fully seated into the epiphysis.
It usually is visible just a few millimeters deep to the articular cartilage, even when the C-arm suggests that it is protruding into the joint (TECH FIG 6D,E).

Humeral Nailing
The deltoid is spread in line with its fibers through a 1.5-cm incision, and the greater tuberosity is exposed.
The guidewire is drilled down into the shaft.
Typically, the diaphyseal deformity involves the mid- to distal shaft of the humerus when the guidewire is passed to the apex of angular deformity.
If a proximal deformity is present, an open or percutaneous osteotomy can be considered.
A distal anterolateral approach is used, and the radial nerve is identified and protected before the distal osteotomy is done.
The guidewires are then drilled down into the ossified capitellum after correction of the varus and anterior bowing.
The canal is then reamed to the size of the female nail down to the distal metaphysis.
The male nail is then placed down into the capitellum, which commonly leaves a slight amount of varus, which is well tolerated (TECH FIG 7A).
In older children, the nail can be placed into the superior segment of the ossified central trochlea, which allows better correction of the distal varus.
The small-bone female nail is used, cut to appropriate length before insertion. The upper end of the female nail should be deep to the articular cartilage to avoid impingement. This is verified by placing the shoulder through full range of motion (TECH FIG 7B–C).

![TECH FIG 7 • A,B. AP and lateral male nail in capitellum. C. Female nail appears to be protruding but is actually deep to the articular cartilage and is not causing impingement. D. Two years postop. Note telescoping of nail. There is no clinical impingement.](image-url)
Fiberoptic intubation rarely is necessary in treated children when the anesthesiologist is
Adequate analgesia upon awakening is necessary to avoid flailing and fracture.

The length of the distal male nail threads also limits the ability to use these nails in some
Lightweight fiberglass lateral or posterior splints for 3 weeks typically are adequate.
Transfusion may be necessary, especially if more than two bones are treated. Judicious use
External rotation is common in most of these children, and typically improves over 12 to

Multiple bones can be safely treated at the same setting in most children if an experi-

Lightweight fiberglass lateral or posterior splints for 3 weeks typically are adequate.
Rotational control is present at 3 weeks.
External rotation is common in most of these children, and typically improves over 12 to

The smallest rods available are 3.2 mm in diameter. Children with smaller canals can be

It is mandatory to work with experienced anesthesia, operating room, physical therapy, occupational therapy, dietetics, and metabolic and nursing teams to safely and effectively

Adequate analgesia upon awakening is necessary to avoid flailing and fracture.
Treatment with Valium is significantly beneficial for spasm.

Blood pressure cuffs can be used for monitoring in many children treated with pamidronate if the pressure is set no higher than neonatal pressures.
Fiberoptic intubation rarely is necessary in treated children when the anesthesiologist is

Adequate analgesia upon awakening is necessary to avoid flailing and fracture.
Treatment with Valium is significantly beneficial for spasm.
Many children have high narcotic requirements for a short period of time when multiple exposures have been done.

Revisions are still necessary as the children outgrow or damage the rods, but the instrumentation allows for a less traumatic experience for the patient and surgeon.

Complications include failure of telescoping of the rod, overgrowth of the greater trochanter, bending and breakage of the rods, as well as delayed union and nonunion.
Treatment for symptomatic complications of the rod is revision.
Fractures can occur even with satisfactory alignment, but recovery is typically rapid and requires short-term restriction of activities rather than long-term immobilization.


Postoperative Care

- Postoperative immobilization can be accomplished safely with lightweight radiolucent fiberglass wrapped under the foot to resist equinus and avoid heel pressure.
- The splint can be extended up to the buttocks to support the femur, and loosely overwrapped with an elastic wrap.
- Rarely, a percutaneous tendo Achilles tenotomy will be required.
- Floor activities can be increased whenever the child is comfortable.
- Weight bearing can begin in water approximately 4 weeks after the osteotomies achieve early healing and rotational control.
- Gentle passive range of motion of the hips, knees, and ankles can begin as soon as the child is comfortable.
- Hip, knee, ankle, and foot orthoses are a time-honored treatment and are used postoperatively in many centers.
  - Their effectiveness in avoiding recurrent fractures and deformity has not been demonstrated, however, and we do not use them in our center.
  - Many of the children are significantly more mobile without these orthoses, and healing is not impaired.
  - I prefer to limit use of orthoses to only those children with significant soft tissue laxity in the feet such that support is required for stability.

Outcomes

- Improved comfort, a decreased rate of fracture, and an increased activity level are achieved in most children.
- Long-term monitoring of these patients and constant improvement in instrumentation are necessary to ensure optimal development, comfort, and function in this patient population.

Pearls and Pitfalls

<table>
<thead>
<tr>
<th>PEARLS AND PITFALLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple bone deformities</td>
</tr>
<tr>
<td>- Multiple bones can be safely treated at the same setting in most children if an experienced team is available.</td>
</tr>
<tr>
<td>- Transfusion may be necessary, especially if more than two bones are treated. Judicious use of tourniquets decreases the likelihood of transfusion.</td>
</tr>
<tr>
<td>Postoperative immobilization</td>
</tr>
<tr>
<td>- Lightweight fiberglass lateral or posterior splints for 3 weeks typically are adequate.</td>
</tr>
<tr>
<td>- Casting rarely is necessary.</td>
</tr>
<tr>
<td>- Rotational control is present at 3 weeks.</td>
</tr>
<tr>
<td>- External rotation is common in most of these children, and typically improves over 12 to 24 months.</td>
</tr>
<tr>
<td>Rod size</td>
</tr>
<tr>
<td>- The smallest rods available are 3.2 mm in diameter. Children with smaller canals can be treated with K-wires or rush rods.</td>
</tr>
<tr>
<td>- The length of the distal male nail threads also limits the ability to use these nails in some smaller children.</td>
</tr>
<tr>
<td>Team approach</td>
</tr>
<tr>
<td>- It is mandatory to work with experienced anesthesia, operating room, physical therapy, occupational therapy, dietetics, and metabolic and nursing teams to safely and effectively treat these children.</td>
</tr>
<tr>
<td>- Blood pressure cuffs can be used for monitoring in many children treated with pamidronate if the pressure is set no higher than neonatal pressures.</td>
</tr>
<tr>
<td>- Fiberoptic intubation rarely is necessary in treated children when the anesthesiologist is experienced, with surgeon stabilizing the head and neck.</td>
</tr>
<tr>
<td>Pain management</td>
</tr>
<tr>
<td>- Adequate analgesia upon awakening is necessary to avoid flailing and fracture.</td>
</tr>
<tr>
<td>- Treatment with Valium is significantly beneficial for spasm.</td>
</tr>
<tr>
<td>- Many children have high narcotic requirements for a short period of time when multiple exposures have been done.</td>
</tr>
</tbody>
</table>

Postoperative Care

- Postoperative immobilization can be accomplished safely with lightweight radiolucent fiberglass wrapped under the foot to resist equinus and avoid heel pressure.
- The splint can be extended up to the buttocks to support the femur, and loosely overwrapped with an elastic wrap.
- Rarely, a percutaneous tendo Achilles tenotomy will be required.
- Floor activities can be increased whenever the child is comfortable.
- Weight bearing can begin in water approximately 4 weeks after the osteotomies achieve early healing and rotational control.
- Gentle passive range of motion of the hips, knees, and ankles can begin as soon as the child is comfortable.
- Hip, knee, ankle, and foot orthoses are a time-honored treatment and are used postoperatively in many centers.
  - Their effectiveness in avoiding recurrent fractures and deformity has not been demonstrated, however, and we do not use them in our center.
  - Many of the children are significantly more mobile without these orthoses, and healing is not impaired.
  - I prefer to limit use of orthoses to only those children with significant soft tissue laxity in the feet such that support is required for stability.

Outcomes

- Improved comfort, a decreased rate of fracture, and an increased activity level are achieved in most children.
- Long-term monitoring of these patients and constant improvement in instrumentation are necessary to ensure optimal development, comfort, and function in this patient population.

Pearls and Pitfalls

<table>
<thead>
<tr>
<th>PEARLS AND PITFALLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple bone deformities</td>
</tr>
<tr>
<td>- Multiple bones can be safely treated at the same setting in most children if an experienced team is available.</td>
</tr>
<tr>
<td>- Transfusion may be necessary, especially if more than two bones are treated. Judicious use of tourniquets decreases the likelihood of transfusion.</td>
</tr>
<tr>
<td>Postoperative immobilization</td>
</tr>
<tr>
<td>- Lightweight fiberglass lateral or posterior splints for 3 weeks typically are adequate.</td>
</tr>
<tr>
<td>- Casting rarely is necessary.</td>
</tr>
<tr>
<td>- Rotational control is present at 3 weeks.</td>
</tr>
<tr>
<td>- External rotation is common in most of these children, and typically improves over 12 to 24 months.</td>
</tr>
<tr>
<td>Rod size</td>
</tr>
<tr>
<td>- The smallest rods available are 3.2 mm in diameter. Children with smaller canals can be treated with K-wires or rush rods.</td>
</tr>
<tr>
<td>- The length of the distal male nail threads also limits the ability to use these nails in some smaller children.</td>
</tr>
<tr>
<td>Team approach</td>
</tr>
<tr>
<td>- It is mandatory to work with experienced anesthesia, operating room, physical therapy, occupational therapy, dietetics, and metabolic and nursing teams to safely and effectively treat these children.</td>
</tr>
<tr>
<td>- Blood pressure cuffs can be used for monitoring in many children treated with pamidronate if the pressure is set no higher than neonatal pressures.</td>
</tr>
<tr>
<td>- Fiberoptic intubation rarely is necessary in treated children when the anesthesiologist is experienced, with surgeon stabilizing the head and neck.</td>
</tr>
<tr>
<td>Pain management</td>
</tr>
<tr>
<td>- Adequate analgesia upon awakening is necessary to avoid flailing and fracture.</td>
</tr>
<tr>
<td>- Treatment with Valium is significantly beneficial for spasm.</td>
</tr>
<tr>
<td>- Many children have high narcotic requirements for a short period of time when multiple exposures have been done.</td>
</tr>
</tbody>
</table>

Revisions are still necessary as the children outgrow or damage the rods, but the instrumentation allows for a less traumatic experience for the patient and surgeon.

Complications

- Complications include failure of telescoping of the rod, overgrowth of the greater trochanter, bending and breakage of the rods, as well as delayed union and nonunion.
- Treatment for symptomatic complications of the rod is revision.
- Fractures can occur even with satisfactory alignment, but recovery is typically rapid and requires short-term restriction of activities rather than long-term immobilization.

References

DEFINITION
- Fibular deficiency, previously known as fibular hemimelia, is a longitudinal deficiency of the fibula. It is the most common long bone deficiency and may be either partial or complete.
- A wide spectrum of associated anomalies also may be seen on the affected limb. The extent of limb shortening and the degree of foot deformity are the most important components that determine treatment. Treatment options include use of a shoe lift, amputation, and limb lengthening.
- Delayed amputation should be avoided whenever possible. Ideally, amputation is performed at 10–18 months of age when the child is beginning to pull to stand. Psychosocial adjustment to amputation and the adjustment to prosthetic wear are rapid at this age.
- A common dilemma for parents and consulting physicians is an unwillingness to commit to a path of either multiple lengthenings or early amputation. It is generally agreed, however, that the least effective approach to fibular deficiency is “let’s try lengthening and if it fails, do an amputation.”
- The Syme amputation and the Boyd amputation are the two common amputations performed for fibular deficiency.
- The Syme amputation is an ankle disarticulation that preserves the heel pad as a weight-bearing surface. This procedure provides better energy efficiency than a transtibial amputation, may be self-suspending, allows weight bearing on the stump without the use of a prosthesis, and is cartilage capped, preventing terminal overgrowth.
- The Boyd amputation is a modified ankle disarticulation in which the calcaneus is preserved with the heel pad and fused to the distal tibia.
- The best indications for an amputation are a large leg-length discrepancy (ie, a difference of more than 30%) at skeletal maturity and a nonfunctional foot.
- The ideal candidate for lengthening has a smaller expected leg-length discrepancy (less than 10%), a stable ankle, and a fully functional foot.
- Because both amputation and multiple lengthenings have significant consequences, care must be individualized. This is especially important for patients with leg-length discrepancies between 10% and 30%, for which both amputation and lengthening have been shown to be effective with excellent functional outcomes.

ANATOMY
- Fibular deficiency is best considered an abnormality that affects the entire limb, not just the fibula (FIG 1A).
- The appearance of the leg can vary from nearly normal to severely deformed (FIG 1B).
Potential ipsilateral deformities associated with fibular deficiency are as follows:
- Femur: mild femoral shortening, femoral retroversion, lateral femoral hypoplasia
- Knee: cruciate ligament deficiency, valgus alignment, patella-femoral instability
- Tibia: shortening, anteromedial diaphyseal bowing
- Ankle: ankle valgus, absent lateral malleolus, ball-and-socket ankle
- Foot: absent tarsal bones, tarsal coalitions, absence of one or more lateral rays

The amount of fibula present does not aid treatment planning. For example, some patients with complete fibular absence have minimal leg-length inequality and foot deformity.

An understanding of the anatomy of the ankle and heel is necessary to perform either the Syme or Boyd amputation procedure.

The posterior tibial nerve and artery course posterior to the medial malleolus and split into the medial and lateral plantar nerves. These structures must be protected for the heel pad to maintain its sensation and viability.

**PATHOGENESIS**

Unlike tibial deficiency, fibular deficiency occurs sporadically with no inheritance pattern.

No genetic defect has been identified, and no common teratogen is linked to fibular deficiency.

Major limb malformations associated with fibular deficiency occur by the 7th week of fetal development.

**NATURAL HISTORY**

Without surgical intervention, the growth of the abnormal limb remains proportional to the normal side. Therefore, a final leg-length discrepancy is predictable.

For example, if the short leg is 85% the length of the long side at age 2 years, the length of the short side at maturity also will be 85% of the estimated length of the long side at maturity.

Tibial bowing is present in most cases of complete absence of the fibula. In some cases this bowing will improve with age.

Unlike anterolateral bowing of the tibia, bowing associated with fibular deficiency does not increase the risk of fracture or pseudarthrosis.

Knee valgus commonly worsens through childhood. It may require surgical treatment when prosthetic modifications are inadequate to compensate for the deformity.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

Classically, the limb is short, with an equinovalgus foot and skin dimpling over the mid-anterior tibia.

Because presentation varies widely, an examination to assess length, alignment, and function is critical to treatment.

Hip range of motion: a common finding is limited internal rotation (less than 20 to 60 degrees), indicating femoral retroversion.

Leg-length assessment: there should be minimal shortening of the thigh. Otherwise, consider proximal femoral focal deficiency. Small leg-length discrepancies can be corrected with a shoe lift or lengthening.

Lachman’s test: severe anterior/posterior laxity increases the risk of subluxation during lengthening.

Valgus alignment and stability: small angulation is accommodated through prosthetic adjustment, but larger angulation requires correction.

Tibial bowing requires prosthetic adjustments or correction.

Ankle alignment and stability: amputation is preferred over lengthening when severe subluxation or instability exists.

Hindfoot mobility: suspect tarsal coalition if subtalar motion is reduced.

Ray deficiency (number of missing rays): amputation is indicated when the foot is nonfunctional.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

Anteroposterior (AP) and lateral radiographs of the leg (including the distal femur) should be obtained.

Absence of the anterior cruciate ligament and hypoplasia of the lateral femoral condyle with a valgus joint alignment are common (FIG 2A, B).

The amount of anterior bowing (tibial kyphosis) also can be assessed (FIG 2C).

Additional radiographs of the affected limb (ie, femur, ankle, and foot) are obtained as necessary (FIG 2D).

A full-length standing radiograph from hips to ankles should be obtained to check alignment in those children able to stand (FIG 2E).

A scanogram and bone age should be obtained to determine the expected leg-length discrepancy at maturity.

The desired limb-length difference at maturity should be at least 3.5 cm to accommodate the height of the prosthetic foot. Epiphysiodysis may be necessary to achieve this and should be planned appropriately.

An ankle and foot series should be obtained when abnormal position or motion is present at the ankle or subtalar joint or when lateral rays are absent. These views may reveal a ball-and-socket ankle (FIG 2F), tarsal coalitions, or absent or hypoplastic tarsal bones (FIG 2G).

**DIFFERENTIAL DIAGNOSIS**

- Proximal femoral focal deficiency
- Tibial deficiency
- Tibial dysplasia

**NONOPERATIVE MANAGEMENT**

- If the leg-length discrepancy is small, the ankle is stable, and the foot is plantigrade, a shoe insert or lift may be all that is required.
- When amputation or lengthening is needed but must be deferred, an atypical prosthesis that accommodates the foot position can be used.

**SURGICAL MANAGEMENT**

**Syme Amputation**

- Meticulous care is needed to preserve the posterior tibial nerve and vessels to maintain a sensate stump.
- Care should be taken not to leave any cartilage remnants of the calcaneus during resection.
- The malleoli should not be resected in children.
- The heel pad may be proximal to the ankle joint and can be difficult to bring distally, even after sectioning the Achilles tendon.
The Pirogoff modification maintains a portion of the calcaneus, which is fused to the distal tibia to better fix the heel pad. Because in young children the distal tibial physis must be resected to obtain fusion of the calcaneus to the tibia, this is really a modification of the Boyd amputation, since distal growth of the tibia will be lost.

**Advantages**
- Simple technique
- Rapid prosthetic fitting
- The stump is shorter and often tapered, which improves cosmesis (but also may inhibit end-bearing)

**Disadvantages**
- Heel pad migration (FIG 3)
- Less end-bearing potential

**Boyd Amputation**

**Advantages**
- Maintains maximum length of limb
- Eliminates heel pad migration
- Flare at the end of the stump improves prosthetic suspension
- Maximizes end-bearing potential. This may be especially important if it preserves end-bearing without a prosthesis (eg, not having to put on a prosthesis to go from the bed to the bathroom).

**Disadvantages**
- Delays prosthesis fitting by several weeks while awaiting fusion

![FIG 2 • A,B. AP and lateral radiographs of a child with fibular absence, hypoplasia of the lateral femoral condyle, and anterior cruciate deficiency. C. Anterior bow of the tibia. D. AP radiograph of the same patient’s foot, revealing severe equinovarus deformity and talocalcaneal fusion. E. Standing AP radiograph of a child with proximal femoral focal deficiency revealing a substantial leg-length discrepancy and abduction of the affected limb. F. Ball-and-socket ankle. G. Nonfunctional foot with hypoplastic tarsal bones, tarsal coalition, and absent rays. (E: Courtesy of Hugh Watts, MD.)

![FIG 3 • Posterior heel pad migration after Syme amputation.]
Excess length may leave less room for energy-storing prosthetic foot options, and the bulbous end may be difficult to hide if it is at the level of the opposite ankle.

Preoperative Planning

**Syme Amputation**

- In patients where the tibial length at skeletal maturity is expected to be equal to that of the opposite side, a Boyd amputation or timed epiphysiodesis should be considered to accommodate the height of the prosthetic foot to achieve equal limb lengths at maturity.
- It usually is not necessary to correct mild bowing (less than 30 degrees) of the tibia in a congenital deficiency in a skeletally immature patient. Bowing of more than 30 degrees should be addressed with osteotomy at the time of amputation.

**Boyd Amputation**

- If anterior tibial bowing is present, it is best to correct it at the same time as the Boyd amputation.
- The tarsal bones and distal tibia epiphysis are primarily cartilaginous in infancy.
- If a Boyd amputation is performed early, it will be necessary to resect a significant portion of the superior calcaneus and distal tibia to achieve bone–bone contact for fusion.
- If maximum length of the tibia is a goal of treatment (eg, to allow occasional end-bearing on the stump end without a prosthesis), consider waiting until the distal tibia epiphysis is ossified adequately to avoid resecting the distal physis.
- Some authors have suggested that routine resection of the distal tibia physis should be performed.

They observed that most children stop walking around the house without a prosthesis in early adolescence and that ideally the short limb should end in the middle fifth of the shank segment of the prosthesis to optimize cosmesis and allow room for a dynamic-response foot-and-ankle unit.²

**Positioning**

- The patient is positioned supine with a small bump under the greater trochanter. A tourniquet is placed around the upper thigh.
- Access to the entire leg from knee to toes is important (FIG 4).

**AMPUTATIONS FOR FIBULAR DEFICIENCY**

**Syme Amputation**

**Incisions**

- The dorsal incision is made at the tip of the lateral malleolus (or where it should be) across the ankle joint to end about 1 cm below the tip of the medial malleolus.
  - In children with congenital fibular absence, the lateral malleolus is not present, and the end of the first incision must be approximated.
- The Achilles tendon (often very tight in patients with congenital fibular absence) can be released through a separate, percutaneous incision posteriorly to improve exposure.
- The plantar incision is made at the midportion of the metatarsals and carried proximally up the medial and lateral sides of the foot to meet the anterior incision (TECH FIG 1).
  - The plantar incision can be cut directly down to bone, with care to be sure that the knife blade remains perpendicular to the skin. Vessels are ligated or cauterized.

**Amputation**

- The foot is now plantarflexed (TECH FIG 2A). The anterior incision is deepened down to bone, again keeping the knife perpendicular to the skin.
- The anterior ankle joint is opened, and the deltoid and tibiofibular ligaments are cut sharply, with care not to injure the posterior tibial nerve and artery coursing behind the medial malleolus.
- The foot is further plantarflexed to expose the posterior ankle joint, which is released, exposing the posterior calcaneus and the Achilles tendon.
- A bone hook or sharp retractor can be used to pull on the talus distally as the posterior joint is opened (TECH FIG 2B).
- The calcaneus is now released from the heel pad extraperiosteally. Care is taken not to separate the calcaneal apophysis from the body of the calcaneus.
- The Achilles tendon is now sectioned.
  - In very tight equinus, the Achilles can be released through a percutaneous incision posteriorly.
  - Once the tendon is easy to visualize, a 1-cm section of the tendon should be removed to prevent late migration of the heel pad.
- The tourniquet is deflated, and perfusion of the heel pad is checked and bleeding is controlled (TECH FIG 2C).
- The distal tibial cartilage and malleoli are left intact.
  - A Steinmann pin or Rush rod may be inserted through the heel pad into the distal tibia to affix the heel pad to the distal tibia (TECH FIG 2D).
**Chapter 38  SYME AND BOYD AMPUTATIONS FOR FIBULAR DEFICIENCY**

**TECH FIG 1**  •  A. Incisions for the Syme amputation. B. Medial incision and identification of the posterior tibial artery and nerve. (B: Courtesy of Hugh Watts, MD.)

**TECH FIG 2**  •  A. The foot is plantarflexed while the dorsal incision is completed. B. A retractor is placed in the talus to expose the posterior capsule and Achilles tendon. C. Intraoperative photograph after deflation of the tourniquet, illustrating a well-perfused heel pad. D. Stump closure with interrupted absorbable sutures after insertion of a Steinmann pin to stabilize the heel pad. (Courtesy of Hugh Watts, MD.)
**TECH FIG 3** • **A, B.** The dorsal and volar parts to the fish-mouth incision meet medially and laterally just distal to the malleoli. **C.** The plantar incision crosses the foot just distal to the heel pad.

**TECH FIG 4** • **A.** The plantar incision is carried down to the bone. **B.** Dorsal structures are transected with the foot in plantar flexion. **C.** Use the forefoot to control the hindfoot. **D, E.** Release the deltoid and lateral capsule. **F, G.** Carefully divide the posterior capsule and remove the talus. **H, I.** Sometimes the talus is small and irregularly shaped, as seen in this case, in which the L-shaped talus hooked around the back of the distal tibia.
Closure is done over a drain using interrupted sutures.
- In young children, an absorbable suture is used to avoid later removal.
- An antibiotic-impregnated gauze is applied followed by fluffs and Webril.

**Boyd Amputation**

**Incision and Dissection**
- A fish-mouth incision is made (TECH FIG 3).
  - The plantar incision crosses the foot where the heel pad ends.
  - The dorsal incision crosses the foot at the level of the ankle joint.
  - The incisions meet medially about 1 cm distal to the medial malleolus and laterally in a similar location (the lateral malleolus often is absent in fibular deficiency).

**Midfoot and Forefoot Removal**
- It is unnecessary to dissect layer by layer on the plantar side. Instead, sharply deepen the plantar incision down to the level of the bone (TECH FIG 4A).
  - Vessels can be ligated or cauterized (depending on their size) as they are cut or after the tourniquet is deflated before closure.
- While maximally plantarflexing the foot, transect the dorsal nerves and extensor tendons, which retract proximal to the incision (TECH FIG 4B).
- Do not remove the midfoot and forefoot at this time. They can serve as a handle to control the hindfoot when releasing the tibiotalar capsule and ligaments (TECH FIG 4C).
- Expose the tibiotalar joint by releasing the anterior capsule and then release the deltoid ligament medially and the talofibular ligament with the lateral capsule (TECH FIG 4D,E).
  - Use care to preserve the posterior tibial artery and vein while dividing the posterior ankle capsule.
  - A bone hook or skin rake on the talar dome will help expose the posterior tibiotalar capsule and Achilles tendon.
- Identify the flexor hallucis tendon and protect the neurovascular bundle that lies just medial to the tendon (TECH FIG 4F).
- Remove the talus after cutting through the talocalcaneal ligaments (TECH FIG 4G).
- Removing the talus may be more difficult in the very young child, in whom the talus is primarily cartilaginous, or when it has an irregular shape (TECH FIG 4D,E).
- The midfoot and forefoot are now removed.

**Completing the Amputation**
- Use an oscillating saw (or, in very young children, a knife) to remove the anterior process of the calcaneus and enough of the superior articular surface to expose cancellous bone (TECH FIG 5A–C).
- Cut the distal tibia (TECH FIG 5D).
- Oppose the cancellous bone surfaces and stabilize with a retrograde K-wire placed through the heel pad and across the tibiocalcaneal surfaces (TECH FIG 5E,F).

**Correction of Tibial Bowing**
- Make a longitudinal anterior incision at the apex of the bowing.
- Expose the tibia subperiosteally and place Chandler or Hohmann retractors to protect the soft tissues.

**TECH FIG 5 • A–C.** Prepare the calcaneus by cutting the anterior and dorsal surfaces. **D–F.** Stabilize the calcaneus to the end of the tibia with a smooth K-wire.
POSTOPERATIVE CARE

- Apply a long-leg cast with the knee flexed 90 degrees to prevent pin migration and keep the cast from slipping off.
- Postoperatively, the patient’s leg is elevated for 24 hours.
- The child should be non-weight bearing.
- The cast and pin are removed in the office at 4 to 6 weeks, and, in the Boyd amputation, after radiographic healing is evident (FIG 5A).
- A stump wrap or shrinker is then applied.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Pearls and Pitfalls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcaneus excision (Syme)</td>
<td>Remove the calcaneus extraperiosteally. This requires careful dissection but decreases the chance of reformation of the calcaneus. Any residual calcaneal cartilage left will result in painful pebbles of bone in the heel pad.</td>
</tr>
<tr>
<td>Tibial bowing (kyphosis)</td>
<td>Correct at the time of amputation if greater than 30 degrees, and fix with the transfixing Steinmann pin or Rush rod.</td>
</tr>
<tr>
<td>Achilles tenotomy</td>
<td>The Achilles tendon often is contracted and may make exposure of the calcaneus difficult. A percutaneous release posteriorly with a small tenotomy knife may make exposure easier without compromising the flap.</td>
</tr>
<tr>
<td>Talus excision (Boyd)</td>
<td>Carefully assess the position and shape of the talus and calcaneus to ensure abnormalities of the talus and calcaneus are known in advance. In rare cases, a Boyd amputation will not be possible because of the severe posterior and proximal position of the calcaneus. If so, perform Syme amputation.</td>
</tr>
<tr>
<td>Tibiocalcaneal fusion</td>
<td>Carefully ensure that cancellous bone is evident on both the distal end of the tibia and the superior surface of the calcaneus.</td>
</tr>
<tr>
<td>Skin closure</td>
<td>The distal extent of the heel pad is difficult to identify in children who are not yet walking. Be sure the plantar part of the incision is distal enough to allow closure without tension. Cut the anterior process of the calcaneus to reduce the anterior prominence and skin tension.</td>
</tr>
<tr>
<td>Angular deformities of leg</td>
<td>Correct tibial deformity early to facilitate prosthetic fitting. Correct progressive genu valgum late (ie, in adolescence).</td>
</tr>
</tbody>
</table>

OUTCOMES

- McCarthy et al reported on a comparison of amputation versus lengthening in the treatment of fibular hemimelia.
- Patients undergoing amputation were more active, had less pain, were more satisfied, and had fewer complications than those undergoing limb lengthening.
Fulp et al. reviewed 25 patients (31 extremities) with longitudinal deficiency of the fibula treated with either Syme amputation or Boyd amputation.

- Patients undergoing Syme amputation had more problems with prosthetic suspension, reformation of the calcaneus, and migration of the heel pad.
- Late progressive genu valgum deformity requiring a stapling or osteotomy of the distal femur occurs in 29% to 58% of cases.

**COMPLICATIONS**

- Wound slough/dehiscence
- Migration of the heel pad
- Penciling of the distal tibia
- Infection
- Pin migration
- Nonunion
- Excess length

**REFERENCES**

DEFINITION

- Ankle valgus is a lateral and upward slope of the tibiotalar joint resulting in foot pronation and sometimes lateral translocation of the talus relative to the tibia.
- In the anteroposterior (AP) plane, the weight-bearing axis and ground reaction force fall lateral to the virtual center of the joint. This may perpetuate the cycle of growth inhibition and progressive valgus.

ANATOMY

- Normal alignment of the ankle involves a horizontal plafond, with a lateral distal tibial angle of 0 to 3 degrees (FIG 1).
  - Accordingly, the fibula normally bears 15% of body weight.
  - The talus lies sandwiched between the malleoli, stabilized by the deltoid ligament medially and the talofibular and calcaneofibular ligaments laterally.
  - In the growing child, the fibular physis lies at or distal to the plafond.
  - The physes and plafond lie parallel to the floor and perpendicular to the ground reaction forces.

PATHOGENESIS

- The common denominator of ankle valgus is a fibula that is relatively foreshortened and fails to buttress the lateral tilt and shift of the talus during weight bearing.
  - As the fibular epiphysis bears more than the customary 15% of body weight, it may expand owing to the Hueter–Volkmann effect (another example of form following function).
  - As the ground reaction force is displaced laterally, the compression of the lateral distal tibial physis exceeds its tolerance and inhibits normal growth, not only of the physis, but of the epiphysis as well (Hueter–Volkmann effect).
  - There may be widening of the medial clear space due to attenuation of the deltoid ligament.
  - Subject to chronic and unremitting medial tension, there may be delayed or fragmented osseousization of the medial malleolus.
  - The physes remain horizontal and perpendicular to gravity.
  - With lateral tilt of the talus, shear forces are introduced and articular cartilage attrition may ensue, commencing at the lateral corner of the ankle.
  - Subtalar valgus alignment or instability may develop and exacerbate the clinical deformity.
  - Concomitant genu valgum imposes an eccentric load on the ankle and may compound the alignment problems (hereditary multiple exostoses, clubfeet; FIG 2).

NATURAL HISTORY

- The natural history of ankle valgus typically is insidious and progressive. It may be noticed around school age and becomes self-perpetuating.
  - The natural history is unaffected by corrective shoes or bracing (FIG 3).
  - In some conditions (spina bifida, cerebral palsy), there may be skin breakdown over the medial malleolus with attempts to control valgus by bracing.
  - Left unattended, the ultimate method of salvage may require a supramalleolar osteotomy.
  - This can be avoided by means of medial malleolar epiphysiodesis using a transmalleolar screw or an eight-plate (FIG 4).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Typically the parents have noted chronic, progressively flat or pronated feet.
  - Asymmetric and accelerated shoewear is common.
  - Activity-related pain is typically lateral, beneath the fibula, as a result of impingement on the talus or calcaneus.
  - There may be medial pain, presumably due to tension on the deltoid ligament or to brace irritation.
  - Concomitant knee or hindfoot valgus will exacerbate the symptoms.
While orthotics may provide support, they will have no beneficial effect. As the deformity progresses, brace tolerance diminishes.

The clinician should observe the patient’s stance from the hindfoot position.

The patient’s knee alignment is observed. Genu valgum or circumduction gait exacerbates hindfoot loading.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Radiographs
  - Weight-bearing AP and lateral views of the ankles
  - Weight-bearing AP lateral of the feet to assess subtalar alignment
  - Weight-bearing AP of the lower extremities, if there is perceived valgus or varus deformity of the knee
- EMED foot pressure studies (optional)
- CT scan or MRI if a distal tibial physeal bar is suspected
- CT scan of the foot if a concomitant tarsal coalition is suspected

**DIFFERENTIAL DIAGNOSIS**

The deformity is often bilateral: some of the conditions that are known to result in progressive ankle valgus include the following.

- Neuromuscular
  - Cerebral palsy
  - Spina bifida
  - Neurofibromatosis
- Hereditary—growth
  - Hereditary multiple exostoses
  - Multiple epiphyseal dysplasia
- Genetic
  - Down syndrome
  - Other syndromes
- Traumatic
- Clubfoot
- Idiopathic

The underlying diagnosis (see above) has often been established, but the underlying cause has little relevance to the
treatment. The degree of deformity and the evolution of symptoms dictate the timing and need for intervention.

**NONOPERATIVE MANAGEMENT**
- Activity restriction and nonsteroidal anti-inflammatories are not helpful.
- Physical therapy remedial exercises are of no benefit.
- Soft orthoses or UCB inserts are temporizing means of reducing foot discomfort and extending shoewear.
  - They are relatively more efficacious for subtalar instability than ankle valgus.
  - They will not effect any growth modulation or improvement in skeletal alignment, however.

**SURGICAL MANAGEMENT**
- The indications for surgery relate to the evolution of activity-restricting pain.
- Valgus may be manifest in children under age 10 but is more prevalent during the adolescent growth spurt.
- Many patients have already exhausted nonoperative options, such as shoewear modifications, nonsteroidal anti-inflammatories, and activity restriction.

**Preoperative Planning**
- Both the clinical examination and appropriate weight-bearing radiographs should verify the presence and magnitude of valgus deformities, not only of the ankles but also (occasionally) of the hindfeet and knees as well.
  - In specific conditions, multilevel surgery may be indicated.
  - When the cause involves neuromuscular conditions, concomitant muscle imbalance may warrant combined procedures such as gastrocnemius recession or tendon transfer.
  - When available, a pedobarograph may be useful for documenting pathologic foot stresses.

**Positioning**
- The patient is positioned supine on the operating table.
- The mini or standard C-arm may be used.
- Calf or thigh tourniquets are optional, at the discretion of the surgeon.

**Approach**
- For a transmalleolar screw, a 5-mm transverse incision below the tip of the medial malleolus will suffice.
- For plate correction, a vertical 12-mm incision over the medial distal tibial physis is optimal.
  - The dissection is subcutaneous, with preservation of the peristeam.
  - The only nearby neurovascular structures are the saphenous nerve and vein. These are anterior to the incision and easily avoided.
  - Supramalleolar osteotomy is the option of last resort.

**MEDIAL MALLEOLAR SCREW HEMIEPIPHYSIODESIS**
- With the patient supine and a calf tourniquet inflated (optional), the tip of the medial malleolus is palpated and a 5-mm transverse incision is marked.
- The subcutaneous tissues may be injected with 0.25% Marcaine.
- The incision is made sharply and deepened with a hemostat, spreading the subcutaneous tissues down to the tip of the malleolus.
- A vertical 1.6-mm guidewire is driven upward, with care taken to avoid the ankle mortise.
  - Its trajectory should be vertical, so that the screw will be just lateral to the medial cortex.
  - The more peripheral the fulcrum, the more efficient and rapid the correction will be.
- The C-arm is used to check the guidewire placement in the AP, mortise, and lateral projections.
- The tip of the malleolus is drilled with a 3.2-mm cannulated drill bit and a single 4.5-mm cannulated, fully threaded, cortical screw 40 to 50 mm in length is inserted (no washer is necessary; **TECH FIG 1**).
- The guidewire is removed and the screw should be tightened so that the screw head is not prominent. However, if the head is buried, the screw may be hard to retrieve in the future.
- The wound is closed with 4-0 Monocryl sutures and covered with Steri-Strips, OpSite, and an Ace bandage.

**TECH FIG 1**
- **A.** Transphyseal cannulated 4.5-mm screw insertion is performed percutaneously over a 1.6-mm guide pin for accuracy. The ideal fulcrum is near the medial cortex of the tibia for maximal angular correction. Screw removal is facilitated using the guide pin to seat the screwdriver. **B.** The growth line (arrows) indicates the angular correction achieved to restore a horizontal plafond. Note the downward slope of the physis and the slight bend in the screw, consequent to the intra-physeal fulcrum and the considerable forces of growth on a rigid implant.
GUIDED GROWTH USING AN EIGHT-PLATE

- With the patient supine and under tourniquet control, the distal medial tibial physis is identified using the image intensifier.
- A 12-mm incision is marked in the skin and (optionally) injected with 0.25% Marcaine.
- The incision is made sharply, carrying the dissection through the subcutaneous tissues, with care taken to avoid injury to the periosteum (TECH FIG 2A).
- A Keith needle is inserted into the physis and its position is checked with the C-arm (TECH FIG 2B).
- A 12-mm eight-plate is inserted, placing its center hole over the needle, and applied extraperiosteally (TECH FIG 2C).
- 1.6-mm smooth guide pins are inserted, first into the epi-physesis and then the metaphysis, avoiding the ankle joint and physis (TECH FIG 2D).
- The cortex is drilled to a depth of 5 mm using the cannulated 3.2-mm drill.
- Fully threaded, cannulated screws are then inserted (TECH FIG 2E). For the ankle, the 16- or 24-mm screws may be used. There is no particular advantage to the short (16-mm) screw, but sometimes there is not sufficient room for the 24-mm one. The screws do not have to match or to be parallel.
- After the plate and screw positions are confirmed on the AP and lateral views, the guide pins are removed and the screws are countersunk into the plate (TECH FIG 2F).
- After routine wound closure, a soft compression dressing is sufficient.

TECH FIG 2 • A. For the eight-plate technique, a 12-mm medial incision is made, preserving the periosteum. B. The physis is localized with a Keith needle. C. The eight-plate is slipped over the needle to center this on the physis. D,E. Two 1.6-mm guide pins are inserted parallel to the physis, followed by the self-tapping, cannulated, fully threaded 4.5-mm screws. F. The guide pins are removed and the screws countersunk into the plate. Shown here are 24-mm screws; the alternative is to use the 16-mm screws.

SUPRAMALLEOLAR OSTEOTOMY (SKELETAL MATURITY)

- An incision is made over the medial metaphyseal flare of the tibia.
- Kirschner wires are inserted to guide the saw or osteotome, and the surgeon triangulates for the closing wedge.
- The tibia is cut, leaving lateral cortex intact if possible.
- The fibula is left intact unless the surgeon intends to correct more than 20 degrees of rotation.
- The tibial wedge is removed.
- Smooth, crossed Steinmann pins or plate fixation is used to stabilize tension band vs. intact fibula.
- A below-knee cast is applied and the patient is kept non-weight bearing for 4 weeks.
PEARLS AND PITFALLS

The surgeon should avoid countersinking a transphyseal screw. ■ Fluoroscopy and overdrilling may be necessary for removal.
A vertical transphyseal screw trajectory is optimal.
The surgeon should avoid partially threaded screws. ■ These are easy to strip and are difficult or impossible to remove.
The surgeon should avoid periosteal damage.

POSTOPERATIVE CARE

- Hemiepiphysiodesis
  - No immobilization is required.
  - Immediate weight bearing is permitted.
  - There are no activity restrictions.
  - Follow-up is at 6-month intervals with weight-bearing AP radiographs of the ankles.
  - The implant is removed when the plafond is horizontal, regardless of fibular length.
- Supramalleolar osteotomy
  - The patient uses a cast and crutches for 1 month.
  - The patient can use a 3D boot for the second month.
  - Implants are removed after healing.

OUTCOMES

- Initially there is no visible difference, and the family needs to be aware of this.
- The correction is slow and subtle, so routine follow-up (every 6 months) is imperative.
- Correction to neutral, or slight varus, will take 12 to 24 months on average.
- The implant is removed on correction of the valgus deformity.
- Follow-up should continue until maturity to watch for recurrence deformity.
- Premature physeal closure is exceedingly unlikely.

COMPLICATIONS

- Complications are predominately related to the transphyseal screws, which are rigid, transgressing the physis and pitted against the dynamic forces of growth (Fig 5).

FIG 5 • A. On the left, the physis blew past the retained screw. B. As a result of stripping, this screw spun in place, migrated proximally, and could not be removed. C. As the valgus deformity corrected, this screw head ended up within the ankle, notching the talus (with pain) and proved challenging to retrieve. D. This patient failed to return before overcorrecting into varus. E. The screw could not be removed, necessitating a corrective opening wedge osteotomy (through the screw). F. This 17-year-old boy with Marfan syndrome presented with a bent implant and varus overcorrection. Luckily his hindfoot valgus compensated and no osteotomy was needed. (continued)
Stripping, bending, or breakage of the transphyseal screw may make implant removal difficult or impossible.
If the physis closes in the presence of varus deformity, the only recourse is a corrective osteotomy.
Compared to the transphyseal screw, the medial plates are easier to locate and remove.

REFERENCES
DEFINITION
- Psoas and adductor contractures are most common in cerebral palsy but can occur in any neuromuscular condition owing to disuse, muscular imbalance, or spasticity.
- The degree of contracture varies depending on the patient’s age and the severity of neuromuscular dysfunction.
- Detecting hip flexion contracture (psoas) is challenging.
- The challenge for the adductors is deciding which muscles to lengthen and how much lengthening to do.

ANATOMY
- The psoas is part of the primary hip flexor group, the iliopsoas.
- The psoas muscle originates from the transverse processes of the lumbar vertebrae. The muscle belly passes over the sacrum into the pelvis (FIG 1A).
- At the level of the pelvic brim (superior pubic ramus), the intramuscular tendon can be found.
- At this level, the psoas lies underneath the muscle belly of the iliacus. The femoral neurovascular bundle is superficial to the iliacus (FIG 1B,C).
- The psoas and iliacus tendons combine below the level of the pelvic brim to form a common tendon that inserts on the lesser trochanter.
- The adductor longus, adductor brevis, adductor magnus, and gracilis are clinically considered the adductor group of the hip. Their origins arise from the pubic and ischial rami as well as the pubic tubercle and they insert medially on the femur (adductors) and proximal tibia (gracilis) (FIG 1D).
- The adductor longus has a tendinous origin, the gracilis has a muscular fascia, and the adductor brevis and magnus have muscular origins.
- The anterior branch of the obturator nerve lies in the interval deep to the adductor longus and superficial to the adductor brevis, while the posterior branch of the obturator nerve lies in the interval deep to the adductor brevis and superficial to the adductor magnus.

PATHOGENESIS
- Hip flexion and adduction contractures develop over time due to:
  - Lack of typical functional activities
  - Muscular imbalance between these muscle groups and their antagonists, the hip extensors and abductors, due to either weakness of the antagonists or spasticity of the agonists
  - A hip flexion contracture is typical at birth and persists in infancy up until the time the child begins to stand and walk. In an older child who has not achieved standing and walking ability, a hip flexion contracture therefore may represent a persistence of the normal fetal alignment.
- At birth, the normal amount of hip abduction range of motion is 60 to 90 degrees, significantly greater than the expected range of motion of adults.
- Appropriate musculotendinous length develops during growth as the muscle responds to bone growth and stretch associated with typical childhood activities such as walking, running, and playing. Growth occurs at the musculotendinous junction because of the addition of new sarcomeres.
- Contractures of these structures do not allow the joint to achieve normal positions for daily activities.

NATURAL HISTORY
- Contractures, if severe and persistent, can lead to hip subluxation, hip dysplasia, and ultimately hip dislocation.
- Hip dysplasia and especially hip dislocation are most common with more severe cerebral palsy (quadriplegia, minimally ambulatory or nonambulatory, Gross Motor Function Classification System [GMFCS] IV and V) and in L2- or L3-level myelodysplasia because muscular imbalance at the hip is most severe (innervated hip flexors and adductors, paralyzed abductors and extensors).
- In more functionally mobile children with cerebral palsy (GMFCS I, II, and III), psoas and adductor contractures lead to anterior pelvic tilt, excessive pelvic motion, and lack of hip extension in terminal stance and contribute to crouch.
- Although a scissoring gait is commonly considered to be due to adductor contractures, this visual appearance most commonly results from the combination of hip and knee flexion with internal hip malrotation due to excessive femoral anteversion.
- In longstanding cases, hip dysplasia can lead to degenerative arthrosis.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Physical examination methods include the following:
  - Hip flexion-extension range of motion: Normal walking function requires 7 degrees of extension beyond neutral pelvic position. Therefore, even small contractures limit functional range of motion, shorten step length, and induce compensatory movements.
  - Hip abduction-adduction range of motion: Maximum abduction range of motion during typical walking is only 5 degrees. Therefore, even moderate limitations of hip abduction range of motion may not have functional significance (unless spasticity is also present). Normal hip development may not occur if abduction range of motion is limited.
  - If resistance is felt as the hip is extended and abducted, spasticity is present. Increasingly severe spasticity increases the risk of development of subsequent contracture. For ambulation, spasticity (even in the absence of contracture) can limit movement.
  - Hip flexion and hip abduction strength are tested in the supine position. Lengthening a contracted and weak muscle may adversely affect function. Weak, antagonistic muscle groups (hip extensors, hip abductors) predispose to
FIG 1 • A. Hip flexor anatomy. The psoas arises from the lumbar spine transverse processes. At the level of the pubic ramus, as it exits the pelvis, it has an intramuscular tendon. Note the proximity of the femoral nerve and artery anteriorly. B,C. Transverse plane anatomy of the hip. B. Even though this cross section is slightly distal to the pubic ramus, the reason for recommending an approach underneath (lateral) to the iliacus is clear. C. If the iliacus is retracted anteriorly and medially, the femoral neurovascular structures are protected by the muscle belly of the iliacus. The psoas muscle and tendon can be directly visualized. D. Adductor anatomy. The surgeon can orient himself or herself by identifying the tendinous adductor longus origin. The pectineus is lateral and the gracilis medial. The anterior branch of the obturator nerve lies on the anterior surface of the adductor brevis (deep to the adductor longus) after emerging from the obturator foramen just lateral to the pectineus.
flexion and adduction contractures and contribute to muscle imbalance.
- When examining a child for hip flexion contracture, the examiner should not be misled by the presence of a knee flexion contracture that prevents full extension of the leg. This can be avoided by moving the patient to the side of the examination table and allowing the lower leg to drop off the side of the table.
- Femoral anteverision must also be examined for and ruled out (see Chap. PE-27).
- Accurately identifying and controlling pelvic position is crucial for evaluating hip extension and abduction range of motion.
- For the nonambulatory patient, the examiner should look for hyperlordosis and a flexed, adducted, internally rotated hip. For the ambulatory patient, observation of gait may show hyperlordosis, limited step length, scissoring gait, or crouch gait.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Supine anteroposterior (AP) pelvis radiograph (**FIG 2**)
  - Pelvic obliquity
  - Adducted hip
  - Lordotic pelvis
  - Varying degrees of hip dysplasia
- Gait analysis may reveal:
  - Pelvic obliquity with affected side elevated
  - Limited hip abduction range of motion in late stance and during swing phase
  - Excessive anterior pelvic tilt with or without excessive pelvic range of motion
  - Limited hip extension range of motion in terminal stance

**DIFFERENTIAL DIAGNOSIS**
- Hip dysplasia or dislocation
- Knee flexion deformity
- Hip abductor or extensor weakness
- Excessive femoral anteverision
- Contracture of secondary hip flexors (eg, myelodysplasia)

**NONOPERATIVE MANAGEMENT**
- Physical therapy for range of motion and strengthening
- Positioning aids:
  - Standers
  - Sleeping prone
  - Hip abduction pillow, Scottish Rite brace with thoracolumbar extension
  - Botulinum toxin injections

**SURGICAL MANAGEMENT**

**Preoperative Planning**
- The AP pelvis radiograph is reviewed to rule out hip dysplasia.
- Examination under anesthesia is performed as described above. Under general anesthesia, hypertonicity is no longer present and the true difference between restricted range due to high muscle tone versus musculotendinous contracture can be appreciated.
- Also, the secondary hip flexors (tensor fascia lata and sartorius) can be palpated to rule out secondary contracture (uncommon in cerebral palsy but common in myelodysplasia).

**Positioning**
- The patient is positioned supine.
- The leg is draped free to allow flexion and extension of the hip and knee joints as well as abduction of the hip.
- Care must be taken with draping to ensure access to the anterior pelvis up to the groin crease to allow adequate surgical exposure.

**Approach**
- Various approaches have been described for psoas lengthening.
  - My preferred incision is a 3- to 4-cm oblique incision along the inguinal ligament that starts at the anterior superior iliac spine and is directed inferomedially.\(^3\)
  - Surgeons less comfortable with dissecting the abdominal musculature near the inguinal ligament prefer a more proximal incision at the iliac crest with the abdominal musculature taken off the subcutaneous border of the ilium. The psoas tendon is approached at the same level (the pelvic brim) and therefore the exposure of the tendon is more difficult from this more proximal incision.
  - Sutherland preferred an exposure distal to the inguinal ligament.\(^5\)
- All approaches use the same deep tissue plane underneath (lateral) to the iliacus muscle belly.
- The proximity of the femoral neurovascular structures has been well documented and is a cause for caution.\(^4\)
- The surgical concept of psoas lengthening at the pelvic brim was adapted from Salter’s description of lengthening the psoas tendon while performing a Salter pelvic osteotomy.

**FIG 2** • AP pelvis radiographs. **A.** Common findings of coxa valga (although femoral anteverision cannot be eliminated as a possibility): break in the Shenton line indicating subluxation, incomplete femoral head coverage, pelvic obliquity (right side elevated), mild windswept hips (right adducted), and mild acetabular dysplasia (right greater than left). **B.** In this case, severe hip flexion contractures result in anterior pelvic tilt. The AP pelvis radiograph results in an inlet view (obturator foramina are not visible).
PSOAS LENGTHENING AT THE PELVIC BRIM

Incision and Dissection

- An oblique incision is made along the inguinal ligament starting at the anterior superior iliac spine and extending distal and medial (TECH FIG 1A–C).
- The external oblique fascia is identified and divided just above its attachment on the inguinal ligament (TECH FIG 1D).
- Blunt dissection through the internal oblique and transversus abdominis just medial and adjacent to the anterior superior iliac spine allows access to the inner table of the ilium extraperiosteally (TECH FIG 1E).
- The lateral femoral cutaneous nerve typically crosses the surgical wound and is identified and protected, but sometimes it is medial and not encountered.

Tendon Identification and Division

- With the hip flexed, a finger is passed down along the superior pubic ramus underneath the iliacus and psoas to identify the psoas tendon by palpation (TECH FIG 2A).
- The psoas tendon is visualized by retracting the iliacus medially with an Army-Navy retractor (TECH FIG 2B).
- A right-angled clamp is passed around the psoas tendon (TECH FIG 2C).
- By isolating it from the surrounding muscle, the structure is confirmed to be the psoas tendon.
- Muscle fibers are retracted and the tendon is divided with electrocautery, leaving the muscle intact (TECH FIG 2D).
- Any inflexible (tendinous or myofascial tissues) should be divided. Many patients have a psoas minor tendon, which must also be identified and divided. Muscular tissues are left intact to maintain hip flexor function.
For the adductors, a short transverse (most often) or longitudinal incision over the palpable origin of the adductor longus is used (TECH FIG 3A).

The adductor longus tendon is separated from the surrounding tissues (pectineus laterally, gracilis medially [TECH FIG 3B], and adductor brevis and anterior branch of the obturator nerve deep).

The adductor longus tendon is divided as proximally as possible (TECH FIG 3C,D). For ambulatory patients, this is typically the only tissue that should be lengthened.

If necessary, for nonambulatory patients and for more severe neuromuscular hip dysplasia, a partial or complete division of the adductor brevis and other contracted tissues can be performed.

**TECH FIG 2** • A. With the hip flexed, the interval between the superior pubic ramus and the iliacus is developed with blunt finger dissection to palpate the psoas tendon. B. The psoas tendon is visualized by retracting the iliacus medially with an Army-Navy retractor. C. A right-angled clamp is passed around the psoas tendon. D. The tendon is divided with electrocautery, leaving the muscle intact.

**TECH FIG 3** • Adductor longus tenotomy. A. A short transverse incision (pubis left, knee right) exposes the tendinous origin of the adductor longus (pectineus laterally, gracilis medially). B. A right-angled clamp isolates the adductor longus tendon and muscle. C. As proximally as possible, the origin is divided. D. The preserved anterior branch of the obturator nerve lies on the adductor brevis.
PEARLS AND PITFALLS

| Indications | • In the nonambulatory cerebral palsy patient, hip flexor pathology is fairly routinely recognized and therefore not missed. On the other hand, identification of pathology and indications for psoas lengthening in the ambulatory cerebral palsy patient are less well agreed upon. As a result, I believe that psoas lengthening is too often not included in the surgical plan. |
| Surgical site | • In the 1970s, Bleck recognized that release of the iliopsoas tendon at the lesser trochanter in the ambulatory patient resulted in excessive weakness. Release at that level must be avoided in ambulatory patients. • In nonambulators, the iliopsoas combined tendon can be released from the lesser trochanter, but care must be taken not to violate the apophysis of the lesser trochanter in order to avoid heterotopic bone formation along the iliopsoas tendon sheath postoperatively. |
| Early recurrence | • If significant spasticity is present, pain and spasm may lead to difficulty in maintaining postoperative positioning in extension and abduction, leading to recurrence of hip flexion or adduction contractures. Botulinum toxin injected into the hip flexors and adductors at the time of surgery, effective pain management, and meticulous care to avoid postoperative positioning in flexion and adduction are essential. |
| Obturator neurectomy | • Overcorrection resulting in abduction contracture is a high risk. Because of this iatrogenic risk with limited corrective options, this procedure should be abandoned. Safer, less aggressive procedures are favored. |
| Femoral neurovascular injury | • The femoral nerve, artery, and vein are very close to the psoas tendon but are anterior to the iliacus muscle. The iliacus muscle belly can provide protection for these structures if the surgical approach is deep to it. Other protection is afforded by performing the lengthening of the tendon with the hip in the flexed position to relax the neurovascular structures, directly visualizing the tendon within the muscle belly, and stimulating the tissue with electrocautery first before cutting (if the nerve is nearby, the knee will extend). |
| Inappropriate adductor lengthening | • The combination of femoral anteversion with hip and knee flexion deformity results in the visual appearance of a scissoring gait in ambulatory cerebral palsy patients and is more commonly the cause of scissoring. In ambulators, only adductor longus tenotomy should be performed, and it should be performed rarely. • The adductors are more commonly spastic and contracted in more severe hemiplegic cerebral palsy. Therefore, adductor longus tenotomy is more often necessary. |

POSTOPERATIVE CARE

- Psoas lengthening
  - Postoperative elevation of the leg is avoided because it leads to a flexed hip position.
  - Prone positioning is done two or three times a day for at least 30 minutes.
  - A knee immobilizer promotes not only an extended knee but also an extended hip.
  - After 3 weeks, an active hip flexor strengthening program is instituted.
- Adductor lengthening
  - An abductor pillow is used full time for 3 weeks and part time for the next 3 weeks, and early range of motion is instituted.
  - After 3 weeks, an adductor strengthening program is instituted.
- For both procedures, weight bearing can be instituted as tolerated. These procedures are commonly performed in conjunction with osteotomy surgery, in which case weight bearing is typically begun 3 to 4 weeks postoperatively.

OUTCOMES

- Psoas lengthening is commonly performed in conjunction with femoral osteotomy with or without pelvic osteotomy for treatment of hip dysplasia in nonambulatory patients. A redislocation rate of less than 10% can be expected. In ambulatory cerebral palsy patients, psoas surgery improves dynamic hip dysfunction. There is no evidence that psoas lengthening causes hip flexor weakness.
- Power production (H3 power burst) is maintained.
- When psoas lengthening is performed in conjunction with femoral derotation osteotomy, excessive anterior pelvic tilt may also improve.

COMPLICATIONS

- Excessive hip flexor weakness with tendon release at the lesser trochanter
- Femoral neurovascular injury
- Early recurrence of flexion-adduction deformity
- Worsened anterior pelvic tilt and forward trunk lean when hip flexion deformity is not recognized and treated
- Pelvifemoral instability if scissoring gait is treated with inappropriate adductor surgery

REFERENCES

DEFINITION

- The gait pattern of children with cerebral palsy (CP) is frequently disrupted by dynamic overactivity of the rectus femoris muscle.
- This disruption is characterized by delayed and diminished peak knee flexion in swing phase.
- Surgical transfer of the rectus femoris muscle to the medial hamstrings is usually performed in conjunction with other surgical procedures selected to address all elements of soft tissue and skeletal dysfunction that compromise gait in children with CP.
- This surgical strategy, termed single-event multilevel surgery (SEMLS), requires a comprehensive assessment of gait dysfunction using quantitative gait analysis.
- Proper management (surgical, orthotic, and rehabilitative) in childhood can result in an improved gait pattern that will be sustainable in the adult years.

ANATOMY

- The rectus femoris muscle is a portion of the quadriceps muscle group, which also includes the vastus lateralis, the vastus medialis, and the vastus intermedius muscles.
- The rectus femoris muscle is the only one of the quadriceps muscle group that is considered to be biarticular, as it crosses both the hip joint and knee joint. The remaining three muscles cross only the knee joint.
- The rectus femoris muscle is innervated by the femoral nerve. It has its origin on the anterior inferior iliac spine (direct head) and the innominate portion of the pelvis just proximal to the superior margin of the acetabulum (reflected head) and its insertion on the superior pole of the patella.
- The rectus femoris muscle fuses with the underlying vastus intermedius muscle several centimeters proximal to the superior pole of the patella.
- The rectus femoris muscle and the other three portions of the quadriceps muscle group envelop the patella to form the patellar tendon, which inserts on the tibial tubercle apophysis of the proximal tibia. It serves as a hip flexor and knee extensor.
- The rectus femoris muscle has a relatively small physiologic cross-sectional area and a relatively large ratio of tendon length to muscle fiber length, indicating that it is designed for maximal excursion and diminished force generation.
- In normal gait, the rectus femoris muscle is active in the stance to swing phase transition, where it acts to control the magnitude of the flexion excursion of the knee as the gait velocity increases. It is also active at the end of the swing phase to properly position the knee in the transition from swing to stance phase.
- The remaining three portions of the quadriceps muscle group are active during the loading response of stance phase, where they are essential in providing shock absorption function about the knee as the limb is loaded.

- From a functional perspective, the quadriceps muscle group is actually two groups, the first consisting of the rectus femoris muscle and the second consisting of the three femoris muscles (remaining three muscles).9

PATHOGENESIS

- CP is the consequence of an injury to the immature brain that may occur before, during, or shortly after birth. The nature and location of the injury to the central nervous system (CNS) determines the components of the neuromuscular and cognitive impairments.
- Common functional deficits are related to spasticity, impaired motor control, and disrupted balance and body position senses.
- Although the injury to the CNS is not progressive, the clinical manifestations of CP change over time owing to growth and development of the musculoskeletal system.
- The muscles typically exhibit a purely dynamic dysfunction during the first 6 years of life, characterized by a normal resting length and an exaggerated response to an applied load or stretch.
- With time, between 6 and 10 years of age, the muscles develop a fixed or myostatic shortening, resulting in a permanent contracture.
- As such, it is best to consider CP not as a single specific disease process, but rather a clinical condition with multiple possible etiologies.17

NATURAL HISTORY

- Ambulatory children with CP whose gait is disrupted by overactivity of the rectus femoris muscle typically walk with delayed and diminished knee flexion in swing phase. This may be associated with decreased velocity of hip flexion in the stance to swing phase transition and increased ankle plantarflexion in swing phase, called a “stiff” gait pattern.14,18
- These dynamic gait deviations at the hip, knee, and ankle disrupt the normal limb segment coordination that contributes to functional shortening of the limb during the swing phase of the gait cycle.16 As a result, children with CP who have a stiff gait pattern will exhibit compromised clearance of the limb in swing phase.14,18

PATIENT HISTORY AND PHYSICAL FINDINGS

- The clinical history, as provided by the child and the parents, usually contains complaints of toe dragging, tripping, abnormal shoe wear about the toes, and inability to keep up with peers in play and sports.
- A thorough examination will include the prone rectus femoris test (also known as the Duncan-Ely test).
- A positive slow rectus test indicates fixed shortening of the rectus femoris muscle.
- A positive fast rectus test indicates the presence of spasticity of the rectus femoris muscle.
IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiographic imaging is not required when determining the need for transfer of the rectus femoris muscle to improve gait in children with CP.
- Relevant data from quantitative gait analysis include temporal parameters, sagittal-plane kinematics at the knee and hip, and dynamic electromyography (EMG) of the rectus femoris muscle.
  - Gait velocity should be greater than 60% of age-matched normal. Children with CP who ambulate with a greatly diminished gait velocity will also exhibit disrupted sagittal-plane knee kinematics in swing phase, which will not be corrected by a rectus femoris muscle transfer.
  - Sagittal-plane knee kinematics will show decreased flexion range and velocity in the stance to swing transition, delayed and diminished peak knee flexion in swing phase, and diminished dynamic range of motion with a rounded or mounded wave form in swing phase (**FIG 1A**).3,10,11
  - Sagittal-plane hip kinematics during the stance to swing phase transition should be evaluated when considering surgical transfer of the rectus femoris muscle (**FIG 1B**).
    - A poor transition at the hip is characterized by decreased flexion range and velocity and is a contraindication to rectus femoris muscle transfer.3
  - Poor hip flexor function in the stance to swing transition will result in delayed and diminished peak knee flexion in swing phase, which will not be corrected by a rectus femoris muscle transfer.

DIFFERENTIAL DIAGNOSIS

- Delayed and diminished peak knee flexion in swing phase may be the consequence of:
  - Inappropriate activity of the rectus femoris muscle in swing phase. Transfer of the rectus femoris muscle is indicated in this situation.
  - Diminished overall gait velocity. This circumstance is a contraindication for transfer of the rectus femoris muscle.
  - Poor hip flexor function in the stance to swing phase transition. This circumstance is a contraindication for transfer of the rectus femoris muscle.
  - Leg-length inequality, when the reference limb is relatively short or the contralateral lower extremity is relatively long. In this situation, there is less need for functional shortening of the reference limb in swing phase. This circumstance is a contraindication for transfer of the rectus femoris muscle.

NONOPERATIVE MANAGEMENT

- In the ambulatory child with CP who is younger than 6 years, neurodevelopmental therapy and gait training may be helpful in improving the stiff gait pattern due to inappropriate activity of the rectus femoris muscle in swing phase.
- In the ambulatory child with CP who is age 6 years or older, there is no effective nonsurgical management of the stiff gait pattern.

**FIG 1** • A. Sagittal plane knee (**A**) and hip (**B**) kinematic plots of a child with a jump gait pattern. The gait cycle appears on the horizontal axis, the direction of motion on the vertical axis. The age-matched normal motion (mean ± 2 SD) appears as a purple band, and the subject’s data are indicated by a blue line. **A.** Kinematic indicators for transfer of the rectus femoris muscle are delayed and diminished peak knee flexion in midswing phase (**circle**), and decreased range and rate of knee flexion in the stance to swing transition (**arrow**). **B.** The kinematic contraindications at the hip for transfer of the rectus femoris muscle at the knee are decreased range and rate of hip flexion in the stance to swing transition (**arrow**). **C.** Dynamic electromyography (EMG) of the rectus femoris muscle in a child with CP. Three gait cycles are shown, separated by the solid black lines. The stance and swing phases of each cycle are separated by the dashed black lines. The normal timing of activation of the muscle is noted by the horizontal red lines at the bottom of the strip. The actual timing of activation of the muscle for the subject is shown by the oscillating red line at the middle of the strip. The dynamic EMG indicator for transfer of the rectus femoris muscle is prolonged and inappropriate activity in midswing phase (indicated by the **circles** in each gait cycle).
SURGICAL MANAGEMENT
- Achieving optimal outcomes after transfer of the rectus femoris muscle requires careful patient selection, proper surgical technique, appropriate postoperative orthotic management, and adequate rehabilitation resources (primarily physical therapy for conditioning and gait training) in the months after the surgery.

Preoperative Planning
- Proper clinical decision making and preoperative planning for surgery to improve gait in children with CP require the integration of data from five fields—clinical history, physical examination, diagnostic imaging, quantitative gait analysis, and examination under anesthesia—in a process described as a diagnostic matrix.

Positioning
- The child is placed on the operating table in the supine position.
- A tourniquet is placed about the most proximal portion of the thigh, and the extremity is carefully cleansed and draped to allow adequate exposure for the surgical approach to the rectus femoris muscle.

Approach
- The rectus femoris muscle is usually exposed via a direct anterior approach at the distal third of the thigh.
- This approach is particularly appropriate when transfer of the rectus femoris muscle and lengthening of the medical hamstring muscles are to be performed at the same time as part of SEMLS.

SOFT TISSUE DISSECTION
- An 8- to 12-cm incision is made over the anterior aspect of the distal third of the thigh, ending one to two fingerbreadths onto the superior pole of the patella (TECH FIG 1).
- The dissection is carried down through the subcutaneous layers to the fascia overlying the quadriceps muscle group.
- This fascial layer is incised for the full length of the incision, exposing the myotendinous portion of the rectus femoris muscle proximally and the superior pole of the patella distally.

ISOLATION OF THE RECTUS TENDON
- The rectus femoris muscle is identified and isolated proximally from the surrounding muscles of the quadriceps muscle group (vastus lateralis muscle laterally, vastus medialis muscle medially, and the vastus intermedius muscle deeply) (TECH FIG 2A).
- The rectus femoris muscle is dissected from proximal to distal, freeing it completely from the surrounding quadriceps muscle group.
- The dissection is carried onto the superior pole of the patella for 1 to 2 cm, and the insertion of the rectus femoris muscle onto the patella is completely released (TECH FIG 2B).
MOBILIZATION OF THE RECTUS FEMORIS TENDON AND TUNNELING

- A transfer stitch is placed into the distal end of the rectus femoris tendon, and the muscle–tendon unit is mobilized from distal to proximal using intermuscular dissection with scissors.
  - The rectus femoris muscle should be completely mobilized proximally to the level between the proximal and middle thirds of the thigh (TECH FIG 3A).
- A subcutaneous tunnel is made between the proximal and medial margin of the incision used to expose the rectus femoris muscle and the distal and anterior margin of the incision used to expose the hamstring muscles (TECH FIG 3B).
  - This tunnel should be superficial to the quadriceps fascia and deep to the majority of the subcutaneous fat of the medial thigh, and expanded to a width of two fingerbreadths.
- The rectus femoris muscle–tendon unit is passed through the subcutaneous tunnel and pulled into the incision overlying the hamstring muscles (TECH FIG 3C).
  - Tension is applied to the rectus femoris tendon using the transfer suture, and the line of pull of the rectus femoris muscle is assessed beneath the proximal margin of the anterior thigh incision.
  - Further proximal release may be necessary to optimize the line of pull of the rectus femoris muscle in its transferred position.

TRANSFER OF THE RECTUS TENDON

- The distal aspect of the rectus femoris tendon is transferred to the distal segment of the semitendinosus muscle tendon, which was previously released in the hamstring muscle lengthening (see Chap. PE-43).
  - The transfer is performed using a single interweaving of the rectus femoris and semitendinosus tendons (modified Pulvertaft technique) (TECH FIG 4).
  - The transfer is tensioned so that the muscle belly of the rectus femoris muscle is slightly tighter to palpation than the muscle bellies of the remaining three muscles of the quadriceps muscle group, when the knee is held in full extension.
- Three separate throws of a nonabsorbable suture are used to secure the transfer.

TECH FIG 3 • Medial views of the right thigh. A. Hip is to the right. Proximal mobilization of the rectus femoris. The rectus femoris muscle is manipulated using the transfer suture (dashed arrow) and released proximally using the scissors (solid arrow). B. Patella is to the left. Orientation of the transfer tunnel between the medial and anterior skin incisions (red arrow). A clamp is placed into the tunnel from distal medial to proximal anterior and used to guide the rectus femoris muscle–tendon unit to its site of transfer insertion (circle). C. The rectus femoris tendon is delivered into the medial incision (solid circle), where it will be transferred to the distal portion of the semitendinosus muscle tendon (dashed circle).

TECH FIG 4 • Medial view of the right thigh (patella is to the left), showing the transfer of the rectus femoris tendon to the semitendinosus muscle tendon using a single interweaving (modified Pulvertaft technique; circle) that will be stabilized by three throws of a nonabsorbable suture.
Distal transfer of the rectus femoris muscle to the medial hamstring muscles should be considered only for children with delayed and diminished peak knee flexion in swing phase due to overactivity of the rectus femoris muscle. When gait velocity is diminished beyond 70% of normal, poor hip flexor function in the stance to swing transition is present, or there is an anatomic or functional leg-length inequality (reference limb short), delayed and diminished peak knee flexion in swing phase will not be improved by transfer of the rectus femoris muscle.

When there is spasticity of the rectus femoris muscle, and the proper kinematic and dynamic EMG indicators are present, failure to perform a rectus femoris transfer at the time of medial hamstring muscle lengthening will result in the development of a stiff gait pattern.²,20

Transfer of the rectus femoris muscle to the sartorius, gracilis, semimembranosus, or semitendinosus muscles will have a comparable benefit on sagittal-plane knee kinematics in swing phase.¹,7,10,11 Of the medial hamstring muscles, the semitendinosus muscle is preferred because of its myoarchitecture (long tendon length) and insertion site on the proximal tibia, which is the furthest from the knee joint center (optimizing the lever arm available for the transferred muscle).⁴

The long anterior thigh incision and intermuscular proximal release of the rectus femoris muscle is a biarticular muscle and should be transferred to another biarticular muscle (such as the semitendinosus).

The line of pull of the transferred muscle–tendon unit should be as straight as possible. The long anterior thigh incision and intermuscular proximal release of the rectus femoris muscle must be performed. Adequate release of the rectus femoris muscle cannot be achieved through a small incision.

The transfer path should occur through a plane that minimizes scarring. The transfer tunnel for the rectus femoris muscle should be at the level of the subcutaneous fat, superficial to the quadriceps fascia.

The muscle transfer should be tensioned so the muscle belly is at a slight stretch, to optimize the length–tension relationship of the transferred muscle. The rectus femoris muscle transfer should be tensioned so the muscle is slightly tighter than the other portions of the quadriceps muscle group.

POSTOPERATIVE CARE

- Transfer of the rectus femoris muscle is rarely performed in isolation for children with CP, but rather a component of SEMLS.
- If complete knee extension has been achieved after lengthening of the medial hamstring muscles and transfer of the rectus femoris muscle, then the knee is protected in a knee immobilizer after surgery. The knee immobilizer is worn full time and the child is kept non-weight bearing for 2 weeks.
- Passive knee range of motion is initiated at 1 to 2 weeks after surgery.
- Weight bearing and gait training are begun 2 to 6 weeks after surgery, depending on which other surgeries have been performed as a part of SEMLS.

Proper rehabilitation under the guidance of an experienced physical therapist is essential, as many children with CP who have undergone simultaneous lengthening of the medial hamstring muscles and distal transfer of the rectus femoris muscle as part of SEMLS will begin to ambulate with a quadriceps avoidance gait pattern. This should be corrected by appropriate gait training early in the rehabilitation phase.

OUTCOMES

- The goals of surgical transfer of the rectus femoris muscle are to improve the timing and magnitude of peak knee flexion in swing phase in order to correct an existing stiff gait pattern or to avoid the development of such a pattern after inappropriate isolated lengthening of the medial hamstring muscles. Improved dynamic alignment at the knee during the swing phase of the gait cycle should result in improved gait efficiency and clearance of the swing limb.
- Improvements in swing-phase knee kinematics after rectus femoris muscle transfer have been documented at 1 year after surgery and have been shown to be maintained at 5 and 10 years of follow-up.¹,5,7,8,10,11,13,15,19,21
- Distal transfer of the rectus femoris muscle to the medial hamstring muscles has been shown to be superior to proximal or distal release alone.¹,10,11,19
- The site of transfer has been shown to have no impact on the dynamic transverse-plane alignment of the hip or knee during stance phase.¹⁰
COMPLICATIONS

■ Theoretical complications, such as suprapatellar rupture of the knee extensor mechanism, lack of knee extension in stance phase due to excessive tightness of the transferred rectus femoris muscle, and weakening of the quadriceps muscle group after transfer of the rectus femoris muscle, have not been reported in the literature.

■ The principal functional complication after transfer of the rectus femoris muscle is persistent quadriceps avoidance gait pattern, which may occur in children with CP who have significant spasticity and anxiety.

■ Proper rehabilitation under the direction of an experienced physical therapist is effective in managing this problem.

■ The principal cosmetic complication after transfer of the rectus femoris muscle is an unsightly scar that may develop at the incision site on the anterior aspect of the thigh. This is a consequence of the preferred incision crossing the skin lines of Langer.

■ Scar formation is minimized by proper incision wound management (pressure applied by massage) during the postoperative rehabilitation phase.

REFERENCES


DEFINITION
- Proximal hamstring lengthenings are primarily performed in the treatment of spastic hip subluxation, mainly in children prior to adolescence.
- Based on modeling studies, the hamstrings are a significant contribution to increasing the force in spastic hip disease, which causes hip subluxation. They are also a component that keeps the knees flexed and secondarily encourages flexion combined with spastic hip flexors, which causes the knee to fall into internal rotation and adduction, magnifying the influence of the concomitant spastic adductors.
- This posture of hip flexion and internal rotation and adduction, with the addition of high muscle force, tends to drive the hip posterosuperiorly out of the acetabulum.
- The primary period during which spastic hip disease occurs is 2 to 8 years of age, although some children are still at risk through their adolescent growth spurt and need to be monitored.

ANATOMY
- Hamstring attachments on the pelvis are very broad muscular attachments and do not have a substantial amount of tendon.
- The exception to this is that the semimembranosus tends to have a tendinous insertion and may be confused with the sciatic nerve if care is not taken.
- There tends to be some broad fascial insertion with both the biceps and the semitendinosus.

PATHOGENESIS
- Spastic hip disease is a pathologic force that has both an abnormal direction of the vector and a force vector that is too high caused by spastic muscles.
- The muscles, in order of their importance, are the adductor longus, the gracilis, the proximal insertion of the hamstrings, and the iliopsoas.
- An important cause of spastic hip subluxation is positioning of the hip into internal rotation and hip flexion and adduction for a significant component of the child’s daily posturing.

NATURAL HISTORY
- Abnormal hip subluxation typically begins around 2 years of age and then has a progression of about 10% of migration every 6 months if the progression is occurring.
- Therefore, physical examination, monitoring of the hip in abduction, and an anteroposterior (AP) pelvis radiograph in which the Reimer migration index is measured every 6 months would be sufficient to pick up early spastic hip disease.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The concern for spastic hip disease is primarily present in children with spasticity, although some adolescents will be at risk.
- The primary physical examination finding is the limitation of hip abduction with hips extended and knees extended.
- Also, a child whose predominant posture both in sitting and lying is with hip flexion adduction and internal rotation is at high risk.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- The primary radiographic investigation is a supine AP pelvic radiograph in which the Reimer migration index is measured.
  - Normal should be 25% or less at all ages. Abnormal is greater than 30%.
  - If there is a question as to whether this is the standard hip subluxation predominantly occurring in the posterosuperior aspect of the acetabulum, a CT scan may be obtained to fully evaluate the position of the hip joint. However, this is not routinely required.

DIFFERENTIAL DIAGNOSIS
- Hip subluxation secondary to developmental hip dysplasia
- Congenital hip dislocation
- Hypotonic hip dislocation

NONOPERATIVE MANAGEMENT
- No conservative treatment options have been documented to be efficacious.
- There have been several attempts at treating spastic hip subluxation with botulinum toxin injection; however, preliminary evidence suggests that the failure rate is high and the need for later reconstruction will be higher than with adequate surgical release.

SURGICAL MANAGEMENT
Preoperative Planning
- The indications for the procedure are a migration index of 30% to 60% in a child who is less than 8 to 10 years of age and has limited hip abduction, meaning less than 30 degrees of hip abduction with hips and knees extended.
- This examination should be performed under anesthesia.
- The goal of the treatment is to have the child lie without any force or pushing with bilateral hip abduction of more than 45 degrees at the end of the operative procedure.
- The indication for proximal hamstring lengthening is a popliteal angle of greater then 45 degrees with the child under anesthesia.

Positioning
- Proximal hamstring release combined with adductor lengthening is performed with the patient supine and with an adhesive drape placed over the groin.
Approach

- There are two approaches to proximal hamstring release.
- One is a straight posterior approach. However, this approach has the negative consequences of going through the area of major weight bearing for sitting.
- For this reason, it is preferred to do an approach through the medial groin as part of an adductor lengthening going through the fascial compartment of the gracilis.
- Only the approach to the gracilis as part of a full adductor lengthening is described here.

EXPOSURE

- An incision is made from the anterior border of the adductor longus for 2 cm posterior in a transverse plane (TECH FIG 1A).
- The adductor longus is identified with a longitudinal opening of the fascia realigning the adductor longus and is completely transected, with vigilance to ensure that the anterior branch of the obturator nerve is protected by visualizing it (TECH FIG 1B).

MYOTOMY

- The gracilis fascia is opened and a complete gracilis myotomy is performed (TECH FIG 2A).
- If the hip abduction with hip extended and under minimal force is now less than 45 degrees, the anterior branch of the obturator nerve is protected and the adductor brevis is identified, and sequential myotomy is performed until more than 45 degrees of abduction is obtained.
- If the child is not and will not be ambulatory and the hip migration is over 50%, the anterior branch of the obturator nerve is transected (TECH FIG 2B).
ILIOPSOAS TENOTOMY

- The interval between the adductor brevis and pectineus or the interval between the pectineus and the neurovascular bundle is opened to the iliopsoas tendon.
- A complete tenotomy of the iliopsoas tendon is performed if the child is nonambulatory. If the child is ambulatory, the tendon is retracted proximally until only the fascia of the psoas is tenotomized, leaving intact the large muscular iliacus (TECH FIG 3).

![TECH FIG 3](image)

HAMSTRING LENGTHENING

- The fascial compartment of the gracilis is opened posteriorly, and, with digital dissection, the posterior compartment muscles of the hamstrings are separated (TECH FIG 4A).
- The interval between the adductor magnus, which does not contract with knee flexion–extension, is separated from the semimembranosus and semitendinosus (TECH FIG 4B).
- The femur is palpated with the finger, and then the semimembranosus and semitendinosus and biceps muscles are all separated, leaving the sciatic nerve against the femur (TECH FIG 4C).
- The sciatic nerve can be palpated on the posterior aspect of the femur along the linea aspera.
- A right-angled clamp is then placed around the muscle mass and it is pulled anteriorly into the surgical wound for visualization with the hip extended and the knees flexed (TECH FIG 4D).
- Electrocautery is used and the muscle is transected.
- Any fascial or tendinous material is carefully inspected and stimulated with a nerve stimulator to make absolutely sure that it is not the sciatic nerve.
- It must be clear that the anesthesiologist has not had the child under paralysis, and there should be good muscle twitches documented by the anesthesiologist.

![TECH FIG 4](image)
COMPLETION AND WOUND CLOSURE

- The popliteal angle is checked again.
- It should have gone from greater than 45 degrees to about 20 to 30 degrees.
- The surgeon should not stretch the popliteal angle without palpating the sciatic nerve, which tends to become very tight, and must be careful not to overstretch the hamstrings at this point for fear of causing sciatic nerve palsy.
- The wounds are closed with a longitudinal closure of the fascial wound and a transverse closure of the subcutaneous wound and skin wound.

POSTOPERATIVE CARE

- The patient is placed in knee immobilizers.
- Pain is controlled typically with morphine and spasticity with diazepam given orally or rectally. Diazepam should be used on a standing order for 48 hours.
- Care is taken not to overstretch the hamstrings, especially in the first 2 or 3 weeks, for fear of causing sciatic nerve palsy, particularly in individuals with severe contractures.
- Removable Velcro enclosed knee immobilizers are used 8 to 12 hours a day.

OUTCOMES

- The goal of the surgical treatment is primarily to improve the child’s standing ability, if the child is able, and secondly to treat the spastic hip disease. About two thirds of patients whose migration index is 30% to 60% and who are 2 to 8 years old will not require further treatment for their spastic hip disease, and the hip subluxation will resolve either completely or to a major level.
- For children whose hip subluxation does not resolve, reconstruction with femoral and pelvic osteotomy may be required.
- It is important to monitor hip radiographs in individuals, even those who have responded well at an early age, throughout their whole adolescent growth, because recurrent subluxation may occur as late as the adolescent growth period.
- After complete maturation of growth, hips should have a migration percentage of less than 40%. There does not need to be further monitoring or concern after the completion of skeletal growth.

COMPLICATIONS

- The primary complication is sciatic nerve palsy. If it occurs, sciatic nerve palsy tends to occur from overstretching the nerve in the postoperative period.
- Wound infections are rare and can usually be treated with local care.
- Heterotopic ossification may occur, especially if the iliopsoas is released through the apophysis of the lesser trochanter.
- Proximal hamstring lengthenings during adolesence also run an increased risk of developing heterotopic ossification in the proximal muscle release site.

REFERENCES

DEFINITION
- The gait pattern of children with cerebral palsy (CP) is frequently disrupted by dynamic overactivity and shortening of the medial hamstring muscles.
- This disruption is characterized by increased knee flexion in stance phase, and decreased knee extension at the end of swing phase.
- Surgical lengthening of the medial hamstrings is usually performed in conjunction with other surgical procedures selected to address all elements of soft tissue and skeletal dysfunction that compromise gait in children with CP.
- This surgical strategy, termed single-event multilevel surgery (SEMLS), requires a comprehensive assessment of gait dysfunction using quantitative gait analysis.
- Proper management (surgical, orthotic, and rehabilitative) in childhood can result in an improved gait pattern that will be sustainable in the adult years.

ANATOMY
- The medial hamstrings consist of three muscles: the gracilis, the semimembranosus, and the semitendinosus. All three are considered biarticular muscles because they cross both the hip joint and knee joint.
  - The gracilis muscle is innervated by the obturator nerve and has its origin on the inferior pubic ramus and its insertion on the anteromedial aspect of the proximal tibia. It serves as a hip adductor and knee flexor. The gracilis muscle has a relatively small physiologic cross-sectional area and a relatively large ratio of tendon length to muscle fiber length, indicating that it is designed for maximal excursion and diminished force generation.7,9
  - The semimembranosus muscle is innervated by the sciatic nerve and has its origin on the inferior pubic ramus and其 insertion on the posteromedial aspect of the proximal tibia. It serves as a hip extensor and knee flexor. The semimembranosus muscle has a relatively large physiologic cross-sectional area and a relatively small ratio of tendon length to muscle fiber length, indicating that it is designed for minimal excursion and increased force generation.7,9
  - The semitendinosus muscle is innervated by the sciatic nerve and has its origin on the inferomedial portion of the ischium and its insertion on the posteromedial aspect of the proximal tibia. It serves as a hip extensor and knee flexor. The semitendinosus muscle has a relatively small physiologic cross-sectional area and a relatively large ratio of tendon length to muscle fiber length, indicating that it is designed for maximal excursion and diminished force generation.7,9
- The lateral hamstrings consist of the biceps femoris muscle, which is innervated by the sciatic nerve. The muscle is considered to be uniarticular, crossing only the knee joint, with its origin on the posterior aspect of the middle third of the femur and its insertion on the fibular head. It serves as a knee flexor.

PATHOGENESIS
- CP is the consequence of an injury to the immature brain that may occur before, during, or shortly after birth. The nature and location of the injury to the central nervous system (CNS) determines the neuromuscular and cognitive impairments.
- Common functional deficits are related to spasticity, impaired motor control, and disrupted balance and body position senses.
- Although the injury to the CNS is not progressive, the clinical manifestations of CP change over time because of growth and development of the musculoskeletal system. The muscles typically exhibit a purely dynamic dysfunction during the first 6 years of life, characterized by a normal resting length and an exaggerated response to an applied load or stretch. With time, between 6 and 10 years of age, the muscles develop a fixed or myostatic shortening, resulting in a permanent contracture.
- As such, it is best to consider CP not as a single specific disease process, but rather a clinical condition with multiple possible causes.14

NATURAL HISTORY
- Ambulatory children with CP whose gait is disrupted by overactivity and shortening of the medial hamstring muscles typically walk with increased knee flexion in stance phase and diminished knee extension in swing phase.
  - This is usually associated with increased ankle plantarflexion in stance phase and is called a “jump” gait pattern.12,16
  - Children with a jump gait pattern will have overactivity of the medial hamstring muscle group; the lateral hamstring muscle group is rarely involved.
  - As the child gets older and heavier, ankle plantarflexor insufficiency (due to muscle weakness and foot segmental malalignment) will eventually occur. This will result in increasing ankle dorsiflexion and knee flexion in stance phase, which is called a “crouch” gait pattern.12,16
  - Teenagers with a severe crouch gait pattern will have involvement of both the medial and lateral hamstring muscle groups.
  - As the ground reaction force falls further and further behind the knee during the stance phase in crouch gait, the demands on the knee extensor muscles increase, eventually resulting in painful patellofemoral overload.
  - For this reason the crouch gait pattern is not sustainable, and by the late teenage or young adult years individuals with this gait pattern frequently lose the ability to ambulate.
PATIENT HISTORY AND PHYSICAL FINDINGS

- The clinical history, as provided by the child and the parents, usually contains complaints of inability to stand up straight, inability to keep up with peers in play and sports, inability to walk distances (such as at the grocery store or the mall), and anterior knee pain after walking activities or at the end of the day.

- A straight-leg raise of 60 degrees or less is indicative of shortening of the medial hamstrings.

- A popliteal angle of 45 degrees or greater is indicative of shortening of the medial hamstrings.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiographic imaging is not required when determining the need for lengthening of the medial hamstrings to improve gait in children with CP.

- If lateral radiographs of the knee are obtained, however, they will frequently show patella alta, with fragmentation of the inferior pole of the patella; these are the sequelae of chronic and progressive patellofemoral overload (FIG 1).

- Relevant data from quantitative gait analysis include sagittal-plane kinematics and kinetics at the knee, and dynamic electromyography (EMG) of the medial hamstrings.

  - Sagittal-plane knee kinematics will show increased knee flexion of greater than 20 degrees at initial contact in loading response at the beginning of stance phase, and diminished knee extension at terminal swing at the end of swing phase (FIG 2A).

  - In jump gait pattern, full knee extension in midstance may occur. This is not a contraindication to lengthening of the medial hamstrings.

  - In crouch gait pattern, increased knee flexion will be of greater magnitude and is present throughout the stance phase.

  - Sagittal-plane knee kinetics will show an increased internal knee extension moment in stance phase (FIG 2B).

FIG 1 • Standing lateral radiograph of the knee in a child with cerebral palsy and a crouch gait pattern. There is a patella alta, with fragmentation of the inferior pole of the patella, indicating chronic overload of the knee extensor mechanism.

FIG 2 • Sagittal-plane knee kinematic plots of a child with a jump gait pattern (A) and kinetic plots of a child with crouch gait pattern (B). The age-matched normal motion (mean ± 2 standard deviations) appears as a light purple band and the subject’s data are indicated by a blue line. A. The gait cycle is on the horizontal axis, the direction of motion on the vertical axis. Kinematic indicators for lengthening of the medial hamstrings are increased flexion at initial contact and diminished extension at terminal swing (arrows). B. The gait cycle is on the horizontal axis, the internal moment on the vertical axis. Crouch gait pattern is characterized by an increased internal extension moment at the knee throughout stance phase (red arrows). C. Dynamic electromyography (EMG) of the medial hamstrings in a child with cerebral palsy. Three gait cycles are shown, separated by the solid vertical lines. The stance and swing phases of each cycle are separated by the dashed vertical lines. The normal timing of activation of the muscle is noted by the horizontal red lines at the bottom of the strip. The actual timing of activation of the muscle for the subject is shown by the oscillating red line at the middle of the strip. The dynamic EMG indicator for lengthening of the medial hamstring muscles is prolonged activity in midstance (indicated by the circles in each gait cycle).
In jump gait pattern, the increased knee moment will occur in the loading response and terminal stance subphases of stance phase.

In crouch gait pattern, the increased knee moment will be of greater magnitude and will occur throughout the stance phase.

Dynamic EMG of the medial hamstrings will show prolonged activity of the muscle group into the mid- and terminal stance subphases of stance phase (FIG 2C).

**DIFFERENTIAL DIAGNOSIS**

- Increased knee flexion in stance phase may be the consequence of:
  - Overactivity or shortening of the medial hamstring muscles
  - Surgical lengthening of the medial hamstring muscles is appropriate.
  - Ankle plantarflexor insufficiency, with disruption of the ankle plantarflexion–knee extension couple. This may be a consequence of muscle weakness or foot skeletal segmental malalignment, resulting in lever arm deficiency.6,8,15
  - The ankle plantarflexor insufficiency must be addressed directly to improve the gait deviation at the knee.
  - Dyskinetic CP, with disrupted balance and body position sense. In such cases, mildly increased knee flexion in stance phase gives a sense of stability to the child and is habitual.
  - Surgical lengthening of the medial hamstring muscles will not correct the gait deviation in this situation.
  - Increased knee flexion at the end of swing phase may be a consequence of:
    - Overactivity or shortening of the medial hamstring muscles
    - Surgical lengthening of the medial hamstring muscles is appropriate.
    - Increased ankle plantarflexion at the end of swing phase. Increased knee flexion will occur in swing phase to promote limb clearance and improve the foot position in the transition from swing to stance phase.
  - Decreased hip flexion in swing phase. Increased knee flexion will occur in swing phase to promote limb clearance.

**NONOPERATIVE MANAGEMENT**

- In children less than 6 years of age, with primarily dynamic deformity of the medial hamstrings, a community- or home-based stretching program may be effective at improving knee extension during gait for a limited period of time.
- Injection of botulinum toxin into the medial hamstrings, which decreases muscle spasticity via a reversible neuromuscular blockade, may also be effective for dynamic deformity in younger children.3
- Serial stretch casting of the knee has been shown to be effective for the treatment of mild myostatic deformity of the medial hamstrings, particularly after surgical lengthening.18
- Use of an ankle–foot orthosis may be effective treatment for increased knee flexion in stance phase that is the consequence of ankle plantarflexor insufficiency and disruption of the ankle plantarflexion–knee extension couple.5

**SURGICAL MANAGEMENT**

- Achieving optimal outcome after lengthening of the medial hamstring muscles requires careful patient selection, proper surgical technique, appropriate postoperative orthotic management, and adequate rehabilitation resources (primarily physical therapy for conditioning and gait training) in the months after the surgery.

**Preoperative Planning**

- Optimal clinical decision making and preoperative planning require the integration of data from five fields—clinical history, physical examination, diagnostic imaging, quantitative gait analysis, and examination under anesthesia—in a process described as a diagnostic matrix.4
- When considering lengthening of the medial hamstrings, the examination under anesthesia should include repeating the straight-leg raise and popliteal angle measurements as described above.
  - In children with CP that includes significant spasticity, it is frequently difficult to determine the relative contributions of dynamic overactivity and myostatic contracture to muscle deformity and dysfunction. When the child is under anesthesia, the spastic component is effectively removed, allowing the physician to perform a clinical examination to determine the presence or absence of myostatic or fixed muscle shortening.
  - Surgical lengthening of the muscle is most appropriate when significant myostatic or fixed shortening is present.
  - Lengthening of the lateral hamstring muscle is not necessary for children with either jump or crouch gait patterns.
  - Lateral hamstring lengthening is indicated only for teenagers with a severe crouch gait pattern, whose popliteal angle measurement fails to improve adequately (as described below) after lengthening of the medial hamstring muscles.

**Positioning**

- The child is placed on the operating table in the supine position.
- A tourniquet may be placed about the most proximal portion of the thigh. The extremity is carefully cleaned and draped to allow adequate exposure for the surgical approach to the medial hamstring muscles. Use of a tourniquet to minimize blood loss and maximize the operative exposure is favored when performing SEMLS that includes both soft tissue and skeletal surgeries.

**Approach**

- The medial hamstring muscles are usually exposed via a posteromedial approach at the distal third of the thigh.
- This approach is particularly appropriate when lengthening of the medial hamstring muscles and transfer of the rectus femoris muscle are to be performed at the same time as part of SEMLS.
LENGTHENING OF THE MEDIAL HAMSTRING MUSCLES (IN CONJUNCTION WITH TRANSFER OF THE RECTUS FEMORIS MUSCLE)

- A 6- to 10-cm incision is made over the posteromedial margin of the distal third of the thigh, ending two or three fingerbreadths proximal to the posterior skin crease of the knee joint (TECH FIG 1A).
- The incision is carried down through the subcutaneous tissues, past the saphenous vein and the sartorius muscle, exposing the three muscles of the medial hamstring muscle group (TECH FIG 1B).
  - The gracilis and semimembranosus muscles are exposed at the level of their myotendinous junction, and the semitendinosus is exposed at the level of its distal tendon.
- A proximal tenodesis is performed between the gracilis (at its myotendinous junction) and the semitendinosus (at its proximal tendon), using two throws of a nonabsorbable suture (TECH FIG 1C).
  - The semitendinosus muscle is then completely transected 1 cm distal to the tenodesis with the gracilis muscle (TECH FIG 1D).
- A fractional lengthening of the semimembranosus muscle is performed, using two transverse incisions, separated by 2 cm, through the broad and thin tendon overlying the muscle at the musculotendinous junction (TECH FIG 1E).
  - Care should be taken not to cut the muscle tissue underlying the tendon at this level.
- A fractional lengthening of the gracilis muscle is performed, using a single transverse incision located 1 cm distal to the tenodesis with the semitendinosus (TECH FIG 1F).
  - Care should be taken not to cut the muscle tissue underlying the tendon at this level.
- Repeat assessment of the popliteal angle is made after lengthening of the medial hamstring muscles.
  - The angle should be improved (ie, decreased) by 30 to 40 degrees.

**TECH FIG 1** • Medial views of the right knee. A. The posteromedial skin incision used for exposure of the medial hamstring muscles. B. The three muscles of the medial hamstrings group—the gracilis (solid arrow), the semimembranosus (dashed arrow), and the semitendinosus (dotted arrow). Each has distinct myoarchitecture. C. Proximal tenodesis of the gracilis and the semitendinosus muscles (circle). D. The tendon of the semitendinosus has been transected (arrow) distal to the tenodesis (red circle). E. A two-level fractional lengthening (arrows) of the semimembranosus muscle has been performed. F. A fractional lengthening (arrow) of the gracilis muscle has been performed distal to the tenodesis of the gracilis and semitendinosus muscles (circle).
LENGTHENING OF THE LATERAL HAMSTRING MUSCLE

- A 3- to 5-cm incision is made over the posterolateral margin of the distal third of the thigh, posterior to the posterior margin of the iliotibial band, ending three to five fingerbreadths proximal to the head of the fibula (TECH FIG 2A).
- The incision is carried down through the subcutaneous tissues, past the posterior margin of the iliotibial band, exposing the biceps femoris at the level of its myotendinous junction (TECH FIG 2B).

The common peroneal nerve, which is located adjacent to the posteromedial margin of the biceps femoris muscle, should be identified and gently retracted away from the muscle before lengthening.
- A fractional lengthening of the biceps femoris muscle is performed, using a single transverse incision (TECH FIG 2C).
- Care should be taken not to cut the muscle tissue underlying the tendon at this level.

FRACTIONAL LENGTHENING OF THE MEDIAL HAMSTRING MUSCLES (WITHOUT CONCOMITANT TRANSFER OF THE RECTUS FEMORIS MUSCLE)

- A 6- to 10-mm incision is made over the posteromedial margin of the thigh, at the juncture between the middle and proximal thirds (TECH FIG 3A).
- The incision is carried down through the subcutaneous tissues, exposing the three muscles of the medial hamstring group.

The gracilis, semimembranosus, and semitendinosus muscles are all exposed at the level of their myotendinous junction (TECH FIG 3B).
- A fractional lengthening of each of the three muscles is performed, using two transverse incisions, separated by 2 cm, for the semimembranosus muscle, and a single...
incision each for the gracilis and semitendinosus muscles, through the broad and thin tendon overlying the muscle at the musculotendinous junction.

- Care should be taken not to cut the muscle tissue underlying the tendon at this level (TECH FIG 3C).

- Repeat assessment of the popliteal angle is made after fractional lengthening of the medial hamstring muscles. The angle should be improved (ie, decreased) by 15 to 30 degrees.

### COMBINED FRACTIONAL LENGTHENING AND TRANSFER OF MEDIAL HAMSTRING MUSCLES (WITHOUT CONCOMITANT TRANSFER OF THE RECTUS FEMORIS MUSCLE)

- A 6- to 10-cm incision is made over the posteromedial margin of the distal third of the thigh, ending two to three fingerbreadths proximal to the posterior skin crease of the knee joint (TECH FIG 4A).

- The incision is carried down through the subcutaneous tissues, past the saphenous vein and the sartorius muscle, exposing the three muscles of the medial hamstrings group.

  - The gracilis and semimembranosus muscles are exposed at the level of their myotendinous junction, and the semitendinosus is exposed at the level of its distal tendon.

  - A clamp is placed on the proximal portion of the tendon of the semitendinosus muscle, and the tendon is transected distally (TECH FIG 4B).

- The gracilis muscle is transected proximally at the myotendinous junction, and the proximal portion of the muscle is released (TECH FIG 4C).

- The gracilis and semitendinosus muscles are retracted to expose the myotendinous junction of the semimembranosus muscle, where a two-level fractional lengthening is performed (TECH FIG 4D).

- The proximal portion of the semitendinosus muscle–tendon unit is transferred to the distal portion of the gracilis tendon and is secured with two throws of a nonabsorbable suture (TECH FIG 4E).

- Repeat assessment of the popliteal angle is made after combined fractional lengthening and transfer of the medial hamstring muscles. The angle should be improved (ie, decreased) by 30 to 40 degrees.

TECH FIG 4 • Medial view of the right knee.

- A. The posteromedial skin incision used for exposure of the medial hamstring muscles. 
- B. A clamp is placed on the proximal portion of the tendon of the semitendinosus muscle (solid circle), and the tendon (dotted line) is released distally (dotted circle). 
- C. The tendon of the gracilis muscle (arrow) is released proximally at the muscle’s myotendinous junction (circle). 
- D. A two-level fractional lengthening (arrows) of the semimembranosus muscle has been performed. 
- E. The proximal portion of the semitendinosus muscle–tendon unit (dotted arrow) is transferred to the distal portion of the tendon of the gracilis muscle (solid arrow). The transfer is secured with two throws of a nonabsorbable suture (circle).
In older children and teenagers with a longstanding jump or crouch gait pattern, lengthening of the popliteal angle should improve by 30 to 40 degrees on the examination after lengthening of the medial hamstring muscles. Aggressive lengthening to “improve” the popliteal angle closer to 0 degrees may result in excessive lengthening, and subsequent weakness, of the medial hamstring muscles. It is the change in, not the absolute magnitude of, the popliteal angle that is the proper goal of the surgical lengthening.

**Hamstring lengthening should be considered only for children with increased knee flexion in stance phase due to overactivity or fixed shortening (ie, contracture) of the hamstring muscles. Increased knee flexion due to ankle plantarflexor insufficiency (best managed by appropriate soft tissue and skeletal surgery at the foot and ankle, and appropriate orthotic management) will not be improved by lengthening of the hamstrings.**

**POSTOPERATIVE CARE**

- Lengthening of the hamstring muscles is rarely performed in isolation for children with CP; rather, it is usually a component of SEMLS.
- If full knee extension against gravity can be achieved immediately after surgery, use of a knee immobilizer is appropriate. Passive knee range of motion is initiated at 1 to 2 weeks after surgery.
- Weight bearing and gait training are begun 2 to 6 weeks after surgery, depending on which other surgeries have been performed as a part of SEMLS.
- If full knee extension cannot be achieved, a long-leg fiberglass cast is applied with the knee positioned in extension against gravity alone.
- The cast is univalved in the operating room to accommodate postoperative swelling and facilitate spreading of the cast in the first few days after surgery.
- Gradual serial stretch casting, correcting the residual knee flexion deformity at a rate of 5 degrees per week, is instituted.
- **Intermediate follow-up at 10 years after SEMLS has shown that kinematic and kinetic improvements after surgery are maintained despite deterioration in the static findings on physical examination.**

**COMPLICATIONS**

- The most common and significant early complication after lengthening of the hamstrings is neuropraxia of the sciatic nerve, which is due to excessive stretching of the nerve after correction of the dynamic and static knee flexion deformities.
- Neuropraxia of the sciatic nerve is characterized by pain and hypersensitivity about the foot. When this problem is encountered acutely in the immediate postoperative period, the position of immobilization of the knee should be adjusted toward increased flexion to relax the nerve.
- If a neuropraxia develops during the period of serial stretch casting of a residual knee flexion contracture, the stretch casting should be terminated for 1 to 2 weeks, and then resumed at a slow rate.
- If a neuropraxia is first appreciated during the rehabilitation period, management with medications such as gabapentin (mechanism of effect unknown) and physical therapy modalities for desensitization are appropriate.
- Recurrence of knee flexion deformity and increased knee flexion during the stance phase of gait may occur in the years after surgery due to a variety of factors.
As children grow, they pass through finite periods of accelerated rates of growth (growth spurts), where the longitudinal growth of the bones is greater than that of the muscles.

- Muscle shortening may recur and is usually effectively treated with a period of home- or community-based stretching exercises.

- As children grow, they get heavier, and as a result greater muscle forces are required to balance external forces during gait. Weakness of the ankle plantarflexor, knee extensor, and hip extensor muscles is common and may result in development of a crouch gait pattern in the years after SEMLS.

- Avoidance of obesity and ongoing muscle strength training and cardiovascular conditioning are important elements for maintaining optimal gait function in children with CP.

REFERENCES

DEFINITION
- Lengthening of the gastrocnemius fascia is commonly performed for conditions in which the patient positions the foot in equinus while either standing or walking.
- Equinus is defined as plantarflexion of the ankle. It can be measured both clinically and radiographically.
- The most common condition in which this procedure is performed is cerebral palsy, but other disorders, such as idiopathic toe walking, posttraumatic or surgical treatments, and other neuromuscular disorders, such as Duchenne muscular dystrophy, can also result in an equinus of the foot.
- Patients with some disorders, such as Charcot-Marie-Tooth disease, may appear to have equinus, but the true deformity is plantarflexion of the midfoot.

ANATOMY
- The medial and lateral heads of the gastrocnemius muscles, the soleus and the plantaris muscles, form the triceps surae. Although all are part of the same muscle group, their structure and function differ.
- The larger medial head of the gastrocnemius arises from the popliteal surface of the femur just above the medial femoral condyle, and the lateral head originates from the superolateral surface of the lateral femoral condyle.
- The medial and lateral muscle bellies insert into a midline tendinous raphe that widens into the aponeurosis of the gastrocnemius at or just above the midcalf. This tendon unites with the soleus and forms the conjoined tendon, which inserts into the calcaneus by way of the tendo Achilles.
- The gastrocnemius spans the ankle and knee joint and therefore can plantarflex the ankle or flex the knee.
  - It typically has fast twitch type II muscle fibers, which are responsible for short, powerful bursts of activity, such as running and jumping.
- The soleus lies deep (anterior) to the gastrocnemius muscle. It originates on the proximal tibia and inserts with the gastrocnemius into the conjoined tendon. Contraction results in only ankle plantarflexion. It is made up of primarily slow twitch type I muscle fibers and is responsible for primarily postural control.
- The plantaris arises just above the lateral head of the gastrocnemius and inserts into the calcaneus. It is largely vestigial and should be released at the time of surgery.
- The gastrocnemius can be selectively released or lengthened either at its origin, which is uncommonly done, or the tendon of the gastrocnemius, proximal to the conjoined tendon.
  - Lengthening at or below the conjoined tendon (ie, the tendo Achilles) lengthens the entire triceps surae.

PATHOGENESIS
- Equinus positioning of the foot can occur due to:
  - Increased tone or spasticity of the triceps surae muscles
  - Shortening of some or all of the muscles
  - Joint contracture
  - Bony deformity
- It is critical to determine the cause of the equinus because the treatment options differ in each circumstance.
- The initiating cause of this disorder varies.
  - Spasticity, weakness, and subsequent shortening of the muscle group can occur secondary to neuromuscular disorders such as cerebral palsy.
  - Relative shortening of the triceps surae, as occurs when the tibia is lengthened, or fixed positioning of the foot in equinus, such as prolonged casting in plantarflexion, can result in equinus of the ankle.
  - Bony changes at the ankle due to trauma or congenital disorders may also result in equinus.

NATURAL HISTORY
- The natural history varies according to each disease process and the prior treatment history.
- In patients with cerebral palsy, equinus tends to worsen if untreated. It may progress from increased tone to muscle tightness, joint contracture, and eventually bony deformity if untreated.
- Other disorders, such as idiopathic toe walking, often improve as the patient matures into adulthood.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Range of motion of the ankle should be assessed with the ankle in a neutral position.
  - Hindfoot valgus will allow for false (pseudo) dorsiflexion.
- The examination should be performed with the knee extended to assess gastrocnemius tightness and flexed to assess the soleus.
  - If the foot remains in equinus with the knee flexed, there is shortening of the soleus or joint contracture or bony deformity.
  - If the ankle can be dorsiflexed with the knee flexed, but not extended, then the equinus is due to gastrocnemius tightness only (Silfverskiöld test).
- Observational or instrumented gait analysis is important to integrate the physical findings with functional deficits. The patient should be evaluated walking and running.
  - Small limitations in dorsiflexion range may have little functional deficit.
  - Standing and walking or running foot position may differ greatly.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standard standing lateral radiographs of the feet are the best method to assess ankle equinus.
- Bony deformity can also be evaluated from this examination.
The angle between horizontal and a line drawn to the plantar aspect of the os calcis should be 15 degrees (0 and 30 degrees) (FIG 1).

The distal tibial should angle open anteriorly 10 degrees (the angle between a line drawn through the tibia and along the distal surface of the tibia should measure 80 degrees anteriorly, or 78 to 82 degrees). Angle B: the angle between horizontal and a line drawn to the plantar aspect of the os calcis should be 15 degrees (0 and 30 degrees).

DIFFERENTIAL DIAGNOSIS
- Cerebral palsy, Duchenne muscular dystrophy, and other neuromuscular disorders
- Idiopathic toe walking
- Congenital (fibular hemimelia)
- Bony deformity (posttraumatic, malalignment, asymmetric growth arrest)
- Prior immobilization
- Prior tibial lengthening

NONOPERATIVE MANAGEMENT
- Physical therapy and stretching is the most common form of treatment for mild deformities and is used in an attempt to maintain range gained by other methods.
  - The knee must be extended and the hindfoot placed in a neutral position when stretching the ankle.
  - Bracing, nighttime splinting, or both can be used in combination with other techniques. It is primarily used to maintain gains or prevent worsening deformity.
  - Botulinum toxin causes paralysis by blocking acetylcholine release at the neuromuscular junction.
  - It can be injected into the gastrocnemius muscle bellies in an attempt to decrease tone.
  - The effect lasts about 3 months, and therapy or casting can be combined with it.
- Serial casting involves a series of short-leg casts that are placed with the knee flexed and gentle dorsiflexion pressure.
  - They are changed weekly or biweekly, each time with increasingly greater dorsiflexion.
  - Usually three or four casts are used until satisfactory range is obtained.
  - Recurrence is common, and if not carefully performed, skin breakdown can occur.

SURGICAL MANAGEMENT
- The surgical management of equinus varies depending on the cause.
- Lengthening of gastrocnemius fasciae is indicated if:
  - The gastrocnemius is selectively tight
  - This results in functional deficits
  - Conservative (nonoperative) treatment has failed

Preoperative Planning
- Planning should involve assessment of the entire patient, especially in patients with underlying neuromuscular disorders.
- Isolated lengthening of the gastrocnemius fascia in patients with cerebral palsy and tight hamstrings may result in a crouch gait.
- The Silfverskiöld test should be repeated under anesthesia.
- The surgeon should be prepared to do additional procedures if lengthening of the gastrocnemius fascia does not result in sufficient dorsiflexion range.

Positioning
- The patient can be positioned either supine, with the leg externally rotated to gain access to the posterior medial calf, or prone.
- Supine positioning allows other concomitant procedures to be done, but prone positioning allows for easier access.
- We typically perform this procedure with the patient in the supine position, with tourniquet control.

Approach
- The procedure is classically performed through a 2- to 4-inch incision made posteriorly over the midcalf, with the patient prone.
- An incision can be made posteromedially with the patient supine (FIG 2).
STRAYER PROCEDURE

- Dissection is carried down to the facial posterior fascia. This should not be confused with the gastrocnemius tendon (TECH FIG 1A).
- The saphenous vein must be protected medially and the sural nerve laterally (TECH FIG 1B).
- The fascia overlying the (superficial) posterior compartment is divided and the underlying tendon is identified. Often the muscle bellies of the medial and lateral head of the gastrocnemius overlie the tendon and need to be carefully retracted (TECH FIG 1C).
- The tendon of the gastrocnemius is identified proximal to the conjoined tendon and the interval in between the gastrocnemius tendon and the underlying soleus fascia may need to be developed. It can be isolated with an instrument (TECH FIG 1D) and carefully divided, avoiding injury to the underlying soleus fascia and muscle (TECH FIG 1E).
- The ankle should now dorsiflex to 10 degrees with the knee extended (TECH FIG 1F).
- The subcuticular closure is performed in layers, and a cast is placed with the foot in neutral or slight dorsiflexion.

TECHNIQUES
BAKER PROCEDURE

- This technique is identical to the Strayer technique with the exception of the cut through the aponeurosis of the gastrocnemius tendon.
- An inverted-U incision is made through the aponeurosis; the lateral and medial portions remain intact with the underlying soleus muscle (TECH FIG 2A).
- The middle (or tongue) portion is dissected from the soleus, and the distal attachments of the lateral and medial portions of the aponeurosis are freed from the tendon (TECH FIG 2B).
- After lengthening, the four corners of the overlapping portion of the tendon are secured with sutures (TECH FIG 2C).
- The closure and postoperative care are similar to the Strayer procedure.

![TECH FIG 2](image)

The Baker technique.
A. Incision. B. The “box” cut in the gastrocnemius fascia. C. The lengthened tendon, with sutures placed.

VULPIUS PROCEDURE

- This technique is similar to the Baker technique, except that an inverted-V incision is used to divide the aponeurosis of the gastrocnemius tendon (TECH FIG 3A).
- More than one incision can be used if needed (TECH FIG 3B).

![TECH FIG 3](image)

The Vulpius technique.
A. Applied surgical anatomy. Accurate incision size is shown in TECHNIQUES FIGURE 2A and reflected in B. The incision in the gastrocnemius is indicated by the dashed line. B. With the fascia of the gastrocnemius and soleus divided, the muscle of the soleus is exposed.
PEARLS AND PITFALLS

| Indications                      | ■ The patient should be carefully examined to ensure that this is isolated gastrocnemius tightness.  
|                                 | ■ In patients with cerebral palsy, the surgeon should assess and lengthen the hamstrings to avoid a crouch gait.  
| Positioning                     | ■ Patient position depends on the surgeon’s preference and what other procedures may be needed.  
|                                 | ■ Tourniquet control is helpful.  
| Avoid over- or underlengthening | ■ If satisfactory dorsiflexion is not obtained, additional procedures may be needed, including capsular release.  
|                                 | ■ The surgeon should not lengthen beyond 10 to 15 degrees of dorsiflexion.  

POSTOPERATIVE CARE

■ Although Strayer and Baker originally described a “toe-to-groin cast,” typically a short-leg weight-bearing cast is worn for 4 weeks, with knee immobilizers to keep the knees extended when not ambulatory.  
■ Bracing and nighttime splinting can be used to help maintain foot position.

OUTCOMES

■ Significant improvements in range of motion, dynamic joint motion during gait, and electromyographic pattern are typically seen.  
■ Little difference has been shown between the different techniques for lengthening the gastrocnemius fascia.

COMPLICATIONS

■ Lengthening of the gastrocnemius fascia is generally a safe procedure, with few complications.  
■ Overlengthening of the triceps surae is considered to be less likely with this technique than by lengthening more distally at the Achilles tendon. Overlengthening is difficult to treat.  
■ Injury to the sural nerve or saphenous vein is possible but uncommon and carries few long-term deficits.  
■ Recurrence is the most common concern and is probably related more to poor postoperative therapy and splinting than surgical technique.

REFERENCES

DEFINITION
- Crouch gait is defined as walking with excessive knee flexion during stance.
- Crouch is a common walking pattern in neuromuscular conditions, particularly for individuals with cerebral palsy.
- Many potential abnormalities of bone alignment and joint flexibility can accompany or lead to crouch gait.
- Persistent crouch in adolescence frequently results in fixed knee flexion deformity and patella alta.
- Potential contributing factors include hamstring contracture, hip flexion deformity, foot deformity, loss of plantarflexion–knee extension couple, excess femoral anteversion, and external tibial torsion. Weakness and impaired motor control are contributing factors. For some patients, disorders of balance or sensory impairments are major contributors.^{1}
- Fixed knee flexion deformity is oftentimes associated with patella alta. Fixed knee contracture and patella alta are the components of the pathology that are treated with these procedures.

ANATOMY
- Typical knee extension range is 0 degrees (full knee extension).
- Posterior capsular contracture can result from the imbalance between spastic or contracted hamstrings and knee extensor dysfunction (often associated with patella alta).
- Distal femoral anatomy is normal, although torsional deformity (excessive femoral anteversion) is commonly seen in neuromuscular conditions, especially cerebral palsy.

PATHOGENESIS
- The pathogenesis of knee flexion deformity and crouch gait in cerebral palsy will be described, as it is the most common condition to be treated with this technique. However, other causes of knee flexion deformity and persistent crouch could be treated similarly.
- Preterm, perinatal, or infantile brain injury leads to static encephalopathy.
- This neurologic disorder causes hypertonia (commonly spasticity), impaired motor control, and weakness.
- Typical muscle growth results from the tension produced by normal bone growth and age-appropriate, typical gross and fine motor activities.
- Musculotendinous growth in children with cerebral palsy is delayed because spastic muscle does not grow normally in response to stretch and delays in attainment of typical functional activities.
- Bone growth and joint development are also adversely affected by a lack of normal functional activities, as well as spasticity and musculotendinous contracture.

NATURAL HISTORY
- Crouch gait is not uncommon at 5 to 7 years of age. At these ages, the primary causes are spasticity, weakness, and impaired balance mechanisms.
- If crouch persists during later childhood, musculotendinous contractures of the two-joint muscles (psoas, hamstrings, rectus femoris, and gastrocnemius) develop. Persistent alignment in a crouch position leads to excessive elongation of the one-joint muscles (gluteus maximus, quadriceps, and soleus), which are primarily responsible for normal upright posture.\(^1\)
- The soleus, in particular, is responsible for restraining the forward movement of the tibia over the plantigrade foot (also known as the plantarflexion–knee extension couple).\(^3\) As a result, the ground reaction force vector typically falls near the knee joint in midstance, minimizing the demand on the quadriceps to maintain knee extension.
- If weak or elongated, the ankle plantarflexors are no longer able to restrain the forward movement of the tibia over the plantigrade foot (loss of the normal plantarflexion–knee extension couple).
- Further growth leads to loss of knee joint mobility and the development of posterior capsular contracture.
- For some patients in adolescence, pain from stress fractures or from excessive stress in the patellofemoral joint itself can lead to a precipitous worsening of crouch.
- Knee pain, decreased ambulatory function, or the loss of walking ability in adulthood in individuals with cerebral palsy is common.\(^3\)

PATIENT HISTORY AND PHYSICAL FINDINGS
- Physical examination methods include the following:
  - Knee range of motion: Loss of extension indicates a posterior capsular contracture; loss of flexion could be due to quadriceps contracture and especially rectus femoris spasticity or contracture if the knee is flexed in the prone position. Normal upright walking requires full knee extension range of motion.
  - The examiner should palpate the inferior pole of the patella and tibial tubercle. This distance is typically equal to patellar length. The patella is pushed medial to lateral to detect patellar instability. Patella alta, which can be a cause of knee pain or can contribute to knee extensor dysfunction, is suspected if:
    - The distance from the inferior pole of the patella to the tibial tubercle exceeds patellar height.
    - The patella is unstable medial to lateral.
    - The patellar tendon (as opposed to the patella) lies in the patellofemoral groove.
    - With the knees in extension, the superior pole of the patella is typically one fingerbreadth proximal to the adductor tubercle.
  - Knee extension lag test: Normal extension lag is 0 degrees. Terminal knee extension strength is required to control knee flexion during loading response.
  - Hamstring contracture: Normal popliteal angle can be as much as 30 degrees during preadolescence. It is commonly
greater in boys than in girls. For differential diagnosis purposes, it is important to identify all potential contributors to crouch gait.

- If resistance is felt as the popliteal angle is being assessed, hamstring spasticity is identified. If the knee is flexed with the patient prone and the hip extended, spasticity of the rectus femoris is identified.
- Spasticity is one of the primary causes of the series of events that ultimately leads to crouch. If severe enough, direct spasticity treatment may be necessary.
- A complete examination of the patient should also include evaluation of associated abnormalities to identify all potential contributors to crouch gait, including hip flexion deformity, hamstring contracture, femoral anteversion, tibial torsion, foot deformity or instability, balance disorder, and visual or sensory disturbances.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- A plain lateral radiograph of the knee in maximum extension should be obtained to assess for fixed knee flexion contracture and patella alta (FIG 1).
- If the knee is held in maximum extension, the femoral–tibial angle on the lateral radiograph represents the degree of true knee flexion deformity.
- The knee is extended maximally with a bolster just below the patella to assess the true degree of patella alta. Patella alta can be documented using the Insall ratio or the Koshino index.²
- Inferior-pole sleeve avulsion injuries of the patella are common in children with spastic cerebral palsy and can be identified on the lateral radiograph. The development of a stress fracture is typically painful and can lead to the rapid progression of crouch over a short period.
- Computerized gait analysis provides much-needed insight to create a problem list to guide treatment decision making by identifying the numerous other contributors to crouch listed above.

**DIFFERENTIAL DIAGNOSIS**

- Knee extensor lag with or without patella alta
- Hamstring spasticity or contracture
- Hip flexor spasticity or contracture
- Femoral anteversion
- Tibial torsion (typically external)
- Ankle plantarflexor insufficiency
- Foot deformity
- Excessive midfoot instability
- Soleus weakness: primary versus iatrogenic from prior Achilles tendon lengthening

**NONOPERATIVE MANAGEMENT**

**Preoperative Planning**

- The lateral radiograph of the knee in maximum extension should be reviewed for the degree of knee contracture, patellar height, presence of a stress fracture at the inferior pole of the patella, and the status of skeletal maturation (see Fig 1).
- Gait analysis data should be reviewed to assess for knee extension lag, degree of crouch, presence of hip flexion contracture, spasticity or contracture of the rectus femoris, and hamstrings length and for the presence of tibial torsion, femoral anteversion, and foot deformity.
- Examination under anesthesia for femoral anteversion and coronal-plane malalignment of the knee should be accomplished before positioning.
- Other deformities can be addressed concurrently under the same anesthetic.

**Positioning**

- If severe femoral anteversion is present, a proximal femoral osteotomy may be required in addition to the distal osteotomy, as it is difficult to correct more than 25 to 30 degrees of malrotation distally.
- Tibial torsion and foot deformity should also be addressed first. While these can be done supine, I prefer prone positioning.
Prone positioning is preferred as it allows accurate examination and correction of rotational profile consistent with the physical examination methods used in the clinic.

- The extension osteotomy and patellar advancement are performed supine with the leg draped free (FIG 2).

Approach
- The extension osteotomy of the distal femur is performed via a lateral distal femoral incision.
- The patellar advancement is performed through a direct anterior incision centered over the tibial tubercle.

DISTAL FEMORAL EXTENSION OSTEOTOMY

- The procedure is performed under tourniquet control.
- Through the lateral distal femoral incision, the fascia is opened and the vastus lateralis is reflected from its posterior origin and elevated to expose the distal femur subperiosteally.
- Circumferential subperiosteal retractors are placed.
- Typically a 90-degree adolescent AO blade plate is used for fixation. If no varus or valgus deformity correction is required, the guidewire for chisel placement is placed at a 90-degree angle to the femoral shaft on an AP image in the plane of the tibia (as this will reflect final coronal plane alignment) (TECH FIG 1A).
- The guidewire entry point is through the anterior portion of the lateral femoral epicondyle in line with the femoral shaft to avoid anterior or posterior translation of the distal fragment. It is placed just proximal to the distal femoral physis if the patient is immature and at the physeal scar if growth is complete.
- Transverse-plane position is in line with the axis from the lateral to the medial femoral condyle.
- The chisel is inserted exactly parallel and just proximal to the pin, with the angle guide for the AO chisel aligned parallel to the tibia (TECH FIG 1B). The angle between the AO chisel guide and the femoral shaft is equal to the degree of knee contracture and the extension to be obtained.

- Depending on preoperative assessment, a second pin can be placed proximal to the osteotomy site to assist with rotational control. It can be placed at a converging angle in the transverse plane to match the degree of derotation desired.
- The distal osteotomy is performed first. The oscillating saw blade is aligned exactly parallel and 10 to 15 mm proximal to the chisel (TECH FIG 1C).
- The second osteotomy is performed perpendicular to the femoral shaft, typically meeting the first osteotomy at the posterior cortex (although with more severe deformities, a cuneiform wedge including several millimeters of posterior cortex may also be removed to avoid neurovascular stretch).
- The anterior wedge of bone is removed (TECH FIG 1D).
- Varus–valgus deformities can be corrected by altering the guide pin placement in the coronal plane or bending the implant to match the desired correction.
- The osteotomy is realigned by derotating if necessary and extending the knee.
- The chisel is replaced with the Synthes AO blade plate.
- The femoral shaft is reduced to the plate and held with a Verbrugge clamp (TECH FIG 1E).
- After an initial screw is placed in compression to hold alignment, final coronal plane alignment is assessed. Proper mechanical axis alignment is confirmed if the elec-
If the patient is skeletally immature, transposition of a tibial tubercle bone block would cause an anterior growth arrest. Instead, the patellar tendon is advanced without violating its insertion (**TECH FIG 2A**).

A T-shaped periosteal incision is made just distal to the tibial tubercle apophysis.

Medial and lateral flaps of periosteum are elevated (**TECH FIG 2B**).

The tendon is separated from the cartilaginous tibial tubercle apophysis using a fresh scalpel, working at the junction of the fibers of the patellar tendon and the cartilage (**TECH FIG 2C**). It is best to err on the side of leaving a few fibers of tendon on the cartilage than to inadvertently injure the cartilage. Care must be taken to maintain an adequate thickness of tendon (about 2 mm) without defects.

The next step is placement of a tension band from the patella to the tibia to protect the repair. A guidewire for the 2.7-mm cannulated AO drill bit is passed percutaneously transversely through the midportion of the patella.

A suture passer is passed retrograde through the drill bit from medial to lateral, and then the drill bit is removed. A 2-mm Fibertape suture is passed through the drill hole using the suture passer.

Using a long right-angle clamp, the ends of the Fibertape suture are passed along the edges of the patellar tendon via a subcutaneous tunnel to the anterior incision.

Using a similar technique as described for the patella, a transverse drill hole is placed in the tibia and the suture is passed through it (**TECH FIG 2D**).

The patella is advanced distally by tensioning the Fibertape until the inferior pole of the patella is at the femoral–tibial joint line, at which point the knot in the Fibertape is tied (**TECH FIG 2E**).

Two baseball (Krackow) stitches are placed in the patellar tendon, one medially and one laterally, using 0 Ethibond suture (**TECH FIG 2F**).

These sutures are tied deeply under the periosteal flaps.

The periosteal flaps are then sewn over the patellar tendon (**TECH FIG 2G**).

The wound is closed in routine fashion.
TIBIAL TUBERCLE ADVANCEMENT

- For skeletally mature patients, the patellar tendon and tibial tubercle are exposed.
- A small tibial tubercle bone block with patellar tendon attached is created with an oscillating saw and completed with an osteotome. The typical size is the width of the patellar tendon, 2 to 2.5 cm in length and 7 to 10 mm thick.
- The 2-mm Fibertape is placed identical to the previous description.
- A receptacle site for the tibial tubercle bone block is created at the appropriate level.
- The distally excised bone block is impacted into the original tibial tubercle site.
- The tibial tubercle is inserted into its receptacle site and secured with a single 4.5-mm AO screw, overdrilling the tibial tubercle fragment to compress the bone block and countersinking to avoid screw prominence.
- The typical advancement is 2 to 2.5 cm.
- By keeping the tibial tubercle bone block relatively short in length, a small bridge of intact anterior cortical bone can provide a proximal buttress to resist proximal migration of the tibial tubercle bone block postoperatively.
- The knee should be able to flex 60 degrees at this point without excessive tension or disruption of the repair.
- The wound is closed in routine fashion.

PEARLS AND PITFALLS

| Recurrence of knee flexion deformity and persistence of crouch | If a distal femoral extension osteotomy is performed without patellar advancement, there is a high risk of these postoperative problems. |
| Patellar advancement in isolation | This is effective to treat crouch in the presence of a knee extension lag without knee flexion contracture. |
| Avoiding sciatic nerve palsy | Postoperative immobilization in flexion during the time of acute swelling (first 3 days) and resection of the posterior bony prominence on the distal fragment have helped minimize this complication. |
| Loss of patellar fixation | Supporting patellar advancements with a Fibertape tension band has minimized this complication. |
| Increased anterior pelvic tilt | Detecting and treating hip flexion deformity as well as rectus femoris spasticity and contracture (simultaneous rectus femoris transfer) have been helpful, but this finding seems to be common with surgical intervention at this age. |
| Genu varum and valgum | Distal femoral osteotomy requires meticulous care to ensure optimal postoperative alignment in all three planes. |
| | Contractures between 10 and 25 degrees are typically appropriate for this compensatory osteotomy of the distal femur. |
| | In growing children with relatively small deformities, anterior distal femoral figure 8 plating may be a consideration. |
| | The treatment of flexion contractures of 30 degrees or greater introduces significant distal femoral deformity. |
| | Modest transverse-plane deformities can easily be corrected but again this requires meticulous attention to detail. |
| | Malrotation greater than 30 degrees is difficult to correct with this technique. |
| | Preoperative coronal-plane deformities can be corrected, and care must be taken to avoid creation of postoperative varus–valgus deformities. |

POSTOPERATIVE CARE

- AP and lateral radiographs are reviewed to confirm proper alignment (FIG 3).
- The knee is immobilized for 3 days in 20 to 30 degrees of flexion in a Robert Jones dressing to avoid sciatic nerve stretch.
- Then a knee immobilizer is used for 6 weeks.
- Use of a continuous passive motion (CPM) machine is begun on the third postoperative day; initially the range is from 0 to 30 degrees, and it is advanced to 90 degrees by 6 weeks postoperatively.
- After 3 weeks, active range of motion and weight bearing are initiated. Once quadriceps strength and control are sufficient, the knee immobilizer can be discontinued.

OUTCOMES

- Knee flexion deformity and patella alta can reliably be corrected.4
- Preoperative stress fractures and knee pain are improved or resolved in the vast majority of patients.
- Worsened anterior pelvic tilt is commonly seen and does not seem to be a result of persisting contracture or weakness.
- Crouch gait is corrected effectively for those who have the combined procedure of extension osteotomy and patellar advancement. Crouch is also effectively treated in the absence of knee contracture with patellar advancement alone, as long as other musculotendinous contractures and bone or joint deformities are concurrently addressed.
Distal femoral extension osteotomy without patellar advancement has a high risk of recurrence of contracture and typically results in only partial improvement in crouch.

- An overcorrection of patellar position compensates for weakness, impaired motor control, and spasticity and has been found to be safe (low rate of persisting anterior knee pain postoperatively) and necessary to treat crouch.
- The natural history of crouch gait is one of worsening. With these procedures, walking ability is either maintained or improved, as indicated by gait analysis and a functional mobility scale.  

**COMPLICATIONS**

- Sciatic nerve palsy
- Loss of patellar fixation
- Recurrence of deformity
- Wound breakdown or infection
- Increased anterior pelvic tilt

**REFERENCES**

DEFINITION

- **Unicameral bone cyst (UBC)**
  - Also known as a simple bone cyst, a UBC is a benign, active or latent, solitary cystic lesion that usually involves the metaphysis of long bones (most commonly the proximal humerus and femur, 40% to 80%).
  - Most (90%) of patients are less than 20 years old.
  - UBCs represent a cavity filled with yellowish or serosanguineous fluid lined by a thin fibrous membrane.

- **Aneurysmal bone cyst (ABC)**
  - ABC is a benign, active, and sometimes locally aggressive, solitary, expansile cystic lesion, eccentric in location.
  - ABCs are most common in the first two decades, and they most often involve the long bones or the spine.
  - The lesion contains blood-filled cystic spaces that are not lined with vascular endothelium. Between the blood-filled spaces are fibrous septa containing giant cells and immature bone.

PATHOGENESIS

- **UBC**
  - Cause is unknown; however, theories range from a reactive or developmental process, caused by obstruction to the drainage of interstitial fluid, to a true neoplasm.
  - Recent isolated cytogenetic analysis has reported on the presence of translocation t(16;20)(p11.2;q13) and TP53 mutations in recurrent UBCs. Further studies are necessary to better understand its pathogenesis.
  - UBCs are characterized by a fluid-filled cyst lined with a thin fibrous membrane without obvious lining cells. However, owing to the high incidence of associated fractures, several nonspecific changes may be seen, such as hemorrhage, hemosiderin deposits, granulation tissue, new bone formation, and others.

- **ABC**
  - The neoplastic basis of primary ABCs has been, at least in part, demonstrated by the chromosomal translocation t(16;17)(q22;p13) that places the ubiquitin protease (UBP) USP6 gene under the regulatory influence of the highly active osteoblast cadherin 11 gene (CDH11), which is strongly expressed in bones.
  - ABCs are characterized by various-size blood-filled cystic spaces without vascular endothelium lining and divided by fibrous septa containing giant cells and immature bone (**FIG 1**).

NATURAL HISTORY

- **UBC**
  - Active cysts are generally located near the growth plate and are usually asymptomatic.
  - Inactive or latent cysts tend to “migrate” away from the growth plate as longitudinal growth occurs.
  - UBCs may regress spontaneously after skeletal maturity.

- **ABC**
  - It is usually an active benign lesion with locally aggressive features.
  - The lesion tends to continue to grow, necessitating intervention.
  - It can occur as a secondary lesion associated with giant cell tumor, osteoblastoma, chondroblastoma, or fibrous dysplasia.

PATIENT HISTORY AND PHYSICAL FINDINGS

- **UBC**
  - UBCs are often asymptomatic. The usual presentation is with a pathologic fracture (50% to 65%).

**FIG 1** • High-power (200× magnification; A) and low-power (40× magnification; B) photomicrographs of a lesion demonstrate blood-filled spaces surrounded by several focal giant cells, as well as spindle-shaped cells lining the walls of these spaces. Some of the spaces are slit-like, whereas the other spaces are dilated. Hemosiderin is also seen.
While about 90% occur before the age of 20 years, calcaneal UBCs tend to occur in a slightly older group. They occur more often in boys (3:1). The most common locations are the proximal humerus and femur, accounting for 50% to 70% of the lesions.

ABCs often present with mild pain. Pathologic fracture is not uncommon, following minor trauma. The spine, femur, and tibia are the most common locations. In the spine, the lesion is more often limited to the posterior elements.

IMAGING AND OTHER DIAGNOSTIC STUDIES

UBC
- Plain radiographs typically demonstrate a centrally located, well-defined, radiolucent lesion (Fig 2), usually surrounded by a sclerotic margin and narrow zone of transition.
- They may demonstrate cortical thinning and mild expansion (unlike ABCs, UBCs do not exceed the width of the nearest growth plate).
- When a pathologic fracture occurs, there is periosteal reaction, and occasionally the typical “fallen fragment” sign is visualized (piece of fractured cortex “floating” inside the cavity).

CT is usually useful to characterize lesions that are difficult to visualize on plain films (ie, spine, pelvis) and to rule out fractures (nondisplaced or minimally displaced).

MRI is useful for differential diagnosis and atypical UBCs. Although variable, they present as low to intermediate signals on T1-weighted images and bright and homogeneous signals on T2-weighted images.

ABC
- Plain radiographs show an eccentrically located, multilobulated, expansile (expands beyond the width of the nearest growth plate), radiolucent lesion with a narrow zone of transition.
- A rim of sclerotic bone is often seen.
- Cortical thinning, disruption, and periosteal reaction are common.
- CT is helpful, especially because these lesions are commonly located in the spine (Fig 3A,B).
- It shows the typical ridges in the interior of the cyst.
- Soft tissue extension can be appreciated, but there is no true soft tissue mass.
- MRI is useful to confirm the lobulated nature of the lesion and the cystic cavities filled with fluid (fluid–fluid levels on T2-weighted signal; characteristic but not pathognomonic; Fig 3C,D).
- There is variable signal intensity in both T1- and T2-weighted images due to the nature of the cyst contents (fresh blood, mixed with degraded blood products).

DIFFERENTIAL DIAGNOSIS

UBC
- Nonossifying fibroma
- Fibrous dysplasia
- Brown tumor of hyperparathyroidism (usually presents with osteopenia and subcortical resorption)
- Bone abscess (commonly shows periosteal reaction).
- For calcaneal lesions, the differential also includes chondroblastoma and giant cell tumor.

ABC
- Latent UBC (diaphyseal)
- Fibrous dysplasia
- ABC
- UBC
- Giant cell tumor

FIG 2 • Lateral radiograph of the foot of a 12-year-old boy demonstrates a well-circumscribed, lucent lesion, consistent with unicameral bone cyst.

FIG 3 • Aneurysmal bone cyst of L4. A. Axial CT scan of the lower lumbar spine shows a destructive, lytic, expansile lesion, involving the body and posterior elements of L4 with disruption of the spinal canal. B. Three-dimensional-reconstruction CT image demonstrates the asymmetric collapse of the vertebra. C. Sagittal T1 MRI shows the collapsed L4 with posterior disruption by the tumoral mass. D. Axial T2-weighted MRI shows the characteristic fluid-fluid level and disruption of the medullary canal.
- Osteoblastoma
- Telangiectatic osteogenic sarcoma

**NONOPERATIVE MANAGEMENT**

### UBC
- Lesions with typical radiographic appearance and lesions in non-weight-bearing bones can be followed with serial radiographs.
- Small lesions (i.e., those that involve less than one third to half of the bone width) in weight-bearing bones that have low risk for fracture can also be observed.
- Following pathologic fracture, up to 14% of UBCs may spontaneously heal, and therefore an attempt for conservative treatment should be made.

### ABC
- There is little place for conservative treatment of ABCs. At least an incisional biopsy for diagnosis confirmation is recommended.
- For small, asymptomatic lesions located in non-weight-bearing bones, observation can be indicated.

**SURGICAL MANAGEMENT**

- The first indication for surgical treatment of benign bone cysts is to confirm the diagnosis (i.e., incisional biopsy).
- Large lesions that involve more than one third to half of the bone width and lesions of weight-bearing bones are usually treated with surgery.
- Pathologic fractures are not an absolute indication for surgical treatment, but when they are associated with ABCs, or are located in the lower extremities, surgery is usually indicated.

### ABCs in nonessential bones (e.g., rib, fibula) can be treated with wide resection to avoid recurrence.

**Preoperative Planning**

- It is very important to pay attention to the details, formulate the differential diagnosis, and rule out a malignant process. It is also very important to rule out physial growth arrest before any intervention.
- For ABCs, an open biopsy is often needed since needle biopsy may get only blood and no tissue.
- An image intensifier is useful for accurate localization of the lesion, during percutaneous procedures, and for intraoperative confirmation that the entire lesion is being addressed.
- For open surgery, headlamps for illumination and loupes for magnification are recommended.

**Positioning**

- Positioning depends on the lesion’s location. For all extremity lesions, the entire affected extremity should be entirely free draped. It is important to confirm that the extremity can be properly imaged by the image intensifier.

**Approach**

- UBCs are less aggressive lesions and therefore are prone to a percutaneous technique.
- ABCs can be quite aggressive and an open and more aggressive approach is usually necessary.
- For lesions in the proximal femur, a more aggressive approach is often necessary; particularly if a pathologic fracture is present, open reduction and internal fixation is indicated (FIG 4).

---

**FIG 4** • Classification and treatment algorithm for proximal femur pathologic fractures through a bone cyst. Type IA: A small cyst is present in the middle of the femoral neck, the lateral buttress is intact, cannulated screws are used avoiding the physis. Type IB: A larger cyst is present, there is compromise of the lateral buttress, and a pediatric dynamic hip screw (DHS) is used. Types IIA and IIB: There is not enough bone between the growth plate and the lesion; therefore, the patient can be kept in traction or a cast until initial healing occurs, or parallel Steinmann pins across the physis can be used. Type IIIA: Since the growth plate is closed, cannulated screws purchasing the femoral head are used. Type IIIB: Because of the loss of the lateral buttress, a pediatric DHS is recommended. A spica cast is generally recommended after the surgical treatment. Internal fixation should be preceded by a four-step approach. (Adapted from Dormans J, Flynn J. Pathologic fractures associated with tumors and unique conditions of the musculoskeletal system. In Beaty JH, Kasser JR, eds. Rockwood and Wilkins’ Fractures in Children, ed 5. Philadelphia: Lippincott Williams & Wilkins, 2001:151.)
UNICAMERAL BONE CYST

Percutaneous Intramedullary Decompression, Curettage, and Grafting With Medical-Grade Calcium Sulfate Pellets

- Under fluoroscopic guidance, a Jamshidi trocar needle (CardinalHealth, Dublin, OH) is percutaneously inserted into the cyst cavity.
- The cyst is aspirated to confirm the presence of straw-colored fluid, which is typical of previously untreated or unfractured UBCs.
- Three to 10 mL of Renografin dye (E.R. Squibb, Princeton, NJ) is injected to perform a cystogram and confirm the single fluid-filled cavity (TECH FIG 1A).
- A 0.5-cm longitudinal incision is then made over the site of the aspiration and a 6-mm arthroscopy trocar is advanced into the cyst cavity through the same cortical hole, and the cortical entry is enlarged manually (TECH FIG 1B).
- Under fluoroscopic guidance, percutaneous removal of the cyst lining is done and curettage is performed using a pituitary rongeur and various-sized angled curettes (TECH FIG 1C).
- An angled curette or flexible intramedullary nail is used to perform the intramedullary decompression in one direction (toward the diaphysis) or in both directions (when the growth plate is far enough, avoid physeal injury) (TECH FIG 1D,E).
- Medical-grade calcium sulfate pellets (Osteoset, Wright Medical Technology, Arlington, TN) are inserted through the same cortical hole and deployed to completely fill the cavity (TECH FIG 1F,G).
- Angled curettes can be used to advance pellets into the medullary canal.
- Tight packing of the cyst is preferred.
- The wound is closed in a layered fashion.

TECH FIG 1 • Unicameral bone cyst. A. Fluoroscopic image showing a proximal femur unicameral bone cyst filling with dye. B. A 0.5-cm incision is made where the Jamshidi needle for the cystogram was placed. C. The cyst is curetted using curettes and a pituitary rongeur. Material is then sent for pathology analysis. Intramedullary decompression of the cyst is done using flexible intramedullary nails (D) or angled curettes (E). F. The cyst is filled with medical-grade calcium sulfate pellets. G. Four-month follow-up radiograph shows complete healing.
ANEURYSMAL BONE CYST

- A four-step open surgical approach is used.
- Under fluoroscopic guidance, a Jamshidi trocar needle is percutaneously inserted into the cyst cavity.
- The cyst is aspirated to confirm the presence of blood-filled cavities or soft tissue septations typical of ABCs.
- A longitudinal incision of roughly the same size of the cyst is made, the neurovascular structures are protected, and the periosteum is opened and retracted.
- Perforation of the thinnest part of the cyst wall is performed with a curette, burr, or drill.
- The fibrous lining of the lesion is completely curetted. Septations are opened and removed to access all components of the cyst.
- The use of headlamps for illumination and loupes for magnification is recommended to ensure a thorough excision. Image intensifier may be helpful to ensure that all cavities were opened.
- A high-speed burr is used to improve the curettage and help with complete excision of any macroscopic tumor (TECH FIG 2A,B).
- The cavity is then cauterized with electrocautery and in selected cases (eg, lesions distant from the growth plate and main neurovascular structures) phenol 5% solution is applied to the cyst wall with a cotton-tipped applicator to extend the margins.
- The cavity is now tightly packed with bone graft. We prefer to use a combination of allograft cubes and demineralized bone matrix paste (TECH FIG 2C–F).
- The wound is closed in a layered fashion.

**TECH FIG 2** • **A.** AP radiograph of the proximal humerus shows an expansile, lytic, loculated aneurysmal bone cyst. **B.** The cyst is thoroughly curetted and a high-speed burr is used to remove any residual cyst lining. **C.** The cyst is completely filled with packed allograft chips and demineralized bone matrix. **D.** Radiographic aspect 2 weeks after the procedure; the cyst was entirely removed and the cavity was entirely grafted. **E,F.** At 4-month follow-up, AP radiographs of the right proximal humerus in internal and external rotation demonstrate that the lesion is completely healed, with good incorporation of the bone graft.
POSTOPERATIVE CARE

- In most cases, the extremity is protected from weight bearing for about 4 to 6 weeks. Before the patient is allowed to return to physical activity, radiographic evidence of bone healing is necessary.

OUTCOMES

- The minimally invasive technique for UBC has shown promising results on a short-term evaluation, with reported success rate (eg, complete or partial healing or opacification) of about 95%. Recently the intermediate to long-term results in a larger cohort were reviewed, and the observed rate of complete or partial response achieved with one surgical intervention was 80%. Nonetheless, the success rate increased to 94% after a repeat surgery, reaching a 100% healing rate in patients who underwent more than two repeat surgeries. These results compare favorably with other outcomes after surgical treatment of UBCs.
- The recurrence rate for any surgically treated ABC varies from 10% to 59% according to the reported results. In a large cohort including 45 children with primary ABC treated by the described four-step approach technique and at least 2 years of follow-up, the recurrence rate was only 18%. Although the recurrence rate was slightly higher among younger children (less than 10 years old), this difference did not show statistical significance.

COMPLICATIONS

- Persistence or recurrence: varies from 10% to 20% for all techniques described
- Infection
- Fracture
- Intraoperative bleeding: for aggressive-looking ABCs and lesions in difficult locations such as the pelvis and spine, arteriography, and sometimes embolization, is helpful.

REFERENCES

DEFINITION

- **Syndactyly** refers to the failure of separation between adjacent digits, resulting in “webbed” fingers.
- Congenital syndactyly is classified according to the extent of digital involvement and the character of the conjoined tissue.
  - *Complete syndactyly* extends to the digital tips (FIG 1A), whereas *incomplete syndactyly* ends proximal to the fingertips (FIG 1B).
  - *Simple syndactyly* refers to digits connected only by skin and soft tissue. *Complex syndactyly* denotes bony fusions between adjacent phalanges.
  - *Complicated syndactyly* refers to the interposition of accessory phalanges or abnormal bones between digits.

ANATOMY

- Understanding of normal digital web space anatomy guides surgical reconstructive efforts.
- Typically, the index–long and ring–small finger commissures are U-shaped, whereas the long–ring web is V-shaped.
- The non-glabrous skin of the normal web space is sloped about 45 degrees from proximal–dorsal to distal–volar, extending to roughly the midpoint of the proximal phalanx.
- The natatory ligaments (or superficial transverse metacarpal ligament) help form the web contour and join adjacent lateral digital sheets.
- Normally, each digit is vascularized in part via a radial and an ulnar digital artery, which arise from the bifurcation of the common digital arteries.
  - In simple syndactyly, adjacent digits are joined by varying amounts of skin and soft tissue.
    - The nail plates may or may not be fused.
    - The joints, ligaments, and tendons of the affected digits usually are normal.
  - It is of critical surgical importance that the bifurcation of the digital arteries and nerves may be abnormally distal in cases of syndactyly.

PATHOGENESIS

- Syndactyly represents a failure of differentiation and is so classified by the embryologic classification of congenital anomalies adopted by the International Federation for Societies for Surgery of the Hand.
  - Embryologically, the digits arise from condensations of mesoderm within the rudimentary hand paddle of the developing upper limb.
  - During the 5th and 6th weeks of gestation, interdigital clefts form through the process of apoptosis, or programmed cell death, beginning at the digital tips and proceeding in a distal-to-proximal direction.
  - The apical ectodermal ridge regulates this embryologic process, in conjunction with fibroblast growth factors, bone morphogenetic proteins, transforming growth factors, homeobox gene products, and the sonic hedgehog protein.
- Interruption of this precise and highly regulated process results in syndactyly.

NATURAL HISTORY

- There is no potential for spontaneous resolution.
- Given the importance of independent digit function in today’s world, surgical release is recommended for simple complete syndactyly, with few exceptions.
- When digits of differing lengths are joined, the syndactyly may lead to deformity and growth disturbance, with the longer digit typically developing a flexion contracture and angular deviation toward the shorter digit.
- Simple complete syndactyly of the long–ring interspace may be well tolerated and may not significantly compromise growth or function in young patients.
- Simple incomplete syndactylies may be aesthetically subtle and cause little functional compromise. In these situations, observation may be considered.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The diagnosis of syndactyly usually is not subtle, and the extent of digital involvement typically is readily apparent.
- Syndactyly is the most common congenital hand anomaly, with an estimated incidence of 1 in 2000 to 2500 live births.
  - The true incidence of syndactyly is unknown, in part because of the difficulty distinguishing mild simple syndactylies from normal web spaces.
The third web space is most commonly affected (50%), followed by the fourth (30%), second (15%), and first (5%) web spaces.

Males tend to be more commonly affected than females, and whites more than blacks or Asians.

Inheritance is thought to be autosomal dominant with incomplete penetrance and variable expression.

The absence of differential motion of the affected digits suggests a complex or complicated syndactyly.

Because the joints and tendons usually are normal, patients typically have flexion and extension creases over the interphalangeal joints and active digital motion.

Syndactyly may exist in isolation or may be seen in the context of associated clinical syndromes, including Poland syndrome, Apert syndrome, and constriction band syndrome. For this reason, careful evaluation of the entire upper extremity, contralateral upper limb, chest, and feet is advised.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs of the affected digits or hand are routinely obtained to accurately classify the syndactyly and assess for bony fusions or interposed or accessory bones (FIG 2).
- MRI, angiography, or other diagnostic studies are not typically obtained, because they do not assist surgical decision-making or operative treatment.

**NONOPERATIVE MANAGEMENT**

- Nonoperative management may be considered for mild, simple incomplete syndactyly.
- Nonoperative treatment also may be favored in cases of complicated syndactyly with the so-called “superdigit” or in cases of complex polysyndactyly, because of the difficulty in achieving reproducible functional improvement with surgical release.
- However, given the importance of independent digital motion—particularly in the current keyboard-driven digital age—nonoperative treatment of simple complete syndactyly is not recommended.

**SURGICAL MANAGEMENT**

- General surgical principles include the following:
  -Digits of differing lengths should be released early to prevent deformity and growth disturbance of the affected digits.
  -Digits should be operated upon on only one side at the same time, to avoid vascular embarrassment.

  - Local skin flaps should be used to recreate the commissure to avoid scar contracture and “web creep.”
  - Zigzag lateral flaps should be created to avoid longitudinal scar contracture.
  - Judicious defatting of the skin flaps should be performed to facilitate skin closure, reduce tension across the flaps, and improve the aesthetics of the reconstructed fingers.
  - Full-thickness skin grafts typically are used to cover “bare areas” after syndactyly release. (In cases of simple complete syndactyly, the combined circumference of the separated digits is 22% greater than the original circumference of the syndactylized digits.)

**Preoperative Planning**

- The timing of surgery must be considered in preoperative planning.
- There is great variability in recommendations of when releases should be performed.
  - Flatt wrote, “I believe one should ask not how soon the operation can be done but rather how late the functional demands of the hand will allow postponement of surgery.”
  - In general, releases are performed between 6 and 24 months of age.
- As mentioned, digits of differing lengths (eg, thumb–index syndactyly) should be released earlier to avoid secondary deformity.
- There is some evidence that releases performed after 18 months have better long-term outcomes with lower incidence of web creep.

**Positioning**

- The patient is positioned supine with the affected limb supported on a hand table.
- Placement of a sterile or nonsterile tourniquet must be sufficiently proximal to allow access to the antecubital fossa, if full-thickness skin graft is to be taken from that site.
- If the skin graft is to be harvested from the inguinal region, the ipsilateral groin is prepared and draped to allow for easy access.
- Before draping, a surgical pen may be used to mark the inguinal skin fold when the hip is flexed; graft harvest along this axis will allow for a more aesthetic skin closure.
- Care should be taken to harvest the skin graft lateral to the femoral artery to avoid transfer of hair-bearing skin.

**Approach**

- The principles of separation for simple complete syndactyly are well accepted; however, there is tremendous variation in the surgical incisions and skin flap designs used for these operations.
- All use local tissue to reconstruct the interdigital commissure, and all employ interdigitating zigzag lateral flaps. Dorsal skin flaps are preferred for commissure reconstruction, because of their pliability and ability to recreate the normal dorsal–proximal to volar–distal slope of the web.
- When dorsal skin is used to create the commissure, the length of the dorsal flap should approximate two thirds of the length of the proximal phalanx to create an appropriate slope to the web. The proximal extent of the volar incision will become the new palmodigital crease (FIG 3A).
- Furthermore, flaps are designed to interdigitate during closure; to achieve this, palmar triangular flaps are based at the level corresponding to the apex of the dorsal flaps. These flaps usually are fashioned to traverse between the midlines of the syndactylized digits.
- **FIGURE 3B** shows examples of skin incisions for simple complete syndactyly releases.
RELEASE OF SIMPLE SYNDACTYLY

Release of Simple Complete Syndactyly Using Full-Thickness Skin Graft

- After the tourniquet is inflated, the skin is incised, and hemostasis achieved with bipolar electrocautery (TECH FIG 1A,B).
- Dorsal skin flaps are raised first, preserving the extensor paratenon.
- Volar skin flaps are then raised, and neurovascular bundles are identified.
- Digits are carefully separated distal-to-proximal, releasing the interdigital fascia that often connects the syndactylized digits (TECH FIG 1C). The transverse metacarpal ligament is not divided.
- The bifurcation of the common digital artery and nerve is identified; if there is a distal bifurcation precluding restoration of the commissure with the dorsal skin flap, consideration may be given to splitting the fascicles of the common digital nerve or ligating one of the proper digital arteries.
- For isolated syndactyly release, the smaller-caliber or nondominant artery may be taken.

- If a syndactyly release is planned on the other side of one of the digits, its proper digital artery should be preserved.
- Skin flaps are then defatted and allowed to interdigitate.
- The dorsal skin flap is then advanced to the palmodigital crease and secured with multiple interrupted 5-0 absorbable sutures (eg, chromic or polyglactin; TECH FIG 1D).
- Interdigitated skin flaps are similarly reapproximated with multiple interrupted 5-0 absorbable suture.
- Skin defects are identified and covered with full-thickness skin graft, which may be harvested from the hypothenar eminence, antecubital fossa, or inguinal region (TECH FIG 1E).
- The tourniquet is deflated, and vascularity of the digits and flaps is confirmed.
- A non-adherent gauze bolstered with moist cotton is then placed into the newly formed web space, applying gentle compression to the skin graft sites.
- Care should be taken to place the dressing deep within the commissure to avoid re-syndactylization during the healing process.

TECH FIG 1 • Dorsal (A) and volar (B) incisions for planned release of simple complete syndactyly of the long and ring fingers. C. The digits have been separated. D. The dorsal skin flap is sewn in to recreate the interdigital commissure. E. Completion of the release with full-thickness skin grafting. (Copyright 2006 Children’s Orthopaedic Surgery Foundation.)
An above-elbow cast is then applied with the elbow in 90 degrees of flexion, with liberal use of casting material to protect the surgical dressing.

Reconstruction of the Paronychium

In cases of simple complete syndactyly, the nail plates of the involved digits are conjoined, a phenomenon known as synonychia.

Although division of the midportion of the nail plate is easily performed, care must be made to reconstitute the nail folds.
- Ideally this is performed using local tissue from the digital pulp.²
- Laterally based flaps are incorporated into the skin incisions, raised from the shared hyponychium at the digital tips (TECH FIG 2).
- The length of the flaps should equal the length of the nail plate.
- Once these flaps are raised and the digits separated, the flaps are easily rotated and reapproximated adjacent to the new nail plates, recreating a paronychial fold.
- Alternative solutions, including the use of skin graft, thenar or hypothenar flaps, or free composite toe grafts, are more involved and may provide less pleasing aesthetic results.

Technique of “Graftless” Syndactyly Release

Simple complete syndactyly releases may also be performed without the need for full-thickness skin grafting.⁵,¹³

In general, principles of syndactyly release mentioned earlier apply.

In “graftless” techniques, however, dorsal skin is raised from the dorsum of the hand and advanced to recreate the interdigital commissure. The resulting defect is closed primarily in the fashion of a V-Y advancement flap (TECH FIG 3).

Because proximal skin is used to recreate the web, more tissue is available to allow for primary closure of the digits following judicious defatting of the flaps, obviating the need for skin grafting.

The use of preoperative tissue expansion to avoid the need for skin grafting for syndactyly release has been proposed. Results have been unpredictable at best, however, and this approach currently is not widely accepted.

Local Skin Flaps for Simple Incomplete Syndactyly

In cases of simple incomplete syndactyly in which the web does not extend beyond the level of the proximal interphalangeal joint (ie, the length of the syndactyly does not exceed the desired depth of the reconstructed interdigital commissure), release may be performed using local skin flaps without the need for full-thickness skin grafting.

Multiple flap designs have been proposed, and, in general, all are variations of double opposing Z-plasties¹⁴,¹⁶ (TECH FIG 4).

In these situations, brief postoperative cast immobilization is recommended until skin flaps have healed.
POSTOPERATIVE CARE

- Cast immobilization usually is discontinued after 2 to 4 weeks.
- The wound is kept dry until the scabs desiccate and fall off.
- Silicone gel sheets, elastomere, or scar molds may be used to minimize hypertrophic scar formation.
- Formal occupational therapy for motion and strengthening is not typically required, because most children will use their hands quite readily with activities of daily living.

OUTCOMES

- Very little has been published regarding long-term outcomes following surgical release of syndactyly.
- Furthermore, interpretation of the available literature is difficult given the diversity of clinical presentations, surgical techniques, and methods of evaluation.
- In general, syndactyly release can be expected to provide excellent independent digital function with acceptable aesthetic results when performed according to the principles outlined in this chapter.
- Colville\(^1\) reported the results of 57 simple syndactyly releases performed over a 10-year period with minimum 2-year follow-up.
- Two patients required reoperation for early graft failure, and three others demonstrated slight angular deformity due to scar contracture, but they did not require additional surgery.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Category</th>
<th>Pearl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient selection</td>
<td>Caution should be used when considering release of the “super digit” or polysyndactyly, because functional results are mixed, and postoperative deformity may ensue.</td>
</tr>
<tr>
<td>Surgical approach</td>
<td>The proximal edge of the volar incision may be placed proximal to the palmodigital crease to account for possible late web creep.</td>
</tr>
<tr>
<td>Commissure reconstruction</td>
<td>Zigzag closure of the interdigital commissure is preferred over transverse incisions to avoid scar contracture and subsequent narrowing of the web space.</td>
</tr>
<tr>
<td>Interdigitating flaps</td>
<td>Judicious defatting of the triangular flaps will allow for tension-free closure and reduce the area of skin graft needed.</td>
</tr>
<tr>
<td>Graft harvest</td>
<td>If skin graft is taken from the inguinal region, care should be taken to avoid transfer of hair-bearing skin. This is difficult to assess in the young child; however, harvest lateral to the femoral artery can serve as a helpful guide.</td>
</tr>
<tr>
<td>Postoperative care</td>
<td>The importance of the postoperative dressing and immobilization cannot be overstated. Non-adherent gauze with appropriate bolsters placed over the skin grafts and deep into the reconstructed commissure will optimize skin graft “take” and lessen the risk of re-syndactylization during the healing period.</td>
</tr>
</tbody>
</table>
D’Arcangelo et al. published their results of 122 releases in 50 patients with minimum 8 years of follow-up. Satisfactory functional and aesthetic results were seen in most patients, but eight patients demonstrated web creep and three patients developed scar contractures. DeSmet et al. reported their results of 50 syndactyly releases in 24 patients. A normal or near-normal web was seen in 74% of cases, and cosmesis was deemed satisfactory in 64%. In their review of 218 releases performed in 100 patients, Percival and Sykes noted that 42 patients required secondary surgery for web creep (22%) and contracture (26%). Toledo and Ger published their results of 176 releases performed in 61 patients with average 14-year follow-up. Secondary procedures were performed in 30% of patients with simple syndactylies. The need for secondary surgery was associated with operations performed before the age of 18 months, the use of split-thickness skin grafts, and the presence of complex or complicated syndactyly.

COMPLICATIONS
With adherence to the principles presented in this chapter and meticulous surgical technique, the risk of complications may be minimized; however, up to one third of patients may require secondary procedures following simple complete syndactyly release. Digital necrosis is the most serious potential complication of syndactyly release. Careful identification and preservation of the digital arteries—in addition to avoidance of surgical release of both the radial and ulnar sides of a single digit at the same time—is critical to avoid vascular embarrassment and digital loss. Skin graft failure may result from hematoma formation beneath the graft or shear stresses imposed on the graft during the healing process. This risk may be greater in younger patients, in whom appropriate graft tensioning is more difficult and in whom postoperative immobilization is a greater challenge. If allowed to heal by secondary intention, subsequent hypertrophic scar formation may lead to suboptimal aesthetic and functional results. Skin flap failure due to devascularization is less common but also may lead to scarring and secondary contracture. Triangular skin flaps should be designed with tip angles greater than 45 degrees to prevent tip necrosis. Careful defatting of the flaps and primary closure without excess tension, in addition to assessment of flap viability after tourniquet release, will further aid in preventing skin flap complications. Contractures and angular deformity of the released digits may occur owing to linear scars on the radial or ulnar aspects of the fingers. Use of zigzag incisions and interdigitating flap designs will minimize this risk. Nail plate deformity is common after simple complete syndactyly release in the presence of a synonychia.

Although techniques of nailfold reconstruction using distal pulp tissue will optimize aesthetic results, patients and families should be counseled in advance regarding this common occurrence. “Web creep” refers to the distal migration of the reconstructed interdigital commissure with continued growth and is a common occurrence following syndactyly release, with a variously reported incidence of between 7% and 60% of cases. Some evidence suggests that the risk of web creep may be diminished if release is performed after 18 months of age. Other factors that may contribute to web creep include inappropriate flap design for commissure reconstruction, the use of split-thickness rather than full-thickness skin grafts, skin graft loss, and creation of a transverse linear scar in the reconstructed web space. In cases of clinically significant web creep, secondary releases may be required.

REFERENCES
DEFINITION
- The thumb-in-palm deformity is a fixed adduction–flexion posture in the affected hand of the patient with spastic cerebral palsy. This influences both hand function and hygiene.

ANATOMY
- Imbalance of the spastic thumb flexor–adductor and the paretic thumb extensor results in thumb-in-palm deformity (FIG 1A).
- The adductor pollicis (AP) is the most commonly involved muscle; the abductor pollicis brevis (APB) is usually not involved.\(^1\)
- The spastic AP, the first dorsal interosseous muscle, or both adduct the thumb and index metacarpals and cause first web space contracture.
- If the flexor pollicis brevis (FPB) is spastic, the thumb metacarpophalangeal (MCP) joint will develop a flexion deformity.
- Involvement of both the AP and FPB results in a thumb flexion and adduction posture with the thumb lying across the palm.
- Involvement of the flexor pollicis longus (FPL) results in added thumb interphalangeal (IP) joint flexion (FIG 1B).
- Weak thumb extensor and abductor pollicis longus (APL) may also contribute to the deformity.

PATHOGENESIS
- Upper motor neuron lesions due to antenatal cerebral infaracts, kernicterus, intraventricular bleeding, head trauma, anoxia, and other causes result in spasticity, which in turn causes shortening of the myotendinous unit and secondary contractures.
- Paresis of muscles may contribute to greater deformity when spastic muscles are unopposed.

NATURAL HISTORY
- A supple thumb-in-palm posture is a normal finding in infants during the first year. Persistence of a tightly closed thumb in palm longer than 1 year is abnormal and should be evaluated.
- The deformity is usually correctable at first and then progresses to a fixed deformity as myostatic contracture develops.
- A progressive and variable-size discrepancy of the involved limb may develop, resulting in a smaller thumb.\(^1\)
- The lack of thumb extension and abduction can impair hand grip, function, appearance, and hygiene.

PATIENT HISTORY AND PHYSICAL FINDINGS
- A complete history and physical examination of a child with cerebral palsy should be done carefully and thoroughly.
- Input from other professionals such as neurologists and occupational therapists is often helpful.
- Repeated observation or videotaping of the child during various activities can also be useful for accurate evaluation.
- The diagnosis and pattern of cerebral palsy should be confirmed before planning treatment.
- Associated deformities of the spastic upper extremity such as finger and wrist flexion, forearm pronation, elbow flexion, and shoulder adduction and internal rotation should also be evaluated. Surgical treatment of thumb-in-palm deformity may be only one part of surgical care of the involved extremity.
- Thumb muscle involvement, motion, and stability should be evaluated in the physical examination before organizing the treatment plan.
- Individual muscle involvement is detected by observing thumb position and palpating spastic or contracted muscles (Table 1).
- Motion and stability are assessed by passive and active range of thumb abduction-adduction, flexion–extension, and palmar abduction and opposition.
- The pattern of voluntary grasp and release of large objects and manipulation of small objects should be determined by observing the child during functional activities.
- Sensory deficits impair function. Assessment of sensation should include stereognosis.
DIFFERENTIAL DIAGNOSIS
- Clasped thumb
- Distal arthrogryposis
- Absence of thumb extensor (faux extensor agenesis)

NONOPERATIVE MANAGEMENT
- Use of tone-reducing medication such as botulinum toxin to the adductor pollicis can soften the deformities and improve joint range of motion for nonoperative management.
- In mild deformity, nonoperative treatment with orthoses may help in maintaining thumb abduction, but too-rigid splinting may result in limited thumb motion.
Surgical Options for Correcting Thumb-in-Palm Deformity

<table>
<thead>
<tr>
<th>Releases</th>
<th>Surgical Options for Correcting Thumb-in-Palm Deformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adductor release in palm</td>
<td>Adductor release in palm</td>
</tr>
<tr>
<td>Adductor tenotomy</td>
<td>Adductor tenotomy</td>
</tr>
<tr>
<td>First dorsal interosseous release</td>
<td>First dorsal interosseous release</td>
</tr>
<tr>
<td>FPB release</td>
<td>FPB release</td>
</tr>
<tr>
<td>FPL slide</td>
<td>FPL slide</td>
</tr>
<tr>
<td>First web-skin and fascia release</td>
<td>First web-skin and fascia release</td>
</tr>
<tr>
<td>Augmentation of APL, EPL, EPB using:</td>
<td>Augmentation of APL, EPL, EPB using:</td>
</tr>
<tr>
<td>Brachioradialis</td>
<td>Brachioradialis</td>
</tr>
<tr>
<td>FDS</td>
<td>FDS</td>
</tr>
<tr>
<td>PL</td>
<td>PL</td>
</tr>
<tr>
<td>EPL to EPB</td>
<td>EPL to EPB</td>
</tr>
<tr>
<td>FCR or FCU</td>
<td>FCR or FCU</td>
</tr>
<tr>
<td>ECRL</td>
<td>ECRL</td>
</tr>
<tr>
<td>APL tenodesis</td>
<td>APL tenodesis</td>
</tr>
<tr>
<td>Through radius to brachioradialis, ECRL, FCR through first dorsal compartment</td>
<td>Through radius to brachioradialis, ECRL, FCR through first dorsal compartment</td>
</tr>
<tr>
<td>Joint stabilization</td>
<td>Joint stabilization</td>
</tr>
<tr>
<td>CMC joint fusion</td>
<td>CMC joint fusion</td>
</tr>
<tr>
<td>MCP joint sesamoid capsulodesis</td>
<td>MCP joint sesamoid capsulodesis</td>
</tr>
<tr>
<td>MCP joint fusion</td>
<td>MCP joint fusion</td>
</tr>
<tr>
<td>IP joint fusion</td>
<td>IP joint fusion</td>
</tr>
</tbody>
</table>

| Table 2                                      | Table 2                                                   |
| Deformity                                    | Deformity                                                 |
| Correcting Thumb-in-Palm                     | Correcting Thumb-in-Palm                                   |
| Surgical Options for                        | Surgical Options for                                       |
|                                                    |                                                     |
| thumb-in-palm deformity                      | thumb-in-palm deformity                                   |
| Preoperative Planning                        | Preoperative Planning                                     |
| General planning for surgery includes        | General planning for surgery includes                    |
| comprehensive evaluation with a multispecialty | comprehensive evaluation with a multispecialty approach  |
| approach                                       | approach                                                 |
| Surgery should be done when the central      | Surgery should be done when the central nervous system has |
| nervous system has matured and the child is  | matured and the child is old enough to cooperate with      |
| old enough to cooperate with postoperative    | postoperative therapy—usually at least 5 to 6 years old.  |
| therapy—usually at least 5 to 6 years old.    | Associated abnormalities (eg, seizures, mental status     |
| Problems should be assessed and the          | Problems should be assessed and the management optimized   |
| management optimized before surgery is        | optimized before surgery is contemplated.                 |
| contemplated                                     | Patient understanding and emotional readiness as well as   |
| Patient understanding and emotional readiness as well as family and social support should be | family and social support should be addressed before      |
| surgery.                                       | surgery.                                                 |
| Physical examination under anesthesia is      | Physical examination under anesthesia is crucial. This can  |
| crucial.                                       | can differentiate spastic from myostatic conditions and   |
| Physical examination under anesthesia is      | can accurately evaluate the stability of thumb joints.    |

Positioning

The patient is placed in the supine position, and surgery is performed under general anesthesia and tourniquet control.

Approach

Surgical approaches for thumb-in-palm deformity depend on the objectives.

Release of static or longstanding intrinsic contracture is usually performed through a curved incision located over the line of the thenar crease to release the origin of the adductor pollicis with or without the origin of the FPB.

Release of a simple intrinsic contracture may be performed through the first web space approach to release the adductor pollicis and the first dorsal interosseous muscle, combined with four-flap or double-opposing Z-plasty to release the secondary web space contracture.

A surgical approach by a small incision over the volar aspect of the distal forearm is used for extrinsic release of the FPL tendon, if necessary.

A dorsal approach to the thumb and a dorsoradial approach over the wrist is used for augmentation of thumb extensors, with a volar-radial approach being used for augmentation of the thumb abductor.
RELEASE OF CONTRACTURES

Release of Static Intrinsic Contracture
- A curved skin incision is performed next to the line of the thenar crease, extending distally from the carpal tunnel area (TECH FIG 1A).
- The superficial palmar arch and median nerve, including its motor branch to the thenar muscle, distal to the transverse carpal ligament are identified and protected. Careful dissection must be performed because occasionally the motor branch comes through the transverse carpal ligament instead of being distal to this structure (TECH FIG 1B).
- The flexor digitorum sublimis and profundi are identified and retracted ulnarly with the neurovascular bundle.
- The transverse head of adductor pollicis is identified and divided from its origin on the third metacarpal (TECH FIG 1C,D).
- The motor branch of the ulnar nerve and the deep palmar arch are identified and protected.
- Release of the oblique head of the adductor pollicis from its origin at the bases of the second and third metacarpal, capitate, and trapezoid is performed.
- The FPB origin at the transverse carpal ligament and trapezium may also be released if this muscle limits abduction and extension of the thumb ray.
- The first dorsal interosseous may be released at the distal portion of the muscle from the ulnar aspect of the first metacarpal if needed to obtain adequate passive abduction and extension of the thumb.

Release of Simple Intrinsic Contracture
- A four-flap Z-plasty over the contracted first web space is designed (TECH FIG 2A,B).
- After the skin incision, the dorsal fascia is incised while protecting the neurovascular bundles.
- The first dorsal interosseous is released at its origin from the thumb metacarpal.
- The adductor pollicis is lengthened by release in an oblique cut at its intramuscular tendon; the surgeon should aim to preserve some adductor function (TECH FIG 2C).
- Four skin flaps are rearranged to increase the first web space (TECH FIG 2D).

Release of Extrinsic Contracture
- A small longitudinal incision over the distal-volar aspect of the forearm is performed.
- The FPL tendon is exposed and incised over the musculotendinous portion.
- The thumb interphalangeal joint is hyperextended until 1 cm of distal sliding of the FPL tendon is identified.
- The FPL may be lengthened by Z-lengthening of the FPL tendon, with 0.5 mm of lengthening for each degree of correction.1

TECH FIG 1 • Intrinsic release. A. A curved incision is made over the thenar crease. B. Thenar release showing motor branch. C,D. Thumb intrinsics are released.
AUGMENTATION OF WEAK MUSCLES

Abductor Pollicis Longus Augmentation

- Two small transverse incisions over the volar wrist crease and the first extensor compartment are made, aiming to expose the palmaris longus (PL) or flexor carpi radialis (FCR) and APL, respectively.
- The superficial branch of the radial nerve is identified and protected.
- The first extensor compartment is then opened, and the APL is identified. Each slip of the APL tendon should be pulled into tension to show the best slip for carpometacarpal joint abduction.
- At the volar incision, the palmar branch of the median nerve is identified and protected. The PL tendon is then divided.
- The selected APL tendon slip is translocated volarly until acceptable thumb metacarpal abduction is achieved.
- The PL tendon is passed through a subcutaneous tunnel to the volar-radial incision.
- End-to-side tendon weave of the PL to the translocated APL is then performed under sufficient tension to obtain appropriate thumb abduction (TECH FIG 3A).
- Alternatively, the APL tendon may be cut and the distal segment rerouted volarly and woven with end-to-end PL or end-to-side FCR. The proximal segment of the APL may be used to augment thumb MCP joint extension by end-to-side anastomosis with the EPB (TECH FIG 3B).
**Extensor Pollicis Longus Rerouting**

- A dorsal skin incision over the thumb MCP and IP joint and another small longitudinal incision just ulnar to the Lister tubercle are used for this procedure. The EPL tendon is identified and divided 10 mm distal to the MCP joint. The tendon is then retracted out to the second incision (TECH FIG 4A).
- The MCP joint is set in 10 degrees of flexion, 10 degrees of abduction, and slight pronation,9 and a small (1 mm in diameter), smooth Kirschner wire is passed through the joint centrally to minimize epiphyseal damage (TECH FIG 4C).

**STABILIZATION OF THUMB METACARPOPHALANGEAL JOINT**

**Thumb Metacarpophalangeal Joint Arthrodesis**

- A dorsoulnar incision is made over the thumb MCP joint. The extensor mechanism is split longitudinally, and the ulnar collateral ligament is then detached from the metacarpal head to expose the joint (TECH FIG 5A).
- The articular cartilage of the metacarpal head is removed with a scalpel and the proximal phalanx epiphysis is shaved until the secondary center of ossification is exposed (TECH FIG 5B). This allows fusion of the epiphyses and preserves the physis.
- The joint is set in 10 degrees of flexion, 10 degrees of abduction, and slight pronation, and a small (1 mm in diameter), smooth Kirschner wire is passed through the joint centrally to minimize epiphyseal damage (TECH FIG 5C).
**Sesamoid Capsulodesis**

- A curved dorsoradial incision is made over the thumb MCP joint.\(^\text{11}\)
- The accessory collateral ligament is divided at its insertion into the volar plate.
- The volar plate is then mobilized to expose the radial sesamoid.
- The articular cartilage of the sesamoid is denuded. A cortical defect is created at the head–neck junction of the metacarpal.

- The suture is passed through the sesamoid–volar plate and metacarpal defect with straight needles by using a Kirschner wire driver (**TECH FIG 6A**).
- The MCP joint is set to 30 degrees of flexion. The intrasosseous suture is then tied over the dorsal surface of the metacarpal under the extensor tendons to secure the sesamoid to the metacarpal neck.
- A Kirschner wire is passed through the joint to maintain the joint position for 6 weeks (**TECH FIG 6B**).
POSTOPERATIVE CARE

- Postoperative care for contracture releases includes immobilization in a short-arm thumb spica cast maintaining full thumb radial abduction and 20 degrees of palmar abduction for 4 weeks.
- Removable splinting is then continued for another 4 to 6 weeks.
- If tendon transfer has been done, immobilization should be extended to 6 weeks, followed by additional splinting for 6 weeks. Dynamic splinting may be considered.
- Immobilization of the MCP arthrodesis with a thumb spica cast should be continued until radiographic healing is detected.

OUTCOMES

- The functional outcome of thumb-in-palm deformity should be assessed before and after surgery by the physician, therapist, parent, and patient.
- House et al\(^2\) demonstrated improved functional grade in all 56 patients postoperatively. Half of patients improved three or more grades.
- Tonkin et al\(^{12}\) found good results in 32 patients after surgical correction of thumb-in-palm deformity. The average follow-up was 32 months (range, 10 to 88 months).
  - The thumb was maintained out of palm in 29 of 32 patients (30 of 33 thumbs).
  - Patients could perform lateral pinch in 26 of 33 thumbs.
  - Many patients improved function, but no patient improved from dependent to independent functioning.

COMPLICATIONS

- Inadequate release of contracted or fibrotic muscle may result in insufficient release of the thumb out of the palm.
- Adhesions along the transferred tendon may cause loss of excursion postoperatively.
- Improper techniques such as overlengthening and an incorrect vector of transfer may result in limited active abduction and extension of the thumb.

UNTREATED OR INADEQUATE TREATMENT OF AN UNSTABLE MCP JOINT MAY RESULT IN FAILED TENDON TRANSFER.

AVOIDING NEUROVASCULAR INJURY IS CRUCIAL. CARE SHOULD BE TAKEN TO PROPERLY IDENTIFY AND PROTECT NEUROVASCULAR BUNDLES THROUGHOUT SURGERY.

AN IMPROPER REHABILITATION PROGRAM AND SOCIAL SUPPORT MAY RESULT IN FAILED TREATMENT.

REFERENCES

DEFINITION

- Pediatric trigger thumb is a condition in which tightness of the first annular (A1) pulley of the thumb and an enlargement or nodule of the flexor pollicis longus tendon interact to prevent normal thumb interphalangeal joint motion.

- This condition appears distinct from pediatric trigger fingers and from adult trigger digits, although similarities in pathoanatomy and presentation have earned it its name. The term “congenital trigger thumb” is a misnomer, as it has yet to be detected at birth in several large series prospectively examining a combined 14,581 newborns in three countries.  

ANATOMY

- The flexor pollicis longus tendon courses through a flexor sheath in the thumb composed of a series of pulleys that prevent bowstringing of the tendon during thumb flexion.

- The most proximal pulley is termed the A1 pulley, given its transverse annular nature. Division of this pulley does not cause bowstringing of the tendon during thumb flexion. The next pulley is the oblique pulley, although some authors have described an intervening distinct second annular pulley analogous to the A2 pulley in the fingers. These pulleys are important constraints against bowstringing.

- The digital nerves to the thumb are in proximity to the flexor pollicis longus tendon sheath. The radial digital nerve obliquely crosses the tendon sheath just proximal to the A1 pulley, and the ulnar digital nerve runs parallel to the tendon immediately alongside the A1 pulley. Injury to these structures is possible during surgical release of the A1 pulley, so knowledge of the precise anatomy is important.

PATHOGENESIS

- The pathogenesis of pediatric trigger thumb is unknown.

- In adults, the pathogenesis of trigger digits has a predominantly inflammatory nature. However, in pediatric trigger thumb, biopsies have been unable to detect signs of inflammation by gross morphology or light or electron microscopy. 

- A genetic predisposition has been considered, especially in cases of bilateral trigger thumb, but a genetic cause for the condition is not established.  

- Traumatic etiologies have been proposed, but with no clear data to support this theory.

NATURAL HISTORY

- The natural history of pediatric trigger thumb has been a focus of recent attention. The earliest reports of the condition described spontaneous resolution as rare, but newer reports have described spontaneous improvement rates of 24% to 63%.  

- The most recent study regarding the natural history of pediatric trigger thumb reported a 63% resolution rate, although the definition of resolution was improvement in passive interphalangeal joint extension to neutral, not to the normal hyperextension. Furthermore, the average time to reach this improvement was 48 months from diagnosis. Therefore, when considering the use of observation to treat a pediatric trigger thumb, the clinician should inform the parents that the thumb motion will improve but not return to normal, and that such improvement will take an average of 4 years.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Children typically present from late infancy through 5 years of age with painless loss of motion at the interphalangeal joint. The “triggering” phenomenon that so commonly occurs in adults is rare in children.

- Parents will usually be unable to determine how long the condition has been present. Some parents will describe a preceding traumatic injury to the thumb, although such an injury may simply call the parents’ attention to the thumb closely enough to notice a pre-existing trigger thumb.

- Functional impairment and pain are unusual complaints, except in the case of active triggering.

- The typical physical examination finding is a flexion contracture of the thumb interphalangeal joint, as the nodule in the flexor pollicis longus tendon typically lies proximal to the A1 pulley, preventing distal excursion of the tendon and extension of the interphalangeal joint (FIG 1A).

- In a few cases, the nodule lies distal to the A1 pulley and the thumb rests in an extended position with the child unable to actively flex the interphalangeal joint. In this case, the passive flexion of the interphalangeal joint is normal, but interphalangeal joint flexion will not occur by tenodesis with wrist extension.

- In even fewer cases, the child will be able to actively “trigger” the thumb with active flexion and passive extension.

- Regardless of the position of the thumb interphalangeal joint, a nodule is easily palpable (and even visible) in the flexor pollicis longus tendon in the region of the palmar digital crease (FIG 1B). The nodule can be felt to move proximally and distally with even the few available degrees of movement of the interphalangeal joint.

- In longstanding cases of fixed flexion deformity, thumb metacarpophalangeal joint hyperextension laxity is common. In other cases, a coronal plane deformity resembling clinodactyly may be present, although a causative relationship has yet to be established.

- Because of the possibility of bilateral involvement, both thumbs should be examined.

- An upper limb neurologic examination should be performed, including an assessment of tone in the intrinsic muscles of the hand, since the thumb-in-palm deformity of cerebral palsy can be confused with trigger thumb.
Chapter 47  RELEASE OF THE A1 PULLEY TO CORRECT CONGENITAL TRIGGER THUMB

Pediatric trigger thumb should not be confused with congenital clasped thumb, in which the metacarpophalangeal joint is fixed in a flexed position, with normal interphalangeal joint motion (FIG 1C,D).

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

Radiographs are unnecessary in the clinically obvious case; if obtained, they only confirm the resting position of the thumb interphalangeal joint.

If the examination reveals signs of trauma (eg, swelling, ecchymosis), radiographs should be considered to rule out underlying skeletal injury.

Advanced imaging is unnecessary.

**DIFFERENTIAL DIAGNOSIS**

- Congenital clasped thumb
- Thumb-in-palm deformity (cerebral palsy)
- Arthrogryposis
- Thumb hypoplasia

**NONOPERATIVE MANAGEMENT**

Nonoperative management of pediatric trigger thumb has been described, including simple observation, daily stretching by parents, splinting, and casting.

Watanabe and colleagues reported the results in 58 patients of passive stretching performed by the patient’s mother 10 to 20 times daily for an average of 44 months. Despite claiming a 96% “satisfactory result,” the authors describe only 25% of patients with locked flexion deformities experiencing improvement, and none recovering normal interphalangeal joint hyperextension. Thus, it is unclear whether their results differ from other reports of natural history, even after years of stretching exercises.

Lee and associates reported their results of splinting for passively correctable trigger thumbs (no locked flexion or extension deformities), finding a greater chance of improvement (decreased frequency of triggering) with splinting than with simple observation. Others have reported improvement in triggering with nighttime splint treatment averaging 10 months, but in a series that included trigger fingers, there was a 24% drop-out rate and there was no control group.

The role of conservative treatment of pediatric trigger thumb remains controversial. It is unclear whether conservative treatment affects the natural history and whether conservative treatment is useful for children who present with a fixed flexion posture at the interphalangeal joint (most cases).

Nonetheless, it is clear from the available data that conservative treatment offers a chance of improvement only after many months to years of daily exercises or splint use, and recovery of truly normal interphalangeal joint motion is uncommon.

Percutaneous needle release of the A1 pulley as an office procedure under local anesthesia has been described for pediatric trigger thumb, but with lower success rates than open surgical release; reported complications include incomplete release and patient intolerance of the procedure.

**SURGICAL MANAGEMENT**

Surgical release of the A1 pulley has long been recognized as a safe and effective treatment for pediatric trigger thumb.

When forming surgical indications, the surgeon must consider the available data regarding the natural history and the outcomes of conservative treatment outlined above and must discuss the options with the family. Nearly all reports of surgical treatment of trigger thumb describe complete resolution of the condition in the immediate postoperative period with a low complication rate, making surgical treatment an attractive option.

The timing of surgery is controversial. Most authors recommend delaying surgery until 1 year of age; some recommend delaying surgery until after 3 or even 5 years of age; and others just recommend an undefined period of observation before surgery. No study has shown a clear detrimental effect of delaying surgery until 3 years or later, although compensatory metacarpophalangeal joint hyperextension laxity, permanent capsular contracture of the interphalangeal joint, and coronal plane deformity of the thumb have been cited as reasons to operate before 3 years of age.

**Preoperative Planning**

Little preoperative planning is required other than preparing the child medically for the surgery and anesthesia and preparing the family for the surgery and early postoperative recovery period.

**FIG 1**

A. A typical pediatric trigger thumb locked in flexion. Note the inability to passively extend the interphalangeal joint.

B. A typical trigger thumb locked in flexion. Note the visibly protruding nodule in the flexor pollicis longus tendon at the level of the palmar digital crease.

C–D. Congenital clasped thumb. C. The flexed resting posture of both the interphalangeal and metacarpophalangeal joints. D. The interphalangeal joint typically has full passive range of motion, while the metacarpophalangeal joint is fixed in flexion, differentiating congenital clasped thumb from pediatric trigger thumb.
Positioning
- The patient is positioned supine on the operating table with the affected arm (or arms) extended on a hand table or armboard.
- A pneumatic tourniquet is placed about the upper arm. The entire limb distal to the tourniquet is prepared and draped.
- The limb is exsanguinated with an Esmarch bandage and the tourniquet is inflated to 200 mm Hg.

Approach
- The approach to the A1 pulley is best performed through a transverse incision in or immediately parallel to the palmar digital crease. Longitudinal incisions can cause loss of metacarpophalangeal joint mobility by scar contracture long term.13
- As mentioned previously, great care must be taken in the volar approach to prevent injury to the digital nerves that lie in proximity to the A1 pulley.

EXPOSURE
- A 7- to 10-mm transverse incision is planned in the region of the palmar digital crease. The exact location of the incision depends on the location of the A1 pulley relative to the crease. In the thumb with a fixed flexion posture, the proximal edge of the A1 pulley is immediately distal to the location of the palpable nodule when the interphalangeal joint is maximally extended.
- The incision need not be in the interphalangeal crease to heal with an almost imperceptible scar.
- Care must be taken to plan the incision directly over the thumb flexor sheath, which is pronated relative to the plane of the palm (TECH FIG 1A).
- The incision is made after exsanguination and tourniquet inflation. Great care must be taken to avoid incising the immediately adjacent digital nerves.
- The subcutaneous tissue is then spread bluntly to reveal the A1 pulley. The digital nerves need not be routinely dissected, as long as the transverse fibers of the pulley are very clearly visualized under loupe magnification (TECH FIG 1B).

OPEN RELEASE OF THE A1 PULLEY
- The distal and proximal edges of the A1 pulley are identified and the A1 pulley is sharply incised longitudinally along its entire length (TECH FIG 2A). The oblique pulley is identified and protected distally. A gentle spread with a blunt scissor or hemostat in the proximal aspect of the sheath entering the thenar eminence will disrupt any remaining fibrous bands that can be a source of recurrent triggering.
- The initial incision in the A1 pulley will produce an elliptical window in the pulley that may allow full extension of the interphalangeal joint (TECH FIG 2B), but the digit will still trigger postoperatively unless the entire pulley is divided.
- After adequate release, the distal edge of the A1 pulley should be separated by several millimeters, with the entire width of the flexor pollicis longus tendon clearly visible (TECH FIG 2C).
- After adequate release, the thumb interphalangeal joint should have full range of motion (TECH FIG 2D). In longstanding cases, that range of motion may not be much beyond neutral.
- If the thumb was locked in an extended position before tendon release, complete release can be confirmed by fully extending the wrist and compressing the distal volar forearm to provide proximal traction on the flexor pollicis longus tendon.
- If the thumb does not have full flexion of the interphalangeal joint with these maneuvers, the release is incomplete.
**TECH FIG 2 • (continued)**

B. Appearance of the A1 pulley after incomplete release. Note the elliptical cut edges of the pulley and the full extension of the interphalangeal joint. The intact proximal and distal ends of the pulley will be sources of recurrent triggering unless the entire pulley is released. C. Complete release of the A1 pulley. The flexor pollicis longus tendon is visible across its entire width. The forceps are holding one cut edge of the pulley. D. Full passive extension of the interphalangeal joint immediately after A1 pulley release of the patient in Figure 1A.

**CLOSURE AND DRESSING**

- The wound is irrigated and closed with simple absorbable sutures.
- The wound is infiltrated with long-acting local anesthetic without epinephrine for postoperative analgesia.
- The wound is covered by a sterile dressing and several layers of bandage and tape to prevent the child from removing the bandage (TECH FIG 3).

**TECH FIG 3 •** Postoperative dressing for trigger thumb release. Loosely wrapped gauze (A) is covered by a loosely wrapped elastic bandage (B) and a doubled-back stockinette (C) with ample tape. The multiple layers prevent premature removal by the patient. Great care must be taken to keep the dressing loose to prevent excessive swelling or even ischemia distally.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Indications</th>
<th>Given the recent literature regarding natural history and possible spontaneous improvement, parents must be made aware of the option of observation before recommending surgery, even if surgery can safely and effectively restore normal motion much faster and more reliably with very low risk.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anesthesia</td>
<td>Because of the close proximity of the digital nerves to the flexor sheath, the patient must be able to remain still during the entire procedure. Thus, while in experienced hands the entire procedure takes fewer than 5 minutes, general anesthesia or sedation is required, administered by an anesthesiologist.</td>
</tr>
<tr>
<td>Incision placement</td>
<td>The thumb is pronated relative to the plane of the hand when the hand and thumb are held flat, making it easy to make the skin incision too radial with respect to the flexor sheath when the hand is held in this position for the surgery. Therefore, it is helpful to have an assistant hold the thumb in a vertical position to allow easier centering of the incision over the flexor sheath.</td>
</tr>
<tr>
<td>Incomplete release</td>
<td>Cases of recurrence of triggering after surgical release have been attributed to incomplete release. After complete release at the distal end of the A1 pulley, the cut ends should be pointing palmarly and not toward each other. Proximally, fibrous bands in the thenar muscles can cause persistent triggering and can be divided by a gentle spread with a blunt scissor or hemostat in the flexor sheath after A1 pulley division.</td>
</tr>
<tr>
<td>Digital nerves</td>
<td>The digital nerves need not be dissected and individually identified as long as the incision is well placed directly over the A1 pulley and subcutaneous dissection clearly reveals the A1 pulley with no overlying tissue.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- Cast or splint immobilization is not necessary postoperatively. However, protecting the incision for 7 days allows less inflamed wound healing and gives the absorbable sutures time to dissolve before the inquisitive toddler is allowed access to them.
- A multilayer dressing of gauze, tape, elastic bandage, tape, stockinette, and tape is reliable and well tolerated.
- Dressings are removed at 7 days. If a determined child manages to escape the dressing prematurely, an adhesive bandage is used in its place until postoperative day 7.
- No activity restrictions are imposed postoperatively, other than routine wound care.
- Postoperative analgesic medication beyond a single appropriate dose of acetaminophen is typically unnecessary.
- Outpatient postoperative follow-up is scheduled for 1 to 2 weeks after the surgery. Full active range of motion and function of the thumb are typically achieved within 1 to 2 weeks of dressing removal. If parents perceive hesitance to use the thumb beyond that time period, a brief course of pediatric occupational therapy may be helpful.

OUTCOMES

- Outcomes of open surgical release of trigger thumbs are excellent. Recovery of full range of motion is reported in all patients in many series.
- Series that report less than 100% surgical cure describe recurrence due to incomplete pulley release as the most common reason for unsatisfactory outcome. In these series, however, success rates exceed 93%, with 100% success after reoperation of the cases with incomplete release.
- Recovery of full range of motion after surgical correction is generally immediate. In longstanding cases, full hyperextension of the interphalangeal joint may take months to achieve despite achieving neutral extension immediately postoperatively. This phenomenon may represent a volar plate or capsular contracture of the interphalangeal joint from a prolonged locked flexion posture.
- A recent study of the long-term results of surgical treatment shows that despite obtaining normal motion postoperatively, 23% of patients followed an average of 15 years postoperatively have mild loss of interphalangeal joint motion.

COMPLICATIONS

- Although rare, recurrence of the flexion posturing or triggering is the most commonly reported complication; it is attributed to incomplete pulley release. Careful attention to surgical technique prevents this complication. If recurrence occurs, revision of the surgery with complete pulley release is curative.
- Longitudinal incisions are associated with scar contracture and patient complaints long term.
- Digital nerve injuries are exceedingly rare and unreported in all series reviewed here.
- Superficial wound infection has been reported but is generally easily treated with oral antibiotics.

REFERENCES

Cerebral palsy is a primary central nervous system dysfunction that leads to significant functional impairment owing to its secondary peripheral manifestations in the upper extremity.

- The upper motor neuron lesion in the brain leads to loss of normal inhibition of tone (ie, spasticity), loss of motor control in the limb (ie, weakness), or impaired coordination of muscle activity (ie, athetosis).
- The most common manifestation is spasticity.
- Spastic hemiplegia is the main type of cerebral palsy for which upper extremity surgery is indicated.
- In spastic hemiplegia due to cerebral palsy, the most common peripheral manifestations in the upper limb are shoulder internal rotation, elbow flexion, forearm pronation, wrist flexion and ulnar deviation, finger clenching or swan-necking, and thumb-in-palm deformity.
- Increased muscle spasticity causes muscle imbalance across joints, which leads to impaired function and over time can lead to joint contractures with skeletal deformation.
- The wrist is the most commonly affected joint and will be the focus of this chapter.

ANATOMY

- Five primary wrist motors control wrist joint position.
- The three wrist extensor muscles are the extensor carpi radialis brevis (ECRB), the extensor carpi radialis longus (ECRL), and the extensor carpi ulnaris muscles (ECU).
- The two wrist flexor muscles are the flexor carpi radialis (FCR) and the flexor carpi ulnaris (FCU).
- The finger and thumb flexor muscles (flexor digitorum profundus [FDP], flexor digitorum superficialis [FDS], and flexor pollicis longus [FPL]) cross the wrist joint and exert a wrist flexion force. The finger and thumb extensor muscles (extensor pollicis longus [EPL], extensor indicis proprius [EIP], extensor digitorum communis [EDC], and extensor digiti quinti [EDQ]) also cross the wrist joint and exert a wrist extension force.
- Each of the muscles that crosses the wrist joint exerts a vector force for wrist extension and flexion, as well as radial and ulnar deviation. These vector force graphs can be used to help determine which muscles are the major deforming force for wrist flexion posturing.
- In cerebral palsy, the most common deformity is wrist flexion associated with ulnar deviation.
  - The muscle with the greatest flexion and ulnar deviation vector is the FCU.
  - The FCU is most commonly the deforming force, particularly because it may be coupled with a weak wrist extensor–radial deviator (ECRL and ECRB).

PATHOGENESIS

- In the early stages of spastic hemiplegia, the joints and muscles will be supple, with full passive range of motion.
- With skeletal growth, the muscle imbalance across joints over time leads to muscle–tendon unit shortening and joint contractures, eventually leading to skeletal deformity.
- Increased FCU tone overpowers the decreased strength of the ECRL and ECRB, leading to a wrist flexion posture.

NATURAL HISTORY

- In spastic hemiplegia due to cerebral palsy, the FCU is the most common deforming force, pulling the wrist into flexion and ulnar deviation.
- Over time, the overpull of the FCU leads to contracture of the muscle, which may lead to fixed contracture of the wrist joint.
- Ultimately, a fixed skeletal deformity can occur by the time of skeletal maturity.
- Initial management involves exercises to keep the FCU stretched and to prevent contracture of the muscle.
- If muscle contractures develop, splinting may be necessary to prevent worsening of wrist joint contractures.
- Tendon transfer surgery is best performed before fixed contractures develop.
- If fixed joint contractures and muscle contractures exist, a salvage procedure with muscle lengthenings, wrist fusion, or both may be necessary.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient evaluation begins with interviewing the parents regarding use of the affected limb.
- Most commonly, children with spastic hemiplegia will show premature hand dominance, favoring the unaffected side even as young as 6 months of age.
- This may be the presenting complaint leading to the diagnosis of cerebral palsy.
- Delay of normal pinch-and-grasp function patterning at 1 year of age is evident.
- Generalized patterns of upper extremity use for activities of daily living, commensurate with the child’s age, are discussed with the parents and child. The clinician also observes for bimanual skills such as doing zippers and buttons, cutting food, and tying shoes.
- The child’s functional use of the hand can be quantified using House’s classification of upper extremity functional use:
  - In this nine-level classification, functional use is assessed as follows: does not use, passive assist (poor, fair, good), active assist (poor, fair, good), and spontaneous use (partial, complete).
  - This provides a baseline that the physician can use to help communicate the functional goals of treatment with the parents.
  - Agreement with the parents on the child’s present overall level of limb function serves as a baseline for comparing the outcome of treatment.
Examinations and tests to perform include:
- Passive range of motion of each joint. If a joint is passively stiff, a joint contracture exists. Tendon transfer surgery is best performed in patients with full passive mobility of all joints.
- Volkman angle test. This test indicates muscle contracture, as the finger flexors are biarticular, crossing both the wrist joint and the finger joints.
- Active range of motion of the wrist. This indicates whether this patient has control to be able to actively extend the wrist. If this is absent, a tendon transfer surgery may be indicated to provide better active wrist extension.
- Active range of motion of the fingers with the wrist held in a neutral position. This test indicates whether a wrist extensor tendon transfer surgery would be helpful. If the patient has better digital control with the wrist in an extended position, then a wrist extensor tendon transfer surgery would be helpful. If the patient has no digital extension, then an FCU tendon transfer should be considered to the EDC. If the patient develops a clenched fist with wrist neutral position, then a wrist extensor tendon transfer would be contraindicated.
- If a patient has full passive mobility of the joints and no muscle contractures of the finger flexors but positions the wrist in significant flexion, leading to impairment with grasp and release or fine motor tasks, then a wrist extensor tendon transfer surgery to improve wrist position would be indicated.
- Stereognosis testing. Impaired stereognosis does not preclude surgical intervention, but it is important to identify it preoperatively as a part of the disability present.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Motion laboratory analysis has been used to assist in determining the position of the joints of the upper extremity during tasks.
- A fine-needle electrode can be used to determine whether phasic control of the muscle occurs during grasp and release.
- A muscle that is well controlled with phasic activity, without significant or continuous spasticity, is the best candidate for muscle–tendon transfer surgery.\(^5\)

**DIFFERENTIAL DIAGNOSIS**
- Wrist flexion posturing due to ineffective wrist extensors, flexor contracture or spasticity, or wrist or carpal abnormalities.

**NONOPERATIVE MANAGEMENT**
- Occupational therapy includes the use of splints, stretching and strengthening programs, and active functional use activities.
- Two types of splints can be used: nighttime serial static splinting for treatment of muscle or joint contractures, and daytime splints for pre-positioning the hand to improve active function.
- The indication for nighttime splinting is contractures.
- If no contractures of the muscles or joints exist, nighttime splinting is not necessary and is a waste of time and money for the child and family!

- If contractures exist at the wrist or fingers and thumb, a nighttime forearm-based wrist–hand orthosis is indicated.
- Daytime splints are usually used to pre-position the wrist in a neutral to slight “cock-up” position to help improve grasp and to pre-position the thumb out of the palm to help improve pinch.
- If the splint is bulky or cumbersome, it will interfere with rather than enhance function, defeating its purpose.
- Care should be given to ensure proper fit of the splint so that its purpose can be achieved.
- Stretching and strengthening programs, along with active functional use activities, are carried out by the therapist as well as taught to the parents and child as a home program.
- For patients with more focal muscle tone imbalance, botulinum toxin type A injections have been shown to be effective in reducing spasticity in the muscles injected and in improving hand function.\(^1,8,9\)
- Botulinum toxin locally blocks the release of acetylcholine at the neuromuscular junction, with a reversible action lasting on average 3 to 4 months. During this period, antagonist muscles can be strengthened and spastic muscles can be stretched, with the benefits lasting beyond the direct effects of the medication.
- For the mildly involved child, treatment with Botox injections may obviate the need for surgical intervention.

**SURGICAL MANAGEMENT**
- The most common deformity of the wrist is flexion, often with ulnar deviation as well. This is the most functionally disabling deformity in hemiplegia as it significantly interferes with grasp and release function.
- Several surgical options exist, with the choice depending on the degree of deformity and the extent of volitional control of each muscle involved.
- The three main options for treatment of a wrist flexion deformity are:
  - Release or lengthening of the deforming spastic muscles (FCU, FCR)
  - Transfer of tendons to augment the weak wrist extension
  - Wrist fusion to stabilize the joint for the severe, fixed, nonfunctioning wrist
- If the wrist flexor deformity is significant and the patient does not have active control of wrist extension, then tendon transfer surgery to augment wrist extension may be necessary.
  - Using the FCU as a transfer to wrist extension has the advantage of removing its force as a spastic wrist flexor and ulnar deviator, and transferring its forces into wrist extension.
  - Care must be taken to prevent overcorrection if the deformity is not severe, or if the transfer is tensioned too tightly, particularly in the younger child.

**Preoperative Planning**
- In all cases of transfer into the wrist extensors, the finger function must be assessed preoperatively with the wrist in neutral, the desired postoperative position.
- If the finger flexors are too tight when the wrist is brought into neutral, a finger flexor lengthening will be necessary as part of the procedure.
If the patient does not have finger extensor control to allow for release of grasped objects, then a transfer into the finger extensors (EDC) may be indicated.

**Positioning**

- The patient is positioned supine on the operating room table, with an armboard to support the upper limb during the procedure (FIG 1).
- A tourniquet is applied above the elbow.

**Approach**

- A volar–ulnar approach to the forearm is used to harvest the FCU tendon, and a dorsal approach to the distal forearm and wrist is used for inserting the tendon transfer.

**Mobilization of the Flexor Carpi Ulnaris**

- The incision for exposure of the FCU is a longitudinal one on the volar and ulnar aspect of the forearm from the proximal third of the forearm to its distal insertion on the pisiform (TECH FIG 1A).
- Dissection is carried out through the subcutaneous layer and the forearm fascia, onto the muscle belly proximally and onto the tendon insertion distally.
  - The ulnar nerve and artery lie radial to the tendon and are carefully identified and protected, including the dorsal ulnar sensory branch in the distal aspect of the wound.
- The tendon is transected at its distal insertion on the pisiform, and a grasping suture is placed (TECH FIG 1B).
- The FCU is then freed of its fascial insertion back to the most proximal aspect of the wound to allow full mobilization of the muscle to its dorsal position (TECH FIG 1C).
- Full mobilization of the muscle to the proximal third of the forearm has been shown to increase its vector as a forearm supinator, in addition to its wrist extension moment arm.²

**Transfer of the Flexor Carpi Ulnaris to the Extensor Carpi Radialis Brevis Tendon**

- A second incision is made over the dorsal radial aspect of the wrist diagonally over the second dorsal compartment (ECRB, ECRL) of the wrist (TECH FIG 2).
- Just distal to where the first dorsal compartment tendons (abductor pollicis longus and extensor pollicis brevis) cross the second dorsal compartment, a generous
fascial window over the second dorsal compartment is made to fully expose the ECRB and ECRL tendons.

- A subcutaneous tunnel is then made in direct line from the proximal end of the ulnar incision to the radial incision to allow a straight line of pull for the tendon transfer.

- The FCU tendon is then woven into the ECRB tendon using the Pulvertaft weave technique and tensioned so that the wrist sits at rest against gravity in a neutral position.

- Standard wound closure is performed after the tourniquet is deflated.

**POSTOPERATIVE CARE**

- The postoperative rehabilitation regimen is imperative to maximize surgical results.
- The limb is immobilized in a cast for 1 month after tendon transfer surgery.
- After 1 month, the cast is removed and a custom splint is used holding the wrist in a neutral position (as well as protecting any other procedures that were done concomitantly).
- The splint is worn full time for an additional month but is removed three to five times a day for active range of motion and light functional activities.
- After 1 month of full-time splinting, the patient then progresses to nighttime splinting only with active functional use of the hand during the day, including lifting and strengthening exercises.
- Individualized sessions with a therapist experienced in tendon transfer rehabilitation are very helpful to maximize use of the limb and incorporate the wrist into activities of daily living, but success may be limited by the overall extent of the patient’s cerebral palsy involvement.

**OUTCOMES**

- The greatest functional benefit in upper extremity surgery has been reported with correction of the wrist flexion deformity, regardless of the transfer used.
- Beach et al. as an example of the correction achieved, reported a postoperative arc of motion of almost 50 degrees, centered around the neutral axis, at greater than 5 years of follow-up.
- Significant aesthetic improvement was noted as well in 90% of patients.
- A functional outcome study of 134 cerebral palsy patients treated surgically showed that the average functional improvement was from use of the hand as a poor passive assist to use of the hand as a poor active assist. This article advocates performing multiple procedures simultaneously for correction of the elbow, forearm, wrist, and thumb in a single surgical setting.

**COMPLICATIONS**

- All surgical procedures carry risk, and this must be weighed against the potential benefits that most commonly are achieved.
- Preoperatively, patients must be screened for anesthetic complications as follows:
  - A bleeding screen for patients on long-term Depakote antiseizure medications
  - Screening for bladder and lung infections, particularly for patients with poor urinary or pulmonary control
  - Nutritional status (height and weight percentiles for age)
  - Intraoperative attention to wound care is imperative to avoid wound healing problems.
  - Wounds may need a postoperative drain to prevent hematoma formation.
Nerve and artery injury can be avoided with appropriate planes of dissection and a thorough knowledge of the pertinent anatomy.

Postoperatively, the splint or cast should be adequate to allow for postoperative swelling and should be split if excessive swelling is encountered.

- Many children with spasticity do not have normal preoperative sensory or motor findings and may not have normal mentation, so normal parameters cannot be used to monitor for compartment syndrome.
- Premature removal of the cast or splint, as well as overzealous patient activities, can lead to tendon rupture or attenuation.
- Excessive immobilization can lead to excessive adhesion formation, diminishing the eventual functional use.
- Long-term problems most commonly involve loss of the muscle balance achieved at the time of the surgery.
  - Many children have tendon transfers as young as 7 years old, with continued skeletal growth, they may have recurrent deformity.
  - Overcorrection can also occur, with the “opposite” deformity occurring. “Fine-tuning” surgery may be necessary to address complications that develop after correction of the original deformity.
  - Several principles will help prevent these complications.
    - Do not overcorrect deformity, particularly in the younger child.
    - Leave options to reverse the surgical correction if necessary.

Keep functional grasp and release as the highest priority in surgical planning.

Avoid wrist arthrodesis, as this precludes the tenodesis effect of the wrist for finger use.

REFERENCES

DEFINITION
- Radial dysplasia represents a spectrum of longitudinal deficiency in radial growth.
- This deficiency can be mild or severe based on the deficiency in the radius.

ANATOMY
- Bayne and Klug\(^1\) have provided a classification based on radiographic findings (Table 1).

PATHOGENESIS
- Radial dysplasia develops during the period of embryogenesis. During this period, other organ systems are developing and may also be affected, as discussed later in this chapter.

NATURAL HISTORY
- The natural history of patients with radial dysplasia clearly depends on the type of dysplasia present and the associated conditions.
- Patients with isolated type I or II radial dysplasia usually do not require surgical intervention.
- Patients with more severe dysplasia can frequently benefit from surgical intervention.
- Many times radial dysplasia is part of a syndrome, and the associated sequelae clearly affect these patients more than the underlying radial dysplasia. The most common associations are with Holt-Oram syndrome, thrombocytopenia-absent radius (TAR) syndrome, Fanconi anemia, and VACTERL (vertebral anomalies, anal atresia, cardiovascular anomalies, tracheoesophageal fistula, esophageal atresia, renal or radial

---

### Table 1: Bayne and Klug Classification of Radial Dysplasia

<table>
<thead>
<tr>
<th>Type</th>
<th>Radiograph</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td><img src="image1" alt="Type I Radiograph" /></td>
<td>Short distal radius; distal epiphysis present, delayed; mild radial deviation</td>
</tr>
<tr>
<td>II</td>
<td><img src="image2" alt="Type II Radiograph" /></td>
<td>Defective growth proximal–distal epiphyses; radius in miniature</td>
</tr>
<tr>
<td>III</td>
<td><img src="image3" alt="Type III Radiograph" /></td>
<td>Partial absence of radius; wrist unsupported</td>
</tr>
<tr>
<td>IV</td>
<td><img src="image4" alt="Type IV Radiograph" /></td>
<td>Total absence of radius</td>
</tr>
</tbody>
</table>

anomalies, limb anomalies) (in front of or above the central axis of the limb).

- An association with several craniofacial syndromes is also common.
- No matter what procedure is used for treating the radial dysplasia, the patients all have a high incidence of recurrent deformity as they get older.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Clearly the most significant finding is radial deviation at the wrist (FIG 1).
- If the patient is older, the affected forearm will also be short.
- Frequently there is also associated thumb hypoplasia.
- Because of its frequent association with systemic conditions, all patients require careful examination of their cardiac, renal, hematologic, and spinal systems.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Radiographs should be taken of both forearms to assess stage of radial dysplasia (see Table 1).
- In addition, all patients warrant a workup for syndromes and associated conditions, such as Holt-Oram syndrome, Fanconi anemia, TAR syndrome, and VACTERL.
  - This requires cardiac, renal, hematologic, and spinal evaluation.

**NONOPERATIVE MANAGEMENT**

- All patients warrant preoperative stretching and splinting before any surgical intervention.
  - This may require external fixation techniques to distract the soft tissues in severe cases.

**SURGICAL MANAGEMENT**

- Patients with type I or II radial dysplasia usually do not require surgical intervention.
- Surgical treatment has generally ranged from soft tissue rebalancing alone to full centralization of the wrist with or without external fixation.
  - Before any procedure is contemplated, the surgeon must remember that the patient must maintain the ability to get his or her fingers to the mouth with the wrist in the surgically altered position.

- We have had experience with various procedures for the treatment of radial dysplasia, including centralization, free toe transfer for stabilization of the radial wrist, and soft tissue release alone. We do not use formal centralization procedures anymore, as we have found the recurrence rate to be similar to our soft tissue release procedure. In addition, we think that this procedure jeopardizes the ulnar epiphysis, which can lead to an extraordinarily short forearm. Also, loss of mobility can result from a successful centralization procedure.
- Vascularized bone transfer can be used in selective cases to provide stabilization of the radial side of the wrist. In the past we have used a vascularized second-toe metatarsophalangeal joint as described by Vilkki. In the future we anticipate using the proximal fibula, as its growth potential may be more similar to the ulna than the metatarsophalangeal joint.
  - The long-term problem for any surgical procedure is the recurrence rate.
- For our patients, soft tissue release with a bilobed flap reconstruction has provided the most reliable, effective results.

**Preoperative Planning**

- Before surgery, the patient must have undergone adequate soft tissue stretching.
  - In the first few months this is accomplished by splinting. In severe cases, serial casting may be necessary.
  - The splints should be large enough so the child cannot swallow it.
  - After about 6 months of age, active stretching is started by the parents with use of nighttime splinting.
- The bilobed flap design must be drawn appropriately to take advantage of the redundant tissue on the ulnar side of the wrist.

**Positioning**

- The patient is placed in the standard supine position, and a general anesthetic is used in all cases.
- We do not use a standard tourniquet as we have found this to be inadequate in young children. Instead, we use the elastic bandage as a tourniquet in the upper arm.

**Approach**

- We use a dorsal surgical approach, although more recently a volar approach has been described that may provide better exposure for soft tissue release.
Part 4 PEDIATRICS • Section VI UPPER EXTREMITY

RELEASE OF RADIAL DEVIATION OF THE WRIST

- After induction of general anesthesia, the upper extremity is prepared and draped in the usual fashion.
- The bilobed flap is then carefully designed using a marking pen (TECH FIG 1A,B).
- The Esmarch bandage is used to exsanguinate the limb; it is then wrapped three times around the upper arm for use as a tourniquet.
- After careful incision and elevation of the skin flaps (TECH FIG 1C), the finger and extensor tendons as well as the median nerve are carefully identified and preserved.
- All other tissues in the radial wrist are released. Care must be taken not to dissect excessively near the ulnar epiphysis, to prevent injury to the vascular supply to this area.
- After release is accomplished, the wrist is placed in a neutral position and pinned with a 0.062-inch Kirschner wire. The Kirschner wire is temporary and is put across the joint from either direction (ie, there is no specific location for the exit or entrance site).
- The flaps are then rotated and sutured in place (TECH FIG 1D,E).
- The tourniquet is removed to ensure perfusion to the fingers, and a long-arm cast is placed.

PEARLS AND PITFALLS

| Adequate preoperative stretching of soft tissues | If not adequate, this may lead to a suboptimal result. |
| Identification of median nerves and tendons, as these structures tend to be in very aberrant locations | There is the potential for injury to nerve or tendon during soft tissue release if this is not done. |
| Careful dissection around the distal ulna | If too aggressive, it can lead to injury to the epiphyseal region, leading to growth problems in the ulna. |
| Pinning of ulnocarpal joint after release | Failure to do this can lead to partial flap loss because of motion at the joint. |
POSTOPERATIVE CARE
- The long-arm cast is left on for 3 to 4 weeks.
- At that point the pin is removed and the patient is changed to a removable splint.

OUTCOMES
- The bilobed flap procedure is an effective procedure for treating radial dysplasia (FIG 2).
- Deformity tends to recur, though the incidence of this appears to be similar to that for other procedures used to treat radial dysplasia.

COMPLICATIONS
- Very few complications are associated with this procedure.
- Partial flap loss can occur, but the risk seems to be minimized by appropriate flap design and immobilization after the procedure.

REFERENCES
DEFINITION
- Multiple hereditary exostoses (MHE), first described by Boyer in 1814,\(^2\) is a familial disorder with an autosomal dominant mode of inheritance.\(^8\) It is also known as multiple osteochondromatosis, multiple osteochondromata, multiple cartilage exostoses, diaphyseal aclasis, or metaphyseal aclasis.\(^5,18\)
- MHE is a developmental disorder affecting numerous sites in the immature skeleton, except the skull. It is characterized by abnormal proliferation of epiphyseal chondroblasts that causes a subsequent defect in remodeling of the metaphysis. In the immature individual this leads to the two main characteristics of this condition: skeletal metaphyseal bony prominences capped with cartilage (exostoses) and retardation of longitudinal bone growth.

ANATOMY
- Knowledge of the normal anatomy and biomechanics of the forearm in the immature individual is instrumental in understanding the pathogenesis of the deformity, and ultimately in planning appropriate treatment.
  - The ulna acts like a swivel hinge around which the radius rotates.
  - During forearm pronation–supination the relationship between the two forearm bones changes. This rotational movement requires perfect alignment of both radius and ulna as well as integrity of the ligamentous structures around the proximal and distal radioulnar joint and the interosseous membrane. Minimal axial or rotational bone deformity, asymmetric bone shortening, or ligament instability can hinder this function.

PATHOGENESIS
- Osteochondromas are the most common benign bone tumor. Histologically, they resemble the epiphyseal growth plate and consist of a bony stalk covered by a cartilaginous cap. They arise from the peripheral aspect of the growth plate of bones that undergo enchondral ossification.\(^10\)
  - About 15\% of osteochondromas occur as MHE.\(^22\) In MHE, the exostoses vary greatly in number, location, size, and configuration. They tend to have a more irregular and bizarre shape than solitary osteochondromas. They also typically involve a significantly greater portion of the metaphysis or diaphysis. Progressively larger and more mature-appearing lesions with ossification are seen on the surface of the bone as the distance from the physis increases, so they appear to be migrating into the diaphysis of long bones.\(^10\)

NATURAL HISTORY
- The prevalence of MHE in the general population is estimated to be at least one in 50,000, with a median age of first diagnosis of 2 to 3 years of life (exostoses rarely develop before 2 years of age).\(^17\)
  - In individuals with MHE an average of five or six exostoses, involving both upper and lower extremities, are found at the time of the first consultation.\(^22\)
  - Over time the upper and lower extremities may appear disproportionately shorter compared to the trunk.
  - The phenotypic penetrance of this condition is age-related. By 2 to 3 years of age, 50\% of the affected individuals show signs of the disease; the presence of exostoses is almost always evident by the age of 12. Once skeletal maturity is achieved most of the lesions will become quiescent and often will ossify.\(^17\) The overall penetrance of the disease in adult obligate heterozygotes ranges between 93\% and 100\%,\(^7,8,28\)
  - Approximately 10\% of individuals with documented manifestations of multiple exostoses have no family history of MHE.\(^17\)
  - It is reported that 30\% to 60\% of the individuals with MHE show a deformity of the forearm.\(^17\) The natural history of forearm deformities is progressive and results in a variable and worsening amount of weakness, pain,\(^4\) functional problems (such as dislocation of the radial head, limited pronation–supination, ulnar deviation at the wrist, and compression on adjacent structures), and cosmetic deformity.
  - The deformities are almost always accompanied by discrepancy in length between the two bones. The asynchronous rate of longitudinal growth in an anatomic region where two bones are paired in close longitudinal relationship leads to a greater risk of anatomic distortion. Most of the longitudinal growth of the ulna occurs at the distal physis,\(^16\) which is also the more commonly affected physis (30\% to 85\% of the cases).\(^17,18\)
  - A serious complication of MHE is the potential for malignant transformation of an exostosis into chondrosarcoma. This can occur at any age but it is exceedingly rare during childhood.\(^17\)
  - The risk of malignant degeneration in adults with MHE is 0.57\% to 5\%.\(^8,17,28\)
  - The clinical course of the chondrosarcoma is slow and the prognosis is in general favorable if the tumor is detected early. Metastases occur late, usually to the lung, via hematologic dissemination.
  - Patients affected by MHE have a normal life expectancy unless malignant degeneration and metastasis develop.\(^22\)

HISTORY AND PHYSICAL FINDINGS
- In the context of progressively enlarging, juxta-articular protuberances, the characteristic forearm deformities may develop.
  - An accurate physical examination of the upper extremity, including evaluation of the comparative length of the forearms as well as range of motion of the elbow, wrist, and forearm (flexion and extension, radial and ulnar deviation of the wrist, varus and valgus angle of the elbow, and pronation–supination of the forearm), is instrumental to assess the progression of the condition.
  - The classic clinical description is a bowed, short, and knobby-appearing forearm with the wrist in an ulnarly deviated position, which limits radial deviation.
During growth the affected ulna typically remains relatively shortened and curved, and this often leads to significant bowing of the radius. When the ulna is shorter the ulnar collateral ligament acts as a tether, causing bowing of the radius. In addition, the local presence of the exostosis itself causes radial bowing by disturbing hemiepiphyseal growth.12 Cubitus varus deformity, radial head dislocation, or both may also occur. Radial head dislocation is reported to occur in 22% of the affected forearms.18 Symptoms of this can be varus deformity of the elbow, limitation of elbow motion, and pain. A mild flexion deformity of the elbow is often present. At the wrist level an increased ulnar tilt of the radial epiphysis, ulnar deviation of the hand, and progressive ulnar translocation of the carpus are often present. These deformities lead to a loss of radial deviation of the hand and loss of pronation–supination of the forearm (FIG 1).

The earliest radiologic sign is an asymmetric or beaked overgrowth of the cortex next to the growth plate.3 Like solitary osteochondromas, the exostoses may be described as sessile, pedunculated, or cauliflower-like; they nearly always point away from the physis. In MHE, the lesions tend to be bigger and have a more bizarre shape. Characteristically

IMAGING AND OTHER DIAGNOSTIC STUDIES

The diagnosis of MHE can be easily made by clinical inspection in a child with a positive family history. Plain radiographic evaluation is usually sufficient to confirm the diagnosis and to determine the number, location, and morphology of the exostoses (FIG 2).
Part 4 PEDIATRICS • Section VI UPPER EXTREMITY

Differential Diagnosis

- Langer–Giedion syndrome
- Madelung deformity
- Chondrosarcoma

in the distal ulna they are often narrow, with a pointed end (FIG 2).

In older children and teenagers, irregular areas of calcification of the cartilaginous cap may be present, particularly in the more voluminous lesions. Extensive calcification with changes in the shape and thickness of the cartilaginous cap should raise suspicion of a possible chondrosarcomatous transformation.

At least two full views of the forearm (true anteroposterior and lateral containing both the elbow and the wrist) are necessary to properly assess the ulna variance, the radial articular angle (RAA), the carpal slip, and the relative radial bow. These radiographic measurements are useful in the surgical planning phase (FIG 3).1

Alterations of the radial head on radiographs must always be assessed. They range from hypertrophy and flattening to a complete radial head dislocation.

The Taniguchii classification correlates the regional involvement of the forearm with the generalized severity of the disease.23

Masada morphologically classified the involvement of the forearm in MHE into three types (FIG 4).12 This classification was also used for treatment planning.

Computed tomography (CT), magnetic resonance imaging (MRI), and magnetic resonance angiography are performed at times for specific and symptomatic lesions. These can be especially helpful to detail the anatomic position relative to soft tissue structures, or when malignant transformation is suspected.24

Differential Diagnosis

- Langer–Giedion syndrome
- Madelung deformity
- Chondrosarcoma

Nonoperative Management

- The only treatment for MHE is surgery, but the mere presence of an exostosis is not, by itself, an indication for surgical removal.
- The conspicuous number of lesions and the fact that they are mostly asymptomatic warrant a cautious surgical approach.

Surgical Management

- Surgical treatment of forearm deformities in MHE remains controversial. A number of operative techniques have been proposed.5,16,12,19
- The main surgical indications are:
  - To improve forearm function (pronation–supination)1
  - To relieve pain from external trauma or irritation of the surrounding soft tissue4
  - To improve appearance
  - To rule out malignancy when there is a rapid increase in size of a lesion15
- When evaluating the surgical indications in an individual patient, it is important to distinguish between the functional deficit and the cosmetic appearance.
  - The postoperative appearance of the forearm has been shown to be unrelated to the functional outcome.14
  - Despite maintaining good function even without treatment,1,14 a percentage of patients find the arm cosmetically unpleasant because of the shortening, angulations, and deformities.14 If surgery is being undertaken for cosmetic rather than functional purposes, the hopes, concerns, and expectations of patient and parents must be thoroughly discussed and accurately outlined.
- If function is the main concern, the goal of surgery is to maintain or improve function until reaching skeletal maturity and not to prevent the deformities.
- Some authors5,12,15 advocate an aggressive approach based on the rationale that forearm deformities are equal to functional impairment. Their surgical treatment employs procedures such as excision of the exostoses and ulnar lengthening, associated at
times with radial hemiepiphyseal stapling or osteotomy. They feel this is the only way to prevent the development or progression of deformity in the upper extremity.

- According to these authors, the surgical indications include relative ulna shortening (with or without bowing) of more than 1.5 cm, RAA of greater than 30 degrees, carpal slip of more than 60 degrees, and bowing of the radius or the ulna (or both).\(^5\)
- However, we and others believe that the mere presence of forearm deformities alone is relatively unrelated to functional impairment,\(^1,14,21\) and therefore we do not recommend surgical correction of the deformities only to prevent a possible, but not predictable, future functional impairment.
- Symptomatic dislocation of the head of the radius is defined as interfering with joint motion or causing significant pain.

**Procedures**

- Exostosis excision alone is indicated when a lesion becomes symptomatic or when it alone causes limitation of forearm pronation–supination. This procedure alone does not correct the forearm deformities that may be present.

  - If significant forearm deformity is present, exostosis excision is combined with ulnar tether release with or without radial osteotomy.
  - Radial osteotomy is performed in the skeletally mature or nearly skeletally mature patient, as significant remodeling of the radius is unlikely.
  - If the patient has significant growth potential remaining, ulna-tether release alone can lead to impressive correction.
  - Ulna lengthening with or without radius epiphyseal stapling remains a common procedure reported in the literature, but we do not use this regularly. We think it can lead to a shorter forearm, as well as bearing the incumbent risks associated with lengthening procedures.
  - The treatment for symptomatic radial head dislocation is usually surgical excision once the patient is skeletally mature. Excision before this time may lead to instability, growth disturbances, and possible worsening of the wrist or elbow deformity. In rare instances, however, exostosis excision with ulnar osteotomy may be effective in relocating the radial head.

---

### EXOSTOSIS EXCISION AND ULNAR TETHERING RELEASE

- The location of the incision in the distal forearm varies depending on where the osteochondroma is located. Planning of this is important, as the ability to access the distal ulna is imperative whether the osteochondroma is located on the distal ulna or radius.
  - If the patient has ulnar involvement only, the incision can be placed on the subcutaneous border of the ulna between the flexor carpi ulnaris and the extensor carpi ulnaris. Care must be taken to identify and preserve the dorsal branch of the ulnar nerve.
  - If the patient has osteochondroma of both the radius and ulna, the incision has to be modified to allow exposure of both bones as well as the distal ulna.
  - A tourniquet of appropriate size is used.

  - Once the initial incision is made, the osteochondroma is carefully exposed and excised (TECH FIG 1A–C). Care must be taken to preserve satisfactory bony cortex for stability.
  - Next, the distal ulna is exposed and the ulna-tethering force is released.
  - This is usually done by transecting the distal ulna through the epiphyseal area, leaving the triangular fibrocartilage complex attached to the distal fragment.
  - In the skeletally mature patient a radial osteotomy can be performed if the forearm bowing and deformity is severe (TECH FIG 1D–F).
  - Wire fixation is usually adequate for the osteotomy.
  - As stated earlier, in the skeletally immature patient, release of the tether alone is usually adequate.

---

**TECH FIG 1**

- **A.** Exposure of large osteochondroma of the distal ulna.
- **B.** Dissection and exposure of the osteochondroma. Significant tethering is present distally. (*continued*)
TECH FIG 1 • (continued) C. After excision of osteochondroma and release of ulnar tethering. D. In a skeletally mature patient, a radial osteotomy is performed after exostoses excision and ulnar-tether release. E. After excision of exostoses, ulnar-tether release, and radial osteotomy. F. Radiograph taken 30 months after surgery shows improved forearm–wrist alignment.

RADIAL HEAD EXCISION

- An incision is made over the prominent radial head with the forearm in pronation to protect the posterior interosseous nerve.
- Dissection is then carried down in the interval between the anconeus muscle and extensor carpi ulnaris.
- The radial head is then exposed and excised (TECH FIG 2).
- Layered closure is then performed and the extremity is immobilized for 2 weeks, followed by institution of range-of-motion exercises.

TECH FIG 2 • A. Patient with painful radial head dislocation. B. Exposure of the radial head. Forearm is in a pronated position. C. Radial head exposed before excision. D. Excised radial head. Significant degenerative changes are present.
To improve the bone formation and reduce the risk of fracture at the lengthening site, when the ulna is lengthened, the cordlike portion of the interosseous membrane tends to pull the radius distally. This action is advantageous when concomitant radial head dislocation is present. Otherwise, the cordlike portion of the interosseous membrane should be dissected to prevent migration of the radius.11

The ulnar lengthening is fraught with complications, reported.1,5,12,13,15,16 This calls into question the indications for this procedure. The main complications in progressive distraction lengthening are nerve damage, fractures at the lengthening site, and pin tract infection. When only the ulna is lengthened, the distraction lengthening of the forearm bones, the bone formation takes longer compared to the lower limb because of the lack of weight bearing. Therefore, one of the disadvantages of this technique is that the external fixator must be kept on for several months.

To improve the bone formation and reduce the risk of fracture at the lengthening site, dynamization techniques are recommended.

When the ulna is lengthened, the cordlike portion of the interosseous membrane tends to pull the radius distally. This action is advantageous when concomitant radial head dislocation is present. Otherwise, the cordlike portion of the interosseous membrane should be dissected to prevent migration of the radius.11

OUTCOMES

Many MHE patients do not need surgery. In patients who require surgery, we feel that ulnar-tether release, with or without exostoses excision, with or without radial osteotomy, provides the most reliable result with the fewest complications. In selected patients this can greatly improve function, in addition to the improved cosmesis of the extremity.

For symptomatic radial head dislocations we prefer excision, as this usually leads to a consistent, reproducible result with little risk.

COMPLICATIONS

The ulnar lengthening is fraught with complications, reported in the literature to range from 0% to 100%.1 Recurrence of the deformity in the skeletal immature patient is commonly reported.1,5,12,13,15,16 This calls into question the indications for this procedure.

The main complications in progressive distraction lengthening are nerve damage, fractures at the lengthening site, and pin tract infection. When only the ulna is lengthened, the distracting tension is not exerted directly on the neurovascular bundle, with minimal risk of nerve dysfunction.

When performing radial head excision, the surgeon has to be careful in the initial dissection to avoid injury to the posterior interosseous nerve as well as to the stabilizing structures of the elbow.

REFERENCES

DEFINITION
- Sprengel deformity is characterized by congenital high elevation of the scapula and medial rotation of the inferior pole of the scapula. The exact cause of the deformity is unknown.
- Associated anomalies include Klippel-Feil syndrome, rib deformities, omovertebral bone formation, muscle anomalies, clavicle hypoplasia, tracheoesophageal fistula, anal stenosis, kidney anomalies, diastematomyelia, and scoliosis.
- Eulenberg first described three cases of congenital “high dislocation of the scapula” in 1863, and in 1880 Willet and Walsham were the first to describe the omovertebral bone—a broad osseous band of bone connecting the scapula with the spinous process of C6.

ANATOMY
- The normal scapula forms in the 5th week of fetal development adjacent to the level of C5 and then descends to the dorsal thoracic area at a level between T2 and T8.
- The scapula in Sprengel deformity is abnormally high, has a decreased vertical diameter, and is deformed in shape.
- The supraspinous region is rotated anteriorly in a convexity near the shape of the dorsal thorax.
- The inferior aspect of the scapula is rotated medially.
- The scapula in Sprengel deformity may be attached to the lower cervical vertebrae (usually C6) by an abnormal band of tissue, which may be fibrous, cartilage, or bone (ie, omovertebral bone).
- The musculature of the shoulder girdle may be hypoplastic, absent, or weak.
- The trapezius muscle, the levator scapulae muscle, and the rhomboid muscles often are hypoplastic.
- The trapezius is the most commonly affected muscle. Other muscle groups that attach to the scapula occasionally are affected.
- Associated bony congenital anomalies include Klippel-Feil syndrome, fused ribs, cervical ribs, congenital scoliosis, cervical spina bifida, hypoplastic clavicle, and short humerus.

PATHOGENESIS
- The normal scapula develops in the cervical region and then descends to the upper posterior area of the thorax by the end of the 3rd month of fetal development.
- Sprengel deformity occurs as a result of interruption of the normal caudal migration of the scapula during fetal development.
- The cause of Sprengel deformity is unknown, but the following theories have been proposed:
  - Cerebrospinal fluid escapes through a “bleb” in the membrane of the roof of the fourth ventricle into the adjacent tissue of the neck to cause malformations.
  - Heredity (there have been several reports of familial occurrence)
  - Increased intrauterine pressure

NATURAL HISTORY
- The Sprengel deformity is present at birth, and the location of the scapula in relation to the neck and thorax remains constant as the child grows.
- The abnormal scapula appears to grow proportionally to the growth of the child.
- Associated congenital anomalies such as congenital scoliosis may progress, thereby changing the appearance of the deformity.

PATIENT HISTORY AND PHYSICAL FINDINGS
- At birth, the shoulder with a Sprengel deformity appears to be displaced upward and forward.
  - In unilateral cases, shoulder asymmetry is evident.
  - The left scapula is involved more commonly than the right (FIG 1A).
  - In bilateral cases, both shoulders appear to be high, and the neck may appear thick and short.
- The scapula may be tilted upward.

FIG 1 • A. Sprengel deformity of the right shoulder.
B. Appearance of Sprengel deformity when the right arm is held in maximum abduction.
Motion of the shoulder is reduced in abduction and elevation (FIG 1B).
- Muscle weakness or hypoplasia can be observed in the shoulder area.
- Torticollis may be present.
- Scoliosis and kyphosis as well as deformities of the chest from rib anomalies may be observed.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Radiographs of the shoulder and neck show the bone deformities (FIG 2).
- Sonography of the spinal cord is helpful in infants younger than about 4 months of age who have congenital spine anomalies.
- Sonography can be performed through the cartilage of the lamina and spinous process, but after about 4 to 5 months of age, ossification blocks the views.
- Congenital spine anomalies have a high association with intraspinal abnormalities.
- Sonography of the kidneys is helpful in cases associated with congenital spine anomalies.
- MRI is extremely helpful for evaluating muscle and soft tissue development.
- CT (with 3D reconstruction) is helpful to define the extent of bone deformity. CT provides excellent visualization of the omovertebral structure.
- Both still and video photography are helpful to record pre- and postoperative appearance and to document function.

**NONOPERATIVE MANAGEMENT**
- In infants and young children, passive and active stretching exercises may be performed daily to maintain motion of the shoulder.

**SURGICAL MANAGEMENT**
- Operative procedures are designed to improve the appearance of the elevated shoulder and, to a limited extent, to improve its function.2,7,8,10,11,13,15
- Operative treatment can be considered in cases in which the deformity is disfiguring and shoulder function is impaired.
- In children with mild deformities in which the appearance of the shoulder is acceptable, operative treatment probably is not indicated.
- The recommended age for surgery is 3 to 8 years.

**Preoperative Planning**
- Preoperative evaluation of the appearance of the deformity with photographs is advised.
- The author prefers full-profile photographs taken from the frontal, posterior, and both side views.
- Motion can be documented by a series of photographs taken with the arms extended, elevated, and abducted.
- Videos of the patient performing motion activities of the shoulder are helpful to determine the degree of deformity and whether or not the appearance is acceptable.
- The Cavendish grading scale is helpful in evaluating appearance:
  - Grade I (very mild): shoulder joints are level, and the deformity is not obvious when the patient is dressed.
  - Grade II (mild): shoulder joints are level, but the deformity is visible when the patient is dressed.
  - Grade III (moderate): the involved shoulder is elevated 2 to 5 cm, and the deformity is obvious.
  - Grade IV (severe): the involved shoulder is greatly elevated, and the superior angle of the scapula is near the occiput.
- Preoperative evaluation of shoulder motion
- Occupational therapy measurement of combined abduction of both shoulders (combined glenohumeral and scapulothoracic movement) as well as other shoulder motion is useful.
- Shoulder functional testing also may be useful.
- The author uses radiographs at the extremes of motion to verify the degree of measurements.
- The anomalies of the shoulder, spine, and rib cage must be evaluated radiographically.
- CT scanning and MRI are helpful to determine both bone and soft tissue abnormalities.
- Currently, the author uses somatosensory evoked potentials and transcranial electrical motor evoked potentials to evaluate the brachial plexus nerve function during surgery.
- Baseline values are obtained after the induction of anesthesia, and monitoring is continued during the procedure.

**Positioning**
- The patient is placed in the prone position with the head positioned as if facing forward.
- The entire arm, the shoulder, and the posterior thorax back area (ie, superiorly from the high cervical area, inferiorly to the lumbar area, and laterally to the contralateral scapular area) are prepared and draped.
- The arm and scapular girdle are left free for manipulation during the operation.
- Leads for the somatosensory evoked potentials and transcranial electrical motor evoked potentials are positioned on the skin and muscles in sterile fashion.

**Approach**
- The Woodward procedure consists of detaching the origins of the trapezius and rhomboid muscles from the spinous process and moving them downward after resection of the omovertebral bone and any fibrous bands from the scapula.17
- The procedure described by Green7 involves division of the muscles connecting the scapula to the trunk, excision of the omovertebral bone, excision of the supraspinous portion of the scapula, and reattachment of the muscles to hold the scapula reduced.

**FIG 2** AP radiograph of the right shoulder of a child with Sprengel deformity.
The modification described by Borges et al\(^1\) is performed as originally described by Woodward,\(^2\) with the addition of excision of the medial border of the scapula and resection of the supraspinous portion of the scapula.

- The muscles attached on the medial and superior borders of the scapula are reflected extraperiosteally to facilitate bony resection.

Bone resection superiorly is medial to the suprascapular notch, and about 1 cm of the medial border of the scapula is excised.

The author does not usually recommend routine osteotomy of the clavicle, but it is indicated if neurologic issues arise during surgery. The procedure may be performed at the discretion of the surgeon to diminish the risk of neurologic problems.

### MODIFIED WOODWARD PROCEDURE

#### Incision and Dissection

- A midline incision is made that extends from the spinous process of the C4 distally to the spinous process of T9 (TECH FIG 1A).

- The skin and subcutaneous tissue are undermined on the involved side laterally to the medial border of the scapula and the lateral border of the trapezius.

- The trapezius is bluntly dissected from the underlying latissimus dorsi.
  - To achieve this, bluntly dissect the lateral border of the trapezius muscle in the inferior aspect of the operative area from the latissimus dorsi muscle.
  - Continue the dissection medially to the origin of the trapezius at the spinous process of T9. The fibers of the trapezius blend into the fibers of the other muscles that originate from the spinous processes.

- Detach the trapezius distally and proceed superiorly by detaching the remainder of the trapezius and then the rhomboid muscles to the level of the spinous process of C4 (TECH FIG 1B).

- Retract the trapezius and rhomboid muscles laterally.
  - The levator scapulae muscle is identified as it originates from the superior medial aspect of the scapula and courses toward the spinous process of the cervical vertebra.
  - Occasionally, the muscles are fibrotic, which makes identification and dissection more difficult.

- The omovertebral structure (which may be fibrotic, cartilage, or bone) is under the levator scapulae muscle.
  - The omovertebral structure is excised extraperiosteally by sharp dissection.
  - Any fibrotic bands in the area that may limit inferior mobility of the scapula are incised.

- During the dissection, the spinal accessory nerve and the nerve to the rhomboids must be protected as they course beneath the trapezius muscle.
  - The spinal accessory nerve is in line with the vertebral border of the scapula.
  - In cases involving significant fibrosis of muscles, the nerves may be difficult to identify, and the use of spontaneous or electrical triggered electromyography may be helpful.

- The levator scapulae muscle is divided at the superior medial corner of the scapula.

- The transverse cervical artery, which is deep to the levator scapulae muscle, must be protected at the superomedial area of the scapula, because bleeding occasionally can be problematic.

#### Scapular Resection and Reduction

- Superiorly, the scapula is excised medially to the suprascapular notch, after which approximately 1 cm of the medial border of the scapular is excised (TECH FIG 2).
- The scapula can be lifted, and any fibrotic bands between the undersurface of the scapula and chest wall are incised.
- The scapula can now be drawn inferiorly and reduced to a more normal anatomic level.
- Any fibrotic bands that prevent the reduction may be incised.
- As the scapula is reduced, the somatosensory evoked potentials and the transcranial electrical motor evoked potentials should verify the function of the nerves to the arm.
  - During reduction, the nerves of the brachial plexus may become entrapped between the clavicle and the chest wall.
  - If the evoked potentials become abnormal, the scapula is replaced in the elevated position, and clavicular osteotomy\(^1\) is recommended.

**TECH FIG 1** • A. Location of the incision. B. Dissection of the trapezius and rhomboid muscles from the spinous processes of the vertebrae.
**Clavicular Osteotomy**
- A 2-cm incision is made over the middle clavicle area.
- Beneath the platysma muscle, the periosteum is incised longitudinally, and the clavicle is exposed by subperiosteal elevation.
- The author prefers to use a rongeur to incise the clavicle.
- The incised bone chips are used as graft in the osteotomy.
- The periosteum and operative wound are closed in layers.
- The scapula is reduced, and the rhomboid muscles (and fascia) and the trapezius muscle are reattached in a more caudad position at the midline to the ligaments between the spinous processes.
- The latissimus dorsi muscle can be lifted to allow the inferior wing of the scapula to be positioned beneath it.
- The inferior tip of the scapula wing can be sutured to the latissimus dorsi muscle.
- The operative wound is closed in layers, and wound suction drainage may be used at the surgeon’s discretion.

**PEARLS AND PITFALLS**
- Somatosensory evoked potentials and transcranial electrical motor evoked potentials are helpful to monitor the neurologic status of the arm. ■ May indicate brachial plexus compromise and the need for a clavicular osteotomy
- Resection of the prominent superior and the medial border of the scapula ■ Offers the opportunity to improve both appearance and functional outcomes
- Osteotomy of the clavicle ■ May prevent brachial plexus palsy

**POSTOPERATIVE CARE**
- Postoperatively, the arm is maintained in a Velpeau bandage for about 4 weeks.
- Physical therapy is initiated after removal of the Velpeau bandage, with emphasis on glenohumeral motion and muscle strengthening.

**OUTCOMES**
- In my patient group, at an average of 8 years postoperatively, the glenohumeral/scapulothoracic motion was 150 degrees (range, 100 to 180 degrees). This represents 45 degrees improvement from preoperative measurements.1
- In the author’s case, the appearance of all of the children was improved by at least one Cavendish grade, and most achieved grade I or II.
- One out of 14 cases was grade III, and that child had multiple spinal deformities and scoliosis adjacent to the Sprengel deformity.1

**COMPLICATIONS**
- Brachial plexus palsy
- Nerve palsy
- Persistent scapular winging
- Incomplete correction
- Vascular problems
- Wound infection
- Operative scar appearance

**REFERENCES**
21. Willet A, Walsham WJ. An account of the dissection of the parts removed after death from the body of a woman the subject of congenital malformation of the spinal column, bony thorax, and left scapular arch; with remarks on the probable nature of the defects in development producing the deformities. Med-Chir Trans London 1880;63:256.
**DEFINITION**
- The sternocleidomastoid (SCM) muscle is a major muscle of the neck that laterally flexes and rotates the head.
- The term torticollis comes from the Latin words tortus (twisted) and collum (neck). It refers to a clinical deformity where the head tilts in one direction and the neck rotates to the opposite side involuntarily.
- Congenital muscular torticollis (CMT) associated with a contracture of the SCM muscle is the most common etiology of torticollis in infants.
- CMT is the third most common congenital deformity, next to developmental dysplasia of the hip and congenital clubfoot. The incidence of CMT ranges from 0.4% to 1.3%.
- Shortening and contracture of the SCM muscle results in tightness that gives the typical clinical appearance, which is detected at birth or shortly thereafter.
- Cheng et al. subdivided the CMT patients into three groups:
  - Clinically palpable sternomastoid “tumor” or pseudotumor
  - Muscular torticollis group without palpable or visible tumor but with clinical thickening or tightness of the SCM on the affected side
  - All the clinical features of torticollis with neither a palpable mass nor tightness of the SCM muscle

**ANATOMY**
- On each side, the SCM muscle passes obliquely across the side of the neck and divides the neck into anterior and posterior triangles.
- It originates from two heads:
  - Sternal head: superior and anterior surface of manubrium sterni.
  - Clavicular head: superior surface of medial third of clavicle. With the two heads combining, the muscle ascends laterally and posteriorly to insert in the mastoid process of the temporal bone.
- The functions of sternocleidomastoid are multiple:
  - With unilateral contraction, it:
    - Flexes the head and cervical spine ipsilaterally
    - Laterally rotates the head to the contralateral side
  - With bilateral contraction, it:
    - Protracts the head
    - Extends the incompletely extended cervical spine
- The SCM is innervated by the:
  - Spinal accessory nerve (XI)
  - Ventral ramus of second cervical nerve (C2)
- The spinal accessory nerve penetrates the deep surface of the SCM muscle, giving off a branch that supplies it. It passes to the posterior aspect of the SCM deep to Erb’s point.
- Erb’s point is located roughly in the middle of the posterior border of the SCM muscle. At this point, the anterior branch of the greater auricular nerve crosses the SCM.
- The external jugular vein is located anterior to the SCM muscle at the proximal part. It crosses the SCM muscle obliquely at its midpoint and ends at the subclavian vein posterior to the SCM muscle.
- The SCM protects the carotid artery and internal jugular vein, both of which lie deep to it.
- The clavicular origin of the SCM muscle can vary in size. In some cases, the width of the clavicular attachment may extend to the midpoint of the clavicle.
- The anatomy of the SCM muscle and important surrounding structures is shown in **FIGURE 1**.

**PATHOGENESIS**
- The most common etiology of CMT in infants is contracture or shortening of the SCM muscle.
- Infants with CMT most often have a history of difficult or traumatic delivery.
- Davids et al. reported that the position of the head and neck in utero or during labor or delivery can lead to local trauma to the SCM muscle. This is the only muscle in the SCM muscle compartment demonstrated by cadaver studies.
- Progressive fibrosis and contracture of the SCM muscle may be the sequelae of an intrauterine or perinatal compartment syndrome.
CMT may occur in association with oligohydramnios, multiple births, first-born children, and developmental dysplasia of the hip (DDH).

These data support the theory of intrauterine restricted fetal motion and malpositioning of the head and neck. These conditions may be associated with more difficult and traumatic deliveries.

However, CMT found in the infants who are delivered by cesarean section is not consistent with the theory of birth trauma.

The data that show 20% coexistence of developmental dysplasia of the hip support the theory of intrauterine malposition and crowding.9

About 50% of patients with CMT are born with a clinically palpable SCM tumor.1,5 This tumor or pseudotumor is believed to be a developing hematoma that undergoes subsequent fibrosis. This could result from either birth trauma or intrauterine malposition.

Electron microscopy studies revealed that the existence of myoblasts in the interstitium of the mass at different stages of differentiation and degeneration might have a significant bearing on the pathogenesis of torticollis.13

Tang et al13 explained the success of conservative management (stretching exercises) with the presence of myoblast cells besides fibroblast cells.

In vitro, myoblasts could be mechanically stimulated to undergo both hypertrophy and hyperplasia by intermittent stretching and relaxation.

The pathogenesis of the torticollis resulting from pathologies other than CMT is affiliated with other conditions or syndromes.

NATURAL HISTORY

Diagnosis of CMT is usually made at or near birth. Other causes of torticollis generally present later (4 months to 1 year).

A mass (SCM tumor) or fullness in the SCM muscle usually exists within a few weeks or months after delivery.

Typically, the mass decreases in size and disappears between 6 and 12 months of age.

If it remains untreated, contraction and sometimes a fibrous bundle can occur in the muscle.

Flexion and rotation deformity of the neck begins in infancy.

Typically the head turns toward the involved side and the chin points to the opposite shoulder.

Plagiocephaly and facial asymmetry may be present early on; they increase with time.

However, in persistent cases, deformity progresses and becomes inflexible.

Flattening of the skull and facial bones can develop on the affected or normal side depending on the sleeping position of the child.

If the child remains untreated until 5 to 7 years of age, contraction of the neck with limited motion becomes resistant to correction. The deformity of the cranium and facial bones also becomes less amenable to spontaneous correction.

Formation of a lateral band is mostly responsible for limited neck mobility.

In older children with persistent deformity, radiographic abnormalities can also occur; they include asymmetry of the articular facets of the axis, tilt of the odontoid process to the side of the torticollis, and possibly cervicothoracic scoliosis.2,12

PATIENT HISTORY AND PHYSICAL FINDINGS

A complete history and physical examination should be done in newborns with torticollis.

The incidence of the breech presentation and birth trauma in children with CMT is higher than the general population.

There is known coexistence of DDH with torticollis.

The reported incidence of DDH with CMT varies from 8% to 20%.9,15

A clinical examination of the hip and ultrasonography screening are thus required for children with CMT.

A previous belief that CMT was associated with metatarsus adductus and clubfoot is not supported by the literature.

Typically, children with CMT hold their head laterally flexed to the affected side and rotate their face to the opposite side.

Range of neck movement can initially be normal in infants with CMT. Later, the typical deformity can usually be observed. This gradually progresses as the muscle contracture becomes tighter.

Any degree of restriction should be noted during the examination.

The facial bones and cranium are observed for asymmetry. Any flattening of the skull bones is also noted.

With palpation, a nontender, soft mass of 1 to 2 cm is occasionally found in the lower or middle third of the SCM muscle. With time, the mass changes to a fibrous bundle, and the SCM tendon can then be identified as a tight band that resists correction (FIG 2).

FIG 2 • A nontender, soft mass of 1 to 2 cm can be found in the lower or middle third of the sternocleidomastoid (SCM) muscle within weeks or a few months after delivery. At later ages (usually after 6 to 12 months of age), the mass changes to a fibrous bundle and the SCM tendon then can be identified as a tight band.
The flexible deformity seen in the early stage can be corrected by gentle stretching.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Neuroradiographs
  - Standard cervical spine anteroposterior and lateral views and open-mouth odontoid views are obtained to rule out bony abnormalities such as atlantoaxial instability or fixation, cervical fusion, cervical scoliosis, and odontoid anomalies.
  - At the later phases of the developing deformity, radiographic abnormalities such as asymmetry of the articular facets of the axis, tilt of the odontoid process to the side of the torticollis, and sometimes cervicothoracic scoliosis may be observed.\(^1^,\(^2\)

- Ultrasound examination should be performed in children with a palpable SCM mass to demonstrate the fibrotic lesion within the SCM muscle and to differentiate the mass from other pathologies in the neck such as neoplasms, cysts, and vascular malformations.
  - In a recent study, Tang et al\(^1\) presented their observations with the use of ultrasound for the long-term follow-up of CMT. They noticed that CMT is a polymorphic and dynamic condition rather than a fixed presentation. The alterations of the fibrosis in muscle can affect the type of treatment.

- Hip ultrasonography should be routinely done in patients born with CMT.
  - There is a relatively high incidence of coexistence between CMT and DDH.

- Some investigators have advised MRI to evaluate the muscle for thickening and fibrosis; however, it does not provide additional information. Further, for infants, MRI requires a general anesthetic, with its associated risks.
  - If a posterior fossa tumor is suspected, MRI is indicated.

**DIFFERENTIAL DIAGNOSIS**

- Ophthalmologic torticollis occurs with oculomotor imbalance, which is usually observed after the development of focusing skills (3 months). Ophthalmologic torticollis is caused by a weakness of one of the oculomotor muscles of the eye (typically the superior oblique). This causes a strabismus that can be observed if the head tilt is manually corrected. (This maneuver is useful in providing a diagnosis.) Other causes are strabismus and nystagmus.

- Neurologic causes such as the postural head tilt seen with posterior fossa tumors must be ruled out.
  - Nucci et al,\(^1\) in a multidisciplinary study, reported 25 ocular and 4 neurologic causes in 65 children with abnormal head posture.
  - About 10% of posterior fossa tumors initially present with torticollis.

- The other orthopaedic causes of torticollis include congenital cervical vertebral anomalies (scoliosis, Klippel-Feil syndrome) and atlantoaxial rotational instability.

- Grisel syndrome: torticollis associated with retropharyngeal abscess or post-tonsilllectomy status.

- Neck abscess or inflammatory disorders

- Sandifer syndrome (reflux)

- Neurologic
  - Posterior fossa tumors
  - Dystonia

**NONOPERATIVE MANAGEMENT**

- The initial treatment of CMT is nonoperative and is successful in the vast majority of infants by 1 year of age.

- A program of gentle stretching exercises should include flexion–extension, lateral bending away from the involved side and rotation toward it.

- Stretching exercises can be done by a physical therapist or by the parents with a home program.
  - In our experience, a supervised home program monitored by a physical therapist is the most successful method.
  - Manual stretching should be continued until full neck rotation is achieved.

- In children 1 year of age or less, the plagiocephaly and facial asymmetry usually remodel spontaneously after the child regains full range of motion of the neck.

- Cervical orthoses may be an adjunct and support for children whose lateral head tilt does not resolve with exercises, or for older children who no longer tolerate stretching.

- The duration of the conservative treatment could be longer in children who have SCM tumor at initial presentation.

- The success rate of manual stretching in these patients is lower than those without a SCM tumor.\(^4\)

- Surgery is recommended for recalcitrant deformity when adequate correction is not achieved by 1 year of age.

- Children who present after 1 year of age with or without previous treatment are candidates for surgery if they have:
  - Significant head tilt with tight band or contracture of the SCM muscle

  - Limitation of passive head rotation and lateral flexion by more than 10 to 15 degrees

**SURGICAL MANAGEMENT**

- Surgical intervention is indicated for children who have not responded to nonoperative treatment applied for a minimum of 6 months and for children who present with a significant deformity after 1 year of age.

- The hypothesis is that the sooner correction of the torticollis is achieved, the better the chance for spontaneous correction of the plagiocephaly and facial asymmetry.

- If there is doubt about the diagnosis of CMT, surgery is contraindicated until a workup has been completed because there could be an underlying disorder causing torticollis, such as ocular or neurogenic pathologies.

- The operative techniques described for CMT are based on release or lengthening of the tight and shortened SCM muscle.

- Most commonly preferred procedures include unipolar release, bipolar release with or without Z-plasty lengthening of the sternal head, and the extended procedure for older children and resistant cases.

- Open, percutaneous, and endoscopic techniques have been described for these procedures. We have no experience with endoscopic technique, and we prefer the open approach.

**Authors’ Preferred Treatment**

- For infants, a home stretching program is taught and supervised by a physical therapist for 6 months.

- In children with appropriate surgical indications, bipolar release (with or without Z-plasty lengthening) is carried out.

- In older children with significant deformity, a bipolar release is the first step. Z-plasty may be appropriate in the older children to provide a symmetric appearance postoperatively.
If satisfactory correction is not demonstrated at intraoperative examination, the distal dissection is extended to permit release of the clavicular head and remaining bands.

Preoperative Planning
- Cervical spine radiographs should be reviewed before surgery to look for bony anomalies or cervical scoliosis.
- In fixed deformities, positioning of the head can be difficult for the anesthesiologist. Flexible fiberoptic intubation should then be considered.
- The ear is taped anteriorly and hair around the mastoid process is shaved.

Positioning
- The procedure is performed under general anesthesia in the supine position. A sandbag is placed to elevate the shoulder on the affected side.

Draping should allow the correction to be evaluated by bending the neck. This determines the adequacy of the release intraoperatively.
- The shoulder draping should permit the anesthesiologist to hold the shoulder, which can maximize tension during this test.
- The neck is bent toward the unaffected side and the head is rotated to the affected side so that the SCM muscle is kept under tension and the origin and insertion can be clearly identified.

INCISION AND DISSECTION
- For the release of the distal pole of the SCM muscle, a transverse, 3- to 4-cm-long incision is made 1 cm superior to the clavicle and between the two heads of the SCM muscle (TECH FIG 1).
- The subcutaneous tissue and platysma muscle are divided in the line of incision and the tendon sheaths of the clavicular and sternal heads are exposed.
- For the proximal pole exposure, a 2- to 3-cm horizontal incision is made just distal to the tip of the mastoid process.
- The dissection is carried deeper until the periosteum of the mastoid process is exposed. The insertion of the muscle is then exposed subperiosteally.

TECH FIG 1 • Proximal and distal incisions (dotted lines).

DISTAL UNIPOLAR RELEASE
- Distal unipolar release includes the release of the sternal and sometimes the clavicular heads of the SCM muscle. It may be enough for mild deformities.
- A transverse incision is placed parallel and 1 cm proximal to the clavicle between the clavicular and sternal heads of the SCM.
- An incision that overlies over the clavicle may result in a hypertrophic scar. A higher incision may jeopardize the external jugular vein and may also lead to an unsightly scar.
- Two heads of the SCM muscle are identified as described.
- Surrounding fascia is cleared and the sternal head or both heads are undermined with a curved clamp.
- The muscles are elevated with the help of a clamp and divided using electrocautery (TECH FIG 2).
- Alternatively, the sternal head can be lengthened by Z-plasty.
- The endotracheal tube should be kept at the unaffected side so as not to interfere with the operative field.

TECH FIG 2 • The origin of the muscle is elevated with the help of a clamp and divided using electrocautery. About 5 to 10 mm of muscle–tendon segment is divided to prevent further contracture and fibrous adhesions.
About 5 to 10 mm of the muscle–tendon segment is excised to prevent further contracture and fibrous adhesions.

The adequacy of the release is checked by bending the neck to the contralateral side and rotating it to the ipsilateral side while palpating the area with a fingertip to identify any remaining tight bands. They are completely released.

The incision is closed with subcuticular suture after careful hemostasis.

**BIPOLAR RELEASE (AUTHORS’ PREFERENCE)**

- Bipolar release includes the release of the mastoid insertion of the SCM muscle along with the distal release just described.
- The procedure starts with a distal incision.
- The two heads of the SCM muscle are identified. After undermining the tendons, the curved clamp is left underneath them.
- The curved clamp is left lying superficial to the wound but deep to the tendon. While applying enough tension, ease the proximal exposure and identification of the insertion. The wound is then covered with a moist sponge.
- With the tension applied by the clamp under the tendon at the distal exposure, a safe identification of the origin has been simplified. Further, the limited exposure avoids the important anatomy (TECH FIG 3A).
- Attention is directed to the proximal insertion and the incision is placed as described before.
- The insertion of the muscle is identified anteriorly and posteriorly. Dissection starts subperiosteally from the mastoid process to avoid the facial nerve anteriorly and the anterior branch of the great auricular nerve inferiorly.
- A curved clamp is passed just deep to the tendon to elevate it so it can be sectioned completely (TECH FIG 3B).
- There is no need to resect a segment of muscle at the proximal part.
- After the proximal release is performed, attention is then directed back to the distal incision and distal release is completed as described before.
- Release of the clavicular head with the lengthening of the sternal head by Z-plasty may be appropriate in older children to provide a symmetrical appearance postoperatively (TECH FIG 3C).
- The neck is rotated and bent with the help of the anesthesia team while checking the area with a fingertip to identify any remaining tight bands; they are completely released.
- Both surgical areas are checked to identify if any remaining tight bands or fascial structures are impediment full correction. They are divided carefully.
- Subcutaneous and subcuticular skin closure is then performed after hemostasis.

**TECH FIG 3 • A.** With tension applied to the tendon at the distal exposure, a safe identification of the origin has been simplified. Further, the limited exposure avoids the important anatomy. **B.** A curved clamp is passed just deep to the tendon to elevate it for complete sectioning. **C.** Bipolar release with the lengthening of the sternal head by Z-plasty. (C. Modified from Ferkel RD, Westin GW, Dawson EG, et al. Muscular torticollis: a modified approach. J Bone Joint Surg Am 1983;65:894–890.)
**POSTOPERATIVE CARE**
- Postoperative management includes immobilization of the head and neck in a slightly overcorrected position with a thermoplastic custom-made brace or pinless halo for 3 weeks (FIG 3).
  - The purpose of the brace immobilization is to avoid a habitual posture followed by postoperative scarring. It might also help to reprogram the corrected posture as a norm for the child.
  - The brace is removed in 3 weeks and passive stretching is recommended as well as active strengthening exercises.
  - Exercises are continued at home for 3 to 6 months.

**OUTCOMES**
- Early conservative management is successful in over 90% of children with CMT who are younger than 1 year.\(^{3,4,6}\)
- In resistant cases there is still controversy between unipolar and bipolar release.
- Cheng et al\(^{3,4,5}\) reported excellent results in children operated on at age 6 months to 2 years with unipolar release.
- Canale et al\(^{1}\) found better results after bipolar release, although the difference was not statistically significant.
- Wirth et al\(^{16}\) reported satisfactory results in 48 of 55 patients who had undergone bipolar release, with low recurrence rates (1.8%).

**PEARLS AND PITFALLS**

**Approach**
- The distal pole incision is made about 1 cm superior and parallel to the clavicle.
- Superficial scars just over the clavicle may result in hypertrophic scar and unacceptable cosmesis.
- Incisions close to the midpoint of SCM may compromise the external jugular vein and neurologic structures and may lead to an unacceptable scar.
- To avoid complications, the proximal horizontal incision is placed just distal to the tip of the mastoid process. Applying tension under the tendon distally simplifies safe identification of the insertion.

**Unipolar release**
- Unipolar release is used only in younger patients with mild deformities. Generally, a bipolar approach is better.

**Bipolar release**
- A bipolar release is more likely to avoid residual and recurrent deformity. The surgeon should not hesitate to perform this procedure before 1 year of age in resistant cases (9 to 12 months).
- The SCM tendon is first exposed at the origin in the distal wound. The tendon or tendons are elevated to provide tension; the proximal release is then performed, and finally the distal release is completed.

**COMPLICATIONS**
- Wound breakdown
- Hematoma
- Residual lateral band
- Neurovascular damage
  - Spinal accessory nerve
  - Anterior branch of the great auricular nerve
  - External jugular vein
  - Carotid artery
- Hypertrophic scar

**REFERENCES**
DEFINITION
- The occipitocervical articulation is formed by the occiput, the atlas (C1), and the axis (C2). This functional unit provides a large degree of mobility and range of motion through the strong ligamentous structures and cup-shaped joints.
- Over 50% of the total axial rotation occurs between the first and second vertebrae, while flexion–extension movement predominantly occurs at the occipitoatlantal junction.2
- Excessive movement at this junction due to either bony or ligamentous abnormalities causes instability. A wide variety of pathologies such as genetic and congenital developmental abnormalities, trauma, tumors, and inflammatory and degenerative conditions can lead to upper cervical spine instability.
- Depending on the degree of displacement and spinal canal compromise, cord compression and myelopathy may occur.
- Major instability is usually addressed with surgical occipitocervical or C1–C2 arthrodesis. Since Foerster first described a technique for occipitocervical arthrodesis using fibular strut graft in 1927, several procedures have been reported with variable rates of fusion and techniques of stabilization.
- In this chapter, brief information on upper cervical spine instability is given and general principles of occipitocervical and C1–C2 arthrodesis are discussed. Also our techniques developed for posterior occipitocervical fusion are described in detail.

ANATOMY
- It is important to understand that the pediatric upper cervical spine is not a “miniature model” of the adult spine. The cervical spine approaches adult size and shape by ages 8 to 12, as growth cartilage fuses and vertebral bodies gradually lose their oval or wedge shape and become more rectangular.
- The upper cervical spine has unique development, anatomy, and biomechanics.
- The atlas develops from three ossification centers, a body and two neurocentral arches, which become visible by age 1 year (FIG 1A).
- The neurocentral synchondroses fuse with the body at about 7 years of age and may be mistaken for fractures on radiographs.14
- The axis is derived from five primary ossification centers: the two neural arches or lateral masses; the two halves of the dens; and the body.
- There are two secondary centers: the ossiculum terminale and the inferior ring apophysis (FIG 1B).
- The two halves of the odontoid are generally fused at birth but may persist as two centers, known as the dens bicornis.13
- The dentocentral synchondrosis, which separates the dens from the body, closes between the ages of 5 and 7 (FIG 1B). Until the ossification is complete, it gives the appearance of a “cork in a bottle” on an open-mouth odontoid view.
- The tip of the dens appears at age 3 years and is fused by age 12.
- Occasionally, it remains as a separate ossiculum.11,15
- After skeletal maturity the atlas does not have a body as such, and is shaped like a ring. The flat, cup-shaped articular surface under the occipital condyle allows for flexion, extension, and some bending. The dens articulates with C1 through the dorsal facet of the anterior arch. C1–C2 articulation allows for rotation.2 The vertebral artery passes through the foramen that is located in the transverse processes.
- The ligamentous structure allows for a wide range of motion of the upper cervical spine while maintaining stability. The short ligaments at the base of the skull are as follows (FIG 1C):
  - Tectorial membrane, which is a continuation of the posterior longitudinal ligament that provides considerable support.
  - Cruciate ligament, which includes transfer ligaments, restrains against atlantoaxial anteroposterior translation.
  - Alar and apical ligaments, which run from foramen magnum to the odontoid, act as secondary stabilizers.

PATHOGENESIS
- Fundamentally, upper cervical spine instability can develop from osseous or ligamentous abnormalities resulting from acquired or congenital disorders. As a result of instability, excessive motion and spinal cord compression may occur at the occipitoatlantal and atlantoaxial joint or both.
- In nontraumatic conditions, ligamentous laxity (particularly in the transverse ligament) or abnormalities of the odontoid cause instability.
- In Grisel syndrome, a type of atlantoaxial rotatory displacement, inflammation of the retropharyngeal space, caused by upper respiratory tract infections or by adenotonsillectomy, spreads through the pharyngovertebral veins to the ligaments of the upper cervical spine. This results in impairment of the transverse atlantal ligament and instability.21
- In Down syndrome, the main cause of atlantoaxial instability is the laxity of the transverse ligament, which holds the dens against the posterior border of the anterior arch. Also, malformation of the odontoid can be observed in this condition.9
- Klippel-Feil syndrome is associated with congenital cervical anomalies, such as occipitocervical synostosis, basilar impression, and anomalies of the odontoid, and can be associated with instability, stenosis, or both.
- Odontoid anomalies include aplasia, hypoplasia, duplication, third condyle, persisting ossiculum terminale, and os odontoideum.
- The atlantodental interval (ADI), which is measured from the anterior aspect of the dens to the posterior aspect of the anterior ring of the atlas, increases in atlantoaxial instability. It is a way of assessing the more important space available for the cord. The transverse ligament serves as the first line of defense, maintaining the atlanto–odontoid interval.
- In older children (older than 8 years) and adults, the ADI should be 3 mm or less, while in younger children, the ADI should be 4 mm or less (some consider 4.5 to 5 mm acceptable).12
In children, we consider an ADI of 4 mm or more as evidence of atlantoaxial instability.

NATURAL HISTORY
- Patients with upper cervical instability frequently have other associated pathologic conditions in the occipitocervical region such as spinal stenosis, basilar impression, cervical fusions, occipitalization, or congenital anomalies of the atlas or axis (dens), and central nervous system abnormalities.
- When one encounters one of these conditions, others should be sought also.
- Instability of the upper cervical spine and stenosis often are two major factors in the development of myelopathy.
- Patients who are symptomatic at initial presentation are often at risk for progressive neurologic symptoms. Once cervical myelopathy develops it rarely resolves entirely.
- Paralysis and death are rare but may be encountered in patients with upper cervical spine instability.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Upper cervical spine instability is rare in patients without predisposing conditions or trauma.
- The instability is usually determined in radiographic examination of the children with syndromes or conditions known to have frequent involvement of the musculoskeletal system. An orthopedic surgeon is usually consulted for children with such conditions.
- Clinical presentation can vary because of the associated syndromes and anomalies.
- Patients may present with symptoms such as loss of range of motion, stiffness, mechanical pain of the head or neck, and torticollis.
- It is not uncommon to see patients presenting with neurologic symptoms, which can vary from minor sensory or motor disturbances to established myelopathy. Neurologic symptoms or signs result from mechanical compression of the spinal cord or nerve roots.
- Torticollis may be the presenting symptom of rotatory or postinfectious atlantoaxial instability.
- According to the degree of compression and the affected site of the spinal cord, signs and symptoms can vary. They may include loss of physical endurance, difficulty walking, weakness, and upper motor neuron signs (spasticity, hyperreflexia, clonus, Babinski sign), which can be seen with anterior spinal column involvement.
- Pain deficits and proprioception and vibratory sense deficits can be seen with posterior spinal column involvement.
- Increased nasal resonance may also be observed. It may occur because of the decreased size of the nasopharynx resulting from anterior displacement of the atlas.
- Vertebral artery distortion and insufficiency may lead to bizarre symptoms such as syncopal episodes, sudden postural collapse without unconsciousness, change in behavior, dizziness, and seizures.
- In cerebellar involvement nystagmus, ataxia and incoordination are the common findings.
- Neurogenic bladder and bowel, cranial nerve involvement, paraplegia, hemiplegia, and quadriplegia should be kept in mind; sometimes the patient presents with only one of these findings.
IMAGING AND OTHER DIAGNOSTIC STUDIES

- Standard radiographs include anteroposterior, open-mouth odontoid, and lateral (neutral and flexion-extension) cervical spine views.
- Instability can be identified on the lateral flexion-extension view. Atlantoaxial instability is diagnosed on the basis of an increased ADI (FIG 2A).
- In children older than 8 years and in adults, the ADI should be 3 mm or less, while in younger children the ADI should be 4 mm or less (some consider 4.5 to 5 mm acceptable).\(^\text{12}\)
- In children, we consider an ADI of 4 mm or more as evidence of atlantoaxial instability. This measurement does not always correlate with the degree of brainstem or cord compression (as seen on MRI), however. An asymptomatic patient may have instability.

- Space available for the spinal cord (SAC) is measured from the posterior border of the dens to the anterior border of the posterior tubercle. According to Steel’s rule of thirds,\(^\text{17}\) SAC should be about one third of the diameter of the ring of atlas (FIG 2A).
- This safe zone allows for some degree of pathologic displacement. Displacement of more than one third of the diameter causes cord compression.
- This measurement directly describes the space available for the spinal cord, which is highly associated with the neurologic involvement.

- The relationship between the foramen magnum, atlas, and odontoid can be determined in lateral radiographs.
- The ADI is measured from the anterior aspect of the dens to the posterior aspect of the anterior ring of the atlas (FIG 2A).
- In older children (older than 8 years) and adults, the ADI should be 3 mm or less.
- In younger children, the ADI should be 4 mm or less (some consider 4.5 to 5 mm acceptable).
- The line of McRae connects the anterior rim of the foramen magnum to the posterior rim (FIG 2A).
- The upper tip of the odontoid should normally be 1 cm below the anterior margin of the foramen magnum.
- If the effective sagittal diameter of the canal (length of the line) is less than 19 mm, neurologic symptoms occur.
- The line of Chamberlain is drawn from the posterior margin of the odontoid to the posterior margin of the foramen magnum (see FIG 2).
- The tip of the odontoid should be 6 mm below this line. It bisects the line in basilar invagination. However, determination of the landmarks can be difficult on plain radiographs.
- The McGregor line is drawn from the most caudal point of the occipital projection to the posterior edge of the hard plate (FIG 2A).
- This line is one of the best for detecting basilar impression because the osseous landmarks can usually be seen at all ages. If the tip of the odontoid process lies more than 4.5 mm above this line, the finding is consistent with basilar impression.
- The line of Wackenheim is drawn parallel to the posterior surface of the clivus (FIG 2A).
- The inferior extension of the line should be in touch with the posterior tip of the odontoid. In basilar invagination it is over that line.
- The Wiesel-Rothman line is drawn connecting the anterior and posterior arches of the atlas. Two lines are drawn perpendicular to this line, one through the basion and the other through the posterior margin of the anterior arch of the atlas (FIG 2B).
- A change in the distance (\(x\)) between these lines of more than 1 mm in flexion and extension indicates increased abnormal translational motion.
- The ratio of Power is calculated from a line drawn from the basion to the posterior arch of the atlas and a second line from

FIG 2 • A. Lateral craniometry of the cranio-vertebral junction with landmarks, commonly used lines, and methods for examining the relationship between the atlas, odontoid, and foramen magnum and measuring the space available for the spinal cord (SAC). The atlanto-dental interval (ADI) is measured from the anterior aspect of the dens to the posterior aspect of the anterior ring of the atlas. The McRae line connects the anterior rim of the foramen magnum to the posterior rim. The Chamberlain line is drawn from the posterior margin of the dens to the posterior aspect of the posterior margin of the foramen magnum. The McGregor line is drawn from the most caudal point of the occipital projection to the posterior edge of the hard palate. The Wackenheim line is drawn parallel to the posterior surface of the clivus. B. Method for calculating the Wiesel-Rothman line for atlanto-occipital instability. A line is drawn connecting the anterior and posterior arches of the atlas (line 1–2). Two lines are drawn perpendicular to this line, one through the basion and the other through the posterior margin of the anterior arch of the atlas (line 3). A change in the distance (\(x\)) between these lines of more than 1 mm in flexion and extension indicates increased abnormal translational motion. C. Lines used to calculate the Power ratio. A line is drawn from the basion (B) to the posterior arch of the atlas (O) and a second line from the opisthion (O) to the anterior arch (A) of the atlas. The length of the first line is divided by the length of the second. (Adapted from Copley LA, Dormans JP. Cervical spine disorders in infants and children. J Am Acad Orthop Surg 1998;6:204–214.)
the opisthion to the anterior arch of the atlas (FIG 2C). The length of the first line is divided by the length of the second.
- A ratio of less than 1.0 is normal.
- A ratio of 1.0 or more is abnormal and is diagnostic of anterior occipitoatlantal dislocation.
- MRI is useful to identify pathologic changes at the dura mater and spinal cord as well as additional soft tissue pathologies.
- Functional MRI scans performed in flexion and extension can be used to assess dynamic brainstem or cord compression.
- CT scan can provide additional information regarding the bony anomalies.
- In atlantoaxial rotational displacement, pathoanatomy is determined by fine-cut dynamic CT scan with left-right rotation of the head.

DIFFERENTIAL DIAGNOSIS
- Pseudosubluxation
- Os odontoideum
- Congenital muscular torticollis
- Ankylosing spondylitis

NONOPERATIVE MANAGEMENT
- Children with known risk of upper cervical instability should be evaluated carefully. Especially patients with congenital syndromes associated with upper cervical spine instability should have periodic clinical and radiographic examinations until maturity.\(^\text{19}\)
- Upper cervical spine radiographs including anteroposterior (AP), lateral (neutral and flexion-extension views), and open-mouth odontoid views are obtained periodically to assess and detect any trends and changes.
- Patients and parents should be educated about the diagnosis and natural history of the disorder and encouraged to report any symptoms as soon as they occur.
- Because of bone and ligament abnormalities, patients with upper cervical spine instability have a greater risk of spinal cord injury even with minor trauma and even when they are asymptomatic.
- As previously described, periodic observation should be done and if any progression is noticed, the patient should be prepared for appropriate surgical stabilization when indicated.
- In children we consider an ADI of 4 mm or more as evidence of atlantoaxial instability. Documented significant instability at the atlanto-occipital or atlantoaxial joints is an indication for posterior arthrodesis of occiput–C2 and C1–C2 arthrodesis, respectively.
- In some congenital disorders such as Morquio syndrome, progression of the instability is frequent; in these cases prophylactic fusion should be considered before neurologic symptoms occur.\(^\text{19}\)
- However, in Down syndrome, the patients with instability are usually asymptomatic and in most cases signs and symptoms progress slowly. Restriction of high-risk activities usually is appropriate. If the clinical symptoms persist or neurologic symptoms are starting to occur in the setting of significant instability, surgical treatment is indicated.\(^\text{9,16}\)
- Children with congenital fusion of cervical vertebrae (mostly in Klippel-Feil syndrome) should be restricted from high-risk sports. Patients with progressive symptomatic seg-

mental instability or neurologic compromise are candidates for surgical stabilization.\(^\text{18}\)

SURGICAL MANAGEMENT
- The main indication for the posterior occiput–C1 or C1–C2 arthrodesis is instability of the atlanto-occipital or atlantoaxial joint.
- For occipitoatlantal instability and instability with congenital or acquired (because of removal of tumor or laminectomy) defects of posterior elements, we developed two techniques of occipitocervical arthrodesis at our institution.
- Rib graft technique
- Iliac graft technique
- Many techniques of atlantoaxial fusion using cables, transarticular screws, plates, and bone graft materials have been described. For isolated atlantoaxial instability, we commonly prefer the Gallie technique, the Mah modified Gallie technique, and the Brooks sublaminar wire technique.

Preoperative Planning
- Plain radiographs and CT scans are reviewed and any osseous findings noted.
- MRI evaluation for the spinal cord compression is recommended.
- An appropriate halo ring is measured for the patient. Somatosensory evoked potentials, transcortical motor-evoked potentials, and electromyography are the preferred neurologic monitoring modalities.
- Flexible fiberoptic intubation with manual in-line axial stabilization should be considered to minimize cervical motion during intubation maneuvers.

Positioning
- After induction of general anesthesia in the supine position, a halo ring is applied, and the patient is carefully turned to the prone position.
- The halo device is fixed to the Mayfield positioning device, which is securely fixed to the operating table (FIG 3).
- Lateral fluoroscopy or radiography should be done before starting the procedure to confirm the alignment of the occiput and cervical spine.
- Donor sites (rib or ilium) are also prepared for graft harvesting.

Approach
- The posterior midline incision is made from the occiput to the intended distal fusion site (usually C2) for occipitocervical arthrodesis.
- The paraspinal muscles are elevated with a Cobb elevator and retracted laterally. Excessive lateral dissection should be avoided to prevent any damage to the vertebral artery, which runs in a serpentine course in relationship to the C2 vertebra.
- For occipitocervical arthrodesis, the dissection is carried proximally to the occipital protuberance and distally to the level planned to include the fusion.
- For atlantoaxial arthrodesis, the dissection is started from the lower occiput and the surgeon identifies the posterior arch of the atlas, the bifid spinous processes, and the lamina of the axis.
- The surgical exposure of vertebra is limited up to the intended level of fusion to prevent unintentional inclusion of the adjacent level in the fusion mass.
OCCIPITOCERVICAL ARTHRODESIS WITH ILIAC GRAFT

- At the level below the transverse sinus, four transverse-oriented holes are drilled through both cortices of the occiput with a high-speed diamond drill.\(^7\)
  - The holes are aligned transversely with two on each side of the midline. At least 1 cm of intact bone should be left between the holes to prevent wire pull-out through the skull (TECH FIG 1A).
- Surgical loupes and a headlamp are recommended for this procedure.
- Using a high-speed diamond burr, the surgeon makes a transverse-oriented trough into the base of the occiput to fit the rectangular superior part of the iliac autograft.
- A single corticocancellous autograft (3 × 4 cm) is harvested through an oblique incision over the posterior superior iliac spine.
- A rectangular graft is taken. The surgeon creates a notch in the inferior base of the graft to be suitable for the base of the spinous process of the second or third vertebra (TECH FIG 1B).
- 16- or 18-gauge wire is passed through the burr holes on each side of the midline and the wire is looped on itself (TECH FIG 1C,D).

- A sublaminar wire is placed under the ring of C2 or C3 (or passed through the base of the spinous process, if structurally sufficient, or if there is canal stenosis).
- The left side of the graft accepts the left end of the wire and the right end of the graft accepts the right end of the wire (TECH FIG 1E).
- The edges of the graft are contoured to fit appropriately into the occipital trough and around the base of the spinous process (TECH FIG 1F).
- The wires are tightened over the graft in figure 8 shape. After satisfactory tightening the edges of the wire are cut and bent away from skin (TECH FIG 1G,H).
- Intraoperative fluoroscopy or radiography is used to confirm the alignment of the occiput and cervical spine, stability, and the position of the graft and wires.
- The graft should be structurally stable at the end of the procedure.
- Flexion-extension of the halo frame, better contouring of the graft, and appropriate tightening of the wires can be used to make adjustments in reduction and alignment.
TECH FIG 1 (continued) C. A Luque wire is passed through the occipital burr hole and another wire is passed sublaminarly under the arch of C2 or through the base of the C2 spinous process. D. Occipital wire is looped on itself. E. Schematic drawing showing occipital wire looped on itself and the wire passed through the base of the C2 spinous process. F. Graft (arrow) placed between the occiput and C2. G. The wires are tightened over the graft in a figure 8 shape, twisted, and cut. H. Schematic drawing showing the graft placement and securing with wires.

OCCIPITOCERVICAL ARTHRODESIS WITH RIB GRAFT

- An oblique incision overlying the posterior rib allows for adequate exposure.3
  - The muscle fibers are separated and dissection is carried down to the periosteum of the rib.
- Adequate rib is exposed and cut.
  - The size of the rib graft is greater than the area to be fused because part of the rib is used as morcelized graft.
  - Using a rib cutter, the graft is cut distally and proximally and removed (TECH FIG 2A).
- Irrigation fluid is placed in the surgical site and positive pressure applied to check for pleural leaks.
- If a pleural tear is detected, air can be removed from the chest cavity by using a red rubber tube and suction.
- A larger leak may require placement of a thoracostomy drainage tube.
  - In all patients, a chest radiograph should be taken after rib harvest to rule out pneumothorax.
- Two full-thickness structural grafts are prepared to fit the arthrodesis site.
  - The rib grafts can span large defects and fit nicely into large or abnormally shaped skull, and we find this best for young infants.
- 16- or 18-gauge wire is looped through the burr holes on each side of the midline (see TECH FIG 1C).
  - The burr holes are drilled and aligned similarly to the ones described for the iliac graft technique.
- There is no need to create a groove at the base of the occiput.
  - Braided cable or no. 5 Mersilene sutures may be used instead of wire.
  - With Mersilene sutures there is a reduced risk of cutting out in thin bone of poor quality.
- After this, purchase of two wires is made to the posterior elements of most caudal vertebra on each side of the midline by sublaminar wiring.
  - Suitable grafts on either side are then secured to the occiput and lamina of the most caudal vertebra by wires.
  - The stability of the grafts is checked under radiographic control and the wires are then crimped and cut (TECH FIG 2B,C).
- Adjustments are made by flexion–extension of the halo frame, contouring of the graft, and appropriate tightening of the wire.
  - Intraoperative radiographs are obtained to confirm acceptable reduction, alignment, and placement of the graft.
- For both techniques, morcellized autograft is packed into the arthrodesis site. The wound is closed in layers.
  - The halo vest is worn for 8 to 12 weeks after both techniques to maintain postoperative stability (TECH FIG 2D,E).
Chapter 55  POSTERIOR CERVICAL ARTHRODESSES: OCCIPUT–C2 AND C1–C2

POSTERIOR C1–C2 ARTHRODESIS

- The preoperative planning is similar to that for the occipitocervical arthrodesis described earlier in the section.

Gallie Technique

- After exposing the posterior arch of the atlas and spinous process of the axis, the two free ends of a single 16- or 18-gauge wire are passed beneath the posterior arch of the atlas from a superior-to-inferior direction.\textsuperscript{10}
- The free ends are passed beneath the posterior arch and are brought around superiorly to loop on themselves.
- A rectangular corticocancellous autograft is harvested from the posterior iliac spine.
  - A notch is created at the distal part of the graft. This part will be placed across the spinous process of the axis.
- The notched graft is placed between the posterior portion of the arch of C1 and the posterior spinous process of C2.
- Now the free ends of the looped wire are brought down over the graft and passed below the spinous process.
- The free ends of the wire are tightened and twisted over the graft (TECH FIG 3).

- Morcellized bone grafts may be packed into the fusion area to add additional support.
- Intraoperative fluoroscopy is necessary to check for satisfactory reduction and alignment of C1–C2.

Mah Modified Gallie Technique

- In 1989, Mah described a modification of the Gallie technique.\textsuperscript{13}
- All the steps of the Mah technique are similar to the Gallie technique, except that a threaded Kirschner wire is placed through the spinous process of the C2 and both ends of the Kirschner wire are cut, leaving about 2.5 cm of the total wire.
- The free ends of the looped wire are brought down below the free ends of the threaded Kirschner wire (TECH FIG 4).
- The free ends of the wire are tightened, secured, and crimped over the graft.

TECH FIG 2 • A. Adequate rib is exposed and harvested. B. Rib graft is placed and fixed with braided cables and #5 Mersilene suture. C. Schematic drawing showing the rib graft fixed with wire. D, E. A 5-year-old-boy immobilized with a halo vest postoperatively. (C: Adapted from Cohen MW, Drummond DS, Flynn JM, et al. A technique of occipitocervical arthrodesis in children using autologous rib grafts. Spine 2001;26:825–829.)

TECH FIG 3 • Gallie technique for atlantoaxial arthrodesis.

TECH FIG 4 • Mah modified Gallie technique for atlantoaxial arthrodesis.
Brooks Technique

- A standard posterior midline incision is used to expose the posterior arch of C1 and the lamina of C2.  
- Two sublaminar wires are passed under both C1 and C2 laminas, one on each side of the midline.  
- Unlike the Gallie technique, two separate corticocancelous grafts are required in this technique. A single rectangular iliac crest graft is harvested; it can be separated into two equal parts.  
- Each iliac crest graft is cut into a trapezoid-like shape (one end is narrower than the other) so that they can be wedged between the C1 and C2 posterior arches (TECH FIG 5A).  
- The grafts are snugly wedged into place. The wires are then tightened around the grafts, twisted, and cut (TECH FIG 5B).

TECH FIG 5 • Brooks arthrodesis. A. Lateral view demonstrating a wedge-shaped graft between the spinous processes to prevent hyperextension. The graft is shaped so that one end is narrower than the other to achieve a good fit. B. The grafts are snugly wedged between the C1 and C2 posterior arches, and the wires are tightened around the grafts.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Approach</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Excessive lateral dissection should be avoided so as not to damage the vertebral arteries and major venous junctions.</td>
<td></td>
</tr>
<tr>
<td>In the case of an open posterior arch, meticulous and blunt dissection should be used to keep from injuring the dura mater and the cord.</td>
<td></td>
</tr>
<tr>
<td>Excessive dissection and extended dissection time are avoided.</td>
<td></td>
</tr>
<tr>
<td>This may increase the risk of inadvertent extension of the fusion mass.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Occipitocervical arthrodesis with iliac graft technique</th>
<th>This technique is associated with stable internal fixation and high fusion rates.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A large occipitocervical segment can be spanned.</td>
<td></td>
</tr>
<tr>
<td>Rib grafts can be shaped easily because of their elastic structure.</td>
<td></td>
</tr>
<tr>
<td>This technique is best for infants, small children, or patients with an abnormally shaped skull.</td>
<td></td>
</tr>
</tbody>
</table>

| C1–C2 arthrodesis with Gallie technique |  |
| This procedure is more suitable in older children who have a competent spinous process. |  |
| It is not always necessary to pass wire or cable underneath the lamina of the axis. |  |
| This technique provides good stability in flexion and extension but may be insufficient in rotational maneuvers. |  |

| C1–C2 arthrodesis with Mah modification | The wire can securely hold behind an insufficiently ossified spinous process with the help of a transverse Kirschner wire. |
| C1–C2 arthrodesis with Brooks technique | This technique provides more rotational stability than the Gallie technique. |
| Disadvantages include the need to pass bilateral sublaminar cables beneath both C1 and C2. |

POSTOPERATIVE CARE

- Postoperative management includes halo vest immobilization for 8 to 12 weeks.  
- Using a standardized method of halo application reduces the rate of complications associated with halo use in children.  
- The rate of pin-track infection with prolonged use of a halo device in children is similar to that in adults. Particular care should be taken to keep the pin-track sites clean.  
- Short-term antibiotic treatment is usually satisfactory in decreasing inflammation at the pin site.  
- When a bony union is documented radiographically, the halo device is removed.  
- Patients can gradually return their daily activities.  
- Special care should be taken to avoid excessive flexion or extension of the neck.  
- Long-term follow-up is necessary for evaluation of potentially progressing junctional instability below the level of fusion.  
- The additional stress placed on the adjacent vertebrae below the level of fusion may result in instability with time.
OUTCOMES

- The senior author (JPD) presented results of the CHOP technique for occipitocervical arthrodesis in 38 children with more than 2 years of follow-up.20
- Thirty-four patients were treated with iliac crest autograft and posterior wiring, or with rib autograft and posterior wiring, and the remaining four with Luque contoured rod and autograft.
- Thirty-four patients had bony union, three patients had fibrous union, and one patient had nonunion.
- Ninety-seven percent of the patients (37 children) showed baseline or improved neurologic status at the most recent follow-up.
- Complications included:
  - Superficial infection treated with oral antibiotics (three patients)
  - Postoperative pneumonia (one patient)
  - Pin-tract infection: most of the patients treated with a halo ring had superficial pin-site infection. All but two patients were treated with oral antibiotics. One patient required intravenous antibiotics and the other required a pin change.
- In 11 patients (29%), we had a distal extension of the fusion mass, seven patients had fusion at one additional level, and four patients had fusion at two additional levels.

COMPLICATIONS

- Graft or wire breakage
- Nonunion, insufficient fusion
- Additional fusion levels and loss of motion
- Junctional instability distal to the fusion mass
- Infection
- Deep wound infection
- Meningitis
- Pin-tract infections (halo)
- Neurologic injury
- Donor site morbidity

REFERENCES

**DEFINITION**

- Scoliosis is a three-dimensional deformity of the spine and rib cage.
- The hallmark of scoliotic spines is curvature in the coronal plane along with abnormal curvature in the sagittal plane (eg, lordoscoliosis in adolescent idiopathic scoliosis) as well as abnormal vertebral rotation in the transverse plane.
- A Cobb angle measurement of greater than 10 degrees distinguishes minor spine asymmetry from true scoliosis.
- The posterior approach to the thoracic and lumbar spine takes advantage of the segmental innervation of the posterior spinal muscles to obtain an internervous and intermuscular plane to provide access to the posterior elements of the spine.
- The posterior approach is the most commonly used route for spinal fusion and instrumentation in the scoliotic spine.

**ANATOMY**

- Surface landmarks in the prone position:
  - The vertebra prominens (C7) is typically the most prominent bony structure palpated at the base of the neck.
  - The superior angle of the scapula is at the level of the T3 spinous process.
  - The scapular spine is at the level of the T4 spinous process.
  - The inferior angle of the scapula is at the level of the T7 spinous process.
  - With the patient in the prone position, the iliac crests are palpated with the fingers and the thumbs brought together at the midline, where they typically overlie the L4–5 interspace.
  - The posterior superior iliac spines are at the level of the L5-S1 interspace.
- Posterior spinal musculature is divided into superficial and deep layers. The superficial layer, also known as the erector spinae, is composed of the iliocostalis, longissimus, and sacrospinalis muscles. The deep layer consists of the short rotators (multifidus and rotatores) as well as the intertransversarii and interspinous muscles (FIG 1A,8).
- Segmental innervation of spinal musculature
  - Provided by the dorsal rami of the thoracolumbar nerve roots
- Segmental blood supply
  - The posterior intercostal arteries branch from the aorta and subsequently send a dorsal branch posteriorly to the spinal musculature. On its way past the neural foramina, the spinal artery branches off and is sent through the foramina. The spinal artery then divides into anterior and posterior radicular branches within the spinal canal, ultimately supplying the anterior and posterior spinal arteries. Care should be taken to cauterize the branches that lie adjacent to the lateral aspect of the facet (FIG 1C).
- In the scoliotic spine there is rotation of the vertebral bodies in the transverse plane with the spinous processes rotating toward the concavity of the curve.

**PATHOGENESIS**

- Idiopathic
- Congenital
- Failure of formation or segmentation of vertebral precursors leading to asymmetric vertebral growth with subsequent abnormal curvature
- Neuromuscular
- Variety of etiologies, such as cerebral palsy, muscular dystrophy, polio, spinal muscular atrophy, and myelomeningocele
- Related to an inability to provide muscular support to the spinal column

**NATURAL HISTORY**

**Idiopathic**

- Infantile (0 to 3 years of age)
- Less than 1% of all cases of idiopathic scoliosis
- More common in boys
- Left thoracic curves predominate
- Most resolve spontaneously
- Juvenile (3 to 10 years of age)
- 8% to 16% of all cases of idiopathic scoliosis
- More even female:male ratio
- Bracing may correct some curves
- Curves of more than 30 degrees usually progress to surgery
- Adolescent (10 to 18 years of age)
- Most common form of idiopathic scoliosis
- Etiology and pathogenesis are not well understood
- Family history is positive in 30% of cases but does not predict curve magnitude or progression.
- More common in girls. The female:male ratio is 1.4:1 for curves 11 to 20 degrees and increases to 5:1 for curves greater than 20 degrees.
- Curves have the greatest chance of progression in the period of peak growth velocity leading up to skeletal maturity (prior to menses in females), after which the potential decreases significantly.
- Scoliotic curves measuring less than 20 degrees are at lower risk for progression.
- Scoliotic curves measuring greater than 50 degrees are at higher risk for further progression during adult life (with a percentage of these progressing at a rate of about one degree per year).
- There are no significant differences in the prevalence of back pain between adults with scoliotic spines and the general population.
- Scoliotic curves measuring greater than 100 degrees have an increased prevalence of cardiopulmonary compromise (eg, cor pulmonale, restrictive lung disease).
### Congenital
- Severity of deformity related to type and location of anomaly
- Highest chance of curve progression with unilateral unsegmented bar with contralateral hemivertebrae (nearly 100%), followed by a lone unilateral unsegmented bar, double convex hemivertebrae, single convex hemivertebrae, and finally the block vertebrae\(^3\)

### Neuromuscular
- Most curves are progressive and are more difficult to manage nonoperatively.
- Curves can cause pelvic obliquity and sitting problems in nonambulatory individuals.

#### PATIENT HISTORY AND PHYSICAL FINDINGS
- Complete history, including age at onset, timing of growth spurts, menses, presence of pain, family history of scoliosis, nerve, or muscle diseases
- A complete examination is important to obtain a diagnosis because certain etiologies can predispose the patient to increased operative risk (eg, cardiac abnormalities in patients with Marfan syndrome).

- The skin is inspected for café-au-lait spots, the axilla for freckling, and the lumbar area for sinus tracts, hairy patches, or dimples. Axillary freckling and multiple café-au-lait spots are associated with neurofibromatosis. Sinus tracts, hairy patches, or dimples in the lumbar area are associated with intraspinal anomaly.
- The Adams forward bending test detects curves by physical examination. Abnormalities in vertebral rotation become apparent as an asymmetrical rib hump, prominence, or fullness, leading to possible identification of patients at risk for having scoliosis.
- Any shoulder or scapular asymmetry is noted. It is important to point out to parents that this is not always corrected by surgery.
- Pelvic obliquity can indicate a possible leg-length discrepancy that can mimic a lumbar scoliosis.
- Trunk shift and sagittal profile are noted; these indicate coronal balance and sagittal balance, respectively.
determine the degree of scoliosis, to identify any skeletal abnormalities (eg, hemivertebra), and to evaluate overall alignment.

- PA views are obtained to decrease exposure of sensitive breast tissue to ionizing radiation in girls.
- Side-bending supine views of the thoracolumbar spine are useful to determine the flexibility of the primary and secondary curves. This information is useful during preoperative planning in choosing fusion levels and determining the approach.
- Risser staging system for gauging skeletal maturity (FIG 2)
  - Ossification of the iliac apophyses proceeds along the iliac crest from the anterior superior iliac spine to the posterior superior iliac spine. When ossification is complete, fusion of the apophysis to the iliac crest occurs.
  - Risser 0 = no ossification
  - Risser 1 = 25% excursion
  - Risser 2 = 50% excursion
  - Risser 3 = 75% excursion
  - Risser 4 = 100% excursion
  - Risser 5 = fusion of iliac apophysis to the iliac crest
- In girls, the end of spinal growth corresponds to Risser stage 4.
- In boys, spinal growth can occur after Risser stage 4 and is less well defined.
- MRI should be obtained for patients with an onset before age 10 years, left thoracic curves, kyphoscoliotic curves, or rapidly progressive curves; patients with moderate to severe back pain; patients with congenital or neuromuscular scoliosis; and patients with abnormal findings on the physical examination.

**DIFFERENTIAL DIAGNOSIS**

- Scoliosis
- Idiopathic
- Congenital
- Neuromuscular
- Limb-length discrepancy
- Osteoid osteoma
- Sprengel deformity

**NONOPERATIVE MANAGEMENT**

- Observation for progression for curves of 0 to 20 degrees. Patients are followed with serial clinical and radiographic examinations.
- Bracing for progressive curves of 20 to 40 degrees if the patient is skeletally immature. Braces cannot correct curves; their purpose is to prevent curve progression.

**SURGICAL MANAGEMENT**

**Preoperative Planning**

- Preoperative radiographs with supine side-bending films are obtained to determine fusion levels according to the Lenke criteria.
- Cobb angles (FIG 3A)
  - Quantitates the degree of curvature
  - Method
    - Determine apex of curve to be measured.
    - Select the most tilted vertebra above the apex of the curve and draw a line along the top of the vertebral endplate.
    - Select the most tilted vertebra below the apex of the curve and draw a line along the bottom of the vertebral endplate.
- Drop perpendicular lines to these previous two lines.
- The angle subtended by the two lines is the Cobb angle.
- The intraobserver intrinsic error in Cobb angle measurements is about 5%; interobserver validity is about 7%.
- Center sacral vertical line (FIG 3B)
  - Used to help determine distal extent of fusion
  - The vertebral body most closely bisected by the center sacral line is the stable vertebra.
- Fusion is usually extended to the stable vertebra or the one immediately cephalad.

Positioning
- Patient is intubated in the supine position on the stretcher.
- Neurologic monitoring leads are placed cranially, on the intercostal and abdominal musculature, and on all four extremities.
- Multiple large-bore intravenous access is obtained for fluid management and an arterial line is placed for intraoperative blood pressure monitoring.
- The patient is transferred to the prone position on a well-padded operating room table such as a Jackson frame (Orthopaedic Systems, Union City, CA).
- Care should be given to the degree of hip flexion-extension, as this can affect the amount of lordosis in the lumbar spine.
- Bolsters underneath the chest and anterior superior iliac spines prevent abdominal compression and allow epidural venous return, thus decreasing epidural bleeding.

INCISION
- A Bovie electrocautery cord is centered over the back using the vertebra prominens and the gluteal crease, and the line for the straight midline back incision is marked (TECH FIG 1A).
- Bupivacaine (0.25%) with 1:200,000 epinephrine may be injected along the course of the incision for local anesthesia and hemostasis (TECH FIG 1B).
- The skin is sharply incised with a no. 10 blade scalpel and electrocautery is then used to dissect through the subcutaneous fat until the thoracolumbar fascia is reached.
- Weitlaner retractors are placed.
- The spinous processes are identified via palpation (TECH FIG 1C).
Electrocautery is used to dissect through the thoracolumbar fascia at the tips of adjacent spinous processes (TECH FIG 1D,E).

These incisions are connected (TECH FIG 1F).

This proceeds throughout the extent of the incision. Care is taken at the cephalad and caudal aspects of the dissection to leave the interspinous ligaments intact.

**SUBPERIOSTEAL DISSECTION**

- Dissection then proceeds subperiosteally.
- In skeletally immature individuals, the apophyses of the spinous processes are further dissected with a Cobb elevator (TECH FIG 2A).
- Electrocautery is used to advance the dissection deep along the spinous processes until the laminae are reached and the retractors are repositioned (TECH FIG 2B).
- In the thoracic spine, dissection proceeds until the tip of the transverse process is fully exposed.
- In the lumbar spine, dissection proceeds until the facet joint, pars interarticularis, and transverse process are exposed.
- At this point the spine is instrumented.
CLOSED

POSTOPERATIVE CARE

No postoperative immobilization is required with multisegmental constructs.

Postoperative restrictions include limitations with lifting, bending, and twisting.

It is important to maintain mean arterial blood pressure above 70 mm Hg overnight and hemoglobin above 10 g/dL to maintain spinal cord perfusion.

Intravenous antibiotics are maintained for 48 hours postoperatively.

Neurovascular checks are made every 2 hours for the first 8 hours, then every 8 hours.

Diet is advanced as tolerated.

Patient-controlled analgesia is used for appropriate patients. Continuous narcotic infusion with demand for the first 24 hours is followed by oral pain medications when tolerating diet.

A 4-day hospital course is typical.

Activity is increased based on the degree of fusion.

OUTCOMES

With meticulous attention to detail with regard to instrumentation and fusion techniques, excellent outcomes in terms of straightening and fusion of the scoliotic spine can be expected.

Long-term outcomes are variable and depend on the underlying diagnosis and the extent of retained spinal mobility.

COMPLICATIONS

Early or late infection: less than 5%

Wound dehiscence

Hematoma

Instrumentation failure

Pseudarthrosis: 1% to 12% depending on type of fusion and method of diagnosis

Neurologic injury

Spinal cord injuries: consider initiating steroid protocol

Nerve root injuries

Wrong-level surgery

REFERENCES

DEFINITION
- Reduction of scoliotic spinal deformity via posterior spinal fusion with instrumentation allows for improvement of the cosmetic appearance of the child or adolescent with scoliosis and prevents curve progression. The goal is to balance these advantages with the inherent risks of instrumentation and reduction maneuvers.
- Instrumentation provides an internal construct holding the spine in its corrected position until spinal fusion is achieved (about 6 months) and obviates the need for postoperative immobilization. A Cobb angle measurement greater than 10 degrees distinguishes minor spine asymmetry from true scoliosis.
- Segmental instrumentation with hooks and pedicle screws provides multiple fixation points, allowing for three-dimensional correction of the scoliotic spine.
- Instrumentation is introduced after posterior exposure of the thoracic or lumbar spine (see Chap. PE-56).

ANATOMY
- A thorough knowledge of scoliotic spinal anatomy is critical for the safe placement of instrumentation.
- In the scoliotic spine there is rotation of the vertebral bodies in the transverse plane, with the spinous processes rotating toward the concavity of the curve.
- Anatomy of the posterior elements
  - In the scoliotic spine, the pedicles on the concave side are narrower than those on the convexity, especially at the apex of the curve (FIG 1A).12
  - The intervertebral foramina in the thoracic spine are larger and deeper than in any other region of the spine, with the exiting nerve root occupying less than 25% of the foramen and coursing through its midportion.
  - Lumbar nerve roots pass adjacent to the inferomedial aspect of the pedicle and lie superior within the foramina.
- Scoliotic deformity affects not only the bony anatomy but also the relationship of the spine to the adjacent soft tissue elements.
  - The aorta is posterolateral to its normal position, putting it at risk for injury with left-sided lateral pedicular breaches (FIG 1B).
  - The spinal cord hugs the concavity of the curve such that the width of the epidural space is less than 1 mm at the thoracic apical vertebral levels on the concave side; it is 3 to 5 mm on the convex side.8

Thoracic Spine Anatomy
- The thoracic facets are more coronally oriented in comparison to the more sagittally oriented lumbar facets.
- Pedicle anatomy for placement of pedicle screws

Dimensions
- In scoliotic spines, average thoracic pedicle length (distance from the posterior cortical starting point to the posterior longitudinal ligament in line with the axis of the pedicle) is 16 to 22 mm.
- Average thoracic cord length (distance from the posterior cortical starting point to the anterior vertebral cortex in line with the axis of the pedicle) is 34 to 52 mm; it is typically greater on the concavity.
- Coronal anatomy
  - In the scoliotic spine, the medial wall is two to three times thicker than the lateral wall at all thoracic levels. This may be why most screw-related pedicle fractures occur laterally.
• The coronal anatomy of the thoracic pedicle varies, moving from anterior to posterior. The likelihood of pedicle wall breach is greatest midway between the lamina and body with placement of screws.
• Pedicle width decreases from T1 to T4 and then gradually increases to T12, while pedicle height and length tend to increase from T1 to T12.
• Main pedicle diameter is 4 to 6 mm in thoracic scoliosis.
• Endosteal pedicle width in the apical region of the thoracic spine measures 2.5 to 4.2 mm on the concavity of the curve and 4.1 to 5.0 mm on the convexity of the curve.
• In the thoracic spine, transverse processes do not align with the pedicle in the axial plane: they are rostral to the pedicle in the upper thoracic spine and caudal to the pedicle in the lower thoracic spine (crossover occurs at T6–7).
• Transverse orientation
  • T12 pedicles are perpendicular to the floor in the transverse plane.
  • T1 pedicles subtend an angle of about 25 to 30 degrees with the midline in the transverse plane.
  • Thoracic pedicles progressively angle outward in the transverse plane, proceeding superiorly from T12 to T1.
• Thoracic pedicle screw starting points
  • As one proceeds proximally from T12 there is a trend toward a more medial and cephalad pedicle starting point as one proceeds proximally from T12 to T1.
  • This then transitions to a trend toward a more lateral and caudal pedicle starting point as one proceeds proximally from the apex.

<table>
<thead>
<tr>
<th>Level</th>
<th>Cephalad-Caudal Starting Points</th>
<th>Medial-Lateral Starting Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Midpoint TP</td>
<td>Junction TP and lamina</td>
</tr>
<tr>
<td>T2</td>
<td>Midpoint TP</td>
<td>Junction TP and lamina</td>
</tr>
<tr>
<td>T3</td>
<td>Midpoint TP</td>
<td>Junction TP and lamina</td>
</tr>
<tr>
<td>T4</td>
<td>Junction between proximal third and midpoint TP</td>
<td>Junction TP and lamina</td>
</tr>
<tr>
<td>T5</td>
<td>Proximal third TP</td>
<td>Junction TP and lamina</td>
</tr>
<tr>
<td>T6</td>
<td>Junction of proximal edge and proximal third TP</td>
<td>Junction TP and lamina and facet</td>
</tr>
<tr>
<td>T7</td>
<td>Proximal TP</td>
<td>Midpoint facet</td>
</tr>
<tr>
<td>T8</td>
<td>Proximal TP</td>
<td>Midpoint facet</td>
</tr>
<tr>
<td>T9</td>
<td>Proximal TP</td>
<td>Midpoint facet</td>
</tr>
<tr>
<td>T10</td>
<td>Junction of proximal edge and proximal third TP</td>
<td>Junction TP and lamina and facet</td>
</tr>
<tr>
<td>T11</td>
<td>Proximal third TP</td>
<td>Just medial to pars</td>
</tr>
<tr>
<td>T12</td>
<td>Midpoint TP</td>
<td>At level of lateral pars</td>
</tr>
</tbody>
</table>

TP, thoracic pedicle.

Lumbar Spine Anatomy
• The lumbar vertebral facets are more sagittally oriented in comparison to thoracic vertebral facets.
• Pedicles
  • Dimensions
    • In scoliotic spines, average lumbar pedicle length is 20 to 22 mm.
    • Average lumbar cord length is 45 to 48 mm.
  • Coronal anatomy
    • Average lumbar endosteal pedicle width is 4.8 to 9.5 mm.
    • The larger size of the lumbar pedicles increases the likelihood of optimal placement of pedicle screws.
  • Transverse orientation
    • L1 pedicles are perpendicular to the floor in the transverse plane.
    • L5 pedicles subtend an angle of about 25 to 30 degrees with the midline in the transverse plane.
    • Lumbar pedicles progressively angle outward in the transverse plane, proceeding inferiorly from L1 to L5.
  • Lumbar pedicle screw starting points
    • The long axis of the pedicle pierces the lamina at the intersection of two lines: a vertical line tangential to the lateral border of the superior articular process, and a horizontal line bisecting the transverse process (FIG 3).
    • The point of intersection for these two lines lies in the angle between the superior articular process and the base of the transverse process.
• Dangers
  • Medial pedicular breaches endanger the dural sac, especially on the concavity of the curve.
  • Inferior pedicular breaches endanger the nerve root, especially in the lumbar spine.
  • Advancement of pedicle screws following a lateral pedicular breach on the left can endanger the lung, segmental vessels, and sympathetic chain (T4–T12) and the aorta (T5–T10).
Advancement of pedicle screws following a lateral pedicular breach on the right can endanger the lung, segmental vessels, sympathetic chain, and azygous vein (T5–T11). Advancement of pedicle screws following a breach of the anterior cortex on the right can endanger the superior intercostal vessels (T4–T5), the esophagus (T4–T9), the azygous vein (T5–T11), the inferior vena cava (T11–T12), and the thoracic duct (T4–T12). Advancement of pedicle screws following a breach of the anterior cortex on the left can endanger the esophagus (T4–T9) and the aorta (T5–T12).

**PATHOGENESIS, NATURAL HISTORY, AND PATIENT HISTORY AND PHYSICAL FINDINGS**

See Chapter PE-56, Posterior Exposure of the Thoracic and Lumbar Spine.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

Placement of a pedicle screw at the thoracolumbar junction followed by intraoperative fluoroscopic imaging accurately identifies vertebral level.

With use of intraoperative fluoroscopic imaging guidance, knowledge of anatomy remains critical in order to orient the intensifier to obtain the best coronal images of the pedicles.

Radiographic criteria used to evaluate accurate screw placement

- Harmonious segmental change of the tips of the pedicle screws on the posteroanterior (PA) radiograph
- No crossing of the medial pedicle wall by the tip of the pedicle screw with reference to vertebral rotation on the PA radiograph
- No violation of the imaginary midline of the vertebral body by the tip of the pedicle screw on the PA radiograph
- No breach of the anterior cortex of the vertebral body on the lateral radiograph

**DIFFERENTIAL DIAGNOSIS**

- Scoliosis
- Idiopathic
- Congenital
- Neuromuscular
- Limb-length discrepancy
- Osteoid osteoma
- Sprengel deformity

**NONOPERATIVE MANAGEMENT**

- Observation for progression for curves of 0 to 20 degrees. Patients are followed with serial clinical and radiographic examinations.
- Bracing for progressive curves of 20 to 40 degrees if the patient is skeletally immature. Braces are unable to correct curves; their purpose is to prevent curve progression.

**SURGICAL MANAGEMENT**

**Preoperative Planning**

- PA and lateral radiographic views of the entire spine.
- Convex apical pedicles greater than 5 mm in diameter on the PA radiographs are large enough to accommodate pedicle screw placement.
- Computed tomographic (CT) imaging can be used to evaluate pedicle morphology, with images oriented perpendicular to the plane of the vertebrae.
- Fusion levels are chosen based on the Lenke criteria.

**Hook Placement**

**Advantages**

- Technically easier, especially at levels with small pedicles (apical concave pedicles)
- Less operative time

**Disadvantages**

- Increased canal intrusion in comparison to pedicular fixation
- Lack of three-column fixation
- Decreased ability to perform correctional derotational maneuvers

**Types of hooks**

- Laminar hooks: should be used with caution in the neurologically intact patient
- Thoracic laminar hooks: downgoing sloped hooks
- Lumbar laminar hooks: upgoing or downgoing C-shaped hooks
- Thoracic transverse process hooks: downgoing C-shaped hooks
- Thoracic pedicle hooks: upgoing claw-tip hooks placed under the lamina
- Offset hooks: offset laterally to lie in line with pedicle screws for use in hybrid constructs
- Hook patterns for an isolated thoracic curve
- Concave side
  - Upgoing pedicle hook on upper end and upper intermediate vertebrae
- Downgoing laminar hook on lower end and lower intermediate vertebra
- Convex side
- Claw construct at upper end vertebrae.
- Downgoing transverse process hook with upgoing pedicle hook at the same level or next-distal level. Splitting the claw over two levels (split claw) better resists rotational forces.

### Pedicle Screw Placement

#### Advantages
- Pedicle screws have significantly higher axial pullout strengths than supralaminar hooks and pedicle hooks.
- Better correction in the coronal and axial planes.
- Less decrease in pulmonary function than anterior surgery.
- No implants in the canal during the correction phase.
- Correction not gained by pure distraction.
- Fewer fusion levels.
- No crankshaft.
- Larger area for bone graft.
- Allows earlier postoperative activity.

#### Disadvantages
- Steep learning curve.
- Caudal or medial penetration can result in dural or neural injury.
- Lateral penetration can cause vascular injury.
- Increased operative time.
- Costly procedures.

#### Complications
- Suboptimal screw position
  - More common in cases of severe deformity
  - Perforation not uncommon (up to 40% of screws in some series)
  - Lateral perforation more common than medial perforation
  - Lowest containment rates in midthoracic spine (T5 to T8)
- Dural, neural, or vascular injuries occur infrequently.

#### Types of pedicle screws
- Monoaxial
  - No motion between the screw and the screw head
  - Can obtain axial correction of deformity
- Uniaxial
  - Motion between the screw and the screw head constrained to one plane
  - Can accommodate sagittal contours while retaining ability to obtain axial correction (derotation)
- Polyaxial
  - Multiaxial motion allowed between screw and screw head
  - For accommodation of sagittal contours
  - Can accommodate malalignment of the starting points in the coronal plane
- Reduction screw
  - Pedicle screw with breakaway extended tabs
  - Useful for seating rod into pedicle screw for difficult reduction maneuvers
- Freehand placement of thoracic pedicle screws
  - The straightforward trajectory allows for fixed-head screws and true direct vertebral derotation.

- Anatomic trajectory has a longer bone channel and allows a longer screw to be placed, but mandates the use of a multiaxial screw to connect it to the rod.
- A straightforward trajectory paralleling the superior endplate has significantly higher pullout strength versus an anatomic trajectory that angles about 22 degrees in the cephalocaudal direction perpendicular to the superior facet.7
- Extrapedicular thoracic pedicle screws
  - Screw inserted at the junction of the cephalad tip of the transverse process and the rib with advancement caudal so that the screw is contained in the pedicle rib unit, defined as the space between the lateral pedicle cortex and medial rib cortex.
  - Similar biomechanical fixation strength of transpedicular screws.

#### Confirmation of screw placement
- Radiographic confirmation (see Imaging and Other Diagnostic Studies)
- Neuromonitoring
  - Electromyography to confirm intraosseous screw placement
  - Somatosensory evoked potentials and motor evoked potentials
- Postoperative CT scan routinely performed before patient leaves the hospital to confirm accurate screw placement

### Positioning

- Patient is intubated in the supine position on the stretcher.
- Neurologic monitoring leads are placed cranially, on the intercostal and abdominal musculature, and on all four extremities.
- Multiple large-bore intravenous access is obtained for fluid management and an arterial line is placed for intraoperative blood pressure monitoring.
- The patient is transferred to the prone position on a well-padded operating room table such as a Jackson frame (Orthopaedic Systems, Union City, CA).
- Care should be given to the degree of hip flexion–extension, as this can affect the amount of lordosis in the lumbar spine.
- Bolsters underneath the chest and anterior superior iliac spines prevent abdominal compression and allow epidural venous return, thus decreasing epidural bleeding.
- All bony prominences are well padded, including medial elbows, knees, pretibial areas, and ankles.
- Care is taken to avoid abduction and forward flexion past 90 degrees at the shoulder and flexion past 90 degrees at the elbow.
- Skin is shaved if excessively hairy.
- Clear adhesive surgical drapes (3M Steri-Drape Towel Drapes) are placed around the perimeter of the surgical site, extending from the hairline to the top of the gluteal crease (regardless of levels to be fused, the entire spine should be draped).
- If a wake-up test is going to be used by the surgical team, a clear plastic C-arm cover or equivalent clear drape is laid over the exposed feet for visualization during the test.
- A disposable plastic ruler used for measuring the pedicle probe for pedicle depth is placed caudal to the field on the buttocks and covered with a clear Tegaderm dressing.
HOOK PLACEMENT

Proper hook-site preparation is critical to obtain a stable construct and minimize the chance of hardware failure.

Ideally, hooks should be placed flush with the bony surfaces to evenly distribute forces and minimize the chance of hook pullout. This is accomplished by meticulous removal of the soft tissues and judicious contouring of the bony surfaces: removing too much bone can weaken hook purchase, whereas removing too little bone can result in improper seating of the hook.

Pedicle Hooks

Initial pedicle hook-site preparation requires removal of a small portion of the inferior facet with an osteotome (TECH FIG 1A,B). The inferior facet of the superior vertebra is osteotomized using an osteotome. A vertical cut is made at the medial edge of the facet, near the base of the spinous process. A horizontal cut in the inferior facet, allowing removal of 3 to 4 mm of bone, follows for insertion of the pedicle hook.

The exposed hyaline cartilage from the facet joint is removed. A pedicle finder is introduced into the facet joint and gently impacted into place with a mallet (TECH FIG 1C,D). Care is taken to avoid canal penetration.

The permanent pedicle hook is subsequently inserted (TECH FIG 1E,F). The surgeon must carefully visualize the facet joint and avoid inserting the pedicle hook into the laminae. If the lamina is split by the hook, fixation will be compromised.

Laminar Hooks

Laminar hooks are placed in a similar fashion but require great care because they are positioned in the spinal canal (TECH FIG 2A,B).

To obtain entrance into the canal, the ligamentum flavum is carefully dissected from the laminae and completely removed with curettes and rongeurs until the dura can be visualized. Small laminotomies are performed to allow room for hook insertion (TECH FIG 2C,D).

A hook starter is then used to create a path for the hook (TECH FIG 2E). The hook is then placed into the path created (TECH FIG 2F).

Transverse Process Hooks

Transverse process hooks do not require extensive bone removal but may require minimal contouring to optimize fit (TECH FIG 3A,B).

The costotransverse ligaments on the superior side of the transverse process are divided with a periosteal elevator. The transverse process hook is seated around the transverse process (TECH FIG 3C,D).

TECH FIG 1 • Placement of pedicle hook. A,B. A small portion of the inferior facet is osteotomized. C,D. Introduction of pedicle finder into facet joint, taking care to avoid canal penetration. E,F. Insertion of pedicle hook.
TECH FIG 2 • Placement of supralaminar hook. A,B. Placement of a supralaminar hook is difficult without bone removal to allow room for hook insertion. C,D. Placement of supralaminar hook. Laminotomies allow room for hook insertion. E. Path for hook created with hook starter. F. Insertion of supralaminar hook.

TECH FIG 3 • A,B. Placement of transverse process hook. Contouring of the transverse process is required to optimize fit. C,D. Placement of transverse process hook. After contouring the transverse process, the transverse process hook is seated.
EXPOSURE FOR THORACIC PEDICLE SCREW PLACEMENT

- Full exposure of the facet joint, the pars interarticularis, and the entire transverse process aids in identification of the ideal starting point.
- Once the entire spine is exposed, each level is considered independently. The surgeon needs to visualize the local topical anatomy and the effects of the scoliosis on the anatomy (rotation).
- Bovie cautery is used to outline the osseous anatomy at each level. This first entails finding the medial and lateral border of the facet and the superior and inferior borders of the transverse process (TECH FIG 4A).
- The inferior facet of the superior vertebrae is osteotomized using an osteotome at the medial edge of the facet (TECH FIG 4B) and at the inferior border of the superior transverse process (TECH FIG 4C).
- At this point, the facet joint should be fully exposed (TECH FIG 4D), thus facilitating identification of the starting point.

![TECH FIG 4 A. The medial and lateral borders of the facet joint are identified. B. The inferior facet of the superior vertebrae is osteotomized at its medial edge. C. The facet is osteotomized at the inferior border of the superior transverse process. D. Full exposure of the facet joint facilitates identification of the starting point.]

THORACIC PEDICLE SCREW PLACEMENT

- A 3.5-mm acorn-tipped burr is then used to create a hole at the desired starting point (see Thoracic Anatomy) (TECH FIG 5A). A cancellous blush often heralds entry into the pedicle but can be a false positive found on entry into the transverse process.
- A specialized thoracic probe with a 2-mm blunt tip and a 35-mm curved segment with a rectangular cross section (Lenke probe) is used to create the tract for the pedicle screw.
- The probe is introduced into the starting point with the curvature oriented so the tip is pointed laterally to avoid medial pedicle cortical violation (TECH FIG 5B).
- The cancellous soft spot signifies entry into the pedicle.
- The probe is advanced using ventral pressure and axial rotation to a depth of about 15 to 20 mm (the length of the pedicle), using the appropriate orientation for the particular vertebral level (see Thoracic Pedicle Anatomy) and taking care to account for the scoliotic deformity.
- The probe is then removed and reintroduced into the previously developed tract with the tip turned medial to avoid lateral vertebral body cortical violation (TECH FIG 5C).
- The probe is advanced to a depth appropriate for the particular vertebral level, taking care to avoid anterior and lateral cortical violation.
- Typical cord lengths (distance from posterior cortical starting point to anterior vertebral cortex in line with the axis of the pedicle):
  - Lower thoracic 40 to 45 mm
  - Midthoracic 35 to 40 mm
  - Upper thoracic 30 to 35 mm
- The tract is probed using a flexible sound and five distinct bony borders are palpated: superior, inferior, medial, and lateral walls and the floor.
- The first 15 to 20 mm of the tract corresponds to the pedicle; its integrity should be critically assessed.
- The depth is measured with the flexible sound in the base of the tract using a hemostat (TECH FIG 5D).
The tract is tapped (TECH FIG 5E). Undertapping by 1.0 mm creates a 93% increase in maximal screw insertion torque.\textsuperscript{5}

The tract is again probed for a breach with the aid of the feel of the tapped threads.

Screw diameter is based on radiographic evaluation of pedicles.

The screw is placed slowly to allow for viscoelastic expansion of the pedicle (TECH FIG 5F).

LUMBAR PEDICLE SCREW PLACEMENT

- Full exposure of the facet joint, the pars interarticularis, and a portion of the transverse process aids in identification of the ideal starting point.
- The facet joint is removed to obtain a flat surface before placing the pedicle screw.
- A 3.5-mm acorn-tipped burr is then used to create a cortical breach at the desired starting point.
- A specialized probe with a blunt spatula tip and a 35-mm curved segment with a rectangular cross section (lumbar probe) is used to create the tract for the pedicle screw.
- The tract is tapped. Undertapping by 1.0 mm creates a 93% increase in maximal screw insertion torque.\textsuperscript{5}
- The tract is again probed for a breach with the aid of the feel of the tapped threads.
- Screw diameter is based on radiographic evaluation of pedicles.
- The screw is placed slowly to allow for viscoelastic expansion of the pedicle.

TECH FIG 5 • A. A burr is placed at the correct starting point. B. After the cortex is breached, a curved probe is placed into the pedicle with the tip pointing laterally to minimize risk of medial pedicle breach and potential cord injury. C. After probing past the pedicle, its tip is then turned to point medially to minimize risk of vertebral body cortical breach. D. After probing the tract, the depth is measured. E. The tract is tapped. F. The pedicle screw is inserted.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Violation of the medial wall</th>
<th>Mini-laminotomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>If pedicle feels large enough, the screw is directed more laterally.</td>
<td></td>
</tr>
<tr>
<td>Hooks or cables can be used.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Neural injury from medial penetration is rare but does occur</th>
<th>Lateral penetration is more common than medial.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intraoperative somatosensory evoked potentials, motor evoked potentials, and electromyography can be used to monitor for neurologic compromise and pedicle wall breach.</td>
<td></td>
</tr>
<tr>
<td>The surgeon should have a low threshold for a mini-laminotomy and palpation of the pedicle with a Woodson elevator.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pedicles at the ends of a construct need to be competent</th>
<th>If there is a structural breach, the surgeon can skip a level as long as it is not at the end of the construct.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hooks can be used in the thoracic level if pedicles are too small.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Screws do not line up well to accept rod</th>
<th>The surgeon should check for aberrant screw placement.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse process can push the screw head medially and the tip laterally. This can be prevented by removing a sufficient amount of transverse process to allow appropriate placement of pedicle screw without impingement by transverse process.</td>
<td></td>
</tr>
<tr>
<td>Polyaxial screws can be used.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unable to locate pedicle entrance</th>
<th>The surgeon should perform a mini-laminotomy.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The surgeon can skip a level and then return if adjacent levels provide additional information.</td>
<td></td>
</tr>
<tr>
<td>Hooks or cables can be used.</td>
<td></td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- No postoperative immobilization is required with multisegmental constructs.
- Postoperative restrictions include limitations with lifting, bending, and twisting.
- It is important to maintain mean arterial blood pressure above 70 mm Hg overnight and hemoglobin above 10 g/dL to maintain spinal cord perfusion.
- Intravenous antibiotics are maintained for 48 hours postoperatively.
- Neurovascular checks are made every 2 hours for the first 8 hours and then every 8 hours.
- Patients are out of bed on postoperative day 1.
- Foley catheter is removed on postoperative day 2.
- Diet is advanced as tolerated.
- Patient-controlled analgesia is used for appropriate patients.

OUTCOMES

- With meticulous attention to detail with regard to instrumentation and fusion techniques, excellent outcomes in terms of straightening and fusion of the scoliotic spine can be expected.
- Long-term outcomes are variable and depend on the underlying diagnosis and the extent of retained spinal mobility.

COMPLICATIONS

- Wrong-level surgery
- Failure of fusion
- Hardware malfunction
- Neurologic injury
- Dural tear
- Pneumothorax
- Crankshaft
- Superior mesenteric artery syndrome
- Loss of lumbar lordosis

REFERENCES

DEFINITION
- Kyphosis in the patient with myelomeningocele can occur at the thoracolumbar junction, the midlumbar spine, or the lumbosacral junction.
- The different types of kyphosis have some bearing on the treatment needed for the repair, but whether the origin is congenital, developmental, or paralytic, the consequences can be devastating for the child with this condition.
- Skin breakdown over the apex of the kyphosis can develop deep wound infections and lead to central nervous system infections.
- Secondary changes in other organ systems can create compromise in the gastrointestinal or genitourinary systems or even potentially disastrous kinking of the great vessels due to compromise in the abdominal height. Diminished absorption frequently occurs in the gastrointestinal tract, and renal calculi may develop from poor urinary drainage.
- Secondary effects on the pulmonary capacity produce thoracic insufficiency syndrome because the abdominal contents are pushed into the thoracic cage. Added to this is a secondary thoracic lordosis cephalad to the kyphosis.
- Bracing generally leads to problems from skin pressure and ultimately does not solve the problem.

ANATOMY
- The kyphotic angle can be gradual or acute.
- The paraspinal musculature is partially innervated in a flexion position lateral to the bony ridges owing to lack of posterior migration from an embryologic origin. In this position, they contribute to forward flexion of the spinal column.
- The bony ridges laterally in the area of the diastasis leave little bone for fusion mass on the posterior side of the vertebral column.
- The midline defect from the original myelomeningocele characteristically is covered by a fragile dura separated from the overlying skin by a thin layer of subcutaneous tissue.
- The soft tissue coverage is made worse by poor nutrition.
- One of the most reliably formed vertebral structures is the sacral ala.
- The great vessels generally do not follow the kyphotic contours into the kyphotic apex.

PATHOGENESIS
- Embryologically the notochord is covered dorsally by closure of the ectoderm over top of it, progressing in a cephalic to a caudal direction. In myelomeningocele, the closure is incomplete, usually at the caudal end.
- Less common types of myelomeningocele occur in the thoracic and cervical area. Thoracolumbar, lumbar, and lumbosacral kyphosis is the most commonly seen type and occurs because of lack of posterior migration of the ectoderm surrounding the notochord, leaving the neural placode in a vulnerable position, exposed at birth.
- Congenital bony defects occurring in this area lead to an early-onset kyphosis that can pose significant problems for the neurosurgeon’s closure at birth. This has led some experts to encourage neonatal correction of the kyphosis.
- With further growth and an upright sitting posture, the paraspinal musculature, which has formed in a lateral and anterior position, pulls the upper torso into a more kyphotic position, both actively through muscle contracture and secondarily from gravity.
- This can lead to further skin compromise and pressure in the soft tissues overlying the kyphosis.
- Skin breakdown can be a serious problem over the kyphosis.
- The C7 lateral plumb line shows the upper torso to be far out of balance in a forward-flexed posture, leading to thoracic insufficiency from the abdominal contents pressing under the diaphragm.
- This can render the child a “functional quadriplegic” since he or she uses the upper extremities for balance and to unweight the diaphragm by pivoting on the extended arms for breathing purposes (marionette maneuver; FIG 1).
- From a developmental standpoint, this can further limit the young child’s upper extremity interaction with his or her environment, which is essential for the development of normal intelligence.

NATURAL HISTORY
- The natural history of unpublished cases of severe kyphosis is one of thoracic compromise from insufficiency syndrome, progressive decline in pulmonary capacity, and death.

FIG 1 • “Functional quadriplegia” in myelokyphosis; lumbar kyphosis with thoracic lordosis.
PATIENT HISTORY AND PHYSICAL FINDINGS
- A careful history and physical examination should elicit possible signs and symptoms of associated anomalies, including:
  - Chiari malformation
  - Tethered cord
  - Respiratory compromise
  - Gastrointestinal malabsorption
  - Urinary hydrostasis and lithiasis
- Physical examination of the child should include flexibility tests of the curve by physically supporting the child under the armpits to suspend him or her against gravity. Bending back supine on the examining table can also indicate the extent of lumbar flexibility.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standard radiographs, anteroposterior (AP) and lateral views of the full spine, in the upright sitting posture assess the effects of gravity upon the curve (FIG 2A,B).
- Supine radiographs are helpful for visualization of bony definition.
- Flexibility films with traction, manual push, or back bending over a bolster with a shoot-through lateral film, are helpful adjuncts.
- CT scans, especially three-dimensional CT scans, offer the best delineation of the anatomy.
- MRI is critical for assessment of the intrathecal structures and assessing for Chiari malformation, syringomyelia, and tethering (FIG 2C).

DIFFERENTIAL DIAGNOSIS
- Congenital versus developmental kyphosis
- Sacral agenesis
- Charcot joints secondary to vertebral column breakdown across the apex of the kyphosis

NONOPERATIVE MANAGEMENT
- Bracing has no place in the treatment of this disorder.
- Occasionally traction is helpful to stretch the kyphosis, especially in a developmental type to aid in correction at the time of surgery.
- This can be done with cervical traction or halo traction, and some authors have promoted the use of this traction during the time of surgery to aid in the correction.

SURGICAL MANAGEMENT
Preoperative Planning
- Vascular monitoring devices are an important adjunct during surgery, and either arterial lines or pulse oximeters on both feet are important to monitor blood supply to the lower extremities at the time of correction.
- A great deal of tension can be placed on the aorta at the time of kyphosis realignment. Thus, arterial and central venous lines are necessary to monitor central pressure and allow for rapid medication administration.
- Areas of skin breakdown should be addressed and healed prior to kyphectomy.
- Preoperative planning may include assessment by a plastic surgeon and possible need for placement of tissue expanders in the posterolateral axillary margins to aid in skin closure at surgery (FIG 3).
- As a part of the preoperative planning, all imaging studies are carefully reviewed to assess flexibility, the adequacy of the vertebral bodies to tolerate pedicle screws, and planning for which levels will need to be decancellized or removed.
- It is recommended that these plans be recorded on a “blueprint” that can be placed on the operating room wall outlining the location of implants, osteotomies, and order of progression for the surgical plan.
- Assessment by neurosurgery is necessary preoperatively regarding shunt functioning and review of the MRIs.
- Preoperative antibiotics are essential, including gram-negative coverage for urinary pathogens. These are continued postoperatively for 6 to 12 weeks.

FIG 2 • A,B. A 13-year-old with myelokhyphosis with diastasis beginning at T6 with 127 degrees of kyphosis. C. Preoperative MRI in a 9-year-old with myelomeningocele before undergoing kyphectomy with growing construct.

FIG 3 • Myelomeningocele in an 11-month-old with tissue expanders placed bilaterally before delayed closure and kyphectomy.
Nutritional status is maximized and may require hyperalimentation via a gastrostomy tube button months ahead of surgery to maximize postoperative healing.

**Positioning**

- During positioning, careful padding with extra foam is essential to protect delicate skin during a prolonged operation.
- Eye protection to guard against intraoperative ocular compromise and a spinal frame that allows for suspension of the abdominal structures will diminish the epidural vascular pressure.
- Preoperative assessment of the hips is important to anticipate the intraoperative positioning, and if the flexion contractures about the hips are too severe, a preliminary release of contractures done a few weeks ahead of time may be necessary to allow for proper positioning of the legs at the time of the kyphectomy.

**Approach**

- The surgical incision may involve excision of compromised skin lesions or scars, although this is best addressed before surgery.
- The previous incisions on a myelomeningocele back may not be midline or ideally placed.
- The best skin incision for kyphectomy should follow the previous skin incisions to maximize blood supply to the skin edges at closure. Maximum skin and subcutaneous tissue coverage is important for good skin closure.
- If a compromise in the quality of soft tissues is anticipated, then previously placed tissue expanders may be removed from the midline at closure and the expanded tissue brought to the midline.
- There may be times when the poorly healed, convoluted scars from previous neurosurgical interventions may be harbingers of bacteria that will not promote adequate healing or may contribute toward postoperative infection. Preliminary excision of the scars by plastic surgery may afford the best defense against outside-in infections.

**INCISION AND LUMBAR DISSECTION**

- The incision—either straight or curvilinear—follows the previous scars. It is extended deep to the spinous processes in those sections where they exist.
  - The caudal portion of the incision is made to the level of the dura, with care taken to avoid laceration of the fragile dura.
- The surgical plane is then deviated to the right and left side superficial to the dura while palpating for the lateral bony elements. The deep portion of the incision is directed toward the bone.
  - It is desirable to maintain as much subcutaneous thickness as possible.
  - If there are lacerations of the dura, it is best to stop and sew them as one proceeds since the thinned dura may require a flap of adjacent tissue for a watertight closure. Sometimes it is necessary to sew in a piece of Duragen sealant to ensure a watertight closure.
  - Four-O Neurolon on a small needle in a running fashion works quite well for an incidental durotomy repair.
- As one proceeds from distal to proximal in the lumbar spine, the lateral elements are palpated and with the use of electrocautery, the soft tissues are incised to bone.
- The muscle and soft tissue attachments to the laterally positioned lumbar bones are released to reveal the underlying bony elements that embryologically would have progressed posteriorly to become the lamina and facets (TECH FIG 1A–C).

**TECH FIG 1** • **A.** Intraoperative dissection with neuroplacode left in place and forceps placed on bilateral bony ridges. **B.** Paraspinal muscles are dissected away from the kyphosis, with frequent irrigation of neural elements. **C.** In a different patient, the kyphosis has been dissected out. **D.** The neuroplacode can be left in place, mobilized to one side by releasing nonfunctioning nerve roots over four levels, or resecting to the level of the diastasis and oversewing.
Chapter 58  
KYPHECTOMY IN SPINA BIFIDA

TECHNIQUES

THORACIC DISSECTION

- Once the lumbar spine is dissected, the thoracic area is approached.
- If one is contemplating a fusion of the thoracic spine, such as in a child over 8 years of age, full dissection out to the tips of the transverse processes should be accomplished.
- If a growing rod construct is being used, such as in a child under age 8 years, this is done with minimal dissection so as to promote growth.
- If the growing construct is desired, the muscle and soft tissue attachments are cleaned from the sides of the spinous processes as far as the facet joints.
- One needs to be able to visualize the ligamentum flavum sufficiently to pass sublaminar wires for the Luque trolley portion of the “growing” construct.
- Generally, four thoracic levels for wires are all that is necessary.
- In the lumbar spine, soft tissues should be cleaned from bone sufficiently to allow for fusion between the lateral elements and to the sacrum.
- At this point in the operation, radiographic C-arm guidance is helpful for placement of pedicle screws.
- The entrance point for the lumbar dysplastic pedicles is in a lateral position, with the pedicles directed obliquely toward the vertebral body (TECH FIG 2).
- Bilateral screws can be obliquely placed for fixation.
- Fixation to the pelvis can be done with multiple types of fixation devices, including S-rods, S-hooks, and iliac threaded bolts.
- Fusion to the sacrum is essential to firmly plant the rod on the pelvis and allow for growth off the top of the rods in the thoracic spine.
- The C-arm is used in both AP and lateral positions to confirm satisfactory placement of the screws in bone. Bicortical fixation is generally not necessary because of the strong fixation supplied by the triangulation of the screws.
- Polyaxial screws are desirable through the lumbar segments.

PEDICLE SCREW PLACEMENT

- The rudiments of these bones can be visualized along with a transverse process at each level in the bony ridge of the diastasis.
- The medial neural placode is left intact since it acts as third-space filler and padding for the implants.
- There may be instances in which the neuroplacode has to be mobilized, and this is done by releasing nonfunctioning roots on one side and reflecting the dura laterally to gain access to the disc space and underlying vertebrae (TECH FIG 1D).
- One needs to be able to visualize the ligamentum flavum sufficiently to pass sublaminar wires for the Luque trolley portion of the “growing” construct.
- Generally, four thoracic levels for wires are all that is necessary.
- In the lumbar spine, soft tissues should be cleaned from bone sufficiently to allow for fusion between the lateral elements and to the sacrum.

DECANCELLIZATION

- Decancellation can be accomplished at multiple levels, leaving adequate vertebral levels for fixation and correction. Ideally, it is accomplished at one or two levels in a location that will leave sufficient midlumbar fixation points to push the vertebrae forward to create lordosis.
- The levels chosen for decancellation are approached after screw placement, based on the preoperative planning.
- The decancellation begins with a burr at the entrance to the pedicle. It continues with enlarging sizes of curettes, saving the bone for the fusion.
- The inside of the vertebral body is completely cored out, and when bleeding points are encountered, the pedicle can be filled with FloSeal and if necessary further packed with some rolled Gelfoam to stop the bleeding.
- Care is taken to avoid violating the posterior cortex of the vertebral body until the very end, since this is where the epidural vessels are most prolific.
- The lateral margins of these vertebral bodies are removed, including the transverse process and posterolateral bone.
- The decancellation should be thorough, leaving only the cortex. This is carried out bilaterally followed by implosion of the posterior cortex with an Epstein curette, pushing the bone fragments into the cavity of the vertebral body (TECH FIG 3).
- Bleeding points are stabilized.
- In most instances, decancellation alone at select levels is all that is necessary to gain the mobility for correction.
Occasionally, removal of a vertebral segment may be indicated. If so, it can be accomplished while maintaining the neuroplacode.

The vertebral section for removal in that instance would be taken from that section of the curve that is horizontal and cephalad to the apex of the kyphosis (TECH FIG 4).

TECH FIG 4 • A. If bone is to be resected (due to extreme stiffness), this should be done in the horizontal section at the top of the kyphosis, not at the apex. B. After horizontal resection, the bone is pushed forward to realign. C. After resection, realignment and fixation are accomplished.

ROD PLACEMENT

Once these corrective maneuvers have been completed, rods linked to the sacrum can then be placed bilaterally to push the vertebral bodies anteriorly into a straight or preferably a lordotic position (TECH FIG 5A).

Through gradual approximation of the rod forward toward the thoracic fixation points, the lumbar segments are brought into alignment and the rods gradually tightened to the wires of the thoracic spine (TECH FIG 5B,C).

TECH FIG 5 • A. Bilateral rods are anchored to L4 and S-hooks in preparation for reduction. B. Decancellized levels are crushed by compressing adjacent screw heads. C. In a different patient, gradual reduction with wires and provisional tightening are accomplished using a growing construct. (continued)
Physiologic kyphosis can be contoured into the thoracic component of the rods to correct the thoracic lordosis.

- Generally, the rods are left one level long at the top to allow for growth in the thoracic spine.
- The final tightening should produce some distraction between the lowest lumbar segment fixation point and the S-hooks pushed against the sacral ala (TECH FIG 5D, E). This will set the S-hooks in place securely.
- Final contouring with the in situ benders can allow for further lordosis of the lumbar spine if desired.

ASSESSING AND MANAGING LOWER EXTREMITY HYPOPERFUSION

- Frequently, the initial maneuvers for correction across the kyphosis are accompanied by a decrease in blood flow to the lower extremities. Therefore, it is important to do this corrective maneuver gradually in small increments.
- The baroreceptors in the aorta can accommodate to the change in alignment and stretch. If the blood flow to the feet is unable to accommodate to the new position of the spine, further decancellation or vertebral body removal will be necessary.
- This decision is based on the flow to the lower extremities reflected in the pulse oximeter or arterial catheters in the feet.

CLOSURE

- As part of the closure, it is important to grasp the paraspinal musculature with clamps to pull the muscles toward the midline by elevating and mobilizing the muscle layer with a Cobb elevator.
- Sometimes release of the fascia on the posterior side of the musculature is necessary, and this is best done in the posterior axillary line with a vertical cut in the fascia.
- The paraspinal musculature should be brought as close as possible toward the midline on both sides and sewn down (TECH FIG 6).
- At least one and more likely two Hemovac drains should be left, one in the deep and one in the superficial layers, for drainage over 1 week to 10 days postoperatively.
- Subcuticular closures can be used, but they should be reinforced with external suture of some kind, either clips or interrupted nylon sutures on a temporary basis.

TECH FIG 5 • (continued) D. Completed reduction in patient in A and B. Allograft and autograft have been applied to decorticated bone for fusion. E. Completed reduction in patient with growing construct in C.

TECH FIG 6 • The paraspinal muscle flaps are brought to midline for final closure.
### Pearls and Pitfalls

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>The surgeon can assess flexibility of the curve by physically supporting the child under the armpits to suspend him or her against gravity. Bending back supine on the examining table can also indicate the extent of lumbar flexibility.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preoperative preparation</td>
<td>Areas of skin breakdown should be addressed and healed before kyphectomy.</td>
</tr>
<tr>
<td>Intraoperative monitoring</td>
<td>Vascular monitoring of the lower extremities is a critical part of the intraoperative monitoring.</td>
</tr>
<tr>
<td>Preoperative preparation</td>
<td>Preoperative antibiotics are essential, including gram-negative coverage for urinary pathogens. These are continued postoperatively for 6 to 12 weeks.</td>
</tr>
<tr>
<td>Managing incidental durotomy</td>
<td>Four-O Neurolon on a small taper needle in a running fashion works quite well for an incidental durotomy repair. Duragen can be sewn over the repair, and occasionally the use of a sealant (Tusseal) is necessary.</td>
</tr>
<tr>
<td>Preventing epidural bleeding</td>
<td>Care is taken to avoid violating the posterior cortex of the vertebral body until the very end, since this is where the epidural vessels are most prolific.</td>
</tr>
<tr>
<td>Setting the S-hook</td>
<td>The final tightening should produce some distraction between the lowest lumbar segment fixation point and the S-hooks pushed against the sacral ala. This will set the S-hooks in place securely.</td>
</tr>
<tr>
<td>Postoperative care</td>
<td>All reasonable measures must be taken to avoid any pressure on the wound or extremities in the postoperative period. All areas of insensate skin must be protected from excessive pressure with frequent change in position on a soft surface. The dressings should be covered with a waterproof covering to protect against secondary contamination from stool.</td>
</tr>
</tbody>
</table>

### Postoperative Care
- For recovery, patients are placed on their back with an extra-thick foam on top of the mattress to avoid excessive skin pressure.
- Logrolling is instituted 6 hours postoperatively and repeated every 2 hours.
- Recovery occurs in the intensive care unit until the patient is sufficiently stable.
- Although postoperative immobilization is not necessary, if desired it can be accomplished with careful molding of a bi-valved jacket with a Plastizote soft lining.

### Outcomes
- Improved sitting
- Improved respiratory function
- Better blood supply to skin

### Complications
- Skin breakdown
- Infection, superficial or deep
- Vascular compromise to feet with stretch on aorta
- Loosening of spinal implants
- Pseudarthrosis

### Reference
DEFINITION
- Thoracic scoliosis and thoracolumbar–lumbar scoliosis are typically curves seen in idiopathic scoliosis and can be treated anteriorly.
- Anterior arthrodesis refers to the fusion of the anterior part of the vertebral bodies, usually with instrumentation for these curve patterns.

ANATOMY
- Thoracic idiopathic scoliosis usually has an apex at T8 or T9. It is the most common right convex curve pattern and has axial-plane rotational deformity as well as hypokyphosis.
- The vertebral bodies are nearly normal in their shape, although some distortion of the vertebral body and pedicles is seen, with thin long pedicles on the concavity and shorter, wider pedicles on the convexity.
- Thoracolumbar–lumbar scoliosis has an apex of the curve at T12 or below and is most commonly a left-sided curve, with or without a compensatory thoracic curve.

PATHOGENESIS
- The cause of idiopathic scoliosis is not yet known.

NATURAL HISTORY
- Idiopathic scoliosis progresses with continued growth of the spine, especially during the peak growth periods and when the curve magnitudes are “large” at the completion of growth.
- Thoracic curves tend to progress at skeletal maturity when the curve is greater than 45 to 50 degrees.
- Thoracolumbar–lumbar curves tend to progress when the curve is greater than 35 to 40 degrees at the time of skeletal maturity.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients with thoracic scoliosis and thoracolumbar scoliosis should be evaluated for their perception of spine and body deformity to include asymmetric shoulder elevation, trunk shift, waistline asymmetry, and rib or flank prominence.
- Pain in the axial spine and pain radiating into the lower extremities should be ascertained with a good history; such symptoms warrant an MRI.
- Neurologic symptoms such as paresthesias, hyperesthesia, or bowel or bladder symptoms are relevant and require further imaging with an MRI.
- Physical examination should assess the trunk imbalance in the coronal plane, which can be seen with isolated thoracic or thoracolumbar–lumbar curves.
- The Adams forward bend test characterizes the axial-plane deformity seen in scoliosis and is used to assess rotational deformity of the thoracic rib prominence or the flank prominence. The rotational deformity of the thoracic and lumbar spine is graded using a scoliometer with the patient bending forward. The rotational deformity seen in scoliosis can be very prominent and the most obvious deformity seen by patient and families.
- Cutaneous manifestations of dysraphism should also be analyzed.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Anteroposterior (AP) and lateral radiographs of the spine should be obtained to review the coronal and sagittal plane deformities, respectively (FIG 1).
- On the AP radiograph, the coronal plane deformity is measured using the Cobb method. Truncal imbalance can be measured using the Floman method (bisecting the distance between the lateral rib margins and comparing this point to the center sacral vertical line [CSVL]).
- The decompensation of the head relative to the pelvis is measured by the distance between the C7 plumb line and the CSVL.
- The Risser sign should be evaluated by assessing the ossification of the iliac apophysis, giving it a grade between 0 and 5.
- The triradiate cartilage status should be assessed as either open or closed.
- The lateral radiograph is used to measure thoracic kyphosis (measured from T3 to T12) and lumbar lordosis (from L1 to S1) as well as the sagittal balance (comparing a C7 plumb bob line to the front edge of S1).
- Supine best-bend radiographs can be used to determine the flexibility of the spine and are especially useful to determine the appropriateness of the surgical procedure.
whether the thoracolumbar–lumbar curve is flexible when a 
primary thoracic curve is present or if the thoracic curve is 
flexible and compensatory when the primary thoracolumbar–
lumbar curve is present.

DIFFERENTIAL DIAGNOSIS

- Idiopathic scoliosis should be differentiated from other 
types of scoliosis in which congenital abnormalities are not 
seen in ambulatory patients. This list includes neurofibromato-
sis, Marfan syndrome, type 3 spinal muscular atrophy, scolio-
sis associated with syringomyelia, or tethered cord.

NONOPERATIVE MANAGEMENT

- Adolescent thoracic and thoracolumbar scoliosis can be 
treated with bracing when curve magnitudes are between 25 
and 45 degrees during peak growth periods.
- Bracing is used for these curve magnitudes to prevent 
curve progression and is indicated in Risser grade 0 to 
2 patients.
- Nonoperative management is primarily indicated when 
the cosmetic appearance of the patient is acceptable to him 
or her.

SURGICAL MANAGEMENT

- Surgical indications for thoracic idiopathic scoliosis are 
curves exceeding 45 to 50 degrees with unacceptable cosmetic 
deformity.
- Indications for surgical treatment of thoracolumbar–lumbar 
curves are curves exceeding 40 to 45 degrees with unaccept-
able cosmetic deformity.

Preoperative Planning

- A careful physical examination as noted above is necessary 
to ensure that there are no neurologic signs or symptoms,
which would indicate neural axis abnormalities. If these are 
present, MRI of the neural axis is indicated.
- Radiographic imaging should be used to ensure the curve is 
characteristic of an idiopathic curve. For thoracic curve mag-
nitudes, this should demonstrate apical lordosis. The atypical 
curves, such as left-sided thoracic curves or those with signifi-
cant decompensation despite minimal rotational deformity, or 
patients who have excessive thoracic kyphosis should be fur-
ther evaluated with an MRI.
- The AP radiograph, the lateral standing radiograph, and the 
supine best-bend radiograph should be used to determine the 
Lenke classification.
- Specific detailed analysis of the compensatory curves should 
be performed to fine-tune a surgical plan to ensure that post-
operative decompensation does not occur. This is especially 
important to determine the flexibility of the lumbar curve and 
the lumbar modifier for primary thoracic curves, as well as the 
flexibility of the compensatory thoracic curve for primary tho-
racolumbar–lumbar curves.
- Anterior fusion levels for thoracic scoliosis are, in general, 
proximal-end vertebra to distal-end vertebra. Occasionally a 
parallel disc is noted at the distal segment. It is controversial 
whether this disc should be included in the fusion levels. When 
the curve is relatively small (50 to 60 degrees) and flexible 
greater than 50% flexibility index) and the patient is skele-
tally mature (triradiate cartilage is closed and Risser grade 1 or 
higher), inclusion of the parallel disc is not often necessary 
(Fig 2A,B).
- Anterior fusion levels for thoracolumbar–lumbar curves in 
general are proximal-end vertebra to distal-end vertebra. When the disc below the planned lowest instrumented vertebra 
is reversing and opening into the fractional lumbosacral curve, 
then disc wedging is not seen postoperatively. However, a disc 
below the lowest instrumented vertebra that is parallel preop-
eratively will often be wedged postoperatively (Fig 2C,D).

![Preoperative radiograph of a 13-year-old girl with a right thoracic curve measuring 52 degrees from T6 to T12. The disc at T11–12 is open into the right thoracic curve while the disc at T12-L1 is parallel.](A)

![Thoracoscopic anterior spinal fusion and instrumentation from T6 to T12 demonstrating excellent correction of the main thoracic curve with excellent response of the proximal thoracic and lumbar curves.](B)

![A left thoracolumbar curve measured between T11 and L2 with a trunk shift to the left.](C)

![Two-year postoperative radiographs following an open anterior fusion and instrumentation from T11 to L2 with dual rod-dual screw system and anterior cages placed at the T12-L1 and L1-L2 levels with excellent coronal plane correction.](D)
Positioning

- Positioning for anterior surgery for either the thoracic or thoracolumbar curves is fairly similar.
- Patients are placed in the lateral decubitus position with the convex side of the curve up.
- An axillary roll is used for safe upper extremity neurologic function (FIG 3).
- An inflatable bean bag is used to position the patient, and body positioners can be added for further patient stabilization.
- For thoracolumbar–lumbar curves, a table that can be flexed allows for greater access to the abdomen and spine. It should be centered over the apex of the curve.
- For thoracic scoliosis surgery, the patient can be placed on a flat radiolucent table.

Approach

- The anterior approach is used for thoracic scoliosis.

OPEN THORACIC ANTERIOR INSTRUMENTATION AND ARTHRODESIS

- A curved incision is made over the proximal rib corresponding to the proximal fusion level (ie, commonly T5 with the fifth rib). The incision is carried through the thoracic and abdominal musculature to the periosteum of the rib.
- Subperiosteal dissection of the rib is performed circumferentially, and the rib is cut posteriorly and anteriorly.
- The parietal pleura is incised in a longitudinal fashion over the vertebral bodies across the intended levels of instrumentation and fusion.
- The segmental vessels can be temporarily ligated and spinal cord monitoring should be observed during temporary ligation.
- Permanent ligation can be performed after 20 minutes of normal spinal cord monitoring.
- Discectomy is performed (see below in the section on the thoracoscopic technique).
- Instrumentation is placed (see below).
- For the remaining procedures, see details under the thoracoscopic approach.

THORACOSCOPIC ANTERIOR INSTRUMENTATION AND ARTHRODESIS

Positioning, Preparation, and Draping

- After true lateral positioning is confirmed, fluoroscopy is used to mark the skin for the proximal-end vertebra and distal-end vertebra on the AP view. The skin markings are made to identify the angle of the proximal-end vertebra on the AP view (TECH FIG 1).
- The anterior and posterior edges of the vertebral bodies are then marked using the lateral fluoroscopy view.
- The chest and flank are prepared and draped in the normal sterile fashion.

Thoracoscopic Portal and Guidewire Placement

- An anterior portal is placed, bisecting the distance between the proximal and the distal intended instrumented vertebra, in the anterior axillary line. This portal is used for placement of the camera (TECH FIG 2A).
- A guidewire is then placed directly over the vertebral bodies over the intended second-most-proximal portal and is visualized with the thoracoscope placed in the anterior portal (TECH FIG 2B).

FIG 3 • Positioning for access for a thoracoscopic anterior spinal fusion and instrumentation in the left lateral decubitus position. The arms are positioned at 90 degrees, axillary rolls are placed on the left axilla, and the patient is secured with a bean bag.

TECH FIG 1 • Fluoroscopic imaging of the spine prior to surgery. A. The lateral radiograph is used to identify the anterior and posterior edges of the vertebral body. B. The AP radiograph is used to mark the skin over the intended fusion levels to direct portal placement. This example demonstrates a T6–T12 fusion.
Part 4 PEDIATRICS • Section VII SPINE

**TECHNIQUES**

- After good placement of the guidewire (directly over the rib head), the portal is placed with a transverse incision centered over the rib. This portal can be used for visualization with a thoracoscope to place the remaining portals.

- The most proximal posterolateral portal is placed after the intended second posterolateral portal to ensure exact location of the proximal portal. The proximal portal position is most important, since the most proximal two screws are often placed in small vertebral bodies and have significant coronal angulation, and retraction of the scapula makes this portal difficult.

- The remaining portals are placed in the posterolateral line.

- The portals will house the camera, a fan retractor to retract the lung, a suction device, a working portal, and then a free portal.

**Discectomy Technique**

- The pleura is incised in the midvertebral line in a longitudinal fashion, keeping the segmental vessels intact (TECH FIG 3A).

- The segmental vessels are then ligated two or three at a time (normotensive anesthesia is used for anterior surgery).

- The parietal pleura is retracted anteriorly, all the way to the opposite side, and access to the anterior longitudinal ligament and the contralateral annulus is allowed (TECH FIG 3B).

- Posterior retraction allows for identification of the rib heads (TECH FIG 3C).

- The disc is incised from the convex rib head to the opposite annulus (TECH FIG 3D).

---

**TECH FIG 2 • A.** The anterior portal is placed in the anterior axillary line with the camera inserted in the portal. The patient is in the left lateral decubitus position: proximal to the right and distal to the left. **B.** A guidewire is placed before placing the posterior lateral portals. The guidewire is directed just anterior to the rib heads and marks a good position for the posterolateral portal.

**Discectomy Technique**

- Electrocautery is used to incise the parietal pleura longitudinally, starting over the disc to avoid the segmental vessels. The segmental vessels are left intact on the first pass. **B,C.** After ligation of the segmental vessels, the pleura is bluntly retracted. **B.** Anterior dissection circumferentially to the opposite side of the pleura. **C.** Posterior retraction of the parietal pleura beyond the rib head. **D.** A scalpel blade is used to incise the annulus from rib head posteriorly all the way to the opposite annulus. Shown here is the incision up against the rib head after incising the annulus and the anterior longitudinal ligament. **E.** Disc shavers are used to break up the disc material. **F.** An angled curette is used to take down the endplate and tease the periosteum around the corner to get full access to the bone. *(continued)*
The rib head is being removed. Electrocautery is used to loosen the soft tissues attaching the rib head to the vertebral body. Part of the rib head has been removed in this photo.

- The periosteum for the proximal and distal vertebra is incised to allow for subperiosteal dissection when the discectomy is performed.
- Disc shavers are used to break up the disc material, using shavers of increasing width (TECH FIG 3E).
- A rongeur is used to remove the annulus and nucleus pulposus.
- An angled curette is used to take down the endplate circumferentially (TECH FIG 3F).

The rib head is removed at the T4–T7 levels. Since it is positioned relatively anterior on the vertebral bodies, it allows for good discectomy and good placement of the screws at these levels (TECH FIG 3G).
- After discectomy, Gelfoam or Surgicel is placed in the disc space to prevent endplate bleeding.

**Implant Placement and Grafting**
- Screw placement is performed beginning at the apex of the curve.
- The proper screw position starts just anterior to the rib head and is angled in line with the midaxial plane of the vertebral body (angled anteriorly at the apex especially, with less angulation at the proximal distal levels) (TECH FIG 4A).
- Screw position should be parallel to the endplate, and the proximal and distal levels should be angled toward the apex of the curve so that during correction, any screw plow will not loosen screws. Visualization of adjacent screws should confirm good alignment (TECH FIG 4B).
- After screw placement, the screw height should be visualized to ensure that rod seating will occur without difficulty (TECH FIG 4C).
- Autologous bone is packed into the disc space after removal of Gelfoam or Surgicel.
- Rod placement is performed; rods can be seated either proximally or distally. Depending on rod flexibility and size, a straight rod is placed on the end and the set screws are engaged to secure the rod (TECH FIG 4D).

The screw-awl device is placed while visualizing a previously placed screw. The starting point is just anterior to the rib head in this photo. **B.** Final placement of a distal screw while visualizing the more proximal screws. The diaphragm is seen in the background. **C.** After screw placement, the height of the screws should be consistent to allow easy seating of the rod. **D.** The rod is inserted into the most distal screws. **E.** Compression across the most distal segment is first performed using the cable compressor. **F.** After distal compression, the rod is cantilevered to the remaining screw heads. (continued)
Compression across the initial levels is then performed to improve the coronal- and sagittal-plane deformity (TECH FIG 4E).

The rod is then cantilevered down to the remaining screws, and compression is sequentially performed over those levels. Often the rod cannot be cantilevered down to all of the screws, so sequential cantilever and compression are performed (TECH FIG 4F).

Radiographs are obtained at this point and the desired correction is compared with the radiographs. Further compression is performed as needed. Care should be taken to ensure that screw plow or loosening is not occurring radiographically or visually (TECH FIG 4G,H).

Set screws are completely torqued down.

The pleura is closed over the instrumentation to ensure correct bone graft positioning, decreased chest tube drainage, and improved long-term pulmonary function (TECH FIG 4I).

The lung is inflated under direct visualization.

A chest tube is placed through the distal portal incision and tunneled to the proximal portal (TECH FIG 4J).

The incisions are closed in the normal fashion.

### OPEN INSTRUMENTATION AND ARTHRODESIS OF THE THORACOLUMBAR–LUMBAR SPINE

#### Preparation and Exposure

- The patient is placed in the lateral decubitus position with the convex side of the spine up.
- An axillary roll is placed.
- The bed is flexed to allow for easier access to the flank (TECH FIG 5A).
- A curved linear incision is made in line with the rib just proximal to the planned upper instrumented vertebra (TECH FIG 5B).
- The incision is carried down through the subcutaneous layer through the various muscle layers down over the rib. The incision can be carried out distally lateral to the umbilicus.
- Subperiosteal dissection is carried out around the rib. The rib is transected posteriorly near its insertion to the spine (TECH FIG 5C).
- The costochondral junction is then incised. A marking suture is placed at the costochondral junction for later reapproximation (TECH FIG 5D).
- Usually at the costochondral level at the 10th rib, access into the retroperitoneal space is quite easy, with retroperitoneal fat evident. The peritoneal contents are then bluntly dissected off the abdominal wall and the undersurface of the diaphragm (TECH FIG 5E).
- The diaphragm is then incised just proximal to its insertion, and marking sutures are placed to ensure proper reapproximation (TECH FIG 5F).
- A pleural incision is made longitudinally in line with the spine, leaving the segmental vessels intact (TECH FIG 5G).
- Segmental vessel ligation is then carried out, maintaining good blood pressure to ensure good spinal cord perfusion (TECH FIG 5H).
**TECH FIG 5** • **A.** Positioning for thoracoabdominal approach to the spine. The table is flexed to allow full access to the thoracoabdominal region. **B.** Skin incision is marked. This example is centered over the 10th rib for a T11–L3 fusion. **C.** The incision is made over the rib and subperiosteal dissection is carried out circumferentially around the rib after sequential dissection through the musculature. **D.** The posterior aspect of the periosteum is then incised and the chest is entered. **E.** After incision of the costochondral junction, the retroperitoneal fat is visualized and the retroperitoneal cavity is entered. **F.** The diaphragm is incised a fingerbreadth proximal to its insertion. **G.** The parietal pleura is incised proximally. **H.** Ligation of segmental vessels after suture tying.
Discectomy

- Discectomies are performed with incision of the annulus fibrosis (TECH FIG 6A).
- Endplate dissection is carried out, using a Cobb elevator to remove the entire endplate disc material back to the posterior aspect of the annulus and to the posterior longitudinal ligament if necessary (for severe curves; TECH FIG 6B).
- The disc material is removed completely using rongeurs and curettes (TECH FIG 6C).
- The disc space is packed with Surgicel.

Implant Placement, Correction, and Fusion

- The instrumentation is then placed using single large screws with a quarter-inch single-rod implant system, or a dual rod with a 5.5-mm rod (shown here).
- Screws are initially placed at the apex in the middle to posterior third of the vertebral body in the midaxial plane (TECH FIG 7A).
- When using a dual-rod system, the posterior screws are initially placed angled in the midaxial plane, while the anterior screws are directed slightly posteriorly. A staple is often used when both the single- and dual-rod screws are used (TECH FIG 7B).
- Once screws are placed, the bone graft material is placed as far back toward the posterior longitudinal ligament as possible, or the posterior rim of the annulus fibrosis.
- The operating table should now be leveled to allow for correction of the spine.
- The posterior rod is initially placed with the dual-rod system, and a 90-degree rod rotation removal can be performed (TECH FIG 7C).
• Alternatively, directed force on the anterior screws to correct the coronal and axial plane is achieved, and then the posterior rod is inserted (TECH FIG 7D).
• After rod rotation with a dual-rod system or single-rod system, or correction with pressure on the anterior screws and fixation with the posterior rod, the anterior structural support is placed. This is most commonly at levels distal to T12 or alternatively at all instrumented levels (TECH FIG 7E).
• Compression can then be performed to further correct coronal-plane deformity.
• The anterior structural support should be placed anteriorly and onto the concavity to ensure maintenance of the lordosis and improvement of coronal-plane correction.
• The second anterior rod should be then placed with a dual-rod system and all set screws completely tightened (TECH FIG 7F).

 Closure

• The remaining bone graft material is then placed in the remaining disc space.

 TECH FIG 7 • (continued) C. Insertion of the posterior rod with lumbar lordosis built into the rod. D. After 90 degrees of rod rotation, scoliosis correction is achieved while restoring lumbar lordosis, as shown here. E. After rod rotation, the anterior structural support is placed anteriorly and toward the concavity of the deformity. F. The anterior rod is seated into the anterior screws.

• The pleura is closed as far distally as possible (TECH FIG 8A).
• The diaphragm is reapproximated with interrupted Neurolon sutures (TECH FIG 8B).
• The costochondral junction is reapproximated, and the periosteum of the rib is reapproximated (TECH FIG 8C).
• A chest tube of fairly large diameter is then placed.
• The abdominal wall is reapproximated in layers (TECH FIG 8D).
• The remaining muscle layers are closed, as well as the skin and subcutaneous layers (TECH FIG 8E).
• The postoperative radiographs are shown in TECHNIQUES FIGURE 8F AND 8G.

 TECH FIG 8 • A. The parietal pleura is closed beginning proximal to the implants. B. Interrupted Neurolon sutures are used to close the diaphragm in an anatomic fashion. (continued)
TECH FIG 8 • (continued). C. The ribs are reapproximated after placing no. 1 sutures under the proximal and distal ribs. D. Sequential closure of the muscle and soft tissue layers. E. Skin closure. F,G. The patient in Figure 1, 1 year postoperatively.

**PEARLS AND PITFALLS**

**Anesthesia**
- During anterior surgery, normotensive anesthesia should be performed to maintain spinal cord perfusion, especially when segmental vessel ligation is performed.
- Complete discectomy is necessary to achieve fusion since pseudarthrosis rates continue to be higher with anterior surgery than with posterior surgery.

**Camera performance**
- Thoracoscopy requires outstanding visualization and camera performance to ensure safe and effective discectomy, as well as instrumentation.

**Rib head removal**
- Rib head removal during thoracic instrumentation from T4 to T7 is necessary to ensure screws are placed posteriorly enough to achieve good purchase.

**Discectomy**
- This is the most important aspect of the procedure to mobilize the spine for correction and to achieve a solid arthrodesis.

**Screw placement**
- Screw placement is always challenging at the proximal and distal levels. Screw trajectories should always be parallel to the endplate, or if anything angled toward the apex of the curve, so that during correction plowing does not result in loosening of the screw.

**Deformity correction**
- Thoracic curve: Compression at sequential levels, followed by cantilever of an undercontoured rod, followed by further compression
- Thoracolumbar–lumbar curve: Rod rotation followed by compression
POSTOPERATIVE CARE

- The chest tube should be placed to wall suction and can usually be removed between 48 and 72 hours, when the drainage decreases below 80 cc per shift and when it turns more straw-colored.
- Serial hemoglobin and hematocrit levels should be obtained in the first 48 hours.
- Advancing activities: Sitting in a chair the first postoperative day and walking on the second postoperative day ensures good postoperative pulmonary status and normal bowel function.
- Postoperative bracing is used for 3 months for single-rod anterior thoracoscopic thoracic arthrodesis and instrumentation. No bracing is necessary with single quarter-inch rod instrumentation or dual-rod instrumentation when anterior structural support is used.
- Normal activities are resumed when arthrodesis is visualized (best seen on the lateral radiograph).

OUTCOMES

- Thoracoscopic anterior instrumentation and fusion achieves a good radiographic and functional outcome.
- Thoracoscopic anterior instrumentation and fusion continues to have a fairly high pseudarthrosis rate of 5% to 6%.
- Pulmonary function is somewhat decreased early in the postoperative period with anterior surgery, but then it can return to baseline at 1 to 2 years.
- Thoracolumbar–lumbar anterior instrumentation and fusion results in excellent coronal-, axial-, and sagittal-plane realignment, especially when dual-rod and large single-rod instrumentation systems with anterior structural support are used.

COMPLICATIONS

- Acute complications
  - Infection is rare in anterior spine deformity surgery.
  - Atelectasis and mucous plugs can be seen, especially with single-lung ventilation with anterior instrumentation. Aggressive pulmonary toilet and resuming activities minimize this risk.
- Late complications
  - Pseudarthrosis: The incidence is 4% to 10% for thoracic scoliosis (usually occurs at the apex of the curve) and 4% to 12% for thoracolumbar scoliosis (usually occurs at the distal fusion level).
  - Loss of correction with kyphosis is seen for thoracolumbar–lumbar curves treated anteriorly when anterior structural support is not used.

REFERENCES

DEFINITION
- Thoracoscopy provides the ability to gain access to the thoracic spine via small incisions (portals).
- *Anterior release* includes removal of the annulus fibrosis, anterior longitudinal ligament, nucleus pulposus, and, if necessary, the rib head.
- *Scoliosis* is a lateral curvature of the spine with axial plane rotation.
- *Fusion* is the healing of two vertebral bodies together, usually fused by bone graft or bone graft substitute.

ANATOMY
- The thoracic spine spans from the first thoracic vertebra (T1) to the twelfth thoracic vertebra (T12).
- The rib head attachment to the vertebral body is more anterior in the proximal thoracic spine than the distal thoracic spine.
- The annulus fibrosis is the circumferential fibrous tissue that surrounds the nucleus pulposus, which is in the center of the disc.
- The anterior longitudinal ligament, which runs on the anterior aspect of the vertebral body, is a strong fibrous tissue that is contiguous throughout the spine. The segmental arteries and veins originate from the aorta and vena cava, respectively, and traverse the vertebral body. The parietal pleura of the chest surrounds the thoracic spine, covering the segmental vessels and the disc and vertebral bodies. The anterior, middle, and posterior axillary lines run (in reference to the axilla) in the anterior, middle, and posterior aspects of the axilla. Scoliotic deformity in the thoracic spine is lateral curvature with axial plane rotation, as well as hypokyphosis (idiopathic scoliosis).
- The arch of the aorta and the arch of the azygous vein typically are located at the T4–T5 levels.

PATHOGENESIS
- Scoliosis can be grouped into many categories based on pathogenesis.
- The most common type of scoliosis seen is idiopathic, in which the etiology and pathogenesis are unknown.
- Theories of pathogenesis include hormonal influences, growth disturbance, genetic factors, muscle imbalance, and proprioception and balance abnormalities.
- Other types of scoliosis include:
  - Congenital: abnormal vertebra due to failure of formation or segmentation
  - Neuromuscular: eg, cerebral palsy, Duchenne muscular dystrophy, spinal muscular atrophy
  - Neurogenic: eg, neurofibromatosis, spinal cord injury

NATURAL HISTORY
- An idiopathic scoliosis curve may progress in two ways:
  - With continued spine growth
  - When curve magnitude is greater than 50 degrees at skeletal maturity
- Curve progression can be rapid during spine growth, or slow following skeletal maturity (approximately 1 degree per year).
- Curve magnitudes above 80 to 90 degrees in the thoracic spine may result in symptomatic pulmonary issues.
- Large curves in adulthood can result in pain.¹

PATIENT HISTORY AND PHYSICAL FINDINGS
- The examination for spine deformity should include standing visualization of the spine to look for shoulder height differences, waist asymmetry, overall trunk balance, or coronal head imbalance (FIG 1).
- Further information is obtained as to the character of the pain (eg, sharp, dull, aching), when the pain occurs (eg, during activity, while attempting to sleep, pain waking from sleep), and the location of the pain (eg, upper, middle, lower back), as well as whether it radiates into the lower extremities.
- Other history should include any information on other neurologic symptoms such as bowel or bladder incontinence.
- Sensory symptoms should be elicited, especially with hyperesthesias along the chest wall, or upper or lower extremities.
- Cutaneous manifestations of dysraphism should be analyzed.
- The neurologic examination should include motor strength and a sensory examination of the upper and lower extremities.
- The abdominal reflexes are the most important neurologic assessment. They are assessed by stroking the skin adjacent to the umbilicus on the left and right and upper and lower quadrants, and should be symmetrically absent or present. When asymmetric, MRI is necessary to evaluate for neural axis abnormalities.
- The lower extremities should be carefully examined for asymmetry with respect to size and strength of the legs, as

FIG 1 • This 9-year-old boy had a left-sided large thoracic scoliosis but no evidence of neural axis abnormalities on preoperative MRI.
well as foot deformities (eg, cavovarus foot deformities) as an indication for the presence of neural axis abnormalities.
- Deep tendon reflexes and the Babinski reflex should be investigated.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiography should include a standing posteroanterior (PA) and lateral radiograph of the spine to include the cervical spine to the pelvis and hips.
- The PA radiograph (FIG 2A) should be evaluated for:
  - Coronal plane deformities using the Cobb method
  - The C7–center sacral vertebral line (CSVL) placement
  - A trunk shift using Floman’s method (the distance between the CSVL and the mid-distance between the lateral rib margins)
  - Evaluation for any congenital abnormalities (eg, hemivertebra, congenital bar)
  - The Risser stage (0 through 5)
  - The status of the triradiate cartilage (open or closed)
- The lateral radiographs (FIG 2B) should be analyzed to determine:
  - Thoracic kyphosis and lumbar lordosis
  - Presence of associated spondylolisthesis or spondylolysis
  - Sagittal balance (distance between C7 plumb line and the posterior edge of the first sacral vertebral body)
  - The Stagnara view is an oblique view to the patient, but an orthogonal view to the coronal curve that is used in severe spinal deformities to better visualize the spine.
- Indications for MRI include neurologic abnormalities, significant back pain associated with scoliosis, atypical curve patterns such as a left thoracic curve, very young age, congenital scoliosis, neurofibromatosis, Marfan disease.
- CT scanning may be useful to fully define the osseous anatomy, especially for extremely large curves and congenital curves.

DIFFERENTIAL DIAGNOSIS
- Idiopathic scoliosis
- Congenital scoliosis
- Neurofibromatosis
- Scoliosis associated with Marfan disease

NONOPERATIVE MANAGEMENT
- Nonoperative management has little or no role for severe deformity.
- Patients who are very young with moderate deformity may be treated with a brace to buy time to allow the patient to grow.
- Bracing can be effective to prevent curve progression for small idiopathic curves (ie, 25 to 40 degrees).

SURGICAL MANAGEMENT
- Anterior thoracoscopic release for spinal deformity has many technical considerations, which are discussed later in this chapter.
- Indications for an anterior release/fusion
  - Severe spinal deformity: scoliosis greater than 80 to 90 degrees with significant rotational deformity or kyphosis greater than 100 degrees with flexibility index less than 50%
  - Skeletal immaturity, to avoid the crankshaft phenomenon. Usually performed for children younger than 10 years of age with open triradiate cartilage and Risser grade 0.
  - Deficient posterior elements, so that a posterior fusion may be difficult. Such deficiencies occur secondary to previous surgery with laminectomies for tumors or the treatment of neural axis abnormalities.

Preoperative Planning
- Each patient should be carefully analyzed with respect to those curves that will undergo an anterior release.
- The radiograph should be viewed to determine preoperatively which levels should be released. Release always includes the apical levels, and usually includes all of the levels within the Cobb measurement.
- For severe curves, traction in the operating room may be helpful in assisting curve correction.

Positioning and Approach

Lateral Position
- Advantages
  - More familiar and traditional approach
  - Conversion to open procedure is easy.
  - All thoracic levels can be accessed.
  - One can effectively obtain access to the T1 to T5 levels, which are not accessible when the patient is in the prone position.
- Disadvantages
  - Repositioning is necessary for the posterior approach.
  - Single-lung ventilation is required.
- Approach
  - Single-lung ventilation is achieved with a double-lumen endotracheal tube or a univent tube.
  - Position the patient in the lateral decubitus position.
  - Check the endotracheal tube position and the single-lung ventilation status.
  - Prepare and drape the chest and side (FIG 3).
  - Place four portals in the anterior axillary line.
Prone Position

Advantages
- Not necessary to reposition patient for the posterior procedure
- No need for single-lung ventilation
- Significantly decreased respiratory complications. Single double lung ventilation is used.

Disadvantages
- Difficult to obtain an anterior release proximal to T5.
- Conversion to open procedure is difficult.

Approach
- Placement of regular endotracheal tube
- Double-lung ventilation with decreased tidal volumes (about 50% to 60% of normal) and increased ventilatory rate
- Placement prone on a spine frame (FIG 4A,B)
- Ensure access to the flank and chest.
- Prepare and drape the back and the chest and flank (FIG 4C,D).

Thoracoscopic Release and Fusion for Scoliosis

Placement of Portals and Visualization
- Place portals as anteriorly as possible, usually in the midaxillary line (TECH FIG 1A,B).
- Insert the camera into the initial portal with the lens directed posteriorly (TECH FIG 1C).
- Find a clear space between the posterior chest wall and the lung and advance the thoracoscope.
- Place a small, blunt-tipped cottonoid to retract the lung, to identify the spine and other anatomic structures.
- Place a fan retractor to fully retract the lung, if necessary (TECH FIG 1D).
- Place suction into the chest.
- Place working portal.
- Visualize the spine in the horizontal plane with the segmental vessels intact (TECH FIG 1E).
Exposure and Disc Removal

- Incise the pleura along the mid-vertebral body line (TECH FIG 2A).
- Spare the segmental blood vessels to preserve perfusion to the spinal cord.
- Bluntly retract the pleura anteriorly and posteriorly (TECH FIG 2B).
- Incise the annulus fibrosis with the scalpel blade circumferentially from lateral rib head to near-opposite rib head (TECH FIG 2C).
- Break up the disc with disc shavers (TECH FIG 2D).

- Remove the disc material with a rongeur (TECH FIG 2E).
- Take down the endplate with a curved curette (TECH FIG 2F).
- Place Surgicel (Ethicon, Inc., Somerville, NJ) or other thrombotic agent.
- Remove the disc from all levels planned.
- Place bone graft if desired (TECH FIG 2G).
- Close the pleura using the Endostitch device (US Surgical, Warsaw, IN), running one suture from proximal and one from distal (TECH FIG 2H–J).
- Place a chest tube (TECH FIG 2K).
- Close the portal incisions.

(a) Using a curved electrocautery blade, the pleura is incised in the longitudinal fashion, sparing the segmental vessels. (b) The parietal pleura is retracted anteriorly, as shown, to allow for complete access to the anterior longitudinal ligament, as well as the opposite annulus. The posterior pleura is also retracted. (c) The annulus is incised parallel to the disc. (d) Disc shavers are used to break up the disc material. (continued)
E. The disc material is removed with a rongeur. F. The endplate is taken down to bone with an angled curette. G. Bone graft is placed. H–J. The pleura is closed with an Endostitch device. H. Closure is started distally with a running suture. I. Final closure of the pleura, in which the proximal suture is brought to the distal suture. J. The pleura is closed nicely with a running suture. K. Placement of the chest tube at the completion of the procedure, from distal to proximal. The lung is still deflated. The pleura, seen in the background, has been closed previously.

PEARLS AND PITFALLS

**Portal placement**
- Placement of portals is key for visualization and achieving good discectomy.
- Place the skin incision for the portal over a rib to allow the portal to be placed above and below the rib (two portals per skin incision).
- Ensure that portals are neither too posterior nor too anterior.

**Preservation of segmental blood vessels**
- Incise the pleura in a longitudinal fashion, staying superficial to the segmental vessels.
- Use a curved harmonic scalpel or electrocautery.
- Incise any adventitial tissue adherent to the pleura over the disc to free up the parietal pleura.
- Bluntly retract the pleura to gain access to the disc.

**Complete removal of the disc**
- Develop the same sequence for disc removal:
  1. Incise the disc with a scalpel blade.
  2. Break up disc material with shavers.
  3. Remove loosened disc material.
  4. Take down the endplates of the vertebral bodies with a curved curette.
  5. Remove excess endplate material.

**Pleural closure**
- Use the Endostitch device with 2-0 Vicryl suture.
- Use two sutures: the first begins in the proximal aspect and is run distally, and the second is started distally and is run proximally.

POSTOPERATIVE CARE

- Chest tube management
  - Connect chest tube to wall suction.
  - Obtain daily chest radiographs.
  - The chest tube may be removed when drainage is less than 80 mL over 12 hours and serous color returns (with good pleural closure, removal usually is done on the first day).
- Mobilize the patient to chair on postoperative day 1.
- Mobilize the patient to ambulation when the chest tube is removed (usually postoperative day 2).
- Serial hemoglobin and hematocrit on postoperative days 1 and 2
- Advanced activities as tolerated to daily activities in the initial 6 weeks
For the following 6 weeks, physical activities are advanced, depending on posterior constructs.

OUTCOMES
- The addition of a thoracoscopic anterior release and fusion results in a decrease in pulmonary function in the first 6 weeks; however, at 1 year it is 30% above baseline.
- Anterior release increases the flexibility of the spine and allows for great coronal, axial plane, and sagittal plane correction.
- With good surgical technique, an outstanding anterior release can be achieved and will allow for exceptional three-dimensional correction of the spine with posterior instrumentation and fusion (FIG 5).

COMPLICATIONS
- Single-lung ventilation
- Intraoperative complications: inability to ventilate adequately secondary to ventilation-perfusion mismatches, high airway pressures and barotrauma, and underlying pulmonary issues
- Postoperative complications: atelectasis secondary to barotrauma or mucous plugs
- Continuous chest tube drainage, especially when the parietal pleura has not been closed
- Pneumothorax following chest tube removal
- Intraoperative injury to the segmental blood vessels or the great vessels
- Intraoperative injury to the thoracic duct, which usually occurs on the right side at the T11–12 area. This can be avoided by dissection deep to the parietal pleura.
- Chylothorax is treated with total parenteral nutrition and avoidance of a fatty diet.
- Intraoperative excessive bleeding secondary to inadvertent segmental vessel injury. Strategies to coagulate the vessel are used.
- Long-term complications secondary to a thoracoscopic anterior release and fusion are limited.

REFERENCES

FIG 5 • The 2-year postoperative AP and lateral radiographs of the patient shown in Figures 1 and 2 demonstrated outstanding coronal and sagittal plane correction after prone thoracoscopic anterior release and fusion followed by a posterior spinal fusion and instrumentation from T2 to L2.
DEFINITION

- Neuromuscular spinal deformity is a result of an abnormal neuromuscular system in childhood, as in cerebral palsy, muscular dystrophy, spinal muscular atrophy, and so forth. It may be related to a pathologic abnormality in muscle tone, motor control, or weakness or a combination.
- While neuromuscular scoliosis (coronal deformity) is the most common neuromuscular spinal deformity, sagittal plane deformity (hyperlordosis and hyperkyphosis) may also occur.

ANATOMY

- The curve patterns of neuromuscular scoliosis are most commonly lumbar or thoracolumbar with associated pelvic obliquity (FIG 1).
- Since many children are nonambulatory, associated pelvic obliquity affects sitting balance.
- Ambulatory neuromuscular patients often have decompensation, with the inability to center their head over the center sacral line.

PATHOGENESIS AND NATURAL HISTORY

- The biologic basis of scoliosis or sagittal plane spinal deformity in neuromuscular disorders differs depending on the cause of the specific neuromuscular disease. In general, however, most neuromuscular spinal deformities are largely due to muscle imbalance (low tone or high tone) and abnormal postural reflexes.
- The natural history of neuromuscular scoliosis is usually that of slow progression, beginning with the development of a flexible scoliosis in middle childhood and the more rapid development of a more fixed scoliosis during the adolescent growth spurt. Some neuromuscular conditions are associated with a more progressive scoliosis than others.
- The clinician must weigh the progressive characteristics of scoliosis within each neuromuscular disease with the natural history of the disease itself when deciding on treatment.
- The pathogenesis and natural history of some of the more common disorders associated with neuromuscular spinal deformity and spinal deformity within the disease follow.

Cerebral Palsy

- Cerebral palsy is a heterogeneous disorder that is characterized by a static lesion (e.g., injury, congenital defect) to the immature motor cortex of the brain. In modern society, it has become the most common cause of neuromuscular spinal deformity.
- The natural history of neuromuscular scoliosis in cerebral palsy is frequently that of progression. The rate of progression can be very severe in adolescent years (2 to 4 degrees per month).
- Progression also occurs after skeletal maturity, and in curves greater than 40 degrees it may occur at a rate of 2 to 4 degrees per year.¹⁶
- Curves in the 60- to 90-degree range begin to affect sitting, arm control, and head control. Further progression may prevent the child from sitting in an upright position.
- Conservative treatment with chair modifications and bracing is only a temporary treatment and does not stop curve progression. Conservative treatment is especially helpful in the younger child with a flexible scoliosis to temporarily maintain upright sitting posture. This will allow the spine to grow to its maximum size so that the resulting fusion can correct the spinal deformity without limiting growth.

Muscular Dystrophy

- Duchenne muscular dystrophy is a sex-linked recessive disorder involving a defect on the Xp21.2 locus of the X chromosome resulting in a marked decrease or absence of the protein dystrophin.⁵
- Affected children become progressively weaker with age, eventually becoming nonambulatory.
- Death typically occurs in the second or third decade secondary to pulmonary or cardiac failure.
- Scoliosis is almost universal when the child becomes nonambulatory, and curve progression correlates strongly with a decline in respiratory function.
- The prevalence of scoliosis approaches 100%.¹⁴ For this reason, surgery is done soon after the child becomes nonambulatory, before an irreversible decline in forced vital capacity occurs.

Myelomeningocele

- Myelomeningocele, a congenital malformation of the nervous system, is due to a neural tube defect and results in a spectrum of sensory and motor deficits.
While the level of the spinal cord defect influences the clinical presentation of the disease, neurologic deterioration may occur at any age owing to hydrocephaly, hydrosyringomyelia, Arnold–Chiari deformity, and tethered cord syndrome.

In general, the higher the level of the defect, the higher the prevalence of scoliosis. Almost 100% of thoracic-level paraplegic patients will develop scoliosis. A long C-shaped curve is associated with a high level of paralysis and usually occurs at a young age.

Hydromyelia and tethered cord syndrome may also be associated with scoliosis and should be suspected if the scoliosis onset is more sudden and associated with other symptoms of acute neurologic deterioration.

Bracing in younger children can be attempted to slow progression, but it does not stop eventual progression.

**Spinal Muscular Atrophy**

This condition is an autosomal recessive disorder resulting in spinal cord anterior horn cell degeneration. Two genes on the chromosome 5q locus have been found to be associated with this disorder: survival motor neuron gene (SMN) and neuronal apoptosis inhibitory gene (NAIP). Clinically, progressive muscular weakness occurs, and eventual pulmonary compromise is common.

Three forms of this disease exist:
- Type 1 (early, acute Werdnig–Hoffmann)
- Type 2 (intermediate, chronic Werdnig–Hoffmann)
- Type 3 (late, Kugelberg–Welander type)

Most children with the early form of the disease die at an early age and therefore do not require treatment.

Most children with the intermediate and late type who survive into adolescence develop a progressive spinal deformity. The curvature typically starts in the first decade. Thoracolumbar and single thoracic patterns are most common.

One third of patients have an associated kyphosis in the sagittal plane. Bracing is ineffective at preventing curve progression but may delay progression in the very young patient to allow further growth of the spine.

**Friedreich Ataxia**

This autosomal recessive disorder results in a slowly progressive spinocerebellar degeneration. A defect on chromosome 9 has been identified.

The incidence of scoliosis is 100%, and progression is related to the age of disease onset. When disease onset is prior to age 10 years and scoliosis onset is before 15 years, scoliosis progression is usually greater than 60 degrees.

Prophylactic bracing may be effective in smaller curves (under 20 degrees). There are no data to support that bracing is effective in preventing progression in established curves greater than 20 degrees.

**Rett Syndrome**

This is an X-linked disorder that affects females almost exclusively. Some children have a mutation on the MECP2 gene. The child’s development is normal until 6 to 18 months of age, followed by a rapid deterioration in cognitive and motor function.

After the initial deterioration in function, the neurologic picture may become relatively static for years. The clinical spectrum is variable, with some children remaining ambulatory and others becoming wheelchair-bound.

Rett syndrome may be mistaken for cerebral palsy.

Scoliosis has been reported in up to 80% of patients. A long C-shaped thoracolumbar pattern is common. Bracing is typically ineffective and curve progression is common. Surgical stabilization allows maintenance of sitting balance.

**Spinal Cord Injury**

Spinal cord injury in the skeletally immature child is associated with a nearly 100% incidence of scoliosis.

The predominant curve type is a long C-shaped curve. The younger the child, the higher the progression.

Prophylactic bracing may be effective in smaller curves (under 20 degrees). There are no data to support that bracing is effective in preventing progression in established curves greater than 20 degrees.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

The medical history is critical for this group of patients.

In patients with cerebral palsy, the medical history correlates very strongly with postoperative complications. This appears to be true also in patients with Duchenne muscular dystrophy and spinal muscular atrophy.

Important historical information includes respiratory status, cardiac status, gastrointestinal status (eg, gastroesophageal reflux, nutritional intake), and the presence of a seizure disorder.

Physical examination should assess sitting or standing balance, the pelvic obliquity, and curve magnitude and stiffness (including the curve’s coronal, sagittal, and rotational components).

Coronal plane stiffness is best assessed by performing the side-bending test (FIG 2).

The physician should also assess for the possible coexistence of hip subluxation or dislocation, which is common in many neuromuscular diseases.

A complete neurologic examination should also be performed.

**FIG 2** Side-bending test. Patient is being bent over the examiner’s thigh at the apex of the curve. If the patient’s curve reverses and the pelvis levels to perpendicular to the trunk, the curve is still flexible enough to correct through posterior fusion and instrumentation alone. If not, an anterior release is performed.
IMAGING AND OTHER DIAGNOSTIC STUDIES

- Anteroposterior (AP) and lateral radiographic views should be obtained to assess the Cobb angle and pelvic obliquity in the coronal plane, and lumbar lordosis and thoracic kyphosis in the sagittal plane.
- If intraspinal pathology is suspected, especially in the ambulatory patient, a preoperative magnetic resonance imaging (MRI) scan should be obtained.

DIFFERENTIAL DIAGNOSIS

- Some neurologic diseases can look similar.
- It is important to diagnose progressive neurodegenerative disorders in which mortality from the disease is more rapid than the progression of the spinal deformity.

NONOPERATIVE MANAGEMENT

- While there was initially some historical enthusiasm for the treatment of neuromuscular scoliosis with casting or bracing, orthotic management has been found to have little or no impact on neuromuscular deformity.
- Flexible curves in younger children may require seating modifications (hip guides and offset lateral seat supports) or a soft thoracolumbar orthosis to maintain balanced seating until the child is at optimal sitting height.
- Orthotic treatment does not affect the rate and eventual progression of neuromuscular scoliosis.

SURGICAL MANAGEMENT

Indications

- The indications for spinal fusion in neuromuscular scoliosis depend largely on the natural history of the specific neuromuscular disease and the natural history of the scoliosis within the specific disorder.
- Examples of two neuromuscular diseases with different indications are Duchenne muscular dystrophy and cerebral palsy.

Duchenne Muscular Dystrophy

- The major comorbidity in Duchenne muscular dystrophy is a restrictive type of pulmonary involvement, with forced vital capacity dropping dramatically with scoliosis progression.
- Due to the natural history, the indication for fusion is a scoliosis curvature greater than 25 degrees and forced vital capacity greater than 35%.

Cerebral Palsy

- The indications for spinal fusion in children with cerebral palsy are a scoliosis curve magnitude approaching 60 degrees in the older child, especially if the curve is becoming stiff by physical examination.
- Surgical correction is indicated when the child is not tolerating seating with a combination of either seating adjustments or a soft orthosis.
- Less commonly, sagittal plane spinal deformity, hyperlordosis, and kyphosis will cause seating problems or back pain. Cerebral palsy patients with sagittal plane spinal deformity of 70 degrees or more causing seating difficulties or back pain can also benefit from surgical correction.
- Typically during the middle part of adolescent growth, the scoliosis becomes much larger and begins to progress and stiffen. Surgical instrumentation and fusion is recommended at this time.

Preoperative Planning

Technical Considerations

- Two main technical preoperative questions require careful consideration:
  - Is fusion to the pelvis necessary?
  - Is an anterior release (discectomies around the stiff portion of the curve) necessary?
- The only treatment that has made a definitive impact on neuromuscular spinal deformity is instrumentation and fusion.
- The standard surgical procedure for neuromuscular scoliosis is a posterior spinal fusion with segmental instrumentation from T1 or T2 down to the sacrum if there is pelvic obliquity.
- Even if the pelvis is not involved in a severely involved non-ambulatory patient or an ambulatory patient with a poor “righting reflex,” the surgeon should still consider fusion to the pelvis to prevent the development of late pelvic obliquity.
- Some children with Duchenne muscular dystrophy who have no pelvic obliquity are an exception and can be treated with fusion ending at L5.
- The gold standard for neuromuscular scoliosis is Luque rod instrumentation (with Galveston extension for the pelvis), cross-linkage to prevent rod shift and rotation, and sublaminar wires.
- The unit rod incorporates these concepts into one instrumentation system

FIG 3 • A. The unit rod is available commercially in a range of sizes. B. Drill guides are provided for placement of the pelvic limbs as well as the impactor and pusher for the rod. (continued)
The unit rod is especially powerful as a cantilever to correct pelvic obliquity (FIG 3C–E).

Anterior release for scoliosis is required for larger stiff curves that do not bend out on the bending test (generally greater than 90 degrees) (FIG 3F).

Anterior release is also recommended for severe hyperlordotic and hyperkyphotic spinal deformities.\(^8\)

**Other Preoperative Considerations**

- The general medical condition of the child should always be considered first. Many children with neuromuscular conditions will have comorbidities such as pulmonary disease, cardiac disease, seizure disorder, poor nutrition, and so forth.
- All patients with complex preoperative medical conditions should have the appropriate preoperative workup.
- The surgeon and anesthesiologist should plan for the possibility of large intraoperative blood loss.
- Type- and cross-matched blood (up to twice the patient’s blood volume), fresh-frozen plasma, and platelets should be available.
- Good vascular access is required, often through central venous access.
- Another consideration is the use of spinal cord monitoring, the role of which is unclear in many patients with neuromuscular scoliosis. On the one hand, most children with neuropathies and myopathies can be monitored, while most severely retarded quadriplegic cerebral palsy patients with poor motor function cannot be reliably monitored. In addition, it is hard to justify removing implant hardware if there are signal changes in the child with minimal motor function since the risk of a repeat operation to reimplant hardware is quite high in this population.
- As a general rule, any child with ambulatory or functional standing (able to assist with standing transfers) should have somatosensory and motor evoked potential monitoring attempted. There may also be some efficacy in monitoring neuromuscular patients with intact sensation and bowel and bladder control.
- A final preoperative consideration is the bone density of the child undergoing spinal fusion. The child who is nonambulatory, poorly nourished, and on seizure medication is at highest risk. Children with low bone density may be difficult to instrument owing to the possibility of sublaminar wires pulling through or screws pulling out of osteopenic bone.
- Any nonambulatory child with a history of low-impact long-bone fracture should be checked for low bone density using dual-energy x-ray absorptiometry (DEXA scan).
- Children on seizure medication should have calcium, phosphorus, and vitamin D levels measured.
Patients with bone density two or more z-scores below the mean should be considered for treatment using intravenous pamidronate.

Positioning
- The patient is positioned prone on a Jackson table (a Relton–Hall frame can also be used) with the abdominal area free (FIG 4).

EXPOSURE
- A posterior approach to the spine is performed from T1 to the sacrum.
- A complete subperiosteal exposure of each vertebra is performed, followed by exposure of the outer wing of each iliac crest down to the sciatic notch and the bottom tips of the posterior superior iliac spines.

PELVIS PREPARATION
- A drill hole is made between the outer and inner cortex of the ilium with a drill bit. Before drilling, the drill bit is marked 10 mm past the drill guide’s hook for the sciatic notch in children less than 45 kg and 15 mm past the hook in children greater than 45 kg.
- The right or left drill guide is next inserted into the right or left sciatic notch, respectively.
- The lateral handle of the drill guide is placed parallel to the pelvis (iliac crests) while the axial handle is held parallel to the body axis.
- The pelvis is drilled from the inferior tip of the posterior superior iliac spine in a line just superior and anterior to the sciatic notch, where the bone is densest (TECH FIG 1).
- The hole is probed to make certain that the pelvic cortex or the sciatic notch is not penetrated.
- The drill hole can be temporarily packed with Gelfoam to control bleeding.
LUQUE WIRE PASSAGE

- After the spine is completely exposed and pelvis is prepared, the spinous processes are completely removed and the ligamentum flavum is carefully removed to expose the sublaminar spaces.
- Double Luque wires are bent (prebent wires are also available) and passed under the lamina from the lamina of L5 up to and including the T1 lamina.
- The radius of curvature for the wire bend must approximate the width of the laminae to allow safe passage of the wire.
- Two double wires are passed at the L5 and the T1 lamina only, while a single wire is passed at each of the other levels (TECH FIG 2A–E).
- Wires are pulled to equal length and next bent, with the midline bent flat down onto the spinous process beds and the beaded end flat down onto the paraspinous muscles (TECH FIG 2F).
- This helps the wires from getting inadvertently pushed into the spinal canal and allows for easier wire organization.

TECH FIG 2 • When passing wires, it is important to roll the wires under the lamina (A–D), being careful not to catch the tip under the lamina (E), which will lever the wire into the canal and place pressure on the spinal cord. F. Wires are bent down to the midline in the middle and the ends are bent down flat against the paraspinous muscles.
ROD SELECTION AND INSERTION

- After the wires are passed, the length of the unit rod is selected.
- This is done by placing the rod upside down with the corner of the rod placed at the drill hole on the elevated side of the pelvis (TECH FIG 3A).
  - The proper-length rod should reach T1 (TECH FIG 3B).
  - A rod one length shorter should be chosen if there is severe kyphosis because the spine shortens with correction.
  - With severe lordosis, a rod one length longer should be chosen because the spine lengthens with correction.
- It is best to err on the side of the rod being too short because the wires can be brought down to the rod several levels if necessary.
- If the rod is more than 2 cm long, it may be too prominent under the skin.
- In such cases, cutting the rod and cross-linking the rod may be advisable.
- Facetectomy and decortication of the transverse processes are performed. Corticocancellous allograft (crushed) bone is added (about 180 to 240 mL).
- Insertion of the rod involves crossing the pelvic limbs of the rod to insert them into the previously drilled pelvic holes (TECH FIG 3C).
- In patients with pelvic obliquity, the pelvic limb of the rod is placed into the drill hole on the low side of the pelvic obliquity first, with this side crossed underneath the other limb.
- With the rod impactor, the surgeon inserts half to three quarters of this pelvic limb of the rod first and then inserts the opposite pelvic limb, using a rod holder to direct it into the correct direction of the previously drilled hole.
- The rod impactor is next used to drive limbs into the pelvis, alternatively impacting each pelvic leg and making certain to direct each of the legs in the direction of the previously drilled holes.
- At this point, intraoperative fluoroscopy should be used to confirm the correct placement of the rod limbs within the pelvis.
- Caution: The surgeon should not try to see if the rod fits by pushing it down into the wound completely in one
move, as this may cause either the pelvic limbs of the rod to pull out of the pelvis or fracture of the ilium.
- The surgeon should push the rod to line up with the L5 lamina only and then twist the wires (we suggest a jet wire twister). The wires are cut 10 to 15 mm long.
- Now the rod is pushed to L4 and the wires are twisted and cut.
- Next the rod is pushed to L3 and the wires are twisted and cut.
- This process continues one level at a time until the surgeon reaches T1 (TECH FIG 3D).

### COMPLETION AND WOUND CLOSURE

- All wires are bent down into the midline of the rod and directly caudally. This allows easier exposure of the rod and wires if reoperation should ever become necessary.
- The remaining bone graft is applied (TECH FIG 4A).
- We mix the last 60 cc of allograft with four 80-mg vials of gentamicin. This has lessened the postoperative infection rate.
- If the child is thin and the sacrum is prominent, the sacral spinous processes and lateral processes are trimmed.
- The sacral lamina and lateral processes can be completely removed if they are severely prominent.
- The fascia is closed tightly.
- No drain is used.
- The subcutaneous tissue and skin are meticulously closed.
- Final radiographs are taken to confirm coronal and sagittal alignment (TECH FIG 4B–D).
- In patients with hyperlordosis, pedicle screws with reduction posts are useful in the apex of the sagittal plane deformity to aid in the correction (TECH FIG 4E,F).
Clinical photographs show correction of pelvic obliquity (C) and good sagittal plane alignment (D). Preoperative (E) and postoperative (F) lateral radiographs of patient with severe hyperlordosis corrected with unit instrumentation and pedicle screws used to correct lordosis in the apex of the deformity.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Severe intraoperative hypotension may suddenly occur, especially after decortication.</th>
<th>Constant communication between the surgeon and the anesthesiologist is critical. Type and cross-matched packed red blood cells (1.5 to 2 times blood volume), fresh-frozen plasma, and platelets should be available.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothermia</td>
<td>Hypothermia can be avoided by keeping the room temperature high and using a heated ventilator, a warmer for intravenous fluids and blood, and an airflow heating device.</td>
</tr>
<tr>
<td>Excessively stiff scoliosis or accompanying sagittal plane deformity (hyperkyphosis or hyperlordosis)</td>
<td>The surgeon should recognize stiffness preoperatively on the physical examination or bending radiographs to plan for anterior release.</td>
</tr>
<tr>
<td>Rod insertion</td>
<td>• Using the wires to pull the rod down to the lamina may cause the wires to cut through the lamina. • Relaxing the push on the rod between levels while correcting the major curve may cause an “unzipper” effect, with several wires tearing through laminae or breaking from too much force on the end vertebrae. • The surgeon should use a rod holder to prevent the pusher from slipping off the rod as the top of the rod is approached. • The force from pushing may become large, preventing the patient from being ventilated or causing a drop in blood pressure. If this occurs, the surgeon should relax the push on the rod just enough to allow ventilation and return of pressure.</td>
</tr>
<tr>
<td>Pelvic insertion of rod limb in severe lordosis</td>
<td>Difficulty occurs as the surgeon attempts to insert the pelvic limb of the rod and cannot get the rod anterior enough to steer the rod into the drill holes. This may allow the rod to perforate into the sciatic notch or through the inner pelvic table. • Intraoperative fluoroscopy should be used to check proper placement of the pelvic limbs. If pelvic penetration of the rod occurs, the penetrated rod limb should be cut, reinserted into the pelvis, and reconnected with an end-to-end or side-to-side connector.</td>
</tr>
<tr>
<td>Misjudgment of rod length</td>
<td>If the rod is too long and prominent, both rods can be cross-linked together and then cut at the T1 vertebrae. If the rod length is misjudged too short by more than two levels, the top of another unit rod can be connected with end-to-end connectors. This is important when there is excessive kyphosis to prevent drop-off of the spine over the top of the rod.</td>
</tr>
<tr>
<td>Wires cut through lamina</td>
<td>Only enough bone should be removed to allow wires to pass through the sublaminar space. Wires should not be used to pull the rod to the laminae. This may also be due to inadequate anterior release in a stiff deformity.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- Neuroromuscular patients are managed in the intensive care unit postoperatively.
  - Most children remain intubated and are ventilated over a 2- to 5-day period. This allows for easier respiratory management and pain management.
  - Core body temperature should be increased to 37°C and maintained. Blood clotting is impaired by low body temperature below 33°C, which can easily develop in this patient population.
  - Hypertensive episodes are avoided by maintaining increased fluid intake and pressor support as needed. Urine output should be maintained at a minimum of 0.5 cc/kg/hour.
  - Most children require aggressive postoperative nutritional support with central hyperalimentation.
    - Typically, a tunneled central venous catheter (Hickman) is placed at the time of surgery.
    - Gastrostomy tube feedings can be started as soon as bowel sounds are present.
    - Gastrojejunostomy or nasojejunostomy tubes may be started as an alternative to hyperalimentation.
  - Pancreatic enzyme levels are monitored carefully postoperatively, as elevated amylase and lipase levels are common and indicative of subclinical pancreatitis.
  - Oral or gastrostomy feedings should be delayed if these values are increasing above normal.
  - Adequate nutritional intake for optimal wound healing usually requires about 1.5 times the child’s normal preoperative requirements and is continued up to 1 month postoperatively.
  - Proper wheelchair assessment postoperatively is also important.

OUTCOMES

- Unit rod instrumentation achieves a scoliosis correction of 70% to 80% of the preoperative curve magnitude and an 80% to 90% correction of pelvic obliquity.4
  - In a subset of 24 ambulatory cerebral palsy patients who underwent posterior spinal fusion with unit rod instrumentation, all patients had preservation of their ambulatory status.20
  - Sagittal plane spinal deformity is also well corrected with unit rod instrumentation. Lipton et al8 showed relief of symptoms and correction of sagittal plane spinal deformity in 24 cerebral palsy patients with hyperlordosis and kyphosis after unit rod instrumentation.
  - In one survey of 190 parents and caretakers assessing functional improvement of children with cerebral palsy after posterior spinal fusion, 95.8% of parents and 84.3% of caretakers would recommend spinal surgery again.18 Positive responses included improved appearance, overall function, quality of life, and ease of care.
  - Overall life expectancy of the cerebral palsy child after posterior spinal fusion is also critically important. A survival analysis showed that the presence of severe preoperative thoracic hyperkyphosis and the number of postoperative days in the intensive care unit correlated with decreased life expectancy after evaluating a number of variables.19

COMPLICATIONS

- Complications are common but are usually not life-threatening and range from minor to major. They include excessive intraoperative bleeding, neurologic complications, atelectasis, pneumonia, prolonged postoperative ileus, pancreatitis, wound infection, and so forth.
  - Mechanical or technical complications also occur and include rod or wire prominence, pseudarthrosis, rod penetration through the pelvis, curve progression after fusion due to crankshifting, and so forth.
  - In one study, the curve magnitude, preoperative pulmonary status, and degree of neurologic involvement had the highest correlation with postoperative complications.9

REFERENCES

Early-onset scoliosis (EOS) is defined by the diagnosis of scoliosis at or before the age of 5 years. The many etiologies of EOS include:

- Congenital vertebral or spinal anomalies: eg, vertebral bars, hemivertebrae, syrinx, tethered cord
- Neuromuscular diseases: eg, cerebral palsy, spinal dysraphism, muscular dystrophy
- Syndromes associated with scoliosis: eg, neurofibromatosis
- Idiopathic causes

Age of onset is an important aspect of pathology, because progressive curves can be associated with growth disturbances as well as cardiopulmonary compromise, including restrictive lung disease and pulmonary hypertension.

Two periods of increased growth velocity are associated with increased incidence of curve progression. The first occurs from birth to 5 years of age; the second includes the adolescent growth spurt occurring after age 10 until just before skeletal maturity.

The growth velocity from T1 to L5 is greatest from birth until the age of 5. Increases in height during this period average 2 cm per year, and by the age of 5, two thirds of the final sitting height is achieved. The years between 5 and 10 years of age exhibit much less growth. Finally, the adolescent growth spurt causes another increase in growth velocity, at a slower rate than the first growth spurt.

The increased spinal growth during the first years of life is paralleled by an increase in thorax and lung dimension. Thoracic volume at birth is about 5% of the adult volume; by 5 years of age, it equals 30% of adult volume. A slower rate of thoracic growth occurs from 5 to 10 years of age, by which time it has reached 50% of the adult volume. The final 50% of adult volume is achieved during the adolescent growth spurt from 10 to 15 years of age.

Lung development also occurs rapidly during the first year of life, and by age 8, most alveolar growth and respiratory branching has occurred.

The pathogenesis of EOS depends on its etiology. Vertebral anomalies cause scoliosis by an imbalance in bone growth, whether an increase on a side associated with a hemivertebrae, or retardation on the side associated with a vertebral bar. In neuromuscular and central nervous disorders, an imbalance in muscular forces is the pathogenesis, likely following the Heuter-Volkmann principle.

The etiology and pathogenesis of infantile idiopathic scoliosis (IIS) (0–3 years of age) is, by definition, unknown. There probably is a genetic component that provides a susceptibility to develop scoliosis. The external factors needed to produce the scoliosis are not yet clearly delineated but may include intrauterine molding as well as infant positioning. The etiology of IIS most likely differs from that of adolescent idiopathic scoliosis (AIS).

The natural history also depends on the etiology. The natural history of EOS due to IIS is favorable when compared with late-onset scoliosis (LOS). Spontaneous resolution occurs in a large number of patients. Progression of congenital curves depends on the type of anomaly and growth potential. EOS due to neuromuscular etiologies usually follows the natural history of the disease in addition to specific problems associated with progressive curves in this age group.

Regardless of the etiology, progression of scoliosis during the first 5 years of life adversely affects growth as well as pulmonary function. Scoliosis inhibits the growth of both the alveoli and the pulmonary arterioles, causing ventilation defects. The scoliotic spine does not distort the architecture of the alveoli; rather, the total number is decreased significantly and is directly proportional to the age of onset. The earlier the onset of scoliosis, the more hypoplastic the lung is, with a diminution of alveoli greater than would be expected from just a lack of space.

Patients with EOS also may suffer from a restrictive pattern of pulmonary dysfunction. Lung compliance is reduced, with an associated decrease in total lung capacity as well as vital capacity. In contrast to patients with LOS, the severity of scoliosis in EOS is proportional to the severity of restrictive disease. The restrictive lung disease causes hypoventilation and vasoconstriction of the pulmonary tree and leads to pulmonary hypertension. EOS is associated with a higher risk of cardiopulmonary decompensation in middle-aged patients, which can lead to disabling and even fatal respiratory failure.

Evaluation of the patient with EOS includes a complete history, including the family history, prenatal history, birth history, and developmental history. IIS has been associated with breech presentation and, in boys, with premature birth. Curve progression also has been correlated with cognitive delay, so it is important to ask parents about the achievement of developmental milestones.

The physical examination of EOS heavily relies on the perceptive capabilities of the clinician and is the same examination that is performed on all scoliosis patients. After a careful history has already been obtained, a thorough physical examination, including inspection, palpation, motor testing, sensory testing, and reflex testing is necessary.

Inspection includes observation of gait, respiration, truncal and pelvic balance in the coronal and sagittal planes, cutaneous lesions, and any prominence on forward bending. Any deficits in
motor, sensory, or reflex function, including abdominal reflexes, may indicate central nervous system pathology and should be thoroughly evaluated with advanced diagnostic studies.

- Flexibility of the curve can be assessed either by the manual application of traction through the cervical spine or by applying a three-point bending force at the apex of the curve. Examination techniques unique for early-onset scoliosis include the thumb excursion test for thoracic expansion and sitting height measurement.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- All patients should have full-length standing anteroposterior (AP) and lateral radiographs (**FIG 1A,B**) covering the cervical spine to the pelvis, including the entire thorax. For patients who are unable to stand, supine radiographs encompassing the same area should be taken.
- The cervical spine, lumbosacral spine, pelvis, and hips all may need to be studied to elicit whether or not developmental hip dysplasia or other vertebral anomalies are contributing to the scoliosis.
- Side-bending or traction radiographs are necessary to help delineate the degree of flexibility of the curves.
- Similar to LOS evaluation, the Cobb technique is used to measure any curve by measuring the angle created by a line through the superior endplate of the most cranial vertebra and a line through the inferiormost point of the most caudal endplate. This should be done in both the coronal and sagittal planes and compared to normal values. These angles can be used to measure progression of the curve with successive visits but are subject to a small amount of user error variability between 5 to 6 degrees.
- Spinal height is obtained by measuring the distance from the top of T1 to the top of S1 on the AP view of the spine (**FIG 1C**). 
- Coronal balance is measured by the distance from the center of C7 to a line drawn up from S1.
- The sagittal balance is measured from the posterior-cranial corner of S1 to a line drawn down from the center of C7.
- All of these measurements should be recorded and compared on successive visits to document any change in curve magnitude or growth of the spine.

- The rib-vertebral angle difference of Mehta (RVAD; **FIG 2**), first described in 1972, measures the amount of rotation at the apex vertebra and has some prognostic value. The angles formed by a line perpendicular to the vertebra and a line drawn down the center of the rib is compared between the convex and concave side. If the difference calculated by subtracting the convex angle to the concave angle is 20 degrees or less, there is an 85% to 90% chance the curve will resolve; when there is a difference of 21 degrees or more it will likely progress.

- The phase of the rib head also is described by ascertaining whether the head of the convex rib overlaps the vertebral body. 
- If there is no overlap (phase 1), then the RVAD is calculated as previously mentioned.
- If there is overlap (phase 2), the risk of progression is high, regardless of RVAD.
- Another method of evaluating rotation is the Nash-Moe method (**FIG 3**). Evaluating the pedicles of the apical vertebra at the convexity, the distance of the pedicle on the convex side is measured.
  - Zero: the pedicles are equidistant from the sides
  - Grade 1: the concave pedicle is partially obscured, and the convex pedicle moves away from the edge toward the center
  - Grade 3: the convex pedicle is in the midline of the vertebral body.
  - Grade 2: between grades 1 and 3
  - Grade 4: the convex pedicle lies past the midline.

**FIG 1** • **A.** Lateral radiograph of a neuromuscular patient with early-onset scoliosis. **B.** AP radiograph with space available for the lung (SAL) of a patient with early-onset scoliosis. **C.** Measurement of vertebral height from T1 to S1.
Differential Diagnosis

- Congenital vertebral or spinal anomalies
  - Vertebral bars
  - Hemivertebrae
  - Syrinx
  - Tethered cord

FIG 2 • The rib-vertebral angle difference (RVAD) measures the angle of a line drawn perpendicular to the apical thoracic vertebra endplate and a line drawn down the center of the concave and convex ribs. The difference is calculated by subtracting the convex from the concave angle. An RVAD of 20 degrees or less indicates a curve that is likely to resolve; an RVAD of 21 degrees or greater often is associated with curves that will progress. The phase of the rib head notes the position of the convex rib head on the apical vertebra. A “phase 1” relationship indicates no overlap of the rib head or neck on the apical vertebra. In cases that have a phase 1 relationship, the RVAD may be calculated and used to determine the likelihood of progression. In a phase 2 relationship, the head of the rib on the convex side of the apical vertebra overlaps with the vertebra, and the curve is likely to progress. (Adapted from Mehta MH. The rib-vertebra angle in the early diagnosis between resolving and progressive infantile scoliosis. J Bone Joint Surg Br 1972;54B:230–243.)

FIG 3 • Measurements performed on apical vertebra. If the pedicles are equidistant from the sides, rotation is classified as zero. If the concave pedicle is partially obscured and the convex pedicle moves away from the edge toward the center, that is considered grade 1. Grade 3 is defined as the convex pedicle in the midline of the vertebral body. Grade 2 lies between grades 1 and 3. Grade 4 indicates that the convex pedicle lies past midline. (Adapted from Nash CL Jr, Moe JH. A study of vertebral rotation. J Bone Joint Surg Am 1969;51A:223–229.)

FIG 4 • CT scan of the chest showing decreased lung volumes due to scoliosis.
Chapter 62  GROWING ROD INSTRUMENTATION FOR EARLY-ONSET SCOLIOSIS

NONOPERATIVE MANAGEMENT

Nonoperative treatment for EOS is indicated in curves that are not expected to progress or that are expected to progress only mildly, taking into consideration the etiology of the curve and the radiographic parameters described by Mehta in cases with IIS.

- Patients with a curve less than 25 degrees and RVAD less than 20 degrees may be followed with serial radiographs every 4 to 6 months to document any progression.
- Active treatment is warranted in:
  - Progression greater than 10 degrees; treatment starts with casting and bracing.
  - Phase 2 rib-vertebral relationship, RVAD greater than 20 degrees, or a Cobb angle greater than 20 degrees in any skeletally immature patient
  - Progression of more than 5 degrees in a patient with a Cobb angle greater than 35 degrees
- Casting usually is done under anesthesia. The cast is changed every 6 to 12 weeks until the ultimate correction is achieved.
- After casting, a Milwaukee brace (FIG 5) is used for 23 hours a day to help maintain the correction. Fully circumferential braces may distort the rib cage and adversely affect pulmonary status, because the immature thoracic wall may deform before any correction of the spine occurs.
- Bracing is continued for a minimum of 2 years until the Cobb angle and RVAD are stable.
- The goal is to correct the deformity completely before the prepubertal growth spurt.

- Nonoperative treatment for neuromuscular or congenital scoliosis can be attempted for curves of lesser magnitudes. Treatment options available include casting and bracing.
- Bracing is less effective for these types of deformities than for idiopathic scoliosis, but can be used in long flexible curves.
- Deformities with large sagittal components are not amenable to brace treatment.
- Brace treatment for congenital or neuromuscular scoliosis should be abandoned when unacceptable curve magnitude or progression is seen.

SURGICAL MANAGEMENT

Surgical treatment of EOS attempts to stop progression of the scoliosis, allowing improvements in growth of the spine, thorax, and lungs.

- Surgery is recommended for progressive curves greater than 45 degrees.
- The age of the patient helps to decide the type of surgery needed.
- Adolescents and more skeletally mature patients may do well with spine fusions, which stabilize the spine but also stop growth.
- Younger patients with substantial growth potential suffer from the “crankshaft” phenomenon if fusion is performed early in life from an isolated posterior approach. They suffer from severe growth retardation in height and thorax volume if fusion is performed using a combined anterior and posterior technique.
- The growing rod technique for EOS was developed to correct spinal deformity while allowing spinal growth to continue or even enhancing that growth.

Preoperative Planning

- Careful evaluation of radiographic studies allows planning of surgical levels. Typically, the cranial level of the construct includes T2 and extends two or three levels caudal to the end vertebra of the curve.
- Either pedicle screws or hooks can be used in the construct. Review of the pedicle structure using radiographs and CT scans is necessary to be sure the desired implants are selected.
- Medical and subspecialty consultations should be obtained before operation if the patient has any history of medical comorbidities.
- Cardiopulmonary, renal, skeletal, and other neuromuscular defects often are associated with scoliosis.
- Pulmonary function tests may be obtained in children who are able to cooperate if thoracic insufficiency is suspected.

Positioning

- The patient is placed under general anesthesia on the stretcher and then placed on the operating room table in the prone position on two longitudinal chest rolls or tightly rolled blankets.
- Neural monitoring is used during the procedure for neurologically intact patients. Leads should be placed before prone positioning, as should a Foley catheter.
- Care must be taken to be sure all bony prominences and compressible nerves are well padded.

Approach

- The growing rod technique is performed posteriorly through either a single long midline incision or two smaller incisions cranially and caudally.
**GROWING ROD INSTRUMENTATION FOR EARLY-ONSET SCOLIOSIS**

**Single-Incision Technique**

**Exposing the Foundations**
- The single-incision technique consists of a long superficial posterior incision beginning 2 to 3 cm cranial to the planned levels and ending caudal to the lowest vertebra by 2 to 3 cm. Infiltration of epinephrine may be used before subcutaneous incision.
- The spinous processes of the cranial and caudal foundations are exposed and marked with a metallic object such as a Kocher clamp, and a lateral radiograph is then used to confirm the levels.
- The foundations are critical to the construct in the dual growing rod technique.
  - They are composed of at least two pair of anchors and usually span two or three vertebral levels.
  - The foundations consist of the vertebral segments at either ends of the constructs, which are internally fixed with anchors.
  - Because the corrective loads are applied to these foundations, it is imperative that strong and stable constructs be achieved to decrease the incidence of implant or fixation failure.
- Limited fusions of the foundation levels often are performed using local bone graft or allograft extenders to provide more stability.
- The posterior elements of the cranial and caudal foundations are exposed subperiosteally out to the level of the transverse processes.
- Vertebral levels not involved in a foundation should not be exposed, to decrease the chance of unwanted fusion.

**Placing the Anchors**
- Once exposure has been obtained, the anchors are placed.
- The foundations may be anchored using either pedicle screws or hooks.
- If hooks are used, the superior edges of the most cranial lamina or transverse processes (TP) on either side are exposed, and supralaminar hooks or TP hooks are placed in a downdragging manner on both sides.
- Contralateral supralaminar hooks may be staggered over two levels if canal stenosis is a concern.
- Next, upgoing hooks are placed, usually under the facet articulations of the same vertebra but sometimes in a staggered arrangement.
- Foundations using supralaminar hooks generally consist of three vertebral levels with supralaminar hooks placed on either side of the cranial two vertebra and the facet hooks placed on the most caudal one.
- If TP hooks are used, only two vertebral levels are used, with the TP hooks placed on either side of the cranial vertebra and the facet hooks placed on the same cranial vertebra.
- For more stability, additional facet hooks can be used to extend the foundation to three levels. It is important to achieve adequate stability at initial surgery.
- Pedicle screws also may be used, usually with four screws spanning two vertebral levels. Pedicle screws may offer increased stability to the construct and are preferred for both foundations as long as the anatomy allows their safe placement.
- Multiple methods for thoracic pedicle screw placement have been popularized. In general, the thoracic pedicle starting point is located at the intersection of the lateral border of the superior articular facet and the cranial aspect of the transverse process.
- The trajectory of the thoracic pedicle screw generally travels lateral to medial about 30 degrees and from cranial to caudal 10 degrees, but varies by level (TECH FIG 1A–C).
- Lumbar pedicle screws start at the junction of the pars interarticularis, the midpoint of the transverse process, and the base of the superior articular process.
- Lumbar screw trajectory also varies, from about 10 degrees at L1 to 30 degrees at L5 from lateral to medial, and varies in the sagittal direction approximately 10 degrees from L1 to L5, depending on lordosis (TECH FIG 1D).
- Fluoroscopy and neural monitoring are helpful in aiding pedicle screw placement, especially in patients with deformity. If needed, a combination of hooks and screws can be used.

**Adding the Rods**
- The dual rod technique employs two rods, each made up of a cranial foundation rod and a caudal foundation rod joined by a connector, for a total of four rods for the entire construct.
- Either of two types of connectors may be used: a tandem connector, which houses the cranial and caudal rods inside a rectangular box so the ends meet end to end, or side-to-side connectors, which allow the rods to overlap.
- Tandem connectors usually are favored. Because they are straight and cannot be contoured, the rods are measured so that they meet inside the tandem connector in the relatively straight thoracolumbar region.
- The ends of the rods that fit inside the connector also must be straight. If any contouring is necessary in the region where the cranial and caudal rods meet, closed dual connectors must be used, with an overlap of 2 to 4 inches to allow future lengthening.
- Bilateral rods are prepared for each foundation by measuring the length of the spine in the corrected position and carefully contouring the rod. The concave side usually is constructed first to gain maximal correction.
- The rods can be placed either subcutaneously or subfascially. Subfascial placement involves a much deeper dissection, both initially and with each lengthening, however, and may increase the risk of premature fusion. Subcutaneous placement may be associated with a higher incidence of skin problems and wound infection.
After the rods are placed in the hooks or screws of each foundation, transverse connectors are placed between the two cranial rods and the two caudal rods, preferably between the points of fixation on each foundation.

If the transverse connectors are close-holed, it may be necessary to preload them onto the rods before they are placed in the anchors, and the spinous processes may be removed to allow proper seating.

These transverse connectors increase the stability of the construct, especially when hooks have been used. There is less need for transverse connectors when screws are used.

The tandem connector is held with a rod holder and slid onto the cranial rod; once the caudal rod is cleared, it is slid onto the caudal rod.

The cranial anchors and transverse connector are tightened first, followed by the caudal anchors and transverse connectors. Cranial and caudal set screws are located on the side of the tandem connector that correlates to the most prominent side.

To create distraction, the caudal set screw is tightened, a distractor is implemented in the slot of the tandem connector between the two rods, and the cranial set screw is tightened (TECH FIG 2A).

Similarly, a rod clamp can be used to distract against if a closed dual connector is used or even on a tandem connector (TECH FIG 2B).

Next, the rod construct on the convex side of the curve is created similarly and tightened. The surgical area is then irrigated, followed by a limited arthrodesis applying autograft bone or other graft extenders between the vertebrae making up each foundation.

Before final closure, anteroposterior and lateral radiographs are taken to confirm alignment and proper position of the implants (TECH FIG 2C,D).

The wound is then closed in standard fashion.

**Dual-Incision Technique**

The dual-incision technique differs from the single-incision technique in a few ways.

The incisions are centered over the foundation sites with a long skin bridge between them (TECH FIG 3).

The subperiosteal dissection is the same, as are placement strategies of either hooks or pedicle screws for anchors.

In placing the rods, however, subcutaneous or subfascial dissection must be performed carefully and bluntly with either a finger or blunt clamp to facilitate rod passage.

Careless dissection or poor control of the rod during passage can lead to pleural violation.

The rods must be placed beneath the skin bridge and the tandem connector placed on the caudal rod before they are fitted into the anchors.

The rest of the procedure is similar to the single-incision technique.

**Lengthening and Exchange**

Lengthening of the dual rod construct may be performed as either an in- or outpatient procedure with neural monitoring for patients with normal neurologic function.

The connector is located through palpation or fluoroscopy, and a small incision is made over that area where the lengthening is planned.
TECH FIG 2 • A. Lengthening may be performed by inserting the distractor between the rods through the slot of the tandem connector. One set screw is loosened, distraction is performed, and the set screw secured. B. Alternatively, a rod clamp can be placed on the rod a few centimeters from the connector and the distractor placed between the rod clamp and the end of the connector. The set screw nearest the rod clamp is then loosened, the distractor employed, and the screw retightened. C. AP radiograph after the dual growing rod procedure was performed on the patient shown in Figure 1B and C. D. Lateral radiograph after the dual growing rod procedure was performed on the same patient. (A,B: Bagheri R, Akbarnia BA. Pediatric Isola instrumentation. In: Kim DH, Vaccaro AR, Fessler RG, eds. Spinal Instrumentation: Surgical Techniques. New York: Thieme, 2005:640,642.)

- After dissection of the connector is performed, lengthening similar to that performed during the index procedure is carried out by loosening the set screw (mostly cranial), distracting between the two rods, and then tightening the set screw again.
- Lengthening is performed every 6 months.
- Once further distraction is no longer achievable, final correction and arthrodesis are performed.

Changing the Connector or Rod
- Exchange of the tandem connector or the rod may be needed if the amount of lengthening exceeds the initial length of the tandem connector.

- In such a case, both set screws should be loosened and the tandem connector slid cephalad until full clearance of the caudal rod is achieved.
- The connector can then be removed off the cranial rod, replaced by a longer connector, and slid onto the caudal rod again.
- Longer than 70 mm connector is rarely used, to minimize the adverse effect on sagittal balance.
- If the needed length exceeds the longest connector or if the longest connector is too long, it is necessary to fashion new rods and remove the old ones.
- This entails exposing and removing the tandem connectors, exposing the foundation, and removing the rods and replacing them with longer rods, creating a construct similar to the initial procedure.
- Replacement of the cephalad rods is most common.

Final Fusion
- Final fusion is performed near the end of the adolescent growth spurt or when the rods can no longer be lengthened.
- The first step entails removing the dual growing rod implants, including the anchors and exploring foundations for solid fusions. One should be careful to cause the least trauma to the soft tissues.
- For most patients, the fusion should extend from the cranial foundation to the cephalad foundation.
Either hooks or pedicle screws can be used in the foundations and at the apices of the curves. Rods are then contoured to the desired shape, keeping in mind that the goal is to achieve global balance rather than a totally straight spinal segment. Thus, upper and lower curves should be considered together when contouring the rods.

A consideration when performing the final fusion is that posterior osteotomies may be required, especially if a subfascial technique is employed, because the posterior elements may become stiff after repeated exposures. This usually can be done safely by finding the neural canal and then osteotomizing the pars on either side.

Another consideration is that the areas around the anchor sites often are overgrown with bone, and taking the implants out often entails osteotomizing the bone around the anchors. Care should be taken to point away from the spinal canal to avoid neural injury. Although pedicle screws offer three-column support in the foundations, replacing hooks in the fusion mass provides sufficient strength if placed properly, and hooks are easier to place, especially if they were used initially for the growing rods.

Sublaminar wires also offer an attractive option and are useful if lateral translation of the spine is required.

### Pearls and Pitfalls

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Avoid subperiosteal dissection anywhere except the foundation to avoid premature fusion. Use careful blunt dissection beneath the skin bridge to avoid pleural violation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implants</td>
<td>Perform a careful radiographic examination if pedicle screws are desired. Use proper rod contouring to correct both coronal and sagittal deformity. Tandem connectors are straight and should be placed at the thoracolumbar region, which also is straight.</td>
</tr>
<tr>
<td>Lengthening</td>
<td>Do not be too aggressive with lengthenings, especially at the index procedure and first lengthening, to avoid implant issues.</td>
</tr>
<tr>
<td>Indications</td>
<td>May not be indicated in very stiff curves, poor bone quality, older children with limited growth potential, or children too young to allow internal fixation.</td>
</tr>
</tbody>
</table>

### Postoperative Care

Patients are braced postoperatively with a thoracolumbosacral orthosis, beginning when they have been upright for up to 6 months and continuing until fusion of the foundations. Rehabilitation proceeds according to the patient’s tolerance and ability.

### Outcomes

Documented outcomes are short-term, and no level I studies are currently available.

One study showed Cobb angle correction from an average of 82 degrees to 36 degrees at last visit or final fusion.

Spine growth is almost equal to normal, averaging 1.21 cm/year.

Some patients averaged almost 12 cm of growth.

SAL increased from 0.87 to 1.

Better balance and cosmesis

### Complications

- Wound breakdown
- Infection
- Junctional kyphosis
- Crankshaft phenomenon
- Curve progression
- Implant failure

Patients with more frequent lengthenings have fewer implant problems but more wound problems, whereas patients with less frequent lengthenings have more implant problems and fewer wound complications. Implant complications often can be treated during scheduled lengthenings, but wound infections should be treated urgently.

### References

DEFINITION
- A hemivertebra is a congenital anomaly of the spine that forms during the 8th to 12th weeks of embryologic development. It is characterized by the formation of half of a vertebral body, a corresponding pedicle, and a corresponding hemilamina.
- Hemivertebra are classified as a congenital failure of formation.
- A hemivertebra may be classified as fully segmented (ie, separated from the bodies above and below by discs); partially segmented (ie, separated from one adjacent body by a disc and fused to the other adjacent body); or unsegmented (ie, fused to the body above and below; FIG 1).3
- Progressive curvatures of the spine caused by a hemivertebra result from unbalanced growth. Full-segmented hemivertebra have a much higher rate of progression, because the presence of an intact disc space above and below signifies the presence of growth plates and potential asymmetrical spinal growth.

ANATOMY
- The hemivertebra has a partial vertebral body, a pedicle, and a hemilamina.
- Anatomically, it may be joined to the level above or below at either the body, the hemilamina, or both. If the hemivertebra is not fused to either adjacent segment, the potential for asymmetric spinal growth is high.
- A local kyphotic or lordotic deformity may occur with hemivertebra if the associated failure of formation is greater anteriorly or posteriorly.

PATHOGENESIS
- Progressive spinal curvatures due to hemivertebra are a result of disordered growth.
- The hemivertebra is a wedge on the convex side of a curve. In the presence of healthy growth plates above and below (ie, a fully segmented hemivertebra) convex growth is faster than contralateral concave growth, causing a progressive scoliosis.
- In cases of hemivertebra, if the vertebral body lies in the posterolateral quadrant, a progressive kyphosis may arise with the scoliosis.
- The disordered growth eventually may cause curvature to such a degree that normally segmented areas of the spine become involved in the curve, causing deformity and spinal imbalance.

NATURAL HISTORY
- The natural history of a hemivertebra depends on its location and the potential for growth and curve progression.
- Hemivertebrae that are fully segmented progress at approximately 2 degrees a year and can exceed over 45 degrees at maturity.5 These require treatment to prevent deformity and also to prevent adjacent spinal curvature.
- Partially segmented hemivertebrae have much less growth potential (less than 1 degree per year), rarely exceeding 40 degrees at maturity. They usually do not require treatment. Unsegmented hemivertebrae require no treatment.
- Hemivertebra at the lumbosacral junction almost always require treatment, because the lumbar spine takes off obliquely from the sacrum, causing a long compensatory curve in normally segmented regions of the lumbar spine, with resultant cosmetic deformity and spinal imbalance.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Embryologic development of the spine occurs between the 8th and 12th weeks of gestation; hence, other organ systems developing at the same time also may have a congenital anomaly.
- A complete musculoskeletal examination looking for diagnoses such as clubfoot, developmental dysplasia of the hip, and limb anomalies is warranted.
- A complete neurologic examination should be performed, because as many as 40% of patients with congenital scoliosis have a corresponding spinal dysraphism. This examination includes sensory, motor, and reflex testing.
- Occult signs of spinal dysraphism include cutaneous manifestations such as midline spinal hemangiomas, penetrating sacral dimples, or midline hairy patches. Foot anomalies such as vertical talus or asymmetric cavus feet can signify spinal dysraphism.
- Cardiac auscultation should be done, because 20% of patients with congenital scoliosis have congenital heart anomalies.
- Observe shoulder position, trunk position, and waist symmetry. Truncal imbalance is an indicator of curvature.
- Observe the flexibility of the patient’s spine.
- Rotation of the spine during the Adams forward bend test is indicative of deformity and points to its location.
IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standing 36-inch posteroanterior (PA) and lateral radiographs are mandatory to define the deformity and assess the Cobb measurement. Apparent progression may be seen from supine radiographs to standing radiographs (FIG 2A).
- Bending radiographs, in which the patient is directed to bend in a concave and then in a convex direction, are necessary to assess the flexibility of curves above and below the hemivertebra.
- MRI scanning of the brainstem and spinal cord is mandatory before any surgical intervention, given the height rate (30% to 40%) of congenital scoliosis with spinal dysraphism.\(^3\)
- CT scans with three-dimensional (3D) reconstructions should be obtained to delineate the anatomy of the anterior and posterior elements as an aid in planning the operation and to avoid intraoperative problems such as unexpected posterior element deficiencies or fusions (FIG 2B).\(^4\)
- A pediatric protocol should be used for CT scans to avoid the significant radiation exposure that results when adult protocols are used for children.
- Preoperative evaluation of the genitourinary system with a screening ultrasound and evaluation of the cardiac system with an echocardiogram are necessary if these have not been performed, given the rate of anomalies associated with congenital scoliosis.

DIFFERENTIAL DIAGNOSIS
- Failure of vertebral formation
- Failure of vertebral segmentation
- Sequela of infection causing partial vertebral body destruction
- Tumor

NONOPERATIVE MANAGEMENT
- Nonoperative management is reserved for nonprogressive curves caused by hemivertebra.
- Hemivertebra associated with little or no curve progression (unsegmented or partially segmented) may be followed during growth with radiographs every 6 to 12 months, depending on the degree of deformity and age of the basis.
- Bracing has no role in the management of a hemivertebra.

SURGICAL MANAGEMENT
- The classic indication for a hemivertebra resection is a patient with a progressive curve secondary to a fully segmented hemivertebra in the thoracolumbar, lumbar, or lumbosacral regions with a resultant deformity.
- We have found that excision is best performed between the ages of 18 months and 4 years.
- Patients younger than this may be more difficult to instrument, and waiting until this age rarely has caused irrevocable deformity.
- Excision in older patients is feasible; we have found, however, that if diagnosed early there is no reason to wait past the age of 4 years given the progression of curvature and its effect on normally segmented regions of the spine.
- Instrumentation at these ages is technically feasible.

Preoperative Planning
- Review of the preoperative MRI of the spine
  - If spinal dysraphism is present, referral to a neurosurgeon is mandatory.
  - If the patient requires neurosurgical intervention for dysraphism, that procedure should precede the hemivertebra excision, either at the same setting or in a staged setting, at the discretion of the spine surgeon and neurosurgeon.
- Review of the 3D CT scans
  - A complete understanding of the anatomy of the hemivertebra is crucial to avoid intraoperative confusion, especially because associated posterior element fusions or absences can make identifying levels difficult.
  - Studying the pedicle anatomy (ie, length and diameter) of the levels above and below is efficacious given the smaller size of these patients.
- Neurologic monitoring is important and should be done using somatosensory evoked potentials and motor evoked potentials.
- Communication between the monitoring and anesthesia teams should be facilitated to prevent any change in neurologic function brought on by anesthetics, hypotension, or low blood volume.

Positioning
- We perform hemivertebra excisions with the patient in the prone position.
  - This is done on a radiolucent operating frame with chest and pelvic support, which leaves the abdomen free.
  - We also have found it useful to slightly “airplane” the table or bolster the patient so that the convex side is slightly higher than the concave side. This helps with visualization anteriorly, control of bleeding, and retraction of the dura and its contents (FIG 3).
- Before draping the patient, we place a marker over the hemivertebra region and obtain a radiograph.
  - This both confirms the side of the hemivertebra and helps limit excessive incisions and dissections.
- In the past we recommended that hemivertebra excision be performed as a simultaneous anterior-posterior procedure.\(^4\)
  - If the surgeon elects to do this, the patient is placed in the lateral decubitus position with the anterior and posterior fields being prepped into the fields. The patient should be

FIG 2 • A. Standing PA radiograph of a 5-year-old patient with a fully segmented hemivertebra at the thoracolumbar junction. B. A three-dimensional reconstructed CT scan of a fully segmented hemivertebra in a different patient.
placed at the edge of the bed to facilitate retractor placement in the posterior field.
- The anterior approach is on the convex side and should be marked before the patient goes to the operating room.
- We still recommend considering an anterior–posterior procedure when medical conditions (eg, congenital heart disease) caution against excessive bleeding, when a lordotic component renders access to the vertebral body difficult, and when the surgeon is unfamiliar with posterior-only approaches to circumferential surgery.

**Approach**
- If an anterior–posterior procedure is being performed, the anterior procedure should be a standard transthoracic, transthoracic-retroperitoneal, or retroperitoneal approach, depending on the location of the hemivertebra. The anterior approach often can be a limited one, because the only exposure needed is of the hemivertebra and the discs above and below.
- The posterior approach is a standard posterior midline incision with subperiosteal dissection out to the tips of the transverse processes.
- Diathermy aids in keeping blood loss to a minimum during dissection.
- Preoperative review of the CT scan should forewarn the surgeon of posterior element fusions and, more importantly, posterior element deficiencies.
- Dissection should proceed with caution over areas of laminar deficiency.
- Once completely dissected, a spot radiograph or fluoroscopic view should be obtained to confirm the appropriate level.

**HEMIVERTEBRA EXCISION**

**Pedicle Screw Placement**
- Implant anchors should be placed before excision, because blood loss at this point should be at a minimum.
- Where possible, we prefer bilateral pedicle screws as a basis for fixation. Pedicle screws may be placed in patients as young as 1 year of age.
- Preoperative CT scans can help assess the feasibility of screw placement.
- Implants should be titanium, and either 3.5- or 4.5-mm rod systems should be used in younger patients.
- Screw diameter and length can be at least estimated based on the preoperative CT scan.
- Screws should be placed in a stepwise manner, beginning with obtaining a cancellous blush with a burr at the appropriate starting position.
- Starting positions in normally segmented areas of the spine are well documented.
- A pedicle awl can then be used to obtain access down the pedicle into the vertebral body.
- Once the pedicle has been accessed, probing of the four walls of the pedicle and floor of the body is necessary to confirm accurate position. We then use the probe as a depth gauge to determine screw length.
- The hole is then tapped 0.5 mm under the expected screw diameter, and the pedicle walls and floor are reprobed.
- A fixed-angle screw of the appropriate diameter and length is then placed (TECH FIG 1A).
- Appropriate screw position is confirmed using triggered EMG stimulation of all screws (TECH FIG 1B) and then checking PA and lateral radiographs and fluoroscopic views (TECH FIG 1C).
Hemivertebra Excision

- The first step in excision is dissecting over the edge of the transverse process and down the lateral wall of the body using a Cobb elevator and curved-tip device, followed by curved retractor placement (TECH FIG 2A).
  - This step aids in protection of structures lateral and anterior to the wall on the hemivertebra. If the hemivertebra is in the thoracic region, it will be necessary to resect the rib head first to obtain access.

- The cartilaginous surfaces of the concave facet should be resected to encourage fusion.

- Resection then begins in the midline with the ligamentum flavum using a Kerrison rongeur (TECH FIG 2B,C), followed by resection of the hemilamina.
  - Resection should extend over to the facet, while the exiting nerve roots above and below the hemivertebra are identified and protected.
  - The transverse process and dorsal cortical bone over the pedicle can be resected in similar fashion until the cancellous bone of the pedicle and cortical outlines of its wall are visualized (TECH FIG 2D,E).
  - Care should be taken to avoid nerve roots, which are present rostral and caudal to the pedicle walls of the hemivertebra.
  - Gelfoam (Pfizer Inc, New York, NY) and cottonoids should be used judiciously to protect the dura and create a space between dura and bone to be resected.
  - The subperiosteal plane down the lateral wall of the pedicle and body is then developed, with a Cobb elevator used to facilitate retraction and protection. The dural contents can be protected by a nerve root retractor.
  - Bipolar sealing of epidural vessels that lie on the medial aspect of the pedicle and down on the inner wall of the body will aid in controlling blood loss and improving visualization.

- Continued resection down the pedicle and into the hemivertebra body can be done by a diamond-tipped burr, which helps protect against unwanted injury to soft tissue structures.

- Working stepwise within the walls of the pedicle and down within the confines of the body helps protect surrounding vital structures and makes removal of the cortical shells easier (TECH FIG 2F). The walls of the pedicle can then be easily resected with a curette or pituitary rongeur, as can the remaining walls of the body of the hemivertebra.

- Protection lateral and anterior to the confines of the hemivertebra wall is necessary to avoid injury to vital structures such as the aorta. Generally, the dorsal cortex of the vertebral body is removed last (TECH FIG 2G).

- This resection is a wedge resection, which includes the discs above and below as well as the concave area of the disc.

- The disc material should be removed with a pituitary rongeur and curettes; the dura and its contents are protected with a nerve root retractor.

- If the disc material above and below is not removed, correction will be limited, and anterior fusion will be less reliable.
**Closure of Wedge Resection**

- We place resected vertebral cancellous bone as well as allograft clips into the wedge resection site anteriorly.
- We have found that it is beneficial to compress and close the resection site with laminar hooks and by external three-point pressure on the body (TECH FIG 3A).
  - We place a downgoing supralaminar hook at the superior level and an upgoing infralaminar hook on the inferior level.
  - We place a rod and compress with closure of the resection site and correction of the deformity. Using this rod avoids having to place large compression forces across pedicle screws. This allows the screws to maintain correction without possible plowing of the screws into the immature bone or pedicles.
- The compression should be slow and controlled, with the dura under visualization so that it is not caught in the closure of the posterior elements (TECH FIG 3B,C).
  - If insufficient correction is achieved or if the adjacent laminae abut prematurely, it may be necessary to resect further along the edges of the laminae.
- Two additional rods are then placed, one on either side of the spine, connected to the corresponding screws. A crosslink should be applied if at all possible (TECH FIG 3D).
- The spine is then decorticated. We prefer to place corticocancellous allograft, because it is effective and avoids harvesting the iliac crest.

---

**TECH FIG 2** • Hemivertebra excision.  
A. Placement of Cobb elevator at lateral border of hemivertebra (arrow).  
B. Resection of the posterior hemilamina using a Kerrison rongeur.  
C. Rongeur resecting down the pedicle with Gelfoam protecting the dura.  
D. Further resection down the pedicle (arrow), with lateral structures protected.  
E. Complete visualization of the vertebral body (arrow) with anterolateral protection.  
F. Axial schematic illustration of working down the pedicle with medial and lateral protection.  
G. Arrow points to the area of complete resection.
**Anteroposterior Excision**

- We routinely place our posterior implant anchors before performing any resection. Once complete exposure (both anterior and posterior) has been performed (TECH FIG 4A), posterior screws are placed.
- Anterior resection begins by creating a full-thickness subperiosteal flap over the hemivertebra after localization is confirmed (TECH FIG 4B).
- Starting at the inferior endplate of the adjacent superior body and the superior endplate of the adjacent inferior body, we create longitudinal full-thickness cuts in the periosteum.
  - At the endplate region, we make anteroposterior cuts in the periosteum and start a full-thickness periosteal flap, working anteriorly to the contralateral side.
  - We move posteriorly until we can visualize the hemivertebra pedicle.
- The discs above and below the hemivertebra are resected all the way posteriorly to the posterior longitudinal ligament.
- We then start resection of the hemivertebra vertebral body back to the posterior cortical wall of the body with rongeurs and a diamond-tipped burr.
  - The posterior wall can be resected and peeled off the posterior longitudinal ligament with a rongeur, obtaining access by starting at the level of the disc resections.
  - Part of the visualized pedicle can be resected.
- Posterior resection can then begin, starting with the hemilamina and proceeding to the pedicle (TECH FIG 4C).
- With both incisions open and fields exposed, resection of the pedicle can be done by working through both regions (TECH FIG 4D). This allows complete visualization and maximum control of the surgical field.
- Once the hemivertebra has been resected, correction of the deformity is the same as described earlier, using a three-rod technique if possible (TECH FIG 4E).
- With this technique, correction is aided by unbreaking the table (or removing any lateral bolster) and pushing down on the convex spine to facilitate closure of the wedge resection.
POSTOPERATIVE CARE

- The immediate postoperative hospitalization and care are similar to that for most patients being treated for spinal deformity.
- When fixation is adequate, we place the patients in a custom-molded thoracolumbosacral orthosis for 3 months.
- In patients who are younger than 2 years of age, or in cases where fixation is not adequate, we recommend a Risser-type cast, to include a shoulder or both thighs for 2 months, followed by a brace for up to a total of 6 months postoperatively.
- The removal of spinal implants is not mandatory; however, given the young age of the patients and individual body habitus, occasionally it is necessary to remove the implants after a year secondary to prominence.

OUTCOMES

- Hemivertebra excision may be performed as a posterior-only technique or as a combined anterior–posterior technique, with excellent curve correction of approximately 70% (FIG 4).6
- The rate of union for this procedure is near 100% in pediatric patients.
- The procedure may be performed safely using either technique with no neurologic complications.

COMPLICATIONS

- Inadequate correction
- Dural injury
- Neurologic injury
- Loss of fixation
- Implant failure
- Excessive blood loss
- Nonunion
- Infection

REFERENCES


FIG 4 • Correction of deformity. A. Postoperative standing radiograph after excision and curve correction of patient shown in Figure 2A. B. Standing lateral radiograph of the same patient showing excellent sagittal balance after excision.
DEFINITION

- Spondylolisthesis refers to translation of one vertebra in relation to another in the sagittal plane.
- In the child and adolescent, this most commonly occurs at the L5–S1 junction.
- Most patients are asymptomatic.
- Most patients commonly present for low-grade back pain and not for radicular symptoms.

ANATOMY

- Pars interarticularis includes portions of the lamina, transverse processes, and pedicle.
- There is anterior forward slippage of the fifth lumbar vertebral body on the sacrum.
- In longstanding cases, the superior endplate of the sacrum becomes dome-shaped, and accordingly the inferior endplate of L5 becomes concave and beaks at the anteroinferior corner (FIG 1).
- The transverse processes are often hypoplastic.
- The posterior elements of L5 are detached (Gill fragment).
- The nerve roots of L5 are draped over the dome of the sacrum.

PATHOGENESIS

- In spondylolisthesis the pars interarticularis is either elongated or discontinuous.
- An isthmic defect is the result of chronic loading of a pars interarticularis that is genetically predisposed to fatigue failure.
- A dysplastic slip is secondary to congenital anomalies of the lumbosacral articulation, including maloriented or hypoplastic facets and sacral deficiency. The pars is poorly developed, allowing for elongation or eventual separation and forward slippage.

NATURAL HISTORY

- Isthmic
  - Most patients have mild or no symptoms.
  - Most present with some degree of slip.
  - Less than 4% demonstrate slip progression.
- Dysplastic
  - Risk factors for progression include diagnosis before the adolescent growth spurt, girls, and greater than 50% slip.
  - Higher frequency of progression
  - More likely to have neurologic problems
  - More likely to require operative treatment

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients typically present with low back pain of insidious onset, occasionally with radiation to the buttock or posterior thigh.
- Radicular symptoms and disturbance of bowel and bladder function are rare with spondylolysis or low-grade spondylolisthesis but may be reported with high-grade slips.
- Specific physical activities and sports participation (sports with repetitive hyperextension of the lumbar spine—for instance, football linemen, gymnasts, divers)
- Tight hamstrings are common, resulting in a mild crouched gait.
- Inspection, palpation, and range of motion
  - Flattened lumbar lordosis
  - Heart-shaped buttocks
  - Sacrum appears vertically oriented
  - Visible or palpable step-off at the spinous processes of the involved levels (FIG 2)
  - Limited lumbar flexion and extension
  - Lumbar hyperextension frequently will elicit pain
- Neurologic examination
  - Lumbar sensory and motor root testing
  - Evaluation of deep tendon reflexes and abdominal reflexes
  - Rectal examination indicated in patients with bowel or bladder dysfunction
- Straight leg-raise testing to assess nerve root irritation and popliteal angle measurements to assess hamstring spasm and contracture
Popliteal angles greater than 40 degrees indicate significant hamstring tightness; this is the most common neurologic finding in patients with spondylolisthesis.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standing posteroanterior (PA) and lateral radiographs of the entire spine
  - Standing PA radiographic view allows for evaluation of coexisting scoliosis secondary to paraspinal spasm, whether idiopathic or olisthetic.
  - Standing lateral view is useful for assessing global sagittal balance.
  - Spot lateral view of the lumbosacral junction is useful for identifying spondylolytic defects and documenting the degree of spondylolisthesis (**FIG 3A**).
  - Supine lateral hyperextension view of lumbosacral junction to assess passive reduction of L5 on S1.

**Meyerding classification**

- Quantifies amount of forward translation
- Based on percentage subluxation of L5 on S1 (**FIG 3B**)
  - Grade I: less than 25%
  - Grade II: 25% to 50%
  - Grade III: 50% to 75%
  - Grade IV: 75% to 100%
  - Grade V (spondyloptosis): more than 100%

**Slip angle**

- Quantifies degree of lumbosacral kyphosis.
- Line drawn parallel to superior border of S1 unreliable because of the rounding of the superior sacrum occurring secondary to the slip.
- Angle subtended by intersection of a line drawn along the superior endplate of L5 and the perpendicular of a line drawn along the posterior cortex of the sacrum (**FIG 3C**).
- Slip angle greater than 50% is associated with a greater risk of slip progression, instability, and development of postoperative pseudarthrosis.

**Single-photon emission computed tomography (SPECT) of the lumbosacral spine**

- Limited utility in spondylolisthesis.
- Most effective method for detecting spondylolysis when plain radiographs are normal and patient history and physical examination are suggestive.
- Increased radionuclide uptake in an intact pars, lamina, or pedicle is consistent with stress reaction (can treat).
- Relative decrease in tracer uptake on serial SPECT scans has been correlated with improvement of clinical symptoms and signs in patients treated for symptomatic spondylolysis.

**Computed tomography (CT) with sagittal and coronal reconstructions is the best modality for defining the bony anatomy (**FIG 3D**).**

- CT can evaluate for degree of cortical disruption, lysis, and sclerosis at the pars, lamina, or pedicle.
- 2D and 3D CT reconstruction of the spine is useful to clarify the pathoanatomy of the region for preoperative planning.

**Magnetic resonance imaging (MRI)**

- For evaluation of the health of the L4–L5 disc (if viable, try to preserve level; if desiccated, include in fusion).
For evaluation of posterior protrusion of the L5–S1 disc. Reduction at this level can cause herniation of the disc, resulting in cauda equina syndrome (FIG 3E).

NONOPERATIVE MANAGEMENT
- Most children and adolescents with low-grade spondylolisthesis respond to nonoperative measures, including activity restriction, physiotherapy, and brace treatment.
- Low-grade isthmic spondylolisthesis rarely progresses and can be followed with serial radiographs at 6-month intervals until the patient is skeletally mature. After this, radiographs can be done on a yearly basis.
- Patients with low-grade dysplastic spondylolisthesis are at greater risk for progression, development of neurologic deficit, and need for operative intervention.
- High-grade spondylolisthesis (over 50% slippage) responds less reliably to nonoperative measures.
- There is no evidence to support prophylactic fusion for asymptomatic high-grade isthmic spondylolisthesis.
- Physical therapy is the mainstay of treatment, with emphasis on hamstring stretching. It is our observation that patients who can overcome their hamstring tightness and spasm tend to have less pain and fare better. Persistent tightness of the hamstrings is associated with continued pain and, perhaps, an ultimate need for operative treatment.

SURGICAL MANAGEMENT
- Indicated for the child with persistent low back or leg pain.
- Rarely indicated in patients with less than 50% slippage. In these patients, all efforts at nonoperative treatment should be exhausted before an operation is considered, as it is known by natural history that the chance of progressive slippage is low.
- Indicated for the symptomatic, skeletally immature or mature individual with greater than 50% slippage.
- Based on the patient’s degree of slippage and symptoms, several operative options are available.
- Posterolateral in situ fusion
  - Gold standard, with longest follow-up.
  - Reserved for patients with no neurologic symptoms.
  - Does not correct deformity unless patient is postoperatively placed in a hyperextension bilateral pantaloon spica cast.
  - With or without instrumentation. Use of instrumentation can obviate the need for postoperative immobilization and may increase fusion rates.
  - Postoperative immobilization ranges from nothing to a brace with thigh extension to a bilateral pantaloon spica cast.
  - Gill procedure (removal of posterior elements of L5) is done if preoperative neurologic symptoms are present or reduction is planned.
- Bohlman posterior transsacral arthrodesis
  - Can be used with or without instrumentation
  - Can reduce slip angle
  - Can provide anterior interbody support through a posterior-only approach
  - Provides opportunity for decompression of L5 and S1 nerve roots
- Instrumented posterolateral fusion with reduction of L5–S1, posterior lumbar interbody fusion, and sacral dome osteotomy
  - Extensive, time-consuming procedure
  - Sacral dome osteotomy effectively shortens the spine and allows for posterior translation of L5 on S1
  - Gill procedure at L5 to allow for displacement after reduction
  - Requires exploration and decompression of L5 and S1 nerve roots
  - Anterior interbody support is achieved by L5–S1 discectomy and posterior lumbar interbody fusion procedure

Preoperative Planning
- Type of incision (midline versus transverse curvilinear)
- Will decompression be needed?
- Should fusion extend to L4?
- What type of bone graft will be used?
- Will instrumentation be used?
- Will postoperative immobilization be used?
- Consultation with neuromonitoring for preoperative baseline somatosensory evoked potentials (SSEPs) and electromyographic (EMG) studies
- Consultation with urology for urodynamic studies

Positioning
- Neurologic monitoring leads are placed for SSEPs and EMGs.
- Multiple large-bore intravenous lines, an arterial line, and a Foley catheter are placed.
- The patient is then transferred to the prone position on a standard operating table, with care taken to ensure that the hips are at the level of the table joint so that flexion and extension of the lumbar spine can be controlled by movement of the table.
- Extension of the hips may direct the superior endplate of the sacrum toward the inferior endplate of L5.
- Flexion of the hips may allow for more of a passive postural reduction (FIG 4).
- Bolsters underneath the chest and anterior superior iliac spines prevent abdominal compression and allow epidural venous return, thus decreasing epidural bleeding during spinal surgery.
- All bony prominences are well padded, including medial elbows, knees, shins, and ankles.
- A lateral fluoroscopic image is taken at the lumbosacral junction to see if passive postural reduction has occurred.
- After the patient is properly positioned on the table, baseline neurologic monitoring is obtained before the start of the procedure.

Approach
- We prefer a standard midline incision from L4 to the sacrum.
- This allows for bilateral posterolateral exposure of the spine out to the tips of the transverse processes.
- If desired, bone graft can be harvested from both ilia.

FIG 4 • Patient positioning. Note flexion of hips.
EXPOSURE

- The patient is prepared and draped in the standard fashion.
- A PA fluoroscopic image is taken to verify levels.
- The incision is marked and Marcaine with epinephrine is injected along the course of the incision for local anesthesia and hemostasis.
- The skin is sharply incised with a no. 15 blade scalpel and retractors are placed.
- Electrocautery is used to dissect through the subcutaneous fat until the fascia is reached.
- The spinous processes are identified via palpation. Care needs be taken at the L5–S1 level because of the displacement of L5 on S1 (TECH FIG 1).
- Bovie cautery is used to subperiosteally expose the posterior elements out to the tips of the transverse processes.
- At L5 the transverse processes are very deep within the wound.
- Care needs be taken while exposing the transverse processes as the nerve roots lie anterior to them.
- The sacrum is exposed posterolaterally out to the level of the ala.

INSTRUMENTATION

- We prefer to place the pedicle screws before performing the decompression and reduction.
- Fluoroscopic imaging is often necessary when placing screws at the L5 level because of the distorted anatomy.
- We use fluoroscopic imaging for the placement of S1 screws to ensure tricortical purchase anteriorly on the sacrum.
- We have found it useful to use polyaxial screws at all levels, with reduction screws at L4 and L5.
- If difficulty is encountered while placing screws at L5, the surgeon can wait until the decompression is done and then use a Woodson elevator to palpate the pedicle within the canal.
- Placement of pedicle screws at L5 can be difficult because the surgeon must direct the screws in an awkward trajectory.
- When placing pedicle screws we prefer an exaggerated lateral trajectory to provide for better pullout strength.
- Consideration can be given to bicortical purchase (anterior penetration) with the L5 screws to increase pullout strength during reduction.

DECOMPRESSION

- Decompression is done if preoperative neurologic symptoms exist or if a reduction is planned.
- Both lamina and the spinous process of L5 are removed en bloc (Gill fragment; TECH FIG 2A).
- The L5 nerve roots are identified and are traced from their exit from the dura out the neural foramina. It is crucial that the nerve roots be decompressed if a reduction is to be considered (TECH FIG 2B).
- The S1 nerve roots are often found draped over the sacrum, and again care should be taken that adequate space exists for their displacement after reduction.


ROD PLACEMENT

- Rod length should be measured and an exaggerated lordosis will be needed to be bent into the rod. If this is not done, the surgeon risks pullout of the L5 screws during rod placement (TECH FIG 3).
- The amount of lordosis will depend on the amount of reduction desired: if no reduction is planned, the rod will have more lordosis to allow for in situ placement.
- Conversely, reduction of L5 can also be achieved by distraction at L4–S1.
- Reduction screws greatly facilitate rod placement at both L4 and L5.

BONE GRAFT

- During the initial exposure of the spine, all soft tissue attachments should have been removed from the posterior elements.
- The facet joints are best removed with a large rongeur.
- The posterior elements are decorticated with a burr.
- Large amounts of bone graft are placed in the posterolateral gutters. An attempt should be made to place bone anterior to the tips of the transverse processes.
- When a Gill procedure is done, this unfortunately removes surface area for fusion at the lumbosacral junction.
- Care should be taken that no bone graft fragments impinge on the exiting nerve roots.

CLOSURE

- At our institution, before closure the wound is assessed for any frank bleeding vessels and bone graft is placed. Drains are placed for wounds considered at risk for hematoma formation.
- Fascia is closed with figure 8 braided absorbable suture (no. 1 Vicryl). The goal is a watertight closure.
- Subcutaneous layers are closed with interrupted braided absorbable suture (no. 0 and 2-0 Vicryl). The goal is to decrease wound tension.
- Skin is closed with a running single filament absorbable (3-0 Monocryl). The goal is cosmetic closure.
- Skin closure is reinforced with 1-inch 3M Steri-Strip Adhesive Tape Closures and surgical adhesive (Mastisol Liquid Adhesive).
- Sterile compression dressings are applied to decrease the risk of postoperative hematoma.
- Extreme care needs to be taken when transferring the patient to the stretcher.
- An assistant is needed to hold the hips and knees flexed at 90 degrees during transfer.
- Pillows need to be placed under the thighs to hold the hips and knees flexed.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Bovie electrocautery</th>
<th>Decreased bleeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurologic monitoring with preoperative baseline studies</td>
<td>Helps minimize risk of neural injury</td>
</tr>
<tr>
<td>Postoperative neurovascular checks</td>
<td>Neurovascular checks must be done frequently postoperatively and all lumbar nerve roots must be tested</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Careful neurologic examinations need to be performed postoperatively, especially if a reduction has been done. All lumbar nerve roots need to be tested.
- The Foley catheter is removed on postoperative day 2 and urinary function is closely monitored.
- If the plan is for the patient to be placed in a spica cast, he or she is returned to the cast room 1 week after surgery and placed on a Risser table in hyperextension. A pantaloon hip spica cast is applied.
- If instrumentation is used, no postoperative immobilization is required.
The hips and knees are progressively extended (pillows removed) as tolerated. This may take several days.

- Patient may be out of bed to a chair the morning after surgery with the hips and knees flexed.
- Ambulation is progressed as the patient is able to tolerate increased flexion at the hips and knees.
- The patient is followed clinically and radiographically at monthly intervals to assess progress (FIG 5). Consideration should be given to performing a CT scan at 6 months to assess the quality of the spinal fusion mass.

OUTCOMES

- If reduction is performed, there may be an improvement in clinical appearance.
- Hamstring spasm is often relieved after operative intervention.

COMPLICATIONS

- Wound hematoma
- Infection
- Pseudarthrosis
- Urinary retention may require prolonged use of a Foley catheter or intermittent straight catheterization.
- Neurologic injury
  - The risk of neurologic complication increases with the amount of reduction performed.
  - Motor deficits that are detected at the conclusion of the procedure are probably best treated with exploration and release of correction.
  - Fortunately, most motor deficits will improve with time, although improvement and recovery may take several months.
  - Postoperative radicular-like symptoms are managed with close observation and liberal use of gabapentin.

REFERENCES

DEFINITION

- **Spondylolisthesis** is the forward displacement of a vertebra over the next adjacent segment.
- In children and adolescents, this most commonly occurs in the presence of a spondylolytic defect or a nonunion of the pars interarticularis. It also may occur in the presence of inherent spinal anomalies such as deficient or maloriented lumbar and lumbosacral facets.
- Spondylolisthesis has been grouped into five different types under the Wiltse-Newman classification: dysplastic, isthmic, degenerative, traumatic, and pathologic.
  - Ordinarily, the dysplastic and isthmic types apply to children (FIG 1A).
- The Meyerding classification is used to grade the degree of slippage (FIG 1B). The classification is divided into five grades:
  - Grade I: 0 to 25% slip
  - Grade II: 26% to 50% slip
  - Grade III: 51% to 75% slip
  - Grade IV: 76% to 100%
  - Grade V: corresponds to spondyloptosis
- Anterior slippage of 50% or more (Meyerding grade III or IV) of the transverse width of the caudal segment is termed a high-grade slip.

ANATOMY

- The vertebral bodies have a tendency to increase in size with progression caudally. This increase is believed to be related to the demands of increased stress and weight bearing placed on the lumbosacral spine.
- The lumbar vertebrae are widest in transverse diameter than in the anterior-posterior plane. The lumbar foramina appear trefoil-like. The spinous processes are large and have an oblong appearance. Its transverse processes are long and slender and project directly lateral. The facet joints of the lumbar spine are oriented more toward the sagittal plane, allowing for more flexion and extension motion.
- The neurovascular structures in the lumbar spine run a similar course when compared to the thoracic spine. The segmental vasculature arises directly from the aorta and run dorsally around the lateral aspect of each vertebral body. Branching occurs near the pedicles, where one branch supplies the spinal...
canal and the other supplies the paraspinal musculature. These vessels run between the transverse processes, where they may be susceptible to injury in more lateral exposures.

- The spinal cord ends most commonly at the level of L1–2. The conus medullaris extends from the most distal portion and goes on to innervate the bowel and bladder. Beneath the conus, the lumbar and sacral nerve roots are arranged to form the cauda equina. Each of these roots exits segmentally below the pedicle of the corresponding vertebrae.

- The pedicles are cylindrical structures that bridge the posterior elements of the spine with the vertebral body. The height and diameter of the pedicles increases from the thoracic to the lumbar spine. The transverse diameter of the pedicle gradually increases from L1 to L5. The transverse angulation of the pedicles is directed medially, increasing gradually from L1 to L5. The sagittal plane orientation of the lumbar spine pedicles is neutral.1,8,20

- The spinal cord and the dural sac lie medial to the pedicles. Corresponding nerve roots are found both superior and inferior to each pedicle, with the inferior nerve root in closer proximity to the pedicle.1,20

- The orientation of the facet joints in the lumbar and lumbosacral spine is related to function. In the upper part of the lumbar spine, the orientation of the joints allows for multidirectional stabilization. This is in contrast to the lumbosacral facet joint, which is flat and more coronally oriented and acts to resist shearing forces through the joint.7

PATHOGENESIS

Spondylolisthesis is a disorder related to upright posture, increasing the forces acting upon the lower segments of the spine, and is never seen in the nonambulatory individual.

- The lumbar spine is subject to high shear forces and compressive loads. The “bony hook,” consisting of the pedicle, the pars interarticularis, and the inferior facets, provides stability by resisting these shear forces and preventing forward slippage or sliding over the inferior endplates.

- In the setting of congenital or dysplastic spondylolisthesis, the spine begins to slip even if the posterior elements are intact. This is brought about by the structural abnormality’s inability to resist the load and shear forces seen in the lumbosacral spine.

- In the isthmic type of spondylolisthesis, secondary to a pars defect, the high shear and compressive forces occurring through the lumbar spine and lumbosacral joint are less well resisted. This is due to the loss of posterior restraint, allowing forward displacement of one vertebral segment over the next more caudal level.7

NATURAL HISTORY

- Harris and Weinstein10 reviewed 38 cases with high-grade spondylolisthesis treated nonoperatively and with in situ fusion with a mean follow-up of 24 years and showed that 36% of patients treated nonoperatively were asymptomatic, 55% had back pain, and 45% had neurologic symptoms.

- Beutler et al,1 in a 45-year follow-up study of 30 patients diagnosed with spondylolysis, screened in the 1950s from a pool of 500 first-grade children, showed that no patients with unilateral pars defects developed spondylolisthesis. They also showed that cases with bilateral pars defects and low-grade slips follow a course similar to that seen in the general populace. Slowing of slip progression was observed with each decade.

- In a comparison of the progression of the slip between isthmic and dysplastic types of spondylolisthesis, dysplastic types showed increased progression.15

PATIENT HISTORY AND PHYSICAL FINDINGS

- In symptomatic patients, the most common clinical manifestation is low back pain, with or without radicular pain radiating through the L5 or S1 dermatome. Onset of pain is usually chronic and insidious, but acute episodes do occur.

- In patients with radicular symptoms, unilateral involvement is more common.

- Flattening of the lumbar lordosis is commonly seen on physical examination (FIG 2).

- Abnormal gait exemplified by a hip-flexed, knee-flexed gait pattern may be present.

- Hamstring tightness, which also may be present, is tested by measuring the popliteal angle. Many patients with high-grade slips will have a tendency to develop tight hamstrings owing to the development of abnormal biomechanics in the lumbar spine.

- Straight leg raise should be done to test for nerve root compression or hamstring tightness. A positive examination with radicular pain denotes either an L5 or S1 nerve root compression. Radicular pain elicited before 70 degrees is indicative of root compression, whereas that elicited above 70 degrees might denote extraspinal compression of the sciatic nerve. Pain in the posterior thigh denotes hamstring tightness.

- A rectal examination should be done in the presence of bladder and bowel dysfunction.

- Examination should also include the Lasgues test. If the pain is exacerbated, that finding supports the diagnosis of a nerve root compression. Posterior thigh pain secondary to tight hamstrings will not be aggravated.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Initial imaging includes standing posteroanterior and lateral radiographs of the spine as well as oblique views (FIG 3A–C).

- Plain radiographs are used to establish the overall alignment of the spine in both the coronal and sagittal planes. The
sagittal alignment should be noted, particularly the degree of lumbar lordosis above the lumbosacral kyphosis. Any structural abnormalities in the spine aside from the slip should be noted. These abnormalities include the presence of spina bifida occulta, scoliosis, or sagittal plane abnormalities. Other spinal problems should be treated as separate entities.

- CT scans are valuable in defining the exact bony abnormality and will help in preoperative planning (FIG 3D,E).
- MRI studies are indicated when there is evidence of neurologic compromise. MRI provides good visualization of nerve root or cauda equina compression (FIG 3F).

**DIFFERENTIAL DIAGNOSIS**
- Mechanical disorders: trauma, overuse syndromes, herniated disc, slipped vertebral apophysis
- Developmental disorders: Scheuermann’s kyphosis
- Inflammatory disorders: discitis, vertebral osteomyelitis, calcific discitis, rheumatologic conditions
- Neoplastic disorders

**NONOPERATIVE MANAGEMENT**
- The treatment of high-grade spondylolisthesis is surgical. Even in asymptomatic cases, the risk of progression or the development of cauda equina syndrome warrants surgical intervention.

**SURGICAL MANAGEMENT**
- The first goal of surgical management is to avoid complications (“first do no harm”).
- Surgical management is indicated in high-grade slips, with or without the presence of neurologic compromise, or in refractory symptomatic patients.
- Selecting the appropriate surgical intervention for each patient requires:
  - A thorough evaluation of the deformity
  - An in-depth understanding of the nature of the pathology
  - An understanding of the indications for treatment
  - Awareness of the limitations of each procedure and its possible complications

**FIG 3** • PA (A), lateral (B), and left and right oblique (C) radiographs demonstrating high-grade spondylolisthesis. Axial (D) and sagittal (E) CT scan sections demonstrating bony deformity. F. MRI demonstrating high-grade spondylolisthesis.
Preoperative Planning
- A detailed assessment of the history and physical and neurologic examinations should be performed.
- All imaging studies must be carefully reviewed and analyzed with attention to trying to correlate physical and neurologic findings with those found in special examinations.
- The degree of the slip as seen on the lateral standing spine radiographs is assessed and graded according to the Meyerding classification.
- Slippage of 50% or more is considered a high-grade slip.
- The slip angle measures the degree of lumbosacral kyphosis.
- A slip angle greater than 50 degrees is associated with progression, instability, and pseudoarthrosis (FIG 4A).
- Pelvic incidence (PI) is a fixed anatomic parameter that estimates the position of the sacral endplates and overall pelvic morphology. It helps determine the overall sagittal profile of the spine.3,12
  - The PI increases with age and stabilizes in adulthood.14
  - The mean PI is 47 degrees in children and 57 degrees in adults.
  - Increased PI is indicative of increased lumbar lordosis and increased shear forces (FIG 4B). Increased PI may predispose to the development of spondylolisthesis.3,11,12
  - In the presence of spondylolisthesis, an increased PI may be indicative of an unbalanced pelvis and is a risk factor for slip progression. Slip reduction is required in these cases to restore proper spinopelvic biomechanics and stabilize the spine. In those cases, where the spine is balanced and PI is low, a fusion in situ may be all that is required for treatment.

Positioning
- The patient is positioned prone on the operative frame.
- Two operative positions are commonly used for posterior approaches to the spine.
  - The first is the knee-chest position, where both the hips and knees are flexed.
  - The second position is with the use of a four-poster frame, where the lower extremities are fairly parallel to the trunk. In this position, the patient is supported under the anterior superior iliac spines and pectoral muscles bilaterally.
  - Our preference is to place the patient in the Jackson spinal table with the hips and knee in the flexed position, allowing for easier access to the lumbar spine.
- The position of the face and arms is important. The face should be adequately supported, making sure that no excessive pressure is applied, especially around the orbits. The neck should be in neutral position. The upper extremities should also be in 90–90 position, in which the arms are in 90 degrees of abduction and the elbows are in 90 degrees of flexion. The upper extremities should be adequately padded to allow for venous and arterial access. Adequate padding, support, positioning, and monitoring of the upper extremities likewise prevents undue neurologic injury due to stretch or excessive pressure.19

**ROUTINE REVISION WITHOUT DIAPHYSEAL DEFECT**

**Bohlman Technique**
- In the Bohlman technique,22 the procedure starts with a standard posterior midline approach extending from the second lumbar vertebra to the level of S2.
- The spine is exposed subperiosteally, revealing all the posterior elements.
- The posterior elements of L5 and S1 are removed (the posterior elements of L4 are removed if needed).
- A wide foraminotomy is performed to decompress the L5 and S1 nerve roots.
- The dura is gently freed and retracted.
- A curved osteotome is used to make a ventral trough through the sacrum to remove pressure from the dura (TECH FIG 1A).
- The dura is retracted, and a ½-inch guide pin is placed in the midline of the sacrum toward the body of L5. This is done under fluoroscopic guidance to ensure proper placement.
- A ½-inch cannulated drill bit is used to drill over the guide pin, taking extra care not to violate the anterior cortex of L5. The depth is approximately 5 cm.
- A mid-diaphyseal fibular graft is trimmed to fit into the drill hole and inserted (TECH FIG 1B). The position of the graft is confirmed fluoroscopically.
- Alternatively, a split fibular graft can be inserted as described by Bohlman in 1982.2
- This is performed by inserting a guide pin through the posterior prominence of the sacrum approximately one cm from the midline to the body of L5, avoiding the first sacral nerve root. The position of the guide pin is confirmed radiographically. This process is done bilaterally.
A wide laminectomy is performed removing the posterior elements of L5 and S1. The dura is retracted gently, and a curved osteotome is inserted to perform a sacroplasty to take pressure off the dura. A fibular strut graft is fashioned and inserted into the sacrum to the body of L5. The procedure is then completed by performing bilateral posterolateral fusion.

- A 3⁄8-inch cannulated drill bit is used to drill over each guide pin, taking extra care not to violate the anterior cortex of L5. The depth is approximately 5 cm on both sides.
- A fibular graft is split in half and trimmed. It is then inserted and countersunk 2 mm into each hole.
- A standard posterolateral transverse process fusion is done, extending from the sacral alae to L4, to complete the procedure.

### Children’s Hospital of Philadelphia (CHOP) Technique

#### Incision and Dissection

- The lumbar spine is approached posteriorly through a direct midline incision extending from L2 to S2 (TECH FIG 2A).
- The dissection is done using loupes for magnification and head lamps for illumination.
- The midline incision is carried down to the fascia through sharp dissection of the skin and subcutaneous tissue.
- The midline dissection is carried down subperiosteally, exposing the posterior elements of the spine, with care taken to protect the most proximal intact facets (TECH FIG 2B,C).
In isthmic spondylolisthesis, removal of loose bodies and the posterior elements of L5 is done.

**Decompression**

- The nerve roots of L5 and S1 are identified, and a wide decompression of the L5/S1 roots is carried out bilaterally (TECH FIG 3A).
- The dura and neural elements over the sacrum are gently retracted, and a sacroplasty is done using an osteotome or a high-speed diamond burr (TECH FIG 3B).

**Reduction and Fusion**

- Pedicle screws are placed into the L4, L5, S1, and S2 pedicles (TECH FIG 4A).
- The anesthetic and spinal monitoring team is informed before any corrective maneuvers are performed.
- The reduction is performed under fluoroscopic guidance, avoiding overcorrection. With the use of reduction tools...
attached to the pedicle screws, the slip angle is gradually reduced under fluoroscopic guidance by applying a dor- sal extension maneuver to the lumbar pedicle screws (TECH FIG 4B).

- The reduction is performed slowly and maintained over time to allow for stretch of the soft tissue. Once a satisfactory correction of the slip angle has been achieved, gradual reduction of the slip is performed by applying force to the sacrum, while a counterforce is applied to the lumbar spine (TECH FIG 4C).

- Reduction of the slip angle is much more important than reduction of the slip itself. Close attention to spinal cord monitoring is crucial during the entire reduction maneuver.

- The rods are templated, cut, and contoured, and then attached to the construct while reduction is maintained.

- Final tightening of the entire construct is done and checked with fluoroscopy or plain radiographs (TECH FIG 4D).

- The L5–S1 disc is identified and removed, a fusion is performed, and the L5–S1 disc space is filled with cancellous autograft or allograft.

- An anterior cage is placed to provide adequate anterior column support (TECH FIG 4E).

- As an alternative, a double split fibular strut graft (modified Bohlman technique) can be inserted from the sacrum to the body of L5 to add anterior column support. The dura is gently retracted to one side, and a guide pin is inserted from the sacrum to the body of L5 (TECH FIG 4F).

- A 6-mm cannulated reamer is then used to ream this channel (TECH FIG 4G).

- A fibular auto- or allograft is then placed through the channel and countersunk (TECH FIG 4H).

- The same procedure is repeated on the contralateral side.

- The procedure is completed by placing bone graft lateral to the implants along the transverse processes from L4 to the sacrum.

- Meticulous hemostasis is carried out, and a layer-by-layer closure of the operative site is performed.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Indications</th>
<th>■ A complete history and physical and neurologic examination must be performed before surgery.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>■ All needed and appropriate imaging studies must be evaluated carefully to identify all aspects of the deformity—including the degree of the deformity and the type (eg, isthmic vs congenital)—as well as any other spinal deformity that may be present (eg, spina bifida occulta).</td>
</tr>
<tr>
<td>Surgical exposure</td>
<td>■ Careful and meticulous technique must be observed. Care should be taken, especially when pathologies such as spina bifida occulta are present, to prevent iatrogenic neurologic injury.</td>
</tr>
<tr>
<td></td>
<td>■ Decompression of at-risk nerve roots is a key component to exposure and operation.</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>■ Careful preparation should be undertaken before performing instrumentation and reduction.</td>
</tr>
<tr>
<td></td>
<td>■ Adequate decompression of all neurologic structures at risk should be ensured to prevent iatrogenic injury.</td>
</tr>
<tr>
<td></td>
<td>■ Close attention must be paid to neurophysiologic monitoring during both instrumentation and reduction.</td>
</tr>
<tr>
<td>Reduction</td>
<td>■ Slow, gentle force is applied during the reduction maneuver. This procedure should be done over time to allow for relaxation of the soft tissue structures.</td>
</tr>
<tr>
<td></td>
<td>■ Avoid excessive reduction. Reduction of the slip angle is more important than complete reduction of the slip. Excessive reduction may result in neurologic compromise.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- High-quality radiographs are taken immediately postoperatively to ensure proper graft and instrumentation placement before the patient is taken out of the operative suite (FIG 5).
- In the immediate postoperative period, the hips and knees are flexed and elevated using pillows to alleviate pain.
- Pain control is institutied (eg, intrathecal analgesia and IV patient-controlled analgesia), and the patient is fitted with a thoracolumbosacral orthosis (TLSO) for comfort. The patient is then encouraged to stand and ambulate as tolerated. Postoperative anteroposterior and lateral standing spine radiographs are taken before discharge.
- Activity restriction (ie, avoidance of bending and rotational motion) is carried out until fusion has occurred.
- The patient may return to sports and strenuous physical activity after 1 year as long as spinal fusion has been confirmed. Adequate precautionary measures should be taken before engaging in any contact sport.
- Full-contact sports, which may entail collision, should still be avoided.

OUTCOMES

- In high-grade spondylolisthesis treated with in situ fusion techniques, clinical improvement in back pain symptoms has been reported in 74% to 100% of cases. Solid fusion rates have also been reported to be 71% to 100%,6,8,13,23,24

- A study on 18 adolescents with high-grade spondylolisthesis treated with instrumented reduction and fusion reports complete resolution of preoperative neurologic symptoms with 100% fusion rates. No loss of fixation or instrument-related failures were reported at a minimum of 2 years’ follow-up.21

- Another series16 comparing in situ fusion, decompression, reduction and instrumented posterior fusion, and circumferential fusion techniques in treating high-grade spondylolisthesis reports a 45% (5 of 11 patients) pseudoarthrosis rate in patients treated with in situ fusion and a 29% (2 of 7 patients) pseudoarthrosis rate in cases treated with posterior decom-pression, instrumentation, and fusion. All of these cases had small transverse processes (less than 2 cm²). Circumferential techniques achieved the highest fusion rates. Excellent functional outcomes were observed in those cases where a solid fusion was achieved. Final outcomes, however, did not differ among the three groups.

- Another study comparing posterior fusion and reduction with posterior fusion and reduction augmented by anterior column support reported a 39% pseudoarthrosis rate in posterior fusion alone. In the cases augmented with anterior column support, 100% fusion rates were achieved.16

COMPLICATIONS

- Pseudoarthrosis
  - Pseudoarthrosis is the most common complication.
  - Signs include lucency around implants, implant breakage, and slip progression.
  - Pseudoarthrosis may be minimized by using meticulous technique and proper preparation of the graft site.

- Neurologic complications
  - Root lesions (L5 root)
  - From direct trauma, manipulation of nerve roots, epidural hematoma formation (compression)
  - Cauda equina syndrome
  - Autonomic dysfunction
  - Chronic pain

- Immediate release of the correction should be done when necessary.
  - Must be thoroughly evaluated with proper imaging techniques
  - May be minimized by good preoperative planning and meticulous surgical technique and by using multimodality spinal cord monitoring

- Transition syndromes
  - Spondylolisthesis acquisita
  - Adjacent segment degeneration
  - S1–S2 deformity
  - Instrument-related complications
REFERENCES

**DEFINITION**
- The treatment of neuromuscular spinal deformities frequently requires fusion to the pelvis with firm fixation. This can be accomplished with a number of devices that allow for correction of pelvic obliquity and pelvic rotation while allowing for a solid base on which to attach rods for correction of curves above.
- One of the most reliable structures in the formation of the spine, even in the dysplastic setting of myelomeningocele, is the sacral ala.
  - The S-rods are contoured to press-fit over the sacral ala.\(^1\,3\,4\)
  - Historically the elongated Harrington hooks were used in a similar manner.

**ANATOMY**
- The sacral ala in children is a structure 1.5 to 2 cm in depth (front to back) and 2 to 3 cm wide.
- The L5 nerve root traverses anterior to the ala in an oblique direction progressing from posterior to anterior and superior to inferior obliquely from the neural foramina.
- Immediately inferior to the pedicle of L5 the nerve transgresses anterior to the sacral ala, separated by a distance of 1.5 cm.
- Besides the L5 root, the tissue anterior to the sacral ala is retroperitoneal fat.

**PATHOGENESIS**
- The multiple types of neuromuscular scoliosis requiring fixation to the pelvis include cerebral palsy, dystrophic muscle conditions, spina bifida, and many others.
- The types of pelvic abnormalities associated with spinal deformities include pelvic obliquity, pelvic rotation, and flexion and extension of the sacrum.

**NATURAL HISTORY**
- The natural history is one of progression and worsening of these deformities.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Special imaging and other diagnostic studies are only occasionally necessary.
- The sacral ala can usually be clearly visualized as a horseshoe-shaped outline on upright or supine lateral radiographic films.
- The Ferguson view (45-degree angle) in the frontal plane provides the clearest view of the width.
- If there is doubt, a CT scan can better elucidate the exact configuration.

**SURGICAL MANAGEMENT**
- The surgical management, in terms of preoperative planning, positioning, and approach, is the same as for neuromuscular scoliosis.
- The techniques include cleaning of the soft tissues from the sacral ala with release of the ileotransverse ligament.
- The sizing of the hook to the size of the sacral ala in its front-to-back diameter can be done at surgery.
- Small and medium sizes are available, and it is important to use the appropriate size rod or hook (right or left) so the rod lies medial to the ala (**FIG 2**).
S-ROD PLACEMENT

- Proper alignment of the S-rod necessitates placement of the sagittal bends in the appropriate plane with reference to the best fit of the S-portion on the ala (TECH FIG 1A).
  - This can be aided by placement of a vise grip on the rod in the plane of the lordosis once the S-portion of the rod is positioned over the sacral ala.
  - The rod is removed from the wound and the three-point bender applied to produce the proper sagittal contours.
- If the S-hook is used instead, the sagittal contours can be made in the rod independent of the hook position.
  - It is best to leave 1 cm protruding from the lower end of the hook when it is first placed on the ala (TECH FIG 1B).
  - The S-hook is temporarily tightened to the rod and spread between the L4 pedicle screw and the S-hook by tightening one Allen set screw on the hook (TECH FIG 1C,D).
  - The correction of the spinal deformity can then occur above this area.

TECH FIG 1 • A. Posterior view of a right-sided S-rod on the spine. B. Initial position of the S-hook on the rod for placement purposes, with 1 cm of rod protruding. C,D. The S-hook shown positioned over the sacral ala and up the spine.
FINAL FIXATION

- Once the final correction has been achieved, the final tightening of the S-hook occurs by distracting once again between the L4 pedicle screw and the concave side S-hook, then the convex side rod, distracting the hooks to the end of the rod (TECH FIG 2).
  - Both Allen set screws are firmly tightened.
  - A strong cantilever force can be created to correct pelvic obliquity by using two sagittally contoured rods fixed to S-hooks positioned against the sacral ala distracted against the L4 pedicle screws.
  - A transverse rod connector above the S-hooks will supply further stability.
  - The pelvis can then be pivoted by grasping the rods above and correcting the pelvic deformity in one maneuver.
  - The final fixation of the S-hook is completed with both set screws firmly tightened.²

PEARLS AND PITFALLS

The surgeon must avoid the pitfall of thinking the transverse process of L5 is the ala and positioning the S-hook or S-rod against this structure.

- This can happen if the ileotransverse ligament is not completely released and the sacral ala clearly visualized (FIG 3).
- An L4 polyaxial pedicle screw works well to ensure proper pressure and fixation between the L4 screw and the sacral ala.

POSTOPERATIVE CARE

- It is important to maintain hip flexion at 45 degrees or greater for the first 6 months to avoid levering on the pelvis with physical therapy.
  - No physical therapy is done about the hips for the first 6 months.

OUTCOMES

- This technique has been used in more than 200 cases since 1984. Outcomes are generally solid fusions, ease of caregiving, and attainment of level pelvis for sitting (FIG 4).
COMPLICATIONS

- Rod migration into myelo pelvis with a growth rod
- I have not experienced any neurologic impairment of the L5 root.

REFERENCES

DEFINITION
- Developmental dysplasia or dislocation of the hip (DDH) is a disorder that may affect the development and stability of the hip joint during the critical period of growth, either in utero or after birth.
- This may lead to dysplasia, subluxation, or frank dislocation of the hip joint.

ANATOMY
- Growth of the hip joint is genetically and mechanically determined.
  - In the first trimester, the structures of the joint begin as a single mass of scleroblastema with a globular femoral head that becomes cartilage at 6 weeks.
  - By 8 weeks’ gestation, the start of the fetal period, vascular invasion leads to enchondral ossification.
  - The joint space develops by degeneration at 7 to 8 weeks and the structure of the joint is well apparent by week 11.
  - A round and reduced femoral head influences the concave shape of the acetabulum to develop.
  - Acetabular growth depends on interstitial, appositional, periosteal new bone and secondary centers of ossification growth.
  - In the first two trimesters of fetal life the acetabulum is a hemisphere with a depth 50% of its diameter. However, by the time of birth the depth is only 40% of its diameter, which may contribute to instability at birth.
  - The acetabular labrum, which resembles an O ring (FIG 1A), contributes considerable mechanical stability and proprioceptive feedback (FIG 1B).
  - By 8 years of age the acetabular shape is for the most part determined and thus surgical reduction is less advised, especially if the dislocation is bilateral.

There is continued growth into adolescence, with the triradiate cartilage fusing by 13 years in girls and 15 years in boys.
- Closure of the triradiate cartilage may occur earlier in the dysplastic hip.
- By adulthood the acetabular depth is 60% of its diameter.
- The proximal femur is formed initially as a single chondroepiphysis (FIG 1C), with the ossific nucleus typically appearing in infancy at 2 to 8 months of age.
- There may be some side-to-side size discrepancy in appearance.
- The greater trochanter nucleus appears at about 3 years in girls and 5 years in boys, with the lesser trochanter appearing by age 6 to 11 years.
- The femoral head vascularity is mostly from the medial and somewhat from the lateral femoral circumflex arteries. Because it is an intra-articular dome-shaped structure, this blood supply is susceptible to injury.

PATHOGENESIS
- Around the time of birth, capsular laxity, a normally shallow acetabulum, and abnormal mechanical forces, such as those seen in breech presentation, may cause the hip capsule to be lax and to dislocate.
- An absent or subluxated femoral head eventually leads to a flat, egg-shaped acetabulum, which is a consistent finding on three-dimensional computer modeling performed of the acetabulum (FIG 2A).
- With time the neolimbus, which is abnormally formed articular cartilage, can develop at the edge of the acetabulum. It can be a barrier to reduction (FIG 2B).
A steep, maloriented growth plate, intra-articular obstructions, and stunting of periosteal new bone formation all in time contribute to further deformity.

Mechanical blocks to reduction include the anteromedial capsule, ligamentum teres, psoas tendon, neolimbus, transverse acetabular ligament (which is an inferior medial extension of the acetabular labrum), and intra-articular pulvinar tissue.

An inverted labrum is rarely a block to reduction.

The average unit load of human and animal joint cartilage is 25 kg/cm².

Hips with acetabular dysplasia, and particularly with subluxation, have about 25% less contact area and more unit load (stress) per area of contact.

There is an inverse relationship between greater contact pressures and the onset of osteoarthritis.

**NATURAL HISTORY**

- Newborn period
  - About 1 in 60 infants have instability at birth, with 60% of cases resolving in the first week of life and 88% by the first 2 months. Thus, about 1.5 in 1000 have a true dislocation.²
  - Muscle activity is considered important for recovery and is the basis of the Pavlik harness success.
  - Untreated acetabular dysplasia with subluxation or dislocation
    - The natural history of hip dysplasia when subluxation or dislocation is present is predictable. The long-term outcome is worse than with acetabular dysplasia without subluxation.¹⁰
    - The onset of symptoms and radiographic deterioration is directly related to the degree of subluxation and dysplasia.

- Clinical symptoms, typically pain, may antecede the radiographic deterioration by 10 years.
- If the hip is completely dislocated, limb-length discrepancy and back and knee pain are common, while painful arthritis correlates with the presence of a false acetabulum and its adverse effect on the femoral head articular cartilage.

- Acetabular dysplasia with no subluxation
  - The natural history of acetabular dysplasia is much less predictable when subluxation or dislocation is absent.¹⁰
  - During childhood, hips that are well centered improve their acetabular dysplasia, although not always to normal, whereas the hip that is radiologically eccentric typically does not improve.
  - If the center-edge angle in the mature hip is less than 20 degrees, the hip will likely develop arthritis sometime during the patient’s lifetime. However, it is difficult to determine how early in life the deterioration will occur.
  - Although hips with acetabular dysplasia can spontaneously improve, this improvement is not predictable or necessarily complete.⁸
  - A hip with a persistently upsloping lateral margin seen on an anteroposterior (AP) radiograph generally develops arthritis by late adulthood.⁵

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- All newborn infants should receive a gentle and focused examination of the hips, including range of motion and Ortolani maneuver.
  - The physical examination of the newborn, rather than imaging studies, should determine the diagnosis of DDH and the need for treatment.
  - An Ortolani-positive hip is dislocated or subluxated and the examiner perceives that the hip partially reduces with abduction. After several months of age the hip may appear stable on examination but may still be dislocated.
  - The child is examined for any abnormal skin creases (FIG 3). Proximal skin creases may indicate a dislocated hip or a short femur. The examiner should also note the level of the popliteal skin crease, the position of the knee, and any lateral displacement of the hip.
  - A simple, high-pitched and commonly felt “hip click” is not a sign of instability or dislocation.
  - Hip instability decreases with time, whereas deformity, such as limited hip abduction, increases with time.
The young infant with a dislocated hip may have normal abduction until several months of age. There may be limited abduction in developmental coxa vara. Abduction may appear to be normal if both hips are dislocated.

The upper extremities, spine, and feet are always inspected to evaluate for possible generalized conditions such as arthrogryposis or neuromuscular conditions.

In the child of walking age, a delay of walking may be the first indicator that the hip is dislocated.

Dipping of the pelvis and shoulder (Trendelenburg gait), female profile (pelvic widening from the dislocation), and shortening of the thigh (Galeazzi sign) are classic signs of a dislocated hip in the older child.

The Galeazzi test may also be abnormal if the child has a congenital short femur.

Additional signs of Trendelenburg gait include side-to-side waddling, indicating weak hip abductors, or the examiner may see lurching, indicating weak hip extensors. The child may stand or walk with hyperlordosis. These are proximal compensations for a hip dislocation and the resulting inadequate muscle strength to support the pelvis.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Ultrasound is a useful imaging method up to 6 months of age (FIG 4A).

  ![Figure 4A: Coronal section ultrasound imaging through the most posterior aspect of the acetabulum. The femoral head is well visualized dislocated from the acetabulum. The acetabulum is steep. The femoral ossific nucleus is not present. There is a break in the Shenton line on the left and it is normal on the right.](image)

  ![Figure 4B: Seven-month-old with a dislocated left hip. The acetabulum is steep. The femoral ossific nucleus is not present. There is a break in the Shenton line on the left and it is normal on the right.](image)

  ![Figure 4C-E: Radiographs of young adult with high-grade right acetabular dysplasia. On the AP pelvic view, the center–edge angle (CEA) on the left is low normal (26 degrees); on the right it is 10 degrees. The Shenton line is intact, indicating that there is no subluxation.](image)

  ![Figure 4D-E: Right hip false profile views. Right hip CEA is 0 degrees and left hip CEA is 22 degrees.](image)

  ![Figure 4F: Left hip intraoperative arthrogram shows concentric reduction. There is no pooling of the intra-articular contrast medially.](image)

The two most common indications for ultrasound imaging are for screening the asymptomatic infant considered to be at high risk for hip dislocation (girls born breech have a 133/1000 risk of DDH) and for following an infant with proven DDH, especially during Pavlik harness treatment.

The AP radiograph is most useful in infants over 6 months of age.

- In children more than 3 years of age, the Shenton line is a reliable indicator of subluxation (FIG 4B).
- The Von Rosen view in abduction and internal rotation shows the ability of the femoral head to reduce.
- In the adolescent or adult hip, a standing AP pelvis view is obtained with measurement of the center–edge angle, as well as standing false profile views of each hip joint (FIG 4C-E).
- The normal center–edge angle on the AP pelvic radiograph is greater than 24 degrees.

  Intraoperative arthrography can show whether the femoral head is fully reducible with no medial pooling of contrast (FIG 4F).

- If the femoral head does not easily reduce and remain stable without excessive hip abduction, an open reduction is used to address the extra-articular and intra-articular blocks to reduction.
- CT scanning is commonly used to evaluate the adequacy of a closed or open reduction after surgery and for preoperative planning of pelvic or femoral osteotomy.
MRI imaging, particularly with intra-articular gadolinium injection, shows labral pathology, the condition of articular cartilage, osteonecrosis, and femoral- acetabular impingement pathology.

DIFFERENTIAL DIAGNOSIS
- Septic hip dislocation: this is the most important diagnosis to consider in the young infant
- Teratologic hip dislocation (arthrogryposis)
- Neuromuscular dislocation (most commonly cerebral palsy and spina bifida)
- Traumatic hip dislocation
- Developmental coxa vara: easy to mistake as DDH before the ossific nucleus is present
- Congenital short femur
- Instability and dysplasia related to underlying condition (Down syndrome, Ehlers-Danlos syndrome, Charcot-Marie-Tooth disease); commonly bilateral

NONOPERATIVE MANAGEMENT
- The basic principles of treatment are to obtain a concentric, stable reduction while avoiding osteonecrosis, to promote normal growth of the hip, and to achieve normal long-term function.
- The treatment of DDH depends on the age of the child and thus the stage of development of the hip joint.
- Generally, the earlier that treatment is initiated, the more likely that less invasive treatment will be successful and that a better outcome will result.
- Treatment options range from observation, to a Pavlik harness (FIG 5) or other brace treatment in the young infant, to closed or open reduction and hip-spi casting, pelvic or femoral osteotomies, and salvage procedures in older patients.
- By the time of skeletal maturity, as normal as possible acetabular anatomy should be restored. Ideally, reconstructive surgery should be performed during early childhood, when the results are believed to be better and the risks acceptable.

SURGICAL MANAGEMENT
- If the hip remains dislocated or subluxated despite conservative treatment with a Pavlik harness or abduction orthosis, or if a concentric and stable reduction cannot be achieved with closed reduction and casting, open surgical reduction is appropriate.

Preoperative Planning
- For the infant who has not achieved walking age, an open reduction without associated femoral shortening or pelvic osteotomy is generally sufficient.
- With age and walking, the deformities in and around the hip become more fixed and require a more aggressive surgical approach.
- Prereduction traction is less frequently used than in the past for the infant and is not recommended for the older child. Generally, a child over age 2–3 years requires a femoral shortening osteotomy if the femoral head is displaced proximally.
- Epidural or caudal regional anesthesia may be helpful to supplement the general anesthesia.
- A type and screen is obtained, but blood transfusion is rarely required.
- An indwelling bladder catheter is used during the surgery, since much of the surgery is intrapelvic.

Positioning
- A radiolucent table is used in case an intraoperative radiograph will be obtained.
- The child is placed in a semilateral position (FIG 6).
- The entire limb is draped free.

Approach
- Several variations of the medial approach to the hip joint have been described. These are very useful in the infant if the femoral head is not excessively high and for bilateral instability surgery done the same day.
- For the older infant and child an anterior approach to the hip joint allows more extensile exposure.
- The anterior approach is especially useful if there is a false acetabulum with a high dislocation and for fixed dislocations in which the hip capsule is adherent to the hip abductors and pelvic wall.
- The anterior approach allows for an associated pelvic osteotomy through the same incision.
- The decision to perform a medial approach or an anterior approach to the hip joint will depend on the child’s age, the location and severity of the pathology, and the surgeon’s experience.

FIG 5 • Pavlik harness. This infant is comfortable in the harness; hips and knees are flexed with abduction provided by gravity, not from the lateral straps.

FIG 6 • Semilateral position. The anterior hip and lateral thigh incisions are generally parallel when the hip is flexed about 30 degrees.
ANTERIOR HIP EXPOSURE

- A modified anterior Smith-Peterson exposure with the incision placed in the inguinal crease just below the anterior iliac superior iliac spine is cosmetically appealing.
- Sharp dissection is carried deep until no more fat can be identified.
  - This is the deep fascia, which can then be further exposed distally by using a sponge on the fascia.
- If femoral shortening is anticipated, a separate direct lateral approach to the proximal femur is used.
  - Both exposures should be completed before osteotomies are performed because of increased bleeding from the bone.
- The tensor–sartorius internervous interval is easier to identify distally where the muscles are divergent (TECH FIG 1A).
- The fascia of the tensor muscle is entered slightly lateral to the fatty interval between the two muscles. The lateral femoral cutaneous nerve is identified and protected.
- Army-Navy retractors are used to separate the tensor and sartorius muscles until the rectus femoris muscle is identified.
  - This dissection is continued proximally and the prows of the pelvis are exposed between the anterior superior and anterior inferior iliac spines.
- The external oblique muscle is gently separated off the iliac crest.
- The iliac crest apophysis is divided exactly in the middle with a single cut using a no. 15 blade down to iliac bone (TECH FIG 1B).
- Periosteal elevators are used to expose the inner and outer tables of the iliac crest (TECH FIG 1C).
- Laparotomy sponges are used to help dissect deep near the sciatic notch and to pack the surgical site for hemostasis.
  - Perforating vessels into the iliac bone on the inner table are consistently present and require bone wax for hemostasis.
- Smooth Lane retractors are used to further dissect the sciatic notch both medially and laterally.
- The reflected and straight heads of the rectus femoris muscle are identified (TECH FIG 1D).
- It is extremely important for the dissection to continue medially onto the pubis by opening the interval between the iliacus and the rectus femoris muscles (TECH FIG 1E).
- By opening the medial periosteum at the level of the pubis, the iliopsoas tendon is identified, which lies deep on the iliacus muscle.
- The tendon is followed distally so that the interval between the iliacus muscle and the rectus femoris muscle is separated more deeply.
- The iliopsoas tendon is brought into the superficial surgical site with a right-angled clamp and divided at the level of the ilipectineal groove on the pubis.

TECH FIG 1 • A. Tensor–sartorius interval. Note the lateral femoral cutaneous nerve (arrow). B. The external oblique muscle has been detached off the iliac crest apophysis, which is being divided by a no. 15 blade. C. Subperiosteal dissection of the iliac inner and outer tables. D. Superior view of the left hip (patient’s head is to the right) showing the rectus femoris (RF), its straight head attachment to the anteroinferior iliac spine (AIIS), and the reflected head attaching to the hip capsule (RH). E. The iliopsoas tendon is identified, dissected distally, and divided at the ilipectineal eminence. (continued)
The femoral nerve is close by, superficial and medial to the psoas tendon.

The reflected and straight heads of the rectus femoris muscle are identified and divided. This allows skeletonization of the femoral head by separating the iliacus, rectus femoris, and hip abductor muscles off the capsule (TECH FIG 1F–H).

- A Cobb elevator is useful for separating these muscles off the hip capsule.

- It is extremely important to carry the dissection around to the deep inferior medial aspect of the hip capsule (TECH FIG 1I).

- With a Kocher clamp, grasp the proximal aspect of the reflected head of the rectus femoris tendon to further expose the capsule. The capsule must be detached from any false acetabulum on the lateral iliac wall. I. The capsule is exposed, particularly the inferior medial aspect.

OPEN REDUCTION

- A T-shaped capsulorrhaphy is made with the redundant proximal limb eventually removed.
  - The incision parallels the acetabular rim but is about a centimeter away so that the labrum is not injured (TECH FIG 2A).
  - The femoral head is examined for deformity (TECH FIG 2B).
  - The ligamentum teres is divided off the femoral head (TECH FIG 2C).
  - The stump of the ligamentum teres is grabbed with a Kocher clamp, and it is followed into the depths of the acetabulum.
    - It is essential to visualize the entire acetabulum and the transverse acetabular ligament.
    - The ligamentum teres is removed with Mayo or cartilage scissors at its deep acetabular attachment.
    - Under direct vision, a pituitary rongeur is used to remove the pulvinar tissue that lies within the acetabulum.
    - The transverse acetabular ligament is divided.
At this point the femoral head should be reducible.
- For children over 2–3 years of age, especially if the reduction is tight or unstable, a femoral shortening osteotomy is performed before the capsule is closed.
- If an acetabular osteotomy is performed, it is also completed before the capsulorrhaphy sutures are tied.
- An adductor longus and gracilis tenotomy is generally not needed but can be included if these muscles feel excessively tight.
- A capsulorrhaphy is performed by advancing the superolateral capsule to the inferior medial aspect of the capsule on the pubis (TECH FIG 2D).
- Nonabsorbable no. 0 sutures are all placed and tagged and then sequentially tied (TECH FIG 2E).
- The iliac crest apophysis is reapproximated with heavy suture and the external oblique muscle is reattached.
- The rectus femoris and iliopsoas muscles are left divided.
- A surgical drain is not required.
- A one-and-a-half spica cast is applied with the hips in a safe “human” position with no more than 30 degrees of flexion and abduction.

TECH FIG 2 • (continued) B. The hip capsule has been opened, exposing the deformed femoral head. C. The ligamentum teres is divided off its femoral head attachment. The vascular contribution of the ligamentum teres to the femoral head is minimal. D. After any associated femoral and acetabular osteotomies are performed, the capsule is advanced medially. E. Nonabsorbable sutures are placed and tied after osteotomies have been completed.

PROXIMAL FEMORAL SHORTENING OSTEOTOMY
- A straight lateral approach to the proximal femur is used.
- The tensor fascia is divided longitudinally.
- The anterior edge of the gluteus medius muscle is identified where it attaches to the greater trochanter.
- Several millimeters of the gluteus medius muscle is detached off the trochanter.
- This allows palpation of the anterior aspect of the femoral head to estimate the amount of femoral torsion (TECH FIG 3A).
- The vastus lateralis muscle is detached off the femur by dividing its proximal attachment in the transverse plane at the trochanteric ridge, leaving enough cartilage attached to the muscle to allow secure fixation during closure (TECH FIG 3B).
- The vastus lateralis muscle should be divided off the posterior intermuscular septum so that the muscle innervation is left completely intact.
- Stiff Steinmann pins are inserted in the proximal and distal femur to ensure that a proper amount of femoral rotation is provided.
- A third pin is placed up the neck of the femur to judge femoral head–neck antetorsion, and a fourth pin is placed just below the lesser trochanter to guide the osteotomy.
- A one-third tubular small fragment plate or a 2.7-mm minifrag dynamic compression plate is generally sufficient in a young child (TECH FIG 3C). A 3.5-mm dynamic compression plate is used for an older child.
The proximal aspect of the plate is fixed loosely. A subtrochanteric osteotomy is believed to be less hazardous to the hip vascularity than an intertrochanteric osteotomy. The femur is shortened by the amount that the cut ends of the femur overlap when the femoral head is reduced (TECH FIG 3D). The shortened fragment of femur can be used for holding open a pelvic osteotomy.

The plate is prebent slightly and is secured with some compression applied. The Steinmann pins are used to judge any rotation that is desired. If excessive femoral torsion was noted, some of this can be judiciously corrected. The tension band effect of the vastus lateralis muscle is restored (TECH FIG 3E). The incision is closed with absorbable suture. No drain is necessary.

### TECHNIQUES

- The proximal aspect of the plate is fixed loosely.
- A subtrochanteric osteotomy is believed to be less hazardous to the hip vascularity than an intertrochanteric osteotomy.
- The femur is shortened by the amount that the cut ends of the femur overlap when the femoral head is reduced (TECH FIG 3D).
- The shortened fragment of femur can be used for holding open a pelvic osteotomy.

- The plate is prebent slightly and is secured with some compression applied.
- The Steinmann pins are used to judge any rotation that is desired.
- If excessive femoral torsion was noted, some of this can be judiciously corrected.
- The tension band effect of the vastus lateralis muscle is restored (TECH FIG 3E).
- The incision is closed with absorbable suture. No drain is necessary.

### TECH FIG 3

- **A.** About 5 mm of the most anterior edge of the gluteus medius muscle is detached from the greater trochanter so that the femoral neck can be palpated and visualized (shown on a left hip). **B.** The vastus lateralis muscle is detached from the trochanteric ridge (TR) and the posterior intermuscular septum (IS) to expose the proximal femur (F). **C.** A one-third tubular plate has been attached to the proximal femur and a 2-cm segment of bone has been removed from the subtrochanteric aspect of the femur. **D.** The femur has been shortened, rotated into less antetorsion, and compressed. **E.** The tension band of the vastus lateralis muscle is re-established with 0 absorbable suture.

### PEARLS AND PITFALLS

#### Diagnosis
- A painful dislocated hip in a newborn or young infant could be a septic dislocation.
- Bilateral hip dislocation may be difficult to determine because the hips may be symmetrically dislocated.
- An adolescent with newly diagnosed hip dysplasia, particularly if bilateral, may have an underlying condition such as Charcot-Marie-Tooth disease.

#### Imaging studies
- Treatment should not be based on a radiology report. The surgeon should personally examine all images.
- An AP pelvis view should be obtained so that the contralateral hip is available for comparison.
- The Shenton line is reliable after age 3 years for indicating subluxation.

#### Nonoperative treatment
- Pavlik harness treatment should not be extended beyond 3 weeks if it is not working.
- A child should be comfortable in a Pavlik harness or a brace. If not, there may be a risk of nerve palsy or osteonecrosis.
- An inadequate closed reduction or a reduction that requires excessive force or extreme position for stability can result in osteonecrosis.

#### Operative treatment
- In the anterior approach, the surgeon should always obtain adequate medial exposure and visualize the entire acetabulum.
- Femoral shortening is necessary for a high dislocation if excessive force is required to bring the femoral head into the joint.
- The acetabular labrum should not be resected.
- The older patient may need a simultaneous acetabular osteotomy for stability or because of excessive acetabular dysplasia.
- Patients older than 8 years with a dislocated hip, particularly those with bilateral dislocation, may have excessive deformity to justify reconstructive surgery.
### Postoperative Care
- A spica cast is applied at the time of surgery.
- A Gore-Tex liner protects the skin from excoriation.
- The cast is removed at 6 weeks.
- A night brace can be used until the acetabulum has remodeled.
- Physical therapy is generally not needed.
- Follow-up radiographs are obtained.
  - The acetabulum will remodel the most in the first year after surgery.
  - If the acetabular shape does not normalize within several years, a pelvic osteotomy is indicated.

### Outcomes
- Patients treated with a Pavlik harness may have persistent acetabular dysplasia in adulthood and should be followed until skeletal maturity.
  - The younger the age at reduction, the better the final Severin grade at maturity. This in turn predicts the need for total hip arthroplasty in later adulthood.
  - About 50% of hips that underwent closed reduction in childhood had residual acetabular dysplasia as adults.
  - The best results occur if there is no osteonecrosis, femoral growth disturbance, or residual subluxation.
  - Persistent acetabular dysplasia, if present past age 7 years, is associated with a poor late outcome. A persistent upsloping sourcil and a centering discrepancy suggest a need for surgical correction in the younger child.
  - Early measurements of the acetabular index (AI) are also predictive for Severin grade at maturity.
  - In particular, an AI of 35 degrees or higher at 5 or more years after reduction has an 80% association with Severin grade III or IV at maturity.

### Complications
- Osteonecrosis
- Late physeal and lateral femoral growth arrest
- Inadequate reduction with persistent subluxation
- Loss of reduction and redislocation
- Stiffness
- Lack of remodeling after reduction
- Infection
- Arthritis

### References
Developmental dislocation of the hip (DDH) occurs in 1.5 babies per 1000 live births. When diagnosed in the newborn period, closed treatment with the Pavlik harness is successful in 95% of dysplastic hips and up to 80% of dislocated hips.

Closed reduction is indicated when Pavlik harness treatment has failed, and when presentation for treatment is delayed past 6 months of age.

Open reduction is reserved for babies in whom closed reduction either is unobtainable or lacks stability, or for those who are diagnosed with a dislocated hip later than 18 to 24 months of age.10

The medial approach for open reduction is used most frequently in the young baby less than 12 to 18 months of age in whom an attempted closed reduction under anesthesia has been unsuccessful.

ANATOMY

Reduction of a dislocated hip is impeded by:
- The iliopsoas tendon, which is tautly stretched across the inferior capsule owing to the displacement of the femoral head
- The inferomedial hip capsule, which becomes constricted
- The transverse acetabular ligament, which spans the inferior aspect of the horseshoe of the acetabulum
- The pulvinar, which is fibrofatty tissue occupying the cavity of the true acetabulum
- The acetabular labrum, which can be infolded and serve as a doorstop blocking a deep and medial reduction
- Anatomic landmarks for the medial approach are as follows:
  - The adductor longus tendon originating on the pubis
  - The pectineus, lying anterior to the adductor brevis (which is deep to the adductor longus)
  - The femoral artery, vein, and nerve, which are located as a bundle anterior to the pectineus muscle
  - The medial femoral circumflex artery, which lies in the interval between the pectineus and the femoral neurovascular bundle and is important for the circulation of the ossific nucleus of the proximal femur

PATHOGENESIS

DDH is more common in female babies and is linked with breech presentation, oligohydramnios, and firstborn children.

DDH is associated with congenital knee hyperextension and may be more likely in babies with torticollis and metatarsus adductus.

A positive family history is present in a minority of babies with DDH and most likely represents familial hyperlaxity.

Idiopathic DDH must be differentiated from the teratologic hip dislocation seen in infants with such disorders as arthrogryposis and Larsen syndrome.

While research has shown that mild dysplasia, seen on ultrasound imaging of the newborn hip, often resolves spontaneously without treatment, the majority of babies with dislocatable or dislocated hips will progress from unstable hips to fixed dislocations in the absence of treatment.

PATIENT HISTORY AND PHYSICAL FINDINGS

The physical examination methods are summarized below. It is very important that the child is relaxed and quiet during the examination.

Limited abduction during range-of-motion testing may signify a dislocation and merits imaging. Abduction can be symmetric in bilateral dislocations.

The patient is examined for the Galeazzi sign. Asymmetry is abnormal and may indicate a hip dislocation or a congenital short femur. The apparent femoral lengths will be equal in bilateral dislocations.

Extra thigh folds may be present in unilateral DDH, but thigh fold asymmetry is often nonspecific.

The child is examined for the Ortolani sign. A positive sign represents the reduction of a dislocated hip. It is usually present in the newborn with DDH but disappears as the dislocation becomes fixed.

A positive Barlow sign represents the ability for a reduced hip to be dislocated because of instability. It disappears as a fixed dislocation develops.

In addition to a complete examination of each hip, the knees, feet, and upper extremities should be examined for contractures to rule out a teratologic dislocation.

The spine should be inspected for signs of dysraphism, which may result in a hip dislocation due to muscle imbalance.

IMAGING AND OTHER DIAGNOSTIC STUDIES

In infants less than 3 months of age, ultrasound of the hip is the preferred imaging study.

The femoral head, acetabulum, and triradiate cartilage can be identified.

The absence of coverage of the femoral head by the bony acetabulum is seen in the dislocated hip, which appears lateralized relative to the pelvis.

The alpha angle, which represents the slope of the bony acetabulum, is decreased (normal is more than 60 degrees), and the beta angle, which represents the cartilaginous acetabulum, is increased (normal is less than 55 degrees) in babies with hip dysplasia and hip dislocation (FIG 1A,B).

In infants 3 months of age and older, an anteroposterior (AP) pelvic radiograph is diagnostic (FIG 1C).

The line of Shenton, drawn along the inferomedial aspect of the proximal femur and the superior aspect of the obturator foramen, is disrupted.
The ossific nucleus may be smaller than the contralateral side, or absent altogether.

The medial proximal femoral metaphysis lies lateral to the Perkins line (drawn vertically from the lateral aspect of the bony acetabulum).

The acetabular index, which is the angle subtended by the Hilgenreiner line (a horizontal line drawn through the triradiate cartilages), and a line drawn along the bony acetabulum, is increased.

A pseudoacetabulum proximal and lateral to the true acetabulum may be present.

DIFFERENTIAL DIAGNOSIS
- Teratologic hip dislocation (ie, arthrogryposis)
- Neuromuscular dislocation (ie, spina bifida)
- Congenital short femur
- Coxa vara

NONOPERATIVE MANAGEMENT
- The Pavlik harness is the treatment of choice for infants with hip dysplasia or instability from birth to age 6 months.
- The Pavlik harness is less successful in patients with fixed dislocations but may be attempted for a period not to exceed 4 weeks, following which a reduction must be documented by either sonogram or radiograph.
- There is no role for nonoperative management of a baby 6 months of age or older with a fixed hip dislocation.

SURGICAL MANAGEMENT
- Surgical management can be delayed in the very young infant until the baby reaches sufficient size for a safe anesthetic and effective cast immobilization. We favor proceeding with surgical reduction (closed or open) at the age of 6 months in the healthy baby.
- The importance of delaying surgery until the presence of ossification within the femoral head remains controversial. While some studies report an increased incidence of avascular necrosis when the ossific nucleus is absent, others report an increased number of surgical procedures in children in whom reduction is delayed. We favor proceeding with reduction rather than waiting for ossification.²

Preoperative Planning
- Traction may be used to increase the likelihood of a successful closed reduction, although current trends in the United States show a declining use of preoperative traction.

Positioning
- The child is positioned supine on a radiolucent operating table.
- The perineum is isolated with adhesive tape.
- Surgical drapes are sutured in place to allow free movement of the extremity.
- Towel clips should be avoided around the groin as they interfere with fluoroscopic visualization of the hip.

Approach
- The medial approach to the dislocated hip is best suited to infants less than 12 months of age, but it has been used by other authors successfully in infants up to 24 months of age.
- The medial approach described by Ludloff³ accesses the hip in the interval between the pectineus and the adductor brevis.
- We favor the approach described by Weinstein,⁸,⁹ which exposes the hip between the femoral neurovascular bundle anteriorly and the pectineus muscle posteriorly. This interval allows for more direct visualization of the hip capsule and the medial femoral circumflex artery.

INCISION AND INITIAL DISSECTION
- With the hip flexed and abducted, a transverse incision is made just lateral to the groin crease, centered over the palpable adductor longus tendon (TECH FIG 1A).
- The fascia overlying the adductor musculature is opened (TECH FIG 1B).
- The adductor longus tendon is isolated and divided (TECH FIG 1C). The tendon can be dissected free from the underlying adductor brevis with two blunt retractors.

The adductor brevis is identified with its overlying anterior branch of the obturator nerve. The pectineus is located anterior to the adductor brevis (TECH FIG 1D). Blunt retractors are used to identify the superior border of the pectineus.
DEEP DISSECTION

- The femoral vessels are retracted gently anteriorly, and the pectineus muscle is retracted posteriorly (TECH FIG 2A).
- The iliopsoas tendon can be identified. The surgeon can rotate the hip and feel the insertion site on the small prominence of the lesser trochanter. The psoas tendon is isolated and divided (TECH FIG 2B).
- The surgeon carefully identifies the medial femoral circumflex artery as it traverses superior to inferior on the capsule of the hip. If possible, a small vessel loop is passed around the vessel to protect it. Otherwise, visualization of the vessel is maintained throughout the procedure.
- The femoral head is palpated beneath the medial femoral circumflex artery. Kidners are used to bluntly expose the hip capsule (TECH FIG 2C).

CAPSULOTOMY AND ACETABULAR EXPOSURE

- The capsule is incised along the rim of the acetabulum using a scalpel.
- The white glistening cartilaginous femoral head is visualized (TECH FIG 3A). The hip is rotated to identify the ligamentum teres insertion on the superior aspect of the femoral head (TECH FIG 3B), and it is released (TECH FIG 3C).
- The stump of the ligamentum is traced into the true acetabulum (TECH FIG 3D).
The incision in the capsule is completed to gain access to the acetabulum.

- The ligamentum teres is excised from the floor of the acetabulum using scissors.
- With a pituitary rongeur, the fibrofatty pulvinar is removed from the acetabulum. The surgeon should take care to preserve the underlying articular cartilage of the acetabulum (TECH FIG 3E).

- The release of the acetabulum is completed by releasing (with scissors) the transverse acetabular ligament at the base of the acetabulum.
- The surgeon should not excise or incise the acetabular labrum: it is an important growth center of the acetabulum and should be preserved.

HIP REDUCTION, CAPSULORRHAPHY, AND CLOSURE

- The hip is reduced under visualization by abducting the hip and lifting the greater trochanter anteriorly (the Ortolani maneuver). The hip should reduce readily and be quite stable in flexion. It will dislocate posteriorly with adduction. The reduced hip will appear relatively superficial, and the femoral head will be visible in the wound.

- The reduction should be verified fluoroscopically at this point. If it is difficult to assess the reduction because of absence of ossification of the femoral head, a small drop of contrast can be placed in the acetabulum.

- If the hip cannot be reduced, or if the reduction requires undue force to pull the hip into the acetabulum, the surgeon should recheck the capsular release and the transverse acetabular ligament.

- In rare instances, the hip cannot be gently reduced and femoral shortening through a separate lateral approach is required. In infants less than 1 year of age who are otherwise normal, this is generally not necessary.

- From this point onward, the hip must remain flexed to 90 degrees and gently abducted to maintain reduction. An assistant should be assigned to observe the position of the hip.

- The vessel loop is removed from the medial femoral circumflex artery, which has been protected throughout the operation.

- The subcutaneous layer and skin are closed. A drain is not necessary.

- The wound is dressed and an occlusive bandage applied to deter contamination from diaper contents.
CASTING

- The child is transferred to an infant spica table, and a double spica cast is applied with the hips flexed 90 degrees and gently abducted no greater than 60 degrees (TECH FIG 4A).
- The surgeon should take care to cover the posterior aspects of the buttocks and mold beneath the greater trochanters to prevent “falling through” the spica posteriorly (TECH FIG 4B).

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Unstable closed reduction or fixed dislocation in an infant less than 1 year of age. The procedure is still possible to age 2 years.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical technique</td>
<td>Drapes are sewn to avoid inability to see the hip on C-arm fluoroscopy. The ligamentum teres is used to find the acetabulum. The medial femoral circumflex artery is always protected. A lighted suction can be invaluable in improving visualization in the small incision. If the reduction cannot be assessed easily, a small drop of contrast can be added in the acetabulum, and then the hip is reduced. The surgeon should never force a reduction; avascular necrosis may result.</td>
</tr>
<tr>
<td>Postoperative care</td>
<td>The reduction is assessed with either radiographs or CT once the child is awake. A limited CT scan of the hip allows accurate assessment. If the hip is dislocated, the cast is removed at once.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- A radiograph is taken before waking the child from anesthesia to document the reduced hip within the spica cast (FIG 2A).
- A limited CT scan may be performed within 24 hours after surgery to visualize the reduced hip after the child moves about in the cast (FIG 2B).
- The cast is changed under anesthesia in 6 weeks and the hip is examined fluoroscopically. At this time, a one-and-a-half spica can be applied.
- On occasion, a third spica will be needed, to be worn between 12 and 18 weeks after medial open reduction.
- Bracing with an abduction orthosis after cast removal is prescribed at the discretion of the surgeon.
Periodic radiographs are needed to monitor the growth of the ossific nucleus and the resolution of acetabular dysplasia.

OUTCOMES
- A satisfactory outcome after medial open reduction of the infant’s hip can be expected in about 75% of children. Reduction can be universally achieved, and redislocation after a medial open reduction is rare. Owing to the limited dissection, prolonged postoperative stiffness is a rare event.
- When an adverse outcome occurs after medial open reduction, it usually is related to the diagnosis of postoperative avascular necrosis or residual acetabular dysplasia.

Avascular Necrosis
- Avascular necrosis has been documented in 9% to 43% of hips after medial open reduction. The large discrepancy in rates between series is due to differing criteria for its diagnosis and variation in the length of follow-up.
- The severity of avascular necrosis varies widely between hips that have temporary irregular ossification of the epiphysis (Bucholz-Ogden type I) to complete avascular necrosis with an aspherical femoral head and coxa breva (type IV).
- The presence of type I avascular necrosis does not preclude a successful outcome at skeletal maturity, while whole-head avascular necrosis dooms the hip to a poor outcome and leg-length discrepancy despite multiple surgical procedures.
- Many series do not include the hips with irregular ossification, so it is imperative when comparing complication rates to ascertain which hips were included in the group with postoperative avascular necrosis. Although the published series of medial open reductions vary in the likelihood of avascular necrosis, it is clear that the proximity of the medial femoral circumflex artery to the medial hip capsule places the hip at greater risk for avascular necrosis during this approach compared to the anterior open reduction.
- Because of variation between series in length of follow-up, the rate of type II avascular necrosis ranges widely. Typically, type II avascular necrosis becomes apparent in late childhood and early adolescence, when the proximal femur seems to grow into valgus because of a lateral physal growth disturbance.
- In series with short-term follow-up, the rate of type II avascular necrosis may be lower than in those where skeletal maturity is achieved. Review of the DDH literature shows that type II avascular necrosis is not specific to the medial approach to the hip, however, as it may also be seen after anterior open reduction, and even closed reduction.

Acetabular Dysplasia
- Persistent acetabular dysplasia may be seen after medial open reduction of the hip. This approach does not facilitate concomitant pelvic osteotomy, unlike the anterior open reduction, in which the iliac crest is exposed. Yet the optimal age for the medial open reduction (age 1 year or less) is young enough that the surgeon can expect the majority of patients to experience resolution of their dysplasia with growth.
- Mankey et al found that one third of babies treated with medial approach open reduction required subsequent pelvic osteotomy for residual acetabular dysplasia.

COMPICATIONS
- Redislocation
- Avascular necrosis
- Infection
- Need for future pelvic osteotomy due to persistent acetabular dysplasia

REFERENCES
DEFINITION
- Septic arthritis of the hip affects children of all ages, from the newborn to adolescents. The principles of treatment include early and accurate diagnosis, prompt surgical drainage, appropriate antibiotic coverage, and judicial management of late sequelae. The worse outcomes occur when there has been a marked delay in the diagnosis.

ANATOMY
- Synovial membrane with its rich blood supply lines the joint capsule.
- Blood supply to the hip is from the medial and lateral femoral circumflex vessels (FIG 1).
- Intra-articular retinacular vessels travel up the femoral neck and enter the femoral head. These vessels do not cross within the proximal femoral physis.
- Because the proximal femur is an intra-articular metaphysis, primary femoral osteomyelitis in this location can decompress into the hip joint.
- Many muscles that are in close proximity to the hip joint, including iliopsoas, piriformis, and obturator internus and externus, may develop pyomyositis or an abscess; this can mimic septic hip arthritis.

PATHOGENESIS
- Bacteria can enter the hip joint cavity directly via the hematogenous route to the subsynovial layer of the capsule or indirectly from the proximal femoral metaphysis and occasionally from adjacent acetabular infection.
- Polymorphonuclear cells enter the joint cavity with plasma proteins and inflammatory fluid.
- The resulting tense effusion can increase intracapsular pressure.
- Articular cartilage destruction occurs from proteolytic enzyme degradation from cells of the synovial membrane and from interleukin-1 from monocytes, which releases proteases by chondrocytes and synoviocytes.
- Animal studies show that proteoglycan matrix can be lost by 5 days and collagen by 9 days after an infection starts. Antibiotics do not completely prevent this degradation if treatment is delayed.

NATURAL HISTORY
- Although most patients have excellent outcomes, the hip joint accounts for about 75% of published reports of poor outcome from septic arthritis.

FIG 1 • A. Anterior hip vascularity. The medial and somewhat the lateral femoral circumflex vessels from the deep femoral artery supply the vascularity to the femoral head. B. Posterior hip vascularity. Intracapsular retinacular vessels from the medial circumflex vessel pierce through the capsule and travel up the posterior femoral neck.
Poor results occur more frequently in infants less than 6 months of age, if there is a delay in treatment of greater than 4 days, and with associated proximal femur osteomyelitis and infection with *Staphylococcus aureus*. The most severe sequelae are more often seen in newborns and infants.

A frequent scenario when there is a poor outcome is the failure to make the diagnosis of septic hip arthritis, either from not recognizing the serious nature of the condition or failure to promptly perform adequate surgical drainage and administer appropriate intravenous antibiotics.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The history should include a detailed timeline of events leading up to presentation.
- In the most recent prospective studies evaluating clinical predictors for septic hip arthritis, a fever above 38.5°C was the strongest predictor.
- The severity of pain, particularly pain at rest and night pain, indicates inflammation.
- Associated illnesses and infections, history of trauma to the hip, recent dental procedures, and underlying medical conditions or steroid use may lead to infection in a susceptible host.
- The clinician should always ask about recent antibiotic treatment, since this may mask many of the findings of septic hip arthritis and change the threshold for obtaining imaging studies and for performing hip aspiration.
- The clinician should conduct a visual inspection with the child lying supine on the table, noting whether the hip is in abduction, flexion, and external rotation (FIG 2).
  - The hip joint assumes a position of least intracapsular pressure.
  - The clinician should inspect for skin rash, erythema, warmth, swelling, and tenderness over overlying muscles and the hip joint.
  - The clinician should palpate the pelvis and lower extremities for local swelling and tenderness.
  - The clinician should examine the child walking. Antalgic limp indicates that the patient is unable to spend much time weight-bearing on the hip joint. The child may have mild pain early or the pain may be so severe that the patient is unable to walk.
  - The clinician should observe the hip range of motion. Gradually, there is limited ability to move the hip joint as inflammation and pressure of the hip joint increase. Pain with hip extension and internal rotation suggests involvement of the psoas muscle.

- The clinician should inspect and palpate the spine. Septic discitis in a young child can present as refusal to walk and can resemble septic hip arthritis.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Imaging and laboratory studies selected are determined by the clinical evaluation, probability of the findings being septic hip arthritis, and need to exclude other conditions.
- Plain radiographs (FIG 3A)
  - Key features include hip abduction, increased soft tissue density, widened medial joint space, osteopenia if the infection is longstanding, and femoral or acetabular osteolytic lesions.
  - A particularly worrisome finding in the neonate is a painful dislocated hip (FIG 3B). Bone lesions and destruction are typically delayed 1 to 2 weeks.
- Ultrasound imaging (FIG 3C) is performed bilaterally, with images obtained along the axis of the anterior femoral neck. This is very specific for detecting intra-articular fluid in the hip.
- Because the pelvis is deep and difficult to examine, MRI is an extremely useful imaging modality to examine the tissues surrounding the hip joint or within the pelvis (FIG 3D–F).

---

**FIG 2** Right hip is held in flexion, abduction, and external rotation.

**FIG 3** Diagnostic imaging. A, B. AP radiographs. A. The right hip is held in abduction with increased soft tissue density and slight lateral displacement of the femoral head. B. Left hip of an infant showing acute displacement from septic hip arthritis. The left proximal femur is laterally displaced compared with the right. (continued)
Femoral head is midway between anterosuperior iliac spine and center of pubis symphysis and about 2 cm distal to midway point.

**Adductor longus**

**Needle inserted just posterior to adductor longus**

**Pubis symphysis**

**FIG 3 (continued)**

**C.** Ultrasound imaging of hip along axis of the femoral neck. The distance between the femoral neck and head is shown by the red line. There is increased intracapsular fluid. **D–F.** MRIs in an 11-year-old boy with fever and pain with internal rotation of the hip. He was limping but able to walk. Erythrocyte sedimentation rate was 50 mm/hr and C-reactive protein level was 5.8 mg/L. The radiograph was normal. **D.** T1-weighted coronal image of pelvis. There is an abscess (*) within the obturator internus muscle. **E.** T2-weighted coronal image of pelvis. The abscess (*) is more apparent, as is the involvement of the acetabulum (solid dot) and small hip joint effusion (dashed outline). **F.** T1-weighted coronal image with gadolinium for enhancement. Cavitary nature of the abscess (*) is even more apparent. Patient underwent percutaneous interventional radiology catheter drainage on two occasions and received intravenous antibiotics for treatment of this methicillin-sensitive *Staphylococcus aureus* infection. **G,H.** Hip aspiration. **G.** Aspiration of right hip through adductor approach. The large-bore needle is inserted just posterior to the adductor longus and is directed toward the femoral head. **H.** Fluoroscopy image of needle tip at the junction of the femoral head and proximal femoral metaphysis. (A: From Sucato DJ, Schwend RM, Gillespie R. Septic arthritis of the hip in children. J Am Acad Orthop Surg 1997;5:249–260. D–F: Courtesy of Mark Sinclair, MD, Children's Mercy Hospital, Kansas City, MO.)
NONOPERATIVE MANAGEMENT

Surgical treatment is indicated when septic hip arthritis has been confirmed.

Nonoperative management is an adjuvant to surgery and includes making an early and specific bacterial diagnosis, administering the correct intravenous antibiotic and dose, and adjusting the antibiotic coverage based on culture and sensitivity results.

Intravenous antibiotics are converted to oral when the child is clearly recovering (feels well, afebrile, able to walk, minimal pain with hip range of motion, and improving laboratory studies). The duration of antibiotic treatment is generally shorter than for osteomyelitis and depends on the severity of infection and the virulence of the organism.

A peripherally inserted central catheter is used if intravenous antibiotics will be given for several weeks. An infectious disease consultation is helpful for cases with an unusual organism, unusual host, or unusual site of infection.

SURGICAL MANAGEMENT

Confirmed septic hip arthritis is a surgical emergency and the hip should be drained without excessive delay.

If the joint aspiration is performed in the operating room, the arthrotomy can be performed in the same setting.

The principles of surgical intervention include open arthrotomy, irrigation of purulence, and débridement of dead tissue.

Preoperative Planning

Radiolucent table
An aspiration of the hip is performed before an arthrotomy if the diagnosis is not clear. In children, the hip joint is aspirated with a spinal needle inserted just posterior to the adductor longus tendon and directed toward the femoral head (FIG 3G,H).

Positioning
Lateral or semilateral position with hip and lower extremity draped free (FIG 4).

Approach
There are several approaches to draining the pediatric hip, including medial, direct anterior, anterior through a modified Smith-Peterson approach, anterolateral, and posterior.

The posterior approach is not recommended because of the femoral head vascularity and potential for posterior hip instability.

DIFFERENTIAL DIAGNOSIS

Transient synovitis
Trauma
Pelvic or proximal femur osteomyelitis
Pyomyositis of the adductors, hamstrings, obturator muscles, or piriformis muscles
Langerhans cell histiocytosis
Leukemia, Ewing sarcoma, metastatic neuroblastoma
Other forms of arthritis, including Lyme disease, tuberculosis, fungal or chronic childhood arthritis
Iliopsoas or iliacus abscess
 Appendicitis or ovarian cyst
Child abuse
Osteonecrosis of the femoral head and sickle cell disease
MODIFIED SMITH-PETERSON ANTERIOR APPROACH

- The entire hip and lower extremity is draped free so that the hip joint can be moved through a full range of motion.
- The incision is a modification of the classic Smith-Peterson approach with a cosmetic and limited incision in the groin, centered just below the anterior superior iliac spine (ASIS) (TECH FIG 1A).
- Sharp knife dissection is used to the deep fascia. The incision is continued until no more fat is apparent and the deep fascia is exposed.
- A sponge is used to separate the distal flap from the deep fascia.
- There is a small interval of fat between the tensor and sartorius muscles several centimeters distal to the ASIS (TECH FIG 1B). The surgeon should incise slightly lateral to the fat on the fascia of the tensor.
- Army-Navy retractors are used to separate this internerous interval until the rectus femoris muscle is visualized.
- A Kidner Sponge is used on the lateral edge of the rectus femoris muscle, and the surgeon dissects along this edge proximally until the reflected head of the rectus femoris muscle is exposed (TECH FIG 1C).
- Just lateral to the reflected head is the hip capsule, which is covered with fat.
- The fat is reflected to expose the hip capsule. The reflected head of the rectus femoris muscle may be divided for better exposure of the hip capsule.
- It is best to visualize a large area of the hip capsule for better orientation before making an incision into it.
- The capsule is incised with a no. 15 blade.
- A 3-mm 45-degree Kerrison rongeur is useful to remove several millimeters of the anterior capsule for continued postoperative decompression (TECH FIG 1D).
- The joint is irrigated with saline through a large-bore intravenous catheter placed deep within the joint.
- A suction drain is placed for several days after surgery until there is only minimal drainage.
- The skin is closed loosely with interrupted nylon sutures to allow potential drainage.
- Closing the deep fascia increases the risk of reaccumulation.

TECH FIG 1 • Modified Smith-Peterson anterior approach to the right hip. A. The incision is placed in the anterior groin crease for best cosmesis. B. The tensor–sartorius muscle interval is identified distally where the muscles begin to separate. (continued)
DIRECT ANTERIOR APPROACH

- The direct anterior approach is especially useful when there is infection in the iliopsoas bursa, which needs to be opened along with the hip joint.
  - This is also a direct approach for dividing the psoas tendon over the pelvic brim for a tight tendon, as seen in cerebral palsy, or a snapping hip related to the iliopsoas tendon.
  - It uses a similar incision as the anterior approach, placed just below the ASIS but centered more medially, between the femoral neurovascular bundle and the ASIS.
- Sharp dissection continues to the deep fascia until no further superficial fat is identified.
- A sponge separates both flaps off the deep fascia.
- The medial border of the sartorius muscle is identified. Just medial and slightly deeper is the fascia of the iliacus muscle, which is opened (TECH FIG 2A).
- The femoral nerve is identified, reflected medially, and protected (TECH FIG 2B). This provides assurance that the femoral artery and vein, which lie medial to the femoral nerve, are out of the field.
- The dissection is continued along the medial border of the iliacus muscle until the iliopectineus eminence of the pubic bone is identified.
- Deep to the iliacus muscle is the large bursa of the iliopsoas (TECH FIG 2C). This is opened and the psoas tendon is isolated proximally and distally.
- Deep and lateral to the psoas tendon is the hip capsule.
  - A small elevator is used to visualize the surface of the capsule before entering it with a no. 15 blade.
- A 3-mm 45-degree Kerrison rongeur is used to enlarge the capsulotomy.
  - The joint is irrigated and a suction drain placed. If this approach is used for infection, the surgeon should not close the deep fascia.
ANTERIOR LATERAL APPROACH

- A straight longitudinal incision centered over the greater trochanter is used.
- The tensor fascia is divided longitudinally in line with the skin incision.
- The interval between the most anterior border of the gluteus medius muscle as it attaches to the greater trochanter and the proximal aspect of the vastus lateralis muscle is identified (TECH FIG 3A).
- Several millimeters of the gluteus medius attachment to the greater trochanter is released. This allows the examiner to palpate the anterior aspect of the femoral neck, up to the level of the femoral head.
- The gluteus medius muscle is retracted proximally and an incision is made in the anterior capsule (TECH FIG 3B). It can be enlarged with the Kerrison rongeur.
- After irrigation and débridement, a drain is left in the hip joint for several days.
- The skin is closed with several interrupted nylon sutures, but the deep fascia should not be closed.

TECH FIG 3 • A. The most anterior fibers of the gluteus medius muscle are divided (dashed line) as they insert on the vastus lateralis and greater trochanter. B. The gluteus medius muscle is retracted and the anterior capsule is palpated and visualized.
POSTOPERATIVE CARE

- A surgical drain is used for several days. It is removed when it is no longer functioning.
- The family needs to understand that repeat drainage is a possibility should symptoms recur or if improvement is inadequate.
- A spica cast is frequently used if the radiograph shows laxity and lateral displacement, especially in the infant.
- Another radiograph is obtained when the antibiotics are discontinued to be sure there is no evidence of osteomyelitis.
- Another radiograph is obtained at 4 to 6 months to document adequate physeal growth.
- In a growing child with a septic joint, the parents should be informed that growth of the bones in that area can be affected.

OUTCOMES

- In reports of poor results from septic arthritis, 75% involve the hip joint.
- Severe sequelae with a destroyed femoral head are most commonly seen in newborns and infants and are often related to a delay in diagnosis and treatment (**FIG 5**).
- Infants in particular should be followed for several years to document adequate development of the hip joint.
- Simple late reconstruction should focus on maintaining pain-free hip range of motion, realignment procedures if there is a reasonably formed femoral head, and simple procedures to achieve comparable limb lengths.2
- Complex late reconstruction should rarely be used unless the functional goal can clearly be stated and the procedure has a reasonable chance of meeting that goal.

COMPLICATIONS

- Avascular necrosis of the hips can lead to complete destruction of the femoral head (**FIG 6**).
- Septic hip dislocation
- Complete separation of the proximal femoral epiphysis
- Proximal femur growth arrest and limb-length discrepancy9
- Closure of the triradiate cartilage
- Late arthritis
REFERENCES

DEFINITION

- The Salter innominate osteotomy is commonly performed in conjunction with an open reduction for the dislocated hip in developmental dysplasia of the hip (DDH).
- The osteotomy can also be performed to treat acetabular dysplasia in the child with a concentrically reduced hip.7

ANATOMY

- The Salter innominate osteotomy rotates around an axis running from the posterior cortex of the sciatic notch to the midpoint of the symphysis pubis.
- The osteotomy rotates the acetabulum to improve anterior and lateral femoral head coverage.
- The distal fragment of the osteotomy undergoes slight distal, posterior, and medial displacement in addition to rotation.5
- An up-to-30-degree bone wedge inserted in the osteotomy site increases anterior and lateral femoral head coverage in a proportion of about 2:1 (the practical limit of correction).5

PATHOGENESIS

- Acetabular dysplasia is caused by the following:
  - Lack of a reduced, spherical head within the growing acetabulum
  - Abnormal interstitial or appositional growth within the acetabular and triradiate cartilage
  - Abnormal development of the secondary centers of ossification of the ilium, pubis, and ischium
  - In the developmentally dislocated hip, the acetabular labrum is flattened and hypertrophied, referred to as the "neolimbus."
  - The acetabular dysplasia in the infant and young child with DDH is predominantly anterior and lateral.8

NATURAL HISTORY

- The natural history of the dysplastic hip with hip subluxation is worse than the hip with acetabular dysplasia alone.
  - Patients with subluxated dysplastic hips develop pain and disability and radiographic evidence of osteoarthrosis. The age of onset of symptoms depends on the degree of subluxation, with severe subluxation leading to symptoms in the third decade of life.10
  - Patients with acetabular dysplasia without subluxation develop radiographic evidence of osteoarthrosis in the sixth decade of life, and some will develop pain and disability, depending on the degree of dysplasia.10

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with developmental hip dislocation may have a positive family history and are usually female and first-born children.
- There can be a history of breech presentation at birth.
- Children with a dislocated hip usually meet their gross motor milestones within the appropriate timeframe.
- The pertinent physical examination findings in the walking child (the timeframe when this operation is typically performed) are listed below.
  - Hamstring tightness test: Normally, the hamstrings will tighten with passive knee extension, and no knee hyperextension should be possible. A positive test implies hip dislocation or flaccid paralysis of the hamstring muscles.
  - Gluteus medius lurch: Trunk lean over the stance phase leg signifies a positive test, which is a nonspecific sign of hip pathology caused by dislocation, coxa vara, or painful hip conditions.
  - Galeazzi sign: Knees at different levels signify a positive test, which indicates hip dislocation or congenital shortening of the femur.
  - Trendelenburg sign: If the pelvis dips away from the affected leg during single limb stance, the test is positive. Like the gluteus medius lurch, a positive test is a nonspecific sign of hip pathology caused by dislocation, coxa vara, or painful hip conditions.
  - Inspection of inguinal skin fold: Normal inguinal skin folds are symmetric and stop short of the anal aperture posteriorly. Asymmetric skin folds are a relatively nonspecific finding in the dislocated hip.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Standing anteroposterior (AP) and supine frog-leg lateral pelvis radiographs
  - On the AP film, the acetabular index should be measured to diagnose acetabular dysplasia. Normal values are 35 degrees at birth, 25 degrees at 1 year of age, and 20 degrees at 2 years of age (FIG 1).9
  - Also on the AP film, the line of Shenton is inspected for discontinuity, which represents hip subluxation (FIG 1).
  - A false-profile view of the hip can identify more subtle cases of acetabular dysplasia, particularly in the walking child.
  - Advanced imaging studies (3D CT scanning of the acetabulum, MRI of the hip) may be of value in older children to assess acetabular morphology.

DIFFERENTIAL DIAGNOSIS

- Proximal femoral focal deficiency
- Congenitally short femur
- Developmental coxa vara
- Legg-Calvé-Perthes disease
**NONOPERATIVE MANAGEMENT**

- The acetabular index should be observed for improvement over 12–18 months after successful closed reduction in the child less than 18 months of age.
  - If residual acetabular dysplasia exists, a Salter innominate osteotomy can be performed at that time.²
  - Whether the osteotomy should be performed concurrently with an open reduction or as a staged procedure is controversial.
  - A child less than 18 months old who fails closed reduction can be treated with an isolated open reduction of a dislocated hip and observed for improvement in the acetabular index into the normal range over 12 to 18 months.
  - A subsequent Salter innominate osteotomy should be performed if acetabular development is deficient after observation.⁴

**SURGICAL MANAGEMENT**

- Surgical indications:
  - Age 18 months to 6 years⁶
  - Concentric hip reduction (either preoperatively or intraoperatively with an open reduction)⁵
  - No or minimal osteoarthrosis of the hip
  - At least 100 degrees of hip flexion and 30 degrees of hip abduction
  - Anterior and lateral acetabular dysplasia

**Preoperative Planning**

- A hip arthrogram is first performed in cases of hip dysplasia before patient positioning to confirm a concentric reduction.
  - If there is not a concentric reduction, other procedures (open reduction, proximal femoral osteotomy) are performed to achieve a concentric reduction before performing a Salter innominate osteotomy.
  - For the dislocated hip, a closed reduction is attempted.
  - If a gentle concentric closed reduction is achieved and the patient is over 18 months old, a Salter innominate osteotomy including intramuscular psoas lengthening without open hip reduction can be performed.
  - An estimation of femoral anteversion with fluoroscopy before patient positioning is used to decide if a concurrent femoral derotational osteotomy is necessary.
  - We perform a femoral derotational osteotomy if femoral anteversion is greater than 45 degrees.

**Positioning**

- The patient is placed supine on the operating table with a gel roll under the thoracolumbar spine on the affected side (but not under the affected pelvis), raising the affected side into an oblique position.
- The hip is prepared from the midline anterior and posterior, to the inferior rib cage proximally, and the entire extremity distally (FIG 2).

**Approach**

- An anterior Smith-Peterson approach to the hip is used, with the incision modified as described in Chapter PE-67 (FIG 3).
EXPOSURE OF THE ANTERIOR HIP AND ILIUM

- The exposure of the anterior hip is the same as for an open reduction of the hip in Chapter PE-67.
- While retracting the external oblique muscle proximal and medial, the iliac apophysis is split with a no. 15 blade scalpel from the iliac tubercle to the anterior inferior iliac spine (AIIS).
- The inner and outer tables of the ilium are subperiosteally dissected with Crego periosteal elevators to the sciatic notch.
- An intramuscular psoas tendon lengthening is performed at the pelvic brim.

SALTER INNOMINATE OSTEOTOMY

- Curved Crego or Rang retractors are placed subperiosteally in the sciatic notch from the medial and lateral sides.
- The medial retractor is placed on top of the lateral retractor in the notch.
- The tip of a right-angled clamp is placed on top of the retractors from the medial side of the sciatic notch.
- The Gigli saw is placed into the right angle clamp laterally and pulled around the sciatic notch (TECH FIG 1A).
- The right-angled clamp is rotated into the notch on top of the medial retractor.
- The operating room table is lowered, and with hands as wide as possible, the Gigli saw is used to make the osteotomy, exiting just above the AIIS (TECH FIG 1B).

HARVESTING BONE GRAFT

- The iliac wing is removed with an oscillating saw laterally or bone-biting forceps from the AIIS to the iliac tubercle (TECH FIG 2A,B).
- The graft is shaped in to a 30-degree bone wedge (TECH FIG 2C).
PLACING THE GRAFT

- Towel clamps are used to stabilize the proximal fragment and hinge the distal fragment anterior and lateral. The distal fragment is pulled anteriorly to prevent posterior slipping, and the posterior part of the osteotomy is kept apposed (TECH FIG 3A).
- If done as an isolated procedure, opening the osteotomy site can be facilitated by placing the leg in the figure 4 position.
- The graft is placed in the osteotomy gap concave side medial, with the medial cortex flush with the medial cortex of the proximal and distal fragments (TECH FIG 3B).
- The graft is secured with two threaded Steinmann pins placed from proximal across the graft into the medial and posterior portion of the distal fragment up to the triradiate cartilage (TECH FIG 3C).
- The acetabulum is palpated (if done with an open reduction) or the hip taken through full range of motion (if done as an isolated procedure) to ensure pins are extra-articular.
- An intraoperative obturator oblique radiograph is taken with the pins in place to ensure they do not enter the triradiate cartilage (TECH FIG 3D).

WOUND CLOSURE

- The iliac apophysis is closed with absorbable suture in a figure 8 fashion. The first loop of the figure 8 is circumferential around the entire apophysis, and the second loop captures only the superficial half of the apophysis.
- The pins are cut above the apophysis, coming to lie in the subcutaneous fat, for easy future removal.
- The common head of the rectus femoris tendon is repaired to its insertion.
- Subcutaneous tissue and skin are closed in the standard fashion.
POSTOPERATIVE CARE
- The patient is placed in a one-and-a-half hip spica cast with the affected hip in the position of maximal hip stability and, if possible, close to the position of weight bearing (about 30 degrees of flexion, 20 degrees of abduction, and 20 degrees of internal rotation).
- When performed as an isolated procedure, young children should be immobilized in a single-leg spica cast for about 6 weeks, when early radiographic evidence of healing is evident.
- Older children who are reliable may be allowed to use crutches and perform touch-down weight bearing on the affected side without the use of a single-leg spica cast.

OUTCOMES
- Patients with concentrically reduced hips and corrected acetabular dysplasia with a Salter innominate osteotomy, in the absence of avascular necrosis, have good to excellent functional outcomes scores at over 30 years after the index procedure.
- Functional outcomes are best when the acetabular dysplasia is initially corrected to near-normal radiographic values.1,4

COMPLICATIONS
- Neurovascular injury to structures in the sciatic notch
- Lateral femoral cutaneous nerve injury during surgical exposure
- Inadequate correction of acetabular dysplasia due to inadequate patient selection preoperatively or inadequate acetabular rotation intraoperatively3
- Injury to the femoral nerve due to prolonged retraction of the psoas muscle or incorrect identification of the psoas tendon during intramuscular tenotomy
- Pin penetration into the hip joint or triradiate cartilage
- Nonunion at the osteotomy site
- Migration of the graft due to inadequate fixation3
- Avascular necrosis of the femoral epiphysis3
- Growth arrest of the triradiate cartilage
REFERENCES

DEFINITION
■ The Pemberton (FIG 1A–C) and Dega (FIG 1D–F) osteotomies are performed for acetabular dysplasia that is either part of a developmental disorder or an acquired disorder due to muscle imbalance in neuromuscular conditions.
■ These are reshaping procedures that alter the shape of the acetabulum and increase its volume.7,12
■ They are used primarily to increase anterior acetabular coverage but can be altered to provide more lateral coverage.

ANATOMY
■ The acetabulum develops at the confluence of the growth centers of the ilium, ischium, and pubis.

PATHOGENESIS
■ Normal growth of the acetabulum requires not only that all of these growth centers remain open and function normally but also that the femoral head remains concentrically reduced and stable within the acetabulum.
■ If the growth centers are damaged, either from pathologic conditions or iatrogenically, or if the femoral head is not stable within the acetabulum, normal growth is unlikely to occur and hip dysplasia develops.

FIG 1 • A–C. Pemberton osteotomy depicted on a bone model viewed from anteriorly (A), from inside the pelvis medially (B), and from outside the pelvis laterally (C). The osteotomy starts at the anterioinferior iliac spine (AIIS) and extends posteriorly following the insertion of the capsule. It then turns caudally and bisects the posterior column to the level of the triradiate cartilage. D–F. Dega osteotomy depicted on bone model viewed from anteriorly (D), from inside the pelvis medially (E), and from outside the pelvis laterally (F). As for the Pemberton, the Dega osteotomy starts at the AIIS and extends posteriorly following the insertion of the capsule. However, it then stops about 1 cm from the sciatic notch on the lateral surface. The medial surface is cut just above the horizontal limb of the triradiate cartilage. The more of the medial surface that is left intact, the more lateral coverage the osteotomy provides.
Even with a concentric reduction of the femoral head, the prior period of abnormal growth may prevent the acetabulum from achieving a normal configuration at maturity. The older the child is at the time of reduction, the more likely an osteotomy will be necessary.

**NATURAL HISTORY**

- Many patients with acetabular dysplasia develop subluxation or dislocation of the femoral head. This can lead to early arthritis in the middle adult years.
- The degree of subluxation does not necessarily correlate with the time to onset of symptoms or the degree of arthritic changes.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Hip dysplasia can be diagnosed clinically in newborns and young infants owing to instability of the hip.
- Patients with a history of hip dysplasia are typically followed radiographically until adulthood to ensure normal acetabular development.
- Older children without a prior history of developmental hip dysplasia are typically diagnosed with radiographs based on clinical suspicion, especially when significant risk factors are present.
- Risk factors include breec position, female, first-born, and oligohydramnios. Developmental hip dysplasia is associated with other “packaging disorders.”
- Patients sometimes present in childhood with a limp, hip pain, limb-length discrepancy, or asymmetric hip abduction, particularly those with underlying neuromuscular conditions.
- Routine screening for hip dysplasia in neuromuscular conditions with radiographs is widely performed.
- Examinations and tests to perform include:
  - Ortolani test: Positive if a clunk is felt as a dislocated hip reduces.
  - Barlow test: Positive if a clunk is felt as a reduced hip dislocates.
  - Hip abduction: In a normal hip, abduction should be more than 60 degrees and symmetric. This may be the only abnormal sign in infants. A difference of 10 degrees or more is significant.
  - Galeazzi sign: A difference in thigh length is a positive result. A positive Galeazzi sign can indicate a dislocated hip, a short femur, or a congenital hip deformity.
  - Abnormal skin folds can occur in normal children but may also indicate asymmetric hip abduction.
  - Limp with ambulation, Trendelenburg sign, or limp associated with limb-length discrepancy may be the only abnormal sign in older children.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Dynamic hip ultrasound can be used to detect hip dysplasia in very young infants (under 6 months of age).
- Plain radiographs, including an anteroposterior (AP) view of the pelvis and false profile views, typically can be used to make the diagnosis in older children.
- Radiographic parameters, including the acetabular index, lateral center-edge angle, anterior center-edge angle, the position of the sourcil, and the line of Shenton, should be evaluated (FIG 2).

**DIFFERENTIAL DIAGNOSIS**

- Dislocation is detected by lack of contact between the acetabulum and femoral head.
- Subluxation is detected by a break in the line of Shenton.
- Acetabular dysplasia can be detected by a decrease in the lateral center-edge angle or an increased acetabular index on the AP pelvic radiograph or a decrease in the anterior center-edge angle on the false profile view.
- A pelvic radiograph with the legs abducted and internally rotated can give some idea about the ability of the hip to reduce, with either increased acetabular coverage or a femoral osteotomy.
- A CT scan can provide a closer look at anterior and lateral coverage.
NONOPERATIVE MANAGEMENT

- Infants are typically treated with full-time braces, such as the Pavlik harness.
- Young children can be treated with a closed reduction and cast immobilization.
- The initial treatment for primary acetabular dysplasia without hip instability or residual acetabular dysplasia following treatment for instability is observation.
  - As long as the acetabular index continues to improve and the hip remains concentrically reduced, observation can be continued.
  - If hip subluxation develops or the acetabular index fails to improve over a 12-month period, operative treatment is indicated.
- Neuromuscular patients with a migration index less than 25% can be observed as long as their abduction remains greater than 45 degrees. Patients with migration indexes over 50% generally will benefit from surgical treatment of their dysplasia, which can include a femoral or pelvic osteotomy.

SURGICAL MANAGEMENT

- The Pemberton and Dega osteotomies are used to treat acetabular dysplasia with anterior and lateral deficiencies.
- They are used when more than 10 degrees of acetabular index correction is needed.
- They are also used to augment the reduction during open reduction in a patient with severe acetabular dysplasia.
- Mubarak’s variation of the Dega osteotomy incorporates a lateral ilium cut that goes all the way to the sciatic notch.
  - It includes a bicortical cut into the sciatic notch with a rongeur.
  - The inner wall of the ilium is cut only anteriorly between the anterosuperior and anteroinferior iliac spines (ASIS and AIIS) and posteriorly at the sciatic notch.

Preoperative Planning

- Hip and knee contractures should be carefully evaluated preoperatively so they can be addressed during the surgical procedure.
- With neuromuscular patients, the femoral head may be deformed. An open capsulotomy to look at the articular cartilage may prove to be beneficial.
- If there is significant articular cartilage damage, particularly laterally from the hip capsule, a resection arthroplasty may be indicated as opposed to a reduction.

The primary area of acetabular deficiency needs to be determined to plan the osteotomy.
- The triradiate cartilage should be open because the osteotomy hinges on this cartilage. Generally this osteotomy can be performed up to 10 years of age.
- Hip mobility must be good, especially abduction and internal rotation.
- A concentric reduction of the femoral head in the acetabulum before the osteotomy is an absolute prerequisite. This can be assessed preoperatively with an abduction internal rotation hip radiograph or can be assessed intraoperatively after a capsulotomy or varus proximal femoral osteotomy.

Positioning

- Patients are positioned supine on a radiolucent table with a bump under the lumbar sacral spine to provide about 30 degrees of elevation of the ipsilateral hip (FIG 3).
- A fluoroscopic evaluation should be done at this time to ensure adequate radiographic visualization.
- The entire limb is prepared from the lower rib cage to midline.

Approach

- A standard anterolateral approach using the interval between the tensor fascia lata and sartorius is used.

Either skin incision is deepened to expose the iliac crest and the interval between the sartorius and tensor fascia lata.
- The deep fascia is incised next on top of the tensor fascia lata muscle to avoid injury to the lateral femoral cutaneous nerve (TECH FIG 1B).
- The tensor–sartorius interval is deepened until the rectus femoris is encountered. The interval is then developed proximally up to the ASIS. The direct head of the rectus attached to the AIIS is identified. It can be released and reattached at the end of the osteotomy or left attached.
TECH FIG 1 • A. Skin incisions. There are two alternatives for the skin incision. The more extensile Smith-Petersen concave incision (red line) can be used for a concurrent femoral osteotomy, but it often leaves an unsightly scar. The more limited “bikini” incision (black line) provides plenty of exposure, leaves an appealing scar, and can be combined with a lateral incision for concurrent femoral osteotomies. B. Superficial exposure. The iliac apophysis has been exposed by elevating the overlying abdominal musculature. The tensor-sartorius interval has been opened. The interval is opened over the tensor musculature to protect the lateral femoral cutaneous nerve. The nerve is on top of the pickup.

PEMBERTON OSTEOTOMY

Deep Exposure

- The exposure is important in this osteotomy. Before any cuts are made the surgeon should be able to clearly see the inner and outer portions of the iliac wing to the sciatic notch posteriorly and the entire hip capsule anteriorly.
- The outer table of the ilium can be exposed either by splitting the iliac apophysis or by dissecting just below the apophysis, in which case the apophysis is then taken off as an entire piece to minimize injury to this growth area.
- The outer and inner tables are exposed in a subperiosteal fashion to the sciatic notch.
- Chandler retractors are placed into the sciatic notch from medial and lateral to protect the neurovascular bundle (TECH FIG 2).
- The reflected head of the rectus is then released and followed posteriorly. It acts as a guide to the border of the hip capsule.

Creating the Osteotomy

- The first cut is made on the outer table starting 1 to 1.5 cm above the AIIS and extending posteriorly and parallel to the joint capsule.
- About 0.5 to 1 cm from the sciatic notch, the osteotome should be turned and directed distally down the ischium to the level of the ischial limb of the triradiate cartilage (TECH FIG 3A).
- The last portion of this cut is made in a blind fashion with fluoroscopic guidance, and care must be taken to avoid cutting into the sciatic notch, the hip joint, or the triradiate cartilage.
- The osteotome should remain midway between the capsular attachment and the sciatic notch, splitting the posterior column in half to the level of the triradiate cartilage.
- The inner cut is started at the same point as the outer cut on the anterior surface, and the cut is generally at the same level as the outer cut running parallel to it (TECH FIG 3B).

Osteotomy Variation

- If more lateral coverage is needed, the inner cut is moved more distal and shortened to make a more oblique osteotomy.
- This changes the fulcrum of rotation from straight posterior to more posteromedial, giving more lateral coverage as the fragment is levered downward (TECH FIG 4).

Separating the Bone

- A special curved osteotome (TECH FIG 5A) is inserted into the osteotomy to connect the two cuts. This osteotome is advanced by hand.
- Once the osteotome is at the level of the triradiate cartilage (TECH FIG 5B), the acetabular roof is gently levered down (TECH FIG 5C).
TECH FIG 4 • Variations in the Pemberton osteotomy. The inner and outer iliac wing cuts determine the amount of coverage based on their direction. A,B. If more anterior coverage is required, then the inner cut is more transverse. C,D. If more lateral coverage is required, then the osteotomy is inclined laterally and both cuts begin a little farther away from the capsule.

TECH FIG 5 • A. Pemberton osteotome. The special curved Pemberton osteotome is necessary to connect the inner and outer wall cuts and make the sharp posterior curve. B. Connecting the cuts. A special curved osteotome is necessary to make the sharp curve of the osteotomy posteriorly. The osteotome is advanced by hand, connecting the inner and outer wall cuts made previously. The osteotome is advanced to the level of the triradiate cartilage. The dotted line represents the anterosuperior iliac spine autograft fragment that can be used to hold the osteotomy open. C. Levering down the osteotomy. The osteotomy is levered downward with the osteotome. A lamina spreader can also be used with caution. In this patient, a femoral shortening osteotomy and open reduction have been performed and sutures are in place allowing for a capsulorrhaphy once Pemberton osteotomy has been completed.
TECH FIG 6 • A. Anterosuperior iliac spine (ASIS) autograft bone wedge. An osteotome is used to harvest the ASIS autograft bone wedge. The height of the wedge is determined by the amount the osteotomy will be levered downward. B. Graft placement. An autograft bone wedge from the ASIS or an allograft wedge can be used. The graft is inserted in an anterior-to-posterior direction and should be stable after it is impacted. Internal fixation is seldom necessary. C. AP postoperative pelvic radiograph of a left Pemberton osteotomy in a spica cast. An open reduction, capsulorrhaphy, and femoral shortening osteotomy have also been performed.

Graft Placement and Closure
- Once the roof is in the desired position (usually an opening of 1 to 2 cm anteriorly), bone wedges are placed in the opening to hold the osteotomy open. Allograft or a wedge of the ASIS can be used. 5
- An autograft wedge of the ASIS can be harvested with a straight cut of the ilium (TECH FIG 6A).
- The graft is usually placed from anterior to posterior. A gouge may be used to make a trough in the iliac wing and the acetabular fragment for the graft to rest in (TECH FIG 6B).
- Internal fixation is usually not necessary.
- The apophysis and muscles are then reattached with suture, and the skin is closed in routine fashion.
- A hip spica cast is then applied (TECH FIG 6C).

DEGA OSTEOTOMY

Exposure
- As for the Pemberton osteotomy, the outer table of the ilium can be exposed either by splitting the iliac apophysis or by dissecting just below the apophysis, in which case the apophysis is then taken off as an entire piece to minimize injury to this growth area.
- The outer table is exposed in a subperiosteal fashion to the sciatic notch. Although it is not necessary to expose the inner table for a Dega osteotomy, it does aid in orientation and adds little to the morbidity of the procedure (TECH FIG 7).
- A Chandler retractor is placed into the sciatic notch from the lateral side to protect the neurovascular bundle.
- The reflected head of the rectus is then released and followed posteriorly. It acts as a guide to the border of the hip capsule.

TECH FIG 7 • Deep exposure. The iliac apophysis has been slit and the inner and outer walls of the ilium have been exposed by subperiosteal elevation. Sponges have been placed posteriorly along the inner and outer ilium to aid in retraction.
Creating the Osteotomy

- A curvilinear osteotomy is performed on the outer wall starting just above the AIIS to a point 1 to 1.5 cm in front of the sciatic notch.
- Guidewires can be inserted at the most cephalad portion of the osteotomy, directed toward the inner wall just above the triradiate cartilage. They are placed under radiographic guidance on the obturator oblique view. They serve as a guide for the chisel when the osteotomy is made.
- Like exposing the inner table, guidewires are not necessary but aid in orientation and add little to the morbidity of the operative procedure (TECH FIG 8A).

Next, an osteotome is used to cut the ilium medially and inferiorly in line with the guidewire down through the inner wall (TECH FIG 8B). If the inner table has been exposed, this can be confirmed with direct visualization. The posterior third of the inner wall should be left intact to act as a fulcrum for rotation.
- The less inner wall that is cut, the more lateral the coverage that will be obtained with rotation (TECH FIG 8C–E).
- The thinner the roof fragment, the deeper the coverage and less redirection you have.
- The cortex is then levered down with a wide osteotome to provide the desired coverage.
**Mubarak Variation**

- The Mubarak variation is a variation of the Dega osteotomy that incorporates a lateral ilium cut that goes all the way to the sciatic notch (TECH FIG 9).
- It includes a bicortical cut into the sciatic notch with a rongeur.

- The inner wall of the ilium is cut only anteriorly between the ASIS and AIIS and posteriorly at the sciatic notch.
- The outer ilium is exposed down to AIIS anteriorly and the sciatic notch posteriorly. The inner wall is exposed only enough to take the upper ilium and ASIS for bone graft.
- Two points are identified, one about 0.5 to 1 cm above the acetabulum and one within the sciatic notch. Bicortical cuts are made at each spot.
- A Kerrison rongeur can be used to make the posterior cut safely.
- A curvilinear cut is made in the outer cortex to connect the two points.
- The osteotome is directed down to the triradiate cartilage but does not enter the cartilage. It is used to lever the roof down 1 to 1.5 cm, and once the bone is levered down, bone graft wedges are used to hold it open.

**Graft Placement and Closure**

- Triangular bone wedges are used to hold the osteotomy open (TECH FIG 10A). Allograft wedges can be used. Autograft wedges from the iliac crest or from a concurrent femoral shortening osteotomy can also be used.
- The wedges are inserted in a lateral-to-medial direction. It is important to place the largest piece of graft where the most coverage is desired (TECH FIG 10B).
- Internal fixation is usually not necessary.
- The apophysis and muscles are then reattached with suture and the skin is closed in routine fashion.
- A hip spica cast is then applied (TECH FIG 10C,D).

**TECH FIG 9** • The Mubarak variation is shown in an anterior and lateral projection. The osteotomy extends anteriorly from the anteroinferior iliac spine posteriorly to the sciatic notch 0.5 to 1.0 cm above the hip capsule. The osteotomy is bicortical only in the area of the iliac spines and the sciatic notch. The sciatic notch cut can be made with a Kerrison rongeur. Osteotomes are then used to cut toward the triradiate cartilage between the hip joint and the medial wall. Once the cut has been extended to the triradiate cartilage, the acetabular fragment is levered downward. If the anterior and posterior cuts are not bicortical, then the fragment may not displace adequately.

**TECH FIG 10** • A. Triangular pieces of autograft or allograft bone can be used as wedges. The size of the wedge depends on the amount the osteotomy is mobilized and the remaining gap left. B. Autograft bone wedges from the anterosuperior iliac spine or allograft can be used. The grafts are inserted in a lateral-to-medial direction. The largest wedge is inserted in the area where the largest amount of coverage is desired. The grafts should be stable after they are impacted. Internal fixation is seldom necessary. C. Postoperative AP pelvic radiograph of a right Dega osteotomy in a spica cast (same child as shown in Fig 2B). Allograft bone has been used. D. An AP pelvic radiograph of the same child 12 months postoperatively. The line of Shenton is now intact, the allograft has incorporated nicely, and the femoral epiphysis remains round.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Inadequate exposure</th>
<th>▪ If the sciatic notch cannot be seen on both the inner and outer walls of the ischium, then the osteotomy is more likely to enter the sciatic notch, potentially causing neurovascular injury.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need lateral coverage</td>
<td>▪ The osteotomy should be more of an oblique osteotomy, and the length of the inner wall cut should be one-half to two-thirds the length of the outer cut. This allows the osteotomy to rotate around a more medial fulcrum, giving more lateral coverage.</td>
</tr>
<tr>
<td>Need anterior coverage</td>
<td>▪ The inner and outer wall cuts should be on the same level and the two cuts should be about the same length. For the Dega osteotomy, the inner cut might be slightly shorter (no less than 75% the length of the outer cut). This allows either osteotomy to rotate around a more posterior fulcrum, giving more anterior coverage.</td>
</tr>
</tbody>
</table>
| Graft loosening | ▪ A gouge can be used to make a trough for the graft.  
▪ Pemberton: The stability of the graft is tested with a Kocher clamp. If it is unstable, then the osteotomy is secured with a temporary Kirschner wire. The Kirschner wire must remain extrarticular.  
▪ Dega: The largest graft is placed in the area that needs the most coverage. The outer cortex of the graft should be buried below the outer cortex of the ilium. |
| Entry into the acetabulum | ▪ Without careful fluoroscopic guidance, the osteotome can be directed into the acetabular cartilage, causing significant damage. |
| Excessive anterior coverage | ▪ In a patient with prolonged subluxation or significant retroversion, the anterior coverage may subsequently leave the posterior acetabulum more unstable. |

POSTOPERATIVE CARE

▪ Patients are almost exclusively treated with a hip spica cast for 6 to 12 weeks. If this is a staged procedure, the patient should be left in half of the spica cast while the second procedure is being done.  
▪ Radiographs are obtained to make sure graft displacement has not occurred.  
▪ Once good radiographic healing has been demonstrated, progressive weight bearing over 4 weeks can be started.  
▪ Children are followed until maturity to detect avascular necrosis and ensure adequate acetabular coverage.  
▪ Physical therapy is typically not needed to regain mobility after immobilization.

OUTCOMES

▪ The Pemberton osteotomy provides excellent long-term acetabular correction in children, particularly those under age 4, 3, 8, 9, 13, 14.  
▪ The osteotomy has also been effective in patients with neuromuscular dysplasia.  
▪ The Dega osteotomy has been successfully used in the treatment of developmental dysplasia of the hip and neuromuscular dysplasia.  
▪ Several studies have found excellent results in younger children (under age 6), with results in older children less reliable.  

COMPLICATIONS

▪ Stiffness  
▪ Subluxation or dislocation  
▪ Closure of triradiate cartilage  
▪ Chondrolysis  
▪ Avascular necrosis of the femoral head

REFERENCES

DEFINITION
- The labral support (shelf) procedure has been used in patients with Legg-Calvé-Perthes disease (or Perthes disease) in Waldenström’s stages of necrosis or fragmentation in which the femoral head shows deformity or is at risk for deformity.\(^6\) (FIG. 1).
- The concept of the labral support (shelf) procedure in patients with Perthes disease includes the following steps:\(^6\):
  - Reducing the necrotic femoral head into the acetabulum
  - Eliminating hinge subluxation and improving femoral head coverage
  - Supporting the labrum and preventing deformity of the acetabulum (femoral–acetabular impingement)
  - Preparing for the (labral support) shelf to reabsorb after reossification of the femoral head
  - Stimulating overgrowth of the acetabulum and remodeling of the femoral head

ANATOMY
- The posterior branch lateral femoral cutaneous nerve
  - The lateral femoral cutaneous nerve arises from divisions of the second and third lumbar nerves.
  - It courses the lateral border of the psoas muscle, crosses the iliacus muscle obliquely, passes under the inguinal ligament, and divides into an anterior and posterior branch.
  - The posterior branch traverses beneath the sartorius muscle and exits the fascia lata about 1 to 2 cm below the anterior superior iliac spine.
  - The nerve supplies sensation to the skin anterolaterally from the level of the greater trochanter to the middle thigh.
  - The medial aspect of the bikini skin incision used in the labral support (shelf) procedure is very near the posterior branch of the lateral femoral cutaneous, which requires protection.
  - The labrum is located at the lateral rim of the acetabulum and has acetabular cartilage medially and fibrocartilage and fibrous tissue laterally.
  - The labrum growth plate contributes depth to the acetabulum and must not be damaged while performing the labral support (shelf).
  - In the adult, the average width of the acetabular labrum is 5.3 mm (standard deviation 2.6 mm).
  - The labrum is wider superiorly and anteriorly than posteriorly.
  - The surface area of the acetabulum without the labrum is 28.8 cm\(^2\) and with the labrum is 36.8 cm\(^2\).

PATHOGENESIS
- Perthes disease is a condition of the immature hip caused by necrosis of the epiphysis and the growth plate of the proximal capital area of the femur.
  - The necrotic tissue is gradually resorbed and replaced by new bone.
  - During the process, the epiphysis may become deformed and the growth of the proximal femur retarded.
  - Typically, the age at onset of symptoms is between 4 and 8 years, but it has been seen in children from 2 years to maturity.
  - There is a male predominance of 4:1, and the condition occurs bilaterally in up to 17% of cases.
  - Factors with the greatest prognostic significance in Perthes disease are:
    - Age at onset of the disease
    - Degree of necrosis of the capital epiphysis
    - Premature capital physeal growth plate closure
    - Persistent stiffness of the hip, with deformity of the femoral head (impingement)
  - At maturity, the hip may be normal or may have one of four patterns of deformity: coxa magna, coxa brevis, coxa irregularis (impingement), and osteochondritis dissecans.
  - In adulthood, patients with irregular (incongruent) hips develop impingement with progressive degenerative joint disease.
  - About 50% of all patients with Perthes disease have severe degenerative arthritis by the sixth and seventh decades of life.\(^{14–16,22}\)
NATURAL HISTORY

- Waldenström described four sequential stages of Perthes disease in childhood (later modified to the following): necrosis, fragmentation (resorption), reossification, and remodeling.\(^{24,25}\)
- The stage of necrosis begins with an infarction of the capital femoral epiphysis and lasts about 6 months.
- After the infarction, the child is usually asymptomatic, but a subchondral fracture subsequently develops in the necrotic bone and the hip becomes irritable (FIG 2).
- A mild effusion develops and the femoral heal begins to lateralize in the acetabulum.
- The hip becomes painful and adduction–flexion–external rotation contractures develop.
- The first radiographic sign of removal of necrotic bone begins the fragmentation stage (resorption).
- Gradually revascularization of the epiphysis begins, usually at the anterolateral area of the epiphysis.
- Over the ensuing months, the necrotic bone is removed, and the epiphysis may begin to deform, subluxate, and impinge on the margin of the acetabulum (hinged subluxation).
- During the fragmentation stage, the height of the lateral pillar of the femoral epiphysis correlates with outcome and predicts the chance of developing arthritis in adulthood (Table 1).
- The first radiographic signs of new bone formation indicate the reossification stage.
- About 12 to 14 months after the initial infarction, new bone begins forming in the epiphysis, usually at the anterolateral margin.
- Once the anterolateral column of the epiphysis has reossified, further epiphyseal deformity does not typically occur.\(^{23}\)
- Reossification continues until the entire epiphysis is healed, which may take up to about 4 years.
- The remodeling stage extends from the end of reossification until skeletal maturity.
- The femoral epiphysis may improve in sphericity with continued growth.
- Premature closure of the physis may cause limb shortening or deformity of the femoral neck.
- Common deformities of the hip following Perthes disease include coxa magna, coxa brevis (premature physeal closure), coxa irregularis (asphericity and incongruence of the hip with acetabular–femoral impingement), and osteochondral loose bodies.\(^{8,26}\)
- Stulberg et al\(^{22}\) classified hips into five groups that predict development of arthritis in adulthood (Table 2).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Perthes disease may present in children as an acute or chronic ache, which is commonly felt in the area of the hip, thigh, or knee. There is often an associated limp and hip stiffness.
- The ache is mild and usually presents immediately after getting up in the morning and after extended exercise, but it does not prevent walking.
- An antalgic limp is observed in the first few weeks of the disease, and then the gait may become a stiff pattern with flexion and adduction–flexion–external rotation contractures.
- The flexion–adduction hip contracture results in an apparent limb shortening, with dipping of the pelvis and a short stride length during ambulation.
- Muscle atrophy is often observed at the buttock, thigh, and knee.
- Additional clinical signs include a positive Thomas test (hip flexion contracture) and a positive log-roll test (loss of internal rotation of the hip).
- Growth in height is decreased during the early stages but returns to normal after healing.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- The diagnosis is typically confirmed by anteroposterior and frog-leg lateral radiographs.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Lateral Pillar Classification(^9,10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>Loss of Height of the Lateral Column of the Femoral Epiphysis</td>
</tr>
<tr>
<td>A</td>
<td>None</td>
</tr>
<tr>
<td>B</td>
<td>≤50% of the original height</td>
</tr>
<tr>
<td>C</td>
<td>&gt;50%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>Description</th>
<th>Prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Normal</td>
<td>Excellent</td>
</tr>
<tr>
<td>II</td>
<td>Loss of height in the femoral neck and the femoral epiphysis remains spherical</td>
<td>Excellent</td>
</tr>
<tr>
<td>III</td>
<td>Elliptical femoral epiphysis</td>
<td>Arthritis in late adulthood</td>
</tr>
<tr>
<td>IV</td>
<td>Femoral head flattening and a congruent acetabulum</td>
<td>Early arthritis</td>
</tr>
<tr>
<td>V</td>
<td>Flattened femoral head and an incongruent acetabulum</td>
<td>Early arthritis</td>
</tr>
</tbody>
</table>
Early in the disease (Waldenström stage of necrosis), radiographs show:
- Increased inferomedial joint space
- Lateral displacement of the femoral head
- Subchondral fracture
- Increased epiphyseal density
- A small proximal epiphysis of the femur

During the Waldenström stage of resorption (fragmentation), there is a gradual removal of the sclerotic necrotic bone and the femoral epiphysis may deform.
- As healing progresses with reossification, the epiphysis returns to a normal density and the femoral neck widens.
- The proximal femoral physis may close prematurely.\(^1\)

If the radiograph is not diagnostic, a bone scan or magnetic resonance imaging usually confirms the bone necrosis.
- The bone scan shows a cold area in the femoral epiphysis in the early stage of necrosis.
- With early revascularization (fragmentation stage of Waldenström), the scan will show the vascular ingrowth before radiographs.
- Magnetic resonance imaging clearly demonstrates the necrotic epiphysis in the early stage of the disease; however, marrow edema should not be confused with the area of necrosis.
- In the early stage, synovitis is observed, collapse and deformity of the cartilage of the epiphysis is usually clearly visible, and the degree of hinged subluxation (impingement) can be determined (FIG 3).\(^17\)
- In the fragmentation and reossification phases, vascular ingrowth is clearly visible.
- Computed tomography shows bone well and is most helpful to evaluate hip incongruity during the late stages of remodeling and during young adulthood.
- Skeletal hand bone age is decreased during the first year of the disease.

**DIFFERENTIAL DIAGNOSIS**
- Toxic synovitis (irritable hip syndrome)
- Infection, such as Lyme disease or tuberculosis
- Avascular necrosis of known etiology such as sickle cell disease, hemoglobinopathies, Gaucher disease, trauma, and steroid bone necrosis
- Arthritis, such as rheumatic fever
- Multiple epiphyseal dysplasia
- Tumors, such as chondroblastoma, leukemia, and lymphoma
- Slipped femoral epiphysis (preslip stage)

**NONOPERATIVE MANAGEMENT**
- Children less than 6 years of age without severe collapse of the femoral epiphysis have a good prognosis and do not require operative treatment.\(^2\)
- Their pain can be treated with nonnarcotic analgesic medications and crutch walking.
- Hip stiffness can be managed with physical therapy that emphasizes hip abduction, internal rotation, and extension.
- Children with necrosis involving less than 50% of the femoral epiphysis often have a good prognosis and operative treatment is often not necessary.
- Children over 11 years of age may be an exception in that a femoral epiphyseal deformity may develop (segmental collapse) even with less than 50% involvement.\(^10,20,26\)

**SURGICAL MANAGEMENT**
- **Indications**
  - Necrosis of over 50% of the proximal capital femoral epiphysis
  - Age 6 to 11 years: Younger children often heal well without operations and adolescents poorly remodel the femoral deformity.
  - Waldenström stages of necrosis or fragmentation. Ideally the operation should be performed before substantial deformity occurs to the capital femoral epiphysis.
  - Mild subluxation of the hip with hinged impingement (acetabular–femoral impingement)
- **Possible indications**
  - Children over 11 years of age with mild femoral epiphyseal collapse: These older children do not have adequate remaining growth to remodel the femoral epiphysis.
  - Children younger than 6 years of age with marked collapse of the femoral epiphysis: Typically children below 6 years of age heal well without treatment, but in severe cases, treatment may be indicated.
  - Patients with collapse of the epiphysis and hinged impingement: This operation may allow remodeling, but the outcome is less predictable.
- **Contraindications**
  - Subluxation that cannot be reduced into the acetabulum
  - Children less than 6 years of age (these patients heal well without treatment)
  - Necrosis less than 50% of the proximal capital femoral epiphysis (these cases typically heal well without treatment)
  - Children who are too old to achieve acetabular overgrowth: Children over 11 years of age may get less benefit.

**Positioning**
- The patient is placed in the supine position with the involved hip elevated by a longitudinal roll under the shoulder and back.
- The roll should not extend down to the hip area.
- The entire leg and hip is prepared and draped sterile to the anterior midline, to the posterior midline, and to the inferior rib line superiorly.

**FIG 3** Magnetic resonance image of the hip of a patient with Perthes disease showing lateral subluxation, synovitis, and acetabular–femoral impingement (hinged subluxation).
Approach
- The approach for the labral support procedure is between the tensor fasciae lata muscle and the sartorius and rectus femoris muscles.
- The dissection continues at the level of the anterior inferior iliac spine, beneath the origin of the gluteus minimus muscle (inferior gluteal line of ilium).
- The triangular interval is developed: the iliac wing medially, the hip capsule inferiorly, and the gluteus minimus laterally.
- With this approach, the origins of the abductor muscles are not elevated from the iliac wing, which we believe preserves the strength of hip abduction.
- The reflected tendon of the rectus muscle is retracted laterally and then used to secure the bone graft of the labral support shelf.

ARTHROGRAPHY
- Arthrography is performed to verify reduction of the subluxation and acetabular–femoral impingement.
- With the arthrographic dye in the hip joint, the degree of femoral epiphyseal deformity and subluxation is observed with the image intensifier.
- The leg is then abducted and the area of hinge abduction (acetabular–femoral impingement) is observed.
  - In many cases, the deformed femoral head will press against the lateral margin of the labrum and block the reduction of the femoral head into the acetabulum (TECH FIG 1A–C).
  - The arthrographic dye will pool in the medial–inferior joint, and with additional attempted abduction of the leg, the lateral margin of the labrum will deform upward.
  - In these cases, an adductor muscle tenotomy is then performed through a medial adductor incision.
  - Afterward, the leg is again abducted to determine the correction of the hinged abduction (ie, reduction of the weight-bearing surface of the femoral epiphysis within the acetabulum).
- The hip is considered to be reduced if the deformed part of the femoral head (weight-bearing area) is under the lateral margin of the acetabulum (contained within the acetabulum), the medial dye pool is reduced, and the lateral margin of the labrum is not deformed.
- If the hip reduces (TECH FIG 1D), proceed to operatively produce a bony shelf as described in the following section.
- If the reduction is incomplete, a capsulotomy of the inferior aspect of the hip capsule can be performed through the same incision as used for the adductor muscle tenotomy. Then the hip can again be tested to determine reduction.
- If reduction is achieved, proceed to operatively produce a bony shelf as described in the following section.
- If hip reduction cannot be obtained, I recommend the procedure be terminated and postoperatively the leg be placed in skin traction or a bilateral broomstick cast until a gradual hip reduction can be obtained.
- This is achieved by the patient’s legs being progressively abducted in the ensuing postoperative days until complete reduction is accomplished.
- The patient then returns to the operating room for continuation of the labral support shelf procedure.

TECH FIG 1 • A–C. Arthrograms of the hip of a patient with Perthes disease in which the leg is progressively abducted. The abnormal femoral head deforms the labrum with progressive abduction of the leg. D. AP radiograph of the hip of a patient with Perthes disease in which the femoral epiphysis is contained within the acetabulum as the leg is placed in abduction.
INCISION AND SUPERFICIAL DISSECTION

- The incision starts at a point 1 cm inferior to the anterior superior iliac crest and extends laterally along the skin lines of Langer for about 3 cm (TECH FIG 2).
- The dissection continues with a Cobb periosteal elevator between the tensor fasciae lata muscle and the sartorius and rectus femoris muscles.
  - The superior origins of the abductor muscles are not elevated from the outer wall of the iliac crest. I believe that maintaining the abductor muscles attached to the outer wall of the iliac wing improves postoperative hip abduction power.
  - With the periosteal elevator, a subperiosteal plane along the outer iliac wing about 3 cm wide is then developed beneath the gluteus medius and minimus muscles just above the hip. The image intensifier is useful to direct the periosteal elevator at a level of about 1 cm above the lateral margin of the acetabulum.

DEEP DISSECTION

- An arthroscope is helpful for visualization during the remainder of the procedure.
- The subperiosteal plane is developed further along the outer iliac wing over the hip capsule from the anterior inferior iliac spine toward the sciatic notch.
  - Caution is taken not to injure the labral growth cartilage of the acetabular margin.
  - The tendon of the reflected head of the rectus femoris, which is adherent to the hip capsule, is retracted laterally and preserved to be used later to support the bony shelf.
- The capsule is exposed with a periosteal elevator: anteriorly to the level of the anterior iliac spine, posteriorly to the sciatic notch, and laterally about 2 cm.
  - While exposing the capsule, do not injure the lateral growth plate of the acetabulum. (The capsule may be thickened, but it is never thinned.)

TROUGH CREATION AND GRAFT COLLECTION

- The level for the buttress shelf along the ilium is identified as about 3 mm above the labral growth plate of the acetabular rim. This corresponds to the superomedial margin of the hip capsule insertion into the ilium, a position that is verified with fluoroscopy by a metal marker (TECH FIG 3A).
- A trough is then developed at this level, as described by Staheli,19 by making a series of 1-cm-deep holes at the edge of the acetabulum using a 5/32-inch drill (TECH FIG 3B).
  - The holes should be directed upwardly about 20 degrees and extended posteriorly and anteriorly sufficiently to provide the needed coverage.
  - Care must be taken not to damage the cartilaginous margin of the acetabular growth plate.
  - An osteotome, narrow rongeur, or power burr (or a combination) is used to connect the holes to make a trough that is about 1 cm deep and angled cephalad about 15 degrees. The floor of the trough is the subchondral bone of the acetabulum and should be level with the capsule (TECH FIG 3C).
- Autogenous bone graft is obtained from the previously exposed outer wall of the iliac wing, which is just superior to the trough and beneath the gluteus medius muscle.
  - The graft is typically about $1 \times 1 \times 1.5$ cm and is cut into three longitudinal strips.
Chapter 72 LABRAL SUPPORT (SHELF) PROCEDURE FOR PERTHES DISEASE

CREATION OF THE SHELF

- Several absorbable sutures (usually three) are placed through the outer fibers of the hip capsule to be used later to secure the pieces of bone graft to the capsule.
- The leg is then placed in about 45 degrees of abduction and the deformed femoral head is again reduced into the acetabulum (contained), and this position is verified by the image intensifier. Caution: The femoral head must be contained within the acetabulum with no hinged subluxation, no deformity of the lateral labrum, and no impingement.
- The leg is held in abduction of 45 degrees, flexion of 15 degrees, and neutral rotation through the remainder of the procedure (and as the spica cast is applied).
- Autogenous bone graft is placed over the capsule, with the strips of bone inserted medially in the trough and laterally under the reflected head of the rectus femoris tendon, and the sutures are tied around the strips of graft to hold them snugly to the capsule (TECH FIG 4A).
- The reflected head of the rectus femoris tendon is placed over the lateral aspect of the graft to add additional support.
- About 30 to 60 mL of donor allograft bone may be added above the labral support (shelf) to create a buttress for additional support (TECH FIG 4B).
- The graft will appear extensive when visualized by the image intensifier.
  - The purpose of the shelf is to support the labrum and prevent the hip from anterolateral subluxation during reossification of the lateral column of the femoral epiphysis.
  - Remember: The shelf is expected to resorb in about 3 years because it is not expected to be weight bearing but only to act as a buttress with support of the acetabular labrum.
- The leg is held in abduction (as described earlier) with the femoral head in the reduced position as the incision is closed in layers.

The patient is placed in a one-and-one-half hip spica cast with the involved leg in abduction of 45 degrees, flexion of 15 degrees, and neutral rotation.

TECH FIG 3 • (continued) B. To begin creation of the trough, a line of upwardly inclined, 1-cm-deep holes is made where the rectus femoris tendon (now reflected) attaches to the acetabular margin. C. The holes are connected using a burr, osteotome, or narrow rongeur to create a slightly angled 1-cm-deep trough. An osteotome is then used to collect strips of cancellous and corticocancellous bone for the outer wall of the iliac wing.

TECH FIG 4 • A. Two layers of autogenous bone graft strips are placed over the capsule, one with the strips inserted lengthwise and the other with the pieces laid side by side widthwise. The strips of bone are inserted medially in the trough and laterally under the reflected head of the rectus femoris tendon. Strong, nonabsorbable sutures are used to anchor the graft into the capsule, and additional morselized bone graft is placed on top of the created shelf. B. AP arthrogram of the hip of a patient with Perthes disease in whom the femoral epiphysis and labrum is supported by a labral support (shelf) procedure.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Small procedure without internal fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>An arthroscope is helpful to visualize the dissection and placement of the labral support (shelf).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Walking in the cast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children can walk in the cast as soon as the postoperative pain resolves.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No permanent deformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>The procedure does not cause a permanent deformity of the femur or acetabulum, and there is no impingement from the graft since the labral shelf resorbs in about 3 years postoperatively.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Containment of the hip</th>
</tr>
</thead>
<tbody>
<tr>
<td>The femoral head must be contained within the acetabulum with no hinged subluxation, no deformity of the lateral labrum, and no impingement.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Do not damage the labral growth plate of the acetabulum.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The buttress shelf is placed on the outer iliac wing above the labral growth plate of the acetabulum. The graft functions only as a buttress to prevent resubluxation of the femoral epiphysis until the lateral column reossifies. The graft is not expected to be weight bearing and is expected to resorb after about 3 years.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hip motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain good hip abduction after cast removal.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- The cast, subsequent abduction contracture, and an abduction hip pillow at night offer initial containment. Later the labral support (shelf) acts as a buttress for the labrum to prevent resubluxation and hinging of the hip until the lateral column of femoral epiphysis reossifies.
- The cast is maintained for 6 weeks and the child is allowed to walk in the cast as soon as postoperative pain resolves.
- When the cast is removed, the patient is allowed to walk with “toe touch” crutch weight bearing for an additional 4 weeks and then allowed full ambulation without support.
- An abduction contracture of the hip is expected to persist additionally for about 6 weeks after cast removal.
- During the month after cast removal, an abduction hip pillow is used at night.
- Exercises of the hip are encouraged to maintain flexion, extension, and abduction; adduction is not encouraged for at least 6 to 8 weeks after the cast is removed.
- Abduction exercises of the hip to maintain at least 45 degrees abduction are continued until reossification of the lateral column of the femoral head.

OUTCOMES

- Domzalski et al reporting the results of 49 consecutive patients treated by the labral support (shelf) procedure for Perthes disease.
  - The procedure has a combined effect to prevent subluxation, to stimulate additional growth of the lateral rim of the acetabulum in a vertical dimension, and to provide temporary osseous containment until the shelf resorbs with time in a manner that is beneficial for preventing impingement of the femoral neck and greater trochanter on the shelf (FIG 4).
- Willett et al27 reported the results of 20 children treated by a lateral shelf acetabuloplasty and recommended its use in children over 8 years of age with Perthes disease of Catterall groups II, III, and IV.
- Van der Heyden and van Tongerloo28 reported on 25 patients with Perthes disease who were treated by a shelf procedure and had good or excellent results.
- Other authors have also reported encouraging results with similar labral support (shelf) procedures, but to my knowledge there has been no controlled, prospective, and randomized study comparing this procedure to other methods of treatment.

FIG 4 • AP radiographs of the hip of a patient with Perthes disease in whom the deformed femoral head was treated by a labral support (shelf) procedure. There is remodeling of the femoral epiphysis, widening of the acetabulum, and resolution of the shelf.
**COMPLICATIONS**

- Infection
- Injury of the labral growth cartilage, which prevents growth stimulation of the acetabulum
- Displacement of the labral support (shelf) bone graft
- Improper placement of the labral support (shelf)
- Neurovascular injury
- Cast problems

**REFERENCES**

Triple innominate osteotomy (TIO) is a surgical procedure that includes osteotomy of the ilium, ischium, and pubis, allowing rotation of the acetabulum around the femoral head (FIG 1). This greater freedom of rotation allows it to be used in cases (more severe dysplasia, older children) when the Salter innominate osteotomy would not provide enough rotation to cover the femoral head.

Because the procedure does not damage the triradiate cartilage, it can be used in skeletally immature patients without the risk of disrupting acetabular growth. Acetabulum size is maintained and redirected around the femoral head; the volume of the acetabulum remains constant but the weight-bearing surface is increased with improved femoral head coverage.

The TIO, often used for severe dysplasia, has the advantage of maintaining hyaline cartilage contact between the femoral head and acetabulum. This is in contrast to other procedures sometimes used to correct severe hip dysplasia or instability (shelf procedure, Chiari osteotomy) that must rely on repair tissue (fibrocartilage) to maintain a joint surface.

TIO is most commonly used for correction of acetabular dysplasia. Dysplasia may be a primary disorder or may result from incomplete treatment of developmental dysplasia of the hip (DDH); it is also seen as a result of neuromuscular conditions such as cerebral palsy, myelomeningocele, Down syndrome, and Charcot-Marie-Tooth syndrome.

TIO is also used to improve coverage and containment of a malformed femoral head, and for a combination of acetabular and femoral head deformities. Patients with Legg-Calvé-Perthes disease (Perthes disease), avascular necrosis (AVN), epiphyseal dysplasia, or an irregular femoral head resulting from a previous septic hip may also have poor femoral head coverage or dysplasia and benefit from TIO.

The acetabulum is formed by the ilium, ischium, and pubis, which in the immature pelvis are joined by the triradiate growth cartilage (FIG 2A,B). This complex, trilanged growth center allows the acetabulum to grow properly, providing a deep, stable hip joint. Injury to the triradiate cartilage by either fracture or an inappropriate acetabular osteotomy can alter the normal growth process, leading to hip dysplasia and subluxation.

The femoral head should be covered by the roof of the acetabulum.

The center–edge angle of Wiberg (angle between a line from the center of the femoral head to the lateral edge of the acetabular roof, and a vertical line drawn through the center of the femoral head) should be more than 25 degrees (FIG 2C).

Lateral subluxation of the femoral head can be measured as the percentage of the femoral head not covered by the acetabulum.

The acetabulum should be concave with a transverse sourcil (“eyebrow” in French) that turns down around the femoral head. Patients with hip dysplasia frequently have a very flat acetabulum with an upturned sourcil. This results in shear forces on the joint, leading to early degenerative joint disease.

The normal hip joint has a spherical femoral head that is congruent with a well-formed acetabulum.

Sphericity of the femoral head can be measured with Mose templates (concentric circles).

Deformity in Perthes disease or AVN can be measured as a percentage of the femoral head (lateral pillar) that has collapsed when compared to the contralateral side.9,10

Conditions that change femoral head sphericity lead to abnormal hip development and increased wear patterns within the joint (FIG 2D).

Hip Dysplasia

The high concordance between twins and studies noting that babies with parents or siblings with dysplasia have a much higher DDH incidence than the general population confirm a genetic component.

Mechanical factors also contribute to the risk for dysplasia. First babies and babies that are large have a higher risk, thought to be secondary to inadequate space in the uterus during development. Hip dysplasia is also commonly associated with torticollis and metatarsus adductus, with each of the three abnormalities thought to be a “packaging” problem.

There also appears to be a hormonal component, as girls and babies with increased laxity are at higher risk of hip dysplasia.
Legg-Calvé-Perthes Disease

- The cause of Perthes disease remains obscure, and it still can be thought of as idiopathic AVN of the hip in childhood.
- A few studies have shown a possible association between passive smoking and Perthes disease.\(^7\),\(^16\)
- Others have postulated that a deficiency in protein C leads to a hypercoagulable state, with thrombosis triggered by prothrombotic insults such as passive smoking.\(^17\)
- Because most Perthes patients have a delayed bone age, some have suggested that Perthes may represent a form of epiphyseal dysplasia. Delayed skeletal maturation is a routine finding in a typical Perthes case. The delay in maturation of the femoral head preossific nucleus may not adequately protect the vessels that ascend the femoral neck to the epiphysis, predisposing to AVN.

### NATURAL HISTORY

**Hip Dysplasia**

- Untreated hip dysplasia is the leading cause of premature hip arthritis that results in early total hip replacement. Abnormal sheer stresses on the hip lead to early osteoarthritis (OA), and the more severe the dysplasia, the more likely the development of arthritis.

**Legg-Calvé-Perthes Disease**

- The natural history for younger patients (under age 8 years at onset) and patients with milder disease (Herring A classification) is more benign, with minimal long-term disability.
- Children who are older at onset and who have more severe disease (Herring B or C classification) are more likely to develop femoral head deformity, which predisposes to early OA.

---

**FIG 2** Lateral (A) and medial (B) view 3D CT scans of an immature acetabulum with femur subtracted show that the triradiate cartilage is a growth center of the acetabulum that contributes to the ilium, ischium, and pubis. **C.** The center–edge (CE) angle of Wiberg is the angle created by a vertical line through the center of the femoral head and a line from the lateral edge of the acetabular roof to the center of the head. The normal hip on the left has a CE angle of 35 degrees; the dysplastic hip on the right has a CE angle of 15 degrees. **D.** Loss of sphericity of the left femoral head after reossification of Perthes disease has led to a noncongruent joint (left hip).
PATIENT HISTORY AND PHYSICAL FINDINGS

Hip Dysplasia
- Acetabular dysplasia is often asymptomatic in childhood and adolescence.
- Patients may have decreased abduction on examination, or pain with internal rotation of the hip. When they are present, symptoms are likely due to increased shear stresses, to labral damage, and later to OA.
- The pain is usually groin pain rather than lateral or trochanteric pain.

Legg-Calvé-Perthes Disease
- The disease may present as hip or knee pain.
- Early pain may be episodic.
- Patients with severe disease may have subluxation and more severe pain.
- A Trendelenburg gait is often noticed.
- Decreased abduction can be mild or severe.

A marked loss of abduction with the hip in the fully extended position (pelvis rotates rather than hip abducting) suggests hinge abduction and is a poor prognostic sign.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Anteroposterior (AP) plus frog-leg lateral plain radiographs provide two orthogonal views of the femoral head. However, to get two views of the acetabulum, a false profile radiograph should be taken in addition to the AP view. Both hips should always be imaged to allow comparison (FIG 3A–C).
- A dynamic arthrogram is the best way to determine the function and motion of the joint, since it allows visualization of the labrum and impingement of the femoral neck on the labrum or acetabulum. We advise a surgeon-performed arthrogram to evaluate the hip deformity and to assess for hinge abduction as well as the desired limb position after surgical correction (FIG 3D,E).
- Three-dimensional CT scans with reconstructions provide a better understanding of pathologic bony anatomy (FIG 3F).
- MRI with arthrogram helps to evaluate the labrum and joint space (FIG 3G).

FIG 3 • A, B. AP and frog-leg lateral radiographs of the pelvis show two views of the proximal femur but not of the acetabulum. C. To get another view of the acetabulum, a false profile view is obtained. Arthrogram (D) shows impingement in the abduction view (E). F. 3D CT scan clearly shows some dysplasia plus subluxation of the left hip. G. An MRI is the best study for evaluating labral tears (superolateral labral tear shown).
Differential Diagnosis
- Dysplasia secondary to DDH
- Dysplasia secondary to neuromuscular disease (eg, cerebral palsy, myelomeningocele, Charcot-Marie-Tooth disease)
- Dysplasia, subluxation secondary to syndromes (Down syndrome)
- AVN secondary to Perthes disease
- AVN secondary to steroid use, chemotherapy, metabolic disruption, infection, sickle cell disease
- Epiphyseal dysplasia with poor femoral head coverage

NONOPERATIVE MANAGEMENT

Hip Dysplasia
- From infancy to childhood (up to 18 months of age), if the hip is located within a dysplastic acetabulum, a Pavlik harness or abduction orthosis can be worn to treat the dysplasia.
- From age 18 months to 5 years, abduction bracing has not been found to predictably improve dysplasia, although nighttime brace use is occasionally recommended. Most advise monitoring during this period with hope that the acetabular growth centers will mature and correct the dysplasia.
- Older children with hip dysplasia are typically asymptomatic until the hip begins to have degenerative changes or a labral tear. Anti-inflammatory medications and activity modification can be used to decrease pain, but these do not correct the underlying problem and by masking symptoms may delay surgical correction. Therefore, medications should not be used for more than a short time. Instead, surgical correction should be performed to cover the femoral head and restore normal biomechanical forces.

Legg-Calvé-Perthes Disease
- Children younger than 8 years and patients with hips classified as Herring A can be treated conservatively with predictable results.
- Conservative treatment includes:
  - Activity modification and observation
  - Abduction exercises
  - Abduction bracing
  - Percutaneous adductor longus lengthening followed by Petrie casting or bracing to maintain abduction (FIG 4)

- Older children and those with Herring B and C hips require prolonged Petrie casting (rarely practiced) or surgical containment.

SURGICAL MANAGEMENT

General Principles

Hip Dysplasia
- Children under age 5 years can be treated nonoperatively unless the hip is dislocated and requires open reduction, or the dysplasia is very severe.
- Patients age 5 to 10 can be treated with an acetabular redirecting osteotomy that bends through the triradiate cartilage (Pemberton osteotomy, Chap. PE-71) or rotates through the pubic symphysis (Salter innominate osteotomy, Chap. PE-70).
- From the age of about 10 years until triradiate cartilage closure, a TIO is preferred for correction of dysplasia.
- Once the triradiate cartilage closes, TIO can still be performed, but a periacetabular osteotomy may be preferred because the posterior column remains intact, allowing earlier weight bearing.

Legg-Calvé-Perthes Disease
- Perthes disease can be treated nonoperatively in young children.
- Children older than 8 years or with more severe disease can be treated with a variety of surgical procedures aimed at containing the capital femoral epiphysis during the phase of reossification when the biologically plastic femoral head is at risk for subluxation, hinge abduction, and the development of permanent femoral head deformity.
- The simplest surgical treatment is adductor lengthening followed by Petrie casting or bracing. This can be used alone for very mild cases, or in preparation for containment surgery. Adductor lengthening and Petrie casting improves mobility of the hip and returns the hip to a more congruous, contained position, beginning the remodeling process that surgical containment will continue.
- Formal containment procedures include varus proximal femoral osteotomy (see Chap. PE-27) designed to direct the capital femoral epiphysis into the acetabulum.
- A Salter innominate osteotomy can also be performed, but Rab has clarified that the degree of acetabular rotation achieved with the Salter procedure is often not enough to cover the femoral head in more severe Perthes disease. A combined femoral and Salter procedure may be a better choice.
- TIO, which rotates the entire acetabulum around the femoral head, allows containment in more severe cases while avoiding the problems of femoral osteotomy (limp, limb shortening). This procedure has the benefit of maintaining hyaline cartilage surface-to-surface contact (as compared to the shelf or Chiari procedure).
- A shelf (labral support) osteotomy or Chiari procedure may be a better choice for a severely deformed femoral head that cannot be congruently centered in the acetabulum. With these procedures, contact between the hyaline (head) and hyaline cartilage (acetabulum) is partially sacrificed.

Preoperative Planning

Hip Dysplasia
- Radiographs and a 3D CT scan (if available) help in better understanding the nature and location of the acetabular...
deficiency. Typical dysplasia patients have an anterolateral deficiency. Children with neuromuscular disorders such as cerebral palsy, due to muscle imbalance around the hip joint and flexion contracture, often have a posterior deficiency.\textsuperscript{1,12,13}

- Once the amount and direction of dysplasia have been determined, acetabular rotation can be planned.
- Overrotation of the acetabulum should be avoided, as this can cause anterolateral impingement, which may hasten degenerative changes.
- Also, external rotation of the acetabulum should be avoided to prevent the creation of acetabular retroversion (which in itself can predispose to hip arthritis).

**Legg-Calvé-Perthes Disease**

- A preoperative dynamic arthrogram is the best study for understanding how to best contain the femoral head. We perform an arthrogram and percutaneous adductor lengthening followed by Petrie casting (for 6 weeks) before definitive containment surgery.

**Positioning**

- The patient is positioned supine on a radiolucent table. A Foley catheter can be considered to minimize any risk for bladder injury with the pubic ramus cut. This is advised for a surgeon’s initial cases but is often not needed once experience has been gained.
- A sandbag bolster is placed under the trunk to tip the patient toward the opposite side, giving better exposure of the hip laterally. The bolster should not be placed directly behind the pelvis because it often distorts the image intensifier views.
- The leg is draped free and the abdomen is prepared past the midline medially, to just below the nipple level superiorly, and around the buttock posteriorly—the ischial tuberosity must be kept in the surgical field (FIG 5).
- The C-arm and screen of the image intensifier are positioned to allow a clear view for the surgeon.

**Approach**

- TIO can be performed through two or three incisions. Using three incisions allows more precise exposure for each osteotomy cut, especially in larger patients.
  - The first incision is below the iliac crest as for a Salter osteotomy.
  - The second incision is distal to the groin crease, slightly below the superior pubic ramus, lateral to the adductor longus tendon origin and medial to the neurovascular bundle. The pubic osteotomy is performed through this incision with the ischial osteotomy also possible with posterior extension of the incision.
  - The third incision (if the surgeon chooses a three-incision approach) is longitudinal, distal to the gluteal crease, and just medial to the ischial spine with the hip flexed to 90 degrees.

**ILIAC OSTEOTOMY**

- An 8- to 10-cm Salter-type incision is made 1 cm below the iliac crest (TECH FIG 1A,B).
- The cartilaginous iliac crest apophysis is split, starting at the anterior superior iliac spine and continuing posteriorly for 6 to 8 cm.
- With care, this cartilage splitting can be carried anteriorly down to the anteroinferior iliac spine (TECH FIG 1C).
- Both sides of the iliac wing are exposed subperiosteally down to the sciatic notch using a Cobb periosteal elevator.
- Specially designed Rang retractors (Jantek Engineering, Paso Robles, CA) can be placed in the
PUBIC OSTEOTOMY

Earlier descriptions of TIO technique advised that the superior pubic ramus (TECH FIG 2A) be cut from the anterolateral Salter incision.
- We initially used this but then changed to a separate medial incision, which makes exposure very easy and avoids risk to the neurovascular bundle (due to overretraction with the anterolateral approach; TECH FIG 2B).
- For the three-incision technique, a 2- to 3-cm transverse incision (parallel to the inguinal ligament) is made just lateral to the adductor longus and 1 cm distal to the groin crease.
- For the two-incision technique, this incision would subsequently be extended medially and distally to allow exposure of the ischium.
- The pectineus muscle is identified just lateral to the adductor longus origin and is partially elevated off the superior pubic ramus. The saphenous vein, which often crosses the field, should be maintained and retracted laterally.
- The ramus is identified and Hohmann retractors are placed above and below the pubis extraperiosteally (TECH FIG 2C).

The extraperiosteal approach allows easier periosteal sectioning since the periosteum is strong in this area and may prevent movement of the pubic segment of the acetabuloplasty.
- Care must be taken to avoid the obturator nerve, which courses just below the superior ramus.
- Those new to the operation might be advised to begin with a subperiosteal approach to the pubic ramus.
- Fluoroscopy is used to confirm Hohmann retractor placement before making the osteotomy (TECH FIG 2D). The closer the surgeon is to the acetabulum, the easier it will be to rotate the acetabulum.
- Once position is confirmed, a narrow rongeur or osteotome can be used to make a slightly oblique osteotomy of the pubis. The cut can be angled slightly to allow subsequent superomedial acetabular displacement.
- If a rongeur is used (the safest method), the bits of excised bone should be maintained and returned to the osteotomy site to avoid the risk for pseudarthrosis.

PSOAS INTRAMUSCULAR LENGTHENING

At the distal end of the Salter incision, the structures are retracted on the medial side of the pelvic brim. The ilioischial muscles are identified and rotated to expose the psoas tendon, which lies posterior and medially in relation to the muscle mass of the ilioischial mass.
- Because the femoral nerve lies just anterior to the psoas muscle, care should be taken to identify the psoas tendon. A right-angled hemostat is placed around the tendon and the tendon is sectioned, leaving the muscle belly intact. This allows an intramuscular lengthening.
- The Salter incision can now be packed with a damp sponge and the wound edges pulled together with a towel clip while the other osteotomies are completed.

SCIATIC OSTEOTOMY

A sciatic notch to improve exposure (TECH FIG 1D), and a Gigli flexible wire saw is passed through the notch (TECH FIG 1E).
- The iliac osteotomy is then performed by bringing the Gigli saw anteriorly through the ilium, exiting at a point just above the anteroinferior iliac spine. In older, larger patients, we make this cut slightly more proximal than in a Salter osteotomy, which allows room to place a temporary Schanz screw to guide the acetabular segment.
**ISCHIAL OSTEOTOMY**

- The three-dimensional nature of the ascending ischium, buried deeply in muscle, is not easy to comprehend. When first performing this procedure, the surgeon should have a skeletal model of the pelvis in the operating room and the circulating nurse should hold it for him or her to inspect as needed. The proximity of the ischial spine to the sciatic nerve must be appreciated.
- One error that we have seen is palpation of a deep bony prominence, thought to be the ischial spine, which was in fact the greater trochanter. The hip should be kept rotated internally to avoid this error.

**Two-Incision Technique**

- Through the adductor incision, blunt dissection is carried out subcutaneously down to the ischial spine.
- The electrocautery is used to take down the posterior portion of the adductor magnus muscle origin just anterior to the proximal origin of the hamstrings.
- The ischial tuberosity is identified and then an initial sharp Hohmann retractor is placed inside the obturator foramen.
- A Cobb elevator is then used to clear the ischium up to its origin just below the acetabulum.
- Blunt Hohmann retractors are then placed extraperiosteally around the ischium, with one retractor in the obturator foramen and the other lateral to the ischium.
- Using a mallet to tap a blunt Hohmann into these spaces makes it easier (helps to safely elevate the thick periosteum and tendon origins; TECH FIG 3A,B).
- This is a very deep exposure, and the neophyte will be surprised at the depth of the ascending ischium.
- Finally, a third Hohmann retractor (sharp) is driven into the ischial bone just below the acetabulum to allow easier superior retraction (TECH FIG 3C).
- Thus, there are a total of three Hohmann retractors—one medial, one lateral, and a sharp-tipped tapped into the bone proximally.
- Fluoroscopy is used to check position. The ischial cut should be just below but not in the acetabulum (about 1 cm below the lower end of the “teardrop”).
TECH FIG 3 • A. The third cut is the ischial cut. B. Two Hohmann retractors are placed around the ischium. Tapping the retractors with a mallet helps to get them positioned. C. A third sharp Hohmann is driven into the ischium in the proximal end of the wound (just below the acetabulum) to help with retraction. The osteotome can then be introduced. D. When the osteotome enters the posterior cortex, it is rotated medially to displace the ischium.

- Once position is confirmed, a rongeur can be used to start the osteotomy, creating a groove for the osteotome to prevent the osteotome from slipping.
- A long straight osteotome is then inserted and used to complete the osteotomy.
  - To encourage proper displacement of the osteotomy, the large wooden handle of the osteotome is used to radically rotate the acetabular segment medially before the osteotome is withdrawn. This begins the desired medial displacement of the ischium (TECH FIG 3D).
  - Using a very long (about 20 inch) wooden-handled osteotome makes this essential rotational maneuver easier.

Three-Incision Technique

- The hip is flexed to 90 degrees and a third incision is made longitudinally in the buttock just distal to the gluteal crease and medial to the ischial tuberosity (TECH FIG 4).
- Otherwise the technique is identical to that noted above.

TECH FIG 4 • If a third incision is to be used, it is made just proximal to the gluteal crease, medial to the ischial spine.
ROTATION OF THE ACETABULUM

- The packing sponges are now removed from the Salter incision. A temporary Schanz screw is placed in the acetabular segment just above the hip joint to use as a handle to guide acetabular positioning (TECH FIG 5A).
- A long ballpoint pusher is placed in the superior pubic ramus just lateral to the pubic cut and impacted into the bone (TECH FIG 5B,C). This is pushed upward and inward while the Schanz screw is levered downward and laterally to rotate the entire acetabulum around the femoral head.
- A Cobb elevator is placed in the Salter (iliac) cut and rotated to encourage lateral positioning of the acetabular fragment in the coronal plane. Care must be taken not to externally rotate the acetabular segment (this is easy to do in a triple osteotomy and will cause undesired acetabular retroversion).
- To avoid undesirable external rotation, Salter’s advice that “even after the osteotomy the anterior superior and anterior inferior iliac spines should remain aligned” should be adhered to as well when a triple osteotomy is performed.
- Through the Salter incision, a wedge of bone is removed from the iliac crest using an oscillating saw (TECH FIG 5D). The base of the wedge should be fashioned to fit tightly in the gap of the iliac osteotomy (TECH FIG 5E).
- This triangular graft is only about half as large as in a Salter osteotomy for the same-size patient since a good deal of the rotation should have occurred in the pubic and ischial cuts.
- The osteotomy is first fixed with temporary, sturdy smooth Kirschner wires (TECH FIG 5F).
- Acetabular position is checked with fluoroscopy to confirm the amount of coverage that has been obtained.

**TECH FIG 5** • A. A Schanz screw is placed just above the hip (arrow); it can be used as a lever to help rotate the acetabulum. B. A ballpoint pusher can be used to push the pubic portion upward and inward while the Schanz screw levers the superior acetabulum anterolaterally. C. Fluoroscopic image showing ballpoint pusher (white arrow) and Schanz screw (black arrow). D,E. Bone graft is taken from the iliac crest and fashioned to fit into the iliac osteotomy. F. The osteotomy is temporarily fixed using smooth Kirschner wires to confirm position with fluoroscopy before final screw fixation.
FIXATION OF THE OSTEOTOMIES

- 4.5-mm fully threaded screws can be inserted from the iliac crest across the bone graft and into the superior acetabular bone.
- Using fully threaded screws minimizes the tendency for loss of correction that can occur when a partially threaded screw is tightened too much, overcompressing the graft and pulling the acetabular edge upward. Instead, the screws should stabilize and maintain some distraction.
- We use two or three screws to adequately fix the acetabular fragment.
  - Threaded Kirschner wires can be used in smaller patients in whom the bone may not be thick (strong) enough to hold the 4.5-mm screw.
  - We prefer screws because later removal is easier.
- In older, larger patients, we often place a single screw from medial to lateral across the pubic osteotomy to prevent further rotation of the acetabular fragment or nonunion of the pubis (TECH FIG 6A).
- A second method for pubic ramus fixation includes a screw on either side of the pubic cut pulled together with a 20-gauge wire (TECH FIG 6B).
- Any remaining bone graft fragments can be packed into the pubic and ischial osteotomies to prevent nonunion.

WOUND CLOSURE

- All of the incisions are thoroughly irrigated.
- The iliac crest apophysis is reapproximated and closed with a running absorbable suture. Hemovac drains are placed in the Salter, pubic, and ischial incisions.
- The incisions are then closed in layers with absorbable suture.
- Sterile dressings are applied. In most cases, a single hip spica is applied.
- If both iliac and pubic fixation is secure in a cooperative patient, we sometimes use a removable bivalve plastic “spica-type” orthosis (made before surgery) or trust the patient with no immobilization (rare).

PEARLS AND PITFALLS

Intraoperative fluoroscopy
- The surgeon must remember that the patient has a bump to slightly elevate the operative side, and fluoroscopy needs to accommodate for this tilt: the pelvis is not parallel to the floor. Before rotating the acetabulum, it is helpful to position the machine to get a good AP view of the pelvis with symmetric teardrops; do not try to calculate the acetabular segment position from an oblique fluoroscopic image.

Acetabular positioning
- Proper rotation of the acetabulum is the most important part of this procedure. Overrotation anteriorly will produce anterior impingement, which is indicated by a crossover sign on the radiograph and an overly prominent ischial spine (FIG 6A) overrotation laterally can produce lateral impingement or hinge abduction.
- We have developed several standards to help us evaluate acetabular rotation on radiography or fluoroscopy (FIG 6B).
In smaller children, threaded pins can be used instead of screws. It is important to have at least three points of fixation in the ilium to prevent postoperative motion and rotation.

If the osteotomies are not well fixed, or weight bearing is started too early, the acetabulum may change position, leading to overcorrection (protrusio-like) or loss of correction.

We have experienced both pubic and ischial nonunions in older children. To prevent this we often add a pubic ramus screw and replace any excised bone back into the osteotomy sites.

The iliac crest will grow over the screw heads or tips of the threaded pins if they are flush with the crest. Leaving the implants slightly prominent or attaching a nonabsorbable suture to the screw head on one end and to the subcutaneous tissues on the other facilitates later implant removal.

We recommend a single-leg spica cast for 6 weeks followed by partial weight bearing with crutches for an additional 4 weeks. If adequate bone healing is noted on radiography, activity can then be advanced as tolerated.

Physical therapy may be useful for regaining abductor strength and motion.

The fixation screws can be removed 6 to 12 months postoperatively (if you elect to remove them). Whether the screw presence will hinder or compromise a later total hip replacement remains unclear. Clearly, femoral implants should be removed, but some consider acetabular screw removal less important. We lean toward removal of all implants from the hip in these patients, as they may require a later total hip replacement.

As TIO is most commonly used for late juveniles, adolescents, and young adults, very long-term follow-up studies are required to evaluate function over a lifetime, with 30 to 60 years of follow-up.

Unfortunately, these long-term studies have not yet been done. There are several studies that look at short- to medium-term results.

Guille et al8 reported more than 10 years of follow-up on 11 patients aged 11 to 16 with symptomatic hip dysplasia treated with TIO. Ten hips improved radiographically, eight improved functionally, and one required total hip arthroplasty.

Faciszewski et al3 followed 56 hips in 44 patients that underwent TIO for 2 to 12 years. Improvement in pain and function was considered good in 53 hips. Three hips were considered failures.

Peters et al20 evaluated 60 hips in 50 patients undergoing TIO. At an average 9-year follow-up, 12 (20%) hips had been converted to total hip arthroplasty and 4 (7%) hips had incapacitating pain. Radiographically, there was significant improvement in the center–edge angle of Wiberg and the acetab-
ular angle of Sharp. There also was a statistically significant relationship between failure of the osteotomy and severity of pre-existing hip arthrosis.

When evaluating any procedure, it is important to evaluate the quality of each individual procedure, which is difficult to do in the literature. We have found through our own experience that the quality of the surgical procedure and the anticipated outcomes improve dramatically with surgeon experience.

When done properly and for the correct indication, TIO can improve the radiographs and symptoms of patients with hip deformity, whether the deformity is acetabular, femoral, or a combination of both.

The procedure is not without risks, and occasional patients have a poor outcome.

- In patients with acetabular dysplasia, indications and outcomes are better understood.
- The application of TIO for patients with femoral deformity (Perthes, AVN, epiphyseal dysplasia) has a shorter track record, but the procedure appears to provide clear benefit in properly selected cases.

**COMPLICATIONS**

- Inadequate coverage or containment
- Creation of impingement either anteriorly or laterally
- Sciatic or peroneal division nerve injury
- Injury to the bladder, spermatic cord, obturator nerve, sciatic nerve
- Loss of fixation or acetabular rotation
- Infection
- Nonunion of pubis or ischium
- Hip stiffness
- Progression to OA
- Need for further surgery (deimpingement procedure, valgus rescue osteotomy of femur, Chiari osteotomy, shelf acetabuloplasty, hip fusion, total hip arthroplasty)

**REFERENCES**

DEFINITION
- The Chiari osteotomy is primarily a “salvage” osteotomy for acetabular dysplasia in the painful, unstable hip.
- It is generally reserved for hips where a congruous reduction is not possible because of arthrosis or femoral head asphericity that prevents use of one of the more standard rotational osteotomies.1,4,5
- It is a single pericapsular osteotomy through the iliac (innominate) bone of the pelvis with medialization of the acetabulum and hip joint to improve posterior and lateral coverage. The ilium forms a shelf over the dysplastic, subluxated hip (FIG 1).
- The goals are improved femoral head coverage, a stable articulation, and metaplastic transformation of the hip capsule to fibrocartilage to create a stable, pain-free hip.
- Contraindications include severe arthrosis, age greater than 45 (relative, where arthroplasty may be a better option), and significant proximal migration of the femoral head (may prevent adequate coverage by thinner proximal ilium).5

ANATOMY
- Developmental acetabular dysplasia most commonly involves deficiency of the anterior and anterolateral acetabulum.
- In cases of spastic hip dysplasia, the lateral and posterolateral acetabulum is most often deficient.
- The location of acetabular deficiency must be considered when planning the shape and orientation of the osteotomy and positioning of the iliac shelf over the hip joint.
- Femoral head deformity may include coxa breva, coxa magna, or coxa plana.
- In cases of trochanteric overgrowth, simultaneous advancement of the greater trochanter may provide improved abductor mechanics (although the risk of heterotopic ossification may be slightly increased).
- This osteotomy may not provide adequate coverage in cases of high dislocation and in the pelvis in patients with advanced neurologic conditions (eg, myelomeningocele, Chapter 74)

FIG 1 • Concept and steps of the Chiari osteotomy. A. The view required to properly perform the osteotomy. B. The proper placement of the osteotomy in the coronal plane is at the superior border of the acetabulum, just above the capsule and angled upward 10 to 15 degrees. C. The acetabular fragment is displaced medially, hinging on the symphysis pubis. D. The proposed osteotomy (dotted line) as seen from the lateral projection. E. The line of the osteotomy as seen from the inside view of the pelvis. It is above the triradiate cartilage.
where the ilium is very thin above the acetabulum). Therefore, careful consideration of the available periacetabular bone stock should be made before considering the Chiari osteotomy.

- The need for additional bone graft to supplement posterior, lateral, and (especially) anterior coverage is common.
- This procedure does not require concentric reduction of the femoral head into the acetabulum.
- It has the advantage of medializing the femoral head and decreasing the force across the hip joint by increasing the surface area of coverage.
- Lateralizing the ilium to form a shelf causes obligatory shortening of the gluteal muscle length and abductor moment arm that weakens the muscle and contributes to postoperative Trendelenburg limp. However, advancing the greater trochanter can restore the resting length of the gluteus medius. Delp et al found that decreasing the obliquity of the supra-acetabular osteotomy may decrease the effect on the abductor lever arm.

**PATHOGENESIS**

- The causes of advanced hip disease requiring salvage surgery are many and include late diagnosis of developmental dysplasia of the hip (DDH), spastic or neuromuscular hip dysplasia, failed prior hip procedures (reduction, periacetabular osteotomy), and acetabular trauma.
- Femoral head conditions that can lead to incomplete or incongruous femoral head coverage include primary malformation, secondary avascular necrosis, slipped capital femoral epiphysis, epiphyseal–metaphyseal dysplasia, and secondary malformation from longstanding subluxation or impingement.

**NATURAL HISTORY**

- Because this osteotomy is used as a salvage procedure for many hip diseases, it can be used to treat any of the several conditions that result in progressive, painful arthrosis and instability.
- The threshold of acetabular dysplasia required to induce arthrosis is incompletely understood. However, when assessing lateral uncovering, Murphy found that a lateral center–edge angle less than 16 degrees on an anteroposterior (AP) view of the pelvis correlated with a significantly increased risk of requiring arthroplasty by age 65.
- Spastic hip dysplasia can lead to progressive subluxation and painful dislocation in 30% to 50% of cases. It is more common in nonambulatory patients.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Key portions of the history include:
  - Personal or family history of or treatment for DDH
  - History of other hip disorders, including Legg-Calvé-Perthes disease
  - Trauma
  - Skeletal dysplasias
  - History of cerebral palsy
  - Birth order and weight
  - Description of pain and mechanical symptoms, including location, duration, activity limitation, giving way, clicking, catching, and popping
- The physical examination should include gait, limb length, assistive devices, and strength.
- Specific hip tests include the following:
  - Trendelenburg test: Demonstrates weakness in abductors
  - Anterior apprehension test with extension and external rotation of the hip: A positive result is a subjective noting of “apprehension” or instability by the patient.
  - Gluteus medius and maximus strength
  - Anterior impingement test (pain with passive hip flexion, adduction, and internal rotation): Test of anterior labral pathology, not just a tear
  - “Bicycle test” for abductor fatigability of the hip while lying in the contralateral decubitus position
  - Range of motion: It is important to test internal and external rotation at multiple degrees of flexion as femoral head and acetabular deformities vary. This can often aid in determining where the pathologic articulation is located.
  - Galeazzi sign: Demonstrates hip subluxation or dislocation
- The Chiari osteotomy can increase abduction. It does not always significantly improve range of motion in other planes, and therefore preoperative flexion to 90 degrees, full (or near full) extension, and at least 10 to 20 degrees of adduction are requirements.
- Gait is assessed preoperatively. It is important to discern whether any limp is antalgic, due to abductor weakness or instability. The Chiari osteotomy classically can improve antalgia and instability. However, the patient should understand that abductor weakness may not be improved.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Radiography should include weight-bearing anteroposterior (AP) views of bilateral hips, false profile of hips, and AP of hips in maximal abduction and internal rotation (FIG 2).
These studies allow assessment of lateral and anterior coverage of the femoral head as well as congruency of the hip joint. Also noted will be the presence of hinge abduction.

- Computed tomography (CT) scan with three-dimensional reconstruction may help in preoperatively assessing the amount and direction of acetabular deficiency.
- Magnetic resonance imaging (MRI) of involved hips with radial sequences centered at the femoral head can also help with preoperative assessment of articular and labral cartilage.

**DIFFERENTIAL DIAGNOSIS**

- DDH
- Spastic hip dysplasia
- Legg-Calvé-Perthes disease, avascular necrosis
- Multiple or spondyloepiphyseal dysplasia
- Posttraumatic hip or femoral dysplasia

**NONOPERATIVE MANAGEMENT**

- The patient being considered for Chiari osteotomy usually presents with pain and arthrosis.
- Activity and job modification and weight loss may be of benefit in delaying or mitigating the onset of arthritic symptoms.
- Physical therapy may be of some benefit in increasing range of motion and strength. To date, there are no data to suggest that a specific physical therapy regimen can stop the onset of arthritis in the dysplastic hip.

**SURGICAL MANAGEMENT**

- Hip adductor tenotomy, lengthening, or Botox can be used in an attempt to delay the onset of spastic hip dysplasia (if performed before age 4 to 6) and if hip abduction is less than 45 degrees with hips flexed and extended.
- This is especially important if a varus intertrochanteric osteotomy is being performed simultaneously.
- Painful, unstable, moderate to severe dysplasia with incongruent articulation with or without femoral head deformity often requires surgical correction.
- Additional options to Chiari include arthrodesis, shelf procedures, and arthroplasty.

**Preoperative Planning**

- A complete physical examination is performed and radiographs are obtained.
- In the case of marked proximal migration, preoperative traction for 2 to 3 weeks may improve the position of the femoral head relative to the acetabulum, thereby increasing proximal ilial fragment coverage after osteotomy.

**Positioning**

- The patient is placed supine on a radiolucent table with a rolled blanket bump under the operative hip.
- All other bony prominences are carefully padded.
- A Foley catheter is placed and prophylactic antibiotics are administered.
- The use of epidural anesthesia depends on patient and surgeon preferences.
- The extremity is prepared free proximally to the costophrenic margin, including the groin and buttock regions.

**Approach**

- The ilioinguinal approach begins along the iliac crest and continues medially for about 10 cm.
- The iliofemoral approach is less cosmetic but can aid in visualization in larger patients and can allow combined pelvic and femoral procedures to be done through one incision.

**EXPOSURE**

- The skin incision begins laterally 1 to 1.5 cm below the iliac crest, extending distally to 1.5 cm below the anterior superior iliac spine and then posteriorly over the lateral thigh or medially across the groin to 1.5 to 2 cm medial to the anterior superior iliac spine (ilioinguinal approach; TECH FIG 1A).
- The tensor fascia lata (TFL) compartment is entered just lateral to its intermuscular septum with the sartorius muscle, which is retracted medially.
- The TFL muscle belly is bluntly dissected off the intermuscular septum and dissection is carried proximally to the ilium. This allows visualization of the anterior ilium and easy continuation of subperiosteal exposure of the ilium (TECH FIG 1B).
- Although the lateral femoral cutaneous nerve is not routinely visualized or isolated, it may be encountered underneath the fascia in the interval between the sartorius and the TFL. Therefore, care should be taken when retracting the medial structures during this dissection, the procedure, and closure of the interval.
- The iliac apophysis is split (in younger patients) or subperiosteally dissected (in skeletally mature patients) to allow subperiosteal exposure of the inner and outer tables of the ilium. A moist sponge is packed along the inner table to provide retraction and hemostasis.
- The outer table of the ilium is subperiosteally cleared of abductor musculature. This is carried out until a firm endpoint is reached, usually indicating that the surgeon has reached the indirect head of the rectus femoris.
- Expose the anterior and superior aspects of the hip joint capsule. Identify the rectus femoris, release the indirect head at its bifurcation from the direct head, and follow...
TECH FIG 1 • (continued) C. The outer table of the ilium is exposed. A Lane bone lever placed subperiosteally into the greater sciatic notch allows excellent visualization of the acetabular rim (arrow) all the way to the ischial spine.

OSTEOTOMY

- Once the exposure is complete, a variety of methods may be used to create the osteotomy.
- The supra-acetabular osteotomy is a curvilinear cut from the anterior ilium, along the capsular edge of the acetabulum, and posterior to the greater sciatic notch. We use a modification advocated by Hall that simply makes a concerted effort to create a dome osteotomy by curving the osteotomy distally when aiming for the notch to maximize the posterior coverage.
- While Chiari originally described a semi-blind osteotomy, it is important to have excellent visualization of the superior hip capsule from the anterior ilium to the greater sciatic notch and along the posterior wall of the acetabulum to the ischial spine. Placement of the osteotomy must be at the capsular edge of the acetabulum (TECH FIG 1C).

TECH FIG 2 • A–C. Bone models demonstrate the planned supra-acetabular osteotomy using a combination of curved and dome-shaped osteotomes. D. Scoring the inner table of the ilium along the projected course of the osteotomy minimizes splintering. E. AP fluoroscopic view of the right hip during osteotomy. The osteotome enters at the edge of the acetabulum and is directed upward at an angle of about 10 to 15 degrees (see Fig 1A). This facilitates “sliding down” of the ilium over the hip joint capsule. When properly completed, the cut surface of the ilium will lie in direct
contact with the hip capsule and will be in continuity with the lateral bony edge of the acetabulum.

**Chiari Conventional Method**
- A Gigli saw is passed through the greater sciatic notch while protecting its contents and is used in a posterior-to-anterior direction.
- We find that as the starting point is crucial, it is helpful to notch the posterior column in the sciatic notch and the outer table of the ilium to create a track for the Gigli.

**Authors’ Preferred Method**
- We prefer a combination of curved and dome-shaped osteotomes used under fluoroscopic guidance to create the osteotomy.
- It is often helpful to score the inner table of the ilium along the projected course of the osteotomy to minimize splintering of the inner table (TECH FIG 2A–F).
- To maximize the amount of posterior coverage, an attempt is made to continue the osteotomy at the acetabular rim as far distal and posterior as possible.
- This is carried out only to a level just above the ischial spine (TECH FIG 2G).

**ACETABULAR DISPLACEMENT**
- The hip is abducted and pushed medially to displace the distal fragment (TECH FIG 3A,B).
- The amount of displacement required is somewhat dependent on the amount of coverage required. One hundred percent displacement is possible and often necessary.

In particular, when posterior coverage is required, the ilium is displaced posteriorly over the sciatic notch; take care to prevent compression or entrapment of the sciatic nerve (TECH FIG 3C).

**OSTEOTOMY FIXATION**
- The osteotomy is fixed in place with 3.5- or 4.5-mm cortical screws placed either along the iliac crest or along the outer table of the ilium under fluoroscopic guidance directed into the posterior column of the ischium (TECH FIG 4A,B).
- If additional coverage is required (especially anterior), a corticocancellous graft is excised from the inner table of the ilium using a saw or osteotome (TECH FIG 4C). This fragment is interposed between the hip capsule and the

(continued)
WOUND CLOSURE

- Drains can be used at the surgeon's discretion.
- The iliac apophysis is closed with heavy, absorbable, interrupted sutures.
- The remainder of the wound is closed in layers.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Proper patient selection. Severe arthrosis or proximal migration may be incompletely managed by Chiari osteotomy. Care should be taken when considering this procedure in young patients or in patients with neuromuscular disease as they may have insufficient thickness of ilium to provide adequate coverage.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteotomy</td>
<td>Curving the osteotomy distally and posteriorly toward the sciatic notch maximizes posterior coverage. The more dome-like the osteotomy, the more anterior coverage is afforded. The posterior osteotomy may follow the posterior acetabulum as far distally as the ischial spine. Then it must be carried posteriorly to the notch, exiting proximal to the sacrospinous ligament. Again, the contents of the sciatic notch must be carefully protected by subperiosteal placement of retractors.</td>
</tr>
<tr>
<td>Screw fixation</td>
<td>Screws are placed at the iliac crest for fixation. However, with increased displacement it may be necessary to start the screws along the outer table of the ilium. They are directed into the posterior column of the ischium under fluoroscopic guidance.</td>
</tr>
<tr>
<td>Additional coverage</td>
<td>A corticocancellous segment of the inner table of the ilium is used as bone graft for augmenting deficient (especially anterior) coverage.</td>
</tr>
<tr>
<td>Sciatic nerve</td>
<td>Careful subperiosteal dissection of the sciatic notch will help to protect the neurovascular contents. We recommend palpation of the posterior edge of the osteotomy after displacement to confirm there is no soft tissue (sciatic nerve) entrapment.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Patients are kept toe-touch weight bearing for 6 weeks.
- Range of motion is allowed from full extension to 70 degrees of flexion.
- Therapy is allowed for gentle passive range of motion within these limits for 6 weeks.
- Weight bearing is advanced with evidence of radiographic healing.
- If trochanteric advancement was performed, active abduction is limited for 6 weeks.
- Patients who have a neuromuscular condition with spasticity or underwent tendon lengthenings in the same surgery are placed in either bilateral long-leg casts held in abduction by a connector bar or knee immobilizers and abduction foam pillow.
- Neuromuscular patients will stay in the immobilization for 3 weeks. After 3 weeks patients come out of immobilization for gentle passive range of motion and bathing for an additional 3 weeks.

OUTCOMES

- In general, reported outcomes with follow-up from 11 to 34 years are good to excellent for pain relief.\textsuperscript{1,2,4,5,7,8}
- Outcomes are better for younger patients with mobile hips (at least 90 degrees of flexion) and adequate corrected coverage.

COMPLICATIONS

- Sciatic neuropraxia from sciatic nerve entrapment or injury during osteotomy or neuropraxia of the lateral femoral cutaneous nerve
- Incomplete correction and resubluxation
- Heterotopic ossification
- Infection
REFERENCES

DEFINITION

- Hip dysplasia is the most common etiology of coxarthrosis, often leading to arthroplasty long before joint replacement can be considered a lifetime solution.³
- Surgical realignment of the congruous dysplastic acetabulum can improve or eliminate symptoms for years, sometimes indefinitely, in a majority of appropriately selected patients, even in those with some degree of preoperative arthrosis.¹³⁴⁶⁸
- Age limits for this procedure are adolescence (closed triradiate cartilage) to an indefinite upper age limit (limited by preoperative arthrosis and other considerations that might make arthroplasty a better choice).

ANATOMY

- The acetabulum lies between the anterior and posterior columns of the pelvis.
- The most common area of acetabular deficiency in developmental dysplasia of the hip (DDH) is anterior and lateral.
- The Bernese periacetabular osteotomy (PAO) differs from the triple osteotomy primarily by maintaining the integrity of the posterior column of the pelvis.
- The Bernese PAO uses five steps to divide the acetabular fragment from the remainder of the pelvis, allowing multplanar realignment.
- Important bony landmarks include:
  - Iliopsoas tendon (which marks the most anterior extent of the acetabulum)
  - Infracotyloid groove (just distal to the acetabulum, where the obturator externus tendon lies; this is the site of the anterior ischial osteotomy)
  - Anterosuperior iliac spine (ASIS)
  - Apex of the greater sciatic notch
  - Ischial spine
- The posterior column is triangular and thickest just posterior to the acetabulum; it becomes much thinner closer to the sciatic notch. For this reason, the optimal plane for the posterior column is angled obliquely to the medial cortex and perpendicular to the lateral cortex of the ischium–posterior column.

PATHOGENESIS

- Genetic and developmental causes exist for “developmental dysplasia.”
- Neuromuscular: Charcot-Marie-Tooth disease and spastic diplegia
- Posttraumatic: injuries to the triradiate cartilage; aggressive excision of the limbus in the infant hip

NATURAL HISTORY

- There is a clear correlation between acetabular dysplasia and osteoarthrosis of the hip.
- The more severe the acetabular dysplasia and any subluxation, the earlier the onset of symptoms from arthrosis.
- Murphy et al⁵ found that every patient with a lateral center–edge angle less than 16 degrees developed osteoarthritis by age 65.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Key portions of the history include:
  - Personal or family history or treatment of DDH
  - History of other hip disorders, including Legg-Calvé-Perthes
  - Trauma
  - Skeletal dysplasias
  - History of cerebral palsy
  - Birth order and weight
  - Description of pain or mechanical symptoms, including location, duration, activity limitation, giving way, “clicking,” “catching,” and “popping”
- Physical examination should include gait, limb length, assistive devices, and strength.
- Specific hip tests include the following:
  - Trendelenburg test: Demonstrates weakness in abductors.
  - Anterior apprehension test: A positive result is a subjective noting of “apprehension” or instability by the patient.
  - Anterior impingement test (pain with passive hip flexion, adduction, and internal rotation): Test of anterior labral pathology, not just a tear.
  - Bicycle test for abductor fatigability.
  - Range of motion (ROM): Dysplastic hips may demonstrate a relative increase in flexion due to anterior acetabular uncoverage. Decreased ROM with pain may indicate arthrosis.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiography includes weight-bearing anteroposterior (AP) views of bilateral hips (FIG 1A), false profile of hips (FIG 1B), and AP views of the hips in maximal abduction and internal rotation (von Rosen view; FIG 1C). These studies allow assessment of lateral and anterior coverage of the femoral head as well as congruency of the hip joint. Additionally noted will be presence of hinge abduction, which is a relative contraindication to PAO.
- Radiographic parameters include the following:
  - Lateral center–edge angle of Wiberg measured from AP view of the hip (lower limits of normal about 25 degrees; see Fig 1A)
  - Anterior center–edge angle of Lequesne and de Seze (lower limits of normal 20 degrees measured on the false profile view; see Fig 1B)
  - Tönnis acetabular roof angle measured on the AP view of the hip (upper limits of normal 10 to 15 degrees; FIG 1D)
Crossover sign (anterior wall shadow crossing posterior wall shadow on AP view of the pelvis)
Assessment of the line of Shenton for breaks indicative of femoral head subluxation
Computed tomography (CT) scan of both hips with three-dimensional reconstruction as well as with axial slices through the femoral condyles may be of assistance in preoperatively assessing the amount and direction of correction required as well as the potential need for proximal femoral osteotomy.
Magnetic resonance imaging (MRI) of involved hips with radial sequences centered at the femoral head allows assessment of articular and labral cartilage.
Delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) is a recently developed technique that assesses the mechanical damage to the articular cartilage. It has been demonstrated to be a better preoperative predictor than plain radiographs in determining outcome after PAO.²

NONOPERATIVE MANAGEMENT
Activity and job modification may be of benefit in delaying or mitigating arthritic symptoms.
Physical therapy may be of some benefit in increasing ROM and strength. To date, there are no data to suggest that a specific therapy regimen can affect the onset of arthritis in the dysplastic hip.

SURGICAL MANAGEMENT
Indication: Symptomatic, congruous acetabular dysplasia (closed triradiate cartilage) with lateral and anterior center-edge angles 18 degrees or less
Contraindications: Tönnis osteoarthrosis grade 2 or more (subchondral cysts, significant joint space narrowing); severe limitation of motion secondary to arthrosis; active joint infection

Preoperative Planning
Radiographs and MRI are evaluated to assess the following:
Degree and character of dysplasia
Amount and direction of correction required to normalize the Tönnis acetabular roof angle (0 to 10 degrees), correct subluxation, and improve mechanical stability
Proximal femoral deformity may also require treatment at time of PAO.
Presence of acetabular articular or labral lesions (seen on MRI) should also be taken into consideration, as treatment either arthroscopically (before the osteotomy) or intraoperatively through limited arthroscopy may be required for best long-term results.
Isolated treatment of a labral lesion in the presence of acetabular dysplasia is contraindicated. Simultaneous acetabular realignment must be considered.
The torn acetabular labrum is usually associated with other structural abnormality within the hip (femoral acetabular impingement or DDH), which may also require correction for best results.⁹
Partial weight-bearing technique is taught preoperatively in preparation for postoperative mobilization.

Positioning
The patient is positioned supine on a radiolucent table.
The operative extremity is prepared and draped free up to the costal margin; the surgeon should be certain to prepare and drape posteriorly to at least the posterior third of the ilium and medially to the umbilicus.
Analgesia: We typically use an epidural for perioperative pain management; it is removed by postoperative day 3. However, this is not mandatory.

Approach
- The standard longitudinal anterior Smith-Petersen incision and approach to the hip provides the appropriate access (FIG 2A).
- As an alternative, an ilioinguinal (bikini) incision may be used followed by a similar deep approach (FIG 2B). This incision typically provides a better cosmetic result but can limit access for the anterior ischial osteotomy. Therefore, we recommend the standard anterior incision for larger and more muscular patients.

FIG 2 • A. Hip with traditional Smith-Petersen incision marked. B. Hip with bikini-type incision marked.

SUPERFICIAL DISSECTION
- The skin is incised into subcutaneous tissue.
- The fascia over the external oblique and gluteus medius is identified and incised posterior to the ASIS and the plane between the two muscles is developed to expose the periosteum over the iliac crest.
- The periosteum is sharply divided over the iliac crest and subperiosteal dissection carried out over the inner table of the ilium. This space is packed with sponges for hemostasis.
- Entry into the tensor fascia lata-sartorius interval is initially accomplished via the compartment of the proximal tensor fascia lata to avoid injury to the lateral femoral cutaneous nerve. The tensor fascia lata is bluntly elevated off the intermuscular septum and the compartment floor is identified proximally until the anterior ilium is palpated. Once hemostasis is attained, the ASIS is predrilled with a 2.5-mm drill and the anterior 1 x 1 x 1-cm portion is osteotomized to facilitate the medial dissection and later repair.
- Alternatively, the sartorius can be taken off with just a thin wafer of bone that will be sewn back in place at the end instead of with a screw.
- Subperiosteal dissection is continued to the anteroinferior iliac spine (AIIS).

DEEP DISSECTION
- Flexion and adduction of the hip facilitates the deep intrapelvic and superior ramus dissection.
- The reflected head of the rectus femoris is divided at its junction with the direct head (TECH FIG 1A,B).
- The direct head and underlying capsular iliaca are elevated as a unit and reflected distally and medially off the underlying joint capsule.
- The iliaca, sartorius, and abdominal contents are reflected medially.
- The psoas sheath is opened longitudinally, and the
psoas tendon is retracted medially to allow access to the superior pubic ramus medial to the iliopsectineal eminence.
- The interval between the medial joint capsule and the iliopsoas tendon is created and sequentially dilated using the tip of a long-handled Mayo scissor, then further by Lane bone levers, with the tips of each palpating the anterior ischium at the infracotyloid groove.
- Proper placement of the scissor and bone levers can be confirmed with the image intensifier (TECH FIG 1C,D).

OSTEOTOMIES

Anterior Ischial Osteotomy
- With the hip flexed 45 degrees and slightly adducted, a 30-degree forked, angled bone chisel (Synthes, USA; in 15- or 20-mm blade widths) is carefully inserted through the previously created interval between the medial capsule and psoas tendon to place its tip in contact with the superior portion of the infracotyloid groove of the anterior ischium, just superior to the obturator externus tendon (TECH FIG 2A–C).
- Staying proximal to the obturator externus tendon helps to protect the nearby medial femoral circumflex artery.

The medial and lateral aspects of the ischium should be gently palpated with the chisel. Proper chisel placement (about 1 cm below the inferior acetabular lip) is confirmed on AP and oblique projections with the image intensifier (TECH FIG 2D).
- The osteotome is impacted in a posterior direction to a depth of 15 to 20 mm in a posterior direction and through both medial and lateral cortices of the ischium (TECH FIG 2E).
- Care should be taken not to drive the osteotome too deeply through the lateral cortex, as the sciatic nerve is nearby.
Superior Pubic Ramus Osteotomy

- The hip is kept flexed and adducted to relax the anterior soft tissues.
- The psoas tendon and medial structures are gently retracted medially (TECH FIG 3A).
- After circumferential subperiosteal dissection of the ramus, either a spiked Hohmann retractor or a large-gauge Kirschner wire is impacted into the superior aspect of the ramus at least 1 cm medial to the iliopectineal eminence (TECH FIG 3B).
- Blunt Hohmann retractors, Rang retractors, or Lane bone levers are placed anteriorly and posteriorly as well as inferior to the ramus to protect the obturator nerve and artery.
- The osteotomy is perpendicular to the long axis of the ramus when viewed from above but oblique from distal-medial to proximal-lateral when viewed from the front and may be carried out either by passing a Gigli saw around the ramus and sawing upward away from the retractors or by impacting a straight osteotome just lateral to the spiked Hohmann or Kirschner wire. In the former method, the Gigli saw is passed with the aid of a Satinsky vascular clamp.
- The key to this osteotomy is to stay medial to the iliopectineal eminence and avoid entering the medial acetabulum (TECH FIG 3C).
- Arthrotomy and intracapsular inspection: At a point before all osteotomies are completed, an arthrotomy may be performed to identify and treat intra-articular lesions such as a torn labrum or impingement lesions of the femoral head and neck.
- This is closed loosely with simple, interrupted absorbable suture before proceeding with the remainder of the osteotomies.
The iliacus is retracted medially with a reverse Hohmann with its tip on the quadrilateral surface. Under direct vision the iliac osteotomy is performed with an oscillating saw and cooling irrigation in line with the Hohmann retractor until reaching a point about 1 cm above the iliopectineal line (well anterior to the notch). This end point of the iliac saw cut represents the posteroinferior corner of the PAO. This corner is also the starting point of the posterior column osteotomy, which will be midway between the sciatic notch and posterior acetabulum (TECH FIG 4).

At this point, a single Schanz screw on T-handled chuck is inserted into the acetabular fragment distal and parallel to the iliac saw cut, well above the dome of the acetabulum, into a hole predrilled with a 3.2-mm drill.

**Posterior Column Osteotomy**

- The leg is once again flexed and adducted to relax the medial soft tissues.
- A reverse blunt Hohmann retractor is placed medially with the tip on the ischial spine. Dissection into the sciatic notch is neither necessary nor recommended.
- The osteotomy is made through the medial cortex with a long, straight 1.5-cm osteotome. It extends from the posterior end of the iliac saw cut, passing over the iliopectineal line, through the medial quadrilateral plate, parallel to the anterior edge of the sciatic notch on iliac oblique fluoroscopy, and is directed toward the ischial spine (TECH FIG 5A).
- This osteotomy must extend at least 4 cm below the iliopectineal line to avoid entry into the acetabulum when completing the final (posteroinferior) infraacetabular osteotomy. This posterior cut is made first through the medial, then second through the lateral wall of the ischium.
- The ischium is wider here than at its anterior extent. If pictured from above, it resembles a triangle with the narrower apex at the anterior edge of the sciatic notch. Therefore, the surgeon should not

**Supra-acetabular Iliac Osteotomy**

- A 1.5- to 2-mm subperiosteal window is started beneath the anterior abductors just distal to the ASIS without disturbing the abductor origin.
- The leg is slightly abducted and extended to allow atraumatic subperiosteal dissection using a narrow elevator posteriorly toward, but not into, the apex of the greater sciatic notch.
- A narrow, long, spiked Hohmann retractor is placed in this window. Correct placement is confirmed with image intensifier; in the lateral projection the spike of the Hohmann should point toward the apex of the sciatic notch (TECH FIG 3C).
ACETABULAR DISPLACEMENT

- A 1-inch straight Lambotte chisel is placed into the supraacetabular iliac saw cut to both confirm completion of the lateral cortex osteotomy and protect the cancellous bone above the acetabulum during displacement.
- The tines of a Weber bone clamp are placed onto the superior ramus portion of the acetabular fragment in such a way as to place its handle anterior and in contact with the Schanz screw (TECH FIG 7A).
- A lamina spreader is placed into the iliac osteotomy between the posterosuperior intact ilium and the Lambotte chisel anteriorly.
- While gently opening the lamina spreader, the Schanz screw and Weber clamp are used to mobilize the acetabular fragment. It is important to ascertain whether the posterior and anterior osteotomies are complete; otherwise, the fragment will not freely rotate and the common outcome will be distal and lateral displacement as you hinge on the lateral, intact cortices. These cuts can be inspected with a narrow or broad 30-degree chisel (TECH FIG 7B).
- Once the fragment is completely free, it may be positioned to obtain the desired correction. As previously noted, the most common deficiency is anterior and lateral. Therefore, the most commonly used maneuvers are to lift the acetabular fragment slightly toward the ceiling, creating an initial displacement, followed by a three-step movement of lateral, distal, and internal rotation.
- When performed properly, the posterosuperior corner of the acetabular fragment should be impacted slightly into the superior intact iliac cut and the prominent superior tip of the acetabular fragment should be roughly in line with the superior intact iliac crest (TECH FIG 7C).
- The radiographic “teardrop” and its relation to the femoral head after fragment positioning should be ele-
ACETABULAR FIXATION

- Once the desired acetabular position is obtained, 3/32-inch smooth Kirschner wires (the approximate diameter of a 2.5-mm drill) are placed proximal to distal through the ilium and into the fragment in a divergent pattern.
- At this point we perform a final fragment position check in the AP and false profile views (TECH FIG 8A,B).
- Importantly, in the false profile view, we check the anterior femoral head coverage in full extension and at 100 degrees of flexion (TECH FIG 8C). In the former view, the sourcil should be roughly horizontal, the femoral head should be well covered, and the line of Shenton should be intact. The false profile view is to confirm that we have neither overcovered the femoral head nor created impingement from a femoral-sided deformity.

(continued)
If there is less than 90 degrees of flexion on palpation or radiograph, it may be necessary to either reposition the fragment or address femoral-sided deformity.

- The Kirschner wires are measured for depth and length and then replaced with either 3.5-mm or 4.5-mm cortical screws.
- The image intensifier is used to confirm extra-articular placement of all screws (TECH FIG 8D,E).
- An additional “home run” screw may be placed anterior to posterior from the AIIS posteriorly into the inferior ilium if required for stability (especially in patients who are ligamentously lax or have a neuromuscular condition or poor bone quality). We prefer not to use this screw unless necessary, as it is our practice to remove these screws once bony healing is confirmed for screw head irritation or in case MRI is to be performed at a later point. The anterior iliac prominence of the acetabular fragment is trimmed and used for bone graft.
- Gelfoam is placed along osteotomy sites to assist with hemostasis.

WOUND CLOSURE

- All sponges are removed and wounds are irrigated copiously.
- Suction drains are placed under the iliacus.
- The ASIS osteotomy (if performed) is reattached either by using a 3.5-mm, partially threaded cancellous screw and washer or by being sewn back with heavy, absorbable suture through thinner wafer.
- Careful attention is paid to proper, tight closure over the iliac crest. This is accomplished by predrilling holes in the iliac crest to facilitate passage of heavy, absorbable sutures to reattach the abductor, iliacus, and external oblique musculature.
- The remainder of the wound is closed in layers.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Patient selection</th>
<th>Appropriate patient selection is paramount.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Risk factors for failure include older age, poor congruency, decreased joint space (less than 2 mm), and advanced arthrosis.</td>
</tr>
<tr>
<td></td>
<td>Presence of a labral tear preoperatively may also be an indicator of degeneration, more than may be apparent on plain radiographs.</td>
</tr>
<tr>
<td>Pubic osteotomy</td>
<td>The hip should be flexed 40 to 50 degrees for making the pubis osteotomy, which takes tension off the iliopsoas and improves access to the brim of the pelvis.</td>
</tr>
<tr>
<td>Ischial osteotomy</td>
<td>If the medial joint is entered while attempting to gain access for the ischial cut, the surgeon can open the psoas sheath and try a second approach dissecting through the floor of the sheath. This technique can be helpful in re-establishing an extra-articular dissection to the ischium.</td>
</tr>
<tr>
<td></td>
<td>Straying too medial risks injury to the neurovascular bundle.</td>
</tr>
<tr>
<td>Iliac osteotomy</td>
<td>In general, given true supine positioning of the pelvis and patient, the iliac wing osteotomy will be roughly directed perpendicular to the floor. This sighting technique gives a second visual reference, which, in combination with intraoperative imaging, will aid in proper positioning of the osteotomy.</td>
</tr>
<tr>
<td>Incomplete osteotomies</td>
<td>Connecting the inferior ischial (infraacetabular) osteotomy and the posterior ischial cuts may require a medial-to-lateral osteotomy cut through their medial junction. This is most commonly necessary when the lateral portion of these osteotomies is incomplete and the finding is an inability to freely move the acetabular fragment at the initial completion of all planned osteotomies.</td>
</tr>
<tr>
<td>Schanz screw placement</td>
<td>The Schanz pin (screw) should be placed nearly in line with and 1 to 1.5 cm below the iliac wing osteotomy. In poorer-quality bone, it may be necessary to place the screw closer to the acetabular subchondral bone. Additionally, the acetabular fragment should be mobilized by using both the Schanz pin and the bone clamp holding the pubic portion of the free fragment.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE
- Sitting is permitted on postoperative day 2.
- Partial weight bearing is reviewed by a physical therapist once the epidural catheter is removed on postoperative day 2 or 3.
- Weight bearing is progressed from partial to full, typically by 6 to 8 weeks with radiographic healing and return of abductor strength.
- Range of motion is limited to 90 degrees of flexion, 10 degrees from full extension, and 10 degrees of adduction, abduction, and rotation for the first 6 weeks.
- Resistive exercises are avoided for 3 months.
- Patients older than 16 years are given either low-molecular-weight heparin or warfarin for 4 to 6 weeks.
- Nonsteroidal anti-inflammatories are avoided.

OUTCOMES
- Outcomes are generally good to excellent in the appropriately selected patient.
- Hips with minimal arthrosis (more than 2 mm of joint space and no significant subchondral changes) in younger (less than 35 years old) patients have demonstrated significant improvement in Harris hip and Merle D’Aubigne scores that can last at least 20 years.1,3,4,6–8
- Hips with moderate to advanced arthrosis in older patients can still show significant improvement in symptoms. However, their symptom relief may be shorter-lived, requiring conversion to either a surface replacement or total hip arthroplasty.

COMPLICATIONS
- Sciatic or lateral femoral cutaneous nerve palsy
- Postoperative wound hematoma requiring return to operating room
- Wound infection
- Nonunion of pubic ramus
- Heterotopic ossification
- Vascular injury
- Intra-articular osteotomy
- Malalignment of fragment leading to insufficient correction or overcorrection

REFERENCES
DEFINITION

- Surgical dislocation of the hip can be done safely to treat a number of conditions, including femoroacetabular impingement (FAI), labral tears, chondral injuries, reduction of femoral neck fractures, reduction of acute severe slipped capital femoral epiphysis (SCFE), or any condition that requires wide complete access to the hip joint.\(^9\)

- There is little morbidity associated with this procedure, and avascular necrosis of the femoral head is a rare complication.\(^2\)

- This technique allows functional assessment of motion intraoperatively.

ANATOMY

- The blood supply to the femoral head is mainly from the medial femoral circumflex artery (MFCA) (FIG 1A).\(^{10}\)

- The intact external rotator muscles, most notably the obturator externus muscle, protect the MFCA during the dislocation (FIG 1B).\(^4\)

PATHOGENESIS

- In FAI, anatomic deformity leads to abnormal contact between the proximal femur and the acetabular rim at the terminal extent of motion.

- In cam impingement, an abnormal bump on the femoral neck passes into the hip beneath the labrum and mechanically damages the labrum and cartilage of the acetabulum.

- Pincer impingement occurs with overcoverage of the acetabular rim impinging on the anterior femoral neck or head–neck junction with terminal flexion.

- Both cam and pincer impingement can, and frequently do, coexist.

- The early chondral and labral lesions that occur in physically active adolescents and young adults can progress and result in degenerative joint disease of the hip.

- Causes of FAI can be idiopathic, secondary to a SCFE, anterior overcoverage of the hip with a retroverted acetabulum, residual deformity from Perthes disease, or posttraumatic changes.

NATURAL HISTORY

- A pistol-grip deformity of the femoral head has been associated with early arthrosis of the hip.\(^6\)

- End-stage osteoarthritis of the hip, once thought to be mainly idiopathic, is now believed to be a result of mild deformities similar to those caused by childhood diseases of the hip such as developmental hip dysplasia, SCFE, and Legg-Calvé-Perthes.\(^1\)

PATIENT HISTORY AND PHYSICAL FINDINGS

- FAI usually presents in active adolescents or young adults with slow-onset groin pain, which may be exacerbated by athletic activities.

---

**FIG 1** • A. Vascular anatomy of the femoral head. Note the proximity of the terminal branches of the medial femoral circumflex artery (MFCA) to the insertion of the piriformis tendon. **B.** Intraoperative photograph showing the path of the MFCA over and behind the intact short external rotators, including the quadratus femoris (Q) and the obturator externus (OE).
Many patients have difficulty sitting for long periods and adjust their seating posture to decrease lumbar lordosis to allow less flexion at the hips. Frequently they complain of difficulty getting into or out of a car.

There can be a family history of hip pain, early arthrosis, or hip arthroplasty.

Patients may walk with an antalgic gait, favoring the side of impingement. A foot-progression angle externally rotated may indicate a chronic SCFE or femoral retroversion.

The impingement test, if positive, shows reproducible groin pain with internal rotation, which is relieved with external rotation.

The physical examination should include both flexion and internal rotation range-of-motion tests.

Patients with impingement will have less than 90 degrees of true hip flexion.

Patients with impingement will have less internal rotation in flexion than extension, and may have a compensatory external rotation of the hip as it is flexed.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

Plain radiographs should include an anteroposterior (AP) view of the pelvis and a true lateral view of the hip held in 15 to 20 degrees of internal rotation (FIG 2A,B).

Computed tomography scans with two- and three-dimensional reconstructions are helpful for preoperative planning and detecting subtle femoral head-neck junction prominence (FIG 2C,D).

Magnetic resonance imaging can further delineate the labral and cartilage pathology (FIG 2E). If the study is performed with gadolinium and high-resolution sagittal oblique or radial sequences, labral pathology can be detected.

**FIG 2** • AP pelvis (A) and true lateral (B) radiographs, which show the lack of femoral head–neck offset anteriorly (arrow in B) that is causing cam impingement. Three-dimensional reconstructions of the same pelvis from an AP (C) and a slightly left-rotated (D) perspective. The large “bumps” (arrows) obscuring the anterior femoral head–neck junction account for the lack of offset appreciated in B. E, T1-weighted sagittal MRI showing a large anterior osteophyte (arrow).
DIFFERENTIAL DIAGNOSIS
- FAI
- Labral tear
- Hip dysplasia
- SCFE
- Acetabular retroversion

NONOPERATIVE MANAGEMENT
- Nonoperative management includes cessation of aggravating activities, and symptomatic treatment using nonsteroidal anti-inflammatories.
- Physical therapy to strengthen the hip musculature does not address the mechanical impingement of FAI.

SURGICAL MANAGEMENT
- Hip pathology may be addressed through hip arthroscopy. However, it may be difficult to dynamically assess hip mechanics before and after débridement.
- Femoral head-neck osteoplasty may be performed through an anterior approach to the hip without a surgical dislocation. However, the articular cartilage of the acetabulum and most of the femoral head cannot be evaluated with this limited approach.

Preoperative Planning
- All imaging studies are reviewed.
- The lack of femoral head–neck offset is best appreciated on the true lateral view of the hip (see Fig 2A,B), or on the axial cuts or 3D reconstruction of a CT scan.

A CT scan that includes cuts through the distal femoral condyles may be used to accurately measure the amount of femoral version.7
- After general anesthesia is administered, the patient’s hips are examined. The amount of true hip flexion and internal and external rotation with the hip extended and hip flexed are noted and compared to the preoperative assessment.

Positioning
- The patient is placed in the full lateral position, secured on a pegboard. A flat-top cushion (with a half-moon-shaped cutout for the down leg) placed beneath the operative side helps to stabilize the leg during the approach (FIG 3A–C).
- A hip drape with a sterile side bag is used, which will capture the leg during the dislocation maneuver (FIG 3D).

Approach
- The approach consists of an anterior dislocation through a Kocher-Langenbeck or a Gibson approach with a trochanteric flip osteotomy (FIG 4A,B).
- A Kocher-Langenbeck incision is followed by splitting the gluteus maximus muscle.
- The abductors and gluteus maximus muscles can be spared by performing a Gibson approach, which proceeds between the gluteus medius and maximus (FIG 4C,D).
- The Gibson approach may result in less hip extensor dysfunction but may make anterior exposure more difficult.
- A Z-shaped capsulotomy is made to allow entry to the hip joint while protecting the deep branch of the MFCA (FIG 4E).2

FIG 3 • A–C. The patient is positioned full lateral on a pegboard. Before patient preparation, the surgeon should ensure that the leg can be flexed and adducted fully and is not blocked by the anterior inferior peg. D. Position of the leg in the sterile leg holder after dislocation. The hip is flexed, adducted, and externally rotated.
**SURGICAL HIP DISLOCATION BY A TRANSTROCHANTERIC APPROACH**

**Approach to Hip Capsule**

- A longitudinal lateral incision is made, centered over the junction between the anterior and middle thirds of the greater trochanter (TECH FIG 1A).
- The fascia lata is split distally in line with the incision. The proximal dissection progresses through the interval between the anterior edge of the gluteus maximus and the tensor (TECH FIG 1B).
- The proximal 4 to 5 cm of fascia of the vastus lateralis is incised and the vastus muscle fibers are reflected anteriorly.
- The gluteus maximus, along with the fascia of the gluteus medius, which is left on the undersurface of the gluteus maximus for protection, is reflected posteriorly to expose the gluteus medius and insertion.
- A 1- to 1.5-cm-thick trochanteric osteotomy is made with an oscillating saw, leaving the piriformis tendon and

**FIG 4 • A,B.** The trochanteric osteotomy with the attached vastus lateralis and gluteus medius. The tendon of the piriformis (arrow) remains attached to the stable trochanteric base. C,D. The Kocher-Langenback approach splits the gluteus maximus while the Gibson approach spares the gluteus maximus by using the plane between it and the gluteus medius. E. Path of the Z-shaped capsulotomy (solid line). The limb along the posterior aspect of the acetabulum protects the entry of the terminal branches of the medial femoral circumflex artery (white dashed line) and allows access to the hip joint and femoral head (black dashed line).
short external rotators intact on the remaining base of the greater trochanter (TECH FIG 1C).
- The fascia overlying the piriformis tendon is incised to identify the tendon and the interval between the piriformis and capsular minimus muscles (TECH FIG 1D).
- The trochanteric wafer is next reflected and flipped anteriorly with its attached sleeve of vastus lateralis and the gluteus medius (TECH FIG 1E).
- The capsular minimus is elevated in an anterior direction off the hip capsule by carefully dissecting in the interval between the posterior edge of the capsular minimus and the piriformis tendon (TECH FIG 1F).
- An assistant may use a right-angled retractor to assist with the exposure of the capsule.

- Progressive hip flexion, external rotation, and adduction further aid the exposure.
- The hip capsule is exposed up to the rim of the acetabulum.

**Hip Arthrotomy and Dislocation**

- A Z-shaped capsulotomy is then performed, with the longitudinal arm of the Z in line with the anterior neck of the femur.
- The distal arm of the capsulotomy extends anteriorly well proximal to the lesser trochanter.
- The proximal arm is extended posteriorly along the acetabular rim, just distal to the labrum and well proximal to the retinacular branches of the MFCA.

**TECH FIG 1**

- A. The proposed incision after the patient is prepared and draped. B. The Gibson approach is between the gluteus maximus and medius. Note the trochanteric branches of the medial femoral circumflex artery on the greater trochanter (black arrow). C. The trochanteric osteotomy is made with an oscillating saw. D. The fascia over the piriformis tendon (bottom arrow) is divided to develop the interval between it and the capsular minimus (top arrow). E. A 1- to 1.5-cm trochanteric wafer is lifted anteriorly with the gluteus medius and vastus lateralis left attached. F. The anterior capsule is completely exposed before the arthrotomy is made.
entering the capsule posteriorly to supply the femoral head (TECH FIG 2).

- Depending on the pathology, the hip is brought through a range of motion to determine areas of impingement in a dynamic fashion.
- The leg is then placed in the sterile side bag, flexed, externally rotated, and adducted while the hip is subluxated anteriorly through the arthrotomy.
- A bone hook placed around the anterior femoral neck may be needed to subluxate the hip.
- The ligamentum teres is then divided using curved meniscus scissors to allow full dislocation of the hip.

**Dynamic Assessment and Osteoplasty**

- The entire femoral head and acetabulum can now be assessed for chondral flaps or labral tears, which can be repaired using suture anchors spaced about 7 to 10 mm apart or débrided.
- The aspherical segment of the femoral head at the head–neck junction can be resected using a quarter-inch osteotome and rongeur (TECH FIG 3A,B).
- After re-establishing sphericity of the femoral head, the hip is reduced and the results of the débridement are assessed by bringing the hip through a range of motion and confirming the relief of impingement and improvement in range of motion.
- Intraoperative fluoroscopy showing a lateral of the hip in 90 degrees of flexion will determine if the femoral head–neck offset has been re-established (TECH FIG 3C).

**Osteotomy Fixation**

- The trochanteric wafer is reduced and held in position with a towel clip.
- Three 3.5-mm small fragment screws are placed to secure the trochanter. Fluoroscopy confirms reduction and fixation of the osteotomy (TECH FIG 4).
POSTOPERATIVE CARE

- The hip is held flexed and in neutral rotation by placing two pillows under the leg and one under the greater trochanter.
- The patient is placed in a continuous passive motion machine for 6 hours a day, set from 30 to 80 degrees of flexion.
- Prophylaxis for deep venous thrombosis is individualized; however, all patients should be started on mechanical compression devices immediately.
- After the epidural is removed, out-of-bed ambulation is permitted with one-sixth body weight partial weight bearing.
- Range-of-motion exercises are started, but care is taken to protect the greater trochanter osteotomy by limiting adduction to midline, and avoiding resisted abduction exercises for 6 weeks.
- Some patients may benefit from heterotopic ossification prophylaxis using indomethacin.
- AP view of the pelvis or hip and true lateral hip radiographs are obtained 6 weeks postoperatively. Weight bearing is increased to full and hip-strengthening exercises are prescribed.

OUTCOMES

- Ganz \(^1\) has performed over 1200 surgical hip dislocations with no cases of osteonecrosis reported.
- Generally, outcomes are excellent if the correct pathology is addressed in a joint without significant pre-existing arthrosis.
- In a clinical assessment in adults by Murphy et al \(^8\) using the Merle d’Aubigne scale, hip scores improved significantly.

COMPLICATIONS

- Avascular necrosis of the femoral head can occur if care is not taken to follow the technique and to preserve the retinacular vessels.
- Femoral neck fracture if the femoral head-neck junction is aggressively debrided
- Sciatic or femoral nerve neurapraxia
- Greater trochanteric nonunion
- Heterotopic ossification
- Repeated labral tear
- Continued arthrosis of the joint
REFERENCES

DEFINITION
- Coxa vara is a deformity of the proximal femur associated with a neck–shaft angle (NSA) of less than 110 degrees.\textsuperscript{12}
- Developmental coxa vara, also referred to as cervical or infantile coxa vara, is not present at birth, but rather develops in early childhood.
  - This is a rare disease entity with a worldwide incidence of 1 in 25,000 live births.
  - This form has not been connected to an increased association with other musculoskeletal abnormalities.
  - The varus deformity does frequently progress with time.
  - This entity must be distinguished from other forms of coxa vara, such as congenital or acquired.
  - As opposed to developmental coxa vara, the congenital form is present at birth. It is presumed to be caused by an embryonic limb bud abnormality, is associated with an increased incidence of musculoskeletal abnormalities and significant limb-length discrepancy (LLD), and shows minimal progression with growth.
  - The acquired forms of coxa vara are secondary to underlying disorders (eg, metabolic, traumatic, tumors).

ANATOMY
- Growth of the proximal femur occurs at the proximal femoral physeal plate, the femoral neck isthmus, and the greater trochanteric apophysis.
  - The growth at these sites determines the size and shape of the proximal femur, specifically the length of the proximal femur and the NSA.
  - Any injury to the proximal physis will result in a varus deformity owing to continued growth of the femoral neck and trochanter.\textsuperscript{4}
  - Between 3 and 6 months of age, the capital femoral epiphyseal ossification center may be seen.
  - The trochanteric secondary center of ossification begins to ossify at 4 years of age.
  - The NSA normally progresses to a more varus position with growth, starting at approximately 150 degrees at birth and finishing near 120 degrees at full maturity.

PATHOGENESIS
- The exact cause of developmental coxa vara is unknown.
  - An attractive theory, proposed by Pylkkanen,\textsuperscript{8} postulates that the varus deformity is due to a primary ossification defect in the medial femoral neck that results in a more vertical physis.
  - Dystrophic bone forms on the medial aspect of the femoral neck.
  - The physiologic shearing stresses that occur during weight bearing fatigue the dystrophic bone in the medial femoral neck, resulting in progressive varus.\textsuperscript{8}
  - Biopsies of the proximal femoral physis reveal findings similar to those seen in the proximal tibia in patients with Blount’s disease or the proximal femoral physis in patients with metaphyseal chondrodysplasia (Schmid type),\textsuperscript{6} revealing an enlarged growth plate with disorganized islands of cartilage in relatively reduced numbers.\textsuperscript{1,3,8}
  - No evidence of osteonecrosis was seen.

NATURAL HISTORY
- As described by Weinstein et al,\textsuperscript{12} the most reliable factor for progression is the Hilgenreiner–epiphyseal angle (HEA), measured between the line of Hilgenreiner and a line parallel to the proximal femoral physis (FIG 1).
  - Patients whose HEA is more than 60 degrees will invariably progress.
  - The increased varus and retroversion can cause a cam-type impingement.
  - This will then lead to premature degenerative arthritis with progressive pain and disability.
  - If left untreated, the decreased NSA may eventually create too great a strain on the femoral neck, leading to a stress fracture of the femoral neck and eventual nonunion.
  - Patients with an HEA between 45 and 60 degrees have a less defined prognosis and must be followed for progression of varus deformity or increased symptoms.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Developmental coxa vara is typically discovered sometime between the initiation of ambulation and 6 years of age.\textsuperscript{5,7}
- Patients commonly present with a progressive painless limp.
- Pain is an uncommon finding.
If a unilateral abnormality is present, the limp will be due to abductor weakness, as well as a minor LLD (usually less than 2.5 cm).

When present bilaterally, the patient will present with a waddling gait associated with increased lumbar lordosis, similar to what is seen in ambulatory children with bilaterally dislocated hips.

As opposed to patients with dislocated hips, however, no telescoping or signs of instability should be noted.\(^5,8,10\)

The greater trochanter may be prominent and elevated.

Because the abductors are not at their optimal length, they will eventually weaken, leading to easy fatigability and muscle aching.

Abductor weakness may also lead to the development of a Trendelenburg gait.

Hip motion is typically limited (mostly abduction and internal rotation).

Additionally, hip flexion may be restricted secondary to impingement.

Physical examination should include several range-of-motion tests.

Passive abduction: Varus deformity may lead to decreased ability to abduct. Normal full abduction is 40 degrees.

Passive internal rotation: Decreased internal rotation may be secondary to retroversion or impingement.

Internal rotation is variable, but at least 20 degrees is expected.

Passive flexion: Loss of flexion may result from femoroacetabular impingement. Normal full flexion is 120 degrees.

A positive Trendelenburg sign—tilting of the pelvis down toward the nonstance leg—indicates abductor weakness.

LLD may indicate growth disturbance of the proximal femur.

### IMAGING AND OTHER DIAGNOSTIC STUDIES

Evaluation consists primarily of an AP radiograph of the pelvis (FIG 2A).

- The NSA is substantially decreased, often less than 90 degrees.
- The proximal femoral physis is wider and more vertical, with a triangular metaphyseal fragment in the inferior neck surrounded by physis, giving an inverted Y pattern—the sine qua non of developmental coxa vara.
- Also notable are decreased femoral anteversion, coxa breva, and possible mild acetabular dysplasia.

A frog-leg lateral radiograph (FIG 2B) as well as a CT (FIG 2C,D) or MRI may also be obtained to provide more information.

### DIFFERENTIAL DIAGNOSIS

- Congenital coxa vara
- Proximal femoral focal deficiency
- Skeletal dysplasia
  - Cleidocranial dysostosis
  - Metaphyseal dysostosis (Jansen type)
  - Spondylometaphyseal dysplasia (Kozlowski type)
Avascular necrosis
- After reduction for developmental hip dislocation
- Trauma (femoral neck fracture or hip dislocation)
- Septic joint
- Slipped capital femoral epiphysis
- Pathologic bone condition
  - Fibrous dysplasia
  - Osteogenesis imperfecta
  - Renal osteodystrophy
  - Osteopetrosis

**SURGICAL MANAGEMENT**

Patients with an HEA greater than 60 degrees are candidates for surgical intervention, as are patients with an HEA greater than 45 degrees who are symptomatic (limp or progressive deformity).

**Preoperative Planning**

- Clinically assess range of motion (ROM) and LLD.
- Review all images.
- Determine the desired alignment (version, NSA, offset).
- Choose implant type based on patient age and size.
- Kirschner wire: for dwarves or children up to 4 years of age with bones too small for a plate
- Custom-made high-angle blade plate: used for older children with bones too large for the Kirschner wire technique
- Wagner plate: an alternative plate for patients with bones too big for the Kirschner wire technique when a custom-made high-angle blade plate is not accessible

**Positioning**

- The patient is supine on a radiolucent table with a folded blanket beneath the pelvis.
- This elevation allows more room for movement, especially when working posteriorly or when trying to drop your hand to aim anteriorly.

**Approach**

- The standard lateral approach to the proximal femur is used.

**EXPOSURE**

- The fascia lata is split longitudinally.
- The vastus lateralis fascia is incised longitudinally about 5 to 10 mm anterior to the intermuscular septum and is elevated atraumatically from the femur.
- This muscle is then released proximally from the femur with a transverse incision just below the level of the greater trochanteric apophysis.
- The periosteum is incised along the anterolateral femur and subperiosteal dissection is performed circumferentially just proximal to the level of the lesser trochanter.
- The anterior neck is visualized to assess femoral version.
- The bone is scored longitudinally with an electrocautery or saw, or Kirschner wires can be placed proximal and distal to the osteotomy site to assess rotation after the osteotomy has been performed.

**VALGUS OSTEOTOMY USING MULTIPLE KIRCHNER WIRE FIXATION**

- Three Kirschner wires (7/64-inch are most common) are inserted in parallel (TECH FIG 1A), lined up in a transverse fashion, up the middle of the neck.11,13
- The lateral cortex is entered 5 to 10 mm distal to the trochanteric apophysis, and the wires are directed up the neck in parallel and advanced into the femoral head.
- Starting more proximally allows for more lateralization of the femoral shaft.
- The starting point may be more anterior if there is increased retroversion.
- The three Kirschner wires are then bent to the desired angle of correction determined preoperatively (typically about 160 degrees) and rotated proximally to be out of the way (TECH FIG 1B,C).
- An additional Kirschner wire is inserted at the level of the lesser trochanter perpendicular to the shaft to act as a guide for the osteotomy.
- A bone tenaculum is placed on the greater trochanter to allow for control of the proximal fragment after the osteotomy.
- Two bone cuts are made parallel to the Kirschner wire, about 5 mm on either side of the wire, and then this cylindrical segment is removed (TECH FIG 1D).
- This allows for some shortening to relieve pressure on the femoral head and to reduce medial soft tissue tension.
- The thick medial periosteum must be divided to allow for valgus correction and lateralization of the shaft.
- The lateral cortex of the proximal fragment is abraded with the saw or with a burr to promote healing.
- Trial reduction is attempted by gently pushing down on the Kirschner wires (without stressing the Kirschner wires to prevent pullout) to adduct the proximal fragment while abducting and translocating the distal fragment.
- The three Kirschner wires are then rotated distally and brought down to the shaft so that the lateral cortex of the proximal fragment lies on or is impacted into the proximal end of the distal fragment (TECH FIG 1E).
- The fragments are temporarily stabilized by holding down the Kirschner wires to the lateral cortex of the distal fragment with a Verbrugge clamp.
- An interfragmentary Kirschner wire may be inserted for added stability.
- The Kirschner wires are then definitively secured to the shaft with a cerclage wire, a small semitubular plate, or both.
- The vastus lateralis should be sutured securely to the greater trochanter to provide a lateral tension band.
VALGUS OSTEOTOMY USING WAGNER PLATE FIXATION

- A Kirschner wire is inserted just proximal to the proposed insertion site parallel to the planned angle of the plate.
- The 115-degree Wagner plate is impacted through the lateral cortex of the femur, starting just above the level of the trochanteric apophysis and aiming toward the inferior aspect of the neck, at a preoperatively determined angle (TECH FIG 2).
  - Starting more proximally allows for more lateralization of the femoral shaft.
- A Kirschner wire is inserted at the level of the lesser trochanter perpendicular to the shaft to act as a guide for the osteotomy.
- A bone tenaculum is placed on the greater trochanter to allow for control of the proximal fragment after the osteotomy.
- Two bone cuts are made parallel to the Kirschner wire, about 5 mm on either side of the wire, and then this cylindrical segment is removed.
  - This allows for some shortening to relieve pressure on the femoral head.
- The thick medial periosteum must be divided to allow for valgus correction and lateralization of the shaft.
- Reduction should be attempted without stressing fixation (prevents pullout).
- The lateral cortex of the proximal fragment is abraded with the saw or with a burr to promote healing.
- The plate is then brought down to the shaft so that the lateral cortex of the proximal fragment lies on or is impacted into the end of the distal fragment and is secured with two screws.
- An interfragmentary screw may be inserted for added stability.
- The vastus lateralis should be sutured securely to the greater trochanter to provide a lateral tension band.

TECH FIG 2 • Wagner plate fixation. Insertion of the plate parallel to the proximal guidewire.
VALGUS OSTEOTOMY USING ADOLESCENT BLADE PLATE FIXATION

- A Kirschner wire is inserted just proximal to the proposed insertion site parallel to the planned angle of the plate.
- The blade plate chisel is impacted through the lateral cortex of the femur, starting just above the level of the trochanteric apophysis and aiming toward the inferior aspect of the neck, at a preoperatively determined angle.
  - Starting more proximally allows for more lateralization of the femoral shaft.
- A Kirschner wire is inserted at the level of the lesser trochanter perpendicular to the shaft to act as a guide for the osteotomy.
- A bone tenaculum is placed on the greater trochanter to allow for control of the proximal fragment after the osteotomy.
- Two bone cuts are made parallel to the Kirschner wire, about 5 mm on either side of the wire, and then this cylindrical segment is removed.
- This allows for some shortening to relieve pressure on the femoral head.
  - The thick medial periosteum must be divided to allow for valgus correction and lateralization of the shaft.
  - Reduction is attempted without stressing the plate (prevents pullout).
  - The lateral cortex of the proximal fragment is abraded with the saw or with a burr to promote healing.
  - The plate is then brought down to the shaft so that the lateral cortex of the proximal fragment lies on or is impacted into the end of the distal fragment and is secured with screws.
  - An interfragmentary screw may be inserted for added stability.
  - The vastus lateralis should be sutured securely to the greater trochanter to provide a lateral tension band.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Implant choice</th>
<th>The Kirschner wire technique should be used for patients with smaller bone, who would not be able to accommodate a larger plate.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positioning</td>
<td>Placing a folded blanket beneath the pelvis to elevate the patient off the bed allows more room to maneuver.</td>
</tr>
<tr>
<td>Instrumentation placement</td>
<td>Insertion of the fixation device more proximally in the proximal fragment allows for more lateralization of the femoral shaft.</td>
</tr>
<tr>
<td></td>
<td>Insertion more anteriorly accounts for any retroversion of the neck.</td>
</tr>
<tr>
<td>Achievement of correction</td>
<td>Removal of a segment of bone allows for less soft tissue tension so that the valgus correction can be achieved and the risk of implant failure can be minimized.</td>
</tr>
<tr>
<td></td>
<td>Dividing the thick medial periosteum allows more freedom of motion to achieve valgus correction and lateralization of the shaft.</td>
</tr>
<tr>
<td>Avoiding pullout</td>
<td>An initial reduction should be attempted without placing pressure on the fixation device to avoid pullout.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Radiographs are evaluated to ensure that instrument placement and alignment are appropriate.
- The child is placed in a well-padded spica cast for 4 to 6 weeks or until bony healing is evident.

OUTCOMES

- If adequate valgus is achieved, the triangular defect will spontaneously close by 3 to 6 months after surgery in nearly all patients.5
- Fifty percent to 89% of operated hips sustain a premature closure of the proximal femoral physeal, which occurs 1 to 2 years postoperatively and has not been found to correlate with patient age, surgical trauma, or degree of valgus.15
- Recurrence has been reported in 30% to 70% of patients, though correction of the HEA to less than 38 degrees has been shown to have a 95% success rate.2
- These patients must be monitored for recurrent varus deformity or significant LLD that may require further surgical intervention.

COMPLICATIONS

- Recurrence
- Proximal femoral physeal closure
- Avascular necrosis
- Implant failure
- Infection

REFERENCES

DEFINITION
- Valgus osteotomy for Legg-Calvé-Perthes disease (Perthes disease) is a salvage operation. It is designed for those hips in which the primary goal of containment is no longer possible owing to hinge abduction. The following sections are focused on hips that have developed hinge abduction rather than a complete discussion of Perthes disease.
- The valgus osteotomy relieves the hinging and improves congruency of the hip joint.

ANATOMY
- A femoral head with normal anatomy moves concentrically within the acetabulum. The lateral aspect of the femoral head glides under the acetabulum with abduction.
- In severe Perthes disease with significant deformity of the femoral head, the lateral aspect of the head may impinge on the acetabulum with attempted abduction. Continued abduction creates a lateral hinge, which pulls the inferomedial portion of the head away from the acetabulum.4

PATHOGENESIS
- Hinge abduction is a consequence of several contributing factors.
- Early in the process of Perthes disease there is cartilaginous overgrowth laterally and anteriorly. Later, during the healing process, this cartilage ossifies, contributing to the ridge of lateral bone.
- Osteonecrosis of the bony epiphysis of the femoral head leads to recurrent subchondral fractures.
- These fractures are associated with a loss of epiphyseal height and a change in shape from round to oval.
- Fragmented portions of the epiphysis may be extruded laterally.
- With collapse, the femoral head migrates proximally and laterally, progressively uncovering the lateral aspect of the femoral head.
- Catterall’s description of “head at risk signs” identified four radiographic findings associated with the later development of hinge abduction.2
  - A lytic area on the lateral aspect of the epiphysis known as Gage’s sign3
  - Calcification lateral to the epiphysis
  - Lateral subluxation of the femoral head
  - A horizontal orientation of the physeal line (as opposed to the normal more medial inclination)
- Hinge abduction is also seen in osteonecrosis of other causes but is commonly associated with Perthes disease.

NATURAL HISTORY
- At maturity, patients with unrelieved hinge abduction would generally be classified as Stulberg category IV (flattened femoral head with a round acetabulum), both of which have been found to be associated with early-onset osteoarthritis.5
- Patients with hinge abduction often develop pain in the second decade of life.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients typically have pain with activity that is relieved by rest.
- The most notable physical finding is limited abduction of the hip. Often the patients are unable to abduct the hip to neutral. Attempted abduction is painful.
- There is generally 1 to 2 cm of shortening.
- Patients walk with an antalgic gait with the hip in adduction.
- A positive Trendelenburg sign indicates weakness of the hip abductor mechanism, which is unable to stabilize the pelvis.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Gross hinge abduction may be visualized on plain radiographs (FIG 1A,B).
- On arthrogram, visualization of pooling of dye medially with abduction of the hip is considered diagnostic. The arthrogram is studied in anteroposterior (AP) and lateral projections with abduction, adduction, and internal and external rotation to determine the position that maximizes congruency and relieves impingement (FIG 1C,D).

DIFFERENTIAL DIAGNOSIS
- Impingement from relative trochanteric overgrowth
- Subchondral fracture

NONOPERATIVE MANAGEMENT
- Perthes disease often does not require any intervention.
- Treatment strategies early in the course of the disease should focus on containment of the femoral head in the acetabulum and preservation of the range of motion.
- Patients with hinge abduction have pain with activity.
- If hinge abduction is seen on radiographs but the patient is symptom-free, an osteotomy would still improve the prognosis. In that scenario it would be reasonable to wait until the patient is symptomatic.

SURGICAL MANAGEMENT
- The valgus osteotomy is considered a salvage operation for late cases in which the femoral head has developed a lateral ridge that can no longer be brought under the acetabulum.

Preoperative Planning
- The arthrogram is reviewed. Extension, flexion, or rotation may be required in addition to valgus to fully relieve impingement and maximize congruency.
Preoperative templating is essential.

- The template is rotated into abduction to check for lateral impingement.
  - The amount of valgus required to allow at least 10 degrees of abduction without lateral impingement is measured. Usually about 20 degrees of correction is required.
  - The oblique limb of the osteotomy should be just below the lesser trochanter.
  - Placing the transverse limb distally will bring the completed osteotomy parallel to the ground when the patient is standing.

Fixation should also be drawn on the template.

- I prefer a 120-degree blade plate with a lateral stepoff, which provides medialization of the distal fragment (FIG 2).
- The placement of the blade plate, rather than the saw cuts, will dictate the final position of the osteotomy.

To calculate the angle for insertion of the blade plate relative to the femoral shaft, the angle of the planned correction is subtracted from 120 degrees.

- Example: For a desired 20 degrees of valgus correction, the blade is inserted at 100 degrees from the shaft. With the blade at 100 degrees, the shaft must come into 20 degrees of valgus to accommodate a 120-degree fixed-angle blade plate.

- The blade plate should occupy 50% to 75% of the width of the femoral neck on the lateral projection for optimum strength.

Positioning

- The patient is placed supine on a radiolucent surgical table with a soft bump under the affected hip.
- The surgeon should check that sufficient AP and lateral radiographs can be obtained.

Approach

- The lateral approach to the hip is used.
EXPOSURE

- The fascia lata is split in line with the fibers over the palpated lateral border of the femur.
- The vastus lateralis is elevated from the intermuscular septum. Perforating vessels are identified and cauterized.
- Proximally, the fascia of the vastus lateralis is opened anteriorly with the electrocautery along the vastus ridge, creating an L shape (TECH FIG 1).
- The femur is exposed subperiosteally. The exposure should be extended sufficiently distal to allow removal of the previously measured segment of bone and the application of a plate.

VALGUS OSTEOTOMY OF THE FEMUR USING A CANNULATED BLADE PLATE

Guidewire Placement

- If using a cannulated blade plate (Smith and Nephew, Memphis, TN), a guidewire is inserted in the proposed location for the blade.
- To insert the wire at the proposed angle, a premeasured triangle equal to the supplement of the desired angle of insertion is held against the lateral aspect of the femur.
  - To use the previous example, 180° - 100° = 80 degrees (TECH FIG 2A).
- In the lateral plane, the wire should parallel the proposed track of the blade plate (ie, centered in the femoral neck) (TECH FIG 2B).
- The length of the inserted guidewire is measured.
- The guidewire is inserted further than the templated blade plate depth.

Chisel Insertion

- The chisel is inserted parallel to the guidewire in the AP and lateral planes (TECH FIG 3A).
  - For pure valgus, the chisel is perpendicular to the lateral shaft of the femur (TECH FIG 3B).
  - To add extension or flexion, the chisel is rotated posteriorly or anteriorly from perpendicular, respectively. The desired amount of flexion or extension should be marked on the bone (TECH FIG 3C).
The chisel is frequently backed up during insertion to prevent incarceration.
The path of the chisel is checked periodically with fluoroscopy.
The chisel is backed up to loosen it before making the osteotomy. The surgeon should verify it has backed up by checking the depth measurement.

**Making the Osteotomy**

The proximal limb of the osteotomy should be planned as far distally from the base of the chisel as possible without interfering with the bend of the plate or the most proximal screw hole for plates without offset. This distance is usually just under 10 mm but should be checked for each plate, as systems vary (TECH FIG 4A).
A precut template wedge (a sterilized piece of a soda can works well) is used to mark the angle of the osteotomy.
The length of lateral cortex to be removed is also measured on the preoperative radiographs, but the measurement should be verified intraoperatively.
A longitudinal mark for rotation is made along the femur before making any cuts. The mark should be long enough not to be excised by the osteotomy. The mark should be well anterior to the plate so it will still be visible while the plate is being applied.
The proximal cut is parallel to the chisel in the lateral plane. This holds true whether the goal is pure valgus or valgus with extension–flexion. The distal cut is perpendicular to the shaft of the femur (TECH FIG 4B,C).

**Blade Plate Placement**

When the chisel is removed, it should be exchanged for the blade plate quickly as the proper orientation is easily lost.
The blade plate should be inserted by hand initially to prevent deviation from the desired path.
The distal portion of the femur is reduced to the side plate and secured with a bone-reduction clamp.
Rotation is confirmed using the previously placed orientation line.
The side plate is secured to the femur using standard technique with the initial screws inserted in compression.

**TECH FIG 4 • A.** Angle of limbs of osteotomy in AP plane. The distal cut is transverse. **B.** In pure valgus, the osteotomy cuts are parallel in the lateral plane. **C.** For added extension, cuts are convergent anteriorly. Note proximal limb parallel to chisel in lateral plane.

**VALGUS OSTEOTOMY OF THE FEMUR USING A NONCANNULATED BLADE PLATE**

The technique using a noncannulated blade plate is the same with the exceptions that follow.
With a solid blade plate, the guidewire should be inserted parallel to the proposed course of the chisel (TECH FIG 5A).

The wire should be far enough away so that it does not interfere with the chisel but should be close enough to follow easily.
This technique requires more frequent fluoroscopic images during chisel insertion to be sure the guidewire is being followed in both the AP and lateral planes. When

**TECH FIG 5 • A.** Solid system insert chisel parallel to guidewire.
TECH FIG 5 • (continued) B. Guide arm of chisel is parallel to the femoral shaft for pure valgus. C. Guide arm of chisel parallel to femoral shaft for pure valgus.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Chisel incarceration</th>
<th>This can be prevented by frequently backing the chisel out.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The surgeon should be sure it really backs up. Check the markings. It is easy to be deceived.</td>
</tr>
<tr>
<td>Loss of guidewire, cannulated system</td>
<td>This happens when the chisel is inserted past the end of the guidewire.</td>
</tr>
<tr>
<td></td>
<td>The surgeon should check with a radiograph while removing the chisel to verify the guidewire is staying in place.</td>
</tr>
<tr>
<td>Loss of guidewire, noncannulated system</td>
<td>This occurs when the chisel is inserted too close to the guidewire, destabilizing it.</td>
</tr>
<tr>
<td>Chisel insertion measurement</td>
<td>The surgeon should verify before insertion whether the system being used puts the numbers above or below the hashmark (FIG 3).</td>
</tr>
<tr>
<td>Osteotomy reduction, blade plate manipulation</td>
<td>The distal femur should be brought to the blade plate as much as possible. Excessive torque on the blade plate should be avoided.</td>
</tr>
<tr>
<td></td>
<td>The blade may break out of the proximal fragment, especially if insufficient distance was maintained between the bottom of the chisel and the osteotomy.</td>
</tr>
<tr>
<td></td>
<td>Radiographs are obtained before final seating to ensure the guidewire is being followed.</td>
</tr>
<tr>
<td></td>
<td>The surgeon should not attempt to move the leg into position for a lateral radiograph until the blade plate is inserted far enough to be secure. Performing this maneuver before there is adequate purchase will cause the blade plate to break out of the hole.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Patients are allowed to bear weight as tolerated with crutches. Patients who are expected to be noncompliant with crutches and activity limitations are placed in a single-leg spica cast.
- Elective hardware removal is controversial. I prefer hardware removal 1 to 2 years postoperatively or after bony union is obtained in patients in whom the likelihood of future surgery, including joint arthroplasty, is high.

OUTCOMES

- Three recent publications\(^1\,\,^4\,\,^6\) reported subjectively satisfactory results (by varying standards) in 66% to 94% of patients at 5 to 10 years of follow-up. Average Iowa hip scores ranged from 86 to 93. Further hip surgery had been performed on 10% to 20% of patients.
- Two of the three recent articles noted no significant changes in the Sharp angle and percent coverage.\(^1\,\,^4\) One study noted a
significant difference in the percent coverage and superior joint space.6

- Bankes et al1 reported two factors associated with favorable remodeling, both concerning the timing of surgery: when the osteotomies were carried out during the healing phase of Perthes disease, and when they were carried out in patients with open triradiate cartilages.

COMPLICATIONS

- Nonunion is rare with the osteotomy in the immediate subtrochanteric region. If the osteotomy is created more distally in the diaphyseal bone, nonunion may occur.
- Hardware failure most commonly occurs via the blade plate breaking out of the proximal fragment, when too small of a bone bridge was preserved.
- Valgus osteotomy for Perthes disease is a salvage procedure. The desired outcome is to relieve pain and delay the progression of osteoarthritis. It is important to communicate preoperatively that the progression of osteoarthritis is not prevented.

REFERENCES

Slipped capital femoral epiphysis (SCFE) is a common hip disorder in adolescents in which the neck and femur displace anterolaterally (most commonly into varus and extension) with respect to the proximal femoral epiphysis. SCFE can be classified as stable or unstable. A child with a stable SCFE has pain and a possible limp but is able to bear weight, whereas a child with an unstable SCFE is unable to bear weight even with crutches. A stable slip has a nearly 0% risk of osteonecrosis, but an unstable slip has a 50% risk of osteonecrosis.

SCFEs have also been described by duration of symptoms as chronic (greater than 3 weeks of symptoms), acute (less than 3 weeks of symptoms), or acute on chronic (longstanding mild symptoms with an increase in symptoms of less than 3 weeks’ duration). This latter classification correlates less well with the risks of avascular necrosis (AVN) and chondrolysis.

The proximal femoral physis and epiphysis are located within the hip capsule. Although the proximal physis provides length and shape to the femoral neck, most SCFEs occur in adolescence, when little growth remains at this growth plate. The blood supply to the proximal femoral epiphysis comes from the medial femoral circumflex artery, which travels along the femoral neck. From the circumflex arise the lateral epiphyseal vessels, which enter the epiphysis posterosuperiorly. Small contributions come from the vessels of the round ligament and the posterior inferior epiphyseal vessels off the medial femoral circumflex artery. Injury to this tenuous capsular blood supply can result in osteonecrosis.

In SCFE, the epiphysis stays within the acetabulum while the neck and distal femur slip (most commonly into extension and varus).

SCFE occurs more commonly in boys than girls (60% of patients are boys). Most patients (up to 75%) are adolescents (boys 13.5 years, girls 12.0 years on average). Most patients are obese and in the 90th to 95th weight percentile for age. SCFE occurs bilaterally in about 25% of patients.

Biochemical factors likely play a role. Hormonal changes that occur during adolescent growth influence the strength of the physis.

Biomechanical factors also likely play a role. The physis in SCFE is subjected to higher shear force. The physis is more oblique during adolescence and in obese children; both factors increase shear in normal activities. The proximal femur is relatively retroverted in many cases of SCFE, which also increases the shear force on the physis. The reinforcing perichondral ring of the proximal physis also weakens with age until growth plate closure.

If the physis of a SCFE patient is studied histologically, it will look widened, with abnormal chondrocyte maturation and endochondral ossification. The slip occurs mainly through the hypertrophic zone of the physis.

Patients under age 10 years should be evaluated for an underlying endocrine abnormality, including hypothyroidism, renal osteodystrophy, and panhypopituitarism.

The natural history of untreated SCFE and the ultimate outcome are difficult to predict, although it is widely accepted in adult reconstructive circles that most cases of degenerative hip arthritis are secondary to an underlying structural cause, such as SCFE. The risk of progression exists while the physis remains open. The slip severity increases with the duration of symptoms.

The development of degenerative joint disease is related to the severity of the slip.

Physical examination methods include the following:

- The resting position of the knee and foot is observed with the patient lying supine and it is compared to the other side. Excessive external rotation is a result of the slip.
- Hip range of motion (ROM) between affected and normal sides (for stable SCFE only) is compared. Because of slip, the affected side has decreased flexion, abduction, and internal rotation of the hip. There may be guarding with ROM.
- In SCFE that presents with knee pain, passive knee ROM is normal and effusion is absent.
- In stable SCFE, the patient has an antalgic gait. The foot may be externally rotated. In unstable SCFE, the patient is unable to bear weight at all on the affected side.
- Patients complain of hip or groin pain, thigh pain, or knee pain, which may be exertional and usually occurs without a history of trauma.
- The patient may have a limp (stable slip) or frank inability to bear weight (unstable slip).
- Examination of the hip can reveal an externally rotated foot and knee, guarding of the hip with ROM, and decreased flexion and internal rotation of the hip.
- Findings on the knee examination are normal.

Plain radiographs of the pelvis, including anteroposterior (AP) and frog-leg lateral views, should be obtained in any pediatric patient with hip, thigh, or knee pain.

A widened physis on AP or lateral views can be an early sign of SCFE.

The Klein line, which can demonstrate SCFE, is drawn along the neck of the femur, superiorly on the AP view. In a
normal hip, this line should intersect the epiphysis, but in SCFE it will not cross the epiphysis (FIG 1).
- The metaphyseal blanch sign of Steel is a crescent-shaped double density along the medial femoral neck where the slipped epiphysis overlaps the metaphysis on the radiograph.
- Images of the contralateral hip should be scrutinized for evidence of bilateral SCFE. If present, both sides should be treated.
- The severity of a SCFE can be described by displacement relative to the width of the metaphysis:
  - Mild: Less than one-third the width
  - Moderate: One-third to half the width
  - Severe: More than half the width
- Another method of describing slip severity is measuring the difference between the epiphyseal shaft angle on each side:
  - Mild: Less than 30 degrees
  - Moderate: 30 to 50 degrees
  - Severe: 50 degrees or greater
- If the patient is under 10 years of age, underlying endocrine abnormalities should be investigated with laboratory studies, including thyroid function tests and basic chemistries.

**DIFFERENTIAL DIAGNOSIS**
- SCFE
- Legg-Perthes disease
- Hip labral tear
- Femoral neck stress fracture
- Septic arthritis of the hip
- Knee derangement
- Greater trochanteric bursitis

**NONOPERATIVE MANAGEMENT**
- Immobilization in a spica cast was the historical treatment but is no longer recommended for SCFE.
- Once SCFE is identified in any patient with an open physis, management is surgical to avoid further slippage and the possible development of femoral head AVN.

**SURGICAL MANAGEMENT**
- When SCFE is identified in a patient with an open physis, surgical management with percutaneous in situ cannulated screw fixation should be undertaken on an urgent basis if the slip is stable or on an emergent basis if unstable. There is a fair amount of evidence that the risk of AVN in unstable SCFE can be reduced if the hip is decompressed in some manner within 24 hours.
- Before surgery, the patient should remain strictly non-weight bearing on the affected leg.
- In unstable SCFE, reduction of the displacement is controversial. Reduction has been associated with osteonecrosis, but the unstable slip itself may be the more likely cause of osteonecrosis.
  - Because of the risk of contralateral slip, prophylactic pinning of the contralateral hip should be considered and discussed with the patient and family, especially if the patient is under age 10 or has an endocrine abnormality.

**Preoperative Planning**
- All imaging studies are reviewed. The plain films of the contralateral hip should be scrutinized for evidence of early or clinically silent slip.
- Laboratory studies should be reviewed in patients under 10 years of age.

**Positioning**
- We place the patient supine on the radiolucent OR table with the entire affected leg prepared and draped free to the umbilicus. The ipsilateral arm is padded and positioned across the chest.
- The fluoroscopy monitor is placed at the patient’s head and the C-arm unit is positioned for AP views of the hip from the contralateral side of the operating table. The hip is flexed 90 degrees and abducted 45 degrees to obtain lateral views. Not using a fracture table allows multiple views to be sure that the guide pin and the bone screws do not penetrate the femoral head.
- Some surgeons prefer to perform in situ screw fixation on a fracture table.

**Approach**
- In situ cannulated screw fixation of SCFE involves placement of the guidewire into the central third of the epiphysis perpendicular to the physis. This is followed by drilling and placement of the screw over the guidewire. Some screws are self-tapping and self-drilling.
- Careful examination of spot fluoroscopy images ensures that the screw tip is within the femoral head, as detailed in the Techniques section.
GUIDEWIRE PLACEMENT

- The goal of guidewire placement is to place the tip of the wire perpendicular to the physis in the middle third of the epiphysis, about 3 mm from the subchondral bone. Spacing of the screw threads can be measured (usually 1 mm) and compared on the image intensification screen as a ruler. For the most common SCFE (varus slip), the starting point is on the anterior neck to place the wire properly in the middle of the epiphysis.

Determining the Course of the Guidewire

- Under image guidance (AP view with the image machine placed vertical), the hip is internally and externally rotated until the neck appears to be its longest. At this position of rotation, the femoral neck is horizontal to the operating table and perpendicular to the image beam (TECH FIG 1A).
- A guidewire is placed on the anterior hip and image intensification is used to align the point of the wire over the center of the femoral head. The guidewire is then aligned along the neck (TECH FIG 1B). The skin is marked at the tip to identify the position of the center of the femoral head.
- The marker then follows the guidewire laterally to the lateral aspect of the femur. This line represents the course along which the guide pin for the bone screw will follow in the AP image (TECH FIG 1C). The marked line is drawn with a pen (TECH FIG 1D).

Determining the Entry Point Along the Femoral Neck

- While we know that the femoral neck is following this marked line, the position of the femoral head in the sagittal plane is determined by flexing the hip 90 degrees and abducting the hip 45 degrees. A line is drawn on the image as a diameter of the femoral head, and then a line is drawn perpendicular to the diameter at its center representing the desired path of the bone screw in the sagittal plane (TECH FIG 2A). The angle this line makes with the femoral neck tells the position of the femoral head with respect to the end of the femoral neck. The position this line crosses the femoral neck line also defines the entry point for the guide pin along the femoral neck (TECH FIG 2B,C). The degree of slip of the epiphysis posteriorly with respect to the neck is estimated.
- Having taken the steps above, the surgeon has now determined how to make the femoral neck horizontal to the operating table and perpendicular to the image beam and has determined the angle that the femoral head is with respect to the end of the femoral neck and the entry point on the anterolateral neck for the guide pin and screw.

Determining the Skin Entry Site

- The final issue for the surgeon to determine is where to enter the skin. The skin is like a circle around the hip. The

TECH FIG 1 • Patient is supine on the operating table. A. The image intensifier is set for an AP view and an image is obtained. The hip to be operated on is rotated internally and externally until the length of the neck appears longest. The femoral neck is now horizontal. This position is maintained. B. A long guidewire is placed on the patient at the hip with the point centered on the center of the femoral head and the guidewire over the center of the neck. C. This is confirmed with an image view. D. An OR pen is used to mark the skin with this line. The femoral shaft is palpated laterally on this line; this point is marked as 0 degrees. The point over the femoral head is marked as 90 degrees. (A,C: Copyright Richard S. Davidson, MD.)
Mark for the center of the femoral head is at 90 degrees and the lateral (palpable) femoral shaft is at 0 degrees (TECH FIG 3A). If the head–neck angle measured is, for example, 30 degrees, the entry point on the skin should be 30 degrees from the lateral palpable femoral shaft toward the femoral head.

Helpful hint: This position can be obtained by taking a length of suture that goes from the femoral head mark to the lateral femur mark (representing 90 degrees) and dividing it into thirds (30 degrees). The surgeon then measures from the lateral femoral shaft (0-degree mark) toward the head along the drawn line.

Tech FIG 2 • The hip is flexed 90 degrees and abducted 45 degrees. A. An AP image is obtained. B. The image shows the femoral neck and the displaced femoral head. C. The neck-to-head angle is measured, and the point at which a line through the center of the head and perpendicular to the physis intersects the neck is noted. This is the entry point for the guide pin and bone screw. (A: Copyright Richard S. Davidson, MD.)

Tech FIG 3 • A. The hip is then returned to the “neck horizontal” position. B. A 1-cm incision is made along the drawn line at the number of degrees from the lateral femur (0 degrees). The fascia is spread with a clamp. C. The guide pin is inserted into this incision along the marked line but at the measured neck–head angle. The level of insertion at the neck is at the point observed in Techniques Figure 2C. (C: Copyright Richard S. Davidson, MD.)
A 1-cm incision is made through skin and spread with a hemostat down to bone along the drawn line, but at an angle of 30 degrees toward the horizontal (ie, the head–neck angle) (Tech Fig 3B).

The guide pin should enter the incision in line with the drawn line and at an angle of 30 degrees to the horizontal (Tech Fig 3C). The point of the guide pin should be positioned on the anterolateral femoral neck where the entry was estimated above.

**Inserting the Guidewire**

- The guide pin is drilled into the femoral neck to the mid-neck and then additional image views are taken to confirm and fine-tune the position. When satisfactory, the guide pin is drilled to within 3 mm of the articular surface and measured, and a bone screw is chosen. Multiple image views should confirm the guide pin position before inserting the bone screw to avoid stress risers from too many holes in the bone.
  - Helpful hint: The surgeon can rotate the hip to prevent bending of the guide pin while flexing to get multiple views.
  - The chosen bone screw is inserted to within 3 mm of the articular surface.
  - Helpful hint: If the end of the guide pin is threaded, the bone screw may advance the guide pin through the articular surface. The hip must not be moved because of the risk of breaking off the end of the guide pin in the hip joint. Instead, the surgeon can retract the guide pin partially into the bone screw and then continue to advance the bone screw to the appropriate position. Again, multiple views are obtained to ensure that the bone screw does not penetrate the articular surface.

**Drilling and Cannulated Screw Placement**

- The guidewire is measured with the cannulated depth gauge to determine desired screw length.
- The cannulated drill is drilled over the guidewire. Care is taken to keep the drill colinear with the guidewire to avoid binding. The drill should stop 1 or 2 mm before the tip of the guidewire to keep the guidewire in place.
- The bone is tapped with the cannulated tap over the guidewire.
- The 6.5- to 7.5-mm cannulated screw is placed over the guidewire.
- The guidewire is removed.

**Radiographic Evaluation**

- Radiographic evaluation (Tech Fig 4) ensures good screw position to minimize risk of complications.
- Spot fluoroscopic AP and frog-leg lateral views are used to make sure that four or five threads of the screw are within the epiphysis to decrease the risk of slip progression.
- The approach-and-withdraw technique allows evaluation of the screw tip to ensure that it remains within the femoral head. With live fluoroscopy, the hip is ranged from internal to external rotation at varying degrees of flexion and the screw tip is observed to approach and withdraw from the subchondral bone. The closest point is observed and the screw should remain within the femoral head.9

---

**Tech Fig 4** Radiographic evaluation of the threads across the physis on the AP (A) and frog-leg lateral (B) views. (Copyright Richard S. Davidson, MD.)
PEARLS AND PITFALLS

Guidewire placement
- In general, the larger the slip, the more proximal the starting point along the anterior neck.
- The guidewire should be placed into the center of the epiphysis parallel to the physis to obtain maximum fixation, like the handle of an umbrella.

Guidewire bending
- When the hip is moved from resting position to frog-leg lateral position or back again, the quadriceps fascia must be meticulously retracted to prevent guidewire bending.

Guidewire pullout
- Drilling should stop 1 to 2 mm before the end of the guidewire to keep it seated in bone. The surgeon should check spot fluoroscopy as the drill is backed out to make sure the guidewire remains in place.
- The guidewire should be gently tapped back into place if it begins to pull out.

Guidewire binding
- During drilling, tapping, or screw placement, the instrument can bind the guidewire and cause unwanted advancement of the guidewire.
- The cannulated instrument must remain perfectly colinear with the guidewire.
- The surgeon should check spot fluoroscopy to make sure the guidewire is not advancing.

POSTOPERATIVE CARE
- No immobilization in recommended. Patients should remain non-weight bearing or touch-down weight bearing on crutches on the affected leg for about 6 weeks to allow healing.
- Patients are gradually allowed to return to activities after 6 weeks.
- If the SCFE and fixation were unilateral, patients and families must be made aware of symptoms to watch for that could indicate slipping in the other hip, like hip, thigh, or knee pain.
- Patients should be followed at regular intervals until the proximal femoral physis closes completely on radiographs.

OUTCOMES
- Outcomes of SCFE treatment are related to the severity of slip and the development of complications. The best long-term results are seen with in situ screw fixation. In patients with mild and moderate SCFE treated with in situ screw fixation, results are good to excellent.

COMPLICATIONS
- Chondrolysis is articular cartilage necrosis of the femoral head that causes hip pain and limited motion.
  - It has been associated with SCFE and its treatment, and the incidence has decreased with modern treatment techniques of in situ screw fixation.
  - Risk factors include unrecognized pin or screw penetration, spica cast treatment, more severe slips, and female sex. The joint space appears narrowed to less than 3 mm on radiographs, and treatment involves revision of prominent hardware, limited weight bearing until symptoms improve, physical therapy, and nonsteroidal anti-inflammatories.
- Overall, patients may have cartilage recovery and good midterm functional outcomes.
  - Osteonecrosis is a difficult and often debilitating complication associated with SCFE and its treatment. It involves the death and possible collapse of the epiphysis because of disruption of its blood supply. Patients present with groin, thigh, or knee pain and limited hip motion.
  - Risk factors for osteonecrosis are unstable SCFE, pins in the posterosuperior quadrant of the epiphysis, an increased number of pins, and severe displacement. A stable slip has a nearly 0% risk of osteonecrosis, but an unstable slip has a 50% risk of osteonecrosis.
  - Treatment involves removal of prominent hardware if the physis has closed, limited weight bearing until healing, symptomatic management, and later reconstructive procedures.
  - Further slippage after in situ fixation occurs most frequently with improper screw placement outside of the desired middle third of the epiphysis and insufficient thread purchase into the epiphysis.

REFERENCES

FIG 2 • Osteonecrosis and collapse of the femoral head in a severe case of slipped capital femoral epiphysis. The in situ fixation had become prominent and has been removed. (Copyright Richard S. Davidson, MD.)
DEFINITION
- Pistol-grip deformity after slipped capital femoral epiphysis (SCFE) can cause anterior impingement leading to pain, cartilage and labral damage, and eventual osteoarthritis.1–3,8
- Realignment of the proximal femur, as well as restoration of the anterior head–neck offset, has been shown to improve hip scores.6
- This technique can be used to correct anterior impingement after a SCFE that has healed with residual posterior displacement.
- The first part of the procedure is a surgical hip dislocation with femoral head–neck osteoplasty.
- If additional deformity correction is needed, the flexion intertrochanteric osteotomy is performed.

PATHOGENESIS
- The true etiology of SCFE is unclear. However, because it occurs mainly in adolescent boys (80%), hormonal factors are thought to be involved.7
- Additionally, the orientation of the growth plate becomes more vertical in adolescents compared to the juvenile hip, leading to increased shear stress across the physis.
- The transition from juvenile to adolescent is a period of rapid weight gain, leading to the stereotypical body habitus in the SCFE patient.

NATURAL HISTORY
- Undetected SCFEs can lead to hip arthrosis. Murray suggested that up to 40% of hips with degenerative arthritis have a “tilt deformity” or other deformities that may be due to an undetected subclinical SCFE or other developmental problems.
- A review by Aronson found that 15% to 20% of patients with SCFE had painful osteoarthritis by age 50. Additionally, 11% of patients with end-stage osteoarthritis had a SCFE.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients will complain of insidious-onset groin or knee pain that may have previously been diagnosed as a sprain.
- They may walk with a limp, but typically they walk with an externally rotated foot progression angle, which may indicate chronic SCFE or femoral retroversion.
- Pain is elicited with hip flexion, adduction, and internal rotation stress (impingement test).
- The physical examination should include flexion and internal rotation range-of-motion tests. Normal, physiologic hip flexion needed for activities of daily living is at least 90 degrees.
- Patients with a chronic SCFE and anterior impingement will have less than 90 degrees of true hip flexion.
- Patients with impingement secondary to SCFE will have less internal rotation in flexion than extension, and may have a compensatory external rotation of the hip as it is flexed.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs include an anteroposterior (AP) and frog-leg lateral views of the pelvis or the involved hip (FIG 1A,B).
- Computed tomography (CT) scans with two- and three-dimensional reconstructions are helpful for preoperative planning (FIG 1C,D).

DIFFERENTIAL DIAGNOSIS
- Femoral or acetabular retroversion
- Hip dysplasia

NONOPERATIVE MANAGEMENT
- Nonoperative management includes cessation of aggravating activities and symptomatic treatment using nonsteroidal anti-inflammatories.
- Physical therapy to strengthen the hip musculature does not address the mechanical impingement associated with a SCFE.

SURGICAL MANAGEMENT
- A chronic slip may be pinned in situ to prevent continued slippage. Remodeling of the SCFE deformity has been described in long-term follow-up studies.
Corrective osteotomies have been described through the femoral neck at the growth plate (cuneiform), at the base of the femoral neck, or subtrochanteric.

Preoperative Planning

The anterior head–shaft angle is measured on the AP pelvis radiograph on both the affected and normal sides. The difference is the amount of varus deformity on the slip side that can be addressed with a valgus-producing intertrochanteric osteotomy (FIG 2A).

The lateral head–shaft angle is measured on the frog-leg lateral view in a manner similar to that used on the AP view. The difference is the amount of posterior deformity present that is corrected with a flexion-producing intertrochanteric osteotomy (FIG 2B).

Positioning

Because the first part of the procedure is done through a surgical hip dislocation, the patient is placed in the full lateral position secured on a pegboard, as shown in Chapter PE-76, Figure 3. A flat-top cushion placed beneath the operative side is helpful to stabilize the leg during the approach.

A hip drape with a sterile side bag is used, which will capture the leg during the dislocation maneuver.

Approach

The incision from the surgical hip dislocation is extended slightly distal, along the lateral aspect of the thigh, in line with the femoral shaft.

The lateral approach to the proximal third of the femur is required for the intertrochanteric osteotomy.

The longitudinal incision from the surgical hip dislocation can be extended distally, in line with the lateral shaft of the femur (TECH FIG 1A).

The vastus lateralis, supplied by the femoral nerve, is reflected anteriorly from the vastus ridge distally.

Several perforating vessels from the profunda femoris artery to the vastus lateralis should be identified and coagulated before they are avulsed by blunt dissection (TECH FIG 1B).

The anterolateral aspect of the femoral shaft is then exposed subperiosteally, and the lesser trochanter is identified.
Chapter 80  FLEXION INTERTROCHANTERIC OSTEOTOMY FOR SEVERE SCFE

**TECH FIG 1**  •  **A.** The proposed incision after the patient is prepared and draped. **B.** Approach to the intertrochanteric region of the femur. The vastus lateralis is reflected anteriorly from its origin at the vastus ridge.

**PLANNING THE OSTEOTOMY**

- A 2-0 Kirschner wire is placed just above the level of the lesser trochanter, beginning in the lateral cortex of the proximal femur. This is placed parallel to the floor in the axial plane and perpendicular to the shaft of the femur in the coronal plane. This is the reference for the level of the osteotomy.

- A second Kirschner wire is placed 3 cm proximal to the first. This is placed parallel to the first guidewire in the axial plane. In the coronal plane, the Kirschner wire is placed with an appropriate amount of valgus, determined from the anterior head-shaft angle difference on preoperative radiographs. This will act as the guidewire for the seating chisel for the blade plate.

**CREATING THE SLOT FOR THE BLADE PLATE**

- The seating chisel is directed parallel to the most proximal guide pin with the appropriate amount of flexion, as determined on the frog-leg lateral head-shaft angle difference.

- A slot for the blade plate should now be made in the trochanteric fragment to allow for anatomic fixation of the trochanter after the osteotomy.

- The blade plate chisel is placed into the proximal fragment after preparation of the trochanteric flip fragment and before cutting the intertrochanteric osteotomy (**TECH FIG 2**).

**OSTEOTOMY**

- Before osteotomy, a rotational reference mark is made at the level of the osteotomy on both the proximal and distal fragments.

- Using an oscillating saw, the proximal femur is cut using the Kirschner wire as a guide. The cut should be made perpendicular to the shaft of the femur.
POSTOPERATIVE CARE

- The hip is held flexed and in neutral rotation by placing two pillows under the leg and one under the greater trochanter.
- The patient is placed in a continuous passive motion machine for 6 hours a day, set from 30 to 80 degrees of flexion.
- Prophylaxis for deep venous thrombosis is individualized; however, all patients should be started on mechanical compression devices immediately.
- After the epidural is removed, out-of-bed ambulation is permitted with one-sixth body weight partial weight bearing.
- Range-of-motion exercises are started, but care is taken to protect the greater trochanter osteotomy by limiting adduction to midline, and avoiding resisted abduction exercises for 6 weeks.
- AP and true lateral hip radiographs are obtained to evaluate healing of the osteotomy (FIG 3A,B).
- Prominent hardware may be removed after 6 months if radiographic evidence of a healed osteotomy is seen (FIG 3C,D).

OUTCOMES

- In Southwick’s original article, where he treated the deformity with a proximal femoral osteotomy without surgical hip dislocation, out of 28 hips (26 patients) with at least 5 years of follow-up, 21 were rated as excellent, 5 as good, and 2 as fair.
In patients who had both osteoplasty and an intertrochanteric osteotomy, Western Ontario and McMaster Universities (WOMAC) pain and function scores improved in four of six patients. In patients who had both osteoplasty and an intertrochanteric osteotomy, Western Ontario and McMaster Universities (WOMAC) pain and function scores improved in four of six patients.

Internal rotation in flexion improved from −20 to +10 degrees.

There were no cases of avascular necrosis in a series of 19 patients treated with osteoplasty or osteoplasty with intertrochanteric osteotomy.

### COMPLICATIONS

- Avascular necrosis of the femoral head can occur if care is not taken to follow the technique and to preserve the retinacular vessels.
- Nonunion of the greater trochanteric osteotomy or the intertrochanteric osteotomy
- Sciatic or femoral nerve neurapraxia
- Heterotopic ossification

### REFERENCES

DEFINITION

- Triple arthrodesis involves fusion of the talocalcaneal, calcaneocuboid, and talonavicular joints. The procedure is most commonly indicated for salvage in severe, rigid deformities of the hindfoot that are unresponsive to less invasive methods of treatment.
- This procedure is typically considered in adolescents but has been reported in children as young as 8 years of age.

ANATOMY

- Joints of the hindfoot include the ankle, subtalar, talonavicular, and calcaneocuboid.
- Motions at the ankle joint include plantarflexion and dorsiflexion. As the ankle joint is oriented along the transmalleolar axis, dorsiflexion is associated with outward deviation of the foot, while plantarflexion is associated with inward deviation.
- The subtalar joint consists of an anterior, a middle, and a posterior facet. The anterior and middle facets are confluent in a subset of patients. While there is considerable variation, this joint is oriented 23 degrees medially in the transverse plane and 42 degrees dorsally in the sagittal plane. The subtalar joint thus functions as a hinge along an inclined axis and serves as the linkage between the ankle and the distal articulations of the foot. During the gait cycle, the subtalar joint is everted at heel strike and then inverts progressively until the time of push-off.
- The talonavicular and calcaneocuboid joints are known as the transverse tarsal joints. When the calcaneus is everted, these joints become parallel, and there is greater flexibility at the articulation. This aids in shock absorption during initial contact and early stance phase. In contrast, the transverse tarsal joints become nonparallel (more rigid) when the calcaneus is inverted. Functionally, the calcaneus becomes inverted during late stance phase, which locks the transverse tarsal joints and provides a rigid lever for push-off.
- From a functional standpoint, the muscles crossing the ankle and subtalar joints may be classified based on their location with respect to each joint axis. There is plantarflexion (gastrocnemius and soleus, tibialis posterior, flexor digitorum longus, flexor hallucis longus) and dorsiflexion (tibialis anterior, extensor digitorum longus, extensor hallucis longus) at the ankle. The movements of inversion (tibialis anterior and posterior, flexor digitorum longus, flexor hallucis longus) and eversion (peroneus longus, brevis, tertiarius, extensor digitorum longus, extensor hallucis longus) occur across the subtalar axis.

PATHOGENESIS

- Foot deformities in children most frequently result from a congenital condition (clubfoot, vertical talus, tarsal coalition) or occur in association with a variety of neuromuscular diseases. In the latter, the cause involves muscle weakness or imbalance, and examples include either flaccid or spastic neuromuscular dys-function (cerebral palsy, poliomyelitis, myelomeningocele, hereditary motor and sensory neuropathies, other).
- The most common deformities are equinovarus, equinovarus, and cavovarus. Calcaneovalgus, calcaneovalgus, calcaneovarus, and equinocavus may also be seen. This spectrum of deformities may result from soft tissue contractures, from bony malalignment, or from both.
- While some deformities have a structural component at birth, most develop gradually, are initially flexible, and become fixed or rigid only over time. While a loss of passive motion may result from contracture of the soft tissue elements, progressive adaptive changes in the osteocartilaginous structures subsequently result in fixed bony malalignment.
- The equinovarus deformity is present at birth in a congenital clubfoot, or may result from spastic muscle imbalance in patients with cerebral palsy (most often spastic hemiplegia) or flaccid muscle imbalance (poliomyelitis). While the cause of congenital clubfoot remains debated, and is most likely multifactorial, the pathogenesis in neuromuscular diseases involves muscle imbalance (strong inversion–plantarflexion and weak eversion–dorsiflexion).
- An equinovarus deformity is most common in patients with a congenital vertical talus or cerebral palsy (most commonly spastic diplegia). A valgus deformity of the hindfoot is common in patients with a tarsal coalition.
- The cavovarus foot is most common in the hereditary motor and sensory neuropathies (Charcot-Marie-Tooth disease) and results from muscle imbalance. Weakness of the tibialis anterior (relative to the peroneus longus) is associated with plantarflexion of the first ray (forefoot valgus), a deformity that is initially flexible.
  - Over time, a contracture of the plantar fascia and neighboring intrinsic muscle groups develops. To compensate for forefoot valgus, the hindfoot aligns in varus during stance phase.
  - Both the forefoot valgus and the hindfoot varus eventually become rigid. The hindfoot also appears to be in equinus because of plantarflexion of the midfoot on the hindfoot. A common mistake is to assume that the equinus occurs at the ankle and to perform an Achilles tendon lengthening.

NATURAL HISTORY

- The natural history depends on the underlying disease process.
- Deformities associated with the neuromuscular diseases will usually progress (and become rigid) over time and will have a significant chance of recurrence despite treatment owing to the underlying disease process.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients present with an abnormality or change in appearance of the foot, gait disturbance, pain in the region of the hindfoot, difficulties with shoe wear, or more than one of these. While the deformities treated by triple arthrodesis may be diagnosed from birth to adolescence and have
often been treated previously, we will focus on the older child or adolescent.

- The history focuses on the presence of symptoms, including functional limitations, cosmetic concerns, and shoe wear, the family history (similar deformities, neuromuscular diseases), and previous treatment.
- A detailed history is especially important in children of walking age, as a foot deformity may be the first clue to the presence of an underlying neuromuscular problem. While unilateral foot deformities may be seen with tethering of the spinal cord (or other problems such as a spinal cord tumor), bilateral deformities may be the initial finding in patients with a hereditary motor and sensory neuropathy.
- The location and character of pain should be determined, in addition to the activities that produce discomfort.
- A comprehensive physical examination is required. The spine should be examined to rule out any deformity or evidence of an underlying dysraphic condition, and a careful neurologic examination should be performed. The extremities are evaluated for alignment, limb lengths, and range of motion. Observational gait analysis should be performed. The shoes should be inspected for patterns of wear, which indicate weight distribution during stance phase.
- The physical examination of the foot and ankle focuses on the skin (presence and location of callosities, points of tenderness), the overall appearance in both the weight-bearing and non-weight-bearing positions (relationship between the forefoot and hindfoot), the range of motion of the hindfoot joints, the relationship between the forefoot and the hindfoot, and the neuromuscular assessment.
- Tests to perform during the physical examination include:
  - Range of motion at the ankle joint (plantarflexion and dorsiflexion) to diagnose and determine the magnitude of equinus contracture
  - Range of motion at the subtalar joint (inversion and eversion), which quantifies motion at the subtalar joint. Generally, the amount of inversion is twice the amount of eversion. The total range is 20 to 60 degrees.
  - Range of motion at the transverse tarsal joints
  - Relationship between forefoot and hindfoot alignment, which identifies any coexisting deformity of the forefoot, either varus (the lateral aspect of the forefoot axis is more plantarflexed than the medial aspect) or valgus (medial aspect of the forefoot axis is more plantarflexed than the lateral forefoot axis)
  - Coleman block test, which determines if hindfoot varus is flexible or rigid
  - Manual muscle testing, which assesses relative strengths of motor units across the ankle and subtalar joints. This helps to diagnose muscle imbalance and to plan tendon transfers if appropriate.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Imaging studies complement the history and physical examination, and plain radiographs in a weight-bearing position are required in all cases. In addition to a standing anteroposterior (AP) and lateral radiograph of the foot, a standing AP of the ankle should be obtained to determine whether the deformity is in the ankle joint, the subtalar joint, or both locations. Other imaging modalities such as a CT scan or MRI may be required in selected cases.
- Plain radiographs are used to evaluate bone and joint morphology, and measuring the angular relationships between the tarsal bones (or segments of the foot) helps to further define both the location and the magnitude of deformities.
- On the standing AP radiograph, measurements include the talocalcaneal (Kite) angle (10 to 36 degrees) and the talus–first metatarsal angle (range –10 to +30 degrees). For the AP talocalcaneal angle, values less than 20 degrees suggest hindfoot varus, while an angle greater than 40 to 50 degrees suggests hindfoot valgus. For the talo–first metatarsal angle, values less than –10 degrees indicate forefoot varus and values greater than +30 degrees indicate forefoot valgus.
- On the standing lateral radiograph of the foot, measurements include the lateral talocalcaneal angle, the tibiotalocalcaneal angle, and the talus–first metatarsal angle.
- For the lateral talocalcaneal angle (range 25 to 55 degrees), values greater than 55 degrees indicate hindfoot valgus or calcaneus, while values less than 25 to 30 degrees indicate hindfoot varus or equinus deformities.
- For the tibiotalocalcaneal angle (55 to 95 degrees), values greater than 95 degrees suggest equinus, while those below 55 degrees are suggestive of calcaneus.
- For the talus–first metatarsal angle, or Meara angle (0 to 20 degrees), values greater than 20 degrees indicate midfoot equinus (cavus), while values less than 0 degrees indicate midfoot dorsiflexion (midfoot break).
- The angle of the calcaneus relative to the horizontal axis (calcaneal pitch) is increased with calcaneus or calcaneo-cavus, or with cavovarus deformities.

**DIFFERENTIAL DIAGNOSIS**

- Equinovarus: congenital clubfoot, poliomyelitis or other flaccid weakness or paralysis, spastic hemiplegia, other
- Equinovarus: congenital vertical talus, spastic diplegia or quadriplegia, tarsal coalition, flexible flatfoot with tight Achilles tendon, other
- Cavovarus: hereditary motor and sensory neuropathies, poliomyelitis or other flaccid weakness or paralysis, myelomeningocele, other

**NONOPERATIVE MANAGEMENT**

- The goals of nonoperative treatment are to achieve correction, to maintain correction, and to prevent recurrence of the deformity. The specific treatments are based on the underlying disease process, and options include physical therapy, injection of botulinum A toxin, serial casting, and orthoses.
- Physical therapy is directed toward improving range of motion and improving strength.
- Serial casting may help to improve range of motion.
- Botulinum toxin injections result in a reversible chemical denervation of the muscle group (for 3 to 8 months) and have been used most frequently in patients with cerebral palsy to decrease spasticity and reduce dynamic muscle imbalance. Such treatment may prevent or delay the need for surgical intervention in patients with spastic equinovarus or equinovalgus.
- Orthoses may be used to maintain alignment during ambulation, or as a nighttime splint to prevent the development of...
contractures. The deformity should ideally be passively correctable. Foot orthoses such as the UCBL may help to control varus–valgus alignment of the hindfoot during ambulation. An ankle–foot orthosis improves prepositioning of the foot during swing phase, provides stability during stance phase, and can be used as a night splint.

**SURGICAL MANAGEMENT**

- Surgical treatment is offered when nonoperative measures have failed to alleviate the symptoms. Triple arthrodesis is a salvage procedure or “last resort” for rigid deformities in older patients, many of whom have been previously treated by both nonoperative and operative strategies.
- The procedure is often performed for the correction of rigid deformities, which typically requires removal of bony wedges. As such, careful preoperative planning is required to determine the appropriate size and location of these wedges. Triple arthrodesis shortens the foot, which may be cosmetically objectionable.
- Arthrodesis transfers additional stresses to neighboring joints, which may result in degenerative changes and pain. While there are reports of the procedure being successful in children as young as 8 years, it has been suggested that surgery should be delayed until the foot has reached adult proportions. One recent study concluded that growth rates were no different in those children treated before or after 11 years of age.
- The deformity should be of sufficient severity that soft tissue releases and osteotomies would be unlikely to achieve correction, or when painful degenerative changes are observed in the joints of the hindfoot. The most common indications are recurrent or neglected (most commonly seen in developing nations) clubfoot, cavovarus associated with Charcot-Marie-Tooth disease, and severe equinovalgus deformities in patients with spastic diplegia.
- The goal of surgery is to achieve a plantigrade foot by restoring the anatomic relationships between the affected bones or regions of the foot, and to relieve pain.
- Additional procedures may be required. An equinus deformity of the ankle will require a lengthening of the tendo Achilles at the time of triple arthrodesis. The treatment of a coexisting forefoot may require soft tissue release, tendon transfer, or osteotomy, or some combination of these (usually as another stage). In patients with neuromuscular diseases, lengthening or transfer of tendons crossing the hindfoot may be required to restore muscle balance and prevent further deformity. Recurrence of deformity may occur when coexisting muscle imbalance has not been treated.³,15
- A hindfoot arthrodesis should be avoided in patients with insensate feet (myelomeningocele, other).
- While triple arthrodesis is routinely performed without fixation (or with minimal fixation such as Kirschner wires or staples) in many parts of the world, fixation with staples or screws reduces the chances of correction loss and pseudarthrosis.
- Biomechanical studies have demonstrated no significant difference in stability when comparing fixation with staples versus cannulated screws.⁸,⁹

**Preoperative Planning**

- Weight-bearing radiographs are used to evaluate the relationships between the tarsal bones, to identify any morphologic abnormalities or degenerative changes, and to identify the location of the deformity. These radiographs help to plan the location of wedge resections.

**Positioning**

- The patient is placed supine, and a bump may be placed under the ipsilateral hip.
- A tourniquet is applied around the thigh.

**Approach**

- Several skin incisions have been described for triple arthrodesis, and the specific choice may depend on the type of deformity and the previous experience of the surgeon. These include the single lateral or anterolateral approach, the medial approach, and a combined lateral and medial approach.
- The lateral approach (Ollier) is used most commonly and allows excellent visualization of all three joints (FIG 1).
- A medial approach may be useful for calcaneovalgus foot, and the Lambrinudi procedure is considered for severe equinus deformity. The articular surfaces of the talonavicular, calcaneocuboid, and subtalar joints are removed to achieve arthrodesis.
- Modifications of this basic technique are based on the underlying deformity and involve bony wedge resections to correct specific components of the deformity.

---

FIG 1 • The lateral approach is used most frequently. **A.** The skin incision extends from distal to the fibular malleolus across the sinus tarsi. **B.** All three joints can be visualized after dissection of the subcutaneous tissues, elevation of the extensor digitorum brevis off the anterior process of the calcaneus, and opening of the joint capsules. **C.** Placement of a laminar spreader may facilitate visualization of the posterior facet of the subtalar joint.
Chapter 81  TRIPLE ARTHRODESIS

PENNY’S MODIFIED LAMBRINUDI TRIPLE ARTHRODESIS

- There are several unique features associated with the neglected clubfoot in adolescents that require special attention when performing a triple arthrodesis.5
  - A lengthening of the tendo Achilles is required and is performed as the first step.
  - The main components are hindfoot equinus and varus, midfoot cavus, and forefoot adduction.
  - In contrast to other hindfoot deformities, there is always significant obliquity of the calcaneocuboid joint, which requires a specially oriented lateral wedge excision of the calcaneocuboid joint.
  - The foot is typically severely plantarflexed, and this component of the deformity comes from both the hindfoot equinus and the midfoot cavus.
  - An aggressive resection of the talar head is commonly required to correct the midfoot cavus and bring the forepart of the foot to a plantigrade position.

Incision and Dissection

- The skin incision is started 1 cm distal to the tip of the fibula. It is curved dorsolaterally and extends to the lateral border of the talonavicular joint.
- After spreading the subcutaneous tissues, the extensor tendons are retracted medially and the peroneal tendons are mobilized and protected. The sural nerve is also identified and protected (TECH FIG 2).
- The extensor digitorum brevis is elevated off its origin and reflected distally, exposing the sinus tarsi, the calcaneocuboid joint, and the lateral aspect of the talonavicular joint.
- Soft tissues are cleared from the sinus tarsi, which promotes visualization of the facets of the subtalar joint. The anterior and middle facets will be confluent in a subset of cases.

Arthrodesis

- The first step of the procedure involves removing a lateral wedge (calcaneocuboid resection) to shorten the lateral border of the foot (TECH FIG 3A). One unique feature of the neglected clubfoot is the obliquity at the calcaneocuboid joint.
  - An osteotome or oscillating saw is used to make a transverse cut perpendicular to the long axis of the lower leg.
  - The second cut removes the joint surface of the cuboid and should be conservative (several millimeters). Most of this wedge resection comes from the calcaneus.
- The second step involves removing an anteriorly based wedge from the anterior process of the calcaneus to correct equinus of the forepart of the foot (TECH FIG 3B).
- The third step involves resecting a portion of the head and neck of the talus (TECH FIG 3C).
  - The cut begins at the dorsal articular margin of the talus and extends in a proximal and plantar direction through the posterior subtalar joint.

TECH FIG 1 • The bony segments are removed to correct the neglected clubfoot. Conservative resection is shown in blue and aggressive resection in red.

TECH FIG 2 • Lateral exposure. (From Penny JN. The neglected clubfoot. Tech Orthop 2005;7:19–24.)
This cut is oriented perpendicular to the long axis of the tibia. This essentially removes the entire talus head and a portion of the talus neck.

The fourth step involves a conservative resection of the articular surface of navicular, as well as removal of the tuberosity of the navicular.

A notch is made in the inferior articular surface of the navicular to accept the anterior portion of the talus.

With the surfaces of the talus and calcaneus apposed, the anterior end of the talus is pushed into the notch under the navicular while abducting the forefoot (TECH FIG 3D).

Fixation is usually achieved with Kirschner wires, staples, or screws (TECH FIG 3E).

The heel varus usually corrects spontaneously.

---

The incision begins 1 cm distal to the tip of the fibula; it curves dorsolaterally and extends to the lateral border of the talonavicular joint.

The extensor tendons are retracted medially, while the peroneal tendons are mobilized and protected. The extensor digitorum brevis is reflected distally, exposing the sinus tarsi, the calcaneocuboid joint, and the lateral aspect of the talonavicular joint.

The sinus tarsi is cleared of soft tissue to expose the anterior, middle, and posterior facets of the subtalar joints.

Sequential osteotomies are made with a broad osteotome or power saw (TECH FIG 4A).
The first osteotomy is made along the inferior part of the talus perpendicular to the long axis of the tibia in both planes. The second osteotomy is made along the superior part of the calcaneus parallel to the sole of the foot in both the longitudinal and transverse planes. The third cut is made at the distal end of the calcaneus at a right angle to the long axis of the calcaneus. The final cut is made along the proximal end of the cuboid at a right angle to the longitudinal axis of the forefoot.

A groove is fashioned in the inferior proximal part of the navicular to accept the anterior end of the talus. The osteotomized surfaces are approximated (TECH FIG 4B) and held with staples. The extensor digitorum is lightly sutured back into place, and the subcutaneous tissue and skin edges are reapproximated.

A 2-cm longitudinal incision is made over the peroneal tendons 10 cm above the level of the ankle joint, and both tendons are delivered using a mosquito clamp and divided sharply. An 8-cm medial longitudinal incision extends from the undersurface of the posterior medial malleolus across the talonavicular joint. The talonavicular joint is exposed, and the tibialis posterior tendon is released from its insertion. The talonavicular capsule is released. Flexor digitorum longus tendon, flexor hallucis tendon, and neurovascular bundle are protected by a retractor.

The talocalcaneal interosseous ligament is divided, and the anterior, middle, and posterior facets of the subtalar joint are visualized. The subtalar and talonavicular joint surfaces are denuded and prepared. The calcaneocuboid joint capsule and bifurcate ligaments are released sharply, and a lamina spreader is inserted to facilitate removal of the joint surfaces. Fixation of the subtalar joint is achieved with a single 6.5-mm cannulated screw from the posterior calcaneus into the talar body. The talonavicular and calcaneocuboid joints are realigned and stabilized with 5-mm cannulated screws.

A lateral approach is employed, as outlined above. Wedges to be removed are shown in TECHNIQUES FIGURE 5A. The articular cartilage of the subtalar and calcaneocuboid joints is denuded. The talar neck is osteotomized from inferior to superior, forming a beak superiorly. The soft tissue structures on the superior aspect of the talus anterior to the ankle are left undisturbed.

The dorsal cortex of the navicular is excised. The forefoot is displaced plantarward and the navicular is locked beneath the remaining part of the talar head and neck. Stability can be maintained while plaster is applied by slight upward pressure under the forefoot (TECH FIG 5B). A staple may be used for fixation.

TECH FIG 5 • Beak arthrodesis technique. A. Wedges to be removed. B. Final alignment after correction.
POSTOPERATIVE CARE
- The limb is typically immobilized in a short- or long-leg cast for at least 6 weeks, and weight bearing is permitted after 6 weeks.
- An ankle-foot orthosis may be required in patients with a neuromuscular diagnosis.

OUTCOMES
- Most studies have involved mixed populations (children and adults) with a variety of diagnoses at early to midrange follow-up, using variable criteria (objective and subjective) to assess outcome.
- Overall, successful results have been reported in most patients, with patient satisfaction in the range of 50% to 95%. Rates of union are 89% to 95%. In general, poor outcomes have been associated with residual deformity or pseudarthrosis.
- Outcomes seem to be similar when comparing children and adults. The results vary somewhat based on the underlying diagnosis, and they seem to deteriorate with longer-term follow-up.
- Most patients have difficulty walking on uneven surfaces. Instrumented motion analysis studies by Beischer et al17 and Wu et al17 revealed an increase in ipsilateral knee flexion during stance phase (including push-off) and a loss of ankle plantarflexion during push-off. Power generation at the ankle is decreased up to 45%.
- Degenerative changes are common in the surrounding joints at long-term follow-up but do not imply the presence of pain or a deterioration in results. Chronic pain is seen in a subset of cases.
- In cerebral palsy, Ireland et al6 found excellent results in all patients at 4.5 years of follow-up. Tenuta et al14 found that 80% of patients were satisfied at 18 years of follow-up, although 25% had occasional pain and 14% had persistent pain. Lack of satisfaction was correlated with residual deformity or pain.
- The results in patients with cavovarus feet (Charcot-Marie-Tooth) are less predictable.
- At 12 years of follow-up, Wukich and Bower18 observed excellent or good results in 88%, with 15% pseudarthrosis and degenerative changes in 64%.
- At 21 years of follow-up, Wetmore et al15 found excellent or good results in only 24%, with recurrence in nearly 50% because of progressive weakness or muscle imbalance. Twenty percent required conversion to a pantalar arthrodesis for ankle pain associated with degenerative changes.
- With flaccid neuromuscular imbalance (poliomyelitis), the results have been adequate in most patients, provided that adequate muscle balance has been achieved in addition to the arthrodesis. Grego et al13 found recurrence in 20% of patients, mostly due to persistent muscle imbalance.

INLAY GRAFTING METHOD FOR VALGUS DEFORMITY
(MODIFIED TECHNIQUE OF WILLIAMS AND MENELAUS)
- The original technique by Williams and Menelaus16 involves placing an inlay graft from the tibia. El-Batouty et al4 modified this to obviate the need for a medially based closing wedge osteotomy for valgus deformity of the hindfoot.
- An anterolateral exposure is used, as described previously.
- The joint surfaces are removed, and the hindfoot is realigned and stabilized with two Kirschner wires.
- An inlay graft is taken from the tibia and placed into a rectangular trough created across the talonavicular, calcaneocuboid, and anterior subtalar joints (TECH FIG 6).
- The posterior subtalar joint is then denuded and local bone graft is placed.
- A cast is applied, and the Kirschner wires are removed.

PEARLS AND PITFALLS
<table>
<thead>
<tr>
<th>Preoperative planning</th>
<th>Weight-bearing radiographs should always be obtained.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft tissue handling</td>
<td>Gentle soft tissue handling should limit the incidence of wound complications.</td>
</tr>
<tr>
<td>Bone graft</td>
<td>Local bone graft is sufficient.</td>
</tr>
<tr>
<td>Screw fixation of the subtalar joint</td>
<td>Placing the screw from the calcaneus into the talus (rather than vice versa) may decrease the incidence of avascular necrosis.</td>
</tr>
</tbody>
</table>

TECH FIG 6 • Modified Williams and Menelaus’s inlay grafting technique.
COMPLICATIONS

- Injury to neurovascular or tendinous structures. The medial neurovascular bundle and flexor hallucis longus tendon must be protected during resection of the posterior facet of the subtalar joint.
- Wound infection
- Wound breakdown or skin necrosis
- Pseudarthrosis of one or more joints, most commonly the talonavicular
- Residual deformity
- Recurrent deformity may be observed in patients with progressive neuromuscular disease (Charcot-Marie-Tooth) or persistent muscle imbalance (poliomyelitis, cerebral palsy).
- Degenerative changes are commonly observed at long-term follow-up (longest study is 44 years) and result from increased stress transmission to the neighboring joints. These changes may be observed in the midfoot (54% to 99%\(^1,11,18\)) or the ankle joint (24% to 100%\(^11,14,18\)).
- Pain from persistent malalignment, degenerative changes, or avascular necrosis of the talus
- Difficulties with shoe wear
- Need for orthotic support or an assistive device for ambulation

REFERENCES

DEFINITION
- Flatfoot is the term used to describe a weight-bearing foot shape in which the hindfoot is in valgus alignment, the midfoot sags in a plantar direction with reversal of the longitudinal arch, the forefoot is supinated in relation to the hindfoot, and the foot points in an externally rotated direction from the knee.
- There is no agreement on strict clinical or radiographic criteria for defining a flatfoot. Therefore, the point beyond which a foot with a low-normal arch becomes defined as a flatfoot is unknown.
- There are three recognized types of flatfoot: flexible (hypermobile) flatfoot, flexible (hypermobile) flatfoot with a short Achilles tendon, and rigid flatfoot.

ANATOMY
- A flatfoot combines valgus deformity of the hindfoot with supination deformity of the forefoot to create a low or absent longitudinal arch (FIG 1). These are rotationally opposite deformities.
- Valgus deformity of the hindfoot, which can also be described as pronation, is one component of eversion of the subtalar joint.
- The other components are external rotation and dorsiflexion of the acetabulum pedis in relation to the plantarflexed talus.
- Acetabulum pedis is a term, coined over 200 years ago by Scarpa, used to describe and compare the subtalar joint with the hip joint, because of certain similarities. It is a cup-like structure consisting of the navicular, spring ligament, and anterior end of the calcaneus that rotates around the talus following the axis of the subtalar joint.
- The axis of the subtalar joint is not in any of the standard planes of motion of the body. In the transverse plane, the subtalar axis deviates about 23 degrees medial to the long axis of the foot. In the horizontal plane, the axis deviates about 41 degrees dorsal from horizontal. The summation of the angles creates an axis for the subtalar joint that produces downward and inward motion during inversion, and upward and outward motion during eversion.
- Eversion of the acetabulum pedis results in loss of support and plantarflexion of the talus. Although the calcaneus dorsiflexes “upward” in relation to the talus, it becomes plantarflexed in relation to the weight-bearing tibia. The navicular also dorsiflexes “upward” at the talonavicular joint as the focal point for the midfoot sag. “Outward” motion of the acetabulum pedis creates the external rotation of the foot in relation to the talus and tibia that is manifest as a positive thigh-foot angle and an out-toeing gait. Convexity of the plantar-medial border of the foot is also a manifestation of “outward” motion of the acetabulum pedis, reflecting the dorsolateral subluxation of the navicular on the head of the talus.
- The forefoot, in a flatfoot, is supinated in relation to the pronated hindfoot. Were it not, forefoot weight bearing would occur solely on the first metatarsal. Finally, these altered relationships create a real, or apparent, shortening of the lateral column (or border) of the foot relative to the medial column.
- The shapes of the bones and the laxity of the ligaments of the foot determine the height of the longitudinal arch. The muscles maintain balance, accommodate the foot to uneven terrain, protect the ligaments from unusual stresses, and propel the body forward. The intrinsic muscles are the principal stabilizers of the foot during propulsion. Greater intrinsic
muscle activity is required to stabilize the transverse tarsal and subtalar joints in a flatfooted individual than in an individual with an average height arch.

**PATHOGENESIS**

- Based on clinical and radiographic studies, flatfoot is ubiquitous in infants and children and is seen in over 20% of adults. The arch increases in height in most children through normal growth and development during the first decade of life. The arch decreases in height in most of those older children and adolescents who have a rigid flatfoot, a condition affecting about 2%–5% of the population that is most often associated with a tarsal coalition.
- Flexibility (hypermobility) in a flexible flatfoot refers to the motion in the subtalar joint. There is full excursion of the Achilles tendon in this class of flatfoot. It is the normal foot shape seen in almost all babies and accounts for about two thirds of the 23% of flatfooted adults. It is the normal contour of a strong and stable foot, not the cause of disability.
- A flexible flatfoot with a short Achilles tendon has the same flexibility in the subtalar joint as a flexible flatfoot, but has limited ankle dorsiflexion owing to contracture of the Achilles tendon. This entity accounts for about one fourth of the 23% of flatfooted adults and often causes pain with callus formation under the head of the talus. The age or point at which the Achilles tendon contracture develops is unknown.
- Rigidity in a rigid flatfoot refers to the restriction of motion in the subtalar joint. This type of flatfoot accounts for about 9% of the 23% of flatfooted adults. It is usually associated with a tarsal coalition and is, therefore, developmental rather than congenital, like the flexible flatfoot. It causes pain in about 25% of cases.
- A contracted Achilles tendon prevents normal dorsiflexion of the talus in the ankle joint during the late midstance phase of the gait cycle. The dorsiflexion stress is shifted to the subtalar joint complex where, as a feature of eversion, the acetabulum pedis dorsiflexes in relation to the talus and also in relation to the tibia. The talus remains rigidly plantarflexed. The soft tissues under the head of the talus are subjected to excessive direct axial loading and shear stresses.
  - These stresses create callus formation and pain at that site.
  - Pain may also be experienced in the sinus tarsi region because of impingement of the beak of the calcaneus with the lateral process of the talus at the extreme range of eversion.

**NATURAL HISTORY**

- Flatfoot is a poorly defined foot shape found in most children and over 20% of adults. For most, it is an anatomic variation from average that does not cause pain or other disability.
- The longitudinal arch develops spontaneously in most children during the first decade of life. Flexible flatfoot with a short Achilles tendon often causes pain with callus formation under the head of the talus or pain in the sinus tarsi area.
- The age or point at which the Achilles tendon contracture develops is unknown.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Children with flexible flatfoot are rarely symptomatic, although they may experience nonspecific leg or foot aches after strenuous activities or at the end of the day. Older children and adolescents with flexible flatfoot with a short Achilles tendon will often experience pain, tenderness, and callus formation under the head of the plantarflexed talus in the midfoot or in the sinus tarsi area or at both sites. About 25% of children and adolescents with a tarsal coalition report activity-related pain that may be located in the sinus tarsi area, along the medial hindfoot, or under the head of the talus.
- Commonly, parents seek consultation for their child with a painless flatfoot because of concerns regarding the appearance of the foot, the child’s uneven shoe wear, or the concern about the potential for future disability. Such concerns about future disability are based on unsubstantiated claims by generations of health care professionals that flatfoot is a deformity that requires treatment to prevent pain and disability.
- Examination of the child’s foot should begin with a screening evaluation of the entire musculoskeletal system. The general examination is aimed at assessing ligament laxity, torsional and angular variations of the lower extremities, and the walking pattern. Their interrelationships are important to keep in mind during evaluation of the foot because all of these features change as the child grows.
- Assessment of the foot begins with the recognition that a flatfoot is not a deformity. It is a combination of deformities that includes a valgus deformity of the hindfoot and a supination deformity of the forefoot on the hindfoot. There is a lateral rotational deformity as well. The axis of the subtalar joint is in an oblique plane, such that eversion creates valgus, external rotation, and dorsiflexion of the so-called acetabulum pedis around the talus.
- The flexibility of the flatfoot pertains to the mobility of the subtalar joint. This can be assessed manually. With the hindfoot in your cupped hand and your other hand on the forefoot, the subtalar joint is inverted and everted around the oblique axis of motion of the joint (FIG 2). Ensure that the motion you appreciate is in the subtalar joint, and not false motion through Chopart’s joints.
- A flexible flatfoot has free and supple subtalar joint motion in the axis of the joint. A rigid flatfoot has restriction of

![FIG 2](image-url) Inversion and eversion of the subtalar joint is assessed by manually moving the acetabulum pedis back and forth along the axis of the subtalar joint. Forefoot supination can be appreciated when the hindfoot is inverted to neutral. While maintaining subtalar joint neutrality, the ankle is dorsiflexed with the knee first flexed and then extended to assess the excursion of the soleus and the gastrocnemius respectively. (From: Mosca VS. Flatfoot and skewfoot. In: Drennan J, ed. The Child’s Foot and Ankle. New York: Raven Press, 1992:355–376.)
motion. This can also be seen dynamically. The arch elevates and the hindfoot corrects from valgus to varus in a flexible flatfoot during toe standing (FIG 3) and with the Jack toe raise test. These two maneuvers take advantage of the windlass action of the plantar fascia to mobilize the subtalar joint into inversion and create a longitudinal arch.

- Supination of the forefoot is revealed when the hindfoot is passively inverted to neutral alignment see Fig 2.
- Functional motion of the ankle joint, as assessed by excursion of the Achilles tendon, is important yet difficult to evaluate accurately. A component of subtalar joint eversion is dorsiflexion of the calcaneus in relation to the talus. Therefore, the subtalar joint must be held inverted to the neutral position to isolate and assess the motion of the talus in the ankle.
- With the subtalar joint inverted to neutral, the knee is flexed to 90 degrees. The ankle is maximally dorsiflexed without allowing the subtalar joint to evert. The degree of dorsiflexion is measured as the angle between the lateral border of the foot and the anterior shaft of the tibia. The knee is then extended while maintaining subtalar neutral, even if it creates plantar flexion of the ankle. The degree of ankle dorsiflexion is once again measured.
- It is normal for the ankle to dorsiflex at least 10 degrees above neutral with the knee flexed, and even further with the knee flexed. The entire triceps surae (gastrocnemius and soleus) is contracted if the ankle does not dorsiflex at least 10 degrees above neutral with the knee flexed or extended. The gastrocnemius is selectively contracted if the ankle dorsiflexes at least 10 degrees above neutral with the knee flexed, but not when it is extended.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Radiographs of the flatfoot are not necessary for diagnosis. They may be indicated for the assessment of pain or decreased flexibility, and for surgical planning.
- Weight-bearing anteroposterior (AP), lateral, medial oblique, and axial (or Harris) views are appropriate for those indications (FIG 4).
- The lateral oblique view is helpful for the identification of an accessory navicular that could be the cause of a painful medial prominence in the midfoot that is not the head of the talus.
- Radiographs can define the static relationships between bones but cannot provide information on flexibility or function. They should not be used as an indication for treatment. A bone scan can help with the assessment of atypical pain in a flatfoot.
- A CT scan is useful for assessment of a rigid flatfoot, particularly when there is a high degree of suspicion for a subtalar tarsal coalition.
- An MRI may be necessary if these other imaging studies fail to reveal the etiology for atypical pain in a flatfoot.

**DIFFERENTIAL DIAGNOSIS**

- Flexible (hypermobility) flatfoot
- Flexible (hypermobility) flatfoot with short Achilles tendon

**FIG 3**• With toe standing, the heel vagus converts to varus and the longitudinal arch elevates in a flexible flatfoot. (From Mosca VS. Flatfoot and skewfoot. In: Drennan J, ed. The Child’s Foot and Ankle. New York: Raven Press, 1992:355-376.)

**FIG 4**• Standing radiographs of a flatfoot. A. AP image demonstrates the external rotation component of eversion or valgus of the subtalar joint. B. The lateral image reveals plantarflexion of the talus, sag at the talonavicular joint, and a low calcaneal pitch. (From the private collection of Vincent Mosca, MD.)
Chapter 82  CALCANEAL LENGTHENING OSTEOTOMY FOR THE TREATMENT OF HINDFOOT VALGUS DEFORMITY

NONOPERATIVE MANAGEMENT
- Flexible flatfoot is a normal foot shape and not the cause of pain or functional disability in most individuals. Therefore, treatment must be applied only to those who have symptoms. “Prophylactic” treatment, even if nonoperative, cannot be justified, based on the literature.
- Some children with flexible flatfoot have activity-related pain or pain at night in the leg or foot. The pain is usually nonlocalized and it is believed to represent an overuse syndrome. This is consistent with the finding that flatfooted individuals demonstrate greater intrinsic muscle activity than normal.
- Over-the-counter and molded shoe inserts have been shown to relieve or diminish symptoms and to increase the useful life of shoes without a simultaneous permanent increase in the height of the arch. There are few, if any, complications of orthotic treatment for flexible flatfoot.
- Children, adolescents, and adults with flexible flatfoot with a short Achilles tendon will often have pain with weight bearing and callous under the head of the plantarflexed talus.
  - The contracted Achilles tendon prevents normal dorsiflexion of the ankle joint during the midstance phase of gait. The dorsiflexion stress is shifted to the subtalar joint complex, which dorsiflexes as a component of eversion. The talus remains rigidly plantarflexed, thereby subjecting the soft tissues under the head of the talus to excessive direct axial loading and shear stress.
- Both firm and hard arch supports concentrate and exaggerate the pressures under the head of the talus in children with flexible flatfeet with short Achilles tendons, thereby exacerbating and enhancing pain. They are, therefore, contraindicated in this condition.
- An aggressive stretching program for the Achilles tendon, performed with the subtalar joint inverted, may relieve symptoms, but is challenging to carry out effectively.
- It is difficult to almost impossible to stretch a contracted Achilles tendon when it is associated with a flexible flatfoot. The subtalar joint must be inverted and held in neutral alignment for the Achilles to stretch. Otherwise, the apparent Achilles tendon stretch will merely create further eversion/varus stretch in the subtalar joint.

SURGICAL MANAGEMENT
- The calcaneal lengthening osteotomy is indicated for the flexible flatfoot with a short Achilles tendon when prolonged attempts at conservative management fail to relieve the pain under the head of the plantarflexed talus or in the sinus tarsi area.
- This procedure is not indicated to change the shape of a pain-free flexible flatfoot.
- Surgery should not be performed in young children with flexible flatfeet who have nonlocalized, activity-related aching foot pain or nighttime pain in the lower extremities.
- Surgery should not be carried out for incongruous signs or symptoms. In such situations, the flatfoot may be an incidental finding and not the cause of the symptoms.
- Finally, the calcaneal lengthening osteotomy is contraindicated in the iatrogenic flatfoot created by overcorrection of a clubfoot in which the talonavicular joint is well aligned and the thigh–foot angle is neutral despite the valgus alignment of the hindfoot.

Preoperative Planning
- Physical examination includes evaluation of the foot in weight bearing and non-weight bearing.
  - In weight bearing, the clinicians should note the valgus alignment of the hindfoot, the depression of the longitudinal arch, and the outward rotation of the foot in relation to the flexion–extension plane of the knee as referenced from the alignment with the patella.
  - Flexibility of the flatfoot is confirmed by observing the creation of the longitudinal arch and conversion of hindfoot varus to varus with toe standing see Fig 3.
- On the examining table, the clinician performs the Silfverskiöld test to determine if the equinus contracture is in the gastrocnemius alone or involves the entire triceps surae.
  - The clinician assesses the thigh–foot angle and the transmalleolar axis with the patient prone. Most commonly, the thigh–foot angle is abnormally positive (excessively turned out versus the thigh), whereas the transmalleolar axis (assessing tibial torsion) is normal.
  - The clinician determines whether the subtalar joint can be inverted to neutral (see Fig 2), although the calcaneal lengthening osteotomy can correct hindfoot valgus even in a rigid deformity.
- Radiographs must be taken with full weight bearing to correlate with the physical examination findings. AP and lateral views are required (see Fig 4). Oblique and Harris axial views of the foot can be added to confirm absence of a tarsal coalition. AP, mortise, and lateral ankle radiographs are useful to determine whether any of the valgus deformity is in the tibiotalar joint.
  - The clinician should discuss with the family the risks and complications of allograft versus autograft for the required tricortical (bicortical) iliac crest bone graft, as well as the possible need for a medial cuneiform plantar-based closing wedge osteotomy.
  - The need for this additional procedure can be accurately determined only intraoperatively after correction of the hindfoot and lengthening of the heel cord.
- Discussion about staged versus concurrent correction of bilateral deformities should include issues relating to the need for strict non-weight bearing on the operated foot or feet for 8 weeks. Most adolescents choose the correction of one foot at a time, with correction of the other foot 6 months later. This interval allows adequate rehabilitation for the operated foot to function comfortably while non-weight bearing on the second foot.

Positioning
- The patient is placed in the supine position with a folded towel under the ipsilateral buttock and prepared from iliac crest to toes. A sterile tourniquet is included if using autograft. If using allograft, only the lower extremity is prepared, and a nonsterile tourniquet is used.
Special equipment includes a narrow sagittal saw, smooth Steinmann pins, straight osteotomes, laminar spreader with smooth teeth, Joker elevators and narrow Crego retractors, and a mini-fluoroscope.

**Approach**
- A modified Ollier incision is used in a Langer skin line for the calcaneal lengthening osteotomy. The superficial peroneal and sural nerves are protected.

**CALCANEAL OSTEOTOMY EXPOSURE AND LATERAL SOFT TISSUE RELEASES**
- Make a modified Ollier incision in a Langer skin line from the superficial peroneal nerve to the sural nerve (TECH FIG 1A). Elevate the soft tissues from the sinus tarsi. Avoid exposure of, or injury to, the capsule of the calcaneocuboid joint.
- Release the peroneus longus and the peroneus brevis from their tendon sheaths on the lateral surface of the calcaneus (TECH FIG 1B).
- Resect the intervening tendon sheaths and, if large, the peroneal tubercle. Z-lengthen the peroneus brevis tendon. Do not lengthen the peroneus longus.
- Divide the aponeurosis of the abductor digiti minimi at a point about 2 cm proximal to the calcaneocuboid joint (TECH FIG 1C).
- Identify the interval between the anterior and middle facets of the subtalar joint with a Freer elevator. Insert

**TECH FIG 1** • A. Modified Ollier incision marked in a Langer skin line halfway between the tip of the lateral malleolus and the beak of the calcaneus (two dots), and extending from the superficial peroneal nerve (dotted line) to the sural nerve. B. The peroneus brevis (above) and the peroneus longus (below) have been released from their tendon sheaths. C. The soft tissue contents have been elevated from the isthmus of the calcaneus. The peroneus brevis is lengthened and the peroneus longus is retracted. The aponeurosis of the abductor digiti minimi is exposed for release. D–F. Finding the interval between the anterior and middle facets of the subtalar joint. D. A Freer elevator is inserted perpendicular to the lateral border of the calcaneus just proximal to the beak of the calcaneus. It makes contact with the middle facet. E. The Freer is rotated distally until the tip falls into the interval between the anterior and middle facets. F. This is confirmed with the mini-fluoroscope. (From Mosca VS. Calcaneal lengthening osteotomy for valgus deformity of the hindfoot. In: Tolo V, Skaggs D, eds. Master Techniques in Orthopaedic Surgery: Pediatric Orthopaedics. Philadelphia: Lippincott Williams & Wilkins, 2008.)
it into the sinus tarsi perpendicular to the lateral cortex of the calcaneus at the level of the isthmus (ie, the lowest point of the dorsal cortex in the sinus tarsi proximal to the beak and distal to the posterior facet) (TECH FIG 1D). The middle facet will be encountered.

- Slowly angle the Freer distally until it falls into the interval between the anterior and middle facets (TECH FIG 1E).
- Confirm that the Freer is in the interval using fluoroscopy (TECH FIG 1F).

- Replace the Freer with a curved Joker elevator. Place a second Joker elevator around the plantar aspect of the calcaneus in an extraperiosteal plane in line with the dorsal Joker.
- Remove the Jokers and prepare the exposures for the other procedures before performing the calcaneal osteotomy.

### MEDIAL SOFT TISSUE PLICATION EXPOSURE AND PREPARATION

- Make a longitudinal incision along the medial border of the foot starting at a point just distal to the medial malleolus and continuing to the base of the first metatarsal.
- Release the tibialis posterior from its tendon sheath. Cut the tendon in a Z-fashion, releasing its dorsal half from the navicular (TECH FIG 2A). The stump of tendon remaining attached to the navicular contains the plantar half of the fibers.
- Incise the talonavicular joint capsule from dorsal-lateral to plantar-lateral, including release of the spring ligament.
- Resect a 3–5 mm-wide strip of capsule from the medial and plantar aspects of this redundant tissue (TECH FIG 2B).

### ACHILLES TENDON OR GASTROCNEMIUS LENGTHENING

- Assess the equinus contracture by the Silfverskiöld test with the subtalar joint inverted to neutral and the knee both flexed and extended.
- Perform a gastrocnemius recession if 10 degrees of dorsiflexion can be achieved with the knee flexed, but not with it extended.
- Perform an open or percutaneous Achilles tendon lengthening if 10 degrees of dorsiflexion cannot be obtained even with the knee flexed (TECH FIG 3).

TECH FIG 2 • A. The tibialis posterior is cut in a Z-fashion, releasing the dorsal slip from the navicular.
B. The talonavicular joint capsule is released from dorsolateral to plantar-lateral, including release of the spring ligament. A 3- to 5-mm-wide strip of redundant capsule is resected from its plantar-medial aspect. (From Mosca VS. Calcaneal lengthening osteotomy for valgus deformity of the hindfoot. In: Tolo V, Skaggs D, eds. Master Techniques in Orthopaedic Surgery: Pediatric Orthopaedics. Philadelphia: Lippincott Williams & Wilkins, 2008.)

TECH FIG 3 • The Achilles tendon or the gastrocnemius tendon is lengthened based on the results of the Silfverskiöld test. (From Mosca VS. Calcaneal lengthening osteotomy for valgus deformity of the hindfoot. In: Tolo V, Skaggs D, eds. Master Techniques in Orthopaedic Surgery: Pediatric Orthopaedics. Philadelphia: Lippincott Williams & Wilkins, 2008.)
CALCANEAL OSTEOTOMY AND BONE GRAFT INTERPOSITION

Replace the Joker elevators, or Crego retractors, both dorsal and plantar to the isthmus of the calcaneus, meeting in the interval between the anterior and middle facets of the subtalar joint.

Perform an osteotomy of the calcaneus using a sagittal saw or osteotome (TECH FIG 4A).

It is an oblique osteotomy from proximal-lateral to distal-medial that starts about 2 cm proximal to the calcaneocuboid joint (at the lowest point of the calcaneus proximal to the beak) and exits between the anterior and middle facets (TECH FIG 4B).

It is a complete osteotomy through the medial cortex. Cut the plantar periosteum and long plantar ligament (not the plantar fascia) under direct vision if necessary (ie, if these soft tissues resist distraction of the bone fragments).

Insert a 2-mm smooth Steinmann pin retrograde from the dorsum of the foot passing through the cuboid, across the center of the calcaneocuboid joint, and stopping at the osteotomy (TECH FIG 4C,D).

This is performed with the foot in the original deformed (everted) position before the osteotomy is distracted. By so doing, the pes acetabulum (navicular, spring ligament, anterior facet of calcaneus) will be maintained intact and the distal fragment of the calcaneus will not subluxate dorsally on the cuboid during distraction of the osteotomy.

Insert a 0.062-inch smooth Steinmann pin from lateral to medial in both of the calcaneal fragments immediately adjacent to the osteotomy. These will be used as joysticks to distract the osteotomy at the time of graft insertion.

Place a smooth-toothed lamina spreader in the osteotomy and distract maximally, trying to avoid crushing the bone (TECH FIG 4E).

Assess deformity correction of the hindfoot clinically and using mini-fluoroscopy. The deformity is corrected when the axes of the talus and first metatarsal are colinear in both the AP and lateral planes (TECH FIG 4F,G).

TECH FIG 4 • A. With Joker and Crego retractors surrounding the isthmus of the calcaneus and meeting in the interval between the anterior and middle facets, the osteotomy is performed with a sagittal saw in line with the retractors. B. Fluoroscopic appearance of the osteotomy in the proper location. C. With the foot in the original flat and everted position, a 2-mm smooth wire is inserted retrograde from the dorsum of the foot through the middle of the calcaneocuboid joint, stopping at the osteotomy. D. Position of the wire at the calcaneocuboid joint is confirmed with fluoroscopy. E. Steinmann pins in the proximal and distal calcaneal fragments can be used as joysticks to distract the osteotomy during graft insertion. The lamina spreader is used to determine the necessary graft size. F,G. Fluoroscopy can help confirm the required graft size by showing, with the lamina spreader opened, when the talonavicular joint is aligned and the talus and first metatarsal axes are colinear. (continued)
MEDIAL SOFT TISSUE Plication

- Plicate the talonavicular joint capsule plantar-medially, but not dorsally (TECH FIG 5A).

- Measure the distance between the lateral cortical margins of the calcaneal fragments. This is the lateral length dimension of the trapezoidal iliac crest graft that will be obtained either from the child's iliac crest or from the bone bank.
  - The trapezoid should taper to a medial length dimension of 20% to 30% of the lateral length (TECH FIG 4H).
  - The calcaneal lengthening osteotomy is a distraction wedge rather than a simple opening wedge, as the center of rotation is the center of the talar head, not the medial cortex of the calcaneus.
  - Remove the laminar spreader and use the Steinmann pin joysticks to distract the calcaneal fragments.
  - Insert and impact the graft with the cortical surfaces aligned from proximal to distal in the long axis of the foot (TECH FIG 4I). This will place the cancellous bone of the graft in direct contact with the cancellous bone of the calcaneal fragments.
  - Advance the previously inserted 2-mm Steinmann pin retrograde through the graft and into the proximal calcaneal fragment. Bend the pin at its insertion site on the dorsum of the foot for ease of retrieval in the clinic.
  - No additional fixation is required. In fact, were the pin not needed to prevent subluxation at the calcaneocuboid joint, no graft fixation would be needed.
  - Repair the peroneus brevis tendon with an absorbable suture after a 5- to 7-mm lengthening.

- Advance the proximal slip of the tibialis posterior about 5 to 7 mm through the distal stump of the tendon using a Pulvertaft weave with an absorbable suture material (TECH FIG 5B,C).
**MEDIAL CUNEIFORM OSTEOTOMY**

- Assess the forefoot for structural supination deformity by holding the heel with the ankle in neutral dorsiflexion and viewing in line with the axis of the foot from toes to heel.
- Visualize the plane of the metatarsal heads in relation to the long axis of the tibia (TECH FIG 6A).
- Also assess the dorsal-plantar mobility of the first metatarsal–medial cuneiform joint.
  - A plantarflexion osteotomy of the medial forefoot–midfoot is required if the metatarsals are supinated.
- A plantar-based closing wedge osteotomy in the midportion of the medial cuneiform is an effective procedure to correct this deformity (TECH FIG 6B). The plantar base of the resected wedge generally measures 4 to 7 mm in length.
- The osteotomy is closed and internally fixed with a 0.062-inch smooth wire staple inserted from plantar to dorsal.
- Check to ensure correction of the forefoot deformity (TECH FIG 6C).

**TECH FIG 6 • A.** The rotational alignment of the forefoot is assessed after correction of the hindfoot deformity and the heel cord contracture. If, as in this case, the forefoot is supinated, an osteotomy of the forefoot is required. **B.** A medial cuneiform plantar-based closing wedge osteotomy will correct the supination deformity of the forefoot. **C.** Forefoot deformity has been corrected. (From Mosca VS. Calcaneal lengthening osteotomy for valgus deformity of the hindfoot. In: Tolo V, Skaggs D, eds. Master Techniques in Orthopaedic Surgery: Pediatric Orthopaedics. Philadelphia: Lippincott Williams & Wilkins, 2008.)

**PEARLS AND PITFALLS**

**Indications**
- Flexible flatfoot is a normal foot shape that rarely causes pain or disability. Associated contracture of the Achilles or gastrocnemius tendon may cause pain that interferes with the enjoyment of desired activities. Pain that cannot be relieved by prolonged attempts at conservative management is the absolute indication for surgery.

**Calcaneal osteotomy location**
- The surgeon should try to find the interval between the anterior and middle facets of the subtalar joint to create an extra-articular osteotomy, although only about 60% of individuals have separate facets.

**Lateral soft tissue management**
- The surgeon lengths the peroneus brevis and the aponeurosis of the abductor digiti minimi to facilitate distraction of the bone fragments. However, the peroneus longus is not lengthened. The latter is the plantarflexor of the medial forefoot. Lengthening the lateral bony column of the foot results in a relative shortening of the peroneus longus, which, in turn, plantarflexes the medial forefoot to help correct the supination deformity.

**Calcaneocuboid joint protection**
- Inadvertent subluxation of the calcaneocuboid joint when the calcaneal osteotomy is distracted can be prevented by inserting a retrograde smooth Steinmann pin across the middle of the joint before the fragments are distracted.

**Forefoot supination deformity**
- The surgeon must not ignore the forefoot deformity. It is assessed intraoperatively after correction of the hindfoot deformity. Significant uncorrected residual forefoot supination deformity will create a bipod, rather than the normal tripod, foot with lack of support under the first metatarsal head. If untreated, this may lead to recurrence of valgus deformity of the hindfoot. A plantar-based closing wedge osteotomy of the medial cuneiform is performed if necessary.

**Achilles or gastrocnemius contracture**
- This is the deformity that changed a normal flexible flatfoot into a painful flatfoot. The contracted tendon should be lengthened.
POSTOPERATIVE CARE

- The incisions are closed with absorbable sutures.
- A well-padded short-leg non-weight-bearing cast is applied and bivalved to allow for swelling overnight.
- Radiographs in the cast are obtained (FIG 5).
- The patient is discharged from the hospital the following day after the bivalved cast is overwrapped with cast material.
- The patient is immobilized in a below-knee cast and is not permitted to bear weight on the operated extremity for 8 weeks.
- At 6 weeks, the cast is removed to obtain simulated standing AP and lateral radiographs and to remove the Steinmann pin. Another below-the-knee non-weight-bearing cast is applied.
- On removal of this cast 2 weeks later, final simulated standing AP and lateral radiographs are obtained.
- Over-the-counter arch supports are used indefinitely.
- Physical therapy is rarely needed.

OUTCOMES

- The calcaneal lengthening osteotomy has the best-reported long-term results for any procedure that has been used to correct flatfoot deformity.
- It has been shown to correct all components of even severe valgus–eversion deformity of the hindfoot, restore function of the subtalar complex, relieve symptoms, and, at least theoretically, protect the ankle and midtarsal joints from early degenerative arthrosis by avoiding arthrodesis.

FIG 5 • Final radiographs in the bivalved cast. A. On the AP view, note the correction of the external rotation deformity at the talonavicular joint as also assessed by the talo-first metatarsal angle. B. The lateral view demonstrates dorsiflexion of the talus, alignment at the talonavicular joint, correction of the talo-first metatarsal angle, and normalization of the calcaneal pitch. (From Mosca VS. Calcaneal lengthening osteotomy for valgus deformity of the hindfoot. In: Tolo V, Skaggs D, eds. Master Techniques in Orthopaedic Surgery: Pediatric Orthopaedics. Philadelphia: Lippincott Williams & Wilkins, 2008.)

COMPLICATIONS

- Subluxation of the calcaneocuboid joint when the calcaneal osteotomy is distracted may occur. This can be avoided by lengthening the peroneus brevis, releasing the aponeurosis of the abductor digiti minimi, releasing the plantar calcaneal periosteeum and long plantar ligament (not the plantar fascia), and pinning the calcaneocuboid joint in a retrograde fashion before the osteotomy is distracted.
- Deformity correction may be incomplete. This can be avoided by performing the procedures listed just above and by releasing the entire dorsal talonavicular joint capsule. The surgeon should use a graft that is large enough to make the axes of the talus and the first metatarsal colinear in both planes. This is confirmed with intraoperative imaging, such as mini-fluoroscopy.
- Persistent equinus can be avoided by lengthening the contracted Achilles tendon or gastrocnemius tendon.
- Persistent supination deformity of the forefoot on the hindfoot can be avoided by identifying it after the calcaneal lengthening and heel cord lengthening. It is treated with a medial cuneiform plantar-based closing wedge osteotomy.

REFERENCES


DEFINITION
- Shortening of the Achilles tendon, gastrocsoleus complex (triceps surae), or both results in an equinus (plantarflexed) position of the calcaneus relative to the tibia.
- An equinus deformity is either congenital or acquired and can be dynamic or rigid.
  - A dynamic deformity will correct with passive manipulation.
  - A rigid, or fixed, deformity does not correct.
- Achilles or gastrocnemius contracture often occurs in combination with other soft tissue contractures.

ANATOMY
- The two heads of the gastrocnemius originate on the posterior aspect of the medial and lateral condyles of the distal femur.
  - The muscle fibers terminate at the muscle–tendon junction at the midcalf.
  - From here, the Achilles tendon is joined by tendon fibers from the posterior aspect of the soleus as the tendon courses distally.
  - The tendon is broad proximally and then becomes rounded at the midsection when it undergoes a 90-degree internal rotation before its insertion on the posterosuperior third of the calcaneus.
  - The rotation causes the medial fibers of the midtendon to insert on the posterior portion of the calcaneus (FIG 1).
- The insertion footprint is delta-shaped, and a small portion of the fibers course distally to meet the origin of the plantar fascia.
- The blood supply of the Achilles tendon is limited.
  - The proximal portion is supplied by branches from within the gastrocnemius muscle.
  - The distal portion is supplied by branches from the tendon–bone interface.
  - There is no true synovial sheath. Instead, the surrounding paratenon, comprising loose connective tissue, supplies the rest of the blood supply via branches from the posterior tibial artery and, to a lesser degree, the peroneal artery.
  - There are two synovial bursae at the Achilles tendon insertion site.
    - One is subcutaneous, located between the skin and tendon, and the other is deep, located between the tendon and the calcaneus.

PATHOGENESIS
- The pathogenesis of congenital equinus is poorly understood and it is often associated with other limb deformities, such as clubfoot or congenital vertical talus.
- Acquired equinus deformity secondary to cerebral palsy results from muscle spasticity or imbalance, leading to subsequent contracture of the Achilles tendon and gastrocsoleus complex.
  - Muscle imbalance and spasticity in spastic diplegic cerebral palsy often results in equinoplanovalgus deformity.
  - Muscle imbalance and spasticity in spastic hemiplegic cerebral palsy often results in equinus or equinovarus deformity.
  - Compensatory balance mechanisms to help maintain ambulation in patients with Duchenne muscular dystrophy also may result in equinus deformity.
- Posttraumatic equinus can also be a result of severe burns and posterior scar contracture, postburn positioning, anterior leg muscle loss, or continued tibial growth in a rigid scar.
  - Talocrural and subtalar capsular adhesions and an abnormal tibiotalar articulation may also contribute to loss of dorsiflexion and equinus deformity.

NATURAL HISTORY
- Fixed equinus deformity will not correct spontaneously and requires prescribed stretching, surgical intervention, or both.
- Equinus associated with cerebral palsy is progressive. Despite both conservative and surgical treatments, the deformity can recur due to persistent spasticity, muscle imbalance, or limb growth.
- Equinus deformity results in abnormal gait because of altered ankle range of motion and decreased ankle plantarflexion moment during terminal stance. It can result in chronic pain, poorly fitting footwear, callosities on the plantar forefoot, and possible skin ulceration in patients with altered sensation.
PATIENT HISTORY AND PHYSICAL FINDINGS

- Birth history may reveal gestational or perinatal complications, such as traumatic brain injury or global hypoxic events, which are risk factors for cerebral palsy.
- Family history may reveal an inherited neuromuscular disease or idiopathic toe walking.
- A delay in gross motor milestones may suggest the presence of a static neurologic disorder such as cerebral palsy, while regression of gross motor function may suggest a progressive neuromuscular disease such as muscular dystrophy or Rett syndrome.
- The age of equinus deformity onset will depend on the type and severity of the underlying condition.
- Posttraumatic equinus, particularly a burn, should prompt questions regarding severity of the soft tissue loss, type of treatment, period of immobilization, and current problems with skin ulceration to assess the severity of scarring and underlying skin quality.
- Physical examination should include a thorough examination of the entire lower extremities to look for associated deformities at the hip, knee, hindfoot, and forefoot.
- The patient is examined supine on the examination table. It is important that the table has a hard surface so as not to mask any other contractures.
- Ankle range of motion: Absence of dorsiflexion beyond neutral is ankle equinus.
- Silfversköld test: A positive test indicates isolated gastrocnemius contracture. This is present if ankle equinus is present with the knee extended, but improves with knee flexion.
- Palpation of Achilles tendon: A tight tendon suggests spasticity of the gastrocsoleus complex or contracture of the Achilles tendon.
- Palpation of posterior tibial and peroneal tendons: Taut tendons suggest additional contracture or spasticity of the involved musculotendinous units contributing to the ankle equinus contracture.
- Ankle clonus: More than two beats of clonus is abnormal and indicates gastrocsoleus spasticity or an upper motor neuron lesion.
- If the child is ambulatory, the clinician should observe the gait in a hallway or large area where the patient can both walk and run.
- Socks, shoes, and clothing that extends below the knee are removed.
- Hindfoot alignment is best observed from behind.
- The foot progression angle (axis of the foot to the axis of progression) and any associated coronal plane abnormalities, such as scissoring (excessive hip adduction during gait), knee progression angle, and pelvic rotation, are best observed from the front.
- Ankle equinus and any associated sagittal plane abnormalities, such as a crouch gait (hip and/or knee flexion contracture) or a stiff-knee gait (decreased knee range of motion during swing phase), are best observed from the side.
- In mild equinus, the normal heel-to-toe gait of the plantargrade foot will be replaced with early lift-off during stance. Subtle deformity in patients with cerebral palsy is often unmasked by asking the patient to run. In severe equinus, the heel will not make contact during heel-strike.
- Equinovarus or equinoplanovalgus deformity will cause initial contact during gait to occur on either the lateral or medial border of the foot, respectively. There may be a callus or foot pain at the area of initial contact.
- The alignment and passive range of motion of the lumbar sacral spine, pelvis, hips, and knees must also be tested, since equinus may be a functional compensation for coexistent contractures.
- Associated muscle spasticity or contracture in cerebral palsy should be diagnosed with the appropriate physical examination maneuvers described in the relevant chapters.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Anteroposterior (AP) and lateral weight-bearing radiographs of the affected ankle should be obtained.
- Ossification centers of the talus, calcaneus, and cuboid are present at infancy. The navicular does not appear until age 3 to 4 years.
- Equinus deformity will result in a decreased lateral tibial-calcaneal angle. Normal values range from 25 to 60 degrees. It can be difficult to measure this angle in young children with a partially ossified calcaneus.
- Although usually associated with hindfoot varus, equinus deformity can also result in a decreased lateral talocalcaneal angle (intersection of a line through the longitudinal axis of the talus and a line along the plantar surface of the calcaneus; FIG 2). The normal range is 25 to 55 degrees.
- Bony abnormalities, such as a flattened talar dome or anterior talar neck and anterior distal tibial osteophytes, can also contribute to ankle equinus contracture.
- Arthrogram may be useful to compare talocrural and subtalar motion during ankle dorsiflexion and plantarflexion to reveal capsular contractures contributing to restricted dorsiflexion and equinus deformity.6

DIFFERENTIAL DIAGNOSIS

- Congenital equinus
- Talipes equinovarus (clubfoot)
- Planovalgus
- Congenital vertical talus
- Arthrogryposis
- Tibial hemimelia
- Acquired equinus
- Neuromuscular
  - Cerebral palsy
  - Myelomeningocele

FIG 2 • Measurement of the lateral talocalcaneal angle. The normal range of 25 to 55 degrees is decreased in equinus.
Charcot-Marie-Tooth
Spinal muscular atrophy
Sacral agenesis
Rett syndrome or other genetic neuromuscular diseases
Posttraumatic
Posterior scar contracture
Posttrauma positioning
Anterior leg muscle loss
Continued tibial growth in a rigid scar
Other
Idiopathic toe walking
Juvenile arthropathy

NONOPERATIVE MANAGEMENT
Many children with equinus deformity secondary to a contracture of the Achilles tendon or gastrocnemius–soleus complex can be successfully managed with nonoperative treatment.
This is typically performed with serial casting for 3 to 6 weeks or more to achieve neutral sagittal alignment.
The success of nonoperative management depends on the age of the patient, the severity of the deformity, and the cause of the equinus.
In patients with equinus and cerebral palsy, early surgery may have an unpredictable outcome, with high rates of recurrence.
For this reason, surgery is often delayed with nonoperative treatments until after age 6 years.
Physical therapy for Achilles tendon stretching helps correct and maintain correction of equinus deformity.
The efficacy of stretching is likely dependent on the duration and frequency of stretching.
Use of an ankle–foot orthosis (AFO) in patients with cerebral palsy and dynamic equinus is a useful adjunct to nonsurgical management.
Botulinum toxin A (BtA) has been shown to be as effective as serial casting, with fewer side effects and more prolonged benefit.
Serial casting and physical therapy are recommended as an adjunct to BtA injections.
Oral medications for muscle relaxation, such as baclofen, diazepam, dantrolene sodium, and tizanidine, can be helpful in selected patients with cerebral palsy if generalized reduction in tone is desired.

SURGICAL MANAGEMENT
Indications for surgical management include fixed ankle equinus that exists with the knee flexed as well as extended and that also interferes with normal gait.
Clinical difficulties may include pain with weight bearing, toe walking, callosities on the plantar forefoot, poorly fitting orthoses, or plantar midfoot pain.
Surgical management of fixed ankle equinus in knee extension that disappears in knee flexion should consist of surgery to the gastrocnemius fascia alone.
Especially in patients with cerebral palsy, surgical management of ankle equinus should include concurrent treatment of all pelvic and lower extremity deformities, particularly hamstring contractures.

The open Achilles Z-lengthening procedure uses the same technique of a sliding Achilles lengthening.
We prefer the supine position for patients undergoing isolated tendo Achilles lengthening.
A thigh tourniquet can be used.
The leg is prepared sterilely from the tourniquet distally.
If other concurrent soft tissue tendon lengthenings are to be performed, the patient is positioned and prepared according to the additional procedures.

Preoperative Planning
The quality of the overlying skin will be crucial for successful wound healing and should be considered during the preoperative planning phase.
Inadequate skin elasticity may require incomplete correction and staged surgery or staged casting in the postoperative period.
In severe posttraumatic cases, tissue loss and significant scarring may require additional tissue transfer procedures.
In cerebral palsy patients with severe spasticity, examination under anesthesia can help determine if equinus deformity is dynamic or fixed, since paralytic medications during anesthesia eliminate spasticity.

Positioning
The patient can be positioned either prone or supine.
The prone position allows improved access to the tibiotalar and subtalar joint capsules but requires careful padding to the hips and knees (FIG 3).
We prefer the supine position for patients undergoing isolated tendo Achilles lengthening.
The prone position allows improved access to the tibiotalar and subtalar joint capsules but requires careful padding to the hips and knees (FIG 3).
For sliding procedures, a modified approach that exposes only the transected portion of the tendon can also be performed.
To avoid postoperative wound complications, a longitudinal incision along the anteromedial border of the Achilles tendon is recommended.
This decreases the risk of wound dehiscence, since the thinnest portion of the overlying skin is directly posterior to the tendon and should remain intact.
For sliding procedures, a modified approach that exposes only the transected portion of the tendon can also be performed.

The open sliding Achilles lengthening technique, first described by White,9 is performed with partial transections at the (1) proximal and medial and (2) distal and anterior portions of the tendon. The 90-degree rotation of the tendon fibers between the transected areas maintains continuity of the tendon fibers as the tendon is lengthened (FIG 4A).
The modified open sliding Achilles lengthening technique decreases the size of the skin incision but uses the same technique of a sliding Achilles lengthening.
The open Achilles Z-lengthening procedure uses the same incision and closure as the modified approach. Here, the entire tendon is divided in a Z-fashion (FIG 4B), and the two sides or ends of the tendon are sutured to each other.
OPEN SLIDING ACHILLES LENGTHENING

- The incision is made along the anteromedial border of the Achilles tendon.
- The skin incision begins just proximal to the calcaneal insertion (TECH FIG 1A) and continues proximally to the proximal extent of the tendon.
- At the proximal portion of the incision, sharply divide the subcutaneous fat in line with the incision.
- There are no neurovascular structures at risk here and the incision can be directed deeply until the paratenon sheath surrounding the tendon has been fully incised to form a small opening.
- The sheath comprises multiple thin layers, and full division of these layers is apparent once the gleaming white tissue of the tendon is encountered and the surgeon’s forceps can no longer grasp any intervening tissue.
- Using round-tipped dissecting scissors directed distally and laterally and aligned longitudinally with the tendon,
pass one blade inside the paratenon and cut both the subcutaneous fat and sheath together until the calcaneal insertion is reached.
- This maintains attachment of the sheath to the subcutaneous fat, preserving the blood supply and providing closure of the sheath with approximation of the subcutaneous fat during wound closure.
- The tendon should now be completely exposed.
- Insert a new blade, cutting edge inferior, just proximal to the calcaneus in the coronal plane between the anterior two thirds and posterior one third of the distal tendon (TECH FIG 1B).
- Rotate the blade so the cutting edge is anterior and divide the anterior two thirds of the tendon transversely.
- Identify the most proximal portion of the tendon that has been exposed.
- Again, transversely divide the medial two thirds of the tendon, taking care to avoid any underlying muscle fibers of the soleus (TECH FIG 1C).

MODIFIED OPEN SLIDING ACHILLES LENGTHENING
- Identify the anteromedial border of the Achilles tendon as described previously and, with a pen, draw the length of incision as if planning a fully open procedure.
- This helps ensure alignment of the two incisions and avoids gaping of the wound after dorsiflexion and subsequent uneven tensioning of the skin.
- Using a skin blade, create two short longitudinal incisions at the distal and proximal ends of the drawn line (TECH FIG 2).
- As previously described, sharply dissect the overlying tissues to reach the Achilles tendon at the proximal and distal incisions and partially divide the tendon at each area of exposure.
- As for the original open lengthening technique, slowly dorsiflex the foot with gentle pressure to cause the divided portions of the tendon to slide past one another until 10 degrees of dorsiflexion is achieved.
- Close the subcutaneous tissues and skin and apply a short- or long-leg cast as described previously.

OPEN ACHILLES Z-LENGTHENING
- Once the entire tendon has been exposed through the anteromedial approach, gently retract the most distal and medial tissues anteriorly to protect the underlying neurovascular structures.
- Align a new no. 15 blade longitudinally with the tendon fibers at the midpoint of the tendon in the sagittal plane. Introduce the blade deeply into the tendon until there is a discernable release in resistance, signifying complete transection through the tendon.
- Alternately, a small osteotome may be introduced along the anterior border of the tendon, and the blade can be carried safely through the entire tendon until metal-on-metal contact.
- Carry the incision distally until the calcaneal insertion is reached (TECH FIG 3A).
- Without removing the blade, rotate the blade medially 90 degrees and with a slight sawing motion, transversely divide the medial portion of the tendon.
- Once this is achieved, retraction of the medial structures can be safely released.
- Return the blade to the proximal starting point and extend the division proximally until an adequate portion of the tendon is involved.
- This is usually about two thirds of the Achilles tendon but will ultimately depend on the desired lengthening and overlap between the two ends.
- Take care to stay along the midline of the tendon.
Complete the proximal division of the tendon laterally in this transverse plane (TECH FIG 3B).

The entire tendon should now be divided in a Z-fashion (TECH FIG 3C).

Dorsiflex the ankle to neutral. Under moderate tension, reapproximate the sides of the tendon with a braided nonabsorbable suture.

This can be done with multiple interrupted simple or vertical mattress sutures (TECH FIG 3D).

Alternately, the overlapping ends of the tendon can be excised for approximation of the ends.

Multiple intratendinous and epitendon suture techniques are acceptable for reapproximation.

The intratendinous technique reduces exposed suture and diminishes inflammatory reaction around the suture, and is recommended.

The simplest of these is the modified Kessler suture (locking loops of the core suture; TECH FIG 3E).

Apply either a long- or short-leg plaster cast as discussed above.

**TECH FIG 3**

**A.** Full exposure of the Achilles tendon has been achieved and the initial transection in the sagittal plane, dividing the medial and lateral halves of the tendon, has been performed with a blade. **B.** The entire tendon is exposed and is being transected in a Z-fashion. **C.** The ankle is dorsiflexed to the appropriate position and the overlapping tendon is noted. **D.** The desired amount of overlapping tendon has been joined with vertical mattress sutures. **E.** Alternately, the tendons can be reapproximated end to end. After Z-lengthening, the remaining overlapping tendon has been removed and the ends of the tendon are joined with a nonabsorbable suture and a modified Kessler repair.

### Pearls and Pitfalls

**Failure to address coexistent contractures**

- All associated joint contractures, particularly in cerebral palsy, should be addressed to achieve optimal surgical results.

**Surgical indications**

- Patients with a positive Silfverskiöld test should not be treated with an Achilles lengthening.

**Overlengthening**

- In an open Z-lengthening, repairing the tendon with the ankle in dorsiflexion or under inadequate tension can lead to overlengthening.
- In a sliding lengthening, dorsiflexing the ankle beyond 10 degrees can lead to overlengthening.

**Wound healing problems**

- The paratenon should not be dissected free from the overlying subcutaneous tissue posteriorly.
- Posterior skin contractures should be treated intraoperatively with tissue transfer procedures or postoperatively with undercorrection and serial casting.

**Inadequate correction**

- Severe equinus deformity often requires a concurrent release of the posterior subtalar and tibiotalar joint capsules; lengthening of the posterior tibial and peroneal tendons; or both.
- Failure to extend the Z-lengthening incision to the most proximal portion of the tendon can lead to insufficient length of tendon at repair and therefore to undercorrection.
- In a sliding lengthening, failure to dorsiflex the ankle to 10 degrees with the knee extended and the subtalar joint inverted can result in undercorrection.

**Revision surgery**

- The normal 90-degree spiral architecture of the tendon is altered with surgery, and an open Z-lengthening procedure is indicated for revision surgery.
POSTOPERATIVE CARE
- Adequate pain control in the acute postoperative setting is imperative. This is both to promote the child’s comfort and to reduce additional muscle spasms, which may alter the desired surgical correction.
- Since children with neuromuscular diseases may have significant communicative barriers, pain should be presumed to be present and should be treated with both morphine derivatives and muscle relaxants.
- The limb should be elevated as much as possible for 2 or 3 days until acute swelling resolves.
- The child can then become ambulatory and weight bearing as tolerated if a sliding tendon lengthening was performed.
- Patients undergoing open Z-lengthening should remain non-weight bearing in a cast until tendon healing is sufficient (6 weeks).
- Once the cast is permanently removed, the child needs postoperative physical therapy or use of an AFO, as dictated by the diagnosis.

OUTCOMES
- Surgical lengthening results in gains in dorsiflexion, from a preoperative average of 25 degrees of plantarflexion to 8 degrees of dorsiflexion, without significant changes in the arc range of motion.
- Correction is maintained in 80% to 90% of patients for at least 7 years postoperatively.4

COMPLICATIONS
- Calcaneovalgus deformity occurs in less than 2% of open Achilles tendon lengthenings.
- Recurrent deformity is common in neuromuscular diseases owing to continued spasticity and normal longitudinal tibial growth.
- After surgical correction, 18% of children with diplegia and 41% of those with hemiplegia will experience recurrence.
- Ambulatory patients maintain correction better than non-ambulatory patients.
- Recurrence is also more frequent in children 4 years or younger.7
- Wound dehiscence and necrosis are infrequent and the incidence is not well reported.
- These can be devastating, however, and should remain a matter of concern as potential complications.

REFERENCES
DEFINITION
- The equinovarus deformity involves hindfoot equinus and varus and results from imbalance between inversion (tibialis posterior, tibialis anterior, or both) and eversion of the foot.
- The deformity is most common in spastic hemiplegia but may also be seen in patients with diplegic and quadriplegic involvement.
- The deformity may interfere with ambulation, orthotic wear, or both.

ANATOMY
- The tibialis posterior muscle originates from the posterolateral aspect of the tibia, the interosseous membrane, and the medial fibula.
  - Although the main insertion is into the tuberosity of the navicular, fibers also insert onto the cuneiforms, the second through fourth metatarsals, the cuboid, and the sustentaculum tali.
- The gastrocnemius muscle originates from the posterior surface of the distal femur, and its tendon blends with the tendon of the soleus muscle to form the Achilles tendon, which then inserts on the posterior tuberosity of the calcaneus.
- The soleus muscle takes origin from the posterior portion of the upper third of the fibula, the fibrous arch between the tibia and the fibula, and the posterior aspect of the tibia.
  - The broad tendinous portion along the posterior aspect of the muscle joins with the gastrocnemius tendon to form the Achilles tendon.

PATHOGENESIS
- The deformity results from muscle imbalance between plantarflexion–inversion (strong) and dorsiflexion–eversion (weak).
  - Spasticity of the tibialis posterior, the tibialis anterior, or both may be responsible for the imbalance.

NATURAL HISTORY
- The deformity is initially dynamic, with a full range of motion on physical examination.
  - A myostatic contracture often develops over time, evidenced by the inability to achieve a full passive range of motion.
  - Tethering of growth may subsequently result in structural bony deformities such as hindfoot varus.
- The equinovarus deformity may result in pathologic changes in both the stance and swing phases of gait, including impaired clearance during swing phase, the inability to preposition the foot in terminal swing, and loss of stability during stance phase.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients present with progressive gait disturbance, with or without pain, and may have difficulty wearing orthotics.
- Pain is due to the abnormal stress distribution on the plantar surface of the foot and is commonly experienced over the distal fifth metatarsal and the lateral border of the foot. Calluses may be observed laterally.
- Recurrent ankle sprains may occur as the hindfoot rolls into varus.
- In addition to a comprehensive examination of the spine and both extremities, the physical examination focuses on observational gait analysis, the presence of and degree of spasticity in the individual muscle groups, the range of motion (active and passive) of the foot and ankle, and the selectivity of motor control.
- Observational gait analysis focuses on the alignment of the foot and ankle during both the swing and stance phases of gait.
  - During swing phase, the foot is inverted and plantarflexed, which impairs clearance.
  - The inability to maintain the foot in neutral plantarflexion–dorsiflexion during mid-swing may be due to muscle weakness (tibialis anterior), muscle spasticity (tibialis anterior or posterior, gastrosoleus), or a fixed equinovarus deformity.
  - There is inadequate prepositioning of the foot for weight acceptance during terminal swing.
  - Initial contact often occurs over the lateral forefoot (no heel contact), or over the lateral border of the foot, and the foot rolls into varus, which interferes with stability during stance phase.
  - The equinovarus deformity may also contribute to in-toeing (internal foot progression angle).
- The presence and degree of spasticity should be documented.
  - The most common system for grading is the modified Ashworth scale. Each muscle is tested by gentle stretch; for example, spasticity of the tibialis posterior is assessed by everting the foot, while the gastrosoleus complex is assessed by dorsiflexion.
  - The strength of individual muscle groups should be graded if possible.
- Testing the passive range of motion determines whether the deformity is dynamic (full passive range of motion) or whether there is a myostatic component (restriction of passive range of motion).
  - While bench examination provides a useful estimate of motion, an examination under anesthesia provides the most accurate evaluation, as spasticity is eliminated. Such an examination is always performed at the time of surgery to finalize the treatment plan.
For patients with an equinovarus deformity, the examination focuses on the degree of passive eversion and dorsiflexion. Equinus contracture is often limited to the gastrocnemius muscle but may also involve the soleus muscle.

The Silverskiold test evaluates the contribution of each component of the gastrosoleus complex to an equinus contracture, and the amount (in degrees) of passive dorsiflexion is quantified with the knee both flexed and extended. The degree of passive dorsiflexion with the knee extended indicates the absolute magnitude of contracture from the gastrocnemius and soleus. Flexion of the knee relaxes the gastrocnemius muscle and allows the contribution of the soleus to be quantified.

Selectivity of motor control is commonly impaired in children with cerebral palsy, and the distal motor groups are more involved than the proximal groups.

Selectivity is tested by asking the patient to contract an isolated muscle group against resistance.

If the patient can isolate the muscle and no “overflow” movement is observed in other muscle groups of the same limb, then adequate selectivity is present.

Most commonly, movements of more than one muscle group, or the entire limb, are elicited when testing individual muscle groups.

IMAGING AND OTHER DIAGNOSTIC STUDIES

While imaging studies are not routinely obtained, plain radiographs of the foot may be helpful in the presence of a fixed deformity.

Weight-bearing anteroposterior (AP) and lateral views are reviewed, and a Harris heel view may be considered to evaluate the degree of hindfoot varus in the weight-bearing position.

Instrumented motion analysis (gait analysis) is used in many centers to assist with surgical decision making.

Slow-motion video is an important component of the assessment and supplements the findings on observational gait analysis.

Dynamic electromyelography (EMG) monitors the electrical activity of the tibialis posterior and tibialis anterior throughout the gait cycle, determining whether individual muscles act out of phase or whether they are continuously active throughout the gait cycle (most common).

While a surface electrode may be used to assess the tibialis anterior, monitoring of the tibialis posterior requires insertion of a fine-needle electrode.

A recent study determined that the deformity was due to the tibialis posterior in 33%, the tibialis anterior in 34%, or both (31%).

The hindfoot varus usually occurs in both the stance and swing phases of gait.

Findings on pedobarography include increased pressure across the lateral midfoot, decreased pressure on the heel at the time of initial contact, and increased pressure on the lateral border of the foot throughout stance phase.

NONOPERATIVE MANAGEMENT

Specific aspects within a comprehensive physical therapy program include stretching exercises to maintain or improve range of motion and strengthening exercises to reduce dynamic muscle imbalance.

An ankle-foot orthosis is often required to maintain alignment of the ankle and hindfoot during ambulation.

The orthotic facilitates clearance during swing phase by maintaining the foot in a neutral position, prepositions the foot for initial contact with the ground, and promotes stability during stance phase.

Night splinting may help to prevent myostatic contracture.

Injection of botulinum toxin A (Botox or Dysport) into the tibialis posterior, the gastrocsoleus, or both results in a reversible chemical denervation that decreases spasticity for about 3 to 6 months.

In addition to reducing dynamic muscle imbalance, a temporary reduction in spasticity may facilitate stretching exercises, improve bracing tolerance, and delay the need for surgical intervention.

SURGICAL MANAGEMENT

Surgical treatment of the spastic equinovarus foot is offered when the deformity impairs ambulation, interferes with braking, or both.

Recent evidence suggests that the recurrence rate may be higher if the procedure is performed before 8 years of age, so it may be beneficial to delay split tendon transfer beyond this age if possible.

Lengthening of the tibialis posterior muscle may be adequate for mild deformities.

Techniques include a distal Z-lengthening of the tendon and an intramuscular recession proximally.

The goal of tendon transfer is to balance the muscle forces across the hindfoot to maintain a neutral position during the swing and stance phases of gait.

A split tendon transfer is preferred as transfer of the entire tendon is associated with a significant risk of overcorrection. A normal passive range of motion is a prerequisite.

In the presence of fixed soft tissue or bony deformity, concomitant muscle lengthening, with or without osteotomy, may be required to restore motion and alignment.

Options for split tendon transfer include both the tibialis anterior and the tibialis posterior.

Dynamic EMG can help to determine whether one or both muscles are contributing to the deformity.

A split tibialis anterior tendon transfer, with or without concomitant intramuscular lengthening of the tibialis posterior, may be required in a subset of patients with an equinovarus deformity.

Several techniques have been described for split tibialis posterior transfer.

The most common involves transferring the split tendon (posterior to the tibia and fibula) to the peroneus brevis, either at its insertion or just behind the lateral malleolus. This approach focuses on balancing inversion–eversion but does not address dorsiflexion weakness.

An alternative technique, which may be considered when there is inadequate active dorsiflexion, involves anterior transfer of the split tendon through the interosseous membrane to the peroneus brevis or the lateral cuneiform.

Biomechanical investigations using cadaveric specimens have studied the technical aspects of the split tendon transfer.

Moran et al found that all routing variations reduce the ability of the tibialis posterior to invert the hindfoot, that...
In the technique described by Kaufer, the split tendon is routed behind the tibia and fibula (A) and inserted into the peroneus brevis tendon (B). C. Alternatively, the split tendon can be woven into the peroneus brevis just behind the lateral malleolus. This approach is easier and works as well when the tendon is not long enough.

In the technique described by Muller et al, the split tendon is passed through the interosseous membrane (A) and through a subcutaneous tunnel to insert into the peroneus brevis tendon (B). C. Saji et al transferred the split tendon through the interosseous membrane into the lateral cuneiform.
there was no difference between attaching the tendon proximally or distally into the peroneus brevis, and that transfer through the interosseous membrane reduced the ability to plantarflex the foot. Calculation of muscle moment arms across the subtalar joint suggested that adequate results could be achieved over a wide range of tensioning.

- Other procedures are commonly performed in concert with a split tibialis posterior tendon transfer.
  - Lengthening of the tendo Achilles (gastrocnemius with or without the soleus) is required in most cases of spastic equinovarus deformity. Depending on the degree of myostatic contracture, this can be achieved with either a recession technique (Vulpius, Baker) or a tendinous lengthening (open Z-plasty, percutaneous or open sliding lengthening).
  - Fixed varus deformity of the hindfoot requires a calcaneal osteotomy, either a lateral closing wedge osteotomy (Dwyer) or a sliding lateral displacement osteotomy of the calcaneus. Options for fixation include a staple, a Steinmann pin, or a screw.
  - Older patients with a severe fixed equinovarus deformity may require a triple arthrodesis.
  - A subset of patients may also have tibial torsion of a degree that warrants surgery. Consideration should be given to staging the procedures, as one study suggested that tibial derotational osteotomy should not be performed at the time of tendon transfer because of the increased risk of failure of the tendon transfer.

### Preoperative Planning
- The indications for surgery are based on the physical examination, with or without an instrumented motion analysis study.
- An examination under anesthesia (eliminates spasticity) is performed to assess the range of motion and helps to finalize the surgical plan with respect to the type of soft tissue lengthening procedure.
- The findings will solidify the operative plan with respect to the need for muscle lengthening, the technique employed for lengthening (Z-lengthening versus recession), and whether any supplementary bony procedures are required.

### Positioning
- The patient is placed supine.

### Approach
- Either three or four incisions are employed for split tibialis posterior tendon transfer.
- The tendon must be released from its insertion, tunneled either anteriorly (through the interosseous membrane) or posteriorly behind the tibia and fibula, and then attached to either the peroneus brevis or lateral cuneiform.

### SPLIT TIBIALIS TENDON TRANSFER TO PERONEUS BREVIS (AFTER KAUFER)

- A longitudinal incision is made over the insertion of the tibialis posterior on the navicular, and the sheath is opened (TECH FIG 1A).
  - The plantar half of the tendon is released, and the tendon is split longitudinally (TECH FIG 1B,C).
- A second incision is made just posterior to the medial malleolus, extending proximally for 4 cm (TECH FIG 1D,E).
  - The sheath of the tibialis posterior is split longitudinally, and the free end of the tendon is delivered into this wound.
  - The longitudinal split in the tendon is extended proximally to the musculotendinous junction.
- The third longitudinal incision is made about 2 cm proximal to the tip of the lateral malleolus, and extends proximally (TECH FIG 1F,G).
  - The peroneal tendon sheath is incised longitudinally.
  - The split tendon is then passed posterior to the tibia and fibula, and anterior to the neurovascular bundle, into the third incision. The split tibialis posterior tendon can be sutured into the peroneus brevis tendon at this level (see Fig 1C) or can be transferred distally, which requires a fourth incision.
- The fourth longitudinal incision is made distal to the lateral malleolus, overlying the insertion of the peroneus brevis into the fifth metatarsal base (TECH FIG 1H).
A second incision is made just posterior to the medial border of the tibia, proximal to the medial malleolus. The fascia is divided longitudinally, and the tibialis posterior muscle is identified. The suture ends are delivered from distal to proximal through the tendon sheath, and the split tendon is brought out from the second incision. A short longitudinal incision is then made over the lateral side of the leg, posterior to the fibula, across from the medial incision. The split tendon is then passed from medial to lateral along the posterior border of the tibia and the fibula, anterior to the neurovascular bundle. The tendon is delivered through the lateral wound. The fourth incision is distal, and just behind the fibular malleolus. The peroneal sheath is incised longitudinally. The split tendon is brought through the sheath from the more proximal incision through this distal incision. The tibialis posterior tendon is then woven through small longitudinal splits in the peroneus brevis and anchored with nonabsorbable suture.

- The split tibialis posterior tendon is then passed through the sheath, along the peroneus brevis, into the distal incision (TECH FIG 1I).
- The tendon is woven through the peroneus brevis and secured with nonabsorbable sutures (TECH FIG 1J,K).
- The foot is held in a neutral position.
- A long-leg cast with the knee extended and the foot at neutral (weight bearing as tolerated) is worn for 4 weeks, and then a short-leg cast is worn for 4 additional weeks.
- No bracing is required if the patient is able to actively dorsiflex the foot to neutral. If not, an ankle–foot orthosis is recommended.

A medial approach extends from 5 cm proximal to the medial malleolus to the insertion of the tibialis posterior tendon on the navicular.

- The anterior (dorsal) half of the tendon is released and split up to the musculotendinous junction, preserving the retinaculum.
- A 2-cm incision is made anteriorly, and a window is made in the interosseous membrane just proximal to the syndesmotic ligament.
- The split tendon is passed anteriorly through the interosseous membrane.
A 2-cm incision is made over the lateral cuneiform, and the split tendon is delivered subcutaneously and then passed through a drill hole in the lateral cuneiform. The tendon is secured over a button on the plantar surface of the foot, with the foot held in a neutral position.

The patient is placed in a below-knee cast with the foot in slight valgus and neutral dorsiflexion–plantarflexion. Weight bearing is allowed after 3 weeks, and a brace is worn for 6 to 12 months.

POSTOPERATIVE CARE

- A longitudinal incision is made at the insertion of the tibialis posterior, and the plantar half of the tendon is released from the navicular. The muscle is split longitudinally as described previously.
- A second incision is made proximally, and the tendon is delivered through this incision and split up to the musculotendinous junction.
- The third incision is made anteriorly, and the tendon is delivered through a window in the interosseous membrane (just above the anterior inferior syndesmotic ligament).

The fourth incision is made over the distal insertion of the peroneus brevis tendon, and the tibialis posterior is passed through a subcutaneous tunnel and woven into the distal peroneus brevis with nonabsorbable suture.

A long-leg cast is used for 3 weeks and then a short-leg cast (weight bearing as tolerated) for an additional 3 weeks.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Define etiology of equinovarus preoperatively</th>
<th>Dynamic EMG may help to determine which muscle is responsible (tibialis posterior, tibialis anterior, or both).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achieve full range of passive motion</td>
<td>The patient may need additional procedures such as osteotomy to restore alignment and motion.</td>
</tr>
<tr>
<td>Avoid overcorrection</td>
<td>The transfer should be tensioned with hindfoot at neutral to slight valgus.</td>
</tr>
<tr>
<td>Avoid recurrence</td>
<td>Concomitant tibial derotational osteotomy should not be performed.</td>
</tr>
<tr>
<td></td>
<td>The surgeon should wait until after 8 years of age to perform the procedure.</td>
</tr>
</tbody>
</table>
COMPPLICATIONS

- While immediate complications are uncommon (wound infection, pull-out of the transferred tendon, undercorrection or overcorrection), late complications are more common and relate to the effects of many variables in a growing child with spasticity and persistent neuromuscular imbalance.
- Recurrent deformity results from persistent muscle imbalance, pull-out of the tibialis posterior from the peroneus brevis, insufficient tension when suturing the tibialis posterior tendon, or other variables associated with growth.
- Overcorrection into valgus is most common in younger children and in patients treated by concurrent tibial derotational osteotomy.

REFERENCES

DEFINITION
- Adolescent bunion is a complex deformity consisting of medial deviation of the first metatarsal (metatarsus primus varus), lateral deviation of the great toe through the first metatarsophalangeal joint (hallux valgus), and enlarged medial eminence of the distal first metatarsal.
- Other findings include contracted lateral and lax medial soft tissues of the first metatarsophalangeal joint, lateral subluxation of the sesamoids, pronation of the great toe, and plantar subluxation of the abductor hallucis muscle.

ANATOMY
- Metatarsus primus varus
- Obliquity of the medial cuneiform–first metatarsal joint
- Medial prominence of the first metatarsal head
- Valgus angulation through the first metatarsophalangeal joint
- Minimal or no deformity through the first interphalangeal joint
- Lateral translation of sesamoids
- Plantar-lateral positioning of the abductor hallucis with unopposed pull of the adductor hallucis muscle
- Lateral subluxation of the extensor hallucis longus and flexor hallucis longus tendons
- Pronation (internal rotation) of the first toe
- Differs from an adult bunion:
  - Physis of the first metatarsal and proximal phalanx are located proximally (this limits ability to perform proximal osteotomies in skeletally immature patients).
  - The first metatarsophalangeal joint does not have osteoarthrosis.
  - The medial eminence is less prominent in adolescent bunions than in adult bunions.

PATHOGENESIS
- Multiple theories exist; it is difficult to differentiate primary findings from secondary ones.
- Extrinsic and intrinsic factors contribute to formation of adolescent bunions.
- Intrinsic
  - Metatarsus primus varus
  - Obliquity of the medial cuneiform–first metatarsal joint
  - Long first metatarsal
  - Ligamentous laxity
  - Heelcord contracture causes foot pronation, which in turn places a valgus force on the hallux while walking
- Extrinsic
  - Shoe wear, particularly those with a narrow toe and elevated heel

NATURAL HISTORY
- Natural history is believed to be favorable. Most patients with adolescent bunions can be treated nonoperatively.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients typically present in late childhood or adolescence.
- Complaints about appearance of foot.
- Complaints of pain over the medial exostosis or about the first metatarsophalangeal joint.
- Pain is exacerbated by shoe wear.
- Complaints about finding shoes that are comfortable.
- Physical examination
  - Areas of tenderness: first metatarsophalangeal joint, medial prominence
  - Alignment when standing and walking
  - Mobility of first metatarsophalangeal joint
  - Skin condition: the clinician should search for calluses, areas of irritation
  - Foot and ankle range of motion
  - Careful neurologic examination

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standing anteroposterior (AP), lateral, and oblique radiographs should be obtained if surgical correction is being contemplated.
- Measurements on the AP radiograph (FIG 1)
  - Intermetatarsal (IM) angle: normal is 9 degrees or less
  - IM angle usually is 12 to 18 degrees in adolescent bunion.

FIG 1 • Measurements made on the AP radiograph.
Expose the medial first metatarsophalangeal joint.

Make a distally based Y-shaped incision in the capsule and periosteum. The stem of the Y is over the metatarsal, while the upper portion of the Y is formed distally.

The joint and medial eminence are then exposed.

A medial release of the first metatarsophalangeal joint is performed. Leave the lateral portion of the joint intact to avoid disrupting the blood supply to the head of the first metatarsal.

The first cut involves removing the prominent medial eminence with an osteotome, starting distally at the sagittal groove (groove of Clark).

The second cut is made at the distal metaphyseal–diaphyseal junction of the first metatarsal. This should be perpendicular to the shaft of the first metatarsal and extend two-thirds the width of the shaft of the first metatarsal (TECH FIG 1A).

The third, proximal cut is made about 2 to 3 mm proximal to the first cut, and is created completely across the first metatarsal. The cut is oriented perpendicular to the shaft of the second metatarsal when viewed from the dorsum of the foot and is angled (when viewed from the medial aspect of the first metatarsal) to create a small plantar-based wedge (TECH FIG 1B). This ensures that the distal fragment does not dorsiflex during reduction of the osteotomy.

The interposed bone is removed.

The osteotomy is reduced and pinned with two smooth 0.062-inch Kirschner wires (TECH FIG 1C).

The prominence of the distal portion of the metatarsal shaft is smoothed off with a rongeur, and a capsulorrhaphy is performed with absorbable sutures.

Sterile dressings are applied and the toe is splinted in neutral to slight plantarflexion. A short-leg cast is usually applied over the dressing for additional protection.
POSTOPERATIVE CARE
- The toe is splinted in slight flexion.
- The dressing is covered with a cast.
- Weight bearing is allowed as tolerated.
- Pins are removed in 6 weeks.

OUTCOMES
- Most studies report 65% to 85% good to excellent results with the Mitchell osteotomy.
- The modified Mitchell osteotomy (described above) produces 81% satisfactory results, with no cases of malunion, nonunion, avascular necrosis of the first metatarsal head, infection, or transfer metatarsalgia.
- Sixty percent good to excellent results are reported in younger patients.

COMPLICATIONS
- Infection
- Neurovascular injury
- Inadequate fixation of the osteotomy
- Malunion or nonunion of the osteotomy
- Avascular necrosis of the first metatarsal head
- Transfer metatarsalgia
- Recurrence
- Stiffness of the first metatarsophalangeal joint
- Hallux varus (overcorrection)
- Pronation
- Pain

REFERENCES
DEFINITION

- Overlapping fifth toe is a congenital condition where the fifth toe is rotated and overrides the fourth toe.
- It is frequently bilateral.
- Males are affected as frequently as females.

ANATOMY

- There are six main components:
  - The fifth toe may be smaller than normal.
  - The fifth toe is adducted toward the fourth toe.
  - The fifth metatarsophalangeal joint has a dorsiflexion contracture.
  - The phalanges of the fifth toe are rotated laterally.
  - The fifth extensor digitorum longus tendon is shortened.
  - The fifth metatarsophalangeal joint is dislocated dorsally.

PATHOGENESIS

- The exact pathogenesis is unknown, but the condition is believed to be secondary to a congenital contracture of the fifth extensor digitorum longus tendon.

NATURAL HISTORY

- This condition rarely causes pain or difficulty in shoe wear in children less than 10 years of age.
- In older children and adolescents there will be painful dorsal callosities about 50% of the time.
- There may also be difficulty in finding shoes that fit appropriately in older children and adolescents.
- Parents are frequently concerned about the cosmetic appearance of the foot.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The fifth toe will be dorsiflexed, adducted, and laterally rotated. It will not be passively correctable into a neutral position.
- A careful neurovascular examination should be performed and documented.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain anteroposterior (AP), lateral, and oblique radiographs may be obtained and will demonstrate a dorsolaterally subluxated fifth metatarsophalangeal joint.

NONOPERATIVE MANAGEMENT

- Conservative treatment (eg, stretching, splinting, taping) is ineffective in the treatment of this condition.

SURGICAL MANAGEMENT

- Surgery is indicated when nonoperative treatment fails, such as failure to find comfortable shoes, or when there is intractable pain from shoes.

Positioning

- The patient is supine, preferably with a bolster beneath the ipsilateral hemipelvis to make the lateral foot more accessible.
- A tourniquet should be used during the procedure.
BUTLER PROCEDURE FOR OVERLAPPING FIFTH TOE

- A dorsal racquet incision is made about the toe with a second handle to the racquet added on the plantar aspect of the toe (TECH FIG 1A).
- The plantar handle should be slightly longer than the dorsal handle and directed slightly laterally.
- The skin flaps are elevated and the tight extensor tendon is exposed.
- Care should be taken to preserve the neurovascular bundles (TECH FIG 1B).
- The extensor tendon is divided, and a dorsomedial release of the fifth metatarsophalangeal joint is performed. If needed, the plantar aspect of the fifth metatarsophalangeal joint may be dissected off the metatarsal head and divided to increase joint mobility (TECH FIG 1C).
- The toe should freely move plantarward and laterally into its corrected position (TECH FIG 1D).
- There should be no tension on the toe, and the toe should rest within the plantar handle of the racquet incision.
- Interrupted sutures are then used to hold the toe reduced in place (TECH FIG 1E).
- A cast or hard-soled shoe can be used postoperatively.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Incomplete release of soft tissues</th>
<th>The surgeon should assess the plantar capsule for tightness as well as the dorsal capsule.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurovascular compromise</td>
<td>The neurovascular bundles should be protected during the procedure, and traction on the fifth toe is avoided. Circumferential dressings about the toe are avoided.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Postoperative care includes sterile dressings, and allowing mobilization and weight bearing as tolerated.

OUTCOMES

- This procedure has a high patient satisfaction rate (about 90%) in various studies.
- Black et al\(^1\) reported 94% good or excellent results.

COMPLICATIONS

- Incomplete correction
- Neurovascular compromise
- Scar contracture
- Infection

REFERENCES

DEFINITION
- A cavus foot deformity in children develops from muscle imbalance that leads to forefoot pronation in relation to the hindfoot. When well established, it is readily recognizable by an abnormally high medial arch that persists with weight bearing (FIG 1).
- Commonly a result of hereditary sensory motor neuropathy (HSMN), it is frequently difficult to determine the underlying cause.

ANATOMY
- The plantar fascia is an extensive fibrous structure that spans the foot between the medial aspect of the calcaneal tuberosity and the transverse metatarsal ligaments at the metatarsal heads (FIG 2). It stabilizes the arch of the foot and protects the underlying neurovascular structures from injury.
- During the gait cycle, the plantar fascia assists in the dynamic changes of the arch.
  - At heel strike there is forefoot supination and heel inversion, while eccentric contraction of the quadriceps muscles absorbs much of the energy.
  - During mid-stance, there is unlocking of the midtarsal joints with hindfoot pronation and internal tibia rotation.
  - At toe off the plantar fascia helps lock the midtarsal joints to assist the foot to be a rigid lever for forward propulsion.
- This is termed the windlass effect, when passive dorsiflexion at the metatarsophalangeal joints tightens the plantar fascia, leading to elevation of the medial arch and tarsal joint stability (FIG 3).

PATHOGENESIS
- In progressive conditions such as HSMN, there is muscle imbalance with weakness of the intrinsic, tibialis anterior, and peroneus brevis muscles. This can lead to a relative overpull of the peroneus longus and posterior tibialis muscles.
- Clinical muscle testing shows that although both peroneal muscles are weak, the larger peroneus longus muscle retains relatively more strength. Differential peroneal nerve compression at the proximal fibula is postulated to cause relative sparing of the peroneus longus innervation.\(^6\)
- CT imaging studies in Charcot-Marie-Tooth disease, a major category of HSMN, showed early foot intrinsic muscle atrophy with sparing of the abductor hallucis and involvement of the peroneus brevis, peroneus longus, and flexor hallucis longus muscles.\(^11\)
- MRI studies have shown dominance in the size of the peroneus longus muscle versus the tibialis anterior.\(^14\)
- The muscle imbalance and intrinsic muscle weakness lead to an unopposed extensor digitorum longus, hyperextension of the lesser toe metatarsophalangeal joints, and phalangeal joint flexion by the long and short toe flexors.
- There is an exaggeration of the windlass effect with claw toe deformities.
- The first metatarsal becomes even more plantarflexed by the action of the peroneus longus and with time becomes fixed in this position.
- The plantar aspect of the foot assumes a tripod position, resulting in hindfoot varus (FIG 4).
- The cavus foot remains a rigid lever throughout stance phase, leading to increased stress and lack of shock absorption, pain, and callosities.
Cavus foot deformity involves either a dorsiflexion deformity of the calcaneus or a forefoot plantarflexion deformity.

The most common cause of progressive bilateral cavus foot deformity is HSMN. HSMN is a group of progressive peripheral nerve diseases and has a heterogeneous genetic classification.

Charcot-Marie-Tooth disease involves types I and II HSMN, with HSMN IA the most common type, seen in 60% of HSMN.

HSMN type I has myelin degeneration, type II is the axonal degeneration form, and type III (Dejerine-Sottas disease) is more severe and presents in infancy.

There are more than 17 different genetic loci determined for CMT.

The prognosis for these progressive conditions is less favorable than for the nonprogressive disorders.

The natural history of HSMN is related to the underlying type.

Progression of muscle involvement begins initially in the intrinsic muscles, followed by the anterior compartment, the peroneal muscles, and then the posterior muscles.

The foot can assume a cavovarus, calcaneocavus deformity or even a valgus deformity and may have more unilateral severity (HSMN type III).

Associated hip dysplasia may be asymptomatic or may present with symptoms. Acetabular dysplasia may be the first indicator of HSMN.

In progressive conditions that are left untreated, a flexible and correctable foot may become rigid with structural bony changes. This can lead to inability to participate in athletics and pain and difficulty with shoe wear and normal walking. Treatment is recommended when the foot is still flexible.

Unilateral cavus foot can have a number of causes. The idiopathic variety may be progressive, with an unpredictable natural history.

**NATURAL HISTORY**

- Cavus foot is rarely present at birth, but develops with time.
- The natural history depends on the underlying diagnosis. The underlying cause affects the outcome, so determination of cause is essential. An underlying diagnosis can be found in the brain, spinal cord, peripheral nerves, or the foot itself.
- Cavus foot deformity can be either progressive or nonprogressive.

**FIG 3** Windlass effect. The foot is an arch. If the plantar tissues tighten and become shorter, the fixed length of the arch forces it to become taller.

**FIG 4** Tripod effect. Weight bearing is shared between the heel and medial and lateral columns of the forefoot. If the medial column is in plantarflexion, the heel is forced into varus with weight bearing.
Patients with nonprogressive conditions, as seen in cerebral palsy or spinal cord disorders, may fare better but still can have long-term problems with athletics, metatarsalgia, plantar fasciitis, and iliotibial band syndrome.\(^9\)

Calcaneocavus deformity is often seen with nonprogressive conditions such as spina bifida or clubfoot deformity with an overlengthened heel cord. Problems include heel pain or heel pad ulceration if sensation is deficient, and weak or no push-off or crouch gait if not braced.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The physical examination is used to determine the underlying diagnosis and to determine characteristics of the cavus foot deformity that would indicate surgical correction is needed.
- Physical examination should include observation of the spine and its range of motion. Skin changes, scoliosis, or kyphosis may represent an underlying spinal cord abnormality.
- The upper extremities are evaluated for intrinsic muscle wasting and weakness. Atrophy or weakness in the hand suggests HSMN.
- The clinician evaluates hip range of motion and looks for Trendelenburg gait. Bilateral hip dysplasia newly diagnosed in a teenager is highly suggestive of HSMN.
- Lower extremities are evaluated for size, muscle strength, and firmness and tenderness along the course of major nerves. Bilateral calf atrophy is seen with spina bifida and may be present in severe HSMN. Unilateral atrophy may be seen with diastatomyelia, tethered spinal cord, or split cord malformation.
- A neural examination is performed. Patients with HSMN may have decreased sensation to light touch, position sense, or vibration. There may be obvious weakness of the anterior tibialis muscle, preventing ability to heel walk. Deep tendon reflexes may be decreased or absent in HSMN and Friedrich ataxia.
- The foot is examined for deformity (cavus, cavovarus, or calcaneocavus). Bilateral deformity is typical for HSMN. Unilateral deformity may be present with a structural abnormality. The clinician locates the apex of the midfoot deformity and determines whether the foot is rigid or flexible. Hindfoot is rarely in equinus.
- The Coleman block test is performed. If hindfoot varus corrects to neutral position, then the hindfoot is flexible and the medial forefoot is the source of hindfoot varus.
- The toes are examined for any deformities. Cavus foot may not have associated toe abnormality. Rigid claw toe abnormality requires surgical treatment.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Bilateral standing anteroposterior (AP) and lateral radiographs are standard.
- On the lateral weight-bearing radiograph the clinician should determine the calcaneal pitch; greater than 30 degrees indicates chronic gastrocnemius-soleus weakness (**FIG 5A**).
- The Meary angle, the angle between the shaft of the first metatarsal and the axis of the talus, is normally 0 degrees (**FIG 5A**).
- Ankle equinus, forefoot equinus, the amount of cavus, and the apex of the midfoot deformity are determined.
- With the foot positioned for the Coleman block test, a lateral radiograph of the foot can document the degree of hindfoot correction.\(^1\)
- In the patient with known or possible HSMN, a standing AP pelvis view is obtained to document the presence of hip dysplasia.\(^15\)
- Standing full-length posteroanterior and lateral spine radiographs are obtained when a spinal abnormality is suspected or if the underlying diagnosis is in question.

**FIG 5 • A.** A 15-year-old boy with hereditary sensory motor neuropathy type 1A with severe bilateral cavus foot deformity. Lateral standing radiograph of right foot. The Meary angle, measured between the axis of the talus and the first metatarsal, is 25 degrees, but it should be 0 degrees. The calcaneal pitch angle, measured between the horizontal and the plantar aspect of the calcaneus, is 26 degrees but should be less than 20 degrees. **B.** A 5-year-old girl with 28-degree right thoracic scoliosis. MRI T1-weighted sagittal view of large cervical thoracic syrinx with Chiari I malformation at foramen magnum. (**continued**)
MRI of the entire brainstem and cervical, thoracic, and lumbar spine is performed when a spinal cord tumor, syrinx, tethered cord, or Chiari I malformation is of concern (FIG 5B,C).

Nerve conduction and electromyelographic (EMG) studies may be done to evaluate for HMSN. In HMSN type I, motor nerve conduction is markedly slowed. In HMSN type II, there is near-normal motor nerve conduction but EMG evidence of denervation. Molecular DNA testing of peripheral blood may be used for diagnosing HSMN; therefore, sural nerve biopsy is generally not necessary.

DIFFERENTIAL DIAGNOSIS

- Hemiplegic cerebral palsy
- Spastic diplegic cerebral palsy with calcaneocavus foot deformity if the Achilles tendon has been overlengthened
- Friedrich ataxia
- Myelodysplasia
- Chiari I malformation with syringomyelia and scoliosis
- Diastatomegaly and split cord malformation
- Poliomyelitis
- Spinal cord tumors
- Guillain-Barré syndrome
- Peripheral nerves: HSMN types I and II
- Sciatic nerve injury
- Peripheral nerve tumor
- Silent compartment syndrome after tibia or foot fracture
- Residual deformity of clubfoot
- Idiopathic
- Subtalar tarsal coalition (rare)
- Severe limb-length discrepancy leading to a fixed equinus gait

NONOPERATIVE MANAGEMENT

Nonoperative management is appropriate for mild or nonprogressive deformity.

- Inserts that support the lateral forefoot and eliminate hindfoot inversion may be helpful.
- Gel heel cups and replacing worn athletic shoes assist the stiff foot in energy absorption.
- Extra-depth shoes and orthotics that unload pressure points may help in more advanced cases.

SURGICAL MANAGEMENT

- Surgical treatment is necessary for more severe nonprogressive cases or for progressive cases. The functional goal is to correct the cavus deformity and to obtain a mobile, plantigrade, and well-balanced foot while avoiding common pitfalls. Treatment is best performed when the foot is still flexible. Staged procedures, correcting deformity first and balancing muscles at a later stage, may be safer for the foot.

Specific principles for surgical decision making include the following:

- Surgical management is usually needed when there is an identified functional problem or progression of the deformity. For progressive cavus deformity, it is better to use simple procedures early.
- Plantar fascia release is the initial procedure of choice in young children with nonprogressive deformity. We prefer to do this through a medial plantar incision with postoperative serial corrective casting used to gain further correction. Plantar fascia release is generally done with other procedures.
- The surgeon can correct any underlying muscle imbalance with tendon transfers or lengthening or by bony correction of the lever arm that the muscles work through.

- In a more rigid deformity, a forefoot osteotomy is used to correct the pronated medial forefoot.

- The goal is to correct the fixed deformity while preserving joint mobility. The site of the osteotomy is determined by the location of the deformity apex. The most common are first metatarsal dorsal closing, medial cuneiform plantar opening, and midfoot wedge osteotomies.

- For marked and rigid forefoot equinus (FIG 6), a more extensive midfoot osteotomy is used, which is typically needed during the patient’s second decade.\(^1^7\)

- Calcaneal osteotomy is used if the Coleman block test indicates a fixed heel varus. We recommend a slide osteotomy through a lateral approach, although a lateral closing wedge alone or combined with the slide may also be used for more correction. Tendon transfers are frequently required to achieve a balanced foot. These may involve a transfer of the relatively strong posterior tibialis tendon to the dorsum of the foot,\(^1^\) a Jones procedure in which the extensor hallucis tendon is transferred to the neck of the first metatarsal with fusion of the great toe interphalangeal joint, a split or complete anterior tibialis tendon transfer if

**FIG 5 • (continued)** C. MRI T1-weighted axial view showing large central cord syrinx.

**FIG 6 •** An 18-year-old girl with hereditary sensory motor neuropathy type 1A with marked cavus and fixed midfoot deformity and shortening. Owing to her age and the degree of rigid deformity, a midfoot osteotomy is required.
the muscle has preserved strength, or a transfer of the peroneus longus to the peroneus brevis.\(^{18}\)
- Calcaneal cavus deformity may need a posterior sliding calcaneal osteotomy to increase the calcaneal lever arm. We prefer this to be a crescent-shaped cut. A plantar fascia release facilitates posterior sliding of the distal fragment.
- Triple arthrodesis is used as a salvage procedure for rigid hindfoot deformity. We are reluctant to recommend this for a foot with sensory deficit since the long-term outcome when this procedure is used is poor.\(^{16}\) With a triple arthrodesis, tendon transfers may still be necessary to maintain a balanced foot.

**Preoperative Planning**
- Intraoperative epidural anesthesia may be continued in the postoperative period.
- Preoperative antibiotics are given.
- A tourniquet allows optimal visualization of the operative site.
- In patients with HSMN, the surgeon must be very careful about tourniquet use, since the sciatic and femoral nerves in the thigh are very sensitive to the pressure and time effects of the tourniquet. We recommend the minimal pressure needed and less than 1 hour of inflation time.

**Positioning**
- The patient is positioned supine on a radiolucent imaging table.

**Approach**
- A combination of surgical procedures may be needed to fully correct the foot deformity.
- For most deformities, an extensive plantar release is used.
- As the extensor hallucis longus muscle function may be spared in HSMN, the Jones procedure is useful for the child with a plantarflexed medial column and dynamic great toe hyperextension during swing phase. It is generally combined with a medial or midfoot osteotomy.
- For more extensive and rigid deformity, an osteotomy may be needed. A younger patient may require only an osteotomy of the proximal first metatarsal or first cuneiform. A midfoot wedge osteotomy is useful for the rigid midfoot deformity in an adolescent or young adult when the midfoot does not sufficiently correct after the plantar fascia release. If the lateral and medial aspects of the midfoot are in equinus, an osteotomy across the entire midfoot will more reliably correct the deformity than a medial column osteotomy.
- The lateral calcaneal slide osteotomy is used to correct fixed hindfoot varus that does not correct with the Coleman block test.
- Advantages include use of a simple single cut with control of the amount of correction needed.
- The posterior slide calcaneal osteotomy is useful in the calcaneocavus foot with a high calcaneal pitch angle.
- Incisions should be longitudinal and placed over the areas of relevant pathology (FIG 7).
- A cavus foot is short and will be lengthened in the course of treatment. It may be safer to obtain some of the correction with postoperative corrective casts rather than doing all of the correction at the initial surgery.

**PLANTAR RELEASE**
- A longitudinal incision is made medially over the plantar fascia. Sharp knife dissection is used through the skin and subcutaneous fat (TECH FIG 1A).
- The abductor hallucis is the first structure identified and is released off its deep fascia (TECH FIG 1B).
- The fascia deep to the abductor hallucis is next exposed. The posterior tibial nerve and artery are identified proximally and followed distally by releasing the overlying fascia. Note the division of the posterior tibial nerve into its plantar medial and lateral branches.
- Posterior to the neurovascular bundle the plantar fascia is exposed as it attaches to the medial tubercle of the calcaneus.
- The flexor digitorum brevis, quadratus plantae, and abductor digiti quinti muscles are released at their proximal origins with Mayo scissors.
- Capsulotomies of the medial talonavicular and subtalar joints may be needed if superficial release is not adequate to achieve correction.\(^{2}\)
- Severe cases may need posterior tibialis tendon lengthening or transfer.
- The incision is loosely closed with interrupted sutures. By widely spacing the sutures, blood can drain and not cause excessive postoperative pressure.
- In severe cases serial casting may be necessary after the release.
A plantar medial release should also be performed if an osteotomy is required. A stiff forefoot, an older patient, or painful forefoot calluses indicate the need for an osteotomy. Depending on the apex of the deformity, the osteotomy can be performed on the medial cuneiform or the first metatarsal. In a younger child, it may be safer to avoid the proximal metatarsal physis and perform a medial cuneiform osteotomy. The osteotomy can be performed either as a first metatarsal dorsal-based closing wedge osteotomy or as a medial cuneiform plantar-based open wedge. The first metatarsal dorsal closing wedge osteotomy does not require a bone graft, has one bony surface to heal, and can be held closed with a single screw. However, it may shorten the metatarsal slightly. The first cuneiform plantar open wedge osteotomy requires only a single cut, the amount of correction can be fine-tuned after the bone has been cut, and it does not shorten the foot, but a bone graft is required to hold it open, typically an allograft. For a proximal, dorsal-based oblique closing wedge first metatarsal osteotomy, a longitudinal incision is made directly over the proximal metatarsal; be careful to protect the dorsal digital nerve (TECH FIG 2A,B). Subperiosteal dissection of the proximal metatarsal is used; be careful to leave the plantar periosteum and soft tissue intact.

Two small-diameter Steinmann pins are drilled at the site of the bone cuts, converging at the plantar apex. The apex of the correction is quite proximal and plantar. A bony and soft tissue posterior hinge is left intact so that the osteotomy is an incomplete closing wedge. A small oscillating saw is used to make the bone cuts. The wires are used to guide the cuts toward the plantar apex. A small osteotome and pituitary rongeur may be used to remove some of the bone at the apex.

MEDIAL COLUMN OSTEOTOMY

- A plantar medial release should also be performed if an osteotomy is required.
- A stiff forefoot, an older patient, or painful forefoot calluses indicate the need for an osteotomy.
- Depending on the apex of the deformity, the osteotomy can be performed on the medial cuneiform or the first metatarsal. In a younger child, it may be safer to avoid the proximal metatarsal physis and perform a medial cuneiform osteotomy.
- The osteotomy can be performed either as a first metatarsal dorsal-based closing wedge osteotomy or as a medial cuneiform plantar-based open wedge.
- The first metatarsal dorsal closing wedge osteotomy does not require a bone graft, has one bony surface to heal, and can be held closed with a single screw. However, it may shorten the metatarsal slightly.
- The first cuneiform plantar open wedge osteotomy requires only a single cut, the amount of correction can be fine-tuned after the bone has been cut, and it does not shorten the foot, but a bone graft is required to hold it open, typically an allograft.
- For a proximal, dorsal-based oblique closing wedge first metatarsal osteotomy, a longitudinal incision is made directly over the proximal metatarsal; be careful to protect the dorsal digital nerve (TECH FIG 2A,B).
- Subperiosteal dissection of the proximal metatarsal is used; be careful to leave the plantar periosteum and soft tissue intact.

A proximal incomplete dorsal-based closing wedge osteotomy of proximal metatarsal. The plantar aspect of the metatarsal and soft tissues are left intact to act as a hinge to allow closure of the osteotomy. Steinmann pins are placed to accurately guide the bony cuts. (continued)
Interphalangeal Joint Fusion

- Through the transverse incision over the IP joint, the incision is carried down to the extensor hallucis tendon.
- The tendon is transected at the level of the IP joint and the IP joint capsule is incised transversely.
- Continue with the no. 15 blade to expose the articular distal aspect of the proximal phalanx.
- A rongeur is used to remove the articular cartilage and some of the subchondral cortical bone on both sides of the IP joint. Only a minimal amount of bone is removed.
- A cannulated 4.0-mm screw is used for fixation. This is placed by retrograde insertion of a guidewire through the center of the distal phalanx, exiting distally just plantar to the nail.
- The IP joint is then reduced in a neutral position and the screw is inserted; be careful to provide compression at the IP joint.
- Proper length places the tip of the screw into the proximal aspect of the proximal phalanx.

When sufficient bone has been removed from the apex, the cut ends can be slowly closed together, while maintaining integrity of the bony hinge. A wire, screw, or dorsal plate can be used to secure the corrected osteotomy.

In a younger child with an open metatarsal physis or when the deformity apex is at the medial cuneiform, the opening wedge osteotomy can be performed at this level (TECH FIG 2C,D).
Transfer of the Extensor Hallucis Tendon to the Metatarsal Neck

- A longitudinal skin incision is made over the distal first metatarsal.
- The extensor hallucis tendon is identified and isolated distally until its cut end can be pulled into the incision.
- A 0 suture whipstitch is placed into the distal tendon.
- Subperiosteal exposure of the distal metatarsal allows a transverse drill hole to be made in the metatarsal neck.
  - The drill diameter is roughly the diameter of the extensor hallucis longus tendon.
  - A wire or suture passer aids passage of the extensor hallucis longus tendon through the hole.
- After the medial column or midfoot osteotomy is secured, the end of the extensor hallucis longus tendon is secured to itself (TECH FIG 4).

**TECH FIG 4** • After denuding the interphalangeal joint articular cartilage, a 4.0-mm screw transfixes this joint. A whipstitch is placed into the cut end of the extensor hallucis longus tendon (inset) and the tendon is passed through a transverse drill hole and sutured to itself.

MIDFOOT OSTEOTOMY

- The osteotomy is placed at the apex of the deformity, which should be proximal to any plantar calluses (TECH FIG 5A,B).
  - Too distal placement results in a rocker-bottom residual deformity.
  - If the deformity is severe, a triple arthrodesis may be needed to bring the forefoot into a plantigrade position.
- Muscle balancing procedures will still be required, since the foot will further deform with time if imbalance remains.
  - Several types of osteotomies have been described.  
  6,7,17
- We recommend a simple procedure that uses a truncated wedge placed at the apex of the deformity.
  - Once cut, the distal fragment may be laterally rotated to compensate for excessive medial column flexion.
- A long single dorsomedial skin incision is used at the apex of the deformity.
  - It is more effective to place the osteotomy proximally so that correction is achieved at the level of the deformity; it is generally at the navicular cuneiform joint.
- The Hohmann retractors are placed dorsal and plantar, with the entire midfoot exposed (TECH FIG 5C).

**TECH FIG 5** • A,B. Midfoot osteotomy is centered at the apex of the deformity, typically through the naviculocuneiform joint. Rotation can be added to decrease the excessive amount of medial column plantarflexion. (continued)
Lateral Calcaneal Slide Osteotomy

- The incision is placed lateral to the calcaneus, parallel to the peroneal tendons.
- The peroneal tendons are reflected proximally to gain access to the lateral aspect of the calcaneus tubercle.
- A sharp Hohmann retractor is placed just anterior to the Achilles insertion and another is placed plantar and distal.
- Fluoroscopy can be used to check the orientation of the osteotomy by the position of the retractors (TECH FIG 6A).
- A 1-inch osteotome or saw is used to make the osteotomy across the calcaneus to the opposite cortex. A smooth lamina spreader is used to distract the fragments, and the medial cortex can be freed up with a pituitary rongeur and a Cobb elevator.
- The calcaneal tubercle with the heel is then slid medially about 50% of its width. The correct position is for the heel to be underneath and in line with the tibial shaft (TECH FIG 6B). A laterally-based wedge can also be removed if more correction is needed.
- A large threaded Steinmann pin is placed in the sinus tarsi and directed toward the most posterior inferior aspect of the tubercle (TECH FIG 6C).
- The pin is removed in the clinic in 3 weeks. A cast is used for a total of 6 weeks.
**PEARLS AND PITFALLS**

| Failure to diagnose underlying spine condition | A child presenting with a foot problem must always have the spine examined.  
| | A markedly small foot or calf may be a sign of a split cord malformation or diastatomyelia. |
| Failure to diagnose a structural lesion of a major nerve | The clinician must examine the entire lower limbs along the course of major nerves to detect a localized peripheral nerve tumor or site of nerve compression. |
| Failure to diagnose HSMN | Bilateral cavus may be subtle.  
| | The clinician should always ask about a family history of cavus feet or peripheral neuropathy.  
| | Sometimes there is not an established diagnosis of HSMN in the family. In these cases the family members may need to be examined.  
| | The hand and foot intrinsics are examined.  
| | HSMN may initially present as bilateral adolescent hip dysplasia. |
| Missing a diagnosis with a very treatable lesion | Several conditions may cause a cavus foot deformity. Subtalar coalition generally causes a rigid valgus hindfoot deformity but may cause a spastic hindfoot varus (FIG 8). |
| Insufficient surgical procedure | With adolescence, severe cavus deformities often require a more extensive midfoot osteotomy to correct the deformity. |
| Severe idiopathic cavus foot deformity often requires repeat surgical procedures | The family should be warned that further surgical procedures may be necessary with time as the child grows and the deformity changes. |

---

**Posterior Slide Calcaneal Osteotomy**

- A lateral approach to the calcaneus is used, similar to the lateral slide osteotomy.
- Hohmann retractors are placed for protection and orientation.
- An oblique straight cut may be used, but we prefer a curved cut using a Chiari chisel (TECH FIG 7).
- Once cut, the distal calcaneal fragment is slid posterior and transfixed with a threaded Steinmann pin.
- Since the bone may continue to bleed, loose interrupted suture closure and a bulky dressing are used.
- The pin is removed in 3 weeks and the foot is casted for a total of 6 weeks.

**TECH FIG 7** • Crescent-shaped calcaneal osteotomy allows posterior positioning of the calcaneus to improve the lever arm function of the gastrocsoleus muscles and to decrease the point pressure on the heel.
POSTOPERATIVE CARE
- After a plantar release, the foot should be wrapped with soft bulky cotton and casted with minimal external correction.
- At 2 weeks the sutures are removed and gentle correction is obtained. This may require serial casting for up to 6 weeks.
- After a midfoot or forefoot osteotomy, weight bearing is restricted until the osteotomy has healed, generally about 6 weeks.

OUTCOMES
- Long-term outcome studies are very limited for progressive conditions such as HSMN.
- Triple arthrodesis for progressive cavus deformity has a poor long-term outcome. Results are further compromised by technical problems at the time of surgery, as well as from undercorrection and overcorrection.
- Most patients with a progressive cavus deformity and a triple arthrodesis performed as a teenager had significant foot problems by their thirties.16
- Nonprogressive deformities such as spastic cavovarus with equinus can be surgically balanced with acceptable results.
- Progressive deformities may require several surgeries during childhood followed by a triple arthrodesis at maturity. The patient and family should be warned about this possibility.

COMPLICATIONS
- Femoral or sciatic nerve injury from tourniquet. This can occur with excessive pressure or time on the tourniquet or even with minimal time and pressure. The tourniquet time should be under 1 hour, using minimal pressure needed for visualization.
- Plantar medial incision dehiscence if excessive correction is attempted at the time of surgery.
- Pressure sores in patients with HSMN.
- Surgical correction of midfoot deformity distal to the apex may result in a rocker-bottom foot deformity.
- Nonunion of the midfoot osteotomy
- Persistent midfoot cavus if the deformity is too severe for a medial column or midfoot osteotomy.
- Persistent hindfoot varus if deformity is fixed and a calcaneal osteotomy is not performed.

REFERENCES
DEFINITION
- A calcaneonavicular coalition is an abnormal connection between the calcaneus and the navicular.
- This extra connection between the tarsal bones typically limits subtalar motion.
- The major consequence of this condition is a rigid flatfoot that may be painful.

ANATOMY
- The coalition typically occurs between the anterior process of the calcaneus and the most lateral aspect of the navicular (FIG 1).
- The connection may comprise bone, cartilage, or fibrous tissue (bony, cartilaginous, or fibrous coalitions, respectively).

PATHOGENESIS
- The cause of calcaneonavicular coalitions remains unknown.
- It has been hypothesized that coalitions may result from failure of segmentation of the individual tarsal bones during fetal development.1
- Symptoms typically develop in later childhood, usually between 8 and 12 years old, for calcaneonavicular coalitions.5
- It is theorized that the reason for the delayed onset of symptoms, despite presumed presence from birth, is that the coalition ossifies over time, making it more rigid and more likely to limit subtalar motion.5
- The pain from a calcaneonavicular coalition may arise from altered kinematics of the foot due to local limitation of motion. It has also been suggested that a fracture through a previously solid coalition could render it painful.

NATURAL HISTORY
- Many people with calcaneonavicular coalitions are probably pain-free, although they may have a rigid flatfoot, with loss of the longitudinal arch and valgus alignment of the heel.6
- If pain develops in a child with a calcaneonavicular coalition, it usually does so between ages 8 and 12.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients present with complaints of foot pain exacerbated by activity, typically localized to the lateral aspect of the foot, just distal to the sinus tarsi, in the region of the anterior process of the calcaneus. They may complain of medial foot and ankle pain or pain at the distal tip of the fibula as well.
- There may be a history of progressive out-toeing and loss of arch height due to an increase in the planovalgus position of the foot.
- Patients may also relate difficulty walking on uneven surfaces, presumably due to decreased subtalar motion.
- The physician should observe the patient’s gait; he or she may walk with an antalgic gait on the affected side (decreased stance phase) and an out-toeing gait.
- The physician should examine the patient’s foot alignment. The heel may be in valgus alignment with the forefoot abducted.
- The physician should examine the rigidity of the patient’s flatfoot. A flexible flatfoot has restoration of the arch upon toe-rise, while a rigid flatfoot has no arch restoration. A rigid flatfoot is a sign of decreased subtalar motion and may indicate a tarsal coalition.
- The physician should palpate over the anterior process of the calcaneus and just distal to the anterior process. Point tenderness is suggestive of a painful calcaneonavicular coalition.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs, including anteroposterior (AP), lateral, and oblique views, should be obtained to visualize the coalition.
- A calcaneonavicular coalition is best seen on the oblique view (inversion oblique).
- A prominent anterior process of the calcaneus, the “anteater nose” sign, may be seen on the lateral view.4
- Standing AP and lateral views can be included to assess foot alignment (FIG 2).
- A Harris axial view or Salzman hindfoot alignment view can be obtained to assess heel alignment.
- A CT scan should be obtained to rule out a concurrent talocalcaneal coalition or the presence of arthritis in adjacent joints. A CT or MRI may also be useful if the diagnosis is in question.
DIFFERENTIAL DIAGNOSIS

- Flexible flatfoot
- Subtalar arthritis
- Other tarsal coalition (talocalcaneal or other less common ones)
- Tumor or infection involving the subtalar joint
- Idiopathic rigid flatfoot

NONOPERATIVE MANAGEMENT

- Nonoperative management is indicated for all patients with calcaneonavicular coalition at first presentation.
- Painless coalitions need no treatment.
- Initial treatment for painful coalitions consists of activity modification, anti-inflammatory medication, and immobilization in a short-leg walking cast for 4 to 6 weeks.

SURGICAL MANAGEMENT

- The indication for surgical management is persistence of pain despite nonoperative management.
- The main goals of treatment are, primarily, elimination of pain and restoration of function.
- Restoration of subtalar motion is a secondary goal.
- Restoration of arch height is unlikely after resection.

Preoperative Planning

- All imaging studies are reviewed.
- An examination of subtalar motion may be performed under anesthesia to serve as a comparison to the examination immediately after resection.

INCISION AND DISSECTION

- The procedure can be done under tourniquet control if desired.
- An oblique incision is made along the lateral side of the foot between the extensor tendons and the peroneal tendons, directly overlying the anterior process of the calcaneus (TECH FIG 1A).
- The skin and subcutaneous tissue are incised sharply, taking care not to undermine the tissues.
- The extensor digitorum brevis is exposed and followed proximally to its origin at the sinus tarsi (TECH FIG 1B,C).

Positioning

- The patient is positioned supine with a bump under the hip of the operative side to slightly internally rotate the leg.
- If subcutaneous fat autograft is to be used as an interposition material after resection, the limb should be prepared up to the buttocks and a sterile tourniquet should be used (FIG 3).
- Alternatively an eschmarch tourniquet may be used just proximal to the ankle.

Approach

- The approach involves exposure and resection of the entire coalition.
- A graft material is interposed between the ends of the resected bone consisting of local muscle (peroneus brevis) or autologous fat.
The coalition is localized with a needle and confirmed fluoroscopically. The coalition is resected with a small osteotome. When performing the medial cut, care is taken to avoid damaging the adjacent articular surface of the talar head.

- Fibrofatty tissue within the sinus tarsi is exposed.
- This fibrofatty tissue is incised and reflected distally along with the attached origin of the extensor digitorum brevis, exposing the anterior process of the calcaneus and the calcaneonavicular coalition (TECH FIG 1D).

- The ends of these two cuts should not meet, as the goal is to resect a trapezoidal piece and not a triangular piece.
- The coalition is resected with a small osteotome. When performing the medial cut, care is taken to avoid damaging the adjacent articular surface of the talar head.

- Fluoroscopic confirmation of the coalition is obtained by placing a surgical instrument or needle directly over it (TECH FIG 1E).

- Bone wax is placed over the exposed cut bone surfaces.

The extensor digitorum brevis is retracted distally and any remaining fibrofatty tissue from the sinus tarsi is retracted proximally.

- A small osteotome is used to remove a trapezoidal piece of bone (TECH FIG 2A,B).

- The first cut is made in the region of what would be the middle of the anterior process of the calcaneus. This cut should be inclined about 40 to 60 degrees from the vertical relative to the plantar surface of the foot and directed medially toward the lateral aspect of the navicular, deep within the wound.

- The next cut is made at the most lateral aspect of the navicular, directed toward nearly the same point as the first cut.

- The ends of these two cuts should not meet, as the goal is to resect a trapezoidal piece and not a triangular piece.
- When making these cuts, especially the medial one, care must be taken to avoid injuring the articular cartilage of the talar head, which lies directly medial and proximal to the osteotome.
- Attention must also be paid to removing sufficient bone so that there is a visible space between the calcaneus and navicular, which is confirmed fluoroscopically on the inversion view. After resection, the lateral edge of the navicular should line up with the lateral aspect of the talar neck and the medial edge of the anterior process of the calcaneus should line up with the medial edge of the cuboid.
- Remaining bone is removed as necessary with rongeurs (TECH FIG 2C).

- Bone wax is placed over the exposed cut bone surfaces.
INTERPOSITION OF FAT GRAFT

- A piece of subcutaneous fat can be taken from just beneath the buttock crease. Use of this donor site allows for a cosmetic incision with minimal donor site morbidity. There is always abundant fat in this location and there are no neurovascular structures at risk during this dissection.
- A transverse incision is made at the base of the buttocks while an assistant elevates the limb.
- A piece of subcutaneous fat about 2 cm in diameter is removed and placed directly into the gap that has been created (TECH FIG 3).

Interposition of Peroneus Brevis Muscle (Alternative Technique)

- After the coalition has been resected, heavy absorbable sutures are woven through the proximal end of the peroneus brevis that had been detached from its origin.
- The ends of the sutures are passed through Keith needles.
- The Keith needles are passed through the space that has been created in the depth of the wound, to exit the medial side of the foot.
- The needles are passed through a piece of sterile felt and a button and the sutures are sewn over the button, drawing the muscle into the gap where the calcaneonavicular coalition was previously (TECH FIG 4).

WOUND CLOSURE

- The tourniquet is released and hemostasis is obtained.
- If fat was used as graft material, the extensor digitorum brevis is sewn back down anatomically to its origin with absorbable suture.
- Subcutaneous tissue and skin are closed in standard fashion.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Approach</th>
<th>The surgeon should avoid undermining the skin to prevent wound complications.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coalition resection</td>
<td>To prevent bone regrowth, the surgeon should ensure adequate bone is removed so that there is a visible gap between the calcaneus and navicular. The surgeon should be cognizant of the local anatomy, specifically the location of the head of the talus, to avoid damaging the talus when making cuts.</td>
</tr>
<tr>
<td>Graft harvesting and placement</td>
<td>When using fat graft, sufficient fat should be removed to fill the defect created by the resection.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- The patient is placed in a cast or splint for 2 to 3 weeks to allow the graft to consolidate and the wound to heal.
- Progressive weight bearing is allowed after cast removal, and range-of-motion exercises are performed to address subtalar motion.

OUTCOMES

- Greater than 90% good or excellent results have been reported in most series.²
- Poor results with persistent pain are attributed to failure to resect adequate bone or the presence of concurrent arthritis in the midfoot or hindfoot.³
COMPLICATIONS

- Failure to resect adequate bone
- Injury to adjacent articular cartilage
- Wound-healing complications
- Recurrence of the coalition

REFERENCES

DEFINITION

- A talocalcaneal coalition is an abnormal connection between the talus and the calcaneus that limits subtalar motion.
- As is the case for calcaneonavicular coalitions, which are described in the prior chapter, talocalcaneal coalitions typically result in a rigid flatfoot that is sometimes painful.

ANATOMY

- Talocalcaneal coalitions occur within the subtalar joint, most commonly involving the middle facet. These connections can be bony, cartilaginous, or fibrous and can involve any amount of the joint.
- The size of the coalition is described with respect to the percentage of the subtalar joint that is coalesced.

PATHOGENESIS

- Like calcaneonavicular coalitions, the cause of talocalcaneal coalitions remains unknown, but they may be the result of failure of segmentation during fetal development.
- Although they are presumed to be congenital in nature, symptoms typically do not appear until early adolescence, ages 12 to 16.
- It is unclear why some coalitions become painful. One theory suggests the possibility of altered talar joint kinematics placing additional stress on adjacent joints. Another is the development of microfractures or stress fractures through the coalition over time, rendering them painful.

NATURAL HISTORY

- Most talocalcaneal coalitions are asymptomatic. They may result in the development of a rigid flatfoot, characterized by valgus alignment of the heel, abduction of the forefoot, loss of the arch, and failure of the arch to reconstitute on toe-rise or when non-weight bearing.
- Pain secondary to talocalcaneal coalitions usually develops between 12 and 16 years of age.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients typically describe pain in the foot that is activity related; it is exacerbated by walking on uneven surfaces and relieved by rest.
- This pain may be generalized to the midfoot or can be specifically localized to the medial aspect of the hindfoot and ankle.
- Patients may also complain of lateral pain at the tip of the fibula.
- There may be a history of progressively worsening out-toeing or loss of the arch.
- The clinician should observe the patient’s gait for an antalgic pattern and torsional alignment, with specific attention to foot position during stance.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs should be obtained in an attempt to identify the coalition. These should include anteroposterior (AP), lateral, oblique, and Harris axial views.
- A talocalcaneal coalition is best seen on the Harris axial view, but it may be difficult to obtain the exact orientation to adequately visualize the middle facet.
- On the lateral view there may be a continuous C-shaped line along the talar dome and into the posterior facet (C-sign).
- On the AP and oblique view one may identify other concurrent coalitions.
- Standing AP and lateral radiographs and a Salzman hindfoot alignment view can be useful for assessing foot alignment, especially hindfoot valgus.
- A CT scan is mandatory to clearly visualize the coalition and determine the percentage of the subtalar joint that is involved.
- An MRI may be useful if the diagnosis is equivocal and a cartilaginous or fibrous coalition is suspected.

DIFFERENTIAL DIAGNOSIS

- Flexible flatfoot
- Subtalar arthritis
- Other tarsal coalition (calcaneonavicular or less common ones)
- Tumor or infection involving the subtalar joint
- Idiopathic rigid flatfoot

NONOPERATIVE MANAGEMENT

- Nonoperative management is indicated for all patients with talocalcaneal coalition at first presentation.
- Painless coalitions need no treatment.
- Painful coalitions may benefit from activity modification, anti-inflammatory medication, and immobilization in a short-leg walking cast.
The indication for surgical management is persistence of pain despite nonoperative management.

The main goals of treatment are, primarily, elimination of pain and restoration of function.

Restoration of subtalar motion is a secondary goal.

Restoration of arch height is unlikely following excision of a talocalcaneal coalition.

Preoperative Planning

- All imaging studies are reviewed.
- An examination of subtalar motion may be performed under anesthesia to compare to the motion obtained after excision of the coalition.

Positioning

- The patient is positioned supine on the operating table.
- Generally the leg assumes an external rotation posture at rest so that the medial ankle and hindfoot are easily accessible. If this is not the case, then a small bump can be placed beneath the opposite hip.
- A tourniquet is placed on the upper thigh or an eschmarch tourniquet may be used just proximal to the ankle.

Approach

- The approach involves identification of the entire coalition with delineation of the normal cartilage on either side.
- The bone representing the coalition is exposed and subcutaneous fat or a portion of the flexor hallucis longus is interposed.

INCISION AND DISSECTION

- The procedure can be done under tourniquet control, if desired.
- A straight horizontal incision is made along the medial aspect of the hindfoot centered over the sustentaculum tali.
- The incision should extend from the anterior margin of the Achilles tendon to the prominence of the navicular tuberosity (TECH FIG 1A).

- If any fibers of the abductor hallucis are encountered, they are retracted plantarly.
- The tibialis posterior tendon is identified dorsally (TECH FIG 1B).
- The flexor digitorum longus tendon is identified and its sheath is opened along the length of the incision (TECH FIG 1C).
EXPOSURE OF THE TALOCALCANEAL COALITION

- The talocalcaneal coalition lies just dorsal to the sustentaculum tali and deep to the sheath of the flexor digitorum longus.
- While retracting the flexor digitorum longus tendon plantarly, palpate the sustentaculum tali.
- The coalition lies deep to the medial portion of the sheath of the flexor digitorum longus and periosteum.
- The medial aspect of the flexor digitorum longus sheath, along with the periosteum just deep to it, should be incised slightly dorsal to the prominence of the sustentaculum tali, taking care to maintain an adequate layer to be used later for closure (TECH FIG 2A,B).
- Because the normal joint in this area is now obscured by the coalition, it is often difficult to determine the appropriate level for bone resection without first identifying some normal joint space.
  - If this is the case, the dissection may be carried posteriorly and anteriorly to identify the posterior and anterior facets of the subtalar joint, respectively, so that the normal articular cartilage in these areas can be identified.
  - The posterior facet can be identified by retracting the neurovascular bundle either posteriorly or anteriorly and dissecting deep to it.
  - The anterior facet is identified just proximal to the talonavicular joint and plantar to the talar neck.
  - Occasionally a stripe of cartilage can be identified traversing through the center of the coalition. In these cases, resection may proceed directly to this level.
- The Achilles tendon is then identified at the most posterior aspect of the wound.
- At this point all of the critical anatomic structures have been identified and the coalition can now be exposed.

- The neurovascular bundle is identified just posterior to the flexor digitorum longus.
- The flexor hallucis longus tendon sheath can be opened if it is to be used as interposition material. If autologous fat graft is to be used, then this step is unnecessary.
- The neurovascular bundle is identified just posterior to the flexor digitorum longus.
- The flexor hallucis longus tendon sheath can be opened if it is to be used as interposition material. If autologous fat graft is to be used, then this step is unnecessary.
- The Achilles tendon is then identified at the most posterior aspect of the wound.
- At this point all of the critical anatomic structures have been identified and the coalition can now be exposed.

TECH FIG 1 • A. Incision marked on the skin. B. The posterior tibial tendon (superior) and flexor digitorum longus tendon (inferior). C. The neurovascular bundle is seen directly posterior to the posterior tibial tendon.

- The neurovascular bundle is identified just posterior to the flexor digitorum longus.
- The Achilles tendon is then identified at the most posterior aspect of the wound.
- At this point all of the critical anatomic structures have been identified and the coalition can now be exposed.

- The neurovascular bundle is identified just posterior to the flexor digitorum longus.
- The Achilles tendon is then identified at the most posterior aspect of the wound.
- At this point all of the critical anatomic structures have been identified and the coalition can now be exposed.

- The neurovascular bundle is identified just posterior to the flexor digitorum longus.
- The Achilles tendon is then identified at the most posterior aspect of the wound.
- At this point all of the critical anatomic structures have been identified and the coalition can now be exposed.
TECH FIG 2 • A,B. The medial aspect of the sheath of the flexor digitorum longus and the periosteum overlying the talus are incised. C. The posterior facet is visualized (just posterior to the curette) and the coalition is entered with a curette. D,E. The coalition has been removed and there is a visible gap between the talus (superior) and calcaneus (inferior). Just beyond the excised bone, normal articular cartilage can be seen.

INTERPOSITION OF FAT GRAFT

- Next, to retrieve fat graft, the neurovascular bundle is retracted anteriorly, exposing the retrocalcaneal fat between the Achilles tendon and the calcaneus (TECH FIG 3A).
- A piece of fat about 1 cm in diameter is excised from the area.
- This fat is interposed into the space from where the coalition was resected (TECH FIG 3B,C).
- The layer of tissue composed of periosteum and flexor digitorum longus sheath is then repaired over this fat with absorbable sutures helping to secure it in place (TECH FIG 3D).

TECH FIG 3 • A. Retrocalcaneal fat is exposed between the Achilles tendon and the neurovascular bundle and harvested for the graft. B–D. The graft is inserted into the area of the resected coalition and the periosteum is closed over the graft.
INTERPOSITION OF A PORTION OF THE FLEXOR HALLUCIS LONGUS TENDON (ALTERNATIVE TECHNIQUE)

- As an alternative to autologous fat graft, half of the flexor hallucis longus tendon may be interposed.\(^2,4\)
- After completely resecting the coalition and confirming adequate motion of the subtalar joint, the flexor hallucis longus tendon is exposed by opening its sheath just inferior to the sustentaculum tali, if this has not been done during the surgical approach.
- The flexor hallucis longus lies in a groove directly inferior to the sustentaculum tali.
- The flexor hallucis is then split longitudinally but left in continuity along its length.
- The superior half of the tendon is then placed in the gap that has been created where the coalition was resected. Care is taken to ensure that the length of tendon that is split is sufficiently long so that the motion of the flexor hallucis longus is not restricted.
- This is accomplished by moving the interphalangeal joint of the great toe through a range of motion and confirming that motion is not restricted.
- The periosteum from the talus is then sutured to the periosteum from the sustentaculum to prevent the tendon from slipping out of place.

WOUND CLOSURE

- The tourniquet is released and hemostasis is obtained.
- The tendon sheath of the flexor digitorum is closed with fine absorbable sutures.
- Subcutaneous tissue and skin are closed in standard fashion.

PEARLS AND PITFALLS

**Indications**

- The preoperative CT scan should be carefully assessed for the extent of the coalition and the presence of subtalar arthritis. Excision of the coalition is contraindicated if greater than 50% of the joint surface is coalesced or in the presence of subtalar arthritis.
- Hindfoot alignment is determined clinically and radiographically to assess for hindfoot valgus. Excessive valgus has been associated with poor outcomes.

**Approach**

- The incision should be long enough to allow adequate identification of normal subtalar joint.
- The periosteum and medial sheath of the flexor digitorum longus are preserved to secure the graft.

**Excision of coalition**

- The surgeon should identify normal articular cartilage posterior and anterior to the coalition so that the level of resection can be identified.
- Bone is resected from the area where the normal joint can be seen toward the center of the coalition.
- It is possible to resect bone into the body of the talus or calcaneus, missing the coalition, if careful attention is not paid to the level of resection.

**Closure**

- The periosteum and medial sheath of the flexor digitorum longus tendon are repaired to prevent extrusion of the graft.

POSTOPERATIVE CARE

- A splint or short-leg cast is applied.
- The foot is immobilized and the patient should remain non-weight bearing for 2 to 3 weeks to allow for wound healing and consolidation of the graft.
- After that, progressive weight bearing and gentle range-of-motion exercises are initiated, focusing on restoring subtalar motion.

OUTCOMES

- Most series report better than 85% good to excellent results.\(^2,4,5,7\)
- Poor results, characterized by persistent pain, have generally been associated with coalitions of more than 50% of the joint surface, subtalar arthritis, or severe valgus alignment of the heel in excess of 21 degrees.\(^3,7\)

COMPLICATIONS

- Failure to adequately resect the coalition
- Recurrence of the coalition
- Residual pain or stiffness due to pre-existing subtalar arthritis

REFERENCES


DEFINITION
- Clubfoot, also known as congenital talipes equinovarus, occurs in approximately 1 in 1000 live births.
- The clubfoot contains four identifiable components that are easily remembered using the acronym CAVE (cavus, adductus, varus, and equinus). Idiopathic clubfoot contains each of the four components to varying degrees.
  - The so-called postural clubfoot is held by the infant in an equinovarus position, but all components are nearly completely correctable with gentle manipulation and resolve over time without intervention.
  - A small proportion of clubfeet are teratologic, occurring as part of other neuromuscular diseases, such as Larsen syndrome, any of the arthrogryposis syndromes, and spina bifida.
  - A severe type of idiopathic clubfoot, the complex clubfoot, has tighter hindfoot and plantar structures.
  - In 1948 Dr. Ignacio Ponseti began manipulating clubfeet through serial casting, completely correcting the clubfoot deformity. The principles of Ponseti casting lay in gradually stretching the soft tissue structures and gently inducing remodeling of the primarily cartilaginous bones of the hindfoot during immobilization.
  - For the definitive publication on clubfoot and the Ponseti technique, the reader is referred to Dr. Ponseti’s book.⁶
  - The success of the treatment protocol that bears his name has been borne out through over 30 years of follow-up, establishing it as the standard for initial treatment of clubfoot.¹
  - Dr. Ponseti has recently published a modification to his original casting technique that addresses the specific deformities characteristic of the complex clubfoot.⁷

ANATOMY
- The Achilles and posterior tibialis tendons, as well as the posterior and medial ligaments between the calcaneus, talus, and navicular, are thickened and fibrotic.⁶
- The clubfoot contains a number of changes in bony alignment and shape (FIG 1).
  - Relative to normal foot anatomy, the first ray is plantarflexed, generating the cavus deformity. By comparison, all rays are plantarflexed in the complex clubfoot, resulting in full-foot cavus.
  - The navicular is medially displaced on the talus, and the cuboid is medially displaced on the calcaneus as part of the adductus deformity. The medial corners of the head of the talus and the anterior calcaneus are flattened.
  - The calcaneus is inverted under the talus, creating the hindfoot varus, while also being in equinus and elevated in the fat-pad of the heel.
  - In children with unilateral clubfoot, the affected foot is smaller, as is the lower leg, relative to the unaffected side.
  - Up to 85% of clubfeet have an insufficient or absent anterior tibial artery.⁵

NATURAL HISTORY
- The exact cause of the fibrotic changes in clubfoot is unknown.
- Left uncorrected, the weight-bearing surface in a clubfoot becomes the dorsolateral surface.
- Thick callosities develop, and the positioning of the foot creates significant functional disability.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Clubfoot may be identified on prenatal ultrasound as early as 12 to 13 weeks (FIG 2).
- Half or more of clubfeet identified on second-trimester ultrasounds have an association with other anomalies or are syndromic.⁸
  - The exact sensitivity and specificity of prenatal ultrasound are unknown, but there does appear to be variation with gestational age: the false-negative rate is thought to approach 0% but the false-positive rate may be as high 40% during the third trimester.⁸ Cases not found on prenatal ultrasound are readily identifiable at birth.
  - All children with clubfeet should be examined for other findings that may suggest a syndromic or neuromuscular association, such as other contractures or joint dislocations (especially hip dislocation), cutaneous lesions, spinal abnormalities, and abnormal facial features.
  - The clubfoot is easily identified by the combined deformities of cavus, adductus, varus, and equinus.
    - Consider complex clubfoot if a deep midfoot crease and cavus extend across the entire plantar aspect of the foot.
    - A deep heel crease, a nonpalpable calcaneus, and tight varus and equinus may suggest complex clubfoot.
  - The ability to abduct or dorsiflex the foot completely suggests etiologies other than idiopathic clubfoot, such as isolated metatarsus adductus, neuromuscular disease, or focal anatomic abnormalities.
    - The fat pad of the heel will feel empty upon palpation due to equinus positioning of the calcaneus. This is especially dramatic in the complex clubfoot.
    - The lateral head of the talus is easily palpable over the dorsolateral surface of the foot. More laterally, the anterior calcaneal tuberosity is also palpable. Care must be taken in differentiating these two structures because Ponseti casting necessitates free motion of the calcaneus under a talus that is stabilized over its lateral head, whereas pressure at the calcaneal tuberosity blocks calcaneal rotation, allowing only forefoot abduction.
    - The complex clubfoot has a crease that extends completely, or nearly so, across the plantar aspect of the foot. Full foot cavus is present, with plantarflexion of all metatarsals. Also, the heel crease is deeper than that of most other clubfeet. The first ray in the complex clubfoot, if not noticeably retracted at presentation, will become retracted during the initial one or
two correctional casts, as the adductus is corrected, and the cavus will persist. All metatarsals remain plantarflexed. It is important to examine the clubfoot before each casting to evaluate for the adjustments that must be made during casting to correct residual deformities or to identify, and modify casting for, a complex clubfoot.

- A number of classification systems have been introduced, the most commonly used being those of DiMeglio and Pirani. Both have utility in evaluating correction and recurrence, but the predictability of recurrence and final function is still unclear.
- The degree of dorsiflexion and abduction, and the distance of the navicular anterior to the medial malleolus, provide other objective measurements.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs at birth are not helpful in diagnosing clubfoot because the ossific nuclei of the talus and calcaneus are spherical, so orientation and relationship are not discernible, and the other tarsal bones are unossified.
- Clinical examination is sufficient to diagnose the congenital clubfoot.
- Once full abduction is obtained by casting, if dorsiflexion of more than 10 degrees is present, forced-dorsiflexion lateral films are helpful in differentiating midfoot breach, producing apparent dorsiflexion, from true dorsiflexion occurring at the ankle, suggesting the need for a percutaneous Achilles tenotomy (FIG 3).

DIFFERENTIAL DIAGNOSIS

- Metatarsus adductus
- Neurologic equinovarus or cavovarus deformity
  - Both deformities may be differentiated from clubfoot by absence of the other components of clubfoot.
- Teratologic or syndromic clubfeet (including neuromuscular disorders)
  - Clubfoot deformity may be more difficult to correct or may tend to recur.
  - “Postural” clubfoot
  - Complex clubfoot

NONOPERATIVE MANAGEMENT

- Ponseti casting of the idiopathic clubfoot involves a specific sequence of corrective maneuvers that correct the deformities of the clubfoot in combination.
  - Each manipulation is maintained with a plaster cast.
  - Resolution of the deformities occurs simultaneously, but complete resolution sequentially follows the acronym CAVE.
  - Ponseti casting can be performed successfully in children up to 2 years old, although any correction obtained by casting in older children may reduce the amount of surgery required for complete correction.
  - An open tendo-Achilles lengthening may be more appropriate than a percutaneous tenotomy in children over 2 years old.
  - Long-leg casts should always be used.
  - A short-leg cast should be applied first so that attention is made solely to molding around the ankle before extending the cast above the knee.
  - Padding should be minimal, and plaster is preferable for its ability to be molded precisely to the contours of the foot and ankle.
  - Four to six casts should correct the cavus, adductus, and varus deformities. If correction is not achieved in eight casts or the child pulls back in the casts (FIG 4A), the possibility of an
FIG 3 • A. Dorsiflexion of right clubfoot after five corrective casts, before tenotomy. Dorsiflexion of 10 degrees would appear to be sufficient to avoid Achilles tenotomy. B. Forced dorsiflexion lateral radiograph of same foot. Dorsiflexion of the metatarsals relative to the axis of the talus reveals the source of clinical dorsiflexion. The calcaneus is still in equinus (relative to the tibial axis) and a percutaneous Achilles tenotomy is required to complete the correction. C. Forced dorsiflexion lateral radiograph of the left (uninvolved) foot. The calcaneus is dorsiflexed and the axis of the first metatarsal is almost parallel to the axis. D. Forced-dorsiflexion lateral radiograph of the right foot 3 weeks after the percutaneous Achilles tenotomy. Now the calcaneus is dorsiflexed relative to the tibial axis and what was seen on the pretenotomy radiograph (B).

FIG 4 • A. A complex clubfoot that has pulled back in the cast. The cast was originally trimmed dorsally to the web spaces of the toes. The heel is elevated in the cast and the toes are no longer visible. B. Purple discoloration of toes after application of the first cast, as the cast begins to cool. C. One hour later, the cast temperature has stabilized and the toes are pink.
unrecognized complex clubfoot or improper casting technique should be considered.

- Casting is facilitated by the child being relaxed and calm. Feeding the infant during casting, playing music, or allowing the child to play with toys may assist in this.
  - For breast-fed infants, it is helpful if the family introduces, and uses once daily, a bottle so that one can be used during casting. If a bottle is not tolerated, having the child suck on a finger that has been dipped in sugar water may be successful.
  - Before leaving the clinic, the toes should be checked to make sure they are pink and well perfused.
  - Some toes will become reddish-purple as the casts cool (appearing much like the acrocyanosis present at birth) but will become more pink if the child is bundled and monitored over 1 hour or so (FIG 4B,C).
  - Toes that become more purple and dusky indicate that the cast is too tight and should be reapplied.
  - Casts are changed every 5 to 7 days. The final cast, following percutaneous Achilles tenotomy, is left in place for 3 weeks.
  - Approximately 95% of clubfeet will require a percutaneous Achilles tenotomy to correct the residual equinus once the other components are corrected.
  - Once complete correction is obtained, correction must be maintained by placing the feet in a foot-abduction orthosis (FIG 5A).
  - Some straight-last shoes will need modifications to keep the feet secured (FIG 5B,C), while others require a custom orthosis (FIG 5D) (see “Postoperative Management”).

**SURGICAL MANAGEMENT**

- Percutaneous Achilles tenotomy is required in 95% of idiopathic clubfeet to correct the residual equinus.
- About 20% of patients require anterior tibialis tendon transfer to correct recurrent or persistent dynamic varus deformity.

**Preoperative Planning**

- Degree of dorsiflexion
  - If dorsiflexion is less than 10 degrees, a percutaneous Achilles tenotomy is required to correct the residual equinus.
  - If dorsiflexion is more than 10 degrees, forced-dorsiflexion lateral foot radiographs help to differentiate midfoot dorsiflexion, with residual calcaneal equinus, from true dorsiflexion occurring at the hindfoot (see Fig 3).
- Location
  - The risk of anesthesia must be balanced against the perceived pain and duration of the procedure, as well as the degree of sedation necessary for safe performance of the procedure and optimizing posttenotomy casting.
  - Many institutions prefer local anesthesia with 1% lidocaine, with the procedure performed in the clinic, for infants owing to the high risk of general anesthesia. Others use a eutectic mixture of lidocaine anesthetic cream left in place over the heel. Some institutions require general anesthesia in the operating room, and some providers prefer the guaranteed sedation and pain control afforded in this setting, especially for children over 6 months old.
  - Sedation in a pediatric sedation clinic may be another alternative.

**Positioning**

- The child should be supine on the table with the contralateral leg held out of the way by the parent or an assistant during casting and tenotomy.

**Approach**

- A medial approach is used to avoid the medial neurovascular bundle.
CASTING

Stretching
- Before casting, the foot should be stretched in the same manner as used for immobilization during casting (TECH FIG 1A,B).
  - The thumb of the examiner’s contralateral hand (e.g., the left hand when manipulating the right foot) should be placed over the head of the talus, and the index finger of the other hand should lie along the medial aspect of the first ray with the second through fourth fingers under the plantar aspects of the forefoot.
  - The calcaneocuboid joint should be avoided, so as not to block subtalar motion.
  - The first cast should focus on elevation of the first ray to correct the cavus deformity (TECH FIG 1C).
  - This places the forefoot in supination, locking the midfoot and aligning the forefoot with the hindfoot, providing a lever arm for correction of the hindfoot deformities during later abduction maneuvers.
  - Some of the adductus may also be corrected during the first casting.

Lower-Leg Cast Application
- A thin layer of cotton padding should be applied.
  - The padding is wrapped three times around the toes distally, then extended proximally over the foot and lower leg to pad with no more than two layers of padding.
  - The foot should be held in the position to be casted throughout (TECH FIG 2A). The popliteal fossa should be avoided proximally.
  - A thin layer of plaster is applied over the foot and lower leg.
  - The plaster may be applied more loosely over the toes but should be snug over the hindfoot and ankle to immobilize the foot properly and allow for precise molding (TECH FIG 2B).

- Avoid making the cast too snug so as to impair venous return or apply pressure on the fat pad of the heel.
- The lower-leg cast should be precisely molded around the malleoli and above the calcaneus posteriorly using the index and middle finger of the same hand as the thumb that is immobilizing the talus.
- Do not apply pressure over the fat pad of the heel.
- Throughout, the foot should be held in the position of correction, but the fingers should be in fairly constant motion to prevent pressure spots within the minimally padded cast.
Completing the Cast

- Once the lower-leg cast has set, padding should be applied over the rest of the leg up to the groin, again in no more than two or three layers.
- The knee should be held at 90 degrees, and the lower leg should be in slight external rotation.
- Padding should be minimized in the popliteal fossa to prevent impingement of the neurovascular structures. The padding should be wrapped three to five times over the proximal thigh to pad adequately.
- Plaster should then be wrapped over the short-leg cast above the ankle and extended proximally over the padded knee and thigh to the groin. A plaster splint of three or four layers of plaster roll should be placed over the knee from the middle of the thigh to the middle of the shin to strengthen the cast against knee extension while minimizing bulk in the popliteal fossa. The plaster is then wrapped distally to incorporate the splint, ending once the lower leg has been completely incorporated.
- The knee should be molded while held at 90 degrees with the lower leg in slight external rotation until set (TECH FIG 3A). Rolling the plaster at the proximal edge of the cast before the plaster sets up completely helps minimize chafing of the thigh.
- The cast should be trimmed distally to expose the toes. The surgeon should confirm that they are pink and well perfused (TECH FIG 3B) before the child is sent home.

A

B

TECH FIG 3 • A. Padding and plaster are applied up to the proximal thigh, incorporating the short-leg cast into a long-leg cast. The knee is flexed to 90 degrees. The proximal margin of the cast is rolled to decrease skin irritation. B. The distal end of the cast is trimmed to the web space of the toes dorsally, revealing pink, well-perfused digits. A plantar toe plate remains.

- Trimming the plaster over the dorsal aspect too far proximally, beyond the web space, may create a tourniquet effect over the forefoot.
- A plantar toe plate should be left to prevent toe flexion and curling, which may facilitate pulling out of the cast.
- Parents should be instructed on signs and symptoms of cast problems before discharge.

Cast Changes and Follow-Up

- Casts are ideally changed every 7 days, although they may be changed as frequently as every 5 days; up to 2 weeks may be tolerated if necessary to accommodate conflicts preventing weekly cast changes.
- Casts should not be removed until just before recasting.
- They can be soaked by the family before coming to the office, then removed with a plaster knife in the clinic.
- Alternatively, dry casts may be removed with a cast saw, using extreme caution.
- Having the parents remove the casts the night before results in varied degrees of recurrence overnight and prolongs casting.
- After the first casting, the cavus deformity should be nearly, or completely, corrected.
- Abduction may be increased.
- Stretching is performed with the forefoot in supination, maintaining alignment of all rays, abducting the foot under the talus.
- The foot is then casted in the newly maintained position, just to where the foot may be comfortably corrected without significant resistance.
- Trying to overabduct the foot during a single casting results in intolerance as the foot tries to return to its position of comfort, and in the worst cases results in pressure sores or vascular compromise of the soft tissues along the medial foot. A keen sense of touch and patience are essential.
- Each subsequent manipulation results in increased abduction of the forefoot and correction of the hindfoot varus (TECH FIG 4A–D).
- Throughout, the forefoot should remain in neutral (appearing supinated due to the hindfoot varus) and the hindfoot in equinus (TECH FIG 4E).
- Dorsiflexion of the calcaneus remains blocked under the neck of the talus until approximately 25 degrees of abduction has been obtained. Dorsiflexion before that point results in midfoot, and not subtalar, dorsiflexion (see Fig 3).
- Subsequent eversion of the calcaneus will bring the forefoot and hindfoot into more neutral positions and dorsiflexion may be obtained by percutaneous Achilles tenotomy.
- Once abduction of 70 degrees is obtained (TECH FIG 4F), correction of the remaining equinus deformity may occur.
- Overabduction to 70 degrees is necessary to accommodate some of the inevitable recurrence, without allowing progression beyond a normal position that would require recorrection.
TECH FIG 4 • A. Adduction is decreased in the second cast. B. By the third cast, the foot is in line with the leg. C. By the fourth casting, the foot is abducted 20 degrees and held in this position with the cast. D. With the fifth cast, the foot is now held at 45 degrees of abduction. E. Before the tenotomy, the foot remains in plantarflexion throughout abduction. F. After removal of the fifth cast, the foot can be abducted 70 degrees and is ready for percutaneous Achilles tenotomy. The amount of dorsiflexion in this foot is seen in Figure 3.

COMPLEX CLUBFOOT
- The complex clubfoot may not be immediately recognizable at presentation.
- Correction usually begins using the standard maneuvers, elevating the first ray with the first cast and continuing abduction with the second cast.
  - Within one or two casts, the foot begins to clearly demonstrate a demarcation from the expected correction as the cavus persists and evolves, involving plantarflexion of all metatarsals, and the first ray becomes retracted.
  - At this point, the technique must be modified.
- In the complex clubfoot, the tight plantar intrinsics and toe flexors induce full-foot cavus. This is exacerbated by the tight hindfoot structures, which also limit correction of the varus to just beyond neutral.
- As a result, the casting technique must be modified not only to correct these features, but also to decrease the propensity for pulling out of even long-leg casts.
- Lateral counterpressure still occurs at the lateral head and neck of the talus, but stabilization of the fibula should also occur.
- The index finger of the contralateral hand (eg, the examiner’s left hand when manipulating a patient’s right clubfoot) should be flexed at 90 degrees at the proximal interphalangeal joint and placed posterior to the distal fibula.
- The thumb of the same hand is placed just anterior to the lateral malleolus along the neck of the talus.
- As the foot begins to approach neutral, the full-foot cavus, along with the dramatic equinus, can pose significant casting difficulties.
- The foot becomes contiguous with the lower leg, absent any ankle dorsiflexion, and the cavus short-
ens the foot, making it even more difficult to immobilize.

- A posterior splint of three or four layers of plaster should be applied under the plantar surface of the foot, extending from beyond the tips of the toes proximally over the posterior lower leg.
- As in the upper-leg portion of the traditional cast, the posterior splint about the foot strengthens the plantar portion of the cast against the forceful plantarflexion of the complex clubfoot without increasing bulk over the anterior ankle, which may impede molding and immobilization.
- Then, a thin layer of plaster may be wrapped in the usual manner to encompass the foot and lower leg. A minimal amount of plaster should be used because precise molding is even more important for the complex clubfoot.
- The pads of the thumbs of both hands may be placed under the forefoot, with the pads of the index fingers placed over the dorsal surface of the talar neck, anterior to the medial and lateral malleoli, with the pads of the middle fingers posterior to the malleoli. The forefoot is then forcefully dorsiflexed against the counterpressure over the dorsal talar neck, enough to produce blanching of the digits (presumably due to tension constriction of the posterior tibial and peroneal arteries) (TECH FIG 5A).
- Further counterpressure to dorsiflexion is applied over the anterior thigh above the flexed knee.
- Upon release of dorsiflexion pressure after setting of the cast, the slight relaxation of the cast will result in revascularization of the digits (TECH FIG 5B).
- Care should be taken not to abduct the foot beyond 45 degrees because the tight hindfoot prevents further progression of the hindfoot into valgus, and abduction of the forefoot only occurs.
- On extending the cast up over the lower leg, the knee should be flexed to 110 degrees to minimize the ability to pull out of the cast. An anterior plaster splint over the thigh and knee should be used just as in the traditional technique.
- Tenotomy occurs once the cavus and adductus deformities are corrected, and about 40 degrees of abduction is obtained.
- Attempting to abduct the complex clubfoot beyond 40 degrees results in no further hindfoot correction and only overabducts the forefoot, making immobilization of the foot in the cast more difficult.

TECH FIG 5 • A. When casting the complex clubfoot, to correct the full-foot cavus, a dorsiflexion force is applied to dorsiflex at the midfoot. The fat pads of both thumbs are placed under the heads of the metatarsals, with the index fingers over the dorsal aspect of the talar neck, anterior to the medial and lateral malleoli, with the pads of the middle fingers posterior to the malleoli. The forefoot is then forcefully dorsiflexed against the counterpressure over the dorsal talar neck, enough to produce blanching of the digits (presumably due to tension constriction of the posterior tibial and peroneal arteries) (TECH FIG 5A).

PERCUTANEOUS ACHILLES TENOTOMY

- The tenotomy should occur 1 to 1.5 cm above the insertion of the Achilles on the posterior tuberosity of the calcaneus.
- In many feet, this is 1 to 1.5 cm above the posterior heel crease.
- Performing the tenotomy too low results in damage to the posterior calcaneal tuberosity.
- For procedures in the clinic, local anesthesia must be used.
- A small amount of 1% lidocaine may be injected locally over the tendon at the site of blade insertion before the procedure, taking care not to inject so much as to obscure the ability to discern the Achilles tendon for the procedure (TECH FIG 6A). Usually less than 0.05 mL is sufficient.
- Alternatively, a eutectic mixture of lidocaine anesthetic cream may be used topically. It should be left in place for at least 45 minutes for maximal effect. Blanching of the skin correlates with the anesthetic effect.
- An assistant should hold the foot in maximal dorsiflexion to increase tension on the Achilles tendon, making it
more easily palpable and able to be transected (TECH FIG 6B).

- A second assistant should hold the contralateral leg and foot out of the field.

- A thin, sharp scalpel should be used to perform the tenotomy. Cataract surgical blades (5100 or 5400 Beaver blades) are well suited for this procedure, although an 11 blade is also acceptable. One of two techniques may be used to insert the blade:
  - The blade of the scalpel may be inserted perpendicular to the skin, anterior to the Achilles tendon, from the medial side, with the blade itself oriented parallel to the longitudinal axis of the tendon. The blade must be advanced far enough to pass beyond the lateral side of the tendon so that complete transection occurs. Once advanced far enough, the blade may be rotated in place, orienting the blade perpendicular to the tendon (TECH FIG 6C).
  - Alternatively, the blade may be advanced anterior to the tendon at a 45-degree angle to the skin, again advancing the tip of the blade deep enough to pass the lateral side of the tendon, but with the blade oriented perpendicular to the tendon from the outset. The handle of the scalpel may then be lifted ventrally, bringing the blade perpendicular to the skin, resting against the tendon (TECH FIG 6D).
E. Transection of the Achilles tendon of the left foot. Pressure is applied with the contralateral thumb, pressing the tendon onto the blade, resulting in tendon transection. The level of the tenotomy is 1 cm above the posterior heel crease. F. The foot is in plantarflexion before the tenotomy. G. After the tenotomy, 30 degrees of dorsiflexion is obtained. In extreme dorsiflexion the digits blanch, presumably due to impingement of the posterior tibial artery. Decreasing dorsiflexion just a few degrees resulted in reperfusion. H. During application and molding of the short-leg cast, the foot should be held in maximum dorsiflexion and abduction. An assistant provides counterpressure above the knee. Dorsiflexion pressure is applied only over the plantar aspect of the midfoot and forefoot and the heel remains untouched, while the cast is molded around the ankle with the fingers of the other hand.

- Once the blade is oriented perpendicular to the fibers of the Achilles tendon, the safest maneuver involves pressing the tendon onto the blade using the contralateral thumb (TECH FIG 6E).
- Complete transection often results in a palpable “pop,” release of the Achilles tendon, and an immediate increase of 15 to 20 degrees of dorsiflexion (TECH FIG 6F). A palpable defect in the tendon confirms complete transection.
- If incomplete transection occurs, the tendon should be revisited, adjusting blade position as necessary, to complete the release.
- Care should be taken not to pull the blade through the tendon lest laceration of the overlying skin occur once the resistance of the tendon disappears following transection.
- The Betadine should be cleansed from the skin to prevent Betadine burns to the neonatal skin, and pressure should be applied to the incision site to stop all bleeding before cast application.
- The foot should now be held in the new position of maximum dorsiflexion and abduction.
- In some cases, the increased dorsiflexion will increase traction on the solitary posterior tibial artery as it passes under the medial malleolus, constricting it and resulting in blanching of the digits (TECH FIG 6G).
- The lower leg is wrapped with sterile cotton in the usual manner, accommodating the increased dorsiflexion.
- The plaster is applied in the usual manner, and the cast must be molded well at the anterior ankle to accommodate the increased dorsiflexion and prevent pulling back in the cast (TECH FIG 6H).
- For the complex clubfoot, the posterior plaster splint should be used in the short-leg cast.
- On release of dorsiflexion pressure after setting of the cast, the slight relaxation of the cast will result in revascularization.
- If revascularization does not occur, the cast may need to be removed and reapplied. Although maximum dorsiflexion is prevented because of vascular compromise, what is gained is usually sufficient for adequate correction without the need for a second tenotomy or later recorrection.

Casting

- Extension of the cast above the thigh as a long-leg cast should occur with the knee in the usual 90 degrees of flexion, first with padding (TECH FIG 7A) and then with plaster, holding the lower leg in slight external rotation (TECH FIG 7B).
- The complex clubfoot should have the knee flexed at 110 degrees.
- An anterior knee splint should be used in both cases.
- The posttenotomy cast should be left on for 3 weeks before removal to allow tendon healing.
- Frequently, blood seeps through the cast and becomes visible, and parents should be alerted to this.
- Persistent bleeding, resulting in a spot above the heel larger than a quarter in size, may signify injury to vascular structures on the lateral aspect of the foot, rarely requiring any intervention other than further assessment.²
- When the cast is removed, complete correction should have been obtained (TECH FIG 7C,D).
A. Cotton padding is applied from the proximal edge of the short-leg cast up to the groin. B. With extension to the long-leg cast, the lower leg is held in slight external rotation, and the knee is held at 90 degrees of flexion. The foot is now in maximum dorsiflexion and abduction. C, D. Three weeks after tenotomy, after the final cast is removed, complete correction is obtained. C. The foot abducts 70 degrees. D. The foot actively dorsiflexes 20 degrees.

**PEARLS AND PITFALLS**

Failure to correct the cavus deformity with initial casting

- Failure to elevate the first ray will result in worsening cavus during abduction, and only the forefoot will abduct. The hindfoot varus will fail to correct. The foot will then pull back in the cast. The same deformities will occur in the complex clubfoot if the full-foot cavus is not corrected before or during early abduction.

Toes turn purple after cast application (see Fig 4)

- Some neonatal feet have poor vascular control and will turn purple as the cast cools. Don’t be too hasty to remove the cast. Bundle the child, elevate the feet, and recheck every 15 minutes ×4. As the cast dries, the toes should become pink (see Fig 4). Increasing purplish discoloration indicates a cast that is too tight and should be reapplied.

An older child who resists casting

- A child who fights casting prevents good molding and too much motion may prevent the cast from setting up in the desired position. A quiet room with music may relax the child. Likewise, entertaining the child with a toy may distract him or her. Feeding may also be helpful. Older children often do better if sitting slightly upright, propped against a pillow, or even in a parent’s lap.

Child pulling out of foot-abduction orthosis

- Add padding in the heel, above the posterior calcaneal tuberosity, use a shoe with a heel cutout, or both (see Fig 5C). If the child has a strong propensity for toe curling, try a Plastizote plate under the toes to keep them extended. For persistent intolerance, try using only the strap without the tongue. Maintenance of complex clubfoot is extremely difficult and may require a custom brace (see Fig 5D).

Child cries while in casts or in bar and shoes

- Make sure the toes are well perfused. Discomfort for 24 hours after the first casting or tenotomy is common and easily relieved with acetaminophen. The child should be seen and the cast might need to be removed if discomfort persists for >48 hours.
- If the child is in an orthosis, examine the feet for sores. If the orthosis is removed whenever crying occurs, the child may associate crying with subsequent bar removal. Feet may be hyperesthetic after casting: massage during diaper changes and other times out of the orthosis accelerates desensitization.

Recurrence

- Monitor for decreases in abduction and dorsiflexion.
- Treating an early identified, minimal recurrence with stretching by the parents with every diaper change may prevent progression. Later or more marked recurrence should be treated with recasting and possibly a second percutaneous tenotomy. For recurrence in older children, an open Achilles tendon lengthening may be more appropriate for feet with minimal dorsiflexion. For residual dynamic varus, a transfer of the anterior tibialis tendon may be necessary (see Chap. PE-92).
POSTOPERATIVE CARE

- After removal of the posttenotomy cast, the child should immediately be placed in a foot-abduction orthosis. Most fully corrected idiopathic clubfeet will tolerate standard orthoses consisting of open-toed, straight-last shoes connected by a bar.
- In the case of bilateral corrected clubfeet, both shoes should be placed in abduction and external rotation on the bar to the degree of comfortable correction, typically 55 to 60 degrees (see Fig 5D).
- For unilateral clubfoot, only the shoe of the affected foot is placed near the extreme of abduction. The shoe of the uninvolved, normal foot is placed at 35 degrees of abduction and external rotation. The shoes should be placed at shoulder width on the bar.
- Mounting the shoes on the bar such that the buckle of the anterior ankle strap is on the medial aspect of the foot cases application of the orthosis (see Fig 5D).
- In cases of unilateral clubfoot, application of the orthosis is easier if the affected foot is placed into its shoe first, followed by the normal foot. In bilateral cases, one foot is usually “tighter” (more resistant to correction or had less correction from the tenotomy), and this is the one that should be placed in the orthosis first.
- The anterior ankle strap secures the foot in the shoe and should be tightened sufficiently to prevent pulling the foot out of the shoe. The laces should be pulled only tight enough to conform the shoe to the foot. Tightening further may cause venous congestion and extreme discomfort.
- If the foot is not secured in the shoe, Plastizote pads should be used. Usually a pad placed in the heel of the shoe, positioned so that the inferior edge rests just above the posterior tuberosity of the calcaneus, is sufficient.
- If necessary, pads on the tongue and/or under the toes may provide further limitations to pulling the foot out of the shoe.
- In some cases, the tongue provides an obstruction to securing the foot, and removing the tongue may actually improve the ability of the strap to secure the foot.
- Other modifications that may help prevent pulling out include lacing the shoes from the ankle down to the toe, slightly decreasing the degree of external rotation of the shoes (no less than 45 degrees), or widening the bar slightly beyond shoulder width.
- Only a single, thin pair of socks should be worn with the shoes. For the first 1 or 2 days, two socks may be used to prevent blisters (much like the double-sock method used by runners), but thereafter only one pair should be used.
- Thick, well-padded socks prevent adequate securing of the foot and make it easier to pull the foot out of the shoe.
- For the first week, the orthosis and socks should be removed with every diaper change to inspect the feet for evidence of developing pressure sores.
- Red spots that do not disappear within 5 minutes signal a potential problem spot and require refitting of the shoes with Plastizote or repositioning on the bar.
- Care should be taken to remove the orthosis when the child is calm to prevent the child from associating crying with subsequent removal, resulting in persistent resistance to orthosis wear with unrelenting crying.
- After casting, the leg and foot are hyperesthetic.
- Massaging the leg, initially deeply and progressing to light touch, with each diaper change during the first week helps with desensitization.
- The lower leg may also develop intermittent purple discoloration when dependent to gravity after casting. This usually resolves over the first month out of casts.
- After the first week, the orthosis should be worn full time, but it may be removed once daily for bathing and a short period of play (1 to 2 hours).
- Full-time wear continues for 3 to 4 months to maintain correction.
- Tighter feet, or those more difficult to correct, may benefit from periodic stretching in dorsiflexion and abduction whenever the orthosis is removed.
- Children should be re-examined in and out of the orthosis after 1 month, then 2 months later.
- After 3 months of full-time wear and maintenance of full correction, children wear the orthosis only during periods of sleep, at nighttime, and during naps.
- Children should be examined every 3 to 6 months, depending on the level of concern regarding recurrence, until bar and shoe wear is complete.
- Any episodes of recurrence warrant recasting as soon as identified.
- Casting is performed in the usual manner to obtain complete correction again.
- Casting is usually sufficient to correct the recurrence. Rarely, a repeat percutaneous tenotomy is necessary for more severe recurrence. Once complete correction is again obtained, orthosis wear occurs for 3 months full time before resuming part-time wear.
- Straight-last shoes may be worn until the child’s toes curl over the edge of the shoe. Then the next appropriate size should be fitted and attached to the bar.
- Part-time wear continues until the child is 4 years old, when orthosis wear may be discontinued. Children should be monitored for recurrence, which occurs rarely after 4 years old.
- Complex clubfeet almost always pull out of standard straight-last shoes. A variety of newer bar-and-shoe constructs have been developed to address the limitations of current standard orthoses, including one developed by Dr. Ponseti (see Fig 5D).

OUTCOMES

- A corrected clubfoot tends to recur to its original position, requiring maintenance of correction in the orthosis. Noncompliance with bar-and-shoe wear increases the likelihood of recurrence to more than 80%. Compliance is increased with close follow-up and explicit discussions with the family and all caregivers.3
- Twenty percent to 50% of corrected clubfeet will require anterior tibialis tendon transfer to correct dynamic varus present during ambulation (see Chap. PE-92).

COMPLICATIONS

- Cast sores, cast saw burns
- Prolonged casting or pulling back in the cast due to improper technique, unrecognized clubfoot, or failure to modify casting for complex clubfoot
- Overabduction from unrecognized complex clubfoot or overabduction in foot abduction orthosis (beyond degree of correction)
- Posterior tibial artery impingement
- Peroneal artery or lesser saphenous vein laceration during tenotomy
- Pulling back in cast from poor cast molding, unrecognized complex clubfoot, or not enough knee flexion in long-leg cast if complex clubfoot
- Recurrence due to incomplete correction or lack of orthosis wear

REFERENCES


Clubfoot, or talipes equinovarus, is a congenital or acquired deformity in which the foot is stiffly positioned in hindfoot equinus and varus, and forefoot varus, supination, and plantarflexion. When the deformity is not corrected, the patient limps, bearing weight on the lateral forefoot. This can limit ambulation and lead to foot and ankle pain, abnormal calluses, and ulcers and infections. The deformity may present as an isolated or syndromic birth defect. Clubfoot has been documented in conjunction with diagnoses of polio, spina bifida, cerebral palsy, as well as other disorders.

The exact cause of clubfoot remains unknown. Many theories and their detractors can be found in the literature. The displacement of these bones differs, producing varying amounts of four different positional deformities: cavus, adductus, varus, and equinus. Eventually, the abnormal forces and positions lead to plantarflexion and medialization of the talar neck. Weakness and underdevelopment of the foot and calf to varying degrees results. While radiographic measurements are hard to reproduce, the anteroposterior (AP) and lateral talocalcaneal angles are reduced from about 28 degrees to about 5 degrees in children with clubfoot.

The deformity of clubfoot is identified at birth as unilateral or bilateral hindfoot equinus and varus and midfoot supination, varus, and equinus. To perform the examination, the leg is extended at the knee and the foot is then dorsiflexed. The foot-to-tibia angle is measured to assess the amount of equinus in the frontal plane and the amount of heel varus in the sagittal plane. The dorsolateral aspect of the midfoot is palpated to locate the talar head. The forefoot is then manipulated to determine if the forefoot can be reduced onto the talar head. The lateral rotation of the foot–thigh angle can be assessed by flexing the knee and ankle to 90 degrees and gently laterally rotating the foot. The angle is measured.

The lateral rotation of the foot–thigh angle can be assessed by flexing the knee and ankle to 90 degrees and gently laterally rotating the foot. The angle is measured.
These examinations do not determine a classification but rather the stiffness of the foot and the amount of improvement attained with serial casting and surgical intervention.

The clinician should investigate associated anomalies, such as spina bifida, spasticity, muscular dystrophy, arthrogryposis, and so forth. By understanding the cause, the likelihood of treatment success can be predicted.

The clinician should observe the shape and size of the foot. The clubfoot is generally shorter and wider than a normal foot.

Examination reveals equinus and varus of the ankle and midfoot. Calf atrophy is expected, particularly in the older child (FIG 1A–C).

Treatment may be altered depending on the presentation of the clubfoot.

Range of motion: equinus

Ankle motion (dorsiflexion and plantarflexion) is assessed in both knee extension and flexion. The os calcis may remain in equinus (palpation) even though the heel pad appears (observation) to come out of equinus (FIG 1D,E).

The foot may “look” as if the equinus is corrected, but the physician must palpate it to know for sure.

Range of motion: subtalar joint

Range of motion is difficult to measure. The resting alignment of the heel to the talus is usually varus in the untreated clubfoot and 5 to 10 degrees of valgus in the corrected foot. The clinician looks at the sole of the foot to observe midfoot varus. The sole is manipulated to see how flexible it is (FIG 1F,G).

Failure to correct the heel into slight varus indicates incomplete correction of the clubfoot. Overcorrection of the heel into valgus can lead to painful pronation. Residual varus

of the lateral border of the foot may be due to subtalar rotation, varus of the calcaneus, medialization of the cuboid on the calcaneus, or varus deformity of the metatarsals. Correction may be required at the site of deformity.

- Range of motion: forehead on the talar head
  - The foot is palpated dorsolaterally at the lateral midfoot. It usually is lined up with the patella, although plantarflexed. Manipulation is used to reduce the forehead (FIG 1H).
  - The more difficult it is to reduce the forehead onto the talar head, the stiffer the deformity.
- Forefoot supination
  - The clinician observes that the forefoot of the clubfoot appears supinated with respect to the tibia. However, supination relates to the position of the forehead to the hindfoot (FIG 1J).
  - If the forefoot appears 30 degrees to the tibia and there is 30 degrees to the hindfoot varus, then the deformity is hindfoot varus and not supination!
  - It is important to know where this deformity is. Errors in this assessment may lead the surgeon to overcorrect the midfoot or surgically create a pronation deformity.
- Forefoot plantarflexion
  - The physician begins with palpation of the medial column from the first metatarsal to the talar head. Plantarflexion of the forefoot on the hindfoot is measured.
  - In the operated foot, the physician checks for dorsolateral subluxation or dislocation of the navicular on the talar head (FIG 1K).
  - Deformity must be corrected where it is. This assessment, in conjunction with radiographs, will help to assess its location in the soft tissues, the ankle, the bone, or the joints (such as subluxation of the talonavicular joint).

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Sonograms may be used to diagnose clubfoot prenatally. While no prenatal treatment is available, many parents want to know the diagnosis of clubfoot so they can learn about the natural history and treatment options available to them.
- The prenatal ultrasonographic diagnosis of clubfoot may be made if the bones of the lower leg are in the same plane as the plantar surface of the fetal foot. To ensure a correct diagnosis, images in which the leg is extended away from the wall of the uterus should be obtained.
  - This deformity may be seen as early as 12 or 13 weeks.
- Plain radiographic images in the newborn period add little to the physical examination. Films are not reproducible and contribute little to the management.
  - With older children, radiographs may be necessary to treat the deformity effectively, as they can identify fixed individual bone deformities such as flat-top talus, varus deformity of the calcaneus, or dorsolateral subluxation of a triangular navicular on the talar head.
  - The most common images used are those of the talocalcaneal angle in both the AP and lateral planes. Both must be obtained while bearing weight or simulated weight bearing on the affected foot.

DIFFERENTIAL DIAGNOSIS

- Identifying the underlying cause is often helpful. Examination should be complete to identify spinal dysraphisms, syndromes, cerebral palsy, spina bifida, and so forth.

NONOPERATIVE MANAGEMENT

- Most would claim that extensive surgical techniques are necessary in less than 5% of cases.
- Two of the major techniques preferred for nonoperative treatment:
  - Optimal for very young patients, the Ponseti method uses weekly manipulations and cast applications to treat the deformity. About 90% of the patients treated with the Ponseti method will need posterior releases, and about 30% will require additional surgical management after age 2, including repeat posterior release, posteromedial release, and complete subtalar release.
  - Also used predominantly in newborns, the French method incorporates daily manipulation and stimulation of the foot muscles with nonelastic adhesive strapping to correct clubfoot.
  - There will always be the recalcitrant clubfoot that resists methods such as the Ponseti technique. These cases usually fall into the “arthrogrypotic” or “teratologic” category and should be treated with the releases described below.

SURGICAL MANAGEMENT

- All authors agree that the goal of surgical treatment is first to release enough of the tight structures to bring the foot into an anatomically correct position without tension.
- Many will add that muscles should be balanced to help maintain the anatomic position.

Preoperative Planning

- The age of the child will play an important role in what must be done to restore anatomic alignment. Generally, soft tissue releases are adequate from age 2 months to 4 years and in some cases to age 6 years. By the age of 4 years, many of the chieffeet are beginning to show bone deformity, which will block correction after soft tissue releases alone.
- The choice of operative procedure depends on not only the age of the patient, but also the degree of rigidity, the deformities present, and the extent of correction by previous treatment.

Positioning

- The child is placed on the operating table in the prone position.
- The patient is supported using bolsters underneath the shoulders and waist.
- The legs are kept free and the knee is fully extended.

Approach

- Surgical release should begin posteriorly and then continue medially. These areas should reveal the tightest structures in an equinovarus foot.
- As recommended by Henri Bensahel, often the “à la carte” approach is used, in which intraoperative evaluation leads the surgeon to release any and all tight structures. The surgeon must be prepared to do as little or as much as needed to accomplish anatomic realignment.
- For each of the soft tissue releases described in Techniques, it is important to evaluate each foot after each step of the surgical release to determine if the anatomy is corrected or if additional release is necessary.
  - The goal is to do as little or as much of a release as will place the foot in a corrected position without force.
  - Lengthening tendons and then capsules and ligaments at each location will minimize scarring and stiffness.
INCISION

Turco Posteromedial Incision
- The Turco incision allows for access to the medial and posterior portions of the foot (TECH FIG 1).
- The technique begins with a medial incision at the first metatarso-medial cuneiform joint.
- The cut is extended proximally until it is just distal to the tip of the medial malleolus.
- Care is taken to curve the incision in a vertical direction, up the calf to expose the Achilles tendon.
- To reach the lateral side, the subtalar joint must be opened like a book, or a separate lateral incision must be made.

Carroll Medial and Posterolateral Incisions
- The Carroll types of incisions allow medial or more posterolateral access (TECH FIG 2).
- For the medial incision, a triangle is cut that is demarcated by the center of the os calcis, the front of the medial malleolus, and the base of the first metatarsal.
- The incision is made parallel with the base of the triangle, then curved proximal-plantar, and then curved distally over the dorsum of the foot.
- For the posterolateral incision, an oblique incision is created that runs from the midline of the distal, posterior calf to a point between the tendo Achilles and the lateral malleolus.
- A lateral incision may be required to reach the lateral talonavicular joint.

Cincinnati Incision (Author’s Preferred Incision)
- The Cincinnati incision provides the most extensive access to the foot, including medial, posterior, and lateral access (TECH FIG 3).
- The incision begins medially over the talonavicular joint, extending posteriorly at the level of the subtalar joint. It is continued distally to the talonavicular joint laterally and may be extended distally on both the medial and lateral sides.
- The Cincinnati incision is most easily performed with the patient prone. Flexing the knee provides excellent access to the Achilles tendon for Z-lengthening.
- For severely deformed feet (equinus), closure may be difficult.
POSTERIOR SOFT TISSUE RELEASE

- In the exsanguinated prone foot, the posterior portion of the Cincinnati incision is made from the distal tip of the medial malleolus around the posterior ankle to the distal tip of the lateral malleolus.
- The Achilles tendon sheath is incised to expose the Achilles tendon. In a child under 18 months, the tendon can be lengthened by tenotomy, but in the older child it should be lengthened by Z-lengthening.
- To facilitate visualization for a Z-lengthening of the Achilles through the Cincinnati incision, the knee is flexed in the prone patient. With the Cincinnati incision, the surgeon is looking at the planter aspect of the foot and through the incision and up the calf.
- The Achilles tendon is lengthened in a notch fashion.
- The medial half of the Achilles insertion is released to reduce the varus force. Fibrotic bands and tendon sheath should also be released.
- If the Achilles lengthening is not sufficient to restore the anatomy, the posterior aspects of the subtalar and ankle joints are sequentially released.
- The first step is to identify and protect the sural nerve and vessels laterally and the posterior tibial neurovascular bundle medially. The flexor hallucis is then identified posteromedially and protected. The peroneal tendons are also identified and protected (TECH FIG 4).
- The ankle capsule is noted and incised from the postero-medial to the posterolateral corners to allow dorsiflexion of the talus in the mortise.

MEDIAL SOFT TISSUE RELEASE

- Medial release is undertaken if the posterior release as described above does not correct the anatomy.
- First, the posterior portion of the Cincinnati incision is extended medially to the medial aspect of the navicular.
- The posterior tibial neurovascular bundle is protected while releasing any thickened fascia as well as the flexor hallucis, which may have been lengthened through the posterior part of the incision.
- The posterior tibial tendon is located just distal to the flexor digitorum tendon and is lengthened in notch fashion as necessary.
- The abductor hallucis muscle is lengthened proximally or distally. The flexor digitorum tendon is identified just anterior to the posterior tibial neurovascular bundle and lengthened in notch fashion as necessary (TECH FIG 5).
- Deciding whether to lengthen the anterior tibialis tendon can be difficult. If the anterior tibialis tendon appears contracted on anatomic correction, it should be lengthened in a Z-lengthening. Occasionally, the anterior tibialis tendon remains overactive and will need to be lengthened at a future time.
- A helpful hint for the lengthening of the tendons on the medial side of the foot: Each of the ends of the lengthened tendons should be tagged with suture, which is then held in a color-coded bulldog clamp. Each group of the proximal and distal sets of clamps can then be held in proper order by a safety pin. This will avoid confusion when it is time to repair the tendons after anatomic realignment of the foot is accomplished.
- Release of the plantar fascia has been recommended in the past but is currently avoided since it can contribute to later pes planovalgus. Do not release the plantar fascia in cases of rocker-bottom deformity during the casting.
- Care should be taken to avoid injury to the medial plantar vessels and nerve.
- If lengthening of these tendons does not permit anatomic alignment, follow this addendum:
  - Identify and release the talonavicular joint. The navicular is medially displaced on the talonavicular joint, making

The subtalar joint is found and incised posteriorly, then medially and laterally to the interosseous ligament. The fibulotalar and fibulocalcaneal ligaments can be released as needed.

This release should allow the ankle joint to dorsiflex at least 20 degrees. If the hallux is tightly flexed, the flexor hallucis can be lengthened through this incision by Z-lengthening.
the talonavicular joint obliquely, rather than transversely, oriented.

- Follow the distal stump of the notch-lengthened posterior tibial tendon to its insertion on the navicular.
- The capsule is released medially, plantarly, and dorsally and as far laterally as can be reached safely. Be careful not to cut the talar neck, as this may lead to avascular necrosis or growth disturbances!
- Release the subtalar capsule from the talonavicular joint to the interosseous ligament medially, including the spring ligament. Be careful not to damage the deep deltoid ligament. A Freer elevator placed into the ankle joint posteriorly can help identify the ankle and subtalar joints.
- Reach the medial aspect of the calcaneocuboid joint by carefully dissecting the soft tissues from the plantar aspect of the talus neck. Release of this capsule will allow a wedge opening of the calcaneocuboid joint to straighten the lateral column. Another landmark to the calcaneocuboid joint from the medial side of the foot is the peroneus longus tendon crossing from lateral to plantar.
- Many authors have described release of the interosseous ligament through this incision. It is important to preserve this ligament as a pivot axis and to preserve its associated blood supply to the talus.

**LATERAL SOFT TISSUE RELEASE**

- A problem often occurs when the calcaneus has rotated under the talus on the interosseous membrane and is tethered by a stiff, fibrotic lateral capsule. If the above posterior and medial releases do not permit anatomic alignment, a lateral release may be needed.
- The posterior portion of the Cincinnati incision, made for the posterior release, is extended laterally at the level of the subtalar joint to the talonavicular joint.
- The extensor digitorum brevis is identified over the sinus tarsi. Its plantar edge is divided from the lateral calcaneus and the muscle is elevated to expose the sinus tarsi and neck and head of the talus.
- The lateral capsule of the talonavicular joint is exposed and released. A circumferential release of the talonavicular joint is thus completed (TECH FIG 6).
- The beak of the calcaneus is then palpated. From the lateral aspect of the talonavicular joint, cut the lateral subtalar capsule, between the beak of the calcaneus and the talar neck, proximally to the interosseous ligament, completing circumferential release of the subtalar capsule.

**REALIGNMENT OF THE BONES OF THE FOOT**

- Once the appropriate soft tissues have been released, the foot can be realigned.
- A finger is placed over the talar head dorsolaterally while the foot is laterally rotated in slight supination. This is similar to the Ponseti manipulation.
- A Freer elevator can be placed in the ankle joint in line with the dome of the talus (axis of the talus). The foot should be rotated until the first metatarsal is just lateral to the talar dome axis.
- This maneuver should correct the lateral border to straight and the heel into slight valgus and reduce the talar head under the navicular (the navicular should be slightly proud to palpation as in normal feet), without wedging open the subtalar joint (TECH FIG 7).
FIXATION

- Holding the foot in the anatomically corrected position until the capsules and tendons heal is best done with a 0.062-inch Kirschner wire, which is passed from the posteromedial talus through the center of the head and into the navicular and the medial cuneiform and out the first web space (TECH FIG 8A).
- Intraoperative radiographic images should be obtained at this point to confirm that all components of the reduction have been obtained (TECH FIG 8B,C).
- All of the joints should be congruous. Wedged-open joints may indicate incomplete release of bone deformity, requiring osteotomy.
- Proper reduction should result in near-normal motion of the ankle. The fixation pin restricts the foot motion.
- If division of the interosseous ligament (rarely needed in my experience) has been performed, a second pin should be placed from the calcaneus into the talus to maintain the alignment of the subtalar joint.

REPAIR OF TENDONS

- Once the foot is anatomically aligned, the tendons are repaired with the foot at 90 degrees to the tibia.
- Do not repair the tendons until the bones have been realigned anatomically. Repairing the tendons at too short a length will result in rapid recurrence.
- Capsules and ligaments should not be repaired surgically. They will heal.
# POSTOPERATIVE CARE

- During the first postoperative week, a Jones-type dressing is preferred to allow for swelling in children under 6 months of age. Bulky dressings and casts are recommended for children over 6 months.
- Ponseti-type casting will help maintain the alignment. Casts should be changed at 1 week and continue for 3 months.
- Braces are helpful for prolonged periods, if recurrence occurs or underlying neuromuscular disease has been identified.
- After incisions, wound closure and positioning in equinus for 2 weeks allows healing and can be followed by serial casting to stretch the soft tissues to dorsiflex the ankle.
- Pins may be removed after 4 to 6 weeks.
- Muscle balancing is better left for a later time, after rehabilitation from extensive surgical release.

# OUTCOMES

- As noted previously, surgery is usually necessary only with the most resistant forms of clubfoot.
- Successful results can be obtained in 52% to 91% of cases, enabling most children to participate in normal activities.\(^4\)
- Stiffness, recurrence, and weakness are common, and no treatment known today can correct the underlying neuromuscular causes.
- The incidence of a poor outcome is higher in children who have surgery before 6 months of age. Waiting to treat young patients may be beneficial since it allows for growth of the anatomy as well as time to fully evaluate the case.\(^3\)
- These children should be referred to centers with the most experience.

# COMPLICATIONS

- The challenges that this deformity presents ultimately may lead to a variety of complications:\(^3\):
  - Skin slough and wound dehiscence
  - Neurovascular complication
  - Physeal damage
  - Osteonecrosis of the talus
  - Aseptic necrosis of the navicular
  - Failure to achieve or loss of correction
  - Overcorrection or undercorrection
  - Hindfoot valgus
  - Forefoot abduction or adduction
  - Calcaneus deformity
  - Pes planus
  - Persistent equinus
  - Heel varus
  - Dorsal forefoot subluxation with apparent cavus
  - Skew foot
  - Dorsal bunion
  - Claw toes
  - Anesthetic foot
  - Sinus tarsi syndrome
  - Restricted motion
  - Reduced calf girth and foot size
  - Recurrence of the deformity
  - Neuromuscular abnormalities, growth disturbances, and simple muscular or mechanical imbalance can lead to recurrence or overcorrection throughout the growth period. Stretching, bracing, casting, and even additional surgery may be needed.

# REFERENCES

DEFINITION
- The incidence of residual deformity in congenital clubfoot ranges from 26.6% to 50%, regardless of the initial treatment provided.²
  - The disparity in the reported incidence is due to varying severity of clubfoot deformity, different methods of treatment, and, in part, differing definitions of residual deformity.
- Residual deformities include isolated equinus, cavus, metatarsus adductus, forefoot supination, and combinations of the above.
- Dynamic forefoot adduction and supination can be observed after clubfoot treatment with or without soft tissue releases.
- Dynamic forefoot supination deformity results from residual medial displacement of the navicular on the head of the talus, which results in muscle imbalance. In this case, because its insertion is medially displaced, the anterior tibialis becomes a forefoot supinator instead of a dorsiflexor. In addition, deformity may also occur because the anterior tibialis muscle is relatively strong in comparison to the peroneal muscles (FIG 1).
- The aim of treatment is to correct any fixed deformity and to rebalance the muscles of the foot, thereby correcting dynamic deformity and improving foot alignment.

ANATOMY
- The anterior tibialis muscle originates from the upper two thirds of the tibia.
  - The anterior tibialis tendon fibers rotate 90 degrees from the musculotendinous junction to its insertion on the medial cuneiform and first metatarsal.
  - Medial rotation begins proximally, so the most medial muscle fibers proximally rotate to the posterior surface of the tendon near the midpoint and continue to rotate so that their final insertion is as the distal–lateral fibers on the first metatarsal.
- Meanwhile, the most lateral muscle fibers proximally rotate to the anterior surface at the midpoint and continue distally to insert on the cuneiform as the proximal–medial fibers (FIG 2).⁴
- The anterior tibialis muscle is active in two important stages of the gait cycle; it concentrically fires during the initiation of swing phase and keeps the foot dorsiflexed during early swing phase and then it relaxes.
- The anterior tibialis muscle then fires eccentrically as the foot is lowered to the floor from heel strike to foot flat in stance phase.
- As a dorsiflexor, the anterior tibialis muscle opposes gravity and the strong gastrosoleus complex. Importantly, the anterior

---

FIG 1 • Normal foot versus supinated foot. Medial subluxation of the navicular, the medial cuneiform, and the first metatarsal results in supination deformity as the line of pull of the tibialis anterior tendon directs the foot into supination instead of dorsiflexion.

FIG 2 • Anatomy of the tibialis anterior muscle-tendon. The anterior tibialis tendon fibers rotate 90 degrees from their musculotendinous junction to their insertion on the medial cuneiform and the first metatarsal such that the proximal-medial insertional fibers on the cuneiform begin as the lateral fibers at the musculotendinous junction (see window).
tibialis muscle may also be a supinator of the forefoot in the face of peroneal longus weakness or medial displacement of the insertion.

There are important bony abnormalities associated with residual clubfoot deformity.

- The subtalar joint may have an absent anterior facet and small, narrow medial and posterior facets, resulting in restricted subtalar motion. In this setting, the calcaneus does not slide fully into valgus with casting such that the navicular remains medially displaced.
- The navicular itself is wedge-shaped and is medially displaced along with the cuneiforms and metatarsals. With medial displacement of its insertion, the biomechanical advantage favors the action of the anterior tibialis muscle as a strong supinator over its role as a dorsiflexor (FIG 3).

PATHOGENESIS

- The cause of residual clubfoot deformity may be incomplete correction or recurrence of deformity as part of the natural history of the resistant clubfoot.
- Electromyographic studies have demonstrated that the peroneal muscle group can be relatively weaker, thus increasing the supinator action of the tibialis anterior muscle. The navicular malleolar distance demonstrates the extent of medial displacement of the navicular. The navicular–medial malleolar distance is decreased compared to the normal foot. In fact, the medial malleolus can be difficult to quantify as midfoot breech will often accommodate and hide the hindfoot equinus (FIG 4).
- Correction of resistant congenital clubfoot often requires more than one surgery, not because of a “failed initial intervention,” but because of dynamic muscle imbalances that may not be fully manifest at the time of the initial intervention. Thus, the need for an additional operation can be perceived as part of the natural history of congenital clubfoot. If left untreated, the dynamic deformity may become stiff and the foot tends to invert. When inversion deformity is combined with residual equinus deformity, hindfoot varus may recur (FIG 4).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Residual deformity is more likely in patients who have clubfoot as a result of myelomenigocele or other neuromuscular syndromes and genetic disorders such as Larsen syndrome. Therefore, it is important to consider neurologic causes, such as tethered cord, when confronted with residual deformity. Recurrent deformity may be found in children with only four toes on the affected foot, as these individuals may have absence of the peroneal muscle group (similar to that seen in fibular hemimelia), thus leaving them prone to recurrence.
- One of the first clinical signs of recurrence is a dynamic inversion of the foot with slight equinus. Equinus may be difficult to quantify as midfoot breech will often accommodate and hide the hindfoot equinus (FIG 5).
- Residual deformity most frequently occurs in severe or atypical cases, which are often associated with a small calf size. These children may also have short, fat feet with a deep planter crease that extends from the medial border to the lateral border of the foot and a shortened first ray. These findings are consistent with severe or atypical clubfeet that have a propensity for residual deformity.
- In maximum pronation or maximum supination, the navicular–medial malleolar distance is decreased compared to the normal foot. In fact, the medial malleolus can be difficult to delineate because it is in contact with the navicular. The navicular malleolar distance demonstrates the extent of medial subluxation.
- It is important to examine gait when possible. During examination of gait, the clinician should identify whether the tibialis anterior is a dynamic supinator; this is best observed in swing phase when no antagonist muscles contract. This finding will confirm the appropriateness of surgery.

NATURAL HISTORY

- Residual deformities are usually encountered within the first year after initial treatment and generally before the age of 5 years, even in congenital clubfeet that had been fully corrected since the first month of life.
- Residual forefoot adduction and supination are the most common deformities after nonoperative treatment and can also be seen after initial operative repair. They can result from undercorrection at the time of the primary intervention.

- Correction of resistant congenital clubfoot often requires more than one surgery, not because of a “failed initial intervention,” but because of dynamic muscle imbalances that may not be fully manifest at the time of the initial intervention. Thus, the need for an additional operation can be perceived as part of the natural history of congenital clubfoot. If left untreated, the dynamic deformity may become stiff and the foot tends to invert. When inversion deformity is combined with residual equinus deformity, hindfoot varus may recur (FIG 4).

FINDINGS

- Correction of resistant congenital clubfoot often requires more than one surgery, not because of a “failed initial intervention,” but because of dynamic muscle imbalances that may not be fully manifest at the time of the initial intervention. Thus, the need for an additional operation can be perceived as part of the natural history of congenital clubfoot. If left untreated, the dynamic deformity may become stiff and the foot tends to invert. When inversion deformity is combined with residual equinus deformity, hindfoot varus may recur (FIG 4).

FIG 3 • Bony abnormalities associated with residual clubfoot deformity. The navicular is wedge-shaped and is medially displaced along with the cuneiforms and metatarsals.
The strength of the tibialis anterior is tested. With dynamic supination deformity, the supinator action of the anterior tibialis muscle will overpower the dorsiflexor action, thus demonstrating the appropriateness of surgery. In addition, good power is needed for a successful transfer.

Range of motion of the ankle is examined. Transfer will work only as long as there is not a fixed contracture.

The clinician should evaluate for other deformities, such as equinus, cavus, varus, adductus, and tibial torsion.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

Anteroposterior (AP) and lateral radiographs may be helpful to study and quantify various deformities.

AP radiographs will demonstrate medial deviation of the metatarsals, which can indicate residual medial displacement of navicular, which is yet to ossify (FIG 6).

- On an AP radiograph of normal feet, the line drawn through the long axis of the talus should point to the first metatarsal, while the line drawn through the long axis of the calcaneus should point toward the fourth metatarsal.
- In clubfeet, these lines become more parallel, depicting “stacking” of the talus and calcaneus.
- Forced maximum dorsiflexion lateral radiographs may reveal hindfoot equinus with midfoot breech.
- Stacking of the metatarsals on the lateral radiograph identifies the presence of residual forefoot supination (a decreased talocalcaneal angle).
Ultrasound evaluation of the foot is not done routinely. However, experimental studies have demonstrated that this technique is capable of documenting the location of the navicular in relationship to the head of the talus. The navicular is subluxated plantarward and medially on the head of the talus.

Similarly, magnetic resonance imaging can be performed to completely identify the relationships of the cartilaginous bones. Although possible, this technology is rarely clinically used as orthopaedists are aware of the classic deformities that are associated with recurrence.

DIFFERENTIAL DIAGNOSIS

Residual deformities in clubfoot may be due to unrecognized tarsal coalitions or other conditions in severe or atypical feet.

Unexpected and rapid recurrent deformity in children with previously corrected feet and with known myelomeningocele may be a result of continued neurologic involvement, such as tethering of the spinal cord.

NONOPERATIVE MANAGEMENT

Treatment of residual deformity depends on the location, severity, and age of the child.

Recasting may be considered in children less than 18 months of age who have residual deformity.

Most residual deformities at this age can be treated by Ponseti manipulation, followed by application of a toe-to-groin plaster cast with the feet in a fully corrected position for 2 weeks.

After 2 weeks, the casts are removed and reapplied.

Usually three casting sessions are required, for a total of 6 weeks.

Thereafter, abduction bracing is reinstituted.

In larger children, ankle–foot orthoses (AFOs) may also be used to prevent recurrence.

Physiotherapy may also be used in patients with residual deformity. The therapist must be familiar with techniques to manipulate residual forefoot adductus and posterior contracture.

In older children and in patients with midfoot breech, it can be difficult to effectively stretch any hindfoot equinus contracture.

With equinus contracture, abduction bracing is difficult.

Unbraceable posterior contracture can then lead to recurrent metatarsus adductus and forefoot supination. Thus, a repeat percutaneous heel cord tenotomy and casting may be required.

SURGICAL MANAGEMENT

In children more than 2 to 3 years of age, it may be preferable to correct any residual deformity using soft tissue lengthenings or transfers with or without bony procedures.

As the anterior tibialis acts as a supinator, lateral transfer of the anterior tibialis tendon is often necessary to correct dynamic supination deformity.

The optimal age for lateral transfer of the anterior tibialis tendon varies from case to case.

Important factors are the rapidity of recurrence, the strength of the anterior tibialis muscle, the presence of fixed forefoot deformity, or the presence of concurrent equinus deformity or cavus.

The surgery should be performed after the lateral cuneiform ossification center appears (2 to 4 years of age). The split anterior tibialis tendon transfer (SPLATT) of Hoffer is rarely used in idiopathic clubfeet but is an excellent method for correcting dynamic supination deformity as a result of spasticity associated with disorders such as cerebral palsy.

This method may have some utility in children with mild, flexible forefoot supination who require surgery for other deformity.

Preoperative Planning

Feet with residual deformity should be extensively evaluated by clinical and radiographic assessment before surgical planning. Each foot should be treated individually, as no single treatment plan is appropriate for all feet.

Associated deformities must be identified. For example, an anterior tibialis transfer will function poorly in the face of a fixed equinus contracture. In this case, it will be necessary to correct equinus deformity with a heel cord tenotomy or lengthening or posterior release.

Residual varus deformity may indicate the need for an opening wedge or sliding calcaneal osteotomy.

Persistent metatarsals adductus may necessitate midfoot osteotomies in order for the lateral border of the foot to be reduced.

Anterior tibialis tendon transfer does not correct restricted subtalar motion.

It is important to confirm that the ossific nucleus of the lateral cuneiform is present in order to place the anterior tibialis tendon into an appropriate anchor site.

Positioning

The patient is placed in the supine position on a standard operating table or a hand table.

Either positioning is done in a way to ensure good fluoroscopic images.

A well-padded thigh-high tourniquet should be placed before preparing and draping the patient.

Approach

A medial incision is based over the insertion of the anterior tibialis tendon.

From this incision the surgeon may be able to perform an opening wedge osteotomy of the medial cuneiform if indicated.

Once the anterior tibialis tendon is detached, a lateral incision is based over the lateral cuneiform.

Fluoroscopic imaging can assist in planning this incision.

The lateral incision may need to be longer and more laterally based should the surgeon decide to perform a cuboid closing wedge osteotomy at the same time.
FULL ANTERIOR TIBIALIS TENDON TRANSFER TO THE LATERAL CUNEIFORM: MODIFIED GARCEAU TECHNIQUE\textsuperscript{5,11}

Approach
- A 4-cm-long dorsal-medial longitudinal skin incision is made over the course of the anterior tibialis tendon from the inferior margin of the ankle retinaculum (the superior limb of the inferior extensor retinaculum) to its palpable distal insertion based over the medial cuneiform (TECH FIG 1).
- Dissection is carried down through subcutaneous tissues and the inferior limb of the inferior extensor retinaculum to expose the tendon sheath.
  - The anterior tibialis tendon sheath is incised sharply and opened as far distally as possible and then proximally to just short of the ankle retinaculum.
- A hemostat is placed under the anterior tibialis tendon to help expose the insertion.
- This broad extensive insertion is detached as far distally as possible to gain maximum length of tendon for the transfer.
  - It is critical to obtain as much length as possible.

Transferring the Tendon
- Once the tendon is freed and detached distally, a strong absorbable suture (eg, 1-0 Vicryl) is woven in a Bunnell-type fashion through the anterior tibialis tendon.
  - Care is taken to weave the suture in a fashion that does not lead to a bulbous end, thus making the tendon difficult to deliver to the lateral wound and subsequently pass into the lateral cuneiform.
  - Occasionally, the loose ends of the tendon insertion are trimmed or incorporated with a 3-0 absorbable suture to facilitate passage and anchoring.
- By pulling on the suture, the tendon is gently pulled distally while the soft tissue attachments to the tendon are freed up to, but not beyond, the ankle retinaculum.
  - To avoid bowstringing of the tendon, it is important not to release the ankle retinaculum.
  - A dorsal-lateral longitudinal incision, 1.5 to 2 cm long, is made over the lateral cuneiform.
  - The lateral cuneiform is identified just proximal to the base of the third metatarsal.
  - Dissection is carried down through subcutaneous tissues to the toe extensors.
  - To expose the lateral cuneiform, the toe extensors are retracted medially and the extensor digitorum brevis muscle is retracted laterally.
  - A cruciate periosteal incision is made directly over the lateral cuneiform, carefully avoiding the adjacent joint articulations.
  - In young children, a Keith needle is used to fluoroscopically locate the center of the ossific nucleus.
  - In older children, a small periosteal elevator is used to elevate the periosteal flaps off the lateral cuneiform.
  - Occasionally, these flaps may be sutured into the transferred tendon, thus supplementing fixation. In young children, however, it may be difficult and futile to elevate perichondrium from the predominantly cartilaginous bone.
  - A blunt hemostat is then passed from the lateral incision over the lateral cuneiform and under the extensor tendons to the point where the anterior tibialis tendon passes beneath the ankle retinaculum.
  - Use the hemostat to develop a tract for the transfer of the anterior tibialis tendon.
  - The hemostat is passed into this same tract into the medial wound to grasp the suture ends and bring the anterior tibialis tendon into the lateral cuneiform (TECH FIG 2).
  - Ensure that the available length of the tendon will reach the proposed transfer site into the lateral cuneiform.
Attaching the Transferred Tendon

- A drill bit is selected to be slightly larger than the diameter of the sutured anterior tibialis tendon end.
  - Once the bit is selected, make a hole directly in the center of the lateral cuneiform, drilling just through the plantar aspect of the bone (dorsal to plantar while aiming for the arch of the foot).
- The suture ends of the tendon are threaded onto Keith needles (TECH FIG 3A).
- While the foot is maximally dorsiflexed and everted, the suture needles are passed through the lateral cuneiform drill hole and out through the plantar aspect of the foot, guiding the tendon through the drill hole.
- The tendon is confirmed to easily and reproducibly slide into its new insertion.
  - This is a critical step: be certain that the tendon reliably enters the anchoring hole after the skin is closed when the foot is dorsiflexed and when the suture is tensioned.
- The suture needles on the plantar aspect of the foot are passed through a nonadhesive dressing (eg, Adaptic) and a sterile felt pad.
- At this time it is advisable to irrigate and close all other associated wounds, leaving the lateral recipient wound for last.
  - This way the surgeon can ensure that the anterior tibialis is in the intended position just before dressing and cast application.
- The periosteum of the lateral cuneiform is sutured with two interrupted absorbable sutures to the transferred anterior tibialis tendon while it is pulled into the recipient site (TECH FIG 3B).
- The lateral wound is irrigated and closed in layers while the foot is held in a dorsiflexed position, thus ensuring that the anterior tibialis remains in the hole and the continuity of the periosteal sutures is preserved.
- Sterile dressings are applied while an assistant simultaneously maintains the foot dorsiflexed with tension on the suture.
- The distal foot and ankle portion of a toe-to-groin cast is applied, while ensuring that the suture ends of the tendon are in tension.
- In the past we have tied the button over the felt underneath the cast. However, a high rate of pressure sores has led us to consider alternative fixation.
  - After the cast is hardened, the suture is tied over a button on the exterior of the plantar aspect of the cast (TECH FIG 3C).
  - To prevent plantar pressure sores, make sure the plaster is sufficiently hardened.
- Some surgeons will perform the exact procedure except transfer the whole tendon into the cuboid. These surgeons choose this insertion site if the foot has a concurrent fixed forefoot deformity and mild hindfoot varus that they choose not to correct.
  - We prefer to correct the fixed deformity and transfer the anterior tibialis into the lateral cuneiform as we fear overcorrection from the more lateral insertion into the cuboid.
- Some surgeons add a third incision at the anterior distal tibia directly over the anterior tibialis tendon and just lateral to the tibial crest. The tendon can be easily palpated. The tendon sheath is incised here and the freed distal tendon end is pulled with a hemostat into this incision. From this incision, the freed distal tendon end is eventually pulled into the lateral incision for attachment.
Tech FIG 3 • A. The suture ends of the tibialis anterior tendon are threaded onto Keith needles and passed into the drill hole through the plantar aspect of the foot. The tendon is guided into the drill hole. B. While the foot is maximally dorsiflexed and everted, the tendon is secured.

C. The cast is molded and hardened with the foot in dorsiflexion and eversion and with the suture ends under appropriate tension. The suture is tied over a button on the exterior of the hardened cast to prevent plantar pressure sores.

### SPLIT ANTERIOR TIBIALIS TENDON TRANSFER (SPLATT)

**Approach**
- A 4-cm-long dorsal-medial skin incision is made over the course of the anterior tibialis tendon from the inferior margin of the ankle retinaculum (the superior limb of the inferior extensor retinaculum) to its palpable distal insertion based over the medial cuneiform.
- Dissection is carried down through subcutaneous tissues and the inferior limb of the inferior extensor retinaculum to expose the tendon sheath.
  - The anterior tibialis tendon sheath is incised sharply and opened as far distally as possible and then proximally to just short of the ankle retinaculum.
  - The lateral half of the anterior tibialis tendon insertion is detached as far distally as possible to gain maximum length of tendon for the transfer.
  - A strong absorbable suture (eg, 1-0 Vicryl) is woven in a Bunnell-type fashion through the lateral half of the anterior tibialis tendon.

**Transferring the Tendon**
- The suture is grasped and pulled, allowing the lateral tendon to be gently dissected proximally but not beyond the ankle retinaculum.
  - To avoid bowstringing of the tendon, it is important not to release the ankle retinaculum.
- A dorsal-lateral longitudinal incision, 1.5 to 2 cm long, is made over the cuboid in line with the fourth metatarsal axis.
- Dissection is carried down through subcutaneous tissues to the toe extensors.
  - To expose the cuboid, the toe extensors are retracted medially.
  - A cruciate periosteal incision is made directly over the cuboid, carefully avoiding the adjacent joint articulations.
  - An appropriate drill hole is then made in the cuboid, drilling dorsal to plantar in line with the fourth metatarsal axis and through the plantar aspect of the bone.
PEARLS AND PITFALLS

**Indications**
- Anterior tibialis transfer will work only as long as there is not a fixed contracture. Flexibility of the foot is the main condition for a successful surgical result, because the surgical procedure is based on the dynamic muscle imbalance of the forefoot.

**Positioning**
- Use of a tourniquet at 200 to 250 mm Hg will allow easier surgery.

**Tendon harvest**
- Too short a tendon can make transfer difficult, so the surgeon should obtain as much length as possible.
- Bowstringing and weakness by inadvertently cutting the extensor retinaculum should be avoided.
- The surgeon should attach a suture to the released tendon to allow ease of handling and passing. This will also keep the tendon from fraying as it exits the donor site.

**Tendon fixation**
- It may be difficult to locate the lateral cuneiform in small children. Therefore, intraoperative fluoroscopy should be available.
- An absorbable suture is used to hold the tendon as it usually dissolves and weakens by 6 weeks.
- Alternative forms of fixation may be considered in older children with large bones, such as a suture anchor (FIG 7).
- Overcorrection can be avoided with insertion of the full tendon transfer along the third metatarsal axis. For the split tendon transfer, the optimal site for insertion to obtain maximal dorsiflexion in biomechanical studies is along the fourth metatarsal axis.9

**Wound closure**
- All wounds are closed except the recipient site to be sure that the transferred tendon stays in the tunnel. Also, the foot is kept in maximum dorsiflexion during final wound closure and casting. A well-trained assistant is paramount.

**Cast management**
- Pressure sores on the bottom of the foot can result from too much tension on the button. Therefore, it should be placed on the exterior of the cast.
- Swelling and pressure sores may result if extensive and lengthy procedures are done. In these cases, prophylactic dorsal splitting of the cast in the operating room is important.
POSTOPERATIVE CARE

- In patients under 5 years of age and those who may be non-compliant, a toe-to-groin bent-knee cast is maintained with the patient non-weight bearing for about 6 weeks.
  - At 6 weeks, the button and suture are removed and the patient is allowed to begin walking.
- In older children, a short-leg cast for an initial 6 weeks is maintained.
  - At 6 weeks, the button is removed and patient is placed in a short-leg walking cast for an additional 3 weeks to ensure healing and to avoid tendon rupture.
- Clinical and radiographic assessment of outcomes is performed at the end of healing. Plain radiographs (standing AP and lateral foot radiographs) are usually sufficient. CT examination may be obtained if indicated (FIG 8).

OUTCOMES

- Successful surgery will be noted by correction of the supination deformity and conversion of the anterior tibialis into the primary dorsiflexor of the foot. Clinical examination of the foot during active dorsiflexion demonstrates the new insertion site of the anterior tibialis tendon.
- Twenty-seven previously treated clubfeet in 25 patients were retrospectively evaluated after tibialis anterior tendon transfer to correct residual dynamic supination deformity.\(^1\) All showed active contraction of the transferred tibialis anterior tendon. There was no case of overcorrection.
- Clinical and radiographic improvement in both forefoot abduction and supination was demonstrated in 71 cases of residual dynamic congenital clubfoot deformity treated by full and split anterior tendon transfer, with an increase in the eversion strength of the tibialis anterior muscle.\(^8\)
- Farsetti et al\(^2\) confirmed the findings of multiple studies, demonstrating that transfer of the anterior tibial tendon to the lateral cuneiform underneath the extensor retinaculum corrects and stabilizes relapsing clubfeet by restoring normal function of foot dorsiflexion–eversion. In their two series of patients reviewed at the end of skeletal growth, none of the operated patients had further relapse.

COMPLICATIONS

- Undercorrection
- Cast sores
- Wound infection
- Loosening of the transferred tendon
- Rupture of the transferred tendon
- Bowstring at the anterior ankle joint resulting in weakness and a cosmetic deformity
- Loss of dorsiflexion force
- Overcorrection

REFERENCES


FIG 8 • Postoperative clinical photograph of patient in Figure 5. Foot alignment is restored after full-thickness anterior tibialis tendon transfer in the right foot. The left foot is shown as comparison.
Part 5 Oncology

Chapter 1
Overview of Musculoskeletal Tumors and Preoperative Evaluation 1695

Chapter 2
Biopsy of Musculoskeletal Tumors 1719

Chapter 3
Overview of Endoprosthetic Reconstruction 1728

Chapter 4
Expandable Prostheses 1740

Chapter 5
Surgical Management of Metastatic Bone Disease: General Considerations 1749

Chapter 6
Cryosurgical Ablation of Bone Tumors 1757

Chapter 7
Overview of Resections Around the Shoulder Girdle 1766

Chapter 8
Total Scapular Resections With Endoprosthetic Reconstruction 1776

Chapter 9
Proximal Humeral Resection With Allograft Prosthetic Composite 1786
Chapter 10
Proximal Humerus Resection With Endoprosthetic Replacement: Intra-articular and Extra-articular Resections 1793

Chapter 11
Distal Humeral Resection With Prosthetic Reconstruction 1807

Chapter 12
Surgical Management of Metastatic Bone Disease: Humeral Lesions 1816

Chapter 13
Axillary Space Exploration and Resections 1825

Chapter 14
Forequarter Amputation 1833

Chapter 15
Above-Elbow and Below-Elbow Amputations 1842

Chapter 16
Primary and Metastatic Tumors of the Spine: Total En Bloc Spondylectomy 1846

Chapter 17
Overview on Pelvic Resections: Surgical Considerations and Classifications 1855

Chapter 18
Surgical Technique for Resection and Reconstruction of Supra-acetabular Metastatic Lesions 1873

Chapter 19
Buttockectomy 1876

Chapter 20
Surgical Management of Metastatic Bone Disease: Pelvic Lesions 1879
Chapter 21
Posterior Flap Hemipelvectomy 1891

Chapter 22
Anterior Flap Hemipelvectomy 1902

Chapter 23
Hip Disarticulation 1911

Chapter 24
Proximal and Total Femur Resection With Endoprosthetic Reconstruction 1917

Chapter 25
Distal Femoral Resections With Endoprosthetic Replacement 1929

Chapter 26
Proximal Tibia Resection With Endoprosthetic Reconstruction 1953

Chapter 27
Fibular Resections 1964

Chapter 28
The Use of Free Vascularized Fibular Grafts for Reconstruction of Segmental Bone Defects 1974

Chapter 29
Use of Allografts and Segmental Prostheses for Reconstruction of Segmental Bone Defects 1982

Chapter 30
Quadriceps Resections 1991

Chapter 31
Adductor Muscle Group (Medial Thigh) Resection 2000
OVERVIEW

- An understanding of the basic biology and pathology of bone and soft tissue tumors is essential for appropriate planning of their treatment.
- This chapter reviews the unique biologic behavior of soft tissue and bone sarcomas, which provides the basis for their staging and resection and the use of appropriate adjuvant treatment modalities.
- A detailed description of the clinical, radiographic, and pathological characteristics for the most common sarcomas is presented.

EPIDEMIOLOGY

- Soft tissue and bone sarcomas are a rare and heterogeneous group of tumors. These neoplasms represent less than 1% of all adult and 15% of pediatric malignancies.
- As of 2006, the annual incidence in the United States, which remains relatively constant, was approximately 6000 to 7000 soft tissue sarcomas and 2750 bone sarcomas.
- In 2006, the overall mortality rate was 30% for soft tissue sarcomas and 45% for bone sarcomas.
- In the U.S., the 5-year survival rates for osteosarcoma and Ewing sarcoma were comparable among 15- to 29-year-olds, about 60% for the most recent era. Survival rates for chondrosarcoma exceeded 90% in the most recent era. The U.S. bone cancer mortality was highest for males and females 15 to 19 years of age.

RISK FACTORS

- Risk factors for soft tissue and bone sarcomas include previous radiation therapy, exposure to chemicals (eg, vinyl chloride, arsenic), immunodeficiency, prior injury (scars, burns), chronic tissue irritation (foreign body implants, lymphedema, chronic infection), neurofibromatosis, Paget disease, bone infa�数, and genetic cancer syndromes (eg, hereditary retinoblastoma, Li-Fraumeni syndrome, Gardner syndrome, Rothmund–Thomson syndrome, Werner syndrome, Bloom syndrome, Marfucci syndrome, Ollier disease, multiple osteochondromatosis, and hereditary multiple exostoses. In most patients, however, no specific etiology can be identified.
- In the past two decades, both survival and quality of life of patients with soft tissue and bone sarcomas have improved dramatically as a result of the multimodality treatment approach. Limb-sparing surgery, used in combination with chemotherapy and radiation therapy, can achieve cure in the majority of patients with soft tissue and bone sarcomas, and resection is performed in lieu of amputation in more than 90% of all patients.
- The three most common soft tissue sarcomas are malignant fibrous histiocytoma (MFH), liposarcoma, and leiomyosarcoma.
- The most common bone sarcomas are osteosarcoma, chondrosarcoma, and Ewing sarcoma.

PATHOPHYSIOLOGY AND BIOLOGIC BEHAVIOR

- Sarcomas originate primarily from elements of the mesodermal embryonic layer.
- Soft tissue sarcomas are classified according to the adult tissue that they resemble.
- Similarly, bone sarcomas usually are classified according to the type of matrix production: osteoid-producing sarcomas are classified as osteosarcomas, and chondroid-producing sarcomas are classified as chondrosarcomas.
- Tumors arising in bone and soft tissues have characteristic patterns of biologic behavior because of their common mesenchymal origin and anatomic environment. Those unique patterns form the basis of the staging system and current treatment strategies.
- Histologically, sarcomas are graded as low, intermediate, or high grade. The grade is based on tumor morphology, extent of pleomorphism, atypia, mitosis, matrix production, and necrosis, with the two main factors being mitotic count and spontaneous tumor necrosis.
- Tumor grade represents the tumor’s biologic aggressiveness and correlates with the likelihood of metastases. Low-grade lesions metastasize in fewer than 15% of patients. High-grade lesions metastasize in over 20% of patients.
- Sarcomas form a solid mass that grows centrifugally, with the periphery of the lesion being the least mature.
- In contradistinction to the true capsule that surrounds benign lesions, which is composed of compressed normal cells, sarcomas usually are enclosed by a reactive zone, or pseudocapsule. This pseudocapsule consists of compressed tumor cells and a fibrovascular zone of reactive tissue with a variable inflammatory component that interacts with the surrounding normal tissues.
- The thickness of the reactive zone varies according to the histogenic type and grade of malignancy. High-grade sarcomas have a poorly defined reactive zone that may be locally invaded by the tumor (FIG 1A).
- Tumor foci within the reactive zone are called satellite lesions.
- High-grade, and occasionally low-grade, may break through the pseudocapsule to form metastases, termed skip metastases, within the same anatomic compartment in which the lesion is located. By definition, these are locoregional micrometastases that have not passed through the circulation (FIG 1B).
- This phenomenon may be responsible for local recurrences that develop in spite of apparently negative margins after a resection.
- Although low-grade sarcomas regularly interdigitate into the reactive zone, they rarely form tumor skip nodules beyond that area (FIG 1C,D).
- Sarcomas respect anatomic borders. Local anatomy influences tumor growth by setting natural barriers to extension. In
Unique features are formation of reactive zone, intracompartmental growth, and, rarely, the presence of skip metastases. Skip nodules are tumor foci not in continuity with the main tumor mass that form outside the pseudocapsule. "Satellite" nodules, by contrast, form within the pseudocapsule. D. Gross specimen. Skip metastases (arrows) from an osteosarcoma of the distal femur. This finding is documented preoperatively in less than 5% of patients. E. Sagittal section of a high-grade osteosarcoma of the distal femur. The growth plate, although not invaded by the tumor in this case, is not considered an anatomic barrier to tumor extension, probably because of the numerous vascular channels that pass through the growth plate to the epiphysis. However, the articular cartilage is an anatomic barrier to tumor extension and very rarely is directly violated by a tumor. F. Coronal section of a high-grade osteosarcoma of the distal femur. Although gross involvement of the epiphysis and medial cortical breakthrough and soft tissue extension are evident, the articular cartilage is intact. This phenomenon allows intra-articular resection of high-grade sarcomas of the distal femur in most cases. Thick fascial planes are barriers to tumor extension. G. Axial MRI, showing a high-grade leiomyosarcoma of the vastus lateralis and vastus intermedius muscles. The tumor does not penetrate, looking in a clockwise direction, the lateral intermuscular septum, the adductor compartment, and the aponeuroses of the sartorius and rectus femoris muscles. (Courtesy of Martin M. Malawer.)
general, sarcomas take the path of least resistance and initially
grow within the anatomic compartment in which they arose.
It is only at a later stage that the walls of the compartment are
violated (either the cortex of a bone or aponeurosis of a
muscle), at which time the tumor breaks into a surrounding
compartment.

- Typical anatomic barriers are articular cartilage, cortical
bone, and fascial borders. The growth plate is not consid-
ered an anatomic barrier, because it has numerous vascu-
lar channels that run through it to the epiphysis (FIG
1E–G).

- Sarcomas are defined as intracompartmental if they are en-
cased within an anatomic compartment.
- Extracompartmental tumors are those that grow out
through the compartment barrier or tumors that have arisen
in extracompartmental spaces (space tumors), ie, popliteal
fossa, groin, sartorial canal, axilla, and antecubital fossa
(FIG 2A,B).
- Most bone sarcomas are bicompartamental at the time of
presentation; they destroy the overlying cortex and extend di-
rectly into the adjacent soft tissues.
- Carcinomas, which typically present in the extremities as
metastatic disease, directly invade the surrounding tissues, ir-
respective of compartmental borders (FIG 2C–E).

- Joint involvement in sarcoma is uncommon, because direct
 tumor extension through the articular cartilage is rare.
Mechanisms of joint involvement in sarcoma are as follows:
- Pathological fracture with seeding of the joint cavity
- Pericapsular extension
- Structures that pass through the joint (eg, the cruciate lig-
aments) may act as a conduit for tumor growth (FIG 3)
- Transcapsular skip nodules: demonstrated in 1% of all
osteosarcomas
- Direct articular extension.

Metastatic Bone and Soft Tissue Sarcomas

- Unlike carcinomas, bone and soft tissue sarcomas dissemi-
nate almost exclusively through the blood. Hematogenous
spread of extremity sarcomas is manifested by pulmonary in-
volvement in the early stages and by bony involvement in later
stages. Abdominal and pelvic soft tissue sarcomas, on the
other hand, typically metastasize to the liver and lungs.
- Low-grade soft tissue sarcomas have a low (under 15%) rate
of subsequent metastasis, whereas high-grade lesions have a
significantly higher (over 20%) rate of metastasis.
- Metastases from sarcomas to regional lymph nodes are un-
common; the condition is observed in only 13% of patients
with soft tissue sarcomas and 7% of those with bone sarcomas

![FIG 2 • Extracompartmental extension. Ewing sarcoma of the distal two thirds of the femur (A) and osteosarcoma
of the proximal tibia (B). Note the extrasosseous component of the tumor. Most high-grade bone sarcomas are
bicompartamental at the time of presentation (ie, they involve the bone of origin as well as the adjacent soft
tissues). Tumors at that extent are staged as IIB. C. Plain radiograph of the proximal femur revealed direct
invasion through the cortical bone with a pathological fracture of the lesser trochanter (arrows). D. Axial MRI,
showing metastatic bladder carcinoma to the posterior thigh. E. In surgery, exploration of the sciatic nerve re-
vealed direct tumor involvement with extension under the epineural sheath. (Courtesy of Martin M. Malawer.)]
at initial presentation. The prognosis is similar to that of distant metastasis (FIG 4).

- Most patients with high-grade primary bone sarcomas, unlike soft tissue sarcomas, have distant micrometastases at presentation; an estimated 80% of patients with osteosarcomas have micrometastatic lung disease at the time of diagnosis. For this reason, in most cases, cure of a high-grade primary bone sarcoma can be achieved only with systemic chemotherapy and surgery.
- As mentioned, high-grade soft tissue sarcomas have a lower metastatic potential. Because of that difference in metastatic capability, the role of chemotherapy in the treatment of soft tissue sarcomas and its impact on survival are still matters of some controversy.

PROGNOSTIC FACTORS

- Prognostic factors for bone sarcomas include grade, size, extension of tumor beyond the bone cortex, regional and metastatic disease, and response of the tumor to chemotherapy (necrosis rate).
- Prognostic factors for soft tissue sarcomas include grade, tumor size, depth, age, margin status, location (proximal vs. distal), histologic subtypes, and metastatic disease.

Staging

- *Staging* is the process of classifying a tumor, especially a malignant tumor, with respect to its degree of differentiation, as well its local and distant extent, to plan the treatment and estimate the prognosis. Staging of a musculoskeletal tumor is based on the findings of the physical examination and the results of imaging studies. Biopsy and histopathological evaluation are essential components of staging but should always be the final step. An important variable in any staging system for musculoskeletal tumors, unlike a staging system for carcinomas, is the grade of the tumor.
- The system most commonly used for the staging of soft tissue sarcomas is the one developed by the American Joint Committee on Cancer (Table 1). It is based primarily on the Memorial–Sloan Kettering staging system and does not apply to rhabdomyosarcoma. Critics of this system point out that it is based largely on single-institution studies that were not subjected to multi-institutional tests of validity. The Musculoskeletal Tumor Society adopted staging systems that
Metastasis in Distant Stage Grade Primary Tumor Regional Lymph Nodes Distant Metastasis
IA G1 or G2 T1a or T1b N0 M0
IB G1 or G2 T2a N0 M0
IIA G1 or G2 T2b N0 M0
IIB G3 or G4 T1a or T1b N0 M0
IC G3 or G4 T2a N0 M0
III G3 or G4 T2b N0 M0
IV Any G Any T N0 or N1 M1

Table 1
System of the American Joint Committee on Cancer for the Staging of Soft Tissue Sarcomas

<table>
<thead>
<tr>
<th>Stage</th>
<th>Grade</th>
<th>Primary Tumor</th>
<th>Metastasis in Regional Lymph Nodes</th>
<th>Distant Metastasis</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA</td>
<td>G1 or G2</td>
<td>T1a or T1b</td>
<td>N0</td>
<td>M0</td>
</tr>
<tr>
<td>IB</td>
<td>G1 or G2</td>
<td>T2a</td>
<td>N0</td>
<td>M0</td>
</tr>
<tr>
<td>IIA</td>
<td>G1 or G2</td>
<td>T2b</td>
<td>N0</td>
<td>M0</td>
</tr>
<tr>
<td>IIB</td>
<td>G3 or G4</td>
<td>T1a or T1b</td>
<td>N0</td>
<td>M0</td>
</tr>
<tr>
<td>IC</td>
<td>G3 or G4</td>
<td>T2a</td>
<td>N0</td>
<td>M0</td>
</tr>
<tr>
<td>III</td>
<td>G3 or G4</td>
<td>T2b</td>
<td>N0</td>
<td>M0</td>
</tr>
<tr>
<td>IV</td>
<td>Any G</td>
<td>Any T</td>
<td>N0 or N1</td>
<td>M1</td>
</tr>
</tbody>
</table>

*IA = Low-grade, small, and superficial or deep; IB = low-grade, large, and superficial; IIA = low-grade, large and deep; IIB = high-grade, small, and superficial or deep; IC = high grade, large, and superficial; III = high-grade, large, and deep; IV = any with metastasis.

Table 2
System of Enneking et al. for Staging of Soft Tissue and Bone Carcinomas

<table>
<thead>
<tr>
<th>Stage</th>
<th>Grade</th>
<th>Site</th>
<th>Metastasis</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA</td>
<td>G1</td>
<td>T1</td>
<td>M0</td>
</tr>
<tr>
<td>IB</td>
<td>G1</td>
<td>T2</td>
<td>M0</td>
</tr>
<tr>
<td>IIA</td>
<td>G2</td>
<td>T1</td>
<td>M0</td>
</tr>
<tr>
<td>IIB</td>
<td>G2</td>
<td>T2</td>
<td>M0</td>
</tr>
<tr>
<td>III</td>
<td>G1 or G2</td>
<td>T1 or T2</td>
<td>M0</td>
</tr>
</tbody>
</table>

*C1 = Low grade; C2 = high grade.
*T1 = Intracompartmental; T2 = extracompartmental
*M0 = No regional or distant metastasis; M1 = regional or distal metastatic.

Table 3
System of the American Joint Committee on Cancer for the Staging of Sarcomas of Bone

<table>
<thead>
<tr>
<th>Stage</th>
<th>Grade</th>
<th>Primary Tumor</th>
<th>Metastasis in Regional Lymph Nodes</th>
<th>Distant Metastasis</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA</td>
<td>G1 or G2</td>
<td>T1</td>
<td>N0</td>
<td>M0</td>
</tr>
<tr>
<td>IB</td>
<td>G1 or G2</td>
<td>T2</td>
<td>N0</td>
<td>M0</td>
</tr>
<tr>
<td>IIA</td>
<td>G1 or G2</td>
<td>T2b</td>
<td>N0</td>
<td>M0</td>
</tr>
<tr>
<td>IIB</td>
<td>G3 or G4</td>
<td>T1</td>
<td>N0</td>
<td>M0</td>
</tr>
<tr>
<td>III</td>
<td>Not defined</td>
<td>T1</td>
<td>N0</td>
<td>M0</td>
</tr>
<tr>
<td>IVA</td>
<td>Any G</td>
<td>Any T</td>
<td>N1</td>
<td>M0</td>
</tr>
<tr>
<td>IVB</td>
<td>Any G</td>
<td>Any T</td>
<td>N0</td>
<td>M0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Any N</td>
<td>M1</td>
</tr>
</tbody>
</table>

*C1 = Well differentiated; C2 = moderately differentiated; C3 = poorly differentiated; C4 = undifferentiated.
*T1 = Tumor confined within the cortex; T2 = tumor extends beyond the cortex.
*N0 = No metastasis in regional lymph nodes; N1 = metastasis in regional lymph nodes.
*M0 = No distant metastasis; M1 = distant metastasis.
mon. Therefore, there was a clear correlation between the extent of the tumor at presentation, its relation to the boundaries of the compartment in which it is located, and the extent of surgery. A close correlation also was found between surgical stage of bone sarcoma and patient survival (FIG 5). Since that time, the use of neoadjuvant chemotherapy has been shown to decrease tumor size and facilitate limb-sparing surgery, as well as reduce the local recurrence rate. As a result, compartmental resections have become rare. Nonetheless, Enneking’s classification is based on the biological behavior of soft tissue and bone sarcomas, and its underlying concept is as relevant today as it was in the early 1980s (Tables 1–4).

Approximate survival rates by stage for extremity soft tissue sarcomas are 90% for stage I, 70% for stage II, and 50% for stage III.

Staging Benign Bone Tumors

Enneking also described a staging system for benign bone tumors, which remains the one that is most commonly used (Table 4). That system is based on the biologic behavior of these tumors as suggested by their clinical manifestation and radiologic findings. Benign bone tumors grow in a centrifugal fashion, as do their malignant counterparts, and a rim of reactive bone typically is formed as a response of the host bone to the tumor. The extent of that reactive rim reflects the rate at which the tumor is growing: it usually is thick and well-defined around slowly growing tumors, and barely detectable around fast-growing, aggressive tumors.

- Latent benign bone tumors are classified as stage 1. Such tumors usually are asymptomatic and commonly are discovered as an incidental radiographic finding. Their natural history is of slow growth, and in most cases, they heal spontaneously. These lesions never become malignant and usually heal following simple curettage. Examples include fibrous cortical defects and nonossifying fibromas (FIG 6A).
- Active benign bone tumors are classified as stage 2 lesions. These tumors grow progressively but do not violate natural barriers. Associated symptoms may occur. Curettage and burr drilling are curative in most cases (FIG 6B–E).
- Aggressive benign bone tumors (stage 3) may cause destruction of surrounding bone and usually break through the cortex into the surrounding soft tissues. Local control can be achieved only by curettage and meticulous burr drilling with a local adjuvant such as liquid nitrogen, argon beam laser, or phenol. Wide resection of the lesion with a margin of normal tissue (FIG 6D,E) is another option.

### Table 4

<table>
<thead>
<tr>
<th>Stage</th>
<th>Definition</th>
<th>Biological Behavior</th>
<th>Soft Tissue Tumor</th>
<th>Bone Tumor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Latent</td>
<td>Remains static or heals spontaneously</td>
<td>Lipoma</td>
<td>Nonossifying fibroma</td>
</tr>
<tr>
<td>2</td>
<td>Active</td>
<td>Progressive growth, limited by natural barriers</td>
<td>Angiolipoma</td>
<td>Aneurysmal bone cyst</td>
</tr>
<tr>
<td>3</td>
<td>Aggressive</td>
<td>Progressive growth, invasive, not limited by natural barriers</td>
<td>Aggressive fibromatosis</td>
<td>Giant cell tumor</td>
</tr>
</tbody>
</table>

EVALUATION OF THE PATIENT WITH A MUSCULOSKELETAL LESION

**Presenting Symptoms**

- Bone sarcomas typically present with pain that starts out as intermittent and progresses to a constant pain. Night pain often is a component. Pain typically is deep-seated and dull and may resemble that of a toothache. Patients with high-grade tumors present with a history of several months of pain. Patients with low-grade tumors, by contrast, present with a history of mild pain, typically lasting more than half a year. Local soft tissue swelling is common.
- Soft tissue sarcomas can arise anywhere in the body, but the lower extremities are the most common site. The incidence is as follows:
  - Lower extremities: 46%
  - Trunk: 19%
  - Upper extremities: 13%
  - Retroperitoneum: 12%
  - Head and neck: 9%
  - Other locations: 1%.
- The presenting symptoms and signs of soft tissue sarcomas are nonspecific. These lesions commonly present as a painless, slow-growing mass, but in 20% of patients they present as a painful, rapidly growing mass.

**Physical Examination**

- Patients with suspected musculoskeletal tumors should be examined thoroughly. The affected site is inspected for soft tis-
sue mass or swelling, overlying skin changes, lymphadenopathy, neurologic deficit, and vascular deficiency.

**Imaging and Other Staging Studies**

**Plain Radiography**
- Plain radiographs remain key in imaging bone tumors. Based on medical history, physical examination, and plain radiographs, bone tumors can be diagnosed accurately in over 80% of cases.
- Because of the fine trabecular detail revealed by plain radiographs, bone lesions of the extremities can be detected at an earlier stage; lesions of the spine and pelvis, however, are not diagnosed until a large volume of bone has been destroyed.
- Plain radiographs can show the location of the tumor in the bone, cortical destruction and thickening, periosteal response to the tumor (e.g., Codman’s triangle, sunburst), type of matrix produced by the tumor (osteoid, chondroid, fibrous), and soft tissue calcifications.

**Computed Tomography**
- Computed tomography (CT) is the imaging modality of choice to evaluate the extent of bone destruction. CT should be performed on a helical scanner that enables improved two-dimensional images and three-dimensional (3D) reconstruction capability. The field of view should be small enough to allow adequate resolution, particularly of the lesion and the adjacent neurovascular bundle and muscle groups. A slice thickness of 1 mm or less through the tumor enables accurate 3D reconstructions. Intravenous contrast dye should be employed to demonstrate the anatomic relation between the tumor and arterial vessels and to enhance soft tissue tumors, unless there is a clear contraindication for its use.
- Three-dimensional CT reconstruction with intravenous contrast accurately demonstrates blood vessels that are likely to be distorted or, less commonly, incorporated directly into the tumor mass. This information helps the surgeon plan the anatomic approach and gauge the likelihood that a major blood vessel has to be resected en bloc with the tumor (FIG 7A).
- Chest CT is the modality of choice when evaluating the patient for metastatic lung disease for both preoperative staging and postoperative follow-up (FIG 7B).

**Magnetic Resonance Imaging**
- Magnetic resonance imaging (MRI) has been proven to be superior to CT in the evaluation of the intramedullary and extrasosseous soft tissue extent of bone tumors (FIG 7C-F) and soft tissue sarcomas.
- Anatomic location and relation of the tumor can be defined accurately, because the signal intensity of a tumor is assessed by comparing it with that of the adjacent soft tissues, specifically skeletal muscle and subcutaneous fat. MRI also make it possible to view a lesion in all three planes (i.e., axial, sagittal, and coronal).
Contrast-enhanced MRI is useful in evaluating the relation between a tumor and the adjacent blood vessels and in characterizing cystic lesions. The anatomic relation between the tumor and peripheral nerves may be assessed. The presence of orthopaedic hardware or surgical clips is not a contraindication to the performance of MRI; however, if a lesion is immediately adjacent to the location of the hardware, the local field may be distorted.

MRI can accurately diagnose a variety of soft tissue tumors, including lipomas, liposarcomas, synovial cysts, pigmented villonodular synovitis, hemangiomas, and fibromatoses. Hematomas often have a characteristic appearance on MRI; however, high-grade sarcomas that have undergone significant intratumoral hemorrhage may resemble hematomas. For this reason, the diagnosis of a simple hemATOMa should be made cautiously, and, once it is made, close clinical monitoring must be made until the condition has been resolved. The general guidelines regarding narrowing of the field and recommended number of slices per tumor are similar to those for CT.

MRI allows accurate evaluation of the medullary extent of bone tumors to determine the level of bone resection with safe but narrow margins.

**Bone Scan**

Bone scan currently is used to determine the presence of metastatic and polyostotic bone disease and the involvement of a bone by an adjacent soft tissue sarcoma. This modality is more sensitive than plain radiographs for identifying bone lesions. The appearance of a bone lesion in the flow and pool phases of a three-phase bone scan reflects its biologic activity and may be helpful in differentiating between benign and malignant lesions. This feature is known as tumor blush. Malignant tumors show uptake in the late flow phase. Response to

---

**FIG 7**

A. Three-dimensional CT angiogram. This is a new technique for evaluating the relation between bony tumors and the adjacent arteries. This radiograph demonstrates the relationship of the popliteal artery and trifurcation to a posterior tibial osteosarcoma. Note the relation of the vessels to the tumor. B. CT scan showing lung metastases. C,D. Primary lymphoma of the distal femur. Plain radiographs suggest cortical integrity. This is confirmed by axial CT (E) and T2-weighted MRI (F), which demonstrates the intraosseous extent of the tumor. (continued)
FIG 7  •  (continued) **G.** MRI of a large thigh high-grade (Stage IIB) soft tissue sarcoma. The thigh is the most common site for extremity soft tissue sarcomas. MRI evaluation is the most useful study in determining the extent of soft tissue sarcomas. **H.** Bone scan of a proximal humeral (RT) osteosarcoma. **I.** Limb-sparing surgery for a proximal humeral osteosarcoma. The defect was reconstructed by a modular segmental prosthesis. **J.** Extensive giant cell tumor of the proximal tibia. Angiography performed prior to a proximal tibia resection documented an absent peroneal artery. A successful effort was made to preserve the anterior tibial artery during the resection; otherwise, the leg would have been dependent on a single vessel. **K.** Angiogram of a distal femoral (diaphyseal) osteosarcoma following induction chemotherapy. Note that the tumor is avascular. The decrease of tumor vascularity is an extremely reliable finding in predicting tumor necrosis. **L.** Gross specimen of a diaphyseal osteosarcoma following resection and induction chemotherapy. There was 100% tumor necrosis. **M.** Axillary venogram showing venous occlusion. Venography is especially useful in evaluating tumors of the pelvis and shoulder girdle. (C–F, J: Courtesy of Martin M. Malawer.)
chemotherapy can be evaluated by comparing the tumor blush before and after neoadjuvant chemotherapy.

**Angiography and Other Studies**

- Angiography is useful in demonstrating arterial displacement and occlusion, which are common in tumors that have a large extraosseous component. It also can detect vascular anomalies (FIG 7J) and establish patency of collateral vessels. Proximal femur resection, for example, often necessitates ligation of the profundus femoral artery (PFA). A patent superficial femoral artery (SFA) must be documented by angiography prior to surgery, otherwise, the extremity will suffer severe ischemia following ligation of the PFA. CT angiography is an emerging modality that will likely replace angiography in preoperative tumor evaluation.

- Preoperative embolization may be useful in preparing for resection of metastatic vascular carcinomas if an intrallesional procedure is anticipated. Metastatic hypernephroma is an extreme example of a vascular lesion that may bleed extensively and cause exsanguination without prior embolization.

- Serial angiographs may demonstrate reduced tumor vascularity as a result of chemotherapy treatment. Such a reduction has been shown to indicate a good response to preoperative chemotherapy (FIG 7K–L).

- **Venography**
  - Contrast venography demonstrates partial occlusion or complete obliteration of major veins as a result of direct tumor invasion or indirect compression by the tumor mass. Venography is used for direct assessment of deep vein thrombosis.
  - Venography also can indirectly assess tumor invasion into major nerves that lie in close proximity. Axillary tumors often are found to have invaded the brachial plexus when venography shows axillary vein occlusion (FIG 7M).

- **PET CT**
  - Positron emission tomography (PET) is a functional diagnostic imaging technique that provides very different information from that obtainable with other imaging modalities.

- The most widely used radiotracer is F-18 fluoro-2-deoxy-D-glucose (FDG), which is an analog of glucose. The FDG uptake in cells is directly proportional to glucose metabolism, which is increased many times in malignant cells. FDG-PET now is the standard of care in initial staging, monitoring the response to therapy and management of various cancers (eg, breast cancer, lung cancer, lymphoma).

- The introduction of combined PET-CT scanners, which provide not only functional but also structural information leading to a detection of subcentimeter lesions, has made this technique useful in the early detection of the disease process and in decreasing false-positive lesions. The FDG uptake is measured in SUV units, quantifying uptake and thereby differentiating malignant disease from other possible causes such as inflammatory or infectious processes.

**FIGURE 8** summarizes the use of the various imaging modalities in the staging process of a primary bone sarcoma.

**Biopsy**

- The concept and practice of biopsy of musculoskeletal tumors are discussed in Chapter ON-2.

**Laboratory Studies**

- Laboratory studies often are nonspecific. For patients younger than 40 years of age, they include a complete blood count with differential, peripheral blood smear, and erythrocyte sedimentation rate. Patients older than 40 years also need blood calcium and phosphate levels, serum and urine electrophoresis, and urinalysis.

- Serum alkaline phosphatase levels in primary osteosarcomas correlate with disease prognosis; therefore, pretreatment levels should be recorded.

**Formulating an Initial Assessment**

- Age of the patient
  - In younger patients (10–25 years), the common malignant bone tumors are osteosarcoma, Ewing sarcoma, and
leukemia. The common benign bone tumors are enchondroma, fibrous dysplasia, and eosinophilic granuloma.

- In the older age groups (40–80 years), the common malignant bone tumors are metastatic bone disease, myeloma, and lymphoma.
- Anatomic location of the tumor within the bone. Certain lesions have a predilection for occurring at particular locations:
  - Adamantinoma: in the tibia
  - Chondroblastoma: in the epiphysis of long bones
  - Giant cell tumor: in the metaphysis and extending through the epiphysis to lie just below the cartilage, typically around the knee
  - Osteosarcoma: in the metaphysis of the distal femur or proximal tibia
  - Parosteal osteosarcoma: in the distal femur (posterior cortex)
  - Chondrosarcoma: in the pelvis
  - Chordoma: in the sacrum
  - Synovial sarcoma: in the foot and ankle
  - Enchondroma and metastatic lung carcinoma: in the fingers
- The effect of the lesion on the bone
  - High-grade lesions spread rapidly, causing early cortical bone destruction and expansion. The typical lytic appearance is permeative or moth-eaten.
  - Low-grade tumors spread at a slower pace, but may still destroy cortical bone and produce a soft tissue mass.
- The response of the bone to the lesion.
  - High-grade lesions spread rapidly and give the bone little ability to contain the process. Cortical destruction, periosteal elevation (eg, Codman’s triangle, onion skin appearance), and soft tissue spread (sunburst appearance) often are seen.
- Matrix production
  - Osteoid mineralization often is cloudlike and is typical of bone-forming tumors.
  - Cartilage calcification often appears stippled and is characteristic of cartilage-forming tumors.
  - Fibrous-forming tumors have a typical “ground glass” appearance

**SURGICAL MANAGEMENT**

**Classification of Surgical Procedures**

- Four basic types of excisions are used, each of which is based on the relation between the dissection plane and the tumor and its pseudocapsule: intralesional, marginal, wide, and radical excisions (FIG 9).
  - An **intralesional excision** is performed within the tumor mass and results in removal of only a portion of the tumor; the pseudocapsule and macroscopic tumor are left behind.
  - In a **marginal excision**, the dissection plane passes through the pseudocapsule of the tumor. Such a resection may leave microscopic disease.
  - **Wide (en bloc) excision** entails removal of the tumor, its pseudocapsule, and a cuff of normal tissue surrounding the tumor in all directions. This is the desired resection margin for sarcoma; however, the adequate thickness of the normal tissue cuff is a matter of some controversy. For both soft tissue and bone sarcomas, it generally is believed to be between 0.5 and 2 cm.
  - **Radical excision** involves removal of the tumor and the entire anatomic compartment within which it arises. Although traditionally mentioned as the fourth excision type, it does not define the component of the tumor that is left behind. In other words, a radical excision can achieve a marginal or a wide margin, depending on how close the tumor is to the border of the compartment. However, radical excision excludes the possibility of skip metastases.
- In general, benign bone tumors are adequately treated by either an intralesional procedure (eg, curettage and burr drilling, cryosurgery) or by marginal excision. Primary bone sarcomas are treated with wide excision. Metastatic tumors are treated according to the general intent of the surgery. When a palliative surgery is performed, metastatic lesions are treated by an intralesional procedure. If a curative procedure is performed, as in the case of solitary breast metastasis, for example, the lesion is treated as if it was a primary bone sarcoma (ie, wide excision).
Successful limb-sparing surgery consists of three phases:
- Resection of tumor. Resection follows the principles of oncologic surgery strictly. Avoiding local recurrence is the criterion of success and the main determinant of the amount of bone and soft tissue to be removed.
- Skeletal reconstruction. The average skeletal defect following adequate bone tumor resection measures 15 to 20 cm. Techniques of reconstruction (eg, prosthetic replacement [FIG 10], arthrodesis, allograft, or combination) vary and are independent of the resection, although the degree of resection may favor one technique over the other.
- Soft tissue and muscle transfers. Muscle transfers are performed to cover and close the resection site and to restore lost motor power. Adequate skin and muscle coverage is mandatory to decrease postoperative morbidity.

Guidelines for Surgical Resection
- The major neurovascular bundle must be free of tumor.
- Wide resection of the affected bone with a normal muscle cuff in all directions should be achieved.
- All previous biopsy sites and all potentially contaminated tissues should be removed en bloc.
- Bone should be resected 3 to 4 cm beyond abnormal uptake as determined by bone scan. (This is a safe margin to avoid intraosseous tumor extension.)
- The adjacent joint and joint capsule should be resected.
- Adequate motor reconstruction must be accomplished by regional muscle transfers.
- Adequate soft tissue coverage is needed to decrease the risk of skin flap necrosis and secondary infection. 5

MALIGNANT BONE TUMORS
- Primary malignancies of bone arise from mesenchymal cells (sarcoma) and bone marrow cells (myeloma and lymphoma). Bone also is a common site of metastasis from a variety of carcinomas. Osteosarcoma and Ewing sarcoma, the most common malignant mesenchymal bone tumors, usually occur during childhood and adolescence. Other mesenchymal tumors (eg, MFH, fibrosarcoma, chondrosarcoma), while occasionally seen in childhood, are more common in adults. Multiple myeloma and metastatic carcinoma typically increase in frequency with increasing patient age and usually are seen in patients over 40 years of age. This section describes the clinical, radiographic, and pathological characteristics and treatment of the primary bone sarcomas.
- Osteosarcoma provides the model on which treatment of all other sarcomas is based. The effectiveness of multiagent chemotherapy regimens has been proven with the increase in overall survival rates from the bleak statistic of 15% to 20% with surgery alone in the 1970s to 55% to 80% today. In par-
Osteosarcoma

- Osteosarcoma is the most common primary bone sarcoma. Osteosarcoma (OS) is a high-grade malignant spindle cell tumor arising within a bone. Its distinguishing characteristic is the production of “tumor” osteoid, or immature bone, directly from a malignant spindle cell stroma. OS typically occurs during childhood and adolescence. In patients over the age of 40, it usually is associated with a preexistent disease such as Paget disease, irradiated bones, multiple hereditary exostosis, or polyostotic fibrous dysplasia.

- The incidence of osteosarcoma peaks to 8 per million per year between the ages of 10 and 20 years. Survival of osteosarcoma patients has improved greatly over the past 30 years. The 5-year survival rate is 60%, except in patients over age 45, where it is 40%.

- The most common bone sites are the knee joint (50%) and the proximal humerus (25%). Between 80% and 90% of osteosarcomas occur in the long tubular bones; the axial skeleton rarely is affected (FIG 11).

- Pain, accompanied by a tender soft tissue swelling, is the most common complaint on presentation, with a firm, soft tissue mass fixed to the underlying bone found on physical examination. Systemic symptoms are rare. The incidence of pathologic fractures is less than 1%.

Radiographic Characteristics

- Typical radiographic findings include increased intramedullary sclerosis due to tumor bone or calcified cartilage; an area of radiolucency due to nonossified tumor; a pattern of permeative destruction with poorly defined borders; cortical destruction; periosteal elevation; and extrasosseous extension with soft tissue ossification. This combination of characteristics is not seen with any other lesion.

- Three broad categories are based on radiographic evaluation (FIG 12A–C): sclerotic osteosarcoma (32%), osteolytic osteosarcoma (22%), and mixed (46%). Although there is no statistically significant difference among overall survival rates of these types, it is important to recognize the patterns. The sclerotic and mixed types offer few diagnostic problems. Errors of diagnosis most often occur with pure osteolytic tumors. The differential diagnosis of osteolytic osteosarcoma includes giant cell tumor, aneurysmal bone cyst, fibrosarcoma, and MFH.

Microscopic Characteristics

- The diagnosis of osteosarcoma is based on the following findings:
  - Identification of a malignant stroma that produces unequivocal osteoid matrix. The stroma consists of a haphazard arrangement of highly atypical cells.
  - Pleomorphic cells that contain hyperchromatic, irregular nuclei. Mitotic figures, often atypical, usually are easy to identify. Between these cells is a delicate, lacelike eosinophilic matrix, assumed to be malignant osteoid (FIG 12D).
  - The predominance of one tissue type in many osteosarcomas has led to a histologic subclassification of this neoplasm.
    - The term osteoblastic osteosarcoma is used for those tumors in which the production of malignant osteoid prevails. Calcification of the matrix is variable.
    - Some tumors reveal a predominance of malignant cartilage production; hence, they are referred to as chondroblastic osteosarcoma. Even though the malignant cartilaginous elements may be overwhelming, the presence of a malignant osteoid matrix warrants the diagnosis of osteosarcoma.
    - Yet another variant is characterized by large areas of proliferating fibroblasts, arranged in intersecting fascicles. Such areas are indistinguishable from fibrosarcoma, and thorough sampling may be necessary to identify the malignant osteoid component.
  - As the neoplasm permeates the cortex, the periosteum may be elevated. This stimulates reactive bone formation and accounts for a distinctive radiologic feature called “Codman’s triangle.” Longitudinal sectioning of the involved bone often reveals wide extension within the marrow cavity. Rarely, skip areas within the medullary canal can be demonstrated. There may be necrotic and hemorrhagic foci. At the time of diagnosis, most tumors already have caused substantial cortical destruction. Continued tumor growth results in involvement of the adjacent soft tissues (FIG 12E).

Natural History and Chemotherapy

- Prior to the development of adjuvant chemotherapy, effective treatment was limited to radical margin amputation. Metastasis to the lungs and other bones generally occurred within 24 months. Overall survival rates 2 years after surgery ranged from 5% to 20%. No significant correlation between overall survival and histologic subtypes, tumor size, patient age, or degree of malignancy was seen. The most significant clinical variable
The three radiographic matrix types of osteosarcoma: osteolytic (A; arrows indicate tumor); mixed (B); and sclerosing (C). There is no prognostic difference in survival based on the radiographic type of matrix formation.

D. Classical high-grade osteosarcoma reveals a population of pleomorphic spindle cells intimately associated with a mesh of immature lacy osteoid. The amount of osteoid can be minimal, or it may be a predominant element forming wide intersecting trabeculae lined by the malignant osteoblasts. Giant cells also can be present.

E. Pathologic specimen. High-grade osteosarcoma of the proximal humerus with cortical breakthrough and tumor extension into the soft tissues.

F. CT scan demonstrating a large pelvic osteosarcoma. (A-E: Courtesy of Martin M. Malawer.)
was anatomic site: pelvic and axial lesions had a lower survival rate compared with extremity tumors, and tibial lesions had a better survival rate than femoral lesions (FIG 12F).

- The dismal outcome associated with osteosarcoma has been altered dramatically by adjuvant chemotherapy and also by aggressive thoracotomy for pulmonary disease. No difference in local recurrence or overall survival was seen between patients undergoing amputation and those undergoing limb-sparing surgery.

**Overall Treatment Strategy**

- The patient with a primary tumor of the extremity without evidence of metastases requires surgery to control the primary tumor and chemotherapy to control micrometastatic disease. From 80% to 90% of all patients with osteosarcoma fall into this category.

- Chemotherapy protocols typically have included various combinations and dosage schedules of high-dose methotrexate (HDMTX), doxorubicin hydrochloride (Adriamycin), and cisplatin. Ifosfamide, which is as effective as Adriamycin in single-agent studies, recently has supplanted methotrexate in many ongoing protocols. Multiagent chemotherapy, using various dosing schedules, now is considered standard treatment for osteosarcoma. Success with adjuvant chemotherapy led to investigation of treatment in the neoadjuvant (preoperative) setting. When used in that setting, tumor response results in shrinkage of the soft tissue components, facilitating surgical excision and subsequent limb salvage. Tumor response is measured by tumor necrosis rate on microscopic pathology and is a significant prognostic factor.

- Limb-salvage surgery is a safe surgical procedure for approximately 85% to 90% of patients. This technique may be used for all spindle cell sarcomas, regardless of histogenesis. The majority of OSs can be treated safely by a limb-sparing resection combined with effective adjuvant treatments. The successful management of localized OS and other sarcomas requires careful coordination and timing of staging studies, biopsy, surgery, and preoperative and postoperative chemotherapy, radiation therapy, or both. The site of the lesion is evaluated as previously described. Preoperative studies allow the surgeon to understand the local anatomy and the volume of tissue to be resected and reconstructed.

- Surgery alone results in a cure rate of 15% to 20% at best. The choice between amputation and limb-sparing resection must be made by an experienced orthopaedic oncologist, taking into account tumor location, size, or extramedullary extent; the presence or absence of distant metastatic disease; and patient factors such as age, skeletal development, and lifestyle preference that might dictate the suitability of limb salvage or amputation. Routine amputations are no longer performed; all patients should be evaluated for limb-sparing options. Intensive, multiagent chemotherapeutic regimens have provided the best results to date. Patients who are judged unsuitable for limb-sparing options may be candidates for presurgical chemotherapy; those with a good response may then become suitable candidates for limb-sparing operations. The management of these patients mandates close cooperation between chemotherapist and surgeon.

**Variants of Osteosarcoma**

- There are 11 recognizable variants of the classic OS. OS arising in the jaw bones is the most common of these. Parosteal and periosteal OS are the most common variants of the classic OS occurring in the extremities. In contrast to classic OS, which arises within a bone (intramedullary), parosteal and periosteal OS arises on the surface (juxtacortical) of the bone. Parosteal osteosarcoma is the most common of the unusual variants, representing about 4% of all osteosarcomas.

**Parosteal Osteosarcoma**

- Parosteal osteosarcoma is a distinct variant of osteosarcoma. Its prevalence is estimated to be 4%. It arises from the cortical bone and generally occurs in an older age group and has a better overall prognosis than osteosarcoma. As in osteosarcoma, the distal femur is the most common location; characteristically, the tumor attaches to its posterior aspect (FIG 13A–C). The proximal humerus and the proximal tibia are the next most common sites. Parosteal osteosarcomas usually present as a mass, occasionally associated with pain. The natural history is slow growth and late metastasis. The long-term survival rate is 75% to 85%. The tumor arises from the cortical surface and presents as a protuberant multinodular mass. The surface of the lesion may be covered in part by a cartilaginous cap resembling an osteochondroma; other areas may infiltrate into the adjacent soft tissues. The tumor usually encircles, partially or completely, the shaft of the underlying bone. In contrast to osteochondromas, the medullary canal of the bone is not contiguous with that of the neoplasm. Radiologically, parosteal osteosarcoma presents as a large, dense, tabulated mass that is broadly attached to the underlying bone without involvement of the medullary canal (FIG 13D,E). If present long enough, the tumor may encircle the entire bone. The periphery of the lesion typically is less mature than the base. Despite careful evaluation, intramedullary extension is difficult to determine from plain radiographs. It is more accurately detected with CT scan.

- Diagnosis of parosteal osteosarcoma, more than that of other bone tumors, must be based on the clinical, radiologic, and pathologic findings (FIG 13F–H). Most parosteal osteosarcomas are low grade; they do not require neoadjuvant and adjuvant chemotherapy, and are best treated with wide excision. This tumor commonly is mislabeled by inexperienced clinicians and pathologists as osteochondroma, myositis ossificans, or conventional osteosarcoma. In the classic low-grade lesion, irregularly formed osteoid trabeculae, usually of woven bone, are surrounded by a spindle cell stroma containing widely spaced, bland-appearing fibroblastic spindle cells (FIG 13I). There may be foci of atypical chondroid differentiation. With the higher grades the likelihood of intramedullary involvement is increased. This, in turn, correlates well with the presence of distant metastases.

**Chondrosarcomas (Central and Peripheral)**

**Clinical Characteristics and Physical Examination**

- Half of all chondrosarcomas occur in persons over the age of 40. The most common sites are the pelvis, femur, and shoulder girdle. The clinical presentation varies. Peripheral chondrosarcomas may become quite large without causing pain, and local symptoms develop only because of mechanical irritation. Pelvic chondrosarcomas often are large and present with referred pain to the back or thigh, sciatica secondary to sacral plexus irritation, urinary symptoms from bladder neck involvement, unilateral edema due to iliac vein obstruction, or as a painless abdominal mass. Conversely, central chondrosar-
FIG 13  A. Gross specimen of a resection of a distal femoral osteosarcoma. The average bony defect is 15 to 20 cm. Note how the biopsy site is removed en bloc with the tumor. The proximal tibia routinely is removed en bloc. The length of bone resected is determined by preoperative CT and MRI evaluation. B. CT scan of a typical parosteal osteosarcoma. C. Gross specimen of a distal femoral parosteal osteosarcoma. There is minimal intraosseous extension. D,E. Plain radiographs of the distal femur, AP (D) and lateral (E) views, show a dense, irregular, sclerotic lesion, attached to the posterior femoral cortex. The posterior aspect of the distal femur is a classic location for parosteal osteosarcomas, and that diagnosis should be considered for any sclerotic lesion in that location. F. The relation of the parosteal osteosarcoma to the medullary canal is better viewed on this CT scan, which shows no tumor extension to the canal. In contrast to osteochondromas, the medullary canal of the bone is not contiguous with that of the tumor. G. Gross pathological specimen. H. Specimen shown illuminated with tetracycline fluorescence, which demonstrates minimal medullary tumor extension through the posterior cortex. I. Parosteal osteosarcoma. There are parallel or intersecting osseous trabeculae (arrows) that may be either lamellar or woven-type bone matrix. The intervening fibrocollagenous tissue is composed of bland, widely-spaced fibroblastic cells. (D–I: Courtesy of Martin M. Malawer.)
Comas present with dull pain. A mass is rarely present. Pain, which indicates active growth, is an ominous sign of a central cartilage lesion. This cannot be overemphasized. An adult with a plain radiograph suggestive of a “benign” cartilage tumor but who is experiencing pain most likely has a chondrosarcoma (FIG 14A).

**Radiographic Findings**
- Central chondrosarcomas have two distinct radiological patterns. One is a small, well-defined lytic lesion with a narrow zone of transition and surrounding sclerosis with faint calcification. This is the most common malignant bone tumor that may appear radiographically benign (FIG 14B,C).
- The second type has no sclerotic border and is difficult to localize. The key sign of malignancy is endosteal scalloping. This type is difficult to diagnose on plain radiographs and may go undetected for a long period of time.
- Peripheral chondrosarcoma is easily recognized as a large mass of characteristic calcification protruding from a bone. Correlation of the clinical, radiographic, and histologic data is essential for accurate diagnosis and evaluation of the aggressiveness of cartilage tumor. In general, proximal or axial location, skeletal maturity, and pain point toward malignancy, even though the cartilage may appear benign.

**Grading and Prognosis**
- Chondrosarcomas are graded 1, 2, and 3; most are either grade 1 or grade 2. The metastatic rate of moderate-grade versus high-grade is 15% to 40% versus 75%. Grade 3 lesions have the same metastatic potential as osteosarcomas.
- In general, peripheral chondrosarcomas are a lower grade than central lesions. Ten-year survival rates among those with peripheral lesions are 77% with 32% among those with central lesions.

Secondary chondrosarcomas arising from osteochondromas (FIG 14D,E) also have a low malignant potential; 85% are grade 1. The multiple forms of benign osteochondromas or en-chondromas have a higher rate of malignant transformation than the corresponding solitary lesions. The pelvis, shoulder girdle, and ribs are the most common sites of malignant transformation of osteochondromas. The risk of malignant transformation is approximately 20% to 25%.

**Microscopic Characteristics**
- The histologic spectrum of chondrosarcomas varies tremendously. High-grade examples are easy to identify, whereas certain low-grade tumors are exceedingly difficult to distinguish from chondromas. Correlation between the histologic features (FIG 14F) and both the clinical setting and the radiographic changes is, therefore, of utmost importance in avoiding serious diagnostic error. The grade of malignant cartilaginous tumors correlates with clinical behavior. Grade I tumors are characterized by an increased number of chondrocytes set in a matrix that is chondroid to focally myxoid.
- Areas of increased cellularity with more marked variation in cell size, significant nuclear atypia, and frequent pleomorphic forms define a grade 2 lesion. Binuclear forms are more common in this group.
- Grade 3 chondrosarcomas, which are relatively uncommon, show even greater cellularity, often with spindle cell areas, and reveal prominent mitotic activity. Chondrocytes may contain large, bizarre nuclei. Areas of myxoid change are common.

**Treatment**
- The treatment of chondrosarcoma is surgical removal. Guidelines for resection for high-grade chondrosarcomas are similar to those for OSs. The sites of origin and the fact that chondrosarcomas tend to be low-grade often make them amenable to limb-sparing procedures. The four most common sites are the pelvis, proximal femur, shoulder girdle, and diaphyseal portions of the long bones.

**Variants of Chondrosarcoma**
- There are three less-common variants of classic chondrosarcoma. Each is briefly described below (FIG 15).
- Clear cell chondrosarcoma, the rarest form of chondrosarcoma, is a slow-growing, locally recurrent tumor resembling a chondroblastoma but with some malignant potential that typically occurs in adults. The most difficult clinical problem is early recognition; it often is confused with chondroblastoma. Metastases occur only after multiple local recurrences. Primary treatment is wide excision. Systemic therapy is not required.
- Mesenchymal chondrosarcoma is a rare, aggressive variant of chondrosarcoma characterized by a biphasic histologic pattern, ie, small, compact cells intermixed with islands of cartilaginous matrix. This tumor has a predilection for flat bones; long tubular bones rarely are affected. It tends to occur in the younger age group and has a high metastatic potential. The 10-year survival rate is 28%. This type responds favorably to radiation therapy.
- Dedifferentiated chondrosarcoma. About 10% of chondrosarcomas may dedifferentiate into either a fibrosarcoma or an OS. They occur in older individuals and often are fatal. Surgical treatment is similar to that described for other high-grade sarcomas. Adjuvant therapy is warranted.

**Ewing Sarcoma**
- Ewing sarcoma is the second most common bone sarcoma of childhood; it is approximately one half as common as osteosarcoma. The lesion is characterized by poorly differentiated, small, round cells with marked homogeneity. The exact cell of origin is unknown. These mesenchymal cells are rich in glycogen and typically manifest a unique reciprocal chromosomal translocation, t(11;22)(q24;q12) that results in a chimeric protein, EWS/FLI-1. This translocation occurs in approximately 90% of these tumors. The clinical and biologic behavior is significantly different from that of spindle cell sarcomas. Within the past 2 decades, the prognosis of patients with Ewing sarcomas has been improved dramatically thanks to a combination of adjuvant chemotherapy, improved radiation therapy techniques, and the select use of limited surgical resection.

**Clinical Characteristics and Physical Examination**
- Ewing sarcomas tend to occur in young children, although rarely in those younger than 5 years. The flat and axial bones are involved in 50% to 60% of cases. When a long (tubular) bone is involved, it most often is the proximal or diaphyseal area that is affected (FIG 16). In contrast, OSs occur in adolescence (average age 15), most often around the knees, and involve the metaphysis of long bones.

Another unique finding with Ewing sarcomas is systemic signs, ie, fever, anorexia, weight loss, leukocytosis, and anemia. All may be a presenting sign of the disease and are seen in 20% to 30% of patients; this is in contrast to the distinct
absence of systemic signs with OS until late in the disease process. The most common complaint is pain or a mass. Localized tenderness often is present with associated erythema and induration. These findings, in combination with systemic signs of fever and leukocytosis, closely mimic those of osteomyelitis.

Radiographic Findings

- Ewing sarcoma is a highly destructive radiolucent lesion without evidence of bone formation. The typical pattern consists of a permeative or moth-eaten destruction associated with periosteal elevation. Multilaminated periosteal elevation (onion skin appearance) or a sunburst appearance is
FIG 15 • A,B. Plain radiographs of the proximal tibia: AP and lateral views show a central chondrosarcoma (arrows). Macrosections of central chondrosarcomas of the proximal tibia (C) and proximal femur (D). E. Plain radiograph of the femoral shaft shows a central chondrosarcoma, presenting as a well-defined lytic lesion with a sharp transition zone, calcifications, and endosteal scalloping. Immunohistochemical stains, differentiation among these tumors has become simpler. F. Cross-section of an intramedullary chondrosarcoma discloses its lobular architecture and translucent, hyaline-like matrix. Note the characteristic endosteal erosions (arrows). G. Low-grade chondrosarcoma maintains a lobular architecture. There is slightly increased cellularity, occasional binucleate cells, and nuclear atypia. These cells typically are found in lacunae. The tumor tends to permeate between the normal osseous trabeculae. H. The juxtaposition of high-grade spindle sarcoma with lobules of low-grade chondrosarcoma is the hallmark of dedifferentiated chondrosarcoma. The spindle cell component usually reveals features of malignant fibrous histiocytoma, osteosarcoma, or it may be unclassifiable. This neoplasm pursues an aggressive clinical course with very low long-term survival. (Courtesy of Martin M. Malawer.)
characteristic. When Ewing sarcoma occurs in flat bones, however, these findings usually are absent. Tumors of flat bones appear as a destructive lesion with a large soft tissue component. The ribs and pelvis are involved most often. Pathologic fractures occur secondary to extensive bony destruction and the absence of tumor matrix.

The differential diagnosis is osteomyelitis, osteolytic osteosarcoma, metastatic neuroblastoma, and eosinophilic granuloma.

**Natural History**
- Ewing sarcoma is highly lethal and disseminates rapidly. Historically, fewer than 10% to 15% of patients remained disease free at 2 years.

Many patients present with metastatic disease. The most common sites for metastases are other bones and the lungs. Ewing sarcoma once was thought to be a multicentric disease because of the high incidence of multiple bone involvement. Unlike other bone sarcomas, Ewing sarcoma is associated with visceral, lymphatic, and meningeal involvement, and all of these areas must be investigated.

**Radiographic Evaluation and Staging**
- No general staging system for Ewing sarcoma exists. The musculoskeletal staging system does not apply to the round cell sarcomas of the bone.

Because these lesions have a propensity to spread to other bones, bone marrow, the lymphatic system, and the viscera, evaluation is more extensive than that for spindle cell sarcomas. It must include a careful clinical examination of regional and distal lymph nodes and radiographic evaluation for visceral involvement. Liver–spleen scans and bone marrow aspirates are required, in addition to CT of the lungs and the primary site. Angiography is required only if a primary resection is planned.

**Microscopic Characteristics**
- Because accurate pathological interpretation often is difficult, and bone heating is subject to several potential problems, the following guidelines have been established for the biopsy of suspected round cell tumors:
  - Adequate material must be obtained for histologic evaluation and electron microscopy.
  - Routine cultures should be made to aid in the differentiation from osteomyelitis.
  - Biopsy of the bony component is not necessary. The soft tissue component usually provides adequate material. Bone biopsy should be through a small hole on the compressive side of the bone. Pathologic fracture through an irradiated bone often does not heal.
  - Large nests and sheets of relatively uniform round cells are typical. The sheets often are compartmentalized by intersecting collagenous trabeculae. The cells contain round nuclei with a distinct nuclear envelope. Nucleoli are uncommon, and mitotic activity is minimal. Occasional rosette-like structures may be found, although neuroectodermal origin has never been confirmed. In the vicinity of necrotic tumor, small pyknotic cells may be observed. Vessels in these necrotic regions often are encircled by viable tumor cells. The cells often contain cytoplasmic glycogen. Thicn neoplasm belongs to the category of small blue round cell tumors, a designation that also includes neuroblastoma, lymphoma, metastatic OS, and, occasionally, osteomyelitis and histiocytosis. When confronted with this differential diagnosis, the pathologist may turn to electron microscopy or immunohistochemistry for additional information.

**Combined Multimodality Treatment**
- Ewing sarcomas generally are considered radiosensitive. Radiation therapy to the primary site has been the traditional mode of local control. Within the past decade, surgical resec-
tumors has become increasingly popular. Although detailed management is beyond the scope of this chapter, the following sections summarize some common aspects of the multimodality approach.

**Chemotherapy**
- Doxorubicin, actinomycin D, cyclophosphamide, and vincristine are the most effective agents. A variety of different combinations and schedules are used. All patients require intensive chemotherapy to prevent dissemination. Overall survival in patients with lesions of the extremities now ranges between 40% and 75%.

**Radiation Therapy**
- Radiation must be administered to the entire bone at risk. The usual dose is 4500 to 6000 cGy, delivered over 6 to 8 weeks. To reduce the morbidity of radiation, it is recommended that between 4000 and 5000 cGy be delivered to the whole bone, with an additional 1000 to 1500 cGy given to the tumor site.

**Surgical Treatment**
- The role of surgery in the treatment of Ewing sarcoma currently is changing. The Intergroup Ewing’s Study recommends surgical removal of “expendable” bones such as the ribs, clavicle, and scapula. In general, surgery is reserved for tumors located in high-risk areas, eg, the ribs, ilium, and proximal femur. Risk is defined as an increased incidence of local recurrence and metastases. In general, surgery is considered an adjunct to the other treatment modalities.
- Interest recently has increased in primary resection of Ewing sarcoma following induction (neoadjuvant) chemotherapy, similar to the treatment of osteosarcoma. When this resection is performed, radiation therapy is not given if the surgical margins are negative (ie, wide resection). The goal of this approach is to increase local control as well as minimize the complications and functional losses that are associated with high-dose radiation therapy given to a young patient.

**Giant Cell Tumor of Bone**
- Giant cell tumor of bone (GCT) is a benign aggressive, locally recurrent tumor with a low metastatic potential (4%–8%). Giant cell sarcoma of bone refers to a de novo, malignant GCT, not to the tumor that arises from the transformation of a GCT previously thought to be benign. These two lesions are separate clinical entities.

**Clinical Characteristics and Physical Examination**
- GCTs occur slightly more often in females than in males. Eighty percent of GCTs in the long bones occur after skeletal maturity; 75% of these develop around the knee joint. A joint effusion or pathologic fracture, uncommon with other sarcomas, is common with GCTs. GCTs occasionally occur in the distal radius, the vertebrae (2%–5%), and the sacrum (10%).

**Natural History and Potential Malignancy**
- Although GCTs rarely are malignant de novo (2%–8%), they may undergo transformation and demonstrate malignant potential histologically and clinically after multiple local recurrences. Between 8% and 22% of known GCTs become malignant following local recurrence. This rate decreases to less than 10% if patients who have undergone radiation therapy are excluded. Approximately 40% of malignant GCTs become malignant at the first recurrence. The remainder typically become malignant by the second or third recurrence; thus, each recurrence increases the risk of malignant transformation. A recurrence after 5 years is extremely suspicious for a malignancy. Primary malignant GCT generally has a better prognosis than does secondary malignant transformation of typical GCT, especially if the transformation occurs after radiation therapy. Local recurrence of a GCT is determined by the adequacy of surgical removal rather than by histologic grade.

**Radiographic and Clinical Evaluation**
- GCTs are eccentric lytic lesions without matrix production occurring at the end of long bones. About 10% are axial. They have poorly defined borders with a wide area of transition. They are juxtaepiphysial with a metaphysial component. Although the cortex is expanded and appears destroyed, at surgery it usually is found to be attenuated but intact. Periosteal elevation is rare; soft tissue extension is common. In the skeletally immature patient, GCT must be differentiated from aneurysmal bone cyst, although both lesions are closely related. GCTs are classified as type I, II, or III using the Enneking staging system.

**Microscopic Characteristics**
- Two basic cell types constitute the typical GCT.
  - The stroma is characterized by polygonal to somewhat spindled cells containing central round nuclei.
  - Benign, multinucleated giant cells are scattered diffusely throughout the stroma. Small foci of osteoid matrix, produced by the benign stroma cells, can be observed; however, chondroid matrix never occurs.

**Treatment**
- Treatment of GCT of bone is surgical removal. In general, curettage of the bony cavity with “cleaning” of the walls with a high-speed burr drill and the use of a physical adjuvant will kill any cells remaining within the cavity wall. We prefer the combined use of cryosurgery (either liquid nitrogen or a closed system of argon and helium) to obtain temperatures of −40°C. The cavity is then reconstructed with bone graft, polymethylmethacrylate, and internal fixation devices, which permit early mobilization.
- Cryosurgery has been used with more success for GCTs than for any other type of bone tumor. Cryosurgery is effective in eradicating the tumor while preserving joint motion and avoiding the need for resection or amputation. Liquid nitrogen is a very effective physical adjuvant and is recommended following curettage resection. Curettage alone is not recommended because of the associated high rate of local recurrence.

**COMMON SOFT TISSUE SARCOMAS**

**Treatment**
- The treatment of high-grade soft tissue sarcomas (STS) has undergone fundamental changes within the past decade. Treatment of these patients requires a multimodality approach, and successful management requires cooperation among the surgeon, medical oncologist, and radiation oncologist. The appropriate role of each modality is continuously changing, but general descriptions are provided in the following sections.

**Chemotherapy**
- The impact of chemotherapy for high-grade STS on survival remains controversial. Combination chemotherapy has been shown to be more effective than single-agent therapy in
preventing pulmonary dissemination from high-grade sarcomas. The most effective drugs in use today are doxorubicin hydrochloride (Adriamycin) and ifosfamide. Dacarbazine, methotrexate, and cisplatin also have activity against these tumors and are included in many current protocols. The various combinations traditionally are given in an adjuvant (postoperative) setting and are presumed effective against clinically undetectable micrometastases. Neoadjuvant (preoperative) chemotherapy is being evaluated in several institutions. Early results have indicated that significant reduction in tumor size can occur, thereby facilitating attempts at limb salvage. In patients with tumors deemed unresectable who are therefore destined for limb amputation, the tumors may shrink drastically in response to preoperative chemotherapy, thereby making them candidates for wide resection and limb-sparing surgery.

Radiation Therapy
- Radiation typically is administered in a dose of 5000 to 6500 cGy over many fractions. This modality is effective in an adjuvant setting in decreasing local recurrence following nonablative resection. The degree to which the initial surgical volume should be decreased in these circumstances is controversial, although the rate of local recurrence following a wide excision and postoperative radiation therapy is 5% to 10%. Radiation therapy includes irradiating all the tissues at risk, shrinking fields, preserving a strip of unirradiated skin, and using filters and radiosensitizers. Local morbidity has been greatly decreased within the past decade. Preoperative radiation is effective in reducing tumor volume but is associated with increased morbidity resulting from significant wound-healing complications and, therefore, is not recommended as often as postoperative radiation.

Surgery
- Removal of the tumor is necessary to achieve local control, by either a nonablative resection (limb salvage) or an amputation. The procedure chosen depends on results of the preoperative staging studies. A prospective randomized National Cancer Institute (NCI) trial established that a multimodality approach employing limb-salvage surgery combined with adjuvant radiation and chemotherapy offered local control and survival rates comparable to those of amputation plus chemotherapy, while simultaneously preserving a functional extremity.
- The use of adjuvant therapy (chemotherapy or radiation) permits limb-sparing procedures for most extremity soft tissue sarcomas. Enneking et al\(^3,4\) have shown that a radical resection for an STS has a local recurrence rate of about 5% with surgery alone. Wide excision (without adjuvant radiation or chemotherapy) has a 50% rate of local failure. Results from the NCI showed that the rate of local recurrence decreased to 5% following local excision (either a marginal or wide excision) when combined with postoperative radiation therapy and chemotherapy. Others have reported similar good results from preoperative radiation, with or without preoperative chemotherapy. Contraindications to limb-sparing surgery are similar to those for the bony sarcomas. In general, nerve or major vascular involvement is a contraindication.
- Studies of referred patients show that approximately half of all patients with soft tissue sarcomas treated with attempted excisional biopsy by the referring surgeon will have microscopic or gross tumor remaining. As a result, referred patients undergo routine re-resection of the surgical site to ensure adequate local control prior to institution of adjuvant treatment.

**GENERAL SURGICAL TECHNIQUE AND CONSIDERATIONS**
- All tissue at risk should be removed with a wide, en bloc excision that includes the tumor, a cuff of normal muscle, and all potentially contaminated tissues. It is not necessary to remove the entire muscle group. The biopsy site should be removed with 3 cm of normal skin and subcutaneous tissue en bloc with the tumor.
- The tumor or pseudocapsule should never be visualized during the procedure (FIG 17). Contamination of the wound with tumor greatly increases the risk of local recurrence.
- Distant flaps should not be developed at the time of resection. This may contaminate a noninvolved area.
- The margin surrounding the surgical wound should be marked with metallic staples to help the radiotherapist determine the high-risk area if radiation treatment is needed later.
- Reconstruction of the defect should include local muscle transfers to protect exposed neurovascular bundles and bone cortex.
- All dead space should be closed, and there should be adequate drainage to prevent hematoma.
- Perioperative antibiotics should be given. These procedures have a low but significant rate of postoperative infection. The risk of infection following preoperative adjuvant therapy is particularly high.

**Malignant Fibrous Histiocytoma**
- Malignant fibrous histiocytoma (MFH) is the most common soft tissue sarcoma in adults. High-grade pleomorphic MFHs are a heterogeneous collection of poorly differentiated sarcomas, many of which can be specifically classified with the application of DNA and protein analysis. It most commonly affects the lower extremity and has a predilection for originating in deep-seated skeletal muscles. The tumor usually presents as a multinodular mass with well-circumscribed or ill-defined infiltrative borders. The size and location at the time of diagnosis often correlate with the ease of clinical detection: superficial variants, presenting as dermal or subcutaneous masses, may be only a few centimeters in diameter, whereas those arising in the retroperitoneum often attain a diameter of 15 cm or more. Color and consistency vary considerably and reflect, in part, the cellular composition. Red-brown areas of hemorrhage and necrosis are not uncommon. The myxoid variant of MFH contains a predomi-
nance of grayish white, soft, mucoid tumor lobules, created by the high content of myxoid ground substance.

About 5% of MFHs undergo extensive hemorrhagic cystification termed telangiectatic transformation, leading to a clinical and radiologic misdiagnosis of hematoma. A needle biopsy can result in a benign diagnosis if only the hemorrhagic center of the tumor is sampled. For these reasons, until proven otherwise, one should assume that an underlying soft tissue sarcoma is present in any adult patient with a deep-seated hematoma that does not resolve after a few weeks, even when there is a history of trauma to that site.

The currently accepted broad histologic spectrum of MFH encompasses many variants that formerly were considered distinct clinicopathologic entities. These lesions, which had been named according to the predominant cell type, include fibroxanthoma, malignant fibroxanthoma, inflammatory fibrous histiocytoma, and giant cell tumor of soft parts. Immunohistochemical studies and electron microscopy can assist in the accurate diagnosis of a significant percentage of these tumors. The basic neoplastic cellular constituents of all fibrohistiocytic tumors include fibroblasts, histocyte-like cells, and primitive mesenchymal cells (Fig 18). Both an acute and a chronic inflammatory cell component usually are present as well. The proportion of these malignant and reactive cell elements, the degree of pleomorphism of the neoplastic cells, and the predominant pattern account for the wide histologic variances.

The histologic pattern most commonly associated with MFH is a storiform arrangement of the tumor cells, which is characterized by fascicles of spindle cells that intersect to form a “pinwheel” or “cartwheel” pattern (Fig 18). Atypical and bizarre giant cells, often containing abnormal mitotic figures, may be present. The histologic grade (almost always intermediate to high) is a good prognosticator of metastatic disease. In the myxoid variant, the second most common histologic type, the tumor cells are dispersed in a richly myxoid matrix. The less common giant cell type (malignant giant cell of soft parts) is characterized by abundant osteoclast-like giant cells that are diffusely distributed among the malignant fibrohistiocytic elements. Myxoid MFH has a more favorable prognosis than other subtypes.

We recently analyzed our data of 150 MFH lesions. Our 5-year survival rates were 74%; the distant recurrence rate was 28%; and the local recurrence rate was 19%. A local recurrence, large tumor size, deep tumors, close margins, and proximal location in the extremity were found to have a significant negative prognostic influence on survival.

Liposarcoma

Liposarcoma is the second most common soft tissue sarcoma in adults. It has a wide range of malignant potential that correlates well with the histologic classification of the individual tumor. The lower extremity is the most common site and accounts for over 40% of all cases. These tumors, particularly those arising in the retroperitoneum, can attain enormous size; specimens measuring 10 to 15 cm and weighing more than 5 kg are not uncommon (Fig 19A). Liposarcomas tend to be well-circumscribed and multilobulated. Gross features usually correlate with the histologic composition. Well-differentiated liposarcomas contain variable proportions of relatively mature fat and fibrocollagenous tissues, vary from yellow to grayish white, and can be soft, firm, or rubbery. A tumor that is soft, is pinkish tan, and has a mucinous surface probably is a myxoid liposarcoma, the most common histologic type. The high-grade liposarcomas (ie, round cell and pleomorphic) vary from pinkish tan to brown and may disclose extensive hemorrhage and necrosis.

Identification of typical lipoblasts is mandatory to establish the diagnosis of liposarcoma. This diagnostic cell contains one or more round, cytoplasmic fat droplets that form sharp, scalloped indentations on the central or peripheral nucleus. Well-differentiated liposarcomas often contain a predominance of mature fat cells and only a few, widely scattered lipoblasts. Inadequate sam-
ploring can, therefore, lead to a misdiagnosis of a benign lipoma (FIG 19B). Well-differentiated liposarcomas that arise in the superficial soft tissues have been called “atypical lipomas.” In the sclerosing variant of a well-differentiated liposarcoma, delicate collagen fibrils that encircle fat cells and lipoblasts make up a prominent part of the matrix. Treatment with wide excision and adjuvant radiation therapy is recommended only if marginal margins were achieved. We treat high-grade liposarcomas like any other high-grade soft tissue sarcoma, with neoadjuvant chemotherapy, wide excision, and adjuvant chemotherapy. Radiation therapy is indicated if wide margins were not achieved.

Synovial Sarcoma

Synovial sarcoma is the fourth most common soft tissue sarcoma. In spite of its name, this tumor rarely arises directly from a joint but, rather, arises in proximity to it, with a propensity for the distal portion of the extremities. Synovial sarcomas occur in a younger age group than do most other sarcomas: most patients are below the age of 40. Typical findings of synovial sarcoma include a painful mass, soft tissue calcifications on radiography, and a malignant tumor of the foot. The tumor typically presents as a deep-seated, well-circumscribed, multinodular, firm mass. Contiguity with a synovial-lined space is rare, and, occasionally, lymphatic spread occurs. Unlike most soft tissue sarcomas, synovial sarcomas may be present as a painless mass for a few years. Plain radiographs often show small calcifications within the mass. That finding should alert the physician to the diagnosis.

Virtually all synovial sarcomas are high grade. These poorly differentiated neoplasms usually present as ill-defined, infiltrative lesions with a soft, somewhat gelatinous consistency. The classic histologic presentation of this tumor is a biphasic pattern, which implies the presence of coexisting but distinct cell populations, namely, spindle cells and epithelioid cells (FIG 20A). The plump spindle cells, usually the predominant component, form an interlacing fascicular pattern that is reminiscent of fibrosarcoma. Within the spindle cell portion of the tumor, areas resembling the acutely branching vascular pattern of hemangiopericytoma are common. The arrangement of epithelioid cells varies, ranging from merely solid nests to distinct, gland-like structures (FIG 20B). When they compose glandular spaces, the constituent cells range from cuboidal to tall columnar; they rarely undergo squamous metaplasia. Histochemical stains demonstrate that the glandular lamina contain epithelial-type acid mucins. The neoplasm may contain extensive areas of dense stromal hyalinization, and focal calcification is common. The presence of extensive areas of calcification, sometimes with modulation to benign osteoid, deserves recognition, because this rare variant imparts a significantly more favorable prognosis than that for other forms of synovial sarcoma.

The existence of a monophasic spindle cell synovial sarcoma has been recognized, although distinguishing it from fibrosarcoma can be difficult. In contrast to fibrosarcoma, the spindle cell variant of synovial sarcoma may contain cytokeratins, as demonstrated with immunohistochemical studies.

REFERENCES

Biopsy of Musculoskeletal Tumors

Jacob Bickels and Martin M. Malawer

BACKGROUND

- Biopsy is a fundamental step in the diagnosis of a musculoskeletal tumor. It should be regarded as the final diagnostic procedure, not as a mere shortcut to diagnosis.
- Biopsy should be preceded by careful clinical evaluation and analysis of the imaging studies. Diagnosis of a musculoskeletal lesion is based on this triad of clinical, pathological, and imaging findings, and all three must coincide. Otherwise, the diagnosis should be questioned.
- Most biopsies are technically simple to perform. Decisions regarding the indication for biopsy, the specific region of the lesion for biopsy, and the anatomic approach and biopsy technique, however, can make the difference between a successful biopsy and a catastrophe.
- A poorly performed biopsy can become an obstacle to proper diagnosis and may impede the performance of adequate tumor resection, as well as having a negative impact on patient survival.
- It has been shown that biopsies executed in a referring institution rather than in a specialized oncology center often are associated with unacceptably high rates of devastating complications, unnecessary amputations, and major errors in diagnosis.

PATHOGENESIS

- Tumors arising in bone and soft tissues share characteristic patterns of biologic behavior, stemming from their common mesenchymal origin and anatomic environment. Those unique patterns form the basis of the staging system and current treatment strategies.
- Histologically, sarcomas are categorized as low, intermediate, or high grade based on tumor morphology, extent of pleomorphism, atypia, mitosis, and necrosis. Grading represents their biologic aggressiveness and correlates with the likelihood of metastases.
- Sarcomas form a solid mass that grows centrifugally, with the periphery of the lesion being the least mature part.

Pseudocapsules

- Unlike the true capsule that surrounds benign lesions, which is composed of compressed normal cells, sarcomas usually are enclosed by a reactive zone, or pseudocapsule. This consists of compressed tumor cells and a fibrovascular zone of reactive tissue with a variable inflammatory component that interacts with the surrounding normal tissues.
- In addition, these cells may break through the pseudocapsule to form metastases (“skip metastases”) within the same anatomic compartment in which the lesion is located. By definition, these are locoregional micrometastases that have not passed through the circulation. This phenomenon may be responsible for local recurrences that develop in spite of apparently negative margins after a resection.
- Although low-grade sarcomas regularly interdigitate into the reactive zone, they rarely form tumor skip nodules beyond that area.

Compartmentalism

- Sarcomas respect anatomic borders. Local anatomy influences tumor growth by setting natural barriers to extension of the lesion. In general, sarcomas take the path of least resistance and initially grow within the anatomic compartment in which they arose.
- In a later stage the walls of that compartment (either the cortex of a bone or aponeurosis of a muscle) are violated, and the tumor breaks into a surrounding compartment.
- Most bone sarcomas are bicompartamental at the time of presentation; they destroy the overlying cortex and extend directly into the adjacent soft tissues.
- Soft tissue sarcomas may arise between compartments (extracompartamental) or in an anatomic site that is not walled off by anatomic barriers such as the intermuscular or subcutaneous planes. In the latter case, they remain extracompartamental and only break into the adjacent compartment at a later stage.
- Carcinomas, on the other hand, directly invade the surrounding tissues, irrespective of compartmental borders.
- Unlike carcinomas, bone and soft tissue sarcomas disseminate almost exclusively through the blood. Hematogenous spread of extremity sarcomas is manifested in the early stages by pulmonary involvement and in later stages by bony involvement.

DIAGNOSTIC STUDIES

- Biopsy of a musculoskeletal lesion should be performed only at the conclusion of staging, in which the imaging studies required to determine local tumor extension, its relation to adjacent anatomic structures, and presence of metastatic spread are performed. Data obtained from the staging process allow the surgeon to determine which region of the tumor represents the underlying pathology and to plan the surgical approach for the definitive resection.
- When appropriately analyzed and combined with results of clinical evaluation, these data allow accurate diagnosis in most musculoskeletal lesions prior to biopsy. Thus, lesions that appear to be benign clinically and radiologically do not need biopsies.
- In contrast, benign-aggressive, malignant, and questionable lesions do require a biopsy for confirmation of the clinical diagnosis and for accurate classification before definitive treatment is initiated.
- A final reason for deferring biopsy until staging is completed is that biopsy superimposes both real and artificial radiologic changes at the biopsy site, and these can alter the interpretation of the imaging studies.
A cut through a high-grade soft-tissue sarcoma showing its thin pseudocapsule, composed of compressed tumor cells, and a fibrovascular zone of reactive inflammatory response. B. Growth pattern of bone and soft tissue sarcomas. Sarcomas grow in a centripetal fashion, with the most immature part of the lesion at the growing edge. A reactive zone is formed between the tumor and the compressed surrounding normal tissues and may be invaded by tumor nodules that represent microextensions of the tumor (satellites) rather than a metastatic phenomenon. High-grade sarcomas may present with tumor nodules that grow outside the reactive zone (“skip” lesions) but within the same anatomic compartment in which the lesion is located. This finding is documented preoperatively in less than 5% of patients. C. High-grade sarcomas may break through the pseudocapsule to form “skip” metastases within the same anatomic compartment. Skip metastases (arrows) from an osteosarcoma of the distal femur. D. A 40-year-old woman presented with a rapidly enlarging mass that had developed in her calf. Physical examination revealed a deep-seated, firm mass, 10 cm in diameter, located at the proximal aspect of the calf. E. MRI demonstrated the primary lesion as well as two additional skip metastases in the substance of the soleus muscle. F,G. Angiograms of the lower extremity clearly show all three lesions. (B: Reprinted from Bickels J, Jelinek JS, Shmookler BM, et al. Biopsy of musculoskeletal tumors. Current concepts. Clin Orthop Relat Res 1999;368:212–219, with permission.)
FIG 2 • High-grade osteosarcomas of the distal femur (A), proximal tibia (B), and proximal femur (C) showing tumor extension to the articular cartilage, which remains intact. This phenomenon allows intra-articular resection in most cases of juxta-articular sarcomas of bone. D. Extension of an osteosarcoma of the distal femur to the knee joint along the cruciate ligaments. The articular cartilage is intact. Knee joint extension of a high-grade sarcoma of the distal femur is a rare event, necessitating extra-articular resection (ie, en bloc resection of the distal femur, knee joint, and a component of the proximal tibia), as shown here.

FIG 3 • Plain radiograph (A) and MRI scans (B,C) showing a classical osteosarcoma of the distal femoral metaphysis breaking through the medial cortex into the adjacent soft tissues. Clinical photograph (D) and plain radiograph (E) showing neglected soft tissue sarcoma of the leg eroding through the overlying skin and into the underlying tibia, causing a pathological fracture.
A. Metastatic carcinoma at the same anatomic location penetrating directly into the nerve and causing an intractable, agonizing sciatic pain. Plain radiographs show metastatic osteosarcoma to the lungs (B) and L3 (C). D. Liposarcoma of the posterior thigh extending to the sciatic nerve. Although the patient presented with sciatic pain, there was a clear plane of dissection between the tumor capsule and the nerve.

FIG 5 • Osteochondroma of the distal femur (A) and deep lipoma of the shoulder (B). These lesions have typical findings on clinical examination and classical appearance on imaging studies. Consequently, biopsy is not required for their diagnosis or for decision-making regarding their management.
SURGICAL MANAGEMENT

Preoperative Planning

- The questions that must be answered before performing a biopsy are:
  - What part of the lesion needs to be biopsied?
  - What is the safest anatomic route to that location?
- The position of the biopsy site within the lesion is of major significance, because soft tissue and bone sarcomas may have regional morphologic variations. As a result of that heterogeneity, when doing a needle biopsy, a considerable volume of tumoral tissue or multiple samples are required to establish a diagnosis.
- The term sampling error refers to an incorrect or inconclusive diagnosis that occurs because the biopsy specimen was taken from a region that does not represent the underlying primary disease.
- In contrast, carcinomas commonly are homogeneous, so a single core biopsy or needle aspirate is usually sufficient for diagnosis.
- The periphery of soft tissue sarcomas usually represents the underlying malignancy authentically, and it should be the target of biopsy. Performing a biopsy on a sample taken from the center of this type of lesion may result in ambiguous findings, because these sites may contain mostly necrotic tissue and blood.
- Similarly, the extraosseous component of a malignant bone tumor is as representative of the tumor as is the bony component, and it should be biopsied if present. Violating the cortex of a bone that harbors a malignant tumor predisposes the patient to a pathologic fracture, and is acceptable only if there is no extraosseous extension of the tumor.
- In planning the definitive surgery, it must be assumed that the biopsy tract is contaminated with tumor cells and, therefore, it should be resected with the same safety margins (ie, wide margins) as the primary tumor (FIG 6A). For these reasons, the surgeon performing the biopsy must be familiar with the planned surgical technique, whether it is limb-sparing surgery or amputation.
- The biopsy incision or the needle puncture hole and the tract to the tumor must be made within the planned surgical incision site so that they will be included within the surgical specimen (FIG 6B–F).

FIG 6 • A. Pathological evaluation of a biopsy tract, resected en bloc with metastatic melanoma of the distal humerus, showing a viable tumor focus. B. The needle biopsy entry site and tract to the osteosarcoma shown in Fig 3A–C are removed en bloc with the tumor. C. The surgical specimen. D. Planned biopsy incision around the proximal humerus. Because most primary bone sarcomas extend into the surrounding soft tissues, the overlying muscle should be removed en bloc with the tumor. In this case, the deltoïd muscle should be removed with the tumor, and the biopsy tract should be included within the surgical specimen, indicating the choice of a transdeltoid approach through the anterior third of the muscle. The traditional deltopectoral approach for such a biopsy would necessitate a wider resection of the pectoralis major muscle, compromise its subsequent use for soft tissue reconstruction, and possibly contaminate the main neurovascular bundle of the upper extremity. (continued)

BIOPSY TECHNIQUES

- A closed biopsy does not involve an incision. The specimen is obtained after skin puncture by a needle or trephine.
- An open biopsy, in contrast, does require an incision. It can be either "incisional," in which case only a representative specimen is removed from the lesion, or "excisional," in which case the lesion is completely removed.
- Open incisional biopsy remains the most reliable diagnostic technique to which all other biopsy modalities should be compared. It allows the pathologist to evaluate cellular morphologic features and tissue architecture from different sites of the lesion.
- Furthermore, it provides material for performing ancillary studies, such as immunohistochemistry, cytogenticics, molecular genetics, flow cytometry, and electron microscopy. These studies may help in the diagnosis and subclassification of bone and soft tissue tumors, and, therefore, guide the choice of definitive treatment.
- Open biopsies are criticized because of the increased risk of complications, which may include iatrogenic injury to blood vessels or nerves, complicated wound healing, wound infection, and tumor cell contamination along the biopsy tract and subsequent local recurrence. Furthermore, open biopsies are associated with considerably higher costs of hospitalization and operating room time.
- Refined techniques and accumulated experience with the interpretation of material obtained from needle biopsies as well as the use of CT-guided trephine biopsies have made possible the accurate diagnosis of most musculoskeletal lesions. Thus, guided needle biopsies have become the standard technique in most orthopaedic oncology centers.9,10
- When a needle biopsy does not make conclusive diagnosis possible, or when it is not compatible with the clinical or radiologic diagnoses that have already been made, the patient should be referred for to an open surgical biopsy rather than to repeated needle biopsy.
Guided Needle Biopsy

- After adequate planning of the biopsy tract, biopsy should be executed according to the following guidelines:
  - Use the smallest longitudinal incision compatible with obtaining an adequate specimen. Transverse incisions are contraindicated, because they will require a wider soft tissue resection at the time of definitive surgery (TECH FIG 1).
  - When a purely intraosseous bone lesion is being biopsied, make a cortical window, giving careful consideration to its shape. Clark et al.3 evaluated the impact of three types of biopsy hole shapes—rectangular hole with square corners, rectangular hole with rounded corners, and oblong hole with rounded ends—on the breaking strength of human femora. They found that an oblong hole with rounded ends afforded the greatest residual strength. They also demonstrated that increasing the width of the hole caused a significant reduction in strength, but increasing the length did not. Therefore, when the biopsy specimen must be taken from the bone, a small circular hole should be made so that only minimal stress-risers are created. If a larger window is needed, an oblong shape should be used (TECH FIG 2).
  - Obtain enough tissue and use a knife or curette to avoid crushing or distorting the specimen's texture.
  - As a general rule, culture what you biopsy and biopsy what you culture.
  - Use meticulous hemostasis. Any hematoma around a tumor should be considered contaminated. A large hematoma may dissect the soft and subcutaneous tissues and contaminate the entire extremity, making limb-sparing surgery impossible.

TECH FIG 1 • A. The smallest longitudinal incision that allows an adequate specimen to be obtained should be used. B. A transverse biopsy incision requires a longer and curved incision to allow its incorporation at the time of the definitive resection. These incisions often cross tension lines, compromise the blood supply to the myocutaneous flaps, and potentially contaminate a larger surgical field. As a result, postoperative radiation therapy, when indicated, is administered to a wider field. C. Open biopsy of a high-grade soft tissue sarcoma of the left buttock by means of a transverse incision. D. A long, curved incision was used at the time of the definitive surgery to allow adequate resection as well as subsequent closure of skin flaps. E. Axial T2-weighted MRI scan of the proximal thigh showing a high-grade soft tissue sarcoma of the adductor compartment. F. Open biopsy was done using a long transverse incision. G. Intersecting long incisions were required at the time of definitive surgery to remove the biopsy site en bloc with the tumor. All compartments of the thigh were grossly contaminated with tumoral tissue. (A: Reprinted from Bickels J, Jelinek JS, Shmookler BM, et al. Biopsy of musculoskeletal tumors. Current concepts. Clin Orthop Relat Res 1999;368:212–219, with permission.)
A tourniquet rarely is indicated for an open biopsy, because bleeding vessels cannot be observed and adequate hemostasis is hard to achieve. If a tourniquet is used, the limb should not be exsanguinated by wrapping with an Esmarch bandage, because this may propel tumor cells to the proximal aspect of the extremity. To allow hemostasis, the tourniquet must be removed before wound closure.

Use drains if necessary. The port of entry must be in proximity with and a continuation of the skin incision, not at an angle to its sides (TECH FIG 3). The drain path is considered contaminated and must be excised with the surgical specimen. Guidelines regarding the excision of the draining tract are similar, therefore, to those that apply to the biopsy tract.

**PEARLS AND PITFALLS**

- Biopsy must be preceded by tumor staging.
- Plan site and tract according to the planned incision and tract of the definitive surgery.
- Use the smallest longitudinal incision possible for an open biopsy.
- The periphery of musculoskeletal tumors is preferable to a central site for biopsy.
- Obtain enough material and avoid crushing or distorting the specimen’s texture.
- Culture what you biopsy and biopsy what you culture.
- Use meticulous hemostasis.
- When biopsy results do not match the results of clinical and radiologic evaluations, carefully reassess all three.
- Despite serious concerns regarding the potential of accelerated growth or metastatic dissemination of a malignant tumor after biopsy, there is no well-founded, objective evidence that biopsy promotes either adverse event. The real risk of open and needle biopsies is that they may spread tumor cells locally and facilitate local tumor recurrence when performed inadequately.
REFERENCES

BACKGROUND

- Limb salvage—reconstruction following resection of malignant tumors of the extremities—has seen dramatic advances in a relatively brief period of time. The traditional surgical approach to the treatment of sarcoma, namely immediate amputation of the extremity, was advocated in the early 1960s and 1970s to ensure local control of disease.
- Early pioneers in orthopaedic oncology worked diligently to define the optimal level of amputation and developed techniques to manage wounds of the pelvis and shoulder girdle following hind- or forequarter amputation. However, such aggressive surgical management failed to impact overall patient survival, with most patients dying of metastatic disease.
- Only after the introduction of effective doxorubicin- and methotrexate-based chemotherapy protocols in the early 1970s could alternatives to amputation be considered. A handful of surgeons began to challenge the orthodoxy of amputation in children and adults with bone sarcomas. Marcove, Francis, and Enneking were among the pioneers who developed the rationale and basic techniques used in limb-sparing surgery. The former two surgeons were the first in the United States to develop endoprosthetic replacements for tumor patients.
- Starting with a very few highly selected patients with extremity osteosarcoma, limb-sparing surgery now is a treatment option for most bone and soft tissue sarcomas, not only of the extremities, but of the pelvis and shoulder girdles as well.
- Today, over 90% to 95% of tumor patients may be expected to undergo successful limb-sparing procedures when treated at a major center specializing in musculoskeletal oncology. This dramatic alteration in patient care required significant advances along many fronts, including the following:
  - Better understanding of tumor growth and metastasis
  - Determination of appropriate surgical margins
  - Use of effective induction (neoadjuvant or preoperative) chemotherapy
  - Development of improved approaches, preserving soft tissue vascularity
  - Deeper understanding of skeletal biomechanics
  - Advanced material engineering and manufacturing techniques
  - Development of inherently stable modular prostheses.
- The chapters in this section outline in specific detail many of the surgical approaches and techniques of oncologic resection and reconstruction currently used by leaders in the field of orthopaedic oncology. The importance of meticulous surgical technique cannot be overstated, because this is vital to ensure an optimal oncologic and functional outcome for the patient.
- A successful limb-sparing surgery consists of three interdependent stages performed in sequence:
  1. Tumor resection with appropriate oncologic margins
  2. Reconstruction and stabilization of the involved bone and joints
  3. Restoration of the soft tissue envelope for prosthetic coverage and function.

History of Endoprosthetic Reconstruction

- Austin Moore and Harold Bohlman, in 1940, were the first to publish an example of endoprosthetic reconstruction for a bone tumor, consisting of a custom-designed Vitallium proximal femur used for a patient with a giant cell tumor of bone.
- In the early 1970s, Francis and Marcove ushered in the current age of endoprosthetic reconstruction by developing prostheses to replace the distal femur and the entire femur for reconstruction following radical resection of osteosarcomas (FIG 1).
- A major drawback for these custom implants quickly became evident: each implant would take 6 to 12 weeks to manufacture, during which time the patient’s tumor could progress significantly. This led to the development of the concept of induction (initially called preoperative or neoadjuvant) chemotherapy, in which the newly proven drugs doxorubicin and methotrexate were administered during the interval between diagnosis and delivery of the manufactured custom implant. Both of these drugs had just been shown to have activity against bone sarcomas. Induction chemotherapy has since been adopted in the management of an increasingly large variety of other cancers.
- As the demand for endoprosthetic reconstruction grew, a wide variety of custom implants became available from a number of orthopaedic manufacturers. Many of these early implants, however, suffered from design flaws and errors in manufacturing, resulting in significant problems with implant failures (FIG 2A).
- However, improved material and manufacturing techniques developed for the profitable and ever-expanding market for total joint replacements eventually were applied to these “mega” prostheses. The adoption of the rotating hinge for implants around the knee and bipolar heads for the hip followed successful use of these designs for total joint replacement. While these advances significantly improved the performance of custom implants, problems with the time required for manufacturing and the lack of flexibility at the time of implantation hampered the widespread acceptance of custom endoprosthetic reconstruction.
- Manufacturers responded to this problem by incorporating the concept of modularity, adapting concepts and designs from modular total hip and knee prostheses to develop interchangeable and easily assembled endoprosthetic systems (FIG 2B,C). Although modularity increased the complexity of the mechanical construct and carried a risk of failure associated with the sum of all of the components, these potential problems were easily outweighed by significant benefits.
- The primary advantage of a modular endoprosthesis is the system’s flexibility: the surgeon can concentrate on performing the best possible oncologic resection knowing that any changes in the preoperative plan can be accommodated by selecting those components that fit the patient’s anatomy and actual skeletal defect optimally.
Modular trial components allow the surgeon to mix and match pieces and test the reconstruction prior to selection and assembly of the actual final prosthesis.

Standardization of components permits the implant manufacturer to increase the level of quality control greatly, while reducing the overall cost of manufacturing through economies of scale.

Modular systems reduce overall inventory and time to delivery while providing a large choice of prosthetic shapes and sizes.

Modular systems permit hospitals to maintain an on-site inventory that has allowed these systems to be available immediately as a backup option for selected non-oncologic patients, such as those undergoing difficult joint revision surgery or patients with significant periarticular fractures.

A first-generation modular endoprosthetic system was the Howmedica Modular Replacement System (HMRS, Howmedica International, Limerick, Ireland), designed and manufactured in Europe. This system featured intramedullary cementless press-fit stems supported by external flanges and cortical transfixation screws, while the knee mechanism consisted of a simple hinge design. Although the system truly was modular, in clinical practice the long-term outcomes were disappointing. Significant problems encountered with this device included aseptic stem loosening (osteolysis), substantial stress shielding with bone resorption, screw fracture and migration, and a polyethylene failure rate higher than 40% for the knee mechanism. Consequently, this system rarely was used in the United States.

An example of a second-generation modular system is the saddle endoprosthesis (Waldemar-Link, Germany; FIG 3A,B). This prosthesis, originally designed for the treatment of infected failed total hip replacements, was modified to allow for reconstruction of the hip following resection of the pelvis.

The unique feature of this system is the saddle itself, which is a U-shaped component that straddles the ilium, allowing motion in flexion–extension, and abduction–adduction in the anteroposterior and lateral planes against the bone.

The saddle is attached with a rotating polyethylene lined ring, increasing the degree of freedom and allowing for hip rotation. These are attached to a series of interchangeable modular bodies that, in turn, connect to a standard cemented femoral stem.

FIG 1 • The first known distal femoral replacement was performed in the United States, by Kenneth Francis, at New York University in 1973. A, Distal femoral osteosarcoma treated with doxorubicin prior to surgical resection. B, Cemented distal femoral replacement with long intramedullary stems. This prosthesis used a modified Walldius fixed knee hinge. C, Scan of the front page of an historic JBJS article. Original publication of the first prosthesis performed in the United States. D, Original prosthesis implanted by Drs. Bohlman and Moore for fibrous dysplasia of the proximal femur. E, Custom segmental prosthesis used during 1980s prior to the development of the Modular Replacement System by Howmedica, Inc. (Rutherford, NJ). (A, B: Courtesy of Martin M. Malawer; C: reprinted from JBJS, 1940, with permission.)
FIG 2 • A. Examples of failed, retrieved, custom endo-prosthetic implants used during the 1980s. The most common mode of mechanical failure was stem breakage or bending, typically due to small stem diameter or from stress risers caused by the sharp transition from the prosthetic body to the stem. B. Modular implant design featuring a Kinematic rotating-hinge knee. Interchangeable components permit easy off-the-shelf flexibility in the operating room, allowing the implant to match the patient’s anatomy. C. Intraoperative assembly of the prosthesis requires impaction of locking Morse tapers to connect the stem, body segments, and joint modules. (Courtesy of Martin M. Malawer.)
This device preserves limb length following resection of the periacetabulum (eg, type 2 pelvic resection, modified internal hemipelvectomy) while functioning like a total hip prosthesis. The clinical and functional results following saddle reconstruction of the pelvis with this system have been promising. The first successful universal modular system was introduced in 1988 as the Modular Segmental Replacement System (MSRS, Howmedica Inc, Rutherford, NJ), renamed the Modular Replacement System (MRS) and now available as the updated Global Modular Replacement System (GMRS; Stryker/Howmedica Inc., Mahwah, NJ). This system was designed to provide modular replacements for the proximal humerus, proximal femur, total femur, distal femur, and proximal tibia and has been instrumental in the widespread adoption of endoprosthetic reconstruction following segmental bone resection.

The growing popularity of endoprosthetic reconstruction has led to the introduction of similar modular systems from several orthopaedic manufacturers (eg, Orthopaedic Salvage System [Biomet, Warsaw, IN], Guardian Limb Salvage System [Wright Medical Technology [Arlington, TN]]).

Current implant manufacturers still offer customized solutions for challenging anatomic issues. However, these custom implants often consist of a custom module mated to an existing modular system to ensure maximal flexibility.

**TYPES OF ENDOPROSTHETIC RECONSTRUCTION**

Specific anatomic examples of endoprosthetic reconstruction are discussed in the following paragraphs.

**Hip**

- Tumors involving the proximal femur are extremely common, and include both primary sarcomas and metastatic carcinomas. Replacement of the proximal femur (FIG 4) is readily accomplished following resection of a primary tumor or fracture through a subtrochanteric metastatic lesion. A bipolar hemiarthroplasty is used for the hip joint, with soft tissue reconstruction of the hip capsule to minimize the risk of dislocation. Reconstruction of the hip abductors is accomplished directly via laterally placed holes or loops, or, if a portion of the trochanter was saved, by use of a trochanteric claw with cerclage cables. Less common are resections of the entire hip joint (ie, type II pelvic resection and its modifications). This defect can be reconstructed with a saddle prosthesis or with the recently designed partial pelvic implants that attach to the remaining ilium. Stability is achieved by balancing the muscle tension between the medial iliopsoas and the lateral hip abductors.

**Distal Femur**

- The distal femur is the single most common site for primary bone sarcomas. Endoprosthetic reconstruction (FIG 5) requires a unique combination of flexibility combined with overall stability, because the knee capsule and the cruciate and collateral ligaments are removed during the resection. The Kinematic rotating hinge knee (GMRS, Stryker/Howmedica, Mahwah, NJ) and similar partially constrained hinged designs permit substantial flexion–extension as well as rotation at the anatomic axis of the knee, while providing inherent stability in the varus–valgus and anterior–posterior planes. Reconstruction of the extensor mechanism rarely is necessary, because the patella often can be saved during the resection. Resurfacing of the patella is possible, but often unnecessary.

**Total Femur**

- Patients presenting with extensive intramedullary tumors (eg, Ewing sarcoma or the rare diaphyseal osteosarcoma), as
well as patients with multiply failed total joints and little remaining bone stock, can be treated with a total femoral replacement (FIG 6). Modular systems provide a readily available solution by combining distal femoral and proximal femoral components by means of interbody segments. This type of reconstruction has proven to be extremely durable because of the combination of the high degree of freedom associated with the two separate but related joints.

Proximal Tibia
- The tibia is anatomically unique in its anterior subcutaneous border and patellar tendon insertion. Routine use of a gastrocnemius rotation flap has dramatically reduced the incidence of postoperative complications, and compound reconstruction of the tendon insertion and careful attention to postoperative rehabilitation can result in minimal extensor lag. Joint stability at the knee is ensured by using the same rotating hinge design used for distal femoral replacements (FIG 7). Meticulous soft tissue reconstruction of the extensor mechanism is crucial for the postoperative function of this prosthesis.

Proximal Humerus
- High-grade sarcomas of the proximal humerus require extra-articular resection, including the entire rotator cuff and deltoid muscles, to minimize the risk of local recurrence (FIG 8). Accordingly, ultimate functional outcome may be greatly restricted. A combination of static and dynamic suspension, including transfer of the pectoralis muscle, stabilizes the proximal humerus to the scapula, permitting painless and functional use of the elbow, wrist, and hand. Low-grade tumors can be treated with intra-articular resections; preservation of the rotator cuff and deltoid can lead to function comparable to that provided by total shoulder replacements.
FIG 5 • Distal femoral replacement. A, B. Kinematic rotating hinge mechanism featuring an all-polyethylene tibial component permits a full range of flexion, rotation, and axial motion while restraining the knee in the AP and medial-lateral planes, respectively. C. Intraoperative view of distal femoral replacement after final assembly of the components. D–E. Distal femoral and proximal tibia modular replacement system. This system permits reconstruction of several segments of various bones simultaneously if required. (A, B: Courtesy of Martin M. Malawer.)

FIG 6 • Total femoral replacement for osteosarcoma of the femur. A. Implant and trial components consist of a modular proximal femoral replacement connected to a modular distal femoral replacement of means of a male-to-male interbody segment. B. Postoperative radiograph demonstrating bipolar hip and rotating hinge joints.
Scapula

- Following scapulectomy, endoprosthetic replacement of the scapula and glenohumeral joint lateralizes the humerus and improves stability and function of the shoulder (FIG 9). New scapular designs feature a locking articulation to improve stability, while use of a large-diameter Gore-Tex (W. L. Gore Ltd., Flagstaff, AZ) vascular graft to restore a joint capsule helps to ensure optimal stability. As with proximal humeral replacement, ultimate functional outcome depends on the amount of muscle that can be preserved during the resection. Multiple muscle transfers are necessary to stabilize and power the prosthesis as well as to provide adequate coverage.

Elbow

- The elbow joint is not often affected by sarcomas or metastatic disease. Customized, hinged implants with small-caliber stems to fit the ulna can be used provided sufficient soft tissue remains to cover the prosthesis. Function depends on preservation of the biceps insertion.

Total Humerus

- As with the total femur, the total humerus implant is a combination of a proximal humeral implant and an elbow replacement. Indications for this procedure are rare, but preservation of a sensate, functional hand remains superior to any amputation prosthesis.

Calcaneus

- One case has been reported of a total calcaneal prosthesis implanted for osteosarcoma in lieu of a below-knee amputation. Ten years after surgery, the patient remained fully ambulatory without assistive devices.
Intercalary Endoprostheses

- Replacement of the central portion of a long bone following diaphyseal resection for tumor has the significant advantage of preserving the patient’s native adjacent joints in the humerus, femur, and tibia. Traditional implants limited the indication for this type of reconstruction due to the amount of remaining bone required to fix the prosthetic stems securely. Customized stems using crosspin fixation and the newer Compress fixation method (Biomet) have greatly expanded the indications for this procedure (FIG 10).

Expandable Implants for Skeletally Immature Patients

- Reconstruction of the axial skeleton in immature patients remains challenging (FIG 11). Children over 10 to 12 years of age often can be treated similarly to adults, using smaller versions of the modular prostheses, occasionally in combination with contralateral epiphysialdysis to equalize leg lengths at skeletal maturity. For children younger than 5 years, primary amputation remains the preferred solution, given the difficulty in obtaining a proper oncologic margin around the critical neurovascular bundles. Between these two age groups, reconstruction is feasible, but limb-length inequality becomes functionally disabling as the child grows. Use of implants that can be expanded multiple times during growth permits prosthetic reconstruction for these children. These custom-created implants have been used in both the upper and lower extremity with mixed results, as mechanical failures of the expansion mechanism is not uncommon. Whereas traditional expandable implants would require multiple invasive procedures to achieve expansion (with some patients undergoing 10 or more surgeries), the recently introduced custom Rephysis noninvasive expandable implant (Wright Medical Technology, Arlington, TN) features a unique method of expansion that does not require surgery.

PATIENT SELECTION FOR ENDOPROSTHETIC RECONSTRUCTION

- Appropriate patient selection for limb-sparing surgery is essential to ensure optimal outcomes. While the introduction of effective chemotherapy for osteosarcoma was a major impetus in the development of limb-sparing techniques, increasing patient survival has placed greater emphasis on functional outcome and durability of reconstruction. Patients expect solutions that address their functional, cosmetic, and psychological needs and demands, and often reject the option of amputation.

- Although tumor size and location often are the determining factors in selecting patients for limb salvage, neoadjuvant (preoperative) chemotherapy may convert formerly unsalvageable
patients to candidates for limb-sparing procedures by inducing significant tumor response. Consequently, a complete reevaluation of the patient following neoadjuvant treatment is necessary before an appropriate surgical plan is selected. For appropriate patients, endoprosthetic reconstruction offers a durable and functional option for skeletal reconstruction.

- Limb-sparing procedures should not be limited to patients with favorable response to treatment. Patients with poor prognostic factors, such as metastatic disease at time of initial presentation or tumor growth during chemotherapy, often require surgery for local control of disease and palliation of symptoms such as pain. Although amputation may be necessary for some, limb-sparing surgery can avoid the significant psychological impact associated with mutilative procedures. Endoprosthetic reconstruction offers immediate stability and rapid mobilization while avoiding the need for prolonged bracing, crutches, or inpatient rehabilitation.

- The proven success and durability of endoprosthetic reconstruction has led to its adoption for other challenging, nontumorous conditions in which restoration of a segmental skeletal structure is desired.
tal defect is required. For example, patients with multiple failed total joint replacements around the hip and knee may develop significant bone loss that cannot be corrected readily with traditional revision total joint components. In this subset of patients, resection of the failed prosthetic joint and removal of all devascularized bone followed by reconstruction with a “tumor” endoprosthesis can lead to significant functional recovery.

- Similarly, severely comminuted periarticular fractures not amenable to internal fixation can be addressed by removal of the fragmented bone and replacement with a segmental endoprosthesis. This procedure is extremely valuable for the obese, elderly patient with osteoporotic bone (often with significant medical comorbidities) who trips and falls on the knee, resulting in a type C distal femur (or, if a total knee replacement is in place, periprosthetic) fracture. Endoprosthetic reconstruction can be performed in a fraction of the time necessary for meticulous internal fixation, and since the prosthesis is inherently stable, the patient can begin immediate weight bearing without functional bracing.

**GUIDELINES FOR ENDOPROSTHETIC RECONSTRUCTION**

- Regardless of the anatomic location, certain basic principles apply to all endoprosthetic reconstructions. Restoration of the normal axis of motion and extremity length depends on component selection. Careful attention to implant size and soft tissue reconstruction also can optimize functional outcomes. Proper stem selection, bone preparation, cementation technique, and use of extracortical fixation can reduce the risk of aseptic loosening and maximize implant longevity.
- Following resection of a bone tumor, careful measurement of the specimen is necessary to select the desired implant length. Trial components, available with all modular systems, permit easy comparison with the specimen and permit multiple trial reductions to determine optimal length and positioning for the final implant.
- Meticulous preparation of the intramedullary canal is done for stem insertion. Selection of the stem diameter depends on the anatomy of the canal, which should be sequentially reamed so that it can accommodate the largest diameter stem possible.
- Tendon and soft tissue reconstruction is determined by the anatomic site and the amount of residual tissue following tumor resection. Again, functional outcome can be enhanced with meticulous attention to details and restoration of proper biomechanics.
- Rotational muscle flaps often are necessary to ensure adequate soft tissue coverage and also may serve to reinforce tendon attachments or capsular tissue.
- Frequently performed transfers include the following:
  - **Shoulder.** Transfer of the pectoralis major and latissimus dorsi muscles covers and dynamically stabilizes a proximal humeral prosthesis. Dacron tapes are used to suspend the prosthesis statically from the scapula.
  - **Hip.** Transfer of the psoas and external rotators is performed to create a pseudocapsule around the prosthetic head. This capsule then is reinforced with circumferential Dacron tapes to prevent dislocation. Reattachment of the abductor muscles is necessary to minimize the Trendelenburg lurch in the postoperative phase. This limp improves over time with strengthening of the abductors.
  - **Knee.** Twenty-five percent of distal femoral replacements and all proximal tibial replacements require rotation of a gastrocnemius muscle (typically the medial head) to repair the soft tissue defect following resection of a tumor around the knee. In addition, this local flap is incorporated into the reconstruction of the patellar tendon for proximal tibial replacements.
- Final closure of the wound may be jeopardized by skin loss following resection of a biopsy tract. In general, patients with very large tumors often have redundant skin because the tumor has acted as an internal skin stretcher. This extra skin may be rotated or trimmed as needed to facilitate wound closure. Excess skin along the incision should be excised to avoid marginal wound necrosis related to disruption of the microvasculature from elevation of large subcutaneous flaps. Patients with tight skin closures are best served by leaving the skin open to avoid pressure-induced ischemia, and performing a primary or secondary split-thickness skin graft.
- Limbs should be elevated maximally in the postoperative phase to reduce swelling that can jeopardize the wound closure.
- Use of large-bore closed suction drains and correction of any postoperative coagulopathies help prevent hematoma formation. Patients who develop hematomas or wound breakdowns require aggressive treatment in the operating room to prevent secondary infection of the endoprosthesis.

**CLINICAL RESULTS FOLLOWING ENDOPROSTHETIC REPLACEMENT**

- Prosthetic survival has improved dramatically as improved surgical techniques, advanced prosthetic designs, and modern manufacturing techniques have been adopted. Results of early custom prostheses were disappointing, leading many surgeons to use allografts or other methods of reconstruction.
- More recently, there has been increased interest in endoprosthetic reconstruction as multiple centers have reported improved outcomes. Informal polling of members of the Musculoskeletal Tumor Society has shown a significant swing from a majority of members using primarily allograft reconstructions to a majority of members using endoprosthetic reconstruction.
- Recently published results looking at long-term survival of 242 cemented endoprosthetic replacements demonstrated an overall survival of 88% at 5 years and 85% at 10 years (Table 1). Prosthetic survival varied by type and location, with the poorest survival seen in patients with early custom-designed implants and in patients with proximal tibial replacements. Infection was the single most common cause of implant failure, with infected patients having an 83% risk of implant failure (FIG 12).
- Functional results vary by implant location. Outcomes following reconstruction of the distal femur in 110 patients were judged as good to excellent in 85% of patients.

**COMPLICATIONS**

- Complications following any type of limb-sparing reconstruction are not uncommon. Most patients have depressed immune systems from chronic disease, chemotherapy, and malnutrition. Patients often are anemic and have clotting abnormalities, including thrombocytopenia. The presence of long-term indwelling catheters for the administration of
Chemotherapy may lead to unrecognized bacteremia and potential hematogenous seeding of the operative site.

The anatomic location of a tumor and necessary resection may result in significant disruption of the venous and lymphatic drainage of the extremity during resection, leading to venous stasis, swelling, and lymphedema. This can lead quickly to flap necrosis during the postoperative period, secondary infection, and eventual amputation.

Finally, oncologic complications, including local recurrence of tumor or tissue necrosis from radiation, may result in failure of a limb-sparing procedure.

Complications specific to endoprosthetic reconstruction may be related to mechanical or biologic factors. Prosthetic fracture, disassociation of modular components, fatigue failure, and polyethylene wear have been described. Improved implant designs, metallurgy, and manufacturing techniques can reduce the incidence of these problems significantly.

Our institutional experience with more than 200 MRS (Materials Research Society, Warrendale, PA) implants over the past 18 years have revealed no stem fractures, body fractures, or taper disassociations to date. Polyethylene bushing failure occurs in fewer than 5% of patients with the Kinematic rotating hinge mechanism (Howmedica, Rutherford, NJ).

Biologic failure of an endoprosthesis may occur as a result of joint instability, aseptic loosening, or periprosthetic fracture of bone around the prosthesis. Meticulous attention to soft tissue reconstruction has virtually eliminated joint instability as a problem. The use of circumferential porous coating, properly sized large-diameter stems, and third-generation cementation techniques has helped to prevent aseptic loosening in our patients. Surgical technique and the use of polished cemented stems have prevented periprosthetic fractures during surgery. Several patients with secondary, late fractures as a result of blunt trauma (eg, falls, auto accidents) have been treated successfully with casting and protected weight bearing.

**FUTURE TRENDS FOR ENDOPROSTHETIC RECONSTRUCTION**

Current modular endoprosthetic reconstruction has greatly facilitated limb-sparing surgery following resection of bone sarcomas. Its success also has expanded the indications to include bone defects for non-oncologic problems. Increasing experience in the salvage of failed total joint replacements, chronic nonunions of fractures, and reconstruction following radical resection of osteomyelitis has shown that the proven

---

**Table 1**

<table>
<thead>
<tr>
<th>Prosthesis Type</th>
<th>No. patients</th>
<th>No. failures</th>
<th>Median F/U (mos)</th>
<th>Survival at median F/U</th>
<th>5-yr survival (95% CI)</th>
<th>10-yr survival (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRS PH</td>
<td>36</td>
<td>4</td>
<td>30</td>
<td>0.89</td>
<td>0.89 (0.70–1.00)</td>
<td>0.76 (0.30–1.00)</td>
</tr>
<tr>
<td>MRS PF</td>
<td>22</td>
<td>0</td>
<td>25</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>MRS DF</td>
<td>78</td>
<td>11</td>
<td>29</td>
<td>0.94</td>
<td>0.86 (0.78–0.94)</td>
<td>0.76 (0.56–0.94)</td>
</tr>
<tr>
<td>MRS PT</td>
<td>31</td>
<td>7</td>
<td>33</td>
<td>0.94</td>
<td>0.86 (0.33–1.00)</td>
<td>0.65</td>
</tr>
<tr>
<td>All MRS</td>
<td>173</td>
<td>22</td>
<td>30</td>
<td>0.93</td>
<td>0.86 (0.82–0.91)</td>
<td>0.76 (0.64–0.88)</td>
</tr>
<tr>
<td>All custom implants</td>
<td>50</td>
<td>23</td>
<td>85</td>
<td>0.71</td>
<td>0.81 (0.77–0.87)</td>
<td>0.55 (0.47–0.62)</td>
</tr>
<tr>
<td>All limbs</td>
<td>242</td>
<td>55</td>
<td>37</td>
<td>0.92</td>
<td>0.88 (0.85–0.90)</td>
<td>0.85 (0.81–0.90)</td>
</tr>
</tbody>
</table>

*Failure was defined as implant removal for any reason; patients were censored at time of last follow-up or at time of death. DF, distal femur; MRS, Modular Replacement System; PF, proximal femur; PH, proximal humerus; PT, proximal tibia.
concepts of limb-sparing surgery can be applied to many different clinical situations. Today, more endoprosthetic reconstructions are performed for non-oncologic reconstructions than for osteosarcomas.

- Ongoing research continually strives to improve the outcome following endoprosthetic reconstruction. Continued work on improved metallurgy and polymers, particularly with the introduction of cross-linked polyethylene, promises improved long-term durability. Routine use of premixed antibiotic cement and experimentation with antimicrobial implant surfaces may help to reduce the risk of periprosthetic infection. New techniques for tendon attachment to the prosthesis include novel clamps and ingrowth surfaces to promote improved junctional strength.

- New implant technologies such as the Rephyisis noninvasive expandable prosthesis offer hope to younger children with few alternative options. New fixation methods, including hydroxyapatite stems with porous coated surfaces, may be of great value in non-oncologic patients.

- The recently introduced Compress system represents the first new method of prosthetic fixation in decades. We have already adapted this system to expand the applicability of intercalary endoprosthetic reconstruction. Although future advances in tissue engineering hold the promise of artificially engineered living bone, we expect that endoprosthetic reconstruction will remain the preferred choice of orthopaedists for many years to come.

**REFERENCES**

BACKGROUND
- The two most common primary malignant bone tumors, osteosarcoma and Ewing sarcoma, are principally diseases of childhood and adolescence, with 45% of patients under the age of 16 and 17% under the age of 12 years at diagnosis.
- In the last 30 years the 5-year survival rate has increased from 10% to 70%. Even in patients with metastases at diagnosis, the 5-year survival rate has reached 20% to 30% due to chemotherapy and surgery for metastases as well as the primary tumor.
- Bone tumors in children occur predominantly in the metaphyseal region, close to the growth plate, so that sacrifice of a major physis often is necessary when the tumor is excised.
- Children who have primary bone sarcoma often require chemotherapy, which may have a subsequent suppressive effect on bone growth.
- Limb salvage surgery for bone tumors in the immature skeleton creates unique problems.
  - Maintenance of limb length after resection of one or more major growth plates
  - High functional and recreational demands of young patients, which require a durable reconstruction
  - At the knee, a constrained endoprosthesis is required (most commonly a fixed or rotating hinge implant), making it necessary for the prosthesis stem to breach the physeal plate on the side of the joint opposite to the tumor.
  - Reconstruction with expandable endoprostheses allows the maintenance of limb length equality, allows early weight-bearing, results in predictable function, has a low risk of early complications, and is readily available.
  - Disadvantages include the expense of the prostheses and the complications that are expected to increase with time in surviving patients.

ANATOMY
- About 60% to 70% of lower limb growth occurs around the knee (distal femur and proximal tibia physis), and about 80% of total growth of the humerus occurs in the proximal physis of the humerus.
- Terminal branches of the diaphyseal nutrient artery form tight loops near the physis, and the epiphysis is invaded by juxta-articular vessels.
- During childhood, the physis becomes an avascular structure that lies between two vascular beds, one epiphyseal and the other metaphyseal.
- The epiphyseal vessels supply oxygen and nutrients; an intact epiphyseal vasculature is essential, therefore, to sustain the chondrocytes. The metaphyseal vessels interact with the physeal chondrocytes in the hypertrophic zone and must be intact to sustain normal ossification. Excessive periosteal stripping must be avoided at surgery to maintain subsequent growth.

INDICATIONS FOR USE OF AN EXPANDABLE ENDOPROSTHESIS
- When the estimated leg-length discrepancy at skeletal maturity is more than 3 cm or when the arm-length discrepancy is more than 5 cm
- When the estimated arm length discrepancy at skeletal maturity is less than 5 cm, a prosthesis made up to 2 to 3 cm longer can be inserted. The operated upper limb initially is longer, but the opposite limb soon catches up.
- The main problem with a slight arm-length discrepancy is cosmetic.
- Problems with bimanual tasks occur only when the difference is significant.
- Patients whose estimated leg-length discrepancy is less than 3 cm can be treated with conventional “adult-type” prostheses made longer by up to 1.5 cm, and a “sliding” prosthetic component can be used across the remaining open physis.
- Girls older than 11 years or boys older than 13 years rarely require expandable prostheses, because the estimated growth discrepancy after these ages is less than 3 cm (FIG 1).

IMAGING AND OTHER STAGING STUDIES
- Pediatric patients with suspected malignancy require the usual staging imaging studies (ie, plain radiograph and MRI scan of affected bone, chest CT scan, and isotope bone scan).
- In addition, they require:
  - Measured full-length radiograph of the affected and contralateral limb (FIG 2)
  - Hand radiograph to estimate bone age based on Greulich and Pyle’s atlas
- The estimated limb length discrepancy at skeletal maturity traditionally has been estimated using the charts devised by Andersen and Green14 or Pritchett14,15 for upper and lower extremities.
- Recently, the validated multiplier method has been shown to be a simple and accurate predictor of discrepancy. It can be computed using chronologic, not bone, age, and requires only a single measurement.

SURGICAL MANAGEMENT
- In our center, the most common sites for the use of expandable endoprostheses are the distal femur (52%), proximal tibia (24%), proximal humerus (10%), and proximal femur (6%).
- Surgical techniques for excision of the sarcoma are similar to those for adult tumors, which are discussed in later chapters (see Chaps. ON-8, ON-10, and ON-24–26). This chapter deals primarily with factors that must be considered with the use of expandable prostheses.
We currently use two main methods of lengthening expandable endoprostheses in our center. Their advantages and disadvantages are outlined in the following paragraphs (Table 1):

- The minimally invasive expandable prosthesis has been in use since 1993. It is lengthened using a worm drive mechanism (FIG 3A,B). The mechanism is encased within the prosthesis shaft, and the telescopic implant is extended using an Allen key. The operative technique for lengthening is described later in this chapter.

- The noninvasive expandable prosthesis has been in use since 2002. Surgery is not required to lengthen the prosthesis. A sealed motor unit inside the prosthesis contains a powerful magnet that can be activated by an external power source (eg, a rotating electromagnetic field). This causes the magnet to turn, and the motor works using a very-low-ratio gearing system (13061:1) to lengthen the prosthesis. The rate of lengthening is directly proportional to the length of time that the power source is applied: lengthening of 4.6 mm takes 20 minutes (FIG 3C–E).

- The physis on the opposite side of the joint can be either preserved using a “sliding” prosthesis or sacrificed and replaced with a fixed cemented prosthesis.

- The sliding component is an uncemented, smooth component placed through a canal made centrally in the remaining preserved physis. In larger children, it is fitted inside a plastic sleeve inside the bone, which acts as a centralizer.

- This sleeve allows the component to slide inside the bone as the remaining open physis grows (FIG 3F–G).

- Care must be taken to minimize damage to the proximal growth plate by avoiding excessive periosteal stripping and carefully drilling out a cylindrical hole in the bone and, preferably, the center of the physis.

- Insertion of the sliding component destroys no more than 13% of the growth plate in the distal femur and proximal
Table 1  Methods of Lengthening Expandable Endoprostheses

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Minimally Invasive Prosthesis</th>
<th>JTS Noninvasive Prosthesis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Prosthesis relatively inexpensive ($14,100)</td>
<td>• No surgery required for lengthening</td>
</tr>
<tr>
<td></td>
<td>• Can have subsequent MRI scans</td>
<td>• No risk of infection</td>
</tr>
<tr>
<td></td>
<td>• Reliable, with published long-term results for all sites (used since 1993)</td>
<td>• No anesthesia risk</td>
</tr>
<tr>
<td></td>
<td>• Available in uncemented versions</td>
<td>• Reduced scarring</td>
</tr>
<tr>
<td></td>
<td>• Can revise easily to another expandable prosthesis without disturbing bone implant interface</td>
<td>• Painless</td>
</tr>
<tr>
<td></td>
<td>• Requires percutaneous operation to lengthen</td>
<td>• Outpatient procedure with reduced hospital costs</td>
</tr>
<tr>
<td></td>
<td>• Increased risk of infection</td>
<td>• Prosthesis is expensive ($26,500)</td>
</tr>
<tr>
<td></td>
<td>• Increased anesthesia risk</td>
<td>• Cannot have subsequent MRI scans (will damage magnet of both prosthesis and MRI)</td>
</tr>
<tr>
<td></td>
<td>• Requires percutaneous operation to lengthen</td>
<td>• Recent advance; therefore, no long-term results available</td>
</tr>
<tr>
<td></td>
<td>• Requires day case admission with increased hospital costs</td>
<td>• Not available in uncemented version (forceful impaction damages motor)</td>
</tr>
<tr>
<td></td>
<td>• Scarring with slight pain after procedure</td>
<td>• Currently unable to exchange lengthening module without removing whole prosthesis (development in progress)</td>
</tr>
</tbody>
</table>

FIG 3 • Minimally invasive prosthesis showing the port used for lengthening (A) and demonstrating the worm drive mechanism (B). C. Internal design of the shaft of the JTS noninvasive prosthesis (Stanmore Implants Worldwide). D. Gearbox and magnet component of a noninvasive prosthesis. E. Patient undergoing lengthening using an electromagnetic coil. Lengthening of 4.6 mm will take 20 minutes but can be done in the outpatient department. F. Schematic illustration of a sliding component in the proximal tibia. The proximal tibial physis is preserved, and the uncemented smooth prosthesis slides within the polyethylene sleeve as the physis grows. G. Illustration of the amount of growth of the proximal tibial physis 6 years after a distal femoral replacement with a sliding tibial component. The amount of growth can be seen by the growth arrest line formed at the time of chemotherapy. Growth on the affected side is only slightly less than that on the normal side. H. The use of hydroxyapatite-coated collars has been shown to reduce the rate of aseptic loosening by encouraging bone ongrowth.
tibia. There is no correlation between the surface area destroyed and continued growth of the physes.14,7
- Animal models of transphyseal pediatric anterior cruciate ligament reconstruction have shown similar results.2
- Physes with “sliders” grow at a slower rate, achieving about 80% of normal growth in the proximal tibia and about 60% of normal growth in the distal femur compared with the contralateral limb4 (Fig 3G).
- Other methods of lengthening prostheses are in use worldwide.
  - A device developed by Kotz allows the prosthesis to be lengthened by a ratchet system that uses knee movement to cause it to lengthen.9
  - The Phenix system (Phenix Medical, Paris, France) is a noninvasive system that relies on a coiled spring located inside the prosthesis, contained within a shield of wax. When a power source is applied to the prosthesis, the wax melts and the spring extends. When the power source is removed, the wax solidifies and the spring is fixed in its new position.12
  - The following factors are important when using expandable prostheses:
    - Resect the tumor with a wide margin and divide the bone at the predetermined level of transection.
    - When an expandable replacement is being used, plan to replace the exact amount of bone that has been removed.
    - If cement is being used, the intramedullary canal must be prepared adequately. We advocate the use of antibiotic-impregnated cement.
    - The use of hydroxyapatite-coated collars and preservation of periosteal sleeve significantly reduces the long-term risk of aseptic loosening by encouraging bony ingrowth to the prosthesis and also avoids the risk of stress shielding seen in uncemented types of implants (FIG 3H).

Preoperative Planning
- Calculate estimated limb-length discrepancy at skeletal maturity
  - Allow for reduced growth from any growth plates disturbed by surgery.
  - Consider whether there any surgical options other than an expandable prosthesis are feasible. These include:
    - The use of a shoe lift if the difference is less than 2 cm
    - Inserting an adult prosthesis (with or without a sliding component) longer than the resected bone at the time of initial surgery.
- Planned epiphyseodesis of the opposite limb
- Decide whether to use an invasive or noninvasive prosthesis, based on factors described previously (Table 1)
- Accurate measured radiographs of the bones to be resected are sent to the engineers, together with clear information about the planned level of transection of the bone (from MRI scan or, in complex cases, cross-sectional imaging of the resection level).
- Screen and treat patients for potential infective foci: dental hygienist review; methicillin-resistant Staphylococcus aureus (MRSA) screening; inspection for common sites of infection such as central venous lines, throat, ingrowing toenails, and fungal skin infections.
- Ensure adequate neutrophil and platelet counts prior to surgery if patient has had recent chemotherapy (our unit requires a neutrophil count greater than 1000/mm³ and platelet count of 75,000/mm³ or higher).

Positioning
- Positioning is chosen according to the usual technique and approach that the surgeon is familiar with for adult prostheses.
- We favor double skin preparation with chlorhexidine followed by an alcohol-based solution. The limb should be draped in such a way as to be left free and mobile during the procedure.
- The standard positions we use for common sites of reconstruction are as follows:
  - Distal femur: supine with removable sterile leg support
  - Proximal tibia: supine with removable sterile leg support
  - Proximal humerus: “beach chair” position, with arm supported on small side table and head turned away supported on head ring
  - Proximal femur: Lateral position

Approach
- Resection of the tumor should be carried out by the usual technique and approach that the surgeon is familiar with for adult prostheses.
- We favor an anteromedial approach to tumors around the knee. We routinely open the knee joint and reflect the extensor mechanism laterally unless there is evidence of frank knee joint invasion (which is a relative contraindication to limb salvage).
- If the knee joint is involved, consider an extra-articular resection if sufficient soft tissue will be left to cover the prosthesis.
- For tumors around the hip we favor a direct lateral approach and for tumors of the proximal humerus we favor the expansile approach of Henry.

SURGICAL TECHNIQUE FOR IMPLANTATION OF EXPANDABLE PROSTHESES

- Surgical technique for the implantation of expandable prostheses is described for each common anatomic site—in greater detail for the distal femur, but with only the salient specific points for each of the other sites.

Distal Femoral Expandable Prosthesis
- Tumor is excised at a predetermined level via an anteromedial incision and medial parapatellar approach, preserving a short periosteal sleeve to cover the hydroxyapatite collar to promote bony ongrowth to the prosthesis (TECH FIG 1).
TECH FIG 1 • Operative technique series for the distal femur. A. MRI scan of distal femoral osteosarcoma. Although the tumor appears to stop short of the physis, subperiosteal extension is present below the physis. The proximal limit of tumor will be more clearly visible on T1-weighted images. B. Anteromedial approach to the distal femur, showing excision of the biopsy tract and incision of the tendon of the rectus femoris. C,D. Dissection through the knee joint, dissecting the popliteal vessels from the posterior femur. E. Resected tumor with components. F. Tibial plateau resected 10 mm below joint line and perpendicular to the ankle joint. A central hole is reamed carefully to accept a sliding component. G,H. A polyethylene sleeve is inserted, uncemented, into the tibial plateau, and the metallic stemmed tibial implant is trialled. I. The distal femoral component is cemented into place and the two prostheses secured with the bushes. J. The range of flexion is tested on the table. K. The resected specimen showing the extent of the tumor, with closest margin indicated by the inked circle. Following neoadjuvant chemotherapy 98% of the tumor was necrotic.
A bone marrow sample is sent from the resection level for histologic review.

The proximal femoral canal is prepared using flexible reamers, bushes, irrigation, and cement restrictors, as appropriate.

The tibial osteotomy should be done perpendicular to the long axis of the tibia so as to be parallel with the ankle joint, removing 1 cm of bone from the proximal tibia.

Great care must be taken to minimize damage to the proximal growth plate by avoiding excessive periosteal stripping and carefully drilling out a cylindrical hole in the bone, of sufficient size to accept the intramedullary stem, which is then inserted uncemented into the bone.

In some cases a plastic tube is placed inside the bone to allow the stem to be centralized and to encourage sliding. This sometimes causes the stem to take a different path from that previously reamed; in such cases, the stem should be retrialed.

A trial reduction should be performed to check the soft tissue tension, because acute over-lengthening may cause neurologic impairment and fixed flexion deformities, with subsequent stiffness.

Once the prosthesis is cemented into place, the site of the screw mechanism can be marked on the skin by a stab incision, to make subsequent percutaneous lengthening easier if a minimally invasive prosthesis is being used.

The skin is closed in layers over a drain, and dressings are applied.

**Proximal Tibial Expandable Prosthesis**

The proximal tibia is a challenging site for limb salvage, with an above-average incidence of complications.

The tumor is excised in a manner similar to that used with adult prostheses, with thick fasciocutaneous flaps to prevent skin necrosis.

The distal femur is cut to accept the prosthesis, avoiding excessive periosteal stripping.

A central drill hole is made carefully to accept the sliding component and distal femoral stem.

The medial gastrocnemius muscle is mobilized on a pedicle based on the medial saphenous artery, and is used to cover the prosthesis and sutured to the anterior muscles.

The tibial implant is cemented into place, and the sliding femoral component is inserted.

The medial gastrocnemius flap replaces the extensor mechanism. Some surgeons have advocated using Dacron grafts attached to the prosthesis and the patella tendon.

**Expandable Prosthesis for the Proximal Humerus**

Resection of the proximal humerus leaves a weak shoulder and rotator cuff but functioning elbow and hand.

If there is a well-innervated deltoid, the humeral replacement head can be placed deep to it.

If the deltoid is damaged in any way, we often use Mersilene mesh (Ethicon Inc, Somerville, NJ) to provide a false capsule extending from the edge of the glenoid around the humeral head to prevent upward subluxation. Other authors have advocated using a polyethylene terephthalate (Trevira) tube to allow soft tissue attachments to prostheses. Attempts are made to preserve the coracoacromial ligament to reduce the risk of proximal subluxation with lengthening.

Care must be taken to prevent proximal migration of the humeral head when carrying out lengthening procedures.

**Proximal Femoral Expandable Prosthesis**

Inserting an expandable prosthesis into the proximal femur is a challenge, because the hip abductors must be detached from the greater trochanter.

They can be reattached to the fascia lata with the leg in slight abduction, which results in reasonable abduction power.

The type of femoral head to use is the subject of ongoing debate.

Uni- or bipolar femoral head replacements are used most frequently.

Both have high failure rates, with a significant risk of late head subluxation in children.

Small-sized femoral heads have a significant risk of dislocation.

Consider a large bearing total hip arthroplasty once the patient has reached skeletal maturity. We currently favor a large bearing metal-on-metal articulation for the increased wear characteristics and reduced dislocation rates.

**Percutaneous Lengthening for Minimally Invasive Prostheses**

The patient is placed in the supine position with access to the lengthening port.

In older children, the lengthening can be performed under a local anesthetic, but general anesthesia is preferred in younger children.

The procedure is performed under radiographic control to keep the incision as small as possible.

After double skin preparation and intravenous antibiotic prophylaxis, a stab incision is made over the jack point down to the prosthesis cavity.

The jack point is identified radiologically, and the Allen key engaged into the mechanism.

Soft tissue occasionally may need to be cleared from the jack point with a small periosteal elevator.

The screwdriver is rotated to lengthen the prosthesis: 10 revolutions of the screw driver lengthen the prosthesis by 0.1 cm; therefore, 100 revolutions are required to lengthen by 1 cm.

Intermittent single-shot images are taken to confirm lengthening.

Most lengthening procedures are done 10 mm at a time. If lengthening of much more than this is attempted, it can lead to complications such as the development of a fixed flexion deformity or occasionally a neuropraxia (eg, a foot drop).
POSTOPERATIVE CARE

- We advocate 24 hours of intravenous broad-spectrum prophylactic antibiotics postoperatively.
- We advocate early removal of surgical drains (within 48 hours).
- Patients with distal femoral replacements:
  - Are allowed to mobilize partial weight bearing at 48 hours
  - Are begun on both active and passive knee exercises
  - Usually can achieve active straight leg raise by day 5 and knee flexion to 90 degrees within 10 days prior to discharge.
- Patients with proximal tibial replacements:
  - Are allowed to mobilize partial weight bearing at 48 hours but can wear an extension brace to protect the extensor mechanism for 4 weeks
  - During that time they are allowed to flex to about 45 degrees but are not permitted to perform active knee extension.
- Patients with proximal femoral replacements are kept on bed rest with the leg abducted for 5 to 7 days before getting up, after which they are permitted partial weight bearing for 6 weeks.
- Patients with humeral replacements are kept in a sling for 6 weeks but with active exercises of the elbow, wrist and hand.
  - At 6 weeks, all patients start intensive physical therapy and hydrotherapy, at which time they commence full weight bearing and active exercises to maximize functional recovery.

Patient Information

- Warn patients that they have an artificial implant, which can fail.
- Caution them to avoid contact sports.
- Walking, swimming, cycling and other non-contact sports are encouraged.
- Any infective process in the body can lead to infection of the prosthesis, and early treatment with antibiotics is recommended
- Antibiotics for prophylaxis during dental procedures is required only if infection is present.
- Patients with noninvasive endoprostheses cannot have an MRI scan.

OUTCOMES

- Over the past 30 years our unit has operated on 615 children under the age of 16 with primary malignant bone tumors.
- 74 patients (12%) required amputation and the remainder (408 patients) had limb salvage using a prosthesis.
- Of the 176 patients with an expandable prosthesis, 117 are still alive and 89 have reached skeletal maturity.
- 60 patients never had a lengthening procedure carried out, either because they developed recurrent disease (metastases or local recurrence) or a complication such as infection.
- 116 patients had one or more lengthening procedures, with a mean of 5.3 lengthening procedures per patient (range 0–17 procedures) with an average total length increase of 32 mm (range 0–120 mm).
- Nineteen patients needed an amputation, either because of local recurrence (11 cases) or infection (8 cases).
- The overall limb salvage using Kaplan Meier survival curves was 83.9% at 20 years from insertion.
FIG 4 • A,B. Aseptic and rotational loosening in the distal femur after 14 years. C. Acute shortening due to displacement of a lengthening ring medially, which required revision to an adult prosthesis. D. Hip subluxation has been a problem in young patients receiving proximal femoral replacements.
COMPLICATIONS

Infection
- Deep prosthetic infection is a major concern in children who have expandable prostheses because of the need for multiple operative procedures.
- The cumulative risk of infection in our series was 21% at 10 years.
- It was related to site (proximal tibia) and previous highly invasive prosthesis designs.
- The use of gastrocnemius flaps and minimally invasive implants has reduced the infection rate to 8% at 10 years.
- The risk of infection has decreased from 3% per lengthening to about 1% with minimally invasive prostheses.
- Noninvasive prostheses should decrease the risk of infection over time.

Loosening
- The use of hydroxyapatite collars has significantly reduced the incidence of aseptic loosening. Revision usually is fairly straightforward, and the prosthesis is changed to an adult model (FIG 4A,B). Always consider the possibility that the loosening may be caused by low-grade infection.

Unplanned Shortening or Lengthening
- An unusual complication due to mechanism failures, which usually requires revision of the implant (FIG 4C)

Stiffness
- Stiffness is a common problem in younger children with prostheses around the knee, or if the prosthesis inserted is longer than the resected bone to try to gain some extra length. In some children, excessive scar tissue builds up around the prosthesis; in such cases, removal of the scar tissue can be helpful, combined with intensive physical therapy. In cases of fixed flexion deformities, intensive physical therapy, including the use of serial plaster casting, may be useful.

Subluxation of Hip or Shoulder
- Subluxation at the shoulder can be reduced by the use of Mersilene mesh. Femoral head subluxation is far more of a problem in younger children with proximal femoral replacements. We have found that in children under age 12 there is an increasing tendency for the superior margin of the acetabulum not to develop properly, and in these children the femoral head will sublux. We have tried several techniques to prevent subluxation, without success, and now revise the unipolar head to a large bearing surface uncemented cup when the triradiate cartilage is fused or subluxation is apparent (FIG 4D).

Outgrowing the Available Extension
- The maximum lengthening available in a prosthesis is 120 mm, but in many cases less than that is needed. Revision usually involves replacing only one component of the prosthesis.

Implant Breakage
- Implant breakage is rare in patients who have reached maturity with a child’s prosthesis still in place. The most common site for a fracture is at the junction of the thinner lengthening portion with the main component. Revision is required in all cases.

Periprosthetic Fractures
- Periprosthetic fractures are rare, but there does seem to be an increased risk of femoral fractures above a sliding femoral prosthesis used in conjunction with a proximal tibial growing prosthesis.

REFERENCES
BACKGROUND

- The skeleton is the third most common site of metastatic disease, after the lungs and liver. Prostate, breast, lung, kidney, and thyroid cancers account for 80% of skeletal metastases. The prolonged survival with disease of increasing numbers of cancer patients has led to growing numbers of patients with metastatic bone disease (MBD). The exact incidence of bone metastasis is unknown, but it is estimated that in the United States alone 350,000 people annually die with bone metastases.

- MBD is a major factor contributing to deterioration of quality of life in patients with cancer. These patients may require surgical intervention for the management of impending or current pathological fractures or for the alleviation of intractable pain associated with a locally progressive lesion.

- Those skeletal crises are associated with a considerable loss of function, pain, and the associated impairment of quality of life. Surgery also may be performed to remove a solitary bone metastasis with the intent of improving long-term survival in selected patients, but other than this rare exception, these surgical interventions are primarily palliative and are aimed at achieving local tumor control, structural stability of the surgically treated site, and restoration of normal function as quickly as possible. Failure to achieve one of these goals usually necessitates a second surgical intervention, and this is associated with additional impairment of an already compromised quality of life.

- Reports show failure rates of surgeries performed for MBD as high as 40%, occurring as the result of a poor initial fixation, improper implant selection, or progression of disease in the operative field.

- An attempt to treat a pathological fracture as one would treat a traumatic fracture will fail, in most cases, because the underlying disease impedes the fracture healing process. The prognosis for union of a pathological fracture also is determined to some extent by the tumor type: fractures associated with metastatic adenocarcinomas of breast and prostate, multiple myeloma, and lymphoma are much more likely to unite successfully than are those associated with malignancies of the lung, kidney, and gastrointestinal tract.

- Furthermore, even when healing does occur, it does so after an unreasonably long period of time and is of less than satisfactory quality. Reduction and immobilization used in the management of traumatic fractures are, therefore, not applicable in the management of pathological fractures due to MBD.

- Gainor and Buchert analyzed 129 pathological fractures and found that the long bone fractures that healed most predictably were those that had been internally fixed and irradiated and were in patients who survived for more than 6 months postoperatively.

- Similar observations were made by Harrington et al. Cemented hardware or prostheses are used preferentially for fixation to achieve immediate stability, and reconstruction techniques that rely on a biologic process of bone healing (eg, autologous bone grafts, allografts, or allograft-prosthetic composites) are inappropriate for the surgical management of MBD. 

INDICATIONS

- Existing pathological fracture
- Impending pathological fracture
- Intractable pain associated with locally progressive disease that had shown inadequate response to narcotics and preoperative radiation therapy
- Solitary bone metastasis in selected tumor types
- Surgical intervention for MBD is appropriate for patients who are expected to survive for more than 3 months. Patients who are expected to survive for less than 3 months are less likely to benefit from an operation, because they usually do not have the physical strength required for rehabilitation or the time needed for its completion. Those patients are treated with nonoperative approaches, such as sling and arm brace for the upper extremities or protected weight-bearing for the lower extremities.

IMAGING AND OTHER STAGING STUDIES

Plain Radiography

- Plain radiographs and CT scans of the affected site should be done, as well as plain radiographs of any additional site in which the patient reports joint or bone pain. The combined results of these studies will define the extent of bone destruction and soft tissue extension.

- If the investigated metastasis is located in a long bone, plain radiographs of reasonable quality of its entire extent should also be obtained to exclude additional metastases, because these data are crucial for surgical planning. Missed metastases could cause pathological fractures on postoperative weight bearing and require an extensive surgery for their repair.

- Chest radiographs also should be done routinely as a screening study to rule out lung metastases, considering that the lungs may be involved in most common cancers. Table 1 summarizes the list of recommended studies for patients with bone metastasis whose primary site of disease is unknown.

Bone Scan

- A total body bone scintigraphic evaluation using technetium Tc 99m (99mTc)-MDP should be done prior to any surgical intervention. This examination provides information for staging of the entire skeleton in the case of additional metastases and also can detect metastases that may require simultaneous surgery. Bone scanning is highly sensitive for bone pathology. Tracer uptake, however, is not specific for MBD and may display spuriously a large variety of inflammatory, infectious, post-traumatic, and other benign conditions. Therefore, plain radiography also should be done of any positive site on bone scan.
Bone scanning is not a substitute for plain radiographs of the entire affected bone or other sites with bone pain, because some tumors (e.g., multiple myeloma, metastatic melanoma, thyroid carcinoma) may not show up on a bone scan (FIG 2).

**Laboratory Studies**

- A complete blood count and blood chemistries should be ordered. The calcium level is of specific concern in those studies, because hypercalcemia may be a life-threatening complication of MBD. An ionized calcium level is helpful in the diagnosis of hypercalcemia, because low albumin levels may lower total calcium levels. Hypercalcemia should be treated before any surgical intervention is undertaken. Levels of specific tumor markers should be evaluated, if applicable to the specific tumor type.

**Biopsy**

- The mere presence of a bone lesion with a presumed diagnosis of metastasis does not mandate a biopsy. Such a lesion in a
patient with an established history of malignancy and with radiologic evidence of other bone metastases does not require a biopsy prior to surgical intervention.

- On the other hand, biopsy must be performed on a solitary bone metastasis in a patient with a known history of malignancy or a lesion with atypical radiologic or clinical manifestations, even in the presence of other bone metastases prior to any intervention.

**PREOPERATIVE PLANNING AND CONCERNS**

- Although planned surgery for patients with MBD should not be delayed, preoperative evaluation and staging must not be compromised but, rather, thoroughly mapped out. This evaluation makes it possible to understand the morphology of the lesion and its relation to adjacent structures, determine the

---

**Table 1**

<table>
<thead>
<tr>
<th>Physical examination</th>
<th>Focus on evaluation of skin, presence of lymphadenopathy, breast, thyroid, prostate, rectal examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory studies</td>
<td>Complete blood count, blood chemistries, liver function tests, erythrocyte sedimentation rate, serum and urine protein electrophoresis, prostate-specific antigen, urinalysis, stool guaiac study</td>
</tr>
<tr>
<td>Imaging studies</td>
<td>CT of chest, abdomen, pelvis</td>
</tr>
</tbody>
</table>

**FIG 2**

- **A.** Plain radiograph showing a pathological fracture of the proximal femur in a 59-year-old woman with multiple myeloma. **B.** Bone scintigraphy revealed no additional bone lesion, and she was treated with open reduction (without tumor removal) and uncemented internal fixation. She reported unrelenting ipsilateral knee pain and was clinically diagnosed as having degenerative joint disease and associated pain. Two weeks after the reduction surgery, she reported an acute onset of severe knee pain and swelling on weight bearing. **C,D.** A pathological fracture of the distal femur was demonstrated on plain radiographs. **E.** This patient underwent total femur resection with endoprosthetic reconstruction.
overall skeletal staging of the patient, and detect any other metastases that may require simultaneous surgery. Because most patients who present with skeletal metastases have an established diagnosis of cancer, clinical and radiologic evaluations usually are aimed at evaluating the extent of the disease and the presence of any complications rather than at identifying its site of origin.

History and Physical Examination

- Medical history should include current oncologic status and related treatments and medications. It is crucial to question the patient or family members about his or her overall functional status and, specifically, about the status of the affected extremity prior to the occurrence of the metastatic lesion. For example, a surgeon would be justifiably reluctant to perform major surgery on a lower extremity in a patient who was bedridden or wheelchair-bound, because stabilization of the extremity for greater ease in maintaining pain-free personal hygiene in that patient would require a less extensive procedure.

- The orthopaedic surgeon also should inform the medical oncologist of the impending operation, verify the oncologic information he or she has received, and be provided with the patient’s estimated life expectancy. The physical examination should include evaluation of the principal symptomatic area as well as other symptomatic sites. Examination should focus on the degree of soft tissue tumor extension and its relation to the neurovascular bundle of the extremity, muscle strength and range-of-motion of the adjacent joints, neurovascular status of the affected extremity, and limb edema.

Impending Pathologic Fractures

- Patients with MBD who have a pathological fracture experience a sudden onset of debilitating pain and loss of function. They require urgent hospitalization, which may interrupt the course of ongoing oncologic treatment. Furthermore, surgery for these fractures often is complicated by the presence of a substantial hematoma, soft tissue edema, and difficulties in obtaining appropriate reduction and alignment because of extensive bone destruction. For these reasons, it is important to identify those metastatic bone lesions that are likely to cause a pathological fracture (ie, “impending” pathological fractures) and to stabilize them prophylactically.

- Although the consensus is that impending fractures require prophylactic fixation, numerous reports have described varying concepts and methods of evaluation of these lesions as well as criteria for defining them. The agreed-to and most commonly used criteria include a lytic bone lesion that measures 2.5 cm, causes circumferential destruction of 50% or more of the adjacent cortical bone, and is associated with increasing pain on weight bearing that has not responded to treatment with radiation therapy (FIG 3).6,7,12

PRINCIPLES OF SURGERY

- The primary goals of surgery for MBD are to achieve local tumor control and structural stability of the surgically treated site. Surgery has no effect on the overall progression of disease or on patient survival. Most failures of these surgeries are attributed to inadequate tumor removal and improper reconstruction. Radiation therapy is most effective when applied to
FIG 4 • (continued)
microscopic disease and is considerably less effective when applied to large tumor volume.

- Surgeries done for impending or current pathological fractures should, therefore, follow the same steps: first, removal of the tumor, and only then reconstruction (FIG 4A–C). The decision to perform intralesional tumor removal or proceed with a resection of the affected bone segment depends on the local extent of bone loss and proximity to the adjacent joint (FIG 4D–K).

- Because bone metastases usually have less soft tissue extension than do primary sarcomas of bone, resection of bone metastases usually does not require en bloc removal of the surrounding soft tissues (FIG 5A,B).

- Reconstruction must provide immediate stability that must not rely on biologic healing processes. Therefore, the use of autologous bone grafts, allografts, or allograft-prosthetic composites is inappropriate in surgery for MBD. Similarly, cementless prosthetic implants have no place in this setting.

- Reconstruction should include the combined use of hardware or prosthetic implants and bone cement (ie, polymethylmethacrylate). The latter is used to reinforce the hardware by increasing the diameter of the construct through which the mechanical load is transmitted and improving its attachment to the neighboring bone, thereby allowing the construct to withstand the mechanical stresses of immediate weight bearing and function.

- Stiffness and strength are related to the diameter of the intramedullary construct: the amount of stiffness in the act of bending is proportional to the diameter raised to the fourth power, and the strength in bending varies with the third power of the diameter (FIG 5C–H).

### POSTOPERATIVE CARE

#### Rehabilitation

- Full weight bearing and passive and active range-of-motion exercises of the adjacent joints should be practiced as soon as possible, depending on wound healing and patient ability.

#### Adjuvant Radiation Therapy

- Postoperative external-beam radiation therapy of 3000 to 3500 Gy routinely is administered to the entire surgical field to control remaining microscopic disease. That dose of radiation does not impede callus formation if it is feasible, as determined by underlying fracture characteristics and the patient’s overall status. Radiation treatment is given to patients once the surgical wound has healed, usually 3 to 4 weeks after surgery.
Primary bone sarcomas usually have considerable extension into the soft tissues. Resection of such tumors at the proximal humerus would require en bloc removal of the overlying deltoid muscle, the rotator cuff tendons, and the joint capsule. Bone metastases, however, usually present with less extensive soft tissue involvement, and their resection involves removal of bony elements with only a thin layer of surrounding soft tissues. A metastatic bone lesion treated by closed nailing. This procedure is simple to perform, but it may fail, because tumor progression leaves the nail as the only load-transmitting component of the lower extremity, ultimately resulting in hardware failure and breakage. D. Plain radiograph showing an impending fracture of the femoral diaphysis due to multiple myeloma. Tumor removal, cemented nailing, and postoperative radiation most likely would have resulted in local tumor control and durable reconstruction. E. Closed nailing was done in this patient, however, and tumor progression (despite radiation) resulted in unavoidable hardware breakage. F. Similar outcome with uncemented fixation of metastatic renal cell carcinoma of the subtrochanteric region. G. Surgery should include meticulous tumor removal and filling of the entire tumor cavity with bone cement. H. Plain radiograph showing renal cell carcinoma (RCC) metastasis to the proximal femur treated with partial removal and cemented intramedullary fixation. RCCs usually are unresponsive to radiation therapy; the remaining tumor in this patient progressed and resulted in hardware failure at the hardware–cement interface.
PEARLS AND PITFALLS

Preoperative
- Acquisition of data regarding patient’s functional status pre-MBD
- Consultation with patient’s medical oncologist for current oncologic status and estimated survival
- General assessment; rule out hypercalcemia
- Plain radiographs of the entire affected bone
- Total body bone scan before surgical intervention
- Evidence of painful lytic long bone metastasis more than 2.5 cm in diameter, occupying over 50% of the cortical diameter, defines an impending fracture that requires prophylactic surgical intervention.

Intraoperative
- Tumor resection is done first
- Reconstruction should include cemented internal fixation—biologic reconstruction is inappropriate

Postoperative
- Immediate weight bearing and range-of-motion exercises
- External-beam radiation therapy

REFERENCES
Cryoablation

A number of mechanisms have been found to be responsible for the tissue necrosis induced by cryoablation. These mechanisms can be grouped into two categories: immediate and delayed.

- Four mechanisms are involved in the immediate cytotoxicity produced by cryoablation: (1) formation of ice crystals and membrane disruption; (2) thermal shock; (3) dehydration and toxic effects of electrolyte changes; and (4) denaturation of cellular proteins. The formation of intracellular ice crystals is considered as being the main mechanism of immediate cellular necrosis.

- The two mechanisms most likely responsible for the delayed, progressive necrosis that is observed following cryoablation and for the problems associated with subsequent repair of frozen tissue are (1) the damage to the microvascular circulation and (2) vascular stasis.

During cryoablation, ice crystals first occur in the extracellular spaces. The withdrawal of water from the system into these crystals creates a hyperosmotic extracellular environment, which, in turn, draws water from the cells. As the process continues, these crystals grow, the cells shrink and dehydrate, electrolyte concentration is increased, and membranes and cell constituents are damaged. Because rapid freezing, such as that achieved by direct pour of liquid nitrogen, does not allow sufficient time for the withdrawal of water from the cells, intracellular ice crystals are formed simultaneously.

Conversely, a slow thaw will cause intracellular recrystallization of the already formed crystals and membrane disruption, whereas a rapid thaw will not.

Repeated freeze–thaw cycles also increase the extent of tissue necrosis because of the improved cold conductivity following the first cycle. Therefore, repeated cycles of rapid freezing and spontaneous thaw achieve the maximal effect of cell necrosis.

Histologically, the most dramatic effect of cryoablation is on the appearance of the bone marrow: a rim of 1 to 2 cm of severe, delayed, progressive necrosis that is observed following cryoablation and for the problems associated with subsequent repair of frozen tissue are (1) the damage to the microvascular circulation and (2) vascular stasis. Because rapid freezing, such as that achieved by direct pour of liquid nitrogen, does not allow sufficient time for the withdrawal of water from the cells, intracellular ice crystals are formed simultaneously.

Conversely, a slow thaw will cause intracellular recrystallization of the already formed crystals and membrane disruption, whereas a rapid thaw will not.

Repeated freeze–thaw cycles also increase the extent of tissue necrosis because of the improved cold conductivity following the first cycle. Therefore, repeated cycles of rapid freezing and spontaneous thaw achieve the maximal effect of cell necrosis.

Histologically, the most dramatic effect of cryoablation is on the appearance of the bone marrow: a rim of 1 to 2 cm of extensive necrosis with minimal inflammatory response appears following direct pour of liquid nitrogen. This is followed by liquefaction and progressive fibrosis. Large, thickened, and thrombosed vessels occasionally are seen as well.

INDICATIONS

Histologic Diagnoses
- Benign–aggressive bone tumors
  - Giant cell tumor
  - Aneurysmal bone cyst
  - Simple bone cyst
  - Fibrous dysplasia
  - Enchondroma
  - Chondroblastoma
  - Eosinophilic granuloma
Osteoblastoma
Chondromyxoid fibroma
Low-grade sarcomas of bone
Low-grade chondrosarcoma
Metastatic tumors

**Morphologic Criteria**
Cryoablation is appropriate for periarticular and sacral lesions in which the circumferential rim of the cortex that remains after tumor removal can hold liquid material and is adequate to ensure a mechanically stable reconstruction.

**SURGICAL MANAGEMENT**
Cryosurgical ablation is carried out in five stages: (1) tumor exposure; (2) thorough curettage; (3) high-speed burr drilling of the tumor cavity; (4) cryoablation; and (5) mechanical reconstruction.5,6,27

**DIRECT POUR LIQUID NITROGEN**
When technically possible, a pneumatic tourniquet is used during the procedure to decrease local bleeding and prevent blood from acting as a heat sink and posing a thermal barrier to cryoablation.
A large cortical window the size of the longest longitudinal dimension of the tumor is made after exposure of the involved bone. It must be elliptical, with its axis parallel to the long axis of bone, to reduce the stress rising effect (TECH FIG 1A–C).

All gross tumor material is removed with hand curettes (TECH FIG 1D–E). This is followed by high-speed burr drilling of all remaining macroscopic disease and the walls of the tumor cavity (TECH FIG 1F).
Bony perforations are identified and sealed with Gelfoam (Upjohn, Kalamazoo, MI) before introduction of the liquid nitrogen. The neurovascular bundle and fasciocutaneous flaps are protected by mobilization and by shielding (with surgical pads) from direct contact with the liquid nitrogen, after which cryoablation is performed.

**TECHNIQUES**

**TECH FIG 1**
A. Plain radiograph showing aneurysmal bone cyst of the proximal humerus. B. The tumor site is widely exposed by a deltopectoral incision, and fasciocutaneous flaps are mobilized to expose the entire extent of the tumor. C. A large cortical window the size of the longest longitudinal dimension of the tumor is made. D. Plain radiograph showing giant cell tumor of the distal femur. E. The tumor is first removed with hand curettes. This should be meticulously performed, leaving only residual microscopic disease in the tumor cavity. (continued)
Curettage is followed by high-speed burr drilling.

The traditional technique of cryoablation entails direct pour of liquid nitrogen through a stainless steel funnel into the tumor cavity, taking care to fill the entire cavity (TECH FIG 2). Thermocouples are used to monitor the freeze within the cavity, cavity wall, adjacent soft tissues, and an area 1 to 2 mm from the periphery of the cavity. The surrounding soft tissues are irrigated continuously with warm saline solution to decrease the possibility of thermal injury.

Freezing (boiling of liquid nitrogen) lasts 1 to 2 minutes and is proportional to the volume of poured liquid nitrogen. It is followed by spontaneous thaw, which occurs over 3 to 5 minutes. The cycle is considered complete once the temperature of the cavity rises above 0°C. The cavity is irrigated with saline after two freeze–thaw cycles have been carried out. At this point, the process of reconstructing the tumor cavity begins.

Reconstruction includes the use of internal fixation and the use of polymethylmethacrylate (PMMA; TECH FIG 3). Subchondral surfaces are reinforced with autologous bone graft before cementation.

CLOSED CRYOABLATION WITH ARGON GAS

Cryoablation using direct pour of liquid nitrogen has several technical drawbacks. First, after it has been poured, there is no control of the overall freezing time or of the temperature at different sites within the tumor cavity. Second, it is a gravity-dependent procedure, ie, the poured liquid cannot reach corners of the tumor cavity that are positioned above the fluid level.

In response to these problems, closed cryoablation using argon gas was developed and became available in the late 1990s. This approach entails filling the tumor cavity with a gel medium, inserting metal probes into the gel, and executing computer-controlled delivery of argon gas through the metal probes.

Argon gas serves as the freezing agent, and the surrounding gel acts as a conducting medium, which distributes the low temperature equally throughout the tumor cavity (TECH FIGS 4, 5, and 6).

Computer-controlled delivery of argon gas allows determination of both the desired temperature throughout the tumor cavity and the overall freezing time, and the use of a viscous gel enables filling of any shape of tumor cavity, regardless of gravity considerations (TECH FIG 7).
Reconstruction includes cemented hardware and reinforcement of subchondral surfaces with autologous bone graft. This principle of reconstruction is applied in all anatomic locations: proximal femur (A), distal femur (B), proximal tibia (C), distal tibia (D), distal radius (E), and proximal ulna (F).
Chapter 6 CRYOSURGICAL ABLATION OF BONE TUMORS

TECH FIG 4 • A. Different sizes of metal probes used for delivery of argon gas. B. The tumor cavity filled with gel medium and the metal probe within it. C. The gel freezes and creates an ice ball within a few seconds after perfusion of the argon gas through the probe.

TECH FIG 5 • A. Plain radiograph showing a giant cell tumor of the proximal tibia. B. Curved incision along the lateral tibial metaphysis. C. Curettage. D. High-speed burr drilling. E. An ice ball is formed around the tip of the probes on perfusion of argon gas.

TECH FIG 6 • A. Recurrent low-grade chondrosarcoma of the distal radius. B. Tumor curettage. C. High-speed burr drilling. (continued)
D. The tumor cavity is filled with gel. E. Cryoablation.

TECH FIG 7 • Cryoablation of the proximal ulna (A) and the fourth toe (B) using the closed, argon-based system. It would have been difficult to freeze these sites with direct pour of liquid nitrogen due to the relatively large size of the funnels.

PEARLS AND PITFALLS

Surgery
- Mobilization of the neurovascular bundle and surrounding soft tissues
- Adequately large cortical window
- Meticulous curettage followed by high-speed burr
- Soft tissue protection and warming throughout cryoablation
- Reconstruction of the tumor cavity with cemented hardware and of the subchondral surface with autologous bone graft

Postoperative
- Protected weight bearing postoperatively

POSTOPERATIVE CARE
- Routine perioperative prophylactic antibiotics are administered for 3 to 5 days. Patients with lesions of the lower extremities are kept non-weight bearing for 6 weeks. Plain radiographs are then obtained to rule out fracture and establish bone graft incorporation. Gradual weight bearing is allowed if healing has progressed satisfactorily.

OUTCOMES
- By far the most extensive experience with cryoablation has involved giant cell tumor of bone, a benign-aggressive primary bone tumor. Two thirds of these lesions occur in the third or fourth decades of life, and, in most cases, they are located in the metaphyseal-epiphyseal region of long bones around the articular cartilage. Because wide excision of such tumors would cause major loss of function due to their proximity to the joint, it had been common practice to opt for intralesional procedures, but the rate of local recurrence, mainly after curettage, was unacceptably high (ie, 40%-55%).
- The use of cryoablation with liquid nitrogen, as an adjuvant to curettage and high-speed burr drilling, substantially lowered the recurrence rate. Malawer et al reported a 2.3% recurrence rate among 86 patients treated primarily with cryoablation. They reported good-to-excellent functional outcome in 92% percent of the patients. Because cryoablation provides a nonselective mechanism for cell destruction, it is not surprising that similar rates of local tumor control and associated good
functions were reported with other benign–aggressive and malignant tumors.\(^3,4,9,14,23–25,28,30,31,34,35,37,38,40,44–46,49\)

**COMPLICATIONS**

- Gage et al\(^13\) observed that cryoablation is a double-edged sword, ie, that it induces tumor necrosis with similar injury to the surrounding normal tissues. This potential drawback initially was underestimated by surgeons who pioneered the application of this technique in clinical practice. Inadequate protection of soft tissues, lack of mechanical fixation, and failure to use perioperative antibiotics resulted in unacceptably high rates of fractures, soft tissue injury, infections, and neurapraxias.\(^32\)

- Those complications gave cryoablation its bad reputation and motivated surgeons to refine the surgical technique to include concomitant soft tissue mobilization and protection, stable reconstruction with cemented internal fixation devices, and the use of perioperative antibiotics. As a result, the same authors reported a later series of patients with a significantly reduced rate of those complications.\(^39,52\)

- Postoperative fractures have been a devastating complication of cryoablation (FIG 2A,B). They were considered pathological because they occurred through a mechanically weakened bone and following a minor trauma.\(^4,20,27,33,39\) These fractures healed slowly (over a period of 3 to 9 months) and were associated with a significant loss of function. Lack of stable fixation and early weight bearing were shown to be the important factors leading to these fractures, and the treatment protocol was changed accordingly: the consensus was that cryoablation must be followed by stable reconstruction that includes internal fixation reinforced with PMMA and a strict rehabilitation protocol of gradual weight bearing.\(^27,32,39\) This regimen resulted in a minimal rate of postoperative fractures, as reported in series published from the 1990s to date.\(^4,24,27,44,46,49,50\)

- When such postoperative fractures do occur, surgical intervention usually is not required. The fracture lines invariably are along the internal fixation device, so the fracture is not significantly displaced, and immobilization and avoidance of weight bearing usually are sufficient for treatment. Infections and flap necrosis also have become rare complications due to mobilization and protection of soft tissues prior to freezing and the use of perioperative antibiotics.

- Mobilization of the neurovascular bundle and surrounding soft tissues away from the tumor site, as well as the use of perioperative antibiotics, has led to low rates of infections, thermal injuries, and nerve palsies (FIG 2C). When the latter do occur, the neurologic damage usually is transient and heals spontaneously. Cryoablation also was shown to be associated with minimal damage to the adjacent articular cartilage, with degenerative changes reported in less than 3% of cases in a large series of patients.\(^29\)

---

**FIG 1** • Full flexion of the knee in a 54-year-old man 3 months following cryoablation of a chondrosarcoma of the lateral femoral condyle. It would have been difficult to achieve such a range and muscle strength after the resection of the distal femur that otherwise would have been offered to this patient.

**FIG 2** • A. Plain radiograph showing pathological fracture of the proximal tibia following cryoablation and on weight bearing. Reconstruction following cryoablation in that patient consisted of autologous bone graft only. B. The wide collapse and destruction of the articular surface made resection of the proximal tibia and reconstruction with endoprosthesis inevitable. C. Thermal injury to the leg due to spillage of liquid nitrogen. The soft tissues apparently were not well protected in this patient during freezing. This complication is rare when adequate padding and warming with saline are carried out. It is even more uncommon when using the closed argon-based system, which does not involve any poured fluid whatsoever.
Cryoaclination achieves best local tumor control when applied for microscopic disease and in tumors that have not caused major cortical destruction and invasion into the surrounding soft tissues. Any compromise of either of these criteria ultimately may result in local tumor recurrence. Better case selection, adequate curettage, and meticulous burr-drilling have led to a drop in local recurrence rates, to less than 5% in most series. A second cryoablative procedure is curative in most local recurrences. Venous gas embolism is a rare complication of open cryoaclination with liquid nitrogen, having been reported in only 4 cases. Liquid nitrogen rapidly produces nitrogen bubbles at room temperature. Although most of the gas exits into the atmosphere through the surgical wound, a considerable amount nevertheless is pushed into the pulmonary circulation under the influence of the pressure caused by boiling of liquid nitrogen in the bony cavity, and exhaled. It usually manifests intraoperatively with decreased O2 saturation level and end-tidal CO2, associated with a drop in blood pressure and a rise in the heart rate. These emboli usually resolve completely with early detection, discontinuation of nitrous oxide administration, and support with oxygen.

REFERENCES

BACKGROUND

- The upper extremity is involved by bone and soft tissue neoplasms only one third as often as the lower extremity. The scapula and proximal humerus are common sites of primary sarcoma, including osteosarcoma and Ewing sarcoma in children and chondrosarcoma in adults. Metastatic tumors, especially hypernephroma, also have a propensity for the proximal humerus. When soft tissue tumors occur in the upper extremity, they tend to favor the shoulder girdle and may secondarily involve the scapula, proximal humerus, or clavicle. The axilla is another site around the shoulder girdle where primary soft tissue tumors may develop or where metastases can spread to and replace the local lymph nodes. The axilla is a relatively “silent” area, where tumors may grow to large sizes before they become symptomatic and are detected.

- The shoulder girdle consists of the proximal humerus, the scapula, and the distal third of the clavicle, as well as the surrounding soft tissues. Each bone may be involved by a primary malignant bone tumor or metastases, with or without soft tissue extension. The bones of the shoulder girdle also may be secondarily involved by a soft tissue sarcoma, which requires resection and reconstruction techniques similar to those of a primary bone tumor (FIG 1).

- Until the mid-20th century, forequarter amputation was the treatment for malignant tumors of the shoulder girdle. Today, about 95% of patients with sarcomas of the shoulder girdle can be treated safely by limb-sparing resection such as the Tikhoff–Linberg resection and its modifications. The relation of the neurovascular bundle to the tumor and other structures of the shoulder girdle is the most significant anatomic factor in determining resectability, removal of the tumor, and reconstruction.

- The resection and reconstruction of tumors of the shoulder girdle consists of three components: (1) surgical resection of the tumor following oncologic principles; (2) reconstruction of the skeletal defect (ie, endoprosthetic replacement); and (3) soft tissue reconstruction using multiple muscle transfers to cover the skeletal reconstruction and provide a functional extremity. The goals of all shoulder girdle reconstructions are to provide a stable shoulder and to preserve normal elbow and hand function. The extent of tumor resection and remaining motor groups available for reconstruction dictate the degree of shoulder motion and function that are retained.

Historical Background

- Some of the earliest discussions concerning limb-sparing surgery focused on techniques for resection of tumors about the scapula. Initial reports of shoulder girdle resections were confined to the individual bones or portions of the scapula. The first reported scapular resection was a partial scapulectomy performed by Liston in 1819 for an ossified aneurysmal tumor. Between this time and the mid-1960s, several other authors discussed limb-sparing resections about the shoulder girdle. In 1965, Papioannou and Francis reported 26 scapulectomies and discussed the indications and limitations of the procedure.

- The Tikhoff–Linberg interscapulothoracic resection or triple-bone resection was described in the Russian literature by Baumann in 1914. He referred to a 1908 report by Pranishkov that described the removal of the scapula, the head of the humerus, the outer one third of the clavicle, and the surrounding soft tissue for a sarcoma of the scapula. The shoulder was suspended from the remaining clavicle by metal sutures. Tikhoff and Baumann performed three such operations between 1908 and 1913, and Tikhoff was named as the originator of the procedure. The technique became established in the Western surgical community only after Linberg’s English publication in 1926.

- Classically, most shoulder girdle resections were done for low-grade tumors of the scapula and periscapular soft tissue sarcomas. Before 1970, most patients with high-grade spindle cell sarcomas (eg, osteosarcoma, chondrosarcoma) involving the shoulder girdle were treated with a forequarter amputation. In 1977, Marcove et al were the first to report limb-sparing surgery for high-grade sarcomas arising from the proximal humerus. These authors reported performing an en bloc extra-articular resection that included the proximal humerus, glenoid, overlying rotator cuff, lateral two thirds of the clavicle, deltoid, coracobrachialis, and proximal biceps. Local tumor control and survival rates were similar to those achieved with a forequarter amputation. Resection, however, preserved a functional hand and elbow. These early results were confirmed by other surgeons. After the 1980s, osteosarcoma, chondrosarcoma, and Ewing sarcoma of the proximal humerus became the tumors most commonly treated with a Tikhoff–Linberg resection. A variety of new techniques and modifications of shoulder girdle resections have been developed. Most have been reported as “Tikhoff–Linberg” or “modified Tikhoff–Linberg” resections. These eponyms are not accurate descriptions, however, because the Tikhoff–Linberg procedure was not intended to refer to sarcomas of the humerus.

- As the popularity of limb-sparing surgery for shoulder girdle sarcomas grew, the extent of resection necessary for various tumors, particularly indications for an extra-articular resection, remained a matter of debate. The best method for reconstruction also came under considerable discussion. In response, Malawer et al. developed a surgical classification system (FIG 2) based on tumor location, extent, grade, and pathologic type. This system was intended to provide guidelines regarding the extent of resection necessary for primary bone sarcomas and soft tissue sarcomas that secondarily involve the bones of the shoulder girdle.

SURGICAL CLASSIFICATION SYSTEM

- The current surgical classification system was described by Malawer and associates in 1991 (Fig 2). It is based on the
indications are described briefly in the following section. The current concepts of surgical margins, the relation of the tumor to anatomic compartments (ie, intracompartamental vs. extracompartamental), the status of the glenohumeral joint, the magnitude of the individual surgical procedure, and precise considerations of the functionally important soft tissue components. It includes six categories:

- Type I: intra-articular proximal humeral resection
- Type II: partial scapular resection
- Type III: intra-articular total scapulectomy
- Type IV: extra-articular total scapulectomy and humeral head resection (classic Tikhoff–Linberg resection)
- Type V: extra-articular humeral and glenoid resection
- Type VI: extra-articular humeral and total scapular resection.

Each type is subdivided according to the status of the abductor mechanism (the deltoid muscle and rotator cuff):

- Abductors intact
- Abductors partially or completely resected

Type A resections, in which the abductors are preserved, usually are recommended for high-grade spindle cell bone sarcomas that are entirely intracompartamental (ie, contained within either the proximal humerus or scapula bone). This is a rare situation, however. This type of resection also is recommended for low grade-bone sarcomas, selected metastatic carcinomas, and, often, round cell sarcomas.

Type B resections, in which the abductors are resected, are extracompartamental resections and are the most common type of resection performed for high-grade spindle cell sarcomas.

All six of these types of shoulder girdle resections and their indications are described briefly in the following section. The surgical techniques for each resection and reconstruction are described in ON-8, 10, and 11–13.

GUIDELINES FOR SHOULDER GIRDLE RESECTION

Local Growth and Transarticular Involvement by Shoulder Girdle Tumors

- The shoulder joint appears to be more prone than other joints to intra-articular or pericapsular (ligamentous) involvement by high-grade bone sarcomas.
- Four basic mechanisms underlie tumor spread across the shoulder joint: direct capsular extension; tumor extension along the long head of the biceps tendon; fracture hematoma from a pathologic fracture; and poorly planned biopsy (FIG 3).
- These mechanisms place patients undergoing intra-articular resections for high-grade sarcomas at greater risk for local recurrence than those undergoing extra-articular resections. Therefore, it often is necessary to perform an extra-articular resection for high-grade bone sarcomas of the proximal humerus or scapula.
- Most tumors arise from the metaphyseal portion of the proximal humerus. They extend beyond the cortices and spread underneath the deltoid muscle, subscapularis muscle, and remaining rotator cuff muscles. As the tumor grows, the extrasosseous component spreads along the long head of the biceps tendon, along the glenohumeral ligaments, and underneath the rotator cuff, heading toward the glenoid or directly crossing the glenohumeral joint. The deltoid, subscapularis muscle, and remaining rotator cuff muscles are compressed into a pseudocapsular layer. These muscles form compartmental boundaries around the tumor. The axillary nerve and circumflex vessels enter this compartment. The major neurovascular bundle is displaced by the tumor; however, in most instances the fascia overlying the subscapularis muscle as well as the axillary sheath that contains the blood vessels and nerves protect the major neurovascular bundle from tumor involvement or encasement.
- Similarly, most scapular sarcomas originate from the metaphyseal portion of the scapula or the scapula neck, and grow centripetally into the soft tissues. They form a soft tissue mass that extends outward and usually is contained by the subscapularis and other rotator cuff muscles. These tumors follow the path of least resistance and are directed toward the glenohumeral joint and proximal humerus. Eventually, the tumor contaminates these structures. The subscapularis muscle and its investing fascia function as a barrier and protect the axillary vessels and brachial plexus from tumor invasion. These neurovascular structures usually are displaced by the adjacent tumor that lies deep to the subscapularis muscle.

Functional Anatomic Compartment of the Shoulder Girdle

- Sarcomas grow locally in a centripetal manner and compress surrounding tissues (muscles) into a pseudocapsular layer. The pseudocapsular layer contains microscopic finger-like projections of tumor, which are referred to as satellite nodules.
- Sarcomas spread locally along the path of least resistance. Surrounding fascial layers resist tumor penetration and,
therefore, provide boundaries to local sarcoma growth. These boundaries form a compartment around the tumor (FIG 4).

- A sarcoma will grow to fill the compartment in which it arises, and only rarely will an extremely large sarcoma extend beyond its compartmental borders. In discussing bony sarcomas that extend beyond the cortices into the surrounding soft tissues, the term functional anatomic compartment refers to the investing muscles that are compressed into a pseudocapsular layer (Fig 4).

- These muscles provide the fascial borders of the compartment, a fact that has important surgical implications. A wide resection of a bone sarcoma removes the entire tumor and pseudocapsular layer and must, therefore, encompass the investing muscle layers (compartmental resection).

- The functional compartment surrounding the proximal humerus consists of the deltoid, subscapularis and remaining rotator cuff, latissimus dorsi (more distally), brachialis, and portions of the triceps muscles. The glenoid and scapular neck also reside within the functional compartment of the proximal humerus, because they are contained by the rotator cuff and capsule and the subscapularis muscle. Sarcomas that arise from the proximal humerus and extend beyond the cortices compress these muscles into a pseudocapsular layer.

- The fascial layers surrounding these muscles resist tumor penetration. The only neurovascular structures that enter this compartment are the axillary nerve and humeral circumflex vessels.

- The main neurovascular bundle (i.e., brachial plexus and axillary vessels) to the upper extremity passes anterior to the subscapularis and latissimus dorsi muscles. These muscles and their
investing fascial layers are particularly important, therefore, for protecting the neurovascular bundle from tumor involvement. They also protect the pectoralis major muscle, which must be preserved during surgical resection for soft tissue coverage.

- High-grade sarcomas that extend beyond the bony cortices of the proximal humerus expand the investing muscles that form the compartmental borders and pseudocapsular layer.
- These sarcomas grow along the path of least resistance and, therefore, are directed toward the glenoid and scapular neck by the rotator cuff and glenohumeral joint capsule.
- Anteriorly, the tumor is covered by the subscapularis, which bulges into and displaces the neurovascular bundle. Only rarely does a very large proximal humerus sarcoma extend beyond the compartmental borders.
- In these instances the tumor usually protrudes through the rotator interval. A wide (compartmental) resection for a high-grade sarcoma must, therefore, include the surrounding muscles that form the pseudocapsular layer (ie, deltoid, lateral portions of the rotator cuff), the axillary nerve, humeral circumflex vessels, and the glenoid (extra-articular resection of the proximal humerus).
- Most high-grade scapular sarcomas arise from the region of the scapular neck. The compartmental borders surrounding the scapular neck consist of the rotator cuff muscles and portions of the teres major and latissimus dorsi muscles. The compartment consists of all of the muscles that originate on the anterior and posterior surfaces of the scapula: the subscapularis, infraspinatus, and teres muscles. The deltoid, although it is not typically considered one of the compartmental borders, since it attaches to a narrow region of the scapular spine and acromion, may be involved secondarily by a large soft tissue extension. In most instances the deltoid is protected by the rotator cuff muscles because the anatomic origin of most tumors is from the neck and body region. Similar to the proximal humerus, the rotator cuff muscles are compressed into a pseudocapsular layer by sarcomas that arise from the scapula. The subscapularis also protects the neurovascular bundle from tumor involvement. The head of the proximal humerus is contained within the compartment surrounding the scapula by the rotator cuff muscles. Wide resection of a high-grade scapular sarcoma must, therefore, include the rotator cuff and, in most instances, the humeral head.
- The axillary nerve is not contained within the compartment and therefore can be spared from resection. Additionally, because the deltoid is not compressed into a pseudocapsular layer, it usually can be preserved.

**INDICATIONS**

**Indications for Limb-Sparing Surgery**

- High-grade and some low-grade bone sarcomas
- Soft tissue sarcomas arising from the shoulder girdle

**FIG 3** Biopsy site. Anatomic drawing illustrating the preference for a core needle biopsy for tumors of the proximal humerus. The biopsy sample should be taken through the anterior third of the deltoid. Great care should be taken to avoid the pectoralis major muscle, the deltopectoral interval, and the axillary vessels. The deltoid is innervated by the axillary nerve posteriorly, so a portion of the anterior deltoid can be resected if necessary without significant compromise to the nerve. (Courtesy of Martin M. Malawer. From Bickels J, Jellinek S, Shmookler BM, et al. Biopsy of musculoskeletal tumors. Current concepts. Clin Orthop Relat Res 1999;368:212–219.)

**FIG 4** Schematic diagram of the compartment of the proximal humerus. A true compartmental site includes the muscles of origin and insertion of a specific group, as well as a major feeding vessel and nerve. This is a conceptual consideration for tumors around the proximal humerus, which does not fit the classic definition of an anatomic compartment. Surgically, however, this area is considered as the shoulder girdle compartment, which consists of the deltoid, the rotator cuff muscles, a portion of the pectoralis major muscle, the latissimus dorsi, and the teres major. The major neurovascular pedicle is the axillary nerve and the circumflex vessels. (Courtesy of Martin M. Malawer. From Wittig JC, Bickels J, Kellar-Graney KL, et al. Osteosarcoma of the proximal humerus: long-term results with limb-sparing surgery. Clin Orthop Relat Res 2002;(397):156–76.)
- Metastatic carcinomas: isolated metastasis or metastatic lesions that have caused significant bony destruction
- Occasionally, benign-aggressive tumors also may require these treatment techniques.
- Selection of patients for limb-sparing surgery is based on the anatomic location of the tumor and a thorough understanding of the natural history of sarcomas and other malignancies.

**Contraindications for Limb-Sparing Surgery**

- Absolute contraindications for limb-sparing procedures include tumor involvement of the neurovascular bundle, or a patient’s inability or unwillingness to tolerate a limb-sparing operation.
- Relative contraindications may include chest wall extension, pathologic fracture, previous infection, lymph node involvement, or a complicated, inappropriately placed biopsy that has resulted in extensive hematoma, which has resulted in tissue contamination.

**Biopsy Site**

- One of the most common causes for forequarter amputation is an inappropriately placed biopsy site that has resulted in contamination of the pectoralis muscles, neurovascular structures, and chest wall. Extreme care must be taken with biopsy placement and technique (see Fig 3).

**Vascular Involvement**

- Fortunately, most tumors of the proximal humerus are separated from the anterior vessels by the subscapularis, latissimus dorsi, and coracobrachialis muscles. It is rare for the axillary or brachial artery to be involved with tumor, although a large soft tissue component may cause displacement and compression.
- In general, if the vessels appear to be involved with tumor, the adjacent brachial plexus also is involved, and a limb-sparing procedure may be contraindicated.

**Nerve Involvement**

- The three major cords of the brachial plexus follow the artery and vein and rarely are involved with tumor. The axillary nerve may be involved by neoplasm as it passes from anterior to posterior along the inferior glenohumeral joint capsule. Resection of the axillary nerve usually is required for stage IIB tumors of the proximal humerus.
- The musculocutaneous and radial nerves rarely are involved. The deficit created by resecting the radial nerve is greater than that for the musculocutaneous nerve, but this should not be an indication for amputation.
- If resection will lead to a major functional loss and a close margin (increasing the risk of local recurrence), amputation should be considered. Direct tumor extension into or encasement of the brachial plexus necessitates a forequarter amputation.

**Lymph Nodes**

- Bone sarcomas rarely involve adjacent lymph nodes; nevertheless, axillary nodes should be evaluated and may require biopsy. In the rare incidence of lymph node involvement documented by biopsy, a forequarter amputation may be the best method for removing all gross disease.
- Alternatively, a lymph node dissection in conjunction with a limb-sparing procedure may be considered. Malawer has found, based on two cases, that local control and long-term survival can be obtained by this method (unpublished data).

**Chest Wall Involvement**

- Tumors of the shoulder girdle with large extraosseous components occasionally may involve the chest wall, ribs, and intercostal muscles.
- Chest wall involvement should be evaluated preoperatively with physical examination and imaging studies; however, such involvement often is not determined until the time of surgery. It is not an absolute indication for forequarter amputation; a limb-sparing procedure combined with a chest wall resection may be performed, depending on the involvement of adjacent soft tissues and neurovascular structures.

**Previous Resection**

- The local recurrence rate is increased in cases in which a wide resection is attempted (1) following a previous inadequate resection around the shoulder girdle or (2) when a tumor already has recurred locally. This possibility must be a consideration especially with tumors of the scapula and clavicle and of soft tissue tumors that involve the proximal humerus.

**Infection**

- In patients with high-grade sarcomas, limb-sparing procedures performed in an area of infection are extremely risky, because these patients must receive postoperative adjuvant chemotherapy. If an infection cannot be eradicated with the primary resection, amputation is advisable.

**SURGICAL MANAGEMENT**

**Preoperative Planning**

**Physical Examination**

- The physical examination is important for assessing tumor resectability and for estimating the extent of resection that may be required. Physical examination is important in determining tumor extension into the glenohumeral joint, neurovascular involvement, or tumor invasion of the chest wall. If tumor has invaded the joint, shoulder range of motion usually is reduced, and the patient may complain about discomfort and pain.
- Neurovascular involvement or compression may be suggested by an abnormal neurovascular examination or by decreased or absent pulses.
- Tumors that move freely with respect to the chest wall usually are separated from it by at least a thin tissue plane through which it is safe to dissect.

**Determining Tumor Resectability**

- High-grade tumors arising from the shoulder girdle region often are large and encroach on the neurovascular bundle. Tumors that encase or invade the brachial plexus are considered unresectable. In many cases it is difficult to determine, both clinically and radiologically, which tumors involve or encase the neurovascular structures directly as opposed to merely displacing these structures. Although most tumors that displace the neurovascular structures are resectable, some are unresectable, and it can be difficult to determine clinically which are in this category.
We have found the clinical triad of intractable pain, motor deficit, and a venogram showing obliteration of the axillary vein to be very reliable in predicting brachial plexus invasion. No single imaging study is available that accurately visualizes the brachial plexus. MRI and CT scans typically show a large tumor juxtaposed to the neurovascular bundle (FIG 5).

Venography, however, is extremely accurate in predicting brachial plexus invasion. The axillary vein, axillary artery, and brachial plexus travel in intimate association within a single fascial sheath, the axillary sheath. The major nerves and cords travel along the periphery of the sheath; therefore only complete obliteration—not just compression—of the brachial or axillary vein denotes direct tumor extension in and around the nerves and also indicates secondary involvement of the venous wall. This progression also explains the clinical triad of pain, motor loss, and venous obstruction. Tumors that invade or encase the brachial plexus obliterate the axillary vein because of that vein’s thin walls and low intraluminal pressure. In these instances arteriography demonstrates displacement of the axillary artery; however, the axillary artery remains patent because of its thick walls and high intraluminal pressures.

The final decision regarding the need for a forequarter amputation should be reserved until surgical exploration of the brachial plexus has been performed.

**Prosthetic Reconstruction**

When endoprosthetic reconstruction was developed in the 1940s, attention initially was focused on reconstruction of skeletal defects of the lower extremity. Use of the technique was broadened gradually to include defects of the upper extremity and shoulder girdle. The MRS shoulder prosthesis has undergone several design changes and improvements since that time. The current components for proximal humerus and scapular replacement are shown in Chapters ON-10 and 8, respectively. The MRS is used in conjunction with both intra- and extra-articular resections, and results are highly predictable and successful.

Reported rates of fracture, infection, nonunion, reoperation, and tumor recurrence are lower, and length of immobilization is shorter with extremity endoprosthetic reconstruction than with allograft, composite reconstruction, or arthrodesis.

Survival of the MRS proximal humeral prosthesis is reported to be 95% to 100% at 10 years.

**FIG 5** • Imaging studies of the shoulder girdle and axillary space demonstrating bony and soft tissue findings. A. CT scan showing a tumor arising from the glenoid and involving the glenohumeral joint. CT scans are the best modality for observing bony detail. B. Coronal MRI scan showing direct tumor extension. C,D. A large soft tissue axillary tumor protruding anteriorly through the pectoralis major and the skin. This is a high-grade fungating soft tissue sarcoma. MRI is the best scan for evaluation of soft tissue masses in relation to other soft tissue structures. E. MRI scan of the axillary space (coronal view) showing a secondary skipped lesion along the axillary vein, coming from a high-grade soft tissue sarcoma lower in the axilla. Metastatic lesions of the axilla and lymph nodes are a common source of large axillary masses and are best evaluated by MRI scans. F. Angiography and embolization of metastatic renal cell carcinoma (hypernephroma) to the distal clavicle. Following embolization, there is no evidence of a tumor blush. Embolization often is performed for large high-grade soft tissue sarcomas prior to a resection. G. On this axillary venogram, the axillary vein is occluded by thrombosis, and there is a small backward filling from the innominate vein. This is the most pathognomonic finding of brachial plexus involvement seen during the time of surgery. Brachial plexus involvement often correlates with the clinical findings of neurologic deficits, numbness, or muscle weakness of the affected extremity.
SKELETAL RECONSTRUCTION FOLLOWING HUMERUS AND SCAPULA RESECTIONS

- Special prosthetic replacements are recommended for skeletal reconstruction following proximal humerus and total scapula resections, although the utilitarian approach may be used with any method of reconstruction (TECH FIG 1).
- Soft tissue reconstruction is accomplished using a dual suspension technique that employs static and dynamic methods of prosthetic stabilization and soft tissue and motor reconstruction.
- Static methods of stabilization include the use of heavy nonabsorbable sutures, Dacron tapes, or Gore-Tex grafts, depending on the site of tumor resection and the prosthesis that is being used. This method offers secure fixation and stabilization of the prosthesis until the soft tissues heal and scar to each other.
- Dynamic methods of stabilization and reconstruction include multiple muscle rotation flaps and muscle transfers that eventually heal, scar to each other and the prosthesis, and provide the necessary motor units for a functional extremity.
- Soft tissue reconstruction follows skeletal reconstruction and static stabilization. The short head of the biceps is attached with a tenodesis proximally to the coracoid (intra-articular proximal humerus reconstruction), or to the clavicle (extra-articular proximal humerus reconstruction) or pectoralis major (total scapula reconstruction). The pectoralis minor also is tenodesed back to its origin, when possible, or to the scapula to protect the neurovascular structures. The pectoralis major is repaired to its humeral insertion or, in cases requiring extra-articular proximal humerus reconstruction, transferred to cover the prosthesis with soft tissues. The latissimus dorsi may be transferred laterally to function as an external rotator following extra-articular proximal humerus resection.
- In total scapula reconstruction, the periscapular muscles are tenodesed to the prosthesis with heavy nonabsorbable sutures or tapes in a manner that covers the entire prosthesis with muscle. Following isolated axillary tumor resection, the distal (humeral) transected edge of the latissimus dorsi muscle is rotated into the defect and sutured to the superficial surface of the subscapularis muscle to fill the dead space. Large-bore closed suction drains are routinely placed prior to skin closure.
The initial steps of the anterior approach of the utilitarian shoulder girdle incision. The key to this approach is the release of the pectoralis major from its insertion on the humerus (1–2 cm away). With the pectoralis major now reflected onto the chest wall, the entire axillary space can be exposed. This is termed the first layer of musculature of the axillary space. The second muscular layer of the axillary space is then visualized. With the pectoralis major layer retracted, the axillary space is completely covered by fascia, similar to the peritoneum. This covers two muscles, the short head of the biceps and the pectoralis minor, which attach to the coracoid process, which must be released. With these two muscles released, the axillary space and infra-clavicular component of the brachial plexus (ie, the axillary vein and artery through its entire length) can be explored completely. If necessary, a portion of the clavicle can be resected to exposed the subclavian artery and vein. (Courtesy of Martin M. Malawer.)

PEARLS AND PITFALLS

Preoperative evaluation
- Physical examination and radiologic imaging modalities are useful for predicting whether a tumor is resectable. The scapula and proximal humerus should move freely from the chest wall. Chronic swelling in the distal extremity, intractable pain, motor loss, and a venogram that demonstrates obliteration of the axillary vein strongly suggest that the tumor is unresectable. The final determination regarding the need for a forequarter amputation is made intraoperatively, after anterior exposure and exploration of the brachial plexus and neurovascular structures.

Neurovascular exploration and mobilization
- The key to a safe and adequate resection of all types of neoplasms around the shoulder girdle lies in adequate visualization, exposure, dissection, mobilization and preservation of all vital neurovascular structures. Full exposure is facilitated by releasing the pectoralis major muscle from its humeral insertion and the strap muscles from the coracoid process.

Type of resection
- High-grade sarcomas that arise from the proximal humerus or scapula are likely to contaminate or cross the glenohumeral joint, either grossly or microscopically. An extra-articular type of resection is used for most high-grade sarcomas arising from the scapula or proximal humerus. Clavicular tumors, although less common, require a slightly different surgical approach (FIG 6).

Soft tissue reconstruction
- Soft tissue reconstruction is just as important as skeletal reconstruction during limb-sparing surgery if a functional extremity is to be provided. Static and dynamic methods of soft tissue reconstruction and stabilization are used. Static methods rely on heavy nonabsorbable sutures, Dacron tapes, and Gore-Tex grafts. Dynamic methods rely on multiple muscle transfers and rotational muscle flaps.
OUTCOMES

- The types of tumors, anatomic locations, and types of shoulder girdle resections performed in 143 patients treated at the authors’ institutions from 1980 to 1998 are shown in FIGURE 7A. Experience in these patients with endoprosthetic reconstruction of the proximal humerus and scapula demonstrates that this is a reliable and durable technique of reconstruction (FIG 7B–E). Survival rates based on Kaplan–Meier analysis demonstrate a 9-year survival rate of 98% to 99% for proximal humeral replacements.
- No mechanical failures or dislocations occurred. Other groups have reported a significant incidence of dislocation following endoprosthetic reconstruction of the shoulder girdle, but this has not been our experience.
- The results shown in Figure 7 reflect the use of “dual suspension” (ie, both static and dynamic) or capsular reconstruction techniques and meticulous attention to soft tissue reconstruction.

FIG 6 • Example of a safe exposure of a clavicular tumor. The tumor arising from the distal clavicle is a solitary metastasis. The trapezius has been mobilized. The pectoralis major has been detached from the clavicle, and the deltoid has been detached from the acromion.

FIG 7 • A. Results of 134 shoulder girdle resections classified as type of resection versus function as measured by the Musculoskeletal Tumor Society (MSTS) scale. B. Composite photograph demonstrating head, body, and stem components for humeral resections. C. Proximal humerus modular replacement system options from Stryker Orthopedics. D. Proximal humerus and scapular prosthesis system. E. Plain radiograph following reconstruction using a constrained total scapula replacement.
REFERENCES

BACKGROUND

- Tumors arising from the scapula may become very large before diagnosis. Initially, they are often contained by muscle, which protects other tissues within the shoulder girdle. Patients with scapular tumors often present with pain, a mass, or both.
- Chondrosarcomas are the most common primary malignancy of the scapula in adults; in children the most common primary malignancy of the scapula is the round cell tumor Ewing sarcoma.
- Soft tissue tumors may involve the periscapular musculature and secondarily invade the scapula.
- The majority of shoulder girdle malignancies can be treated safely with limb-sparing surgeries in lieu of forequarter amputation. Indications for limb-sparing surgeries at this location include most high-grade bone sarcomas and some soft tissue sarcomas, depending on the tumor extension.
- Scapular tumors, like tumors of the proximal humerus, require careful preoperative staging, appropriate imaging studies, and a thorough knowledge of local anatomy. Selection of patients whose tumor does not involve the neurovascular bundle, thoracic outlet, or adjacent chest wall is required.
- It is rare when forequarter amputation is indicated. It is mainly reserved for patients with large, fungating tumors or infected tumors; those in whom limb-sparing resection has failed; and those with tumors invading the major nerves and vessels or the chest wall.
- Before 1970, most patients with high-grade sarcomas arising from the scapula were treated with a forequarter amputation. The first limb-sparing surgeries for high-grade sarcomas arising from the shoulder girdle were reported by Marcove et al in 1977. They reported that the Tikhoff-Linberg resection (FIG 1A) achieved local tumor control and survival similar to that achieved with a forequarter amputation. Most importantly, a functional hand and elbow were preserved. Limb-sparing surgery for patients with high-grade sarcomas in this location soon became standard treatment. Today, the majority of malignancies arising from or involving the scapula can be treated safely with limb-sparing surgery in lieu of a forequarter amputation.
- Shoulder motion and strength are nearly normal after a partial scapular resection (type II). However, there is significant loss of shoulder motion, predominantly shoulder abduction, after a total scapular resection (type III), alone or in conjunction with an extra-articular resection of the shoulder joint and proximal humerus (types IV and VI). Suspension of the proximal humerus and meticulous soft tissue reconstruction are the keys to providing shoulder stability and a functional extremity. If significant periscapular muscles remain after tumor resection (especially the trapezius and deltoid muscles), a total shoulder–scapula prosthesis may be the optimal reconstructive option (FIG 1B–F).

ANATOMY

- The local anatomy of a scapular tumor determines the type of scapular resection and subsequent reconstruction. Because these tumors become quite large before diagnosis, the surgeon should thoroughly inspect the chest wall, axillary vessels, proximal humerus and rotator cuff, and periscapular tissue to ensure that an appropriate procedure is planned.
- Sarcomas involving the glenoid, scapular neck, or supraspinatus musculature usually involve the glenohumeral joint and adjacent capsule. Therefore, an extra-articular resection through a combined anterior and posterior approach should be performed for tumors in this location.
- Large sarcomas of the scapula with soft tissue extension can involve the axillary vessels and the brachial plexus. Likewise, lymph nodes in the surrounding region should be evaluated to determine resectability.
- Suprascapular tumors are difficult to palpate on physical examination. Even sophisticated imaging modalities may incorrectly estimate the extent of these tumors. Tumors in this location can extend into the anterior and posterior triangles of the neck, making resection impossible except in the cases of palliation.

Key Anatomic Structures of the Scapular Region

Neurovascular Bundle

- The subclavian artery and vein join the cords of the brachial plexus as they pass underneath the clavicle. Beyond this point the nerves and vessels are surrounded by a fibrous sheath and can be considered one structure (ie, the neurovascular bundle).
- The suprascapular, dorsal scapular, and circumflex scapular vessels form an extensive vascular network around the posterior scapula. Each of these vessels must be ligated and transected to resect the scapula.

Axillary Vessels

- The axillary blood vessels are a continuation of the subclavian vessels as they pass underneath the clavicle and are called the brachial vessels once they pass the inferior border of the latissimus dorsi muscle. The axillary vessels pass medial and inferior to the coracoid process en route to the proximal humerus. They are surrounded by the brachial plexus throughout their entire course.
- The artery yields several branches during its course. The first branch arises as the artery passes over the first rib and is called the supreme thoracic artery. While the artery is deep to the pectoralis minor muscle, the thoracoacromial artery arises followed by the lateral thoracic artery and then the subscapular artery. The thoracoacromial artery gives rise to four branches, one of which supplies the area around the acromion.
- The subscapular artery divides into the thoracodorsal artery and the circumflex scapular artery that wraps around the lateral border of the scapula and tethers the axillary vessels to the scapula.
The anterior and posterior humeral circumflex arteries are the final branches of the axillary artery. They arise at the level of the inferior border of the subscapularis muscle and wrap circumferentially around the humeral neck. The axillary nerve runs with the posterior humeral circumflex vessels. The humeral circumflex vessels tether the neurovascular structures down to the proximal humerus and hence to any neoplasm that arises from this site. Early ligation of the circumflex vessels is a key maneuver in resection of scapular sarcomas because it permits mobilization of the axillary and brachial vessels and brachial plexus away from the tumor mass. The humeral head articulated with a polyethylene glenoid but was held in place only by muscle transfers and/or the use of a Gore-Tex sleeve. The second-generation of the scapula that was used in the late 1990s. This prosthesis offered fenestrations within the body of the scapula to allow the adjacent muscles to tenodese to give the recreated shoulder a new and more stable attachment. The proximal humeral component could, at this point, be mated with the Modular Replacement System for resections of the proximal humerus. This greatly increased the surgeon’s ability to reconstruct the proximal humerus and shoulder girdle. The third-generation scapular prosthesis that was developed by Howmedica, Inc. (now Stryker Orthopedics, Mahwah, NJ). This prosthesis is the first articulating scapular prosthesis. The bipolar proximal humeral head fits into the glenoid with a polyethylene retaining rim. Gross specimen after an extended Tikhoff-Linberg resection (type IV) that included the entire scapula, an extra-articular resection of the glenohumeral joint, and a portion of the proximal humerus with all of the muscles attached.

The suprascapular nerve arises from the superior trunk of the brachial plexus as it passes over the first rib. It travels posterior through the scapular notch deep to the transverse scapular ligament and supplies the supraspinatus and infraspinatus muscles.

Musculocutaneous and Axillary Nerves

These two nerves are often in close proximity to or in contact with tumors around the scapula. The musculocutaneous nerve is the first nerve to arise from the brachial plexus. It arises from the lateral cord just distal to the coracoid process, passes through the coracobrachialis, and runs between the brachialis and biceps. It should be preserved, if possible, to maintain elbow flexion.

The path of this nerve may vary extensively. It usually passes 2 to 7 cm inferior to the coracoid process. Tumors that arise from the scapula often displace this nerve anteriorly so that it occupies a position only 1 to 2 mm deep to the fascia. Care should be taken when opening the fascia overlying this nerve in the interval between the coracobrachialis and pectoralis minor muscles. The nerve should be identified and protected before releasing any muscles from the coracoid process because it can be easily injured during the resection.

The axillary nerve arises from the posterior cord of the brachial plexus and courses, along with the posterior humeral circumflex vessels, inferior to the distal border of the sub-
scapularis. It then passes between the teres major and minor muscles to innervate the deltoid muscle posteriorly. Tumors of the scapula usually displace and stretch the axillary nerve. The nerve is usually protected from the tumor by the subscapularis muscle.

**Radial Nerve**
- The radial nerve arises from the posterior cord of the brachial plexus. It passes anterior to the latissimus dorsi—teres major insertion on the humerus. Just distal to the latissimus dorsi insertion, the nerve courses into the posterior aspect of the arm, just lateral to the long head of the triceps, to run in the spiral groove between the medial and lateral heads of the triceps. The radial nerve must be isolated and protected before resection.

**Upper and Lower Subscapular Nerves and Thoracodorsal Nerve**
- The upper and lower subscapular nerves and the thoracodorsal nerve arise from the posterior cord of the brachial plexus near where the subscapular artery and humeral circumflex vessels arise from the axillary artery. The upper and lower subscapular nerves descend and enter directly into the substance of the subscapularis muscle. These nerves are routinely ligated during a scapulectomy. The thoracodorsal nerve passes with the thoracodorsal artery distally, directly anterior to the subscapularis muscle, to supply the latissimus dorsi muscle. The thoracodorsal nerve can usually be spared during most scapular resections.

**INDICATIONS**
- Limb-sparing surgery is indicated for most sarcomas of the scapula (FIG 2).

**Contraindications for Limb-Sparing Surgery for Scapula Tumors**
- Tumor invasion or encasement of the brachial plexus and axillary vessels. Involvement of a single nerve is not an absolute contraindication.
- Extensive chest wall involvement
- Relative contraindications include:
  - An inappropriately placed biopsy that has resulted in extensive contamination of the surrounding soft tissues
  - An active or previous infection

**FIG 2** • Indications for scapulectomy. **A.** MRI (T2-weighted signal) shows an extensive tumor arising from the coracoid and involving the scapula and the glenohumeral joint. **B.** Bone scan of a large giant cell tumor of the scapula with complete scapula involvement. This study revealed that there was minimal bone remaining. **C.** An extremely large periscapular soft tissue sarcoma arising adjacent to the scapula and scapular musculature and also involving the musculature of the proximal humerus. The initial procedures performed by Tikhoff and Linberg (reported in 1928) were resections for periscapular soft tissue sarcomas and not primary or metastatic bony sarcomas. **D.** Angiography of an osteosarcoma of the scapula before induction chemotherapy. There is marked vascularity and displacement of the axillary artery as well as the circumflex vessels.
A recurrent sarcoma that cannot be adequately resected without performing a forequarter amputation

Presence of a displaced pathological fracture secondary to a sarcoma, which does not heal after preoperative chemotherapy

**IMAGING AND OTHER STAGING STUDIES**

**Plain Radiography**
- Plain radiography is often the first imaging modality in the diagnosis of tumors of the scapula. This will reveal most bony and some soft tissue involvement. The scapula can sometimes be difficult to visualize on plain radiographs because it is often obscured by the rib cage. Mineralization shown on plain radiographs may help categorize a bone sarcoma as either an osteosarcoma or chondrosarcoma.

**Computed Tomography and Magnetic Resonance Imaging**
- CT and MRI are the most valuable means of determining the size and extent of extraosseous disease and its relationship to the axillary vessels, glenohumeral joint, and chest wall (see Fig 1C–E).
- CT is extremely important for evaluating the rib cage. Subtle erosion of the rib cage by an adjacent scapula tumor is better visualized on a CT scan than an MRI. It is the best test for detecting subtle mineralization within tumors as well as for detecting subtle areas of scapular involvement by adjacent soft tissue sarcomas. Contrast-enhanced CT is particularly helpful for determining the proximity of the tumor to the axillary and brachial vessels and brachial plexus.
- MRI is most accurate for determining intraosseous and extraosseous tumor extent as well as for detecting skip metastases. An appreciation of the intraosseous extent is necessary for determining the length of bone resection. The proximal humerus is usually transected approximately 2 to 3 cm distal to the intramedullary extent of the neoplasm as visualized on a T1-weighted MRI image. The proximity of the extraosseous component to the axillary and brachial vessels and brachial plexus can also be evaluated.

**Bone Scan**
- A bone scan is helpful in identifying bony involvement of the proximal humerus or ribs in the regional area, and metastatic disease in the entire bony skeleton. Since the scapula is very thin throughout the major part of its body, the bone scan may not be as accurate as when evaluating the long bones for tumor extent.
- The bone scan should be correlated with an MRI.
- It is also used to detect bony metastases.
- The bone scan can also be beneficial when evaluating the chest wall and proximal humerus for local extension.

**Angiography and Other Studies**
- Angiography can determine vascular involvement and reveal any anomalies of the vascular anatomy. Displacement of the axillary vessels is indicative of anterior tumor extension into the axilla.
- Axillary venography is performed if there is any clinical suspicion of brachial plexus involvement, such as nerve pain or distal edema, the hallmarks of invasion of the brachial plexus. Occluded axillary veins seen on venography correlate with brachial plexus infiltration.

**Biopsy**
- We recommend fine-needle or core biopsies be performed under CT or fluoroscopic guidance in an attempt to protect the neurovascular bundle.
- One puncture site is required. The needle is then reintroduced through that site at various angles to obtain cores from several different regions of the tumor.
- The biopsy site should be placed along the intended incision site of the resection (FIG 3).
- A posterior needle biopsy is recommended for tumors arising within the body of the scapula; the anterior approach should be avoided to minimize the risk of soft tissue contamination by tumor.

**Scapular Biopsies**
- Biopsies of the scapular body are more difficult to perform than biopsies of the proximal humerus. They should be performed along the lateral or axillary aspect of the scapula and not along the vertebral (medial) border or directly posterior through any potential skin flaps.
- The biopsy site should be along the intended incision site of the resection. A posterior needle biopsy is recommended for tumors arising within the body of the scapula; the anterior approach should be avoided.
Biopsies of tumors in the lateral aspect of the scapula or glenoid region should be performed along the lateral or axillary aspect of the posterior scapula directly through the infraspinatus or teres minor muscles.

SURGICAL MANAGEMENT

Preoperative Planning

- All imaging studies, particularly CT, MRI, angiography or venography, are reviewed before surgery to determine surgical resection type and feasibility.
- The patient is examined for distal edema and motor loss, which may indicate brachial plexus infiltration, an unresectable situation. The scapula should also move free from the chest wall, indicating that gross chest wall invasion is unlikely.
- Distal pulses are checked before surgery to ensure adequacy.
- The MRI and CT are reviewed to determine the proximity of the neoplasm to the brachial plexus and axillary vessels as well as to the chest wall. The soft tissue extent of the lesion is determined and a judgment is made about preservation of important periscapular muscles, essential for prosthetic reconstruction of the scapula. The arteriogram and venogram are also reviewed. Final determination of resectability and the use of a total scapula prosthesis, if the tumor is deemed resectable, is made intraoperatively.

Positioning

- The patient is placed in a lateral or semilateral position that permits access to the posterior aspect of the shoulder girdle all the way to the spinous processes. The affected extremity is prepared and draped free (FIG 4A).

Approach

- Most tumors of the scapula or periscapular soft tissues that require a total scapula resection are resected through a combined anterior and posterior approach. Most of these tumors have a large anterior soft tissue component that is juxtaposed to or that displaces the axillary vessels and brachial plexus.
- The anterior approach is crucial in these instances to explore and mobilize these structures away from the neoplasm so that a safe and adequate resection can be performed. The procedure uses both incision A (anterior extended deltopectoral incision) and incision B (posterior incision) of the utilitarian shoulder girdle incision (FIG 4B).
- Occasionally, a total scapula resection can be performed solely through a posterior approach for neoplasms that do not have an anterior soft tissue component. The surgeon must have a thorough knowledge of the course of axillary vessels, brachial plexus, and all of its branches to perform this procedure safely entirely through a posterior approach. If there are any uncertainties, then the procedure is most safely performed through a combined anterior and posterior approach.
- The axillary vessels and plexus are explored and mobilized anteriorly. This requires the pectoralis major to be detached and reflected for adequate exposure.
- The posterior incision permits the release of all muscles attaching to the scapula.
- The glenohumeral joint is removed extra-articularly. The osteotomy is performed below the level of the joint capsule.
- A scapular prosthesis is used if sufficient musculature remains; specifically, the deltoid, trapezius, rhomboids, and latissimus dorsi muscles are required for a prosthetic replacement.
- If there is not sufficient musculature after the resection, the remaining humerus is supported from the clavicle with Dacron tape (static suspension) and the conjoin tendon (dynamic suspension) and a pectoralis major rotational flap is also performed.
A utilitarian incision of the shoulder girdle. Occasionally a scapula resection can be performed completely through the posterior incision; however, if there is a large anterior tumor extension with displacement of the axillary vessels or an extraosseous soft tissue component, it is much safer to proceed with an anterior approach similar to the proximal humeral resections.

**EXTRA-ARTICULAR TOTAL SCAPULA AND HUMERAL HEAD RESECTION (TYPE IV): THE TIKHOFF-LINBERG PROCEDURE**

- This procedure is an extra-articular en bloc resection of the scapula, glenohumeral joint and humeral head, and distal clavicle.
- Incision: A utilitarian anteroposterior approach is used.
- A large posterior fasciocutaneous flap is developed.
- The rhomboids and trapezius muscles are released from the vertebral border of the scapula and the latissimus dorsi muscle is mobilized but not transected.
- If the tumor does not involve the deltoid or the trapezius, the muscles are preserved and are reflected off the scapular spine and acromion. The classic Tikhoff-Linberg resection does not preserve the deltoid or trapezius muscles.
- An osteotomy below the humeral head (i.e., a scapulectomy and extra-articular resection of the glenohumeral joint in conjunction with the scapula) is performed.
- Prosthetic reconstruction: If there are significant remaining muscles after a type IV shoulder girdle resection, then a scapula prosthesis is used (TECH FIG 1A).
- The scapula prosthesis is fenestrated to permit the muscles to tenodese to themselves. It has holes drilled along the axillary and vertebral borders for fixation with Dacron tapes.

- The scapula prosthesis is sutured first to the rhomboid muscles with Dacron tape, and then the latissimus dorsi is rotated over the body of the scapula prosthesis and sutured along the vertebral border.
- The humeral component is then inserted into the osteotomized proximal humerus. A Gore-Tex graft is used to reconstruct the capsular mechanism (TECH FIG 1B).
- The Gore-Tex is sutured to the proximal humerus prosthesis and the glenoid neck on the scapula prosthesis with 3-mm Dacron tape (TECH FIG 1C, D).
- The muscle closure consists of tenodesis of the deltoid to the trapezius and the latissimus over the rhomboids and to the serratus anterior muscles. The scapula prosthesis fits between the serratus anterior and the latissimus dorsi and rhomboid muscles.
- The deltoid and trapezius muscles have been preserved and are tenodesed together. The latissimus dorsi is rotated up to the lower border of the deltoid and to the rhomboid muscles.
- The latissimus is sutured to the holes in the axillary border of the scapula prosthesis and the adjacent musculature using Dacron tape and Ethibond sutures, respectively.
A scapula prosthesis in place with a proximal humeral prosthesis seated. The proximal humeral prosthesis is cemented in place before suturing the scapula to the chest wall. Technique of Gore-Tex capsule reconstruction. Reconstruction of an artificial capsule is essential for appropriate function and stability. Even though the third-generation scapular prosthesis offers a “snap-fit,” it can dislocate due to the continuous traction forces caused by the weight of the arm. Muscle reconstruction is completed by rotating the latissimus dorsi over to the rhomboids and the trapezius to the deltoid. All of these muscles are then tenodesed to themselves.

**TECH FIG 1 • A–D.**

**INTRA-ARTICULAR SCAPULAR RESECTION (TYPE III)**

- This resection is an intra-articular total scapulectomy. It is most commonly performed for soft tissue sarcomas that secondarily invade the scapula.
- A posterior and anterior incision is used, respectively.
- The posterior deltidoid is released from the acromion and scapular spine. The trapezius muscle is released and retracted.
- The rhomboid muscles are released starting at the inferior angle of the scapula.
- The tip is then elevated and the scapula is retracted away from the chest wall as muscle release continues medially, laterally, and then superiorly to permit visualization of the axilla and chest wall.
- The inferior tip of the scapula is rotated, and traction is applied with the arm abducted. The axillary contents are gently retracted.
- The neurovascular structures are approached from the back, unless the tumor has an anterior extraosseous component.
- The neurovascular structures are visualized as the scapula is retracted away from the chest wall.
- The infraspinatus and supraspinatus muscles are transected and the joint is entered.
- The anterior capsule and the subscapularis tendon are transected.
- The long head of the biceps is identified, tagged with suture, and divided.
- The acromioclavicular joint is entered and released or the distal portion of the clavicle is resected with the specimen.
- As the scapula is gently elevated, the short head of the biceps and the coracobrachialis and pectoralis minor muscles are released from the coracoid.
- The musculocutaneous nerve must be protected as it passes near the coracoid.
- The dual suspension technique using Dacron tape to suspend the proximal humerus from the clavicle can be used.
- Dacron tape (3-mm) is used to suspend the remaining humerus from the distal clavicle. The biceps, coracobrachialis, and triceps are reattached through drill holes in the distal clavicle.
- If the deltidoid muscle has been preserved, it is tenodesed anteriorly to the pectoralis major and trapezius muscles to further reconstruct the anterior aspect of the shoulder girdle.
- If adequate musculature remains, a total scapular prosthesis (see Tikhoff-Linberg Techniques) can be used to reconstruct the defect (TECH FIG 2).
- There are two major pairs of muscles that must be reconstructed: the trapezius muscle to the remaining portion of the deltidoid (this is tenodesed over the superior third of the prosthesis and glenohumeral joint) and then the rhomboid muscles to the prosthesis (covered by the transfer of the latissimus dorsi from its origin). This forms a nice pocket for the prosthesis to sit in between the latissimus dorsi and rhomboids and against the serratus anterior and chest wall.
**TECH FIG 2** • **A.** A scapula prosthesis in place with a proximal humeral prosthesis seated. The proximal humeral prosthesis is cemented in place before suturing the scapula to the chest wall. This allows for correct positioning and retroversion of the humeral component. **B.** Muscle reconstruction.

**PEARLS AND PITFALLS**

**Preoperative evaluation**
- MRI and CT are important for evaluating the proximity of the tumor to the neurovascular structures, chest wall invasion, and involvement of other key muscles around the scapula.

**Resection**
- Most total scapula resections (extra-articular and intra-articular) are performed through an anterior and posterior approach. This is the safest method when a large anterior soft tissue component exists.

**Exposure of neurovascular structures**
- The axillary vessels and brachial plexus are best exposed through an anterior approach (extended deltopectoral incision) that involves releasing the pectoralis major muscle from its humeral insertion and the coracobrachialis muscle and the short head of biceps and pectoralis minor muscle from their coracoid attachments.

**Posterior exposure and exploration**
- During the posterior portion of the resection it is important to preserve the periscapular muscles, which are crucial for prosthetic reconstruction, if possible. These muscles include the rhomboids, trapezius, deltoid, serratus anterior, and latissimus dorsi muscles. The axillary nerve must also be preserved.

**Prosthetic reconstruction**
- A small scapular component is used if it will facilitate better soft tissue coverage. The humeral component is chosen to allow for up to 2 cm of shortening of the extremity, which also facilitates soft tissue closure. A constrained total scapula is preferred. A Gore-Tex aortic graft is used to reconstruct the glenohumeral joint capsule. The scapula prosthesis is positioned as medial as possible (1 to 2 cm away from the spine) in a pocket between the rhomboids and serratus anterior muscles. The deltoid and trapezius muscles are retensioned as they are sutured to each other and to the prosthesis. The latissimus provides final coverage of the prosthesis. At the conclusion of the procedure, the entire prosthesis must be thoroughly covered with muscle.

**Postoperative care**
- The patient is kept in a brace for 6 weeks with the arm abducted 45 to 60 degrees and the elbow flexed 45 degrees.
POSTOPERATIVE CARE

- Epineural catheters are routinely used with a continuous bupivacaine (4 to 8 mL of 0.25% bupivacaine) infusion for 3 to 5 days.
- A special brace is recommended for 6 weeks postoperatively that will hold the arm in 45 to 60 degrees of abduction and the elbow flexed 45 degrees.
- Postoperatively, a sling is required for 4 to 6 weeks.
- In the immediate postoperative period the patient is instructed on motion exercises for the wrist and hand, and elbow flexion is encouraged within the confines of the sling.
- Neck motion and shoulder elevation exercises are instituted within 1 to 2 days after surgery.
- Once the incision has healed and the sutures are removed, at 2 to 4 weeks after surgery, pendulum exercises and gentle shoulder motion (flexion, extension, internal and external rotation) are done with the help of a family member or physical therapist.
- Elbow flexion, extension, supination, and pronation are also performed.
- Gentle strengthening is instituted once motion has returned, with the use of active motion and isometric exercises and light weights (2 to 10 pounds). At 12 weeks postoperatively, strengthening is initiated with Thera-Bands and other resistance exercises up to a 10-pound weight limit. Ultimately the patient is restricted to a 15- to 20-pound weight limit.
- Long-term weightlifting restrictions of less than 20 pounds are generally recommended.

OUTCOMES

- Prosthetic reconstruction of the scapula is a very reliable method of reconstruction after an intra-articular or extra-articular resection of the scapula.
- All patients have a painless, stable shoulder girdle and functional use of the hand and elbow. Rotation below the shoulder is preserved and ranges from –10 degrees of external rotation to T6 for internal rotation. Internal rotation, adduction, and extension strength are virtually normal.
- Active forward elevation and abduction (combined glenohumeral and scapulothoracic motion) range from 25 to 45 degrees and are grade 3 to 4 in terms of motor strength.
- Scapular protraction, retraction, and elevation are restored. These muscles participate in stabilizing the upper extremity when lifting objects. Patients can lift and carry objects up to 20 pounds. Most patients can perform push-ups. Upper extremity strength is better than when the shoulder is left flail or the remaining humerus is suspended from the clavicle. The Musculoskeletal Tumor Society Score for Upper Extremity Function ranges from 24 to 27 out of 30 points (80% to 90%) (FIG 5).
- Elbow, wrist, and grip strength are normal in all patients.
- All patients can reach the tops of their heads, opposite shoulder and armpit, and perineal area with their hand. There are no limitations in activities of daily living, including feeding, dressing, and personal hygiene. Lifting ability is normal with the arm at the side of the body. Cosmesis is acceptable.
- The major limitations have been with recreational activities and other activities that require the arm to be lifted above the shoulder level.

COMPLICATIONS

- Complications from a prior biopsy with extensive contamination of tissues may make a limb-sparing scapular resection inadvisable; therefore, an appropriately placed and performed biopsy must occur.

FIG 5 • A. Wound closure with good approximation and no tension. The perineural catheter is placed into the brachial plexus sheath before wound closure. This provides excellent postoperative anesthesia with minimal sensory deficit when 0.25% bupivacaine is used. B. Posterior view of a scapular prosthesis 13 years after reconstruction. Quite impressive symmetry has been attained when comparing the operative and contralateral sides. C. Push test, which is designed to test the rhomboids, serratus anterior, and latissimus dorsi. There is minimal winging of the scapula. In addition, the cosmetic effect of retaining the trapezius and the deltoid is impressive and evident. D,E. Patient performing a push-up. Great strength and stability of the shoulder girdle is seen here. This stability permits the patient to place the hand in three dimensions in space, the anatomic function of the normal shoulder girdle. Hand and elbow function is normal after these resections. It is extremely rare to have to resect any chords of the brachial plexus, which would result in loss of function of the distal portion of the arm.
■ If the deltoid muscle cannot be preserved, a scapular prosthesis may not be used.
■ Loss of function of activities above the level of the shoulder girdle should be anticipated: the goal of this surgery is to permit good use of the hand and elbow.
■ Skin necrosis occurs rarely. Dislocation of the reconstructed scapular mechanism is rare. In less than 5% of patients, glenohumeral dissociation occurs; it can usually be treated conservatively.

REFERENCES
Several types of resections are available for tumors of the shoulder girdle. The type of resection has a major influence on the choice of reconstruction. Resections can range from intra-articular resection of the proximal humerus to extra-articular resection of the humerus and scapula. Varying amounts of soft tissue also can be resected.

Functional recovery is related to preservation of the axillary nerve and the shoulder abductors. If the glenoid and abductor mechanism can be preserved, a “functional” arthroplasty can be performed.

Three types of arthroplasty are possible:
- A metallic humeral prosthesis can be implanted. The soft tissues (rotator cuff, capsule, and deltoid) cannot be sewn to the prosthesis effectively; therefore, limited function is achieved.
- The most common arthroplasty is an osteoarticular allograft, in which the upper humerus and joint are replaced with a frozen bone allograft. The soft tissues can be repaired to the graft, allowing significant functional recovery. This reconstruction, however, is associated with joint collapse, fracture, and secondary arthrosis.
- Another alternative is an allograft prosthetic composite. This procedure replaces the removed bone stock with an allograft but combines it with a metallic implant. It allows for soft tissue attachment to the allograft. The rotator cuff, deltoid, and capsule can be sewn to the soft tissues of the humeral allograft to maintain shoulder stability and improve shoulder active range of motion. The metallic device has potential to decrease long-term complications of the osteoarticular allograft.

A “functional” arthroplasty is possible only after an intra-articular resection with abductor preservation (FIG 1). It makes little sense to do an arthroplasty if neither the axillary nerve nor the abductors are available. In that case, other reconstructive options, including arthrodesis to a “spacer” metallic hemiarthroplasty, are more appropriate.

**INDICATIONS**

Intra-articular resection of the upper end of the humerus is indicated for benign but aggressive tumors, such as giant cell tumors or low-grade sarcomas, including chondrosarcoma. It also may be a reasonable choice for a sarcoma that has been pretreated with chemotherapy with a good response, including osteosarcoma, Ewing sarcoma, and malignant fibrous histiocytoma.

Appropriate imaging studies should be performed to ensure that the axillary nerve and abductor muscles, along with the rotator cuff, can be preserved.

If an intra-articular resection can be performed, the two most functional reconstructions to maintain shoulder stability and elevation include an allograft prosthetic composite arthroplasty and an osteoarticular allograft. Allograft prosthetic composite (APC) arthroplasty potentially avoids long-term complications of a frozen osteoarticular allograft, including fracture, joint collapse, and arthritis.

**ANATOMY**

- Tumors of the upper end of the humerus either are contained within the bone or have soft tissue extension. Soft tissue extension can be either very limited or extensive. The critical musculature of the upper end of the humerus includes the deltoid, innervated by the axillary nerve, and the rotator cuff, innervated by the suprascapular nerve (FIG 2).
- Other important muscles that must be detached from the upper humerus include the pectoralis major, latissimus dorsi, and teres major. The biceps and coracobrachialis, along with the musculocutaneous nerve, usually can be preserved by dissection and displacement. In the area of the coracoid, the brachial plexus nerves and the axillary artery and vein that become the brachial artery and vein must be dissected and protected.
- The axillary nerve and posterior humeral circumflex artery that pass through the quadrangular space before innervating the deltoid must be preserved to maintain abductor function. It also is important that the radial nerve be protected as it passes behind the humerus distal to the deltoid insertion. The subscapularis is detached away from the tumor and the lesser tuberosity. An arthrotomy then is performed to ensure there is no contamination of the shoulder joint by tumor, and then a circumferential arthrotomy is performed so that the upper end of the humerus can be detached once the bone is divided.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Patients with a tumor of the upper end of the humerus present with pain, loss of function, and a mass. Restricted range of motion typically occurs. Some patients actually present with neuropathic symptoms, including anesthesia or paresthesia involving nerves around the upper end of the humerus. Pain is the most common complaint. The pain is both activity-related and at night and usually requires analgesia. It is not uncommon for the patient to report some form of work-related or athletic injury at the time of presentation. Symptoms can last anywhere from days to months.
- Examination of the shoulder girdle includes range of motion, palpation, and a careful neurologic examination.
  - Range of motion can vary considerably but usually is diminished, especially abduction and flexion.
  - Palpation of the shoulder girdle and axilla may detect a mass or lymph node enlargement. It is important to note the location of the mass, especially if it extends into the axilla or in other areas of the shoulder girdle.
  - The neurologic examination includes examination of the axillary, radial, median, ulnar, and musculocutaneous nerves. Loss of any function of these nerves is a more ominous physical finding that often precludes an intra-articular resection of the upper humerus.
It also is important to check the circulation of the limb, starting with the axillary vessel, and examining the brachial vessel all the way to palpation of the radial artery, and to perform an Allen test to make sure there is an ulnar artery.

**IMAGING AND OTHER STAGING STUDIES**

**Imaging**

- For tumors of the upper end of the humerus, a series of imaging studies is performed to determine resectability and reconstruction.
- Radiographs, including anterior-posterior, external rotation lateral, and axillary lateral views, (FIG 3A,B), give important clues to the diagnosis. The plain radiograph is the most important initial diagnostic tool in coming up with a differential diagnosis of the type of neoplasm present. Three-dimensional imaging of the upper end of the humerus also is important.
- MRI is very useful for looking at the soft tissue extent of the tumor and its relation to the neurovascular bundle (FIG 3C).

MRI also is very helpful in determining the intramedullary extent of the tumor. This is particularly important for tumors such as chondrosarcoma, where the intramedullary extension goes well beyond the prediction by the plain radiograph.
- CT scans are better for defining bone involvement and may be helpful for some tumors.
- A bone scan is performed to determine whether there are skip lesions or involvement of other bones, suggesting polyostotic disease (FIG 3D). Multicentric osteosarcomas, for instance, are not terribly rare and can be detected by a technetium Tc 99m bone scan.
- Angiograms rarely are needed nowadays because of the availability of sophisticated three-dimensional imaging with infusion, such as MRI.
- If the plain radiograph suggests a sarcoma, then a CT scan of the chest for staging typically is performed before the biopsy so that the area is not distorted by general anesthesia and postanesthesia atelectasis.

**Biopsy**

- The biopsy of tumors of the upper end of the humerus is very important for ultimate resectability. The types of biopsies can be fine needle, for cytology; core needle, for histology; or open incisional.
- Placement of the biopsy is critical (FIG 4). The location usually is determined by the MRI scan and the presence of a soft tissue mass.
- Typically, the soft tissue component of the tumor is biopsied rather than going deep into the bone. The biopsy site should be located so that it can be resected along with the upper end of the humerus when the definitive operation is performed.
- The biopsy site for the soft tissue mass usually is reached by going through muscle. Because most surgical resections of the upper end of the humerus use the deltopectoral groove, this groove should be avoided during the biopsy. The surgeon should, instead, go through muscle, either the deltid or the pectoralis, on one side of the groove or the other.
- An adequate amount of tissue should be biopsied to obtain a correct diagnosis.
- The surgeon consults with the pathologist to determine the appropriate type of biopsy.
For most high-grade bone sarcomas, including osteosarcoma, Ewing sarcoma, and malignant fibrous histiocytoma, neoadjuvant chemotherapy is delivered prior to the primary resection. Neoadjuvant chemotherapy, if effective, causes tumor necrosis and margination. This makes limb salvage surgery, including an intra-articular resection of the humerus, a safer procedure.

**SURGICAL MANAGEMENT**

### Preoperative Planning

- Special equipment is necessary for intra-articular resection of the humerus followed by an allograft prosthetic composite arthroplasty. The most notable is the frozen bone allograft, along with a long-stemmed humeral prosthesis. The surgeon must contact a tissue bank, preferably one accredited by the American Association of Tissue Banks, to ensure that a frozen humerus is available before the procedure.
- The surgeon should receive a radiograph of the allograft for sizing purposes. For an allograft prosthetic composite arthroplasty, the allograft must be long enough to replace the resected bone and of an appropriate size to accept a long-stemmed humeral prosthetic hemiarthroplasty device. A template of that device with a sizing ruler is helpful in choosing the right allograft. The allograft radiograph also should have a sizing device.
- The humeral allograft must have a retained soft tissue cuff for repair. Some humeral allografts come without this cuff; this operation cannot be done with that type of allograft.
- The surgeon also should template the glenoid to ensure that the appropriate metallic hemiarthroplasty is available (FIG 5A). A long-stem metallic device usually is used. Sometimes the long stem, which passes through the allograft and into the host bone, provides for a rigid press fit, and no additional internal fixation is necessary. In other cases, the stem acts only as a partial fixation device that provides bending stability, but an additional dynamic compression or locking plate will be necessary to provide rotational stability at the junction between the allograft and the host bone junction (FIG 5B).

### Positioning

- Positioning of the patient on the operating table must allow for an extensile exposure of the shoulder girdle. A towel roll typically is placed behind the medial border of the scapula so that access to the front and the back of the shoulder is obtained and the scapula and glenoid are stabilized. The limb is then prepped and draped in a free manner so that it can be manipulated during the operative procedure.
Development of the Deltopectoral Groove

- The biopsy site must be excised as the deltopectoral groove is dissected. The cephalic vein is either retracted or suture ligated, and the groove is developed from the clavicle to the deltoid insertion. The dissection can be carried down between the insertions of the deltoid and the pectoralis major.
- The exposure can be extended distal to the lateral aspect of the biceps and brachialis if necessary (TECH FIG 1A).
- The musculocutaneous nerve and the biceps attachment to the coracoid are identified along with the nerves of the brachial plexus and vessels. These structures are dissected and retracted medially.

Soft Tissue Detachment

- The deltoid is detached from the deltoid tuberosity. The pectoralis major, teres major, and lattisimus dorsi muscles are detached from the humeral shaft. The rotator cuff tendons—subscapularis from the lesser tuberosity, and the supraspinatus, infraspinatus, and teres minor tendons from the greater tuberosity—are detached.
- The tendons are tagged with sutures for control and identification.
- The shaft of the humerus is isolated distal to the tumor.

Arthrotomy

- The anterior capsule is divided to determine tumor contamination of the joint. Then a circumferential arthrotomy is done until the humeral head can be dislocated. The inferior capsule must be released from the humeral neck, with the incision continued posteriorly. The axillary nerve can be protected by doing the release with the patient’s arm adducted and progressively rotated externally while incising the capsule off the humerus.

Bone Division

- The humerus is then divided with a power oscillating saw distal to the tumor. The cut must have a significant margin of normal bone and marrow distal to the tumor, as determined by the preoperative MRI scan and measurements.
- Chandler retractors are placed around the bone to ensure protection of the radial nerve (TECH FIG 1B).

Dissection of the Quadrilateral Space

- The axillary nerve and the posterior humeral circumflex vessels are identified in the quadrilateral space and dissected and preserved all the way to the deltoid muscle.

Removal of Specimen and Inspection of Margins

- The humeral specimen is removed after the remaining soft tissue attachments are cut. It usually is divided on the back table with a power oscillating saw, and gross inspection of margins is done (TECH FIG 1C). Microscopic margins also can be sent from the marrow space.

Reconstruction

- The reconstruction is performed with new gowns, gloves, and instruments. Before the resected specimen is removed, it is measured precisely. The allograft that has been procured is thawed in room-temperature lactated Ringer’s solution.

Preparation of the Allograft

- After thawing, the allograft is measured and the soft tissue cuff inspected. The humeral allograft is divided with a power oscillating saw at the appropriate position to replace all resected humerus.
- The articular portion of the humeral allograft is resected at the anatomic neck, from the greater to the lesser tuberosity, with a power saw. The allograft is then prepared on the back table for the metallic humeral device using the system chosen by the surgeon.
- The bone of the upper end of the humerus typically is opened with a high-speed, high-torque burr. The humeral canal is prepared with the appropriate cylindrical reamers. The humeral allograft is then opened with the appropriate-sized rasps or broaches to accept the humeral component.
**Techniques**

- Long-stemmed humeral components are available in 170-mm and 200-mm lengths. Depending on the length of the humeral resection, the humeral component length is chosen to allow the stem to extend at least 2 cortical diameters into the host bone. The diameter of the prosthetic stem is determined by the size of the allograft canal and the size of the host bone canal.
- The long-stemmed humeral device is then inserted through the allograft with the stem extending beyond the end of the allograft to engage the host bone canal. All shoulder prosthetic systems now offer various humeral head sizes, and have eccentric offsets to match anatomy and fine tune stability. A trial humeral head is placed on the stem. A trial seating of the humeral construct into the native canal and into the glenoid is performed to ensure humeral head size, height, and position within the glenoid. This also allows the surgeon to evaluate available rotator cuff length and soft tissue tension for repair around the prosthesis. If anything, a slightly larger humeral head is chosen.

**Preparation of the Host Bone**

- The diaphysis of the humeral host bone is cylindrically reamed to accept the allograft prosthetic composite implant. If a press fit is possible, then line-to-line reaming is performed. If not, the host bone is cylindrically reamed larger than the humeral stem but then will need to be additionally fixed with an internal fixation device.

**Trial Seating of the Device**

- The allograft prosthetic composite implant is inserted into the humeral host bone, and then the shoulder is reduced. The appropriate retroversion of the humeral head is selected.
Retroversion typically is 30 degrees from the epicondylar axis of the elbow to the humeral head. Another way to determine the correct rotation is to have the prosthetic humeral head pointing directly into the glenoid with the forearm in neutral rotation. The chosen retroversion position is marked at the junction between the allograft and the host bone.

Rotation should be evaluated to ensure stability, because retroversion is a variable in the proximal humerus.

**Cementing of the Allograft**

- On the back table the humeral allograft is washed and dried, and cement is mixed. The cement is pressurized into the humeral allograft, and then the metallic prosthesis is inserted cephalad to caudal through the allograft with the stem extending beyond the bone cut. It is important to clean the stem of all cement while it is doughy so that the cement does not interfere with insertion into the humeral host bone.

- The cemented allograft prosthesis composite then is either press fit into the host bone or simply inserted, followed by internal fixation. Obviously, the more proximal the resection, the more native humeral canal is available, and the easier it is to obtain press-fit stability.

- The appropriate rotation for the 30 degrees of humeral retroversion is critical. If adequate rotational stability is not available at the allograft–host bone junction, a lateral dynamic compression plate or locking plate is used, applying the appropriate principles.

- If screws are used, they can be either unicortical or bicortical with compression principles at the allograft–host bone junction. Locking plates also allow for cerclage wire, which can be inserted around the humerus for additional fixation. It is important not to place unfilled screw holes in the allograft, because they act as stress risers and areas of revascularization that could lead to fracture.

**Soft Tissue Repair**

- The allograft prosthetic composite arthroplasty then is reduced into the shoulder joint, and a circumferential repair of soft tissue is performed. Nonabsorbable suture, of at least no. 2 or no. 5, is used for the repair. The capsule is repaired to the capsule of the allograft circumferentially in an interrupted manner.

- The supraspinatus, infraspinatus, and teres minor tendons are reattached to their corresponding tendons with nonabsorbable suture. It is easiest to begin the rotator cuff repair posteriorly and proceed to the supraspinatus and then the subscapularis.

- Subscapularis tendon repair is critical for anterior stability. The native capsule and rotator cuff tendons should be repaired to their corresponding allograft structures. The deltoid is reattached to the deltoid tendon on the allograft, and, if possible, the pectoralis major is reattached to its tendon.

- Using the appropriate tension for this repair is important. Placing the shoulder and arm in the “salute” position and then tying the tendons helps in obtaining the correct tension. Based on the compression obtained at the allograft–host bone junction, the surgeon can elegantly graft this junction with a bone graft substitute or even an autogenous graft (TECH FIG 1D).

**Closure and Immobilization**

- The wound is then closed over drainage tubes in multiple layers, and the shoulder is placed in an abduction shoulder brace, with the shoulder abducted 30 degrees and internally rotated 45 degrees.

---

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Selecting an allograft with a retained soft tissue envelope is critical for success.</th>
<th>Some grafts come without these tendons, making this procedure impossible.</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is important to clean the prosthetic stem of all cement after it has been inserted through the allograft.</td>
<td>This cement can impede implantation into the host bone.</td>
</tr>
<tr>
<td>A trial reduction of the allograft prosthetic composite, marking rotation, is critical for function and shoulder stability.</td>
<td>Usually 30 degrees of retroversion is marked before internal fixation of the allograft to the host bone to prevent instability from component malposition.</td>
</tr>
<tr>
<td>When placing a lateral plate to stabilize the allograft prosthetic composite to the host bone, drilling through the cement can be challenging.</td>
<td>It is important to angle the screws away from the prosthetic stem when using a dynamic compression plate. This is not possible with a locking plate. Therefore, cerclage wires or unicortical screws are used with a locking plate around the stem.</td>
</tr>
<tr>
<td>No unfilled holes should be left in the allograft.</td>
<td>Such holes can lead to fracture.</td>
</tr>
</tbody>
</table>

---

**COMPLICATIONS**

- The risk of infection is 1% to 2% and the risk of nonunion is 10% to 20%.
- The most common problem is subluxation of the gleno-humeral joint, depending on the amount of soft tissue available for reconstruction.

**POSTOPERATIVE CARE**

- The patient is maintained in an abduction orthosis for the early postoperative period. The Hemovac drain is discontinued, and the patient is discharged.
- Tendon healing and repair is allowed for approximately 4 weeks, after which gentle shoulder exercises are begun. At
first, pendulum exercises of the shoulder are performed, with some gentle passive and passive-assisted exercises to follow.

- Approximately 6 weeks postoperatively, gentle active exercises are initiated, but no resistance is applied to the soft tissue repair for 2 months. At that point, more aggressive range-of-motion and muscle exercises are started to maximize the functional recovery.

- Serial radiographs are performed to check for healing at the allograft–host bone junction. Typically, union at this junction occurs somewhere between 3 months and 12 months postoperatively. If a nonunion develops and 1 year has passed, then autogenous grafting is performed to augment the healing.

OUTCOMES

- Although allograft prosthetic composite arthroplasty is one reconstructive option available for most tumor surgeons, little has been published on this operation.6

- In 2003, Dudkiewicz et al4 reported on 11 patients treated with an allograft prosthetic composite arthroplasty of the upper humerus. All patients were treated for an osteosarcoma, most of which were stage IIB. At the most recent follow-up, 10 of the 11 patients were alive, and they reported good function of the upper extremity. The function was not detailed in terms of range of motion, muscle strength, or joint stability. The authors reported several complications, including nonunion at the allograft–host bone junction and wound infections.

- Jensen and Johnston7 reported on four patients with an allograft prosthetic composite using the Neer prosthesis and found excellent outcomes.

- In 2005, Kassab et al8 reported on three patients with an allograft prosthetic composite of the humerus. The Musculoskeletal Tumor Society (MSTS) functional score for this small series was 76%.

- Damron et al2 functionally evaluated shoulder reconstruction and concluded that the osteoarticular allograft procedure had the best outcomes if the abductors of the shoulder are preserved.

- O’Connor, Sim, and Chao9 reported on one of the largest series of upper humerus reconstructions (57 patients). An osteoarticular allograft, which was used in eight patients, had the best functional outcomes in their cohort. Four of eight of these grafts fractured. Other authors reported outcomes with osteoarticular allograft reconstruction after an intra-articular resection.1,10

- DeGroot et al3 reported a 37% allograft fracture rate and recommended the osteoarticular allograft be filled with cement to decrease this problem. Some of the fractured allografts were salvaged with an allograft prosthetic composite arthroplasty.

- Wang et al11 reported osteoarticular allograft fractures in 14 of their 20 patients.

- In 1999, Getty et al5 reported on 16 patients who had undergone intra-articular resection of the proximal humerus with an osteoarticular allograft reconstruction. The MSTS functional evaluation showed a mean recovery of 70%. Complications reported in this series included four fractures of the allograft and one infection. Survivorship of the frozen allograft at 5 years was 68%. Other complications reported included glenohumeral instability in three patients and dislocation of the glenohumeral joint in eight patients. The authors concluded that an osteoarticular allograft has a high complication rate, and were reluctant to continue to perform this procedure. Whether an allograft prosthetic composite arthroplasty will improve these outcomes remains to be seen.

- At this time, the advantage of allograft prosthetic composite arthroplasty over osteoarticular allograft arthroplasty remains questionable.

REFERENCES

BACKGROUND

- The proximal humerus is a common site for both primary osteosarcomas and chondrosarcomas. Metastatic tumors occasionally involve the shoulder girdle and often are treated using the same resection and reconstruction techniques (FIG 1A).
- Limb-sparing resection of the proximal humerus is challenging. Despite their complexity, these resections can be performed in about 95% of patients with high- or low-grade sarcomas. Amputations rarely are required.
- Endoprosthetic reconstruction is the most common technique for reconstructing large proximal humeral defects. It is used following both intra-articular (type I) and extra-articular (type V) resections. This type of reconstruction is combined with local muscle transfers to create shoulder stability, cover the prosthesis, and provide a functional elbow, wrist, and hand (FIG 1B).
- The surgical and anatomic considerations of limb-sparing procedures of the proximal humerus and the specific surgical techniques for type I and type V resection and reconstruction are described in this chapter. Total humeral replacement is described briefly.
- The proximal humerus is one of the most common sites for high-grade malignant bone tumors in the adult, and it is the third most common site for osteosarcoma.1 Tumors in this location tend to have a significant extrasosseous component. The proximal humerus also may be involved by metastatic cancer (especially renal cell carcinoma) and secondarily by soft tissue sarcomas, which require a resection similar to that used for primary bone sarcomas with extrasosseous extension.
- About 95% of patients with tumors of the shoulder girdle can be treated with limb-sparing resections.
- The Tikhoff–Linberg resection and its modifications are limb-sparing surgical options for bone and soft tissue tumors in and around the proximal humerus and shoulder girdle. Portions of the scapula, clavicle, and proximal humerus are resected in conjunction with all muscles inserting onto and originating from the involved bones. Careful preoperative staging and selection of patients whose tumor does not encase the neurovascular bundle or invade the chest wall are required.
- A classification system for resection of tumors in this location is described in Figure 1B. The most common procedure for high-grade sarcomas of the proximal humerus, type VB, is described.
- We do not recommend type I resection for high-grade tumors, due to the increased risk of local recurrence.
- Optimal function is achieved with muscle transfers and skeletal reconstruction. A prosthesis is used to maintain length and stabilize the shoulder and distal humerus following resection. A stable shoulder with normal function of the elbow, wrist, and hand should be achieved following most shoulder girdle resections and reconstructions performed using the techniques described.

INDICATIONS

- Indications for limb-sparing procedures of the proximal humerus and shoulder girdle include high-grade and some low-grade bone sarcomas, as well as some soft tissue sarcomas that secondarily invade bone.
- Occasionally, solitary metastatic carcinomas to the proximal humerus are best treated by a wide excision (ie, type I resection).
- The decision to proceed with limb-sparing surgery is based on the location of the tumor and a thorough understanding of its natural history. Recently, we have treated patients with pathologic fractures with induction chemotherapy, immobilization, and limb-sparing surgery if there is a good clinical response and fracture healing.
- Absolute contraindications include tumor involvement of the neurovascular bundle or extensive invasion of the adjacent chest wall (FIG 2).
- Relative contraindications include chest wall extension, tumor contamination of the operative site from hematoma following a poorly performed biopsy or pathologic fracture, a previous infection, or lymph node involvement.

UNIQUE ANATOMIC CONSIDERATIONS

- Resection and reconstruction of the proximal humerus and shoulder girdle is a technically demanding procedure.
- The local anatomy of the tumor often determines the extent of the operation required. The surgeon should be experienced with all aspects of shoulder girdle anatomy and the unique considerations it may present.

Proximal Humerus

- Malignant tumors often present with large soft tissue components (stage IIB) underneath the deltoid that extend medially and displace the subscapularis and coracobrachialis muscles.2 Pericapsular and rotator cuff involvement occur early and must be evaluated.

Glenohumeral Joint

- The shoulder joint appears to be more prone to intra-articular or pericapsular involvement by high-grade bone sarcomas than are other joints.
- Four basic mechanisms exist for tumor spread: direct capsular extension; tumor extension along the long head of the biceps tendon; fracture hematoma from a pathologic fracture; and poorly planned biopsy.
- These mechanisms place patients undergoing intra-articular resections for high-grade sarcomas at greater risk for local recurrence than those undergoing extra-articular resections.
FIG 1 • A. Anatomy of the shoulder girdle. B. Surgical classification of shoulder girdle resections. This system was initially proposed by Malawer in 1991. Types I through III are intra-articular resections, whereas types IV through VI are extra-articular.

A, abductor muscles retained; B, abductor muscles resected.

Chapter 10 PROXIMAL HUMERUS RESECTION WITH ENDOPROSTHETIC REPLACEMENT

Musculocutaneous and Axillary Nerves
- The musculocutaneous and axillary nerves often are in close proximity or contact with tumors around the proximal humerus.
- The musculocutaneous nerve is the first nerve that leaves between the teres major and minor to innervate the deltoid muscle posteriorly.
- Tumors of the proximal humerus are likely to involve the axillary nerve as it passes adjacent to the inferior aspect of the humeral neck, just distal to the joint. Therefore, the axillary nerve and deltoid almost always are sacrificed during proximal humerus resections.

Radial Nerve
- The radial nerve comes off the posterior cord of the plexus and continues anterior to the latissimus dorsi and teres major. Just distal to the teres major, the nerve courses into the posterior aspect of the arm to run between the medial and long head of the triceps.
- Although most sarcomas of the proximal humerus do not involve the radial nerve, it must be isolated and protected prior to resection.

Axillary and Brachial Arteries
- The axillary artery is a continuation of the subclavian artery, and is called the brachial artery after it passes the inferior border of the axilla. The axillary vessels are surrounded by the three cords of the brachial plexus and brachial plexus. The axillary artery typically leaves the lateral cord just distal to the coracoid process, passes through the coracobrachialis, and runs between the brachialis and biceps. Preservation of the musculocutaneous nerve and short head of the biceps muscle is important to ensure normal elbow function.
- The path of this nerve may vary extensively (within 6–8 cm of the coracoid) and should be identified before any resection is performed, because the nerve can easily be injured.
- The axillary nerve arises from the posterior cord and courses, along with the circumflex vessels, inferior to the distal border of the subscapularis. It then is tethered to the proximal humerus by the anterior and posterior circumflex vessels. Early ligation of the circumflex vessels is a key maneuver in resection of proximal humeral sarcomas, because it allows the entire axillary artery and vein to fall away from the tumor mass.
- Occasionally, anatomic variability in the location of the branches of the nerve may lead to difficulty in identification and exploration if the variation has not previously been recognized. A preoperative angiogram is helpful in determining vascular displacement and anatomic variability.
- Final determination of tumor resectability is made at surgery. Early exploration of the neurovascular structures is performed following division of the pectoralis major muscle. This approach does not jeopardize subsequent formation of an anterior flap in patients who require forequarter amputation.

IMAGING AND OTHER STAGING STUDIES
- Appropriate imaging studies are key to successful resections of tumors of the proximal humerus and shoulder girdle (Fig 3A–E).

Therefore, it often is necessary to perform an extra-articular resection for high-grade bone sarcomas of the proximal humerus or scapula.

Neurovascular Bundle
- The subclavian artery and vein join the cords of the brachial plexus as they pass underneath the clavicle.
- Beyond this point, the nerves and vessels can be considered as one structure (ie, the neurovascular bundle). Large tumors involving the upper scapula, clavicle, and proximal humerus may displace the infraclavicular components of the plexus and axillary vessels.

Fig 2 • A. Schematic drawing showing a resectable tumor. The tumor is compressing and displacing the neurovascular bundle; however, there is no invasion or encasement. This situation commonly arises in the treatment of a sarcoma. An angiogram or venogram would show patency of the axillary vessels. B. Schematic drawing showing an unresectable tumor. The tumor is infiltrating the neurovascular structures and obliterating the axillary vein. Venography would show a non-patent axillary vein, whereas angiography would show a displaced but patent artery. (Courtesy of Martin M. Malawer.)
FIG 3 • A. Osteosarcoma of the proximal humerus showing typical intramedullary ossification and an extraosseous soft tissue ossification. In general, a sarcoma of the proximal humerus involves one third to one half of the length of the bone. This length of bone must be resected in addition to the adjacent joint. B. Bone scan showing the amount of uptake corresponding to the radiograph shown in (A). In general, a resection is performed 3 to 4 cm distal to the area of uptake, as correlated with findings on an MRI scan, which is the imaging modality that best shows intramedullary extension of the tumor. C. Plain radiograph showing a radiolucent tumor of the proximal humerus. A needle biopsy confirmed that this was a giant cell tumor. CT shows minute fractures through the cortices, and the tumor was determined to be a stage III GCT. This patient was treated by primary resection of the proximal humerus. The procedure was classified as a type IA resection, and the humerus was reconstructed with an endoprosthetic modular prosthesis. Intra-articular resections are unusual for the proximal humerus, because most tumors are high grade with soft tissue components. D, E. Postoperative imaging studies are useful to determine response to induction chemotherapy. D. The CT scan shows complete reossification of a lesion of the proximal humerus without any major soft tissue component. The plain radiograph shows healing at the site of a former pathological fracture without any evidence of extraosseous formation. In general, CT scanning and plain radiography are reliable to demonstrate a good clinical response. E. Osteosarcoma of the proximal humerus, which does not show any evidence of an extraosseous component or any joint involvement. F. Schematic diagram of biopsy technique for tumors of the proximal humerus. The biopsy should be performed through the anterior one third of the deltoid, and the deltopectoral groove must be avoided. A core biopsy is recommended. (F: Reprinted with permission from Bickels J, Jelinek JS, Shmookler BM. Biopsy of musculoskeletal tumors. Current concepts. Clin Orthop Relat Res 1999;368:212–219.)
The most useful imaging studies are plain radiography, CT scans, MRI, arteriography, and bone scan. Venography occasionally is required.

**Computed Tomography**
- CT is most useful for evaluating cortical bone changes and is considered complementary to MRI in evaluating the chest wall, clavicle, and axilla for tumor extension (FIG 3D).

**Magnetic Resonance Imaging**
- MRI is useful to identify intraosseous tumor extent, which is necessary for determining the length of bone resection. It is the best imaging modality for evaluation of soft tissue tumor involvement, especially around the glenohumeral joint, suprascapular region, and chest wall.

**Bone Scintigraphy**
- Bone scintigraphy is used to determine the intraosseous tumor extent and to detect metastases (FIG 3B).

**Angiography**
- Angiography is extremely useful for evaluation of tumor vascularity and tumor response to neoadjuvant chemotherapy. It also is essential for determining the relation of the brachial vessels to the tumor or the presence of anatomic anomalies. A brachial venogram also may be necessary if there is evidence of distal venous obstruction suggesting a tumor thrombus.
- Repeat staging studies are typically performed following surgical resection to determine patient response to chemotherapy.

**Biopsy**
- Needle or incisional biopsies of tumors of the proximal humerus should be performed through the anterior one third of the deltid muscle, not through the deltoid interval (FIG 3F).
- A biopsy through the anterior one third of the deltoid results in a limited hematoma that is confined by the deltoid muscle.
- This portion of the muscle and any biopsy hematoma are easily removed at the definitive resection. A biopsy taken through the deltoid interval will contaminate the major pectoralis muscle, which is necessary for reconstruction, increase the risk of hematoma spread along the axillary vessels to the chest wall, and make a local resection difficult, if not impossible.
- If an open biopsy is required, a short longitudinal incision should be made just lateral to the deltoid interval. The dissection should be directly into the deltoid muscle and proximal humerus.
- The bone should be exposed lateral to the long head of the biceps. No flaps should be developed, and the glenohumeral joint should not be entered.

**Resection Techniques**
- It is important to be extremely familiar with shoulder girdle anatomy and axillary and vascular structures.
- A utilitarian incision is used (TECH FIG 1A–D). The anterior component is an extended deltopectoral incision that exposes the pectoralis major muscle, which is then released and retracted toward the chest wall. This exposes the axillary contents and permits exploration and safe dissection of the vascular structures and infraclavicular plexus (TECH FIG 1E).
- An extra-articular resection is performed. Thus, the axillary nerve is identified and transected. The musculocutaneous nerve is identified and preserved (TECH FIG 1F). The radial nerve, which crosses the humerus posteriorly at the level of the deltoid insertion, is preserved.

**Endoprosthetic Replacement of the Proximal Humerus**
- The Modular Replacement System (MRS), which is used for reconstruction of the shoulder girdle, is shown. Results of the MRS are predictable and successful, and the device is used for both intra- and extra-articular resections.
- Endoprosthetic reconstruction following tumor resection entails the following steps:
  1. Fixation of the endoprosthesis in the remaining distal humerus.
  2. Fixation and stabilization of the prosthetic humeral head to the scapula to provide a stable shoulder joint.
  3. Soft tissue reconstruction to cover the prosthesis completely and optimize postoperative function.

**Dual Suspension Technique**
- A dual suspension (ie, static and dynamic) technique is used to create shoulder stability (TECH FIG 4). In the static reconstruction, drill holes are made in the distal...
TECH FIG 1 • A. Utilitarian incision used by the authors for exposure of the proximal humerus, scapula, or shoulder girdle. B. The utilitarian approach is used for extra-articular resections of the shoulder girdle. Exposure of the anterior aspect and the axillary space routinely is performed by releasing two layers of muscle. The pectoralis major is released from its insertion onto the proximal humerus and reflected back onto the chest wall. This step exposes the entire axillary area, including the infraclavicular portion of the brachial plexus, the axillary artery and vein, the coracoid and scapula, and the corresponding muscles. C. Following reflection of the pectoralis major, the second muscle layer must be developed and detached and retracted. This layer consists of the pectoralis minor and the short head of the biceps. Each of these muscles has attachments to the coracoid. It is important to dissect the musculocutaneous nerve from around the coracoid as it enters the short head of the biceps to avoid nerve injury. These muscles are detached and retracted medially and distally, respectively, to expose the entire axillary fascia, which then can be opened to accomplish the following dissection. It is important to dissect the musculocutaneous nerve from around the coracoid as it enters the short head of the biceps. (continued)
TECH FIG 1 • (continued) D. Position and incision. Antibiotics are begun preoperatively and continued until suction drains are removed. The patient is placed in an anterolateral position that allows some mobility of the upper torso. A Foley catheter is placed in the bladder, and an intravenous line is secured in the opposite extremity. The skin is prepared down to the level of the operating table, to the umbilicus and cranially past the hairline. The incision starts over the junction of the inner and middle thirds of the clavicle. It continues along the deltopectoral groove and then down the arm over the medial border of the biceps muscle. The biopsy site is excised, leaving a 3-cm margin of normal skin. The posterior incision is not opened until the anterior dissection is complete. E. Exploration of the axilla to determine resectability. The skin is opened through the superficial fascia, but care is taken to preserve the deep fascia of muscles. Anteriorly, the skin flap is dissected off the pectoralis major muscle to expose its distal third, and the short head of the biceps muscle is uncovered. The pectoralis major muscle overlying the axilla is dissected free of axillary fat so that its insertion on the humerus can be visualized; this muscle is divided just proximal to its tendinous insertion on the humerus, and the portion of the muscle remaining with the patient is tagged with a suture. Next, the axillary sheath is identified and the coracoid process visualized. To expose the axillary sheath along its full extent, the pectoralis minor short head of the biceps and coracobrachialis muscles are divided at their insertion on the coracoid process. All proximal muscles are tagged with sutures for later identification and use in the reconstruction. (continued)
**TECH FIG 1 • (continued)**

**F.** Dissection of the neurovascular bundle. Vessel loops are passed around the neurovascular bundle near the proximal and distal ends of the dissection. Medial traction on the neurovascular bundle allows visualization of the axillary nerve, posterior circumflex artery, and anterior circumflex artery. These structures are ligated and then divided. If the neurovascular bundle is found to be free of tumor extension, dissection for the limb salvage procedure proceeds. The musculocutaneous nerve is isolated and carefully preserved, although this nerve sometimes must be sacrificed to preserve tumor-free margins. Its loss results in lack of elbow flexion following surgery. The deep fascia between the short and long heads of the biceps muscle is divided below the tumor mass to separate the short and long heads of the biceps maximally, permitting easy visualization of the musculocutaneous nerve. The radial nerve is identified at the lower border of the latissimus dorsi muscle, passing around and behind the humerus into the triceps muscle group. The profunda brachialis artery that accompanies this nerve may be ligated. The radial nerve passes posterior to the humerus in its midportion (spiral groove). To dissect it free of the bone, a finger is passed around the humerus to bluntly move the nerve away from the bone. **G.** Division of the muscle groups anteriorly to expose the neck of the scapula. The short and long heads of the biceps are widely separated to expose the humerus. The site for the humeral osteotomy is determined, and then the long head of the biceps and brachialis muscles are transected at this level. The inferior border of the latissimus dorsi muscle is identified, and a fascial incision is made that allows one to pass a finger behind the latissimus dorsi and teres major muscles several centimeters from their insertion into the humerus or scapula. The latissimus dorsi and teres major muscles are transected using electrocautery. External rotation of the humerus exposes the subscapularis muscle, which is transected at the level of the coracoid process. Care must be taken not to enter the joint space. The portions of these muscles that are not to be removed during the resection are tagged for future reconstruction. By transecting these muscles the anterior portion of the neck of the scapula has been exposed. (**C,D,F,G:** Courtesy of Martin M. Malawer; **E:** Reprinted with permission from Malawer MM. Tumors of the shoulder girdle. Technique of resection and description of a surgical classification. Orthop Clin North Am 1991;22:7–35.)
Chapter 10 PROXIMAL HUMERUS RESECTION WITH ENDOPROSTHETIC REPLACEMENT

**TECH FIG 2** Various methods used for reconstruction of the proximal humerus following resection for high-grade sarcomas between 1960 and 1990. **A.** The first attempts to regain length used the Kirschner rod fixated into the distal humerus and sutured to the clavicle with wires or heavy sutures. This failed, and often caused proximal protrusion through the skin. **B.** The long-stemmed Neer prosthesis was developed to re-establish humerus length and to avoid the problem of proximal migration. **C.** The first custom prosthesis, developed in the mid-1970s to reconstruct the proximal humerus in an anatomic format. This had both external phlanges and a small stem. **D.** The Modular Replacement System (Stryker Orthopedics, Mahwah, NJ) is the type of prosthesis currently used. A modular replacement system has a head, body, and stem of various diameters and lengths so that it can be modified intraoperatively for each patient’s anatomic needs. No waiting period for a custom prosthesis to be made is required, as formerly was the situation. The first proximal humerus prosthesis of the MRS type was implanted in Washington, DC in 1988. (**A–D:** Courtesy of Martin M. Malawer.)

Soft Tissue Reconstruction

- The remaining muscle groups are tenodesed to the pectoralis major and osteomized border of the scapula with Dacron tape. This mechanism offers dynamic support, assists in the suspension of the prosthesis, and provides soft tissue coverage. Soft tissue coverage is essential to cover the prosthesis and prevent skin problems and secondary infections.

**Type I Resection**

- Intra-articular resection of the proximal humerus is indicated for low-grade sarcomas or high-grade sarcomas confined to the bone without extraosseous extension (stage IIA; **TECH FIG 5A,B**).
- The abductor mechanism and axillary nerve usually are preserved. This procedure is not recommended for high-grade sarcomas with soft tissue extension.
- The prosthesis is suspended from the glenoid with a Gore-Tex graft, which is reinforced by any remaining capsule (**TECH FIG 5C–E**).
- Anterior utilitarian shoulder incision is not required. The posterior component is not used.
TECH FIG 3 • A. Securing the prosthesis. If a prosthesis is to be used, 5 to 7 cm of distal humerus must be preserved. A power reamer is used to widen the medullary canal of the remaining humerus; it is reamed until it is 1 mm larger than the stem of the prosthesis. The bony specimen is measured so that a prosthesis of appropriate length is used. Methylmethacrylate cement is injected into the medullary canal, and the prosthesis is positioned. The head of the prosthesis should be oriented so that it lies anterior to the transected portion of scapula while the arm is in neutral position. The radial nerve should be positioned anterior to the prosthesis so it does not become entrapped between muscle and prosthesis during the reconstruction. Drill holes are made through the scapula at the level of its spine, and also through the distal portion of the transected clavicle. The head of the prosthesis is secured by 3-mm Dacron tape to the remaining portion of the scapula so that the prosthesis is suspended mediolaterally, providing horizontal stability. It is suspended in a cranio-caudal direction by a second 3-mm Dacron tape from the end of the clavicle, for vertical stability. B. Reconstruction. The pectoralis minor muscle is sutured to the subscapularis muscle over the neurovascular bundle to protect it from the prosthesis. The pectoralis major muscle is closed over the prosthesis to the cut edge of the scapula and secured with nonabsorbable sutures through drill holes. Following this the trapezius, supraspinatus, infraspinatus, and teres minor muscles are secured to the superior and lateral borders of the transected pectoralis major muscle. The teres major and latissimus dorsi muscles are secured to the inferior border of the pectoralis major muscle. The tendinous portion of the short head of the biceps is secured anteriorly under appropriate tension to the remaining clavicle. The long head of the biceps and the brachialis muscles are sutured to the short head of the biceps muscle under appropriate tension so that these two muscles can work through the short biceps tendon. The remaining triceps muscle is secured anteriorly along the lateral border of the biceps to cover the lower and lateral portion of the shaft of the prosthesis. Ideally, when the proximal and distal muscular reconstruction is complete the prosthesis is covered in its entirety by muscle. C. Closure. Large-bore suction catheter drainage is secured. The superficial fascia is closed with absorbable suture, and the skin is closed with clips. Povidone-iodine ointment is applied to the incision along with a dry sterile dressing. A sling and swathe are applied in the operating room. (A,B: Reprinted with permission from Rubert CK, Malawer MM, Kellar KL. Modular endoprosthetic replacement of the proximal humerus: Indications, surgical technique, and results. Semin Arthroplasty 1999;10:142–153. C: Courtesy of Martin M. Malawer.)
The axillary nerve is explored early and preserved. If there is tumor extension to the nerve, then the procedure is converted to a type V resection.

The humeral prosthesis is suspended from the glenoid labrum with 32-mm Gore-Tex®. The remaining capsule is sutured to the new Gore-Tex® capsule. This step avoids glenohumeral joint subluxation and dislocation.

**Total Humeral Resection and Prosthetic Reconstruction**

Total humeral replacement is unusual but is indicated when the tumor involves a large portion of the diaphysis, such as in Ewing sarcoma, or when an extremely short segment of distal humerus remains following adequate tumor resection.

The surgical technique is a combination of that used for proximal and distal humerus resections. Reconstruction provides stability of both shoulder and elbow joints.

**Exposure and Extension of Type V Procedure (TECH FIG 6)**

The surgical approach is similar to that used for a type V resection (ie, anterior utilitarian approach), but it requires additional distal exposure and identification and mobilization of the brachial artery and vein and the radial, ulnar, and median nerves.

The incision and exposure are continued down the anteromedial aspect of the arm, across the antecubital fossa, and, if necessary, down the anterior aspect of the forearm. The brachial vessels, along with the median and ulnar nerves, are identified medially in the arm.

The medial intermuscular septum is transected to allow further dissection and mobilization of the ulnar nerve so that it can be retracted medially with the brachial vessels and median nerve.

The biceps is retracted medially with the neurovascular bundle. The radial nerve is identified where it passes around the humerus and into the interval between the brachialis and brachioradialis muscles and continues into the forearm.

The pronator teres and common flexor origins are transected medially, and the brachioradialis, extensor carpi radialis longus, and common extensor origins are released laterally to expose the distal humerus. A small cuff of muscle is left around the tumor as needed. The medial triceps muscle usually is resected with the tumor, but the lateral and long heads are retained. The triceps tendon is kept attached to the olecranon. The olecranon is not osteotomized. The elbow joint is opened anteriorly and the capsule released circumferentially. The humero-ulnar and radiohumeral joints are then disarticulated.

**Prosthetic Reconstruction, Muscle Reconstruction, and Postoperative Management**

Reconstruction of the total humerus is similar to that of the proximal humerus. Distally, an ulnar endoprosthetic component with an intramedullary stem is cemented, with the olecranon left intact. Several articulating elbow devices are available.

The reconstruction technique is similar to that used for the proximal humerus, with the addition of distal soft tissue and joint capsule reconstruction.

The brachioradialis, pronator teres, and flexor carpi radialis muscles are sutured to the remaining biceps and triceps muscles to secure soft tissue around the flared distal portion of the humeral endoprosthesis.

The remaining muscles are closed in layers in an attempt to cover the entire prosthesis.

A posterior splint is used to protect the elbow reconstruction for 7 to 10 days. The surgical incision and wounds are examined on the fourth to fifth postoperative day.
Intraoperative photographs of an intra-articular resection. A. The tumor has been removed, demonstrating the relation of the axillary nerve to the capsule and the glenoid. The brachial vessels have been mobilized and are seen in the vessel loop. The structures around the proximal humerus are in close proximity to the subscapularis muscle and the joint capsule. These vessels are initially identified and retracted prior to resection. B. Reconstruction of the proximal humerus is performed with the MRS. It is essential to reconstruct the capsule, because soft tissue reconstruction alone will not maintain any stability either of the humeral head or to the shallow glenoid. Therefore, a Gore-Tex graft is used and is sutured to the rim of the glenoid. The humeral head then is reduced within this sleeve and sutured, using Dacron tape, through holes in the humeral head. This is the technique routinely used for intra-articular resections of the proximal humerus. C–E. Schematic of a proximal humerus reconstruction with static and dynamic transfers as well as a proximal humeral prosthesis. This technique, which has been used by Malawer since 1988, provides excellent coverage of the prosthesis and stability with active motion of the new glenohumeral joint. The prosthesis is suspended from the remaining axillary border of the scapula with two Dacron tapes, and with additional tapes from the prosthesis to the clavicle. Therefore, both longitudinal and horizontal stabilizing forces are in place. The soft tissue reconstruction consists of the long head of the biceps being attached to either the clavicle or the transferred pectoralis major muscle. The prosthesis is covered with four muscles. The pectoralis major and subscapularis muscles are sutured over the prosthesis to the remaining border of the scapula through drill holes using Dacron tape. This provides immediate stability and good coverage of the prosthesis. The prosthetic head is placed anterior to the scapula, not at the lateral border, and is then placed in the subscapular fossa. The remaining muscles of the teres and the infraspinatus are brought anteriorly and sutured, and the trapezius muscle is mobilized at the base of the neck to the area of muscle reconstruction. (C–E: Reprinted with permission from Rubert CK, Malawer MM, Kellar KL. Modular endoprosthetic replacement of the proximal humerus: Indications, surgical technique, and results. Semin Arthroplasty 1999;10:142–153.)
This chapter contains a complete description of the technique for a modified Tikhoff–Linberg procedure in patients with sarcomas of the proximal humerus. Modifications of the procedure also have been used for tumors at other anatomic sites. Proximal humeral lesions require resection of about two thirds of the humerus. The technique of resection and reconstruction requires a thorough knowledge of the regional anatomy and technique of musculoskeletal reconstruction. Essential aspects of the treatment plan should be emphasized.

- This initial biopsy should be performed through the anterior portion of the deltoid muscle for a lesion of the proximal humerus. The deltopectoral interval should not be used, because biopsy here would contaminate the deltopectoral fascia, the subscapularis, and the pectoralis major muscles, and would jeopardize the possibility of performing an adequate resection through uninvolved tissue planes.

For the definitive resection, the initial incision extends along the medial aspect of the biceps muscle, divides the pectoralis major, and exposes the neurovascular structures, thereby enabling the surgeon to determine resectability early in the dissection.

This incision does not jeopardize construction of an anterior skin flap in patients who will require forequarter amputation.
Resection

- The length of bone resection is determined preoperatively from a bone scan and MRI. To avoid a positive margin at the site of humeral transection, the distal osteotomy is performed 3 to 5 cm distal to the area of abnormality on the scan.
- Alternatively, other surgeons use autografts (usually fibulas) or allografts as spacers in obtaining an arthrodesis. We do not recommend osteoarticular allografts or intra-articular resections for high-grade bone sarcomas; those techniques were developed during the 1960s and 1970s and are inferior to current standards. Superior results routinely are obtained with modular prosthetic replacements combined with reconstruction of the soft tissues (FIG 4).

Reconstruction

- Segmental reconstruction of the resultant humeral defect is necessary to create shoulder stability. We do not leave a flail extremity. Reconstruction is necessary to maintain length of the arm and to create a fulcrum for elbow flexion. We recommend a custom or modular prosthesis.
- The key to success is reconstruction of the stability of the joint and soft tissue coverage of the prosthesis.

FIG 4 • Original photograph taken following an extra-articular resection of a large section of the proximal humerus and scapula involved by an osteosarcoma during the late 1960s. This was one of the first shoulder girdle resections performed in the United States. Notice the marked shortening of the limb, but the fairly normal functioning of the hand and elbow. Subsequently, multiple techniques have been utilized to maintain the length and function of the shoulder girdle. (Courtesy of Ralph C. Marcove, MD.)

REFERENCES


BACKGROUND
- The distal humerus is a relatively rare site for primary bone sarcomas. It is more commonly involved by neoplasm through metastatic spread. The distal humerus or elbow joint also can be secondarily involved by soft tissue sarcomas arising from the adjacent musculature or intermuscular soft tissues. Sarcomas that arise from the most proximal portions of the flexor–pronator group or common forearm extensor muscles may involve the distal humerus by direct invasion or by growing around the circumference of the distal humerus. Sarcomas that arise from the distal brachialis muscle or triceps muscle also may secondarily involve the distal humerus.
- Tumors arising in this area that involve the soft tissues are technically challenging to resect. These tumors usually are juxtaposed to and displace the adjacent neurovascular structures that lie in immediate proximity to the distal humerus and within the antebrachial fossa.
- The key to a safe and successful resection lies in identifying and mobilizing all important neurovascular structures (eg, brachial artery and vein, median nerve, ulnar nerve, and radial nerve) away from the neoplasm and distal humerus. The biceps muscle must be preserved in order to restore elbow flexion after reconstruction.
- Each of the neurovascular structures is identified proximal to the tumor, in normal tissue, in the distal one third of the arm. These structures are dissected in a proximal-to-distal direction, separated from the neoplasm, and mobilized across the elbow joint. Once these structures are mobilized and protected, it is safe to proceed with removing the distal humerus and tumor en bloc.
- In most cases, even the most extreme cases, the neurovascular structures are displaced and not encased by neoplasm, making limb-sparing surgery an option in lieu of an amputation (FIG 1). Gross tumor involvement of a single nerve is not an absolute indication for an above-the-elbow amputation. Involvement of more than one major nerve or the main vascular supply is an indication for an above-the-elbow amputation when treating a sarcoma with curative intention. In cases of metastatic carcinomas, where treatment is palliative, adjuvant treatments such as radiation or chemotherapy should be considered before proceeding with an amputation.
- Prosthetic reconstruction of the distal humerus and elbow joint with a modular, segmental, tumor prosthesis including a semiconstrained, hinged elbow joint is a reliable means of skeletal reconstruction following resection. Multiple muscle rotation flaps, retensioning the biceps muscle, and flexorplasty of the forearm musculature are key steps to restoring elbow flexion power.

ANATOMY
Neurovascular Structures
- In the middle one third of the arm, most of the important neurovascular structures lie within a fibrous sheath, in the groove between the biceps and triceps muscles, along the medial side of the arm, just medial to the brachialis muscle. These structures include:
  - The brachial artery, which is surrounded by two small brachial veins
  - The median nerve, which lies directly anterior to the brachial artery
  - The cephalic vein and medial antebrachial cutaneous nerve, which lie superficial to the brachial artery
  - The ulnar nerve, which is surrounded by the superior ulnar recurrent artery and two veins that lie just medial and posterior to the brachial artery
  - The medial brachial cutaneous nerve, which lies in the superficial subcutaneous tissue at this level.
- At this level, the radial nerve lies within the spiral groove of the humerus along the posterolateral aspect of the arm.
- The brachial artery and veins are the continuation of the axillary artery and vein at the level of the lower border of the subscapularis muscle. The brachial artery and veins travel distally along the medial side of the arm, deep to the fascia, in the interval between the biceps and triceps muscles, medial to the brachialis muscle.
- The profunda brachii artery arises proximally from the brachial artery at the lower border of the latissimus dorsi muscle. It traverses dorsally and laterally with the radial nerve and enters the spiral groove.
- The brachial artery gives off several branches along its course to the biceps, brachialis, and triceps muscles. In the antebrachial fossa, the brachial artery lies on the anterior surface of the brachialis muscle, immediately adjacent and lateral to the median nerve. The brachial artery passes just deep to the bicipital aponeurosis to enter the forearm. The inferior ulnar collateral artery arises from the brachial artery just proximal to the bicipital aponeurosis and passes medially just along the proximal aspect of the medial condyle of the humerus. After the brachial artery passes underneath the bicipital aponeurosis, it branches into the ulnar artery, radial recurrent artery, and radial artery.
- The median nerve travels distally in the arm, closely applied to the anterior aspect of the brachial artery. As the median nerve approaches the antebrachial fossa, it crosses over medially so that it occupies a position immediately medial to the brachial artery and lateral to the pronator teres muscle in the antebrachial fossa.
- The ulnar nerve occupies a position slightly more medial and posterior to the brachial artery in the mid-arm. In the distal one third of the arm, the ulnar nerve travels posteriorly and pierces the medial intermuscular septum. It travels along the medial side of the triceps muscle and enters a groove (cubital tunnel) along the posterior aspect of the medial epicondyle of the humerus. The ulnar nerve is tethered within this groove by ligamentous tissue. It then travels distally and enters the forearm by passing through the humeral and ulnar heads of the pronator teres muscle. In the forearm, the ulnar nerve lies along the deep surface of the flexor carpi ulnaris muscle.

PROSTHETIC RECONSTRUCTION
- Prosthetic reconstruction of the distal humerus and elbow joint with a modular, segmental, tumor prosthesis including a semiconstrained, hinged elbow joint is a reliable means of skeletal reconstruction following resection. Multiple muscle rotation flaps, retensioning the biceps muscle, and flexorplasty of the forearm musculature are key steps to restoring elbow flexion power.
The medial antebrachial cutaneous nerve is a small nerve that lies deep to the fascia between the median and ulnar nerves at the mid arm level. In the distal one third of the arm, the nerve occupies a more superficial position in the subcutaneous tissue.

The radial nerve arises from the posterior cord of the brachial plexus. At the inferior border of the latissimus dorsi muscle, the radial nerve passes posteriorly, along with the profunda brachii artery, through the interval between the long head of the triceps and the humerus. The radial nerve enters the spiral groove of the humerus and travels distally, wrapping around the posterior aspect of the humerus, in the interval between the medial and lateral heads of the triceps muscle. In the distal one third of the arm, the radial nerve passes through the lateral intermuscular septum and enters the anterior compartment of the arm, where it resides in the interval between the brachioradialis muscle and brachialis muscle. The radial nerve continues distally into the forearm. At the lower, lateral border of the brachialis muscle, just proximal to the supinator muscle, the radial nerve divides into the posterior interosseous nerve and the superficial radial nerve. The posterior interosseous nerve passes through the substance of the supinator muscle. The superficial radial nerve travels distally along the deep surface of the brachioradialis muscle.

INDICATIONS AND CONTRAINDICATIONS

Indications for Surgical Resection

- High-grade and some low-grade bone sarcomas
- Soft tissue sarcomas that surround or invade the distal humerus or elbow joint secondarily
- Solitary metastatic carcinomas to the distal humerus
- Metastatic carcinomas that have destroyed a significant portion of the distal humerus, which precludes other methods of resection and fixation
- Local complications resulting from other treatments for tumors involving the distal humerus, eg, nonunion of a pathological fracture following radiation

Contraindications to Surgical Resection

- Absolute contraindications include tumor involvement of the neurovascular bundle.
- Involvement of a single major nerve is not an absolute contraindication. The nerve can be resected with the neoplasm.
- Encasement of the brachial artery and veins or two or more major nerves usually precludes a limb-sparing resection.
- Final determination regarding the need for an amputation is made at the time of surgery, after the neurovascular structures are explored. Adjuvant treatments such as radiation and chemotherapy should be considered for palliation of metastatic carcinomas prior to proceeding with an amputation.
- Relative contraindications include tumor contamination of the operative site from hematoma following a poorly performed biopsy or pathologic fracture or a previous or active infection. Recently, we have successfully treated patients with pathologic fractures with induction chemotherapy, immobilization, and limb-sparing surgery if there is a good clinical response and fracture healing; survival has not been compromised, and local recurrence is less than 10%.

IMAGING AND DIAGNOSTIC STUDIES

- The most useful imaging studies are plain radiography, CT, MRI, arteriography, and bone scan. These studies are useful for diagnosis, evaluating local and distant extent of disease, and, for select sarcomas, gauging the response to preoperative chemotherapy. Radiologic studies are necessary to determine the exact anatomic extent of the neoplasm so that the surgical procedure can be planned accurately.

Plain Radiographs

- Plain radiographs of the humerus and elbow are used to localize the anatomic origin of the tumor, formulate a differential diagnosis, and estimate tumor extent (FIG 2A).
- After preoperative chemotherapy for an osteosarcoma, plain radiographs can be used to estimate the response of the tumor to the chemotherapeutic agents. A good response (> 90% tumor necrosis) is indicated by extensive tumor calcification, periosteal new bone formation, and healing of pathologic fractures.

Computed Tomography

- CT is most useful for evaluating cortical bone changes and extent of cortical destruction by tumor. In the case of a metastatic carcinoma, it aids with decision making regarding the indication for a resection and prosthetic reconstruction versus curettage and internal fixation. Extensive cortical destruction throughout a significant circumference of the bone is an indication to proceed with a resection of the distal humerus and prosthetic reconstruction.
- CT also is useful for detecting subtle mineralization, calcification, or ossification within the neoplasm that may assist in diagnosis.
- CT is considered complementary to MRI in evaluating the soft tissue component of the neoplasm and proximity to the neurovascular structures, particularly a contrast-enhanced CT scan.
- CT also assists with detection of subtle cortical erosion and frank invasion of the distal humerus by adjacent soft tissue sarcomas that may not be clearly delineated on MRI or plain radiographs.
- After preoperative chemotherapy of an osteosarcoma, CT characteristically shows a rimlike calcification in those tumors that have had a good response.
- Chest CT is most sensitive for detecting lung metastases.
Magnetic Resonance Imaging

- MRI is most accurate for determining intra- and extracortical tumor extent as well as for detecting skip metastases. An appreciation of intraosseous extent is necessary for determining the length of bone resection.
- The humerus usually is transected approximately 2 to 3 cm proximal to the intramedullary extent of the neoplasm as visualized on a T1-weighted MRI scan.
- Proximity of the extraosseous component to the brachial vessels, median nerve, ulnar nerve, and radial nerve also can be evaluated, as can secondary involvement of the distal humerus and elbow joint by adjacent soft tissue sarcomas.
- Standard T1-weighted, T2-weighted, fat-suppressed, and gadolinium-enhanced images are recommended (FIG 2B).

Bone Scintigraphy

- Bone scintigraphy is used to determine intraosseous tumor extent and is compared to the MRI scan to ensure accuracy. It also is used to detect bony metastases and skip metastases.

Thallium Scintigraphy

- Thallium 201 is a potassium analog that is actively transported by the sodium–potassium ATPase pump. A quantitative thallium scan has been useful for determining viability of bone tumors, particularly osteosarcomas.
- The affected side is compared to the unaffected side; a ratio below 4:1 is consistent with tumor necrosis greater than 90% (a good response).

Angiography

- Angiography is extremely useful for evaluation of tumor vascularity and is considered the gold standard for evaluating tumor response to neoadjuvant chemotherapy. High grade sarcomas, such as osteosarcoma, demonstrate a tumor blush on an arteriogram when viable (fill with contrast dye because of extensive neovascularization of the tumor). The neovascularization and hence the tumor blush disappear when the tumor has had a good response to a preoperative chemotherapy regimen.
- It is also essential for determining the relationship of the brachial vessels to the tumor or the presence of anatomic anomalies. The soft tissue component of distal humeral tumors routinely displaces the brachial vessels. Soft tissue sarcomas that arise around the distal humerus also usually routinely displace the brachial vessels. The direction in which these structures are displaced can be determined with a biplanar arteriogram.

Biopsy

- Needle or incisional biopsies of tumors of the distal humerus should be performed through the brachialis muscle in line with the proposed skin incision so the biopsy tract can be excised at the time of the definitive procedure.
- The biopsy should never be performed through the biceps muscle; it should, rather, be performed along either side of the muscle. The biceps must be spared in order to be able to reconstruct the distal humerus and preserve elbow flexion.
- In general, the biopsy is best made directly anterior, just lateral to the biceps tendon or distal biceps muscle, close to the antecubital crease. In this manner, the biopsy tract can be excised with the transverse portion of the incision that crosses the antecubital crease.
- Occasionally, a very large soft tissue component that protrudes anteriorly and medially will displace the neurovascular structures medially. In these instances, it may be possible to biopsy the tumor, under CT guidance for visualization of the neurovascular structures, just medial to the medial margin of the distal biceps muscle or biceps tendon. The tumor will occupy a subcutaneous position in this location and is easily biopsied. With either approach it is important to perform the biopsy through the brachialis muscle and to avoid contaminating the biceps muscle. The portion of the brachialis muscle and biopsy hematoma are easily removed at the definitive resection.
- Biopsy of a tumor arising from the brachioradialis or common extensor muscle origin is performed anteriorly, directly over the mass, along the lateralmost 1 to 2 cm of the antecubital crease. Extreme care is taken to avoid contaminating the radial and posterior interosseous nerves.
- Biopsy of a tumor arising from the flexor–pronator muscle group is performed at the most medial extent of the antecubital crease, directly over the mass and at a distance from the median nerve and brachial artery.
SURGICAL MANAGEMENT

Preoperative Planning

- Staging studies are thoroughly reviewed before the surgical procedure.
- The T1-weighted coronal MRI scan of the entire humerus is reviewed. The length of the bone resection is based primarily on this study. The transection level is determined so that it will permit a 2 to 3 cm margin proximal to the intraosseous tumor extent. In the case of an adjacent soft tissue sarcoma, the bone is transected 2 cm to 3 cm proximal to the soft tissue involvement of the humerus. Surgical resection is modified to account for skip metastases, both intraosseous and transarticular. The length of the resection can be determined preoperatively to ensure all components of the prosthesis needed for reconstruction will be present. Nowadays, modular segmental prostheses are utilized that are assembled intraoperatively. The size can be adjusted intraoperatively to accommodate for the resection.
- The MRI and CT scans are reviewed to evaluate the exact degree of soft tissue extension and proximity to the neurovascular structures. CT and MRI results are evaluated to determine areas of the distal humerus or elbow joint that may be directly involved by an adjacent soft tissue sarcoma.
- The arteriogram provides a “road map” showing the direction of displacement of the neurovascular structures and also alerts the physician to any anomalies that may be encountered during surgery.
- Flexible reamers, sagittal saw, drill or high-speed burr, osteotomes, cement, cement gun, ball-tip guide wire, no. 5 non-absorbable sutures, vessel loops, and 1/4-inch Penrose drain will be required.

Positioning

- The patient is placed in a supine position with the arm abducted and placed on a padded and draped Mayo stand. A small bump is placed under the ipsilateral scapula, to elevate the shoulder girdle slightly off the bed. The entire upper extremity, from the middle of the clavicle and shoulder girdle through the fingertips, is prepped and draped in a sterile manner.

Approach

- A limb-sparing distal humeral resection has three major components:
  - Oncologic resection
  - Skeletal reconstruction
  - Soft tissue reconstruction or coverage (or both).
- The goal of the resection is to remove the entire tumor en bloc or, in other words, in one piece with the distal humerus. The key to the resection involves meticulously dissecting, separating, and mobilizing the important neurovascular structures away from the neoplasm.
- Skeletal reconstruction is done with a modular, segmental replacement that can be assembled and have its size adjusted intraoperatively. The length of the prosthesis may be downsized as much as a few centimeters to facilitate soft tissue coverage of the prosthesis, if necessary.
- Soft tissue reconstruction that involves rotating and reattaching muscles and restoring the length–tension relationship of the forearm muscles and biceps is most important for achieving a good functional result and for protecting the prosthesis from infection.

DISTAL HUMERAL RESECTION

- The S-shaped incision begins in the middle of the arm along the medial side of the biceps muscle (TECH FIG 1A,B). It is extended distally along the medial border of the biceps muscle to the antecubital crease; the biopsy tract is included in the incision in an elliptical manner. At the antecubital crease, the incision curves laterally along the volar aspect of the elbow to the volar margin of the brachioradialis muscle, where it then turns distally and is extended distally along the forearm for a short distance.
- Medial and lateral cutaneous flaps are raised (TECH FIG 1C,D). Wherever possible, fasciocutaneous flaps are raised. Medial and lateral antebrachial cutaneous nerves are preserved.
- Proximally in the arm (proximal to the neoplasm in normal-appearing tissues), in the interval between the biceps and triceps muscles, the neurovascular structures are identified within their sheath. The deep investing fascia of the arm (superficial layer of the sheath) is opened longitudinally directly over these structures. While protecting the underlying structures, the fascia is opened from proximally to distally all the way down to the neoplasm or antecubital fossa. The neurovascular structures can be visualized easily, and the brachial artery can be palpatied once the sheath is opened. Proximally, the brachial artery and accompanying veins are isolated and surrounded with a vessel loop. Likewise, the median, ulnar, and medial antebrachial cutaneous nerves are each identified, isolated, and individually surrounded with a vessel loop.
- The brachial artery and veins are meticulously dissected away from the surrounding tissues and from the pseudo-capsule of the neoplasm down to and across the antecubital fossa. The biceps aponeurosis is incised to permit visualization of the brachial artery to the point where the ulnar and radial arteries arise. The radial and ulnar arteries are each identified and surrounded with a vessel loop. The inferior ulnar collateral vessels, as well as muscular branches to the biceps, brachialis or triceps muscle, may require ligation to mobilize the brachial vessels away from the neoplasm, depending on the location and position of the tumor. Once the artery is freed from the neoplasm, attention is turned to mobilizing the major nerves.
- The median nerve is dissected from a proximal to distal direction across the antecubital fossa, where it lies just medial to the brachial artery. It is dissected distally to where the anterior interosseous nerve arises from it and the median nerve continues deep to the flexor digitorum superficialis muscle.
- The ulnar nerve also is isolated and dissected from a proximal to distal direction. The medial intermuscular septum is opened to allow further dissection and mobilization of the ulnar nerve to the cubital tunnel along the medial
TECH FIG 1 • A. An anterior surgical incision is routinely used for resection and prosthetic replacement of the elbow joint and distal humerus. The surgeon can palpate the normal anatomic structures. The longitudinal incision is made along the biceps–triceps interval. The joint is exposed through an S extension of the proximal incision. B. Schematic drawing of the anterior exposure. The neurovascular structures are identified (ie, brachial artery, median nerve, radial nerve, ulnar nerve) and retracted. This is essential for a safe procedure. C. Wide medial and lateral flaps are required for adequate exposure. D. The biceps as well as the neurovascular structures are retracted.

**Epicondyle of the Distal Humerus.** The fascia or ligamentous tissue overlying the cubital tunnel is opened longitudinally, and the ulnar nerve is gently mobilized from the tunnel all the way to where the nerve passes between the humeral and ulnar heads of the pronator teres muscle. This enables the ulnar nerve to be retracted medially with the brachial vessels and median nerve.

- The radial nerve is identified in the interval between the brachioradialis and brachialis muscles. It is dissected distally across the elbow joint to the juncture where the posterior interosseous nerve originates from the radial nerve. It also is dissected proximally as it passes through the lateral intermuscular septum around the posterior aspect of the humerus in the spiral groove. The lateral intermuscular septum is opened, and the radial nerve is mobilized away from the posterior aspect of the humerus up to the latissimus dorsi muscle insertion.
- The biceps muscle is isolated, dissected away from neoplasm and the underlying brachialis muscle. Usually, the biceps is not involved by any neoplasm. If it is involved, a portion may require removal. (Be aware that the biceps or brachialis muscle is required for elbow flexion; removal of both in entirety prohibits elbow flexion postoperatively.) The biceps muscle is isolated so it can be retracted medially and laterally when necessary.
- The pronator teres and common flexor muscles are released from their origins from the distal humerus medially. The brachioradialis, extensor carpi radialis longus, and common extensor muscles are released laterally from the distal humerus. A small cuff of muscle is left around the tumor as needed. Occasionally, a distal humerus resection is performed for a soft tissue sarcoma that originates from one of these muscle groups. In such a case, the muscle or muscles that are involved by neoplasm are transected distally to the tumor in such a manner that an adequate margin is maintained. When resecting the flexor-pronator group, the branch of the median nerve that supplies the flexor digitorum superficialis is identified and protected, if possible. On the lateral side of the elbow, if the brachioradialis and common extensor muscles require resection, the posterior interosseous nerve is identified and protected to preserve wrist and digit extension.
- A portion of the brachialis muscle, or even the entire brachialis muscle, may require resection, depending on the extent of the tumor. If there is no soft tissue component arising from a distal humerus tumor or if the brachialis muscle is not involved by an adjacent soft tissue sarcoma, then the brachialis muscle is incised longitudinally along the anterior aspect of the distal humerus. The brachialis muscle is then elevated off the
1812 Part 5 ONCOLOGY Section II SHOULDER GIRDLE AND UPPER EXTREMITIES

TECHNIQUES

**TECH FIG 2** • A. The appropriate length of resection is determined preoperatively from the MRI scan. In general, a 2- to 3-cm margin of normal bone is removed. B. Schematic drawing of the resection defect. C. Operative photograph of the surgical defect. Note the wide exposure. This is required for accurate positioning of the prosthesis and reaming of the ulnar canal. The triceps remains attached to the surrounding soft tissues.

Distal humerus and preserved. If there is a soft tissue component arising from a tumor of the distal humerus or if the brachialis muscle is involved by an adjacent soft tissue sarcoma, then the brachialis muscle is released in a subperiosteal manner from its insertion on the ulna or simply transected distal to the elbow joint.

- The triceps muscle is elevated off the distal humerus and may require partial or complete resection of the medial head, depending on tumor extent. The lateral and long heads usually can be preserved. The triceps tendon is kept attached to the olecranon. The olecranon is not osteotomized.
- The elbow joint is opened anteriorly and the capsule released circumferentially from the ulna–olecranon and radial head. The humero-ulnar and radiohumeral joints are then disarticulated.
- The humerus is osteotomized at a level approximately 2 to 3 cm proximal to the intramedullary extent of the neoplasm (TECH FIG 2A). The area where the humerus will be osteotomized is cleared of overlying brachialis muscle and triceps muscle. The radial nerve is identified and protected before cutting the bone. The bone usually is transected with a sagittal saw (TECH FIG 2B,C).

**PROSTHETIC RECONSTRUCTION**

- Reconstruction of the distal humerus and elbow joint is performed with a modular segmental distal humerus tumor prosthesis. The distal humeral component consists of a semiconstrained hinge component that is attached to an ulnar component to recreate the elbow joint.
- Proximally, the distal humeral component can be fit to a body segment via a Morse taper. The body segment is available in different lengths, so the size can be adjusted intraoperatively. The body segment is fit to a stem via a Morse taper. The stem then is cemented into the more proximal remaining humeral canal.
- The ulnar component consists of a stem that is cemented into the olecranon and proximal ulna. The ulna component is available in two lengths.
- The length of the prosthesis is chosen. It may be downsized 2 to 3 cm to help facilitate soft tissue closure. The prosthesis is assembled on the field.
- The remaining humerus is flexibly reamed to accommodate as wide a stem as possible. It is overreamed 1 to 2 mm to accommodate for a cement mantle. The olecranon fossa is opened with a small high-speed burr (TECH FIG 3) to enter into the medullary canal of the proximal ulna. The proximal tip of the olecranon is shaved slightly to accommodate the ulna stem, so that it can be inserted directly into the ulnar canal without being inserted on an angle. The canal of the ulna is reamed with hand reamers. Trial components are available to be used to ensure that the ulna component will sit properly within the medullary canal of the proximal ulna.
- Both components are cemented into place separately. The distal humerus is cemented so the hinge will face anteriorly. It is important to identify the anterior surface of the humerus before the distal humeral component is inserted. The ulna component is placed so that it sits as deep as possible within the olecranon fossa without
TECH FIG 3 • Technique of preparing the ulnar notch. A high-speed burr is recommended.

Soft tissue closure.

A. It is important for the prosthesis to be completely covered by muscle. The flexors (from the medial condyle) and the brachioradialis (mobile wad of 3) from the lateral condyle are reattached to the adjacent soft tissue. It is not necessary to attempt reattachment to the prosthesis.

B. Reattachment of the elbow flexors. An ulnar nerve transposition may be performed, although this is not done routinely. The passive range of motion of the elbow is tested prior to closure. If there is any restriction, the radial head should be examined or removed.

C. The origin of the flexor–pronator forearm muscles also is transferred as far proximal as possible and sutured to the medial border of the biceps and triceps muscles.

Soft tissue and muscle reconstruction

- The brachioradialis and extensor carpi radialis muscles are sutured to the remaining biceps and triceps muscles to secure soft tissue around the flared distal portion of the humeral endoprosthesis. A flexorplasty is performed. With the elbow held in 60 degrees of flexion and the forearm fully supinated, these muscles are transferred to as proximal a position as possible and sutured to the biceps muscle with no. 5 nonabsorbable sutures. The biceps is pulled distally and placed under tension while these muscles are sutured to it. This step is especially important if the prosthesis has been shortened, because it restores the length–tension relation of the biceps muscle. The elbow is kept in 60 degrees of flexion and fully supinated for the remainder of the procedure.

- The origin of the flexor–pronator forearm muscles also is transferred as far proximal as possible and sutured to the medial border of the biceps and triceps muscles.

- At this time, for postoperative analgesia, an epidural catheter can be threaded proximally along the median nerve, deep to the vascular sheath, to a level where it can bathe the entire brachial plexus with bupivicaine. A drain is also placed at this time.

- The remaining muscles, usually the biceps–brachialis muscles and triceps muscles, are sutured to each other to close over the entire prosthesis and neurovascular structures (TECH FIG 4).

- Sometimes, depending on the amount of soft tissue that is resected with the neoplasm, it is useful to shorten the prosthesis an additional 2 to 3 cm to facilitate soft tissue coverage. The biceps requires retensioning with sutures if this situation arises. Likewise, proximal transfer (ie, tensioning) of the brachioradialis and forearm flexor origins (ie, flexorplasty) is beneficial for restoring elbow flexion power.
**POSTOPERATIVE CARE**

- Edema control is essential in the early postoperative period. Patients are covered from hand to shoulder with a bulky dressing and a splint that maintains the elbow in 60 degrees of flexion. Elastic bandages are applied for light compression. The extremity is elevated and the patient remains primarily at bed rest for 3 to 4 days. Drains and the perineural catheter are removed at this time. The dressings are changed approximately 4 days postoperatively, and the splint is reapplied to maintain the elbow in 60 degrees of flexion.

- The extremity is kept in a splint for a total of 6 weeks to allow for sufficient muscle healing and scarring. Elbow motion is prohibited for 6 weeks.

- Immediately after surgery, active and passive range of motion of the wrist, hand, and digits, along with hand strengthening, is initiated and continued for 6 weeks while the arm is in the splint. Hand and wrist strengthening is continued throughout the entire rehabilitation process.

- At 6 weeks, the patient is placed in a hinged elbow brace and permitted active, active assisted, and passive range of motion from 30 degrees of flexion to 130 degrees of flexion. The patient is not permitted to extend the elbow for the next 6 weeks past approximately 30 degrees of flexion. At 12 weeks after surgery, the brace is adjusted to allow full motion of the elbow. Strengthening of the elbow is initiated at this time, with a 2-pound weight limit. The brace is worn for 6 more weeks, usually until approximately week 18. The patient can wear a sling after week 18 when necessary for comfort. At week 18, resistance strengthening can be increased to a 3-pound weight limit if the patient is now able to handle 2 pounds. At 6 months after surgery, the weight limit for resistance strengthening is increased to 10 pounds. Patients are advised not to lift more than 10 pounds with the extremity.

**OUTCOMES**

- **Oncologic results:** Local recurrence is less than 5%. In our series of 16 patients, there were no local recurrences.

- **Prosthetic survival:** In our small series of 16 patients, there were no instances of prosthetic loosening (FIG 3).

- **Function:** All patients are pain free and have stable elbows. Patients do not require a brace. Elbow, wrist, and hand function are virtually normal. All patients could flex their elbows up to 110 to 130 degrees. No patients lacked 10 to 30 degrees of terminal extension. All patients could carry out activities of daily living. The Musculoskeletal Tumor Society score ranged from 24 to 27 of 30 possible points (80% to 90%). The main restrictions are in recreational activities.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Evaluating intraosseous tumor extent</th>
<th>T1-weighted MRI scans are the most accurate for determining intraosseous tumor extent. The T2-weighted image often is associated with significant peritumoral edema, which overestimates tumor extent.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biopsy</td>
<td>The biopsy should be taken through the brachialis muscle and in line with the proposed skin incision that would be used for definitive resection. The biceps must not be penetrated or contaminated. Preservation of the biceps muscle is crucial for restoring elbow flexion following reconstruction.</td>
</tr>
<tr>
<td>Neurovascular structures</td>
<td>The major neurovascular structures are all identified in normal tissue proximal to the neoplasm along the medial side of the mid-arm. Dissection is initiated in a proximal to distal direction. All important structures (ie, brachial vessels, median nerve, ulnar nerve, and radial nerve) are identified, separated, and mobilized away from the neoplasm and distal humerus. Once all vital structures are preserved and protected, the resection can begin. Care is taken to preserve the nerve to the flexor digitorum superficialis when tumors of the flexor–pronator group are resected. Likewise, care is taken to preserve the branches of the posterior interosseous nerve when tumors of the brachioradialis and common extensor muscle group are resected.</td>
</tr>
<tr>
<td>Skeletal/endoprosthetic reconstruction</td>
<td>The endoprosthesis is downsized 2 to 3 cm to facilitate soft tissue coverage, if necessary. The elbow flexors are retensioned to accommodate for the shortening. The prosthesis is cemented so that the hinge faces anteriorly. The ulna component must be seated as deep as possible within the olecranon.</td>
</tr>
<tr>
<td>Soft tissue reconstruction</td>
<td>It is important to maintain the elbow in 60 degrees of flexion and fully supinated when performing the soft tissue reconstruction. Proximal transfer under tension of both the common extensor muscle origin and the flexor–pronator origin to either side of the biceps muscle accomplishes a flexorplasty of the elbow that assists with restoring elbow flexion power. It may be necessary to restore the length–tension relation of the biceps by pulling the biceps distally and suturing it to the forearm musculature under tension.</td>
</tr>
</tbody>
</table>
activities. Most patients can flex their elbows against 10 pounds of resistance.

COMPlications

- Transient nerve palsies (over 10%; 1 out of 16 patients); resolved within 6 months
- Skin necrosis and wound infections (over 10%; 1 out of 16 patients); resolved with debridement and closure
- Aseptic loosening (0 out of 16 patients)
- Local recurrence (0 out of 16 patients)
- In one instance the axle broke and was replaced.

REFERENCES

BACKGROUND

The humerus is a common site of metastatic bone disease requiring surgery. A metastasis at that site, especially when it involves the dominant extremity, has an immediate and profound impact on the affected individual’s ability to perform activities of daily living. The quality of surgery, therefore, is an important factor in restoring vital function.

A detailed preoperative clinical and imaging evaluation is mandatory for defining the morphologic characteristics of the lesion and, in turn, establishing the indications for surgical intervention, as well as distinguishing between lesions that can be managed with curettage and cemented fixation and those that require resection with endoprosthetic reconstruction.2,3,5,6

Unlike primary sarcomas of the humerus, metastatic tumors usually have a small soft tissue component, even in the presence of extensive bone destruction. This characteristic allows resection of bony elements only, permitting sparing of the extracortical structures, such as the joint capsule, overlying muscles, and muscle attachments, and affords the opportunity to use them to reconstruct and preserve function (FIG 1A,B). To this end, exposure of the proximal humerus is done by splitting the deltoid muscle rather using the deltopectoral interval, as is done in the case of a primary sarcoma of bone, which necessitates en bloc resection of the deltoid muscle with the tumor. Moreover, a few centimeters of upper limb shortening following resection of bone segment has minimal impact on function, because a slight difference in positioning of that extremity in space can easily compensate for such limb-length discrepancy.

In contrast, a similar discrepancy in the lower extremities, which require almost equal length for normal gait, would result in an inevitable limp, the extent of which would be proportional to the shortening of the operated extremity.2

Because of different anatomic and surgical considerations, surgeries around the proximal humerus (type I), humeral diaphysis (type II), and distal humerus (type III) are discussed separately (FIG 2).1

ANATOMY

Proximal Humerus: Type I Metastasis

The proximal humerus is covered anteriorly and laterally by the deltoid muscle.

The joint capsule encircles the humeral head and attaches to the base of the anatomic neck.

The proximal humerus is the attachment site for the rotator cuff muscles. The long head of the biceps muscle crosses the anterior aspect within the bicipital groove.

Humeral Diaphysis: Type II Metastasis

The upper half is occupied by muscle insertions:

- Medial aspect: teres major, latissimus dorsi, coracobrachialis
- Lateral aspect: pectoralis major, deltoid
- The radial nerve curves at the back from medial to lateral at the mid-arm level.
- The lower half is occupied by muscle origins:
  - Medial aspect: Brachialis
  - Lateral aspect: Brachioradialis
  - Neurovascular bundle along its medial aspect

Distal Humerus: Type III Metastasis

The neurovascular bundle lies along its medial aspect between the biceps and brachialis muscles.

- The radial nerve lies along its lateral aspect between the brachialis and brachioradialis muscles.

INDICATIONS

- Pathological fracture
- Impending pathological fracture
- Intractable pain associated with locally progressive disease that has shown inadequate response to narcotics and preoperative radiation therapy
- Solitary bone metastasis in selected patients

IMAGING AND OTHER STAGING STUDIES

Plain radiographs of the entire humerus are mandatory to rule out synchronous metastases that may change the extent and technique of surgery. A CT scan of the lesion will clearly define the extents of bone destruction and soft tissue component. Total body bone scintigraphy is done to detect synchronous metastases elsewhere in the skeleton. At the conclusion of imaging, the surgeon should be able to answer the following questions:

- Are there additional humeral metastases and, if there are, can they be managed by nonoperative techniques or do they require surgery?
- Are there additional skeletal metastases and, if there are, can they be managed by nonoperative techniques or do they require surgery?
- What is the appropriate surgery? As a rule, the tumor curettage and cemented fixation approach is used for lesions in which the remaining cortices allow containment of the fixation device; otherwise, surgery involves resection of the affected bone segment with prosthetic reconstruction.
Chapter 12  SURGICAL MANAGEMENT OF METASTATIC BONE DISEASE: HUMERAL LESIONS

FIG 1 • A. Primary bone sarcomas usually have considerable extension into the soft tissues. Resection of such tumors at the proximal humerus would require en bloc removal of the overlying deltoid muscle, rotator cuff tendons, and the joint capsule. 
B. Bone metastases, however, usually present with less soft tissue involvement, and their resection involves removal of bony elements with only a thin layer of surrounding soft tissues.

FIG 2 • A,B. Type I humeral metastasis extending across the anatomic neck to the humeral head. C,D. Type II humeral metastasis involving the humeral diaphysis between the anatomic neck and the supracondylar ridges of the humerus. E,F. Type III humeral metastasis extending to the humeral condyles below the supracondylar ridges. (From Bickels J, Kollender Y, Wittig JC, et al. Function after resection of numeral metastases. Analysis of 59 consecutive patients. Clin Orthop Relat Res 2005;437:201–208, with permission.)
TYPE I AND II METASTASES

Position and Incision
- The patient is placed in a semilateral position, and an anterior utilitarian shoulder girdle incision is made. It begins at the junction of the inner and middle thirds of the clavicle and continues over the coracoid process, along the deltopectoral groove, and down the arm over the medial border of the biceps muscle (TECH FIG 1A,B).

Exposure
- The deltoid muscle is divided longitudinally to expose the humeral head and the proximal third of the humeral diaphysis. Exposure of the remaining diaphysis is achieved by similarly dividing the brachialis muscle. Electrocautery and rasps are used to detach and reflect the periosteum and muscle attachments from the underlying cortex (TECH FIG 1C,D).

Tumor Removal
- Type I metastasis
  - Using electrocautery, the rotator cuff tendons are detached from the humerus, the long head of the biceps is cut at its insertion site around the glenoid, and the joint capsule is opened. Osteotomy is carried out at the required level below the surgical neck, 1 to 2 cm below the distal margin of the tumor, and the proximal humerus can now be removed (TECH FIG 2).

**TECH FIG 1 • A,B.** The utilitarian shoulder incision is used for exposure of type I and II metastases. It begins at the junction of the inner and middle thirds of the clavicle and continues over the coracoid process, along the deltopectoral groove, and down the arm over the medial border of the biceps muscle up to the distal arm, if required. **C,D.** The deltoid and brachialis muscles are divided longitudinally to expose the humeral head and humeral diaphysis. The periosteum is divided similarly and reflected with muscle to expose the underlying cortex.
Chapter 12  SURGICAL MANAGEMENT OF METASTATIC BONE DISEASE: HUMERAL LESIONS 1819

TECHNIQUES

TECH FIG 2 • A–C. Resection of the type I metastatic renal cell carcinoma seen in the plain radiograph in Figure 1C is executed by detaching the rotator cuff tendons and the long head of the biceps and opening the joint capsule. An osteotomy is performed and the proximal humeral segment is removed. D. Surgical specimen.

■ Type II metastasis
- A longitudinal cortical window with oval edges is made just above the lesion (TECH FIG 3A). Gross tumor is removed with hand curettes (TECH FIG 3B,C). Curettage should be meticulous and leave only microscopic disease in the tumor cavity. It is followed by high-speed burr drilling of walls of the tumor cavity (TECH FIG 3D–F). Occasionally, the cortices of the involved segment are completely destroyed, leaving no option but an intercalary resection of the affected segment. This is achieved by an osteotomy 1 to 2 cm above and below the segment (TECH FIG 3G–I).

Soft Tissue Reconstruction and Wound Closure
- Type I metastasis
  - The rotator cuff tendons are attached to the prosthetic head using 3-mm Dacron tapes (Deknatel, Falls River, MA) or no. 5 Ethibond sutures (Ethicon, Somerville, NJ; TECH FIG 6). The pectoralis major, teres major, latissimus dorsi, and coracobrachialis muscles are similarly attached. Using the same technique, the prosthetic head also is secured to the drill holes within the bony elements around the shoulder joint, acromion, clavicle, and glenoid. The second, overlying muscular layer includes the deltoid and brachialis muscles, which are sutured to cover the implant.

TYPE III METASTASES
- Type III metastases extend to the humeral condyles below the supracondylar ridges. In most of these cases, the extent of bone destruction allows tumor curettage and reconstruction with cemented hardware (the technique is described in the following section). Rarely will extensive destruction of the distal humerus necessitate formal resection with endoprosthetic reconstruction.
A longitudinal cortical window with oval edges is made just above the lesion. Gross tumor is removed with hand curettes. Curettage should be meticulous and should leave only microscopic disease in the tumor cavity. Curettage is followed by high-speed burr drilling of walls of the tumor cavity. Tumor cavity following curettage and burr drilling. Plain radiograph of type II thyroid carcinoma metastases. The extent of cortical destruction may does not allow curettage and burr drilling and so intercalary resection of the affected segment is indicated. Intercalary resection is achieved by proximal and distal osteotomies 1 to 2 cm above and below the tumor margin.
Position and Exposure

- The patient is placed supine on the operating table with the ipsilateral arm lying across the chest. A slightly curved incision is made on the lateral aspect of the arm over the supracondylar ridge of the elbow (TECH FIG 7A).
- The distal humerus is exposed using the plane between the brachioradialis and triceps muscles. The brachioradialis is reflected anteriorly and the triceps posteriorly. Further posterior reflection of the anconeus muscle combined with detachment and anterior reflection of the common extensor origin exposes the radial head (TECH FIG 7B).

Tumor Removal and Mechanical Reconstruction

- A longitudinal cortical window with oval edges is made just above the lesion. Gross tumor is removed with hand curettes (TECH FIG 8A), and this is followed by high-speed burr drilling (TECH FIG 8B).
- An intramedullary rod is introduced through the tumor cavity, which is then filled with cement. A reconstruction plate along the lateral supracondylar ridge is used to reinforce the reconstruction (TECH FIG 8C).

TECH FIG 4 • Intraoperative photograph (A) and plain radiograph (B) showing a proximal humeral tumor prosthesis used for reconstruction after resection of a type I metastasis.

TECH FIG 5 • A. An intramedullary nail is introduced. B. After proper position and length are verified, the nail is partially pulled back, and the entire tumor cavity is filled with cement. The nail is then pushed back into the medullary canal and fixed with interlocking screws. Intraoperative photograph (C) and plain radiograph (continued)
TECH FIG 5 • (continued) (D) showing side plate reinforcement of a cemented intramedullary humeral nail. Plain radiograph (E) and intraoperative photographs (F,G) showing side plate reinforcement of a cemented intramedullary humeral nail following intercalary resection of a type II metastasis. The remaining bone defect is filled with cement.

TECH FIG 6 • 3-mm Dacron tapes (A) or no. 5 Ethibond sutures (B) are used for securing the prosthetic head to the neighboring acromion, clavicle, and glenoid and for reattachment of the rotator cuff tendons. C. Rotator cuff tendons are sutured to the prosthetic head.
TECH FIG 7 • A. To expose a lesion at the distal humerus, the patient is placed supine on the operating table with the ipsilateral arm lying across the chest. A slightly curved incision is made on the lateral aspect of the arm over the supracondylar ridge of the elbow. B. The distal humerus and radial head are exposed using the plane between the brachioradialis and triceps muscles.

TECH FIG 8 • A. Gross tumor is removed with hand curettes. B. Curettage is followed by high-speed burr drilling. C. A cemented intramedullary rod that is reinforced by a reconstruction plate along the supracondylar ridge is used for reconstruction.
POSTOPERATIVE CARE

Type I and II Metastases
- Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed. If endoprosthetic reconstruction was done, the shoulder is immobilized in a sling for 3 weeks. During that time, the rehabilitation program emphasizes range of motion (ROM) of the elbow, wrist, and fingers with gravity assistance. Gradual passive and active ROM of the shoulder is then started, with emphasis on forward flexion, abduction, and shrugging.
- If tumor curettage has been carried out, ROM exercises should be practiced without delay. Once the wound has healed, usually 3 to 4 weeks after surgery, patients are referred to adjuvant radiation therapy. Radiation therapy usually is not required in patients who have undergone proximal humerus resection with endoprosthetic reconstruction.

Type III Metastases
- The wound is closed over suction drains. Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed.
- Passive and active ROM exercises of the elbow joint are initiated when the suction drains are removed.
- Once the wound has healed, usually 3 to 4 weeks after surgery, the patient is referred to adjuvant radiation therapy. Radiation therapy usually is not required, however, for patients who have undergone distal humerus resection with endoprosthetic reconstruction.

OUTCOMES
- Most patients who undergo resection of a humeral metastasis experience immediate relief of their metastasis-related pain. Patients who had a type II metastasis and who have undergone either curettage or intercalary resection have better ROMs and superior functional outcome than those who underwent proximal or distal humeral resection with endoprosthetic reconstruction.

Bickels et al.2 reported that overall total function in their 56 patients (95%) who had undergone resection of a humeral metastasis was over 68% of full normal upper extremity function, which is the mean functional outcome score after reconstruction of the upper extremity.4

COMPLICATIONS
- Thromboembolic complications, deep wound infections, and prosthetic loosening (rare)
- Proximal humeral prosthetic dislocation, from poor securing to the adjacent bones and inadequate soft tissue coverage
- Decreased ROM around the shoulder, due to poor attachment of the rotator cuff tendons to the prosthesis
- Decreased elbow ROM after surgery around distal humerus lesions
- Local tumor recurrence of less than 5% if adjuvant tumor removal was done adequately and adjuvant radiation therapy was administered.

REFERENCES
BACKGROUND

- The axilla is a common site for primary soft tissue sarcomas as well as for metastatic disease that involves the axillary lymph nodes, such as advanced breast cancer or melanoma.
- Sarcomas typically arise from the muscles defining the axillary space (FIG 1). Occasionally, however, they may arise directly from the brachial plexus or axillary vessels (eg, malignant peripheral nerve sheath tumors, neurosarcoma, leiomyosarcoma). Several types of malignant tumors may involve the axillary space and may require surgical resection. Primary sarcomas occur within the muscles (ie, the pectoralis major, latissimus dorsi, teres major, and subscapularis muscles) that make up the borders of the axillary space. Rarely do they develop within the axillary fat itself. More commonly, large metastatic deposits to the regional lymph nodes create large, matted masses that may require resection. The most common of these are metastatic melanoma and recurrent breast carcinoma. In addition, there are primary tumors that arise from the brachial plexus, either the nerves or the vessels. These include leiomyosarcomas of the axillary vein and neurofibrosarcomas of the adjacent nerves.
- Small masses may be clinically silent, but large masses inevitably will result in significant pain or loss of function due to involvement of the brachial plexus.
- Venous occlusion may be seen in neglected, massive tumors and is a harbinger of loss of limb and possibly even of life due to gangrene.
- Historically, surgical management of tumors in this location consisted of forequarter amputation; advances in radiographic imaging, adjuvant therapies, and surgical techniques have greatly improved our ability to perform limb-sparing resections in this location. The key to adequate and safe surgical resection of axillary tumors is the complete visualization and mobilization of the infracavicular portion of the brachial plexus and the axillary artery and vein and the cords that surround them. In general, imaging studies of the axillary space are not reliable for determining vascular or nerve sheath involvement. Multiple imaging studies are required, but the ultimate decision to proceed with a limb-sparing surgery is based on the intraoperative findings at the time of exploration.
- Axillary tumors extending along the chest wall often can be elevated off the underlying ribs; however, tumor extension into the intercostal spaces may require thoracotomy and rib resection to ensure adequate margins.

ANATOMY

- The axilla is a pyramid-shaped space between the chest wall and the arm defined by its surrounding muscles; it appears triangular when seen from either the coronal or axial views.
- The superior apex of the pyramid is formed by the junction of the clavicle and the first rib, approximately 1 to 2 cm medial to the coracoid process.
- The muscular boundaries of the axilla consist of the pectoralis major muscle anteriorly; the subscapularis, teres major, and latissimus dorsi muscles posteriorly; and the coracobrachialis, short head of the biceps, and triceps muscles laterally.
- Vital structures in the axilla include the major branches of the infracavicular portion of the brachial plexus and the axillary vessels. Any surgery in this region requires detailed knowledge of and familiarity with these structures.

Infracavicular brachial plexus

- The lateral, posterior, and medial cords of the infracavicular brachial plexus are found at the level of the pectoralis minor muscle, where they then give rise to five major branches: the median, ulnar, radial, musculocutaneous, and axillary nerves. The cords and branches run along the axillary vascular sheath as it passes through the axilla.
- The lateral cord gives rise to the musculocutaneous nerve, which travels along the medial aspect of the conjoint tendon, where it innervates the coracobrachialis and short head of the biceps. This nerve is the first to be identified during the exploration, because it is located in the superficial axillary fat inferior to the coracoid process. The largest portion of the lateral cord combines with the medial cord to create the median nerve.
- The posterior cord gives rise to the axillary nerve, which travels deep in the space and passes inferior to the glenohumeral joint and subscapularis muscle, where it innervates the deltoid muscle. The main portion of the posterior cord becomes the radial nerve, which travels posterior to the sheath and exits the axillary space along with the axillary sheath.
- The medial cord gives rise to the ulnar nerve, which travels along the most medial aspect of the sheath and exits distally along with the sheath. Because of its medial position along the sheath, the ulnar nerve is the nerve most commonly involved by tumors arising inferior to the brachial plexus, which can present with symptoms of either weakness or neuropathic pain. The median nerve, formed by a combination of the lateral and medial cords, is found on the lateral aspect of the sheath and exits the inferior aspect of the axillary space along the sheath.

Axillary vessels

- The axillary artery and vein are the continuation of the subclavian vessels, changing name as they enter the apex of the axilla below the clavicle and first rib. These vessels run in a single sheath, surrounded by the cords of the brachial plexus. The vessels pass through the axillary space medial to the coracoid to the medial aspect along the humeral shaft. Distal to the teres major, the vessels are renamed the brachial vessels. Major vascular branches in the axillary space include the thoracoacromial artery (with its pectoral, deltoid, clavicular and acromial branches), the lateral thoracic artery, the subscapular artery, and the anterior and posterior humeral circumflex vessels.
Lymphatics
- A substantial amount of fat surrounds the vascular sheath as it runs through the axilla along with the lymphatics and lymph nodes. Major clusters of lymph nodes are found along the brachial and axillary vessels, the lateral thoracic vessels (anterior axillary nodes), and the subscapular vessels (posterior axillary nodes). Axillary tumors may arise from lymph node metastases anywhere along the axillary vessels; the most common sites are nodes along the distal portion of the axillary vessels.

INDICATIONS
- Any mass in the axillary space should be considered for biopsy or resection given the propensity for malignant tumors to develop in the axilla and the predictability of neurogenic pain arising from continued tumor growth.
- Palpate radial and ulnar pulses and inspect for venous congestion or swelling. Consider venography to evaluate loss of venous drainage indicative of tumor involving the brachial plexus.
- Dimunition of arterial flow is a late sign indicative of potential loss of limb—consider forequarter amputation.
- Test sensation and strength of the axillary, radial, median, and ulnar nerves. Loss of nerve function typically is a very late finding indicative of major tumor involvement of the brachial plexus—consider forequarter amputation.

IMAGING AND OTHER STAGING STUDIES
- Three-dimensional imaging of the axillary space is important for accurate anatomic tumor localization and surgical planning. CT, MRI, angiography, and three-phase bone scans are used in the same manner as in other anatomic sites. In addition, we have found that venography (of the axillary and brachial veins) is essential to the evaluation of tumors of the axilla and brachial plexus.

Plain Radiography
- Careful inspection of posterior–anterior chest, anterior shoulder, and axillary view radiographs may reveal the presence of increased soft tissue density corresponding to an axillary mass.
- Bone involvement and the presence of calcifications in the soft tissues should be noted.

Computed Tomography and Magnetic Resonance Imaging
- Multiplanar MRI is extremely helpful in visualizing the anatomic contents of the axillary space and defining the anatomic extent of the tumor (FIG 2A–C).
- Axial CT imaging, with administration of IV contrast, demonstrates the major vascular structures, outlines the major muscle planes, and can detect subtle matrix formation within the tumor. CT is most useful in evaluating the bony walls of the axilla, specifically the humerus, glenohumeral joint, and scapula (FIG 2D).
- Certain tumors, such as lipomas or hemangiomas, may have characteristic findings on T1- and T2-weighted MRI sequences suggestive of the proper histologic diagnosis. The presence or absence of lymphatic involvement should be noted, particularly in patients with a history of metastatic carcinoma.
- Although the brachial plexus may be very difficult to visualize, particularly when tumors distort or compress the surrounding fatty planes, the anatomic relationship of the nerve sheath to the vessels helps pinpoint their location.
- Although CT imaging of the lungs is routinely performed as part of patient staging, the chest wall should always be inspected carefully to rule out tumor involvement of the rib cage and pleural cavity.

Nuclear Imaging
- Positron emission tomography (PET) imaging, particularly when fused with MRI or CT imaging data, may significantly improve the ability to detect lymphatic spread of tumor in and around the axilla. Standardized uptake values (SUV) correlate...
with tumor metabolism and may help to distinguish between benign and malignant lesions.

**Angiography and Other Studies**

- **Angiography** remains a valuable method of imaging the axilla, particularly for preoperative planning, because tumors may significantly distort the regional vascular anatomy through mass effect as well as through angiogenesis (ie, formation of abnormal vessels feeding the tumor; **FIG 3**). Venography, either alone or in conjunction with angiography, can demonstrate venous compression from surrounding tumors. The axillary arterial wall is thick and rarely shows signs of occlusion, whereas the axillary vein is a thin-walled structure that is easily compressed and infiltrated by tumor. Therefore, occlusion is almost synonymous with involvement of the vascular sheath and brachial plexus. Venous occlusion, visualized as absent filling of the axillary vein, is characteristic of significant tumor involvement of the brachial plexus and warrants careful thought as to whether a limb-sparing procedure is possible. The triad of axillary venous occlusion, distal motor weakness, and neuropathic pain is a very reliable predictor of tumor infiltration of the brachial plexus sheath.

- **Infraclavicular brachial plexus and vascular exploration** is mandatory before resection is attempted. Tumor involvement of these structures usually indicates that a forequarter amputation is required.

**Biopsy**

- **Core needle biopsy** is the preferred method of diagnosis, because it minimizes risk of injury and contamination of the axillary contents. If a metastatic lesion is suspected, fine needle aspiration is the most appropriate means to identify carcinoma cells.

- **Large or superficial palpable masses** are amenable to needle biopsy in the clinic, whereas deep lesions are best approached with radiographic guidance using CT or ultrasound.

- **The biopsy tract should be positioned after consultation with the treating surgeon** to ensure proper location along the path of planned resection. The biopsy should be performed through the base of the axillary space, not through the pectoralis major muscle or near the vascular sheath. It can easily be performed under CT guidance. Deep-seated lesions near the chest wall also can be approached in this manner. Anterior lesions, on occasion, can be approached through

**FIG 2** - Imaging studies of the axillary space. **A.** T2-weighted MRI scan showing a large mass (arrow) occupying the axillary space. **B.** Coronal T2-weighted MRI scan showing a large tumor below the pectoralis major that fills the entire axillary space, from the clavicle to the lower end of the base of the pyramid that forms the axillary space. **C.** Axial MRI scan of a large fungating tumor from the axillary space. There are no muscle or skin components adjacent to the tumor, which protrudes anteriorly. **D.** CT scan of a primary bony sarcoma with a large extraosseous component that extends into the axilla. This finding is an excellent indication for the use of the anterior portion of the utilitarian incision for resections of large tumors of the proximal humerus. It demonstrates that the axillary space must be completely visualized and that the vessels must be mobilized.

**FIG 3** - Schematic representation of an axillary tumor with its relationship to the axillary sheath. **A.** The tumor does not involve the sheath but it displaces the artery, vein, and accompanying nerves. **B.** The tumor has invaded the axillary sheath, occluding the axillary vein. This is a significant finding on venography that almost always indicates vascular infiltration. **C.** Axillary venogram performed and shows complete occlusion of the axillary vein (red line). Collateral filling is seen around the mass. Obliteration of the vein almost always indicates infiltration of the infraclavicular plexus. **D.** Gross specimen following forequarter amputation showing tumor infiltration around the nerves and cords of the brachial plexus and surrounding the axillary artery and vein.
the lower portion of the pectoralis major muscle. The biopsy site must be removed in its entirety during resection of the tumor.

Open biopsy should be reserved for those patients in whom core needle biopsy was nondiagnostic or in those cases when additional samples of tumor are necessary for research purposes. Great care must be taken to avoid contamination of critical structures and otherwise uninvolved tissue planes. A small laterally placed incision, avoiding the pectoralis major muscle and the axillary sheath, is recommended.

Although small tumors are amenable to excisional biopsy, care must be taken to remove the entire pseudocapsule in the event that the tumor is found to be a sarcoma.

SURGICAL MANAGEMENT

Although many patients can safely undergo limb-sparing resections of the axillary space, extremely large or neglected tumors may present with significant involvement of the axillary vessels and brachial plexus.

Evidence of vascular involvement and, therefore, nerve sheath invasion should raise the question as to whether the patient is suitable for a limb-sparing resection; forequarter amputation may be necessary.

Proper placement of the biopsy tract is critical in limiting potential injury or contamination of the axillary space; large, poorly planned open biopsy tracts may necessitate forequarter amputation.

Adjuvant radiation to the axilla carries an increased risk of significant lymphedema, which can be functionally disabling, as well as potential wound problems.

Preoperative Planning

Careful review of preoperative imaging studies is necessary to formulate a surgical plan.

Extent of resection is determined by tumor size and stage and whether a palliative or curative option exists.

Consideration should be given to preoperative angiography or venography when vascular involvement is suspected on the basis of CT or MRI scans.

A double-lumen endotracheal tube should be used whenever preoperative imaging suggests significant rib involvement. Deflation of the underlying lung protects the lung during the rib resection.

Positioning

Positioning of the patient for axillary resection is determined by the size and anatomic extent of the tumor to be removed.

Most axillary tumors are best approached via an extensile anterior incision with the patient in the supine position. The patient is brought to the edge of the table, and a large padded bump is placed under the medial portion of the scapula to facilitate exposure. After prepping and draping the arm, axilla, and anterior shoulder girdle, the arm is placed over a padded Mayo stand, and the surgeon stands inside the axilla for the procedure. The surgical assistant is best placed superior to the arm to facilitate retraction.

Less commonly, the posterior or inferior portion of the axilla is involved, requiring access to the back of the axilla and shoulder girdle. When this is the case, the patient should be placed in the lateral decubitus position so that the entire shoulder girdle may be easily accessed. The arm is elevated over the patient’s head and supported by an assistant to permit access to the axilla. The surgeon should stand anterior to the patient, closest to the brachial plexus.

Approach

Anterior/medial utilitarian approach. The most commonly used approach for axillary resections is the common extensile approach to the shoulder girdle and arm, running along the deltopectoral groove. As the pectoralis major comprises the anterior anatomic boundary of the axilla, release of its broad tendon insertion into the humerus is vital to proper exposure of the axillary contents (FIG 4).
The traditional incision along the inferior boundary of the axilla offers a very limited view of the axillary contents and makes identification of the brachial plexus difficult. This incision is best used only for patients with tumor limited to the chest wall (inferior axillary resection) or posterior (latissimus) axilla.

A combination of the traditional axillary incision with the anterior extensile incision may be performed by extending the skin incision across the pectoralis muscle, meeting the anterior incision near the coracoid process (FIG 5). This is useful in the salvage of patients having attempted resections or open biopsies through the inferior axilla.

**FIG 5**  Surgical technique of exposure and resection of axillary tumors. A. The anterior portion of the utilitarian shoulder girdle incision is used. This is an extended deltopectoral incision, which may be curved in a posterior direction toward the axilla. The pectoralis major is then released 1 cm from its insertion onto the humerus. This is the first layer of axillary space musculature. B. Operative photograph showing the second muscle layer. The short head of the biceps and the pectoralis minor attach to the coracoid. The axillary contents with the vessels and nerves are not seen, because they are enclosed within the axillary fat and fascia. C. The musculocutaneous nerve is found 1 to 2 cm distal to the coracoid, below the insertion of the pectoralis minor and adjacent to the short head of the biceps. This nerve must be identified before the second layer of muscles is released. D,E. Resection bed following removal of the tumor of the axillary space. It is necessary to begin at the level of the clavicle and ligate all branches that pass distal and inferior to the tumor mass. Most tumors arise inferior to the neurovascular bundle.

**Axillary Exploration Through Anterior Approach**

- Identify landmarks.
  - Palpate and mark the bony landmarks: coracoid process, acromion, acromioclavicular joint.
  - Palpate the groove between the deltoid and pectoralis muscles.
- Incision
  - The skin incision should extend along the deltopectoral groove to the coracoid process and may curve into the axilla as needed. Open this interval, sparing or ligating the cephalic vein as necessary.
- Detachment of pectoralis major (TECH FIG 1)
  - Identify the pectoralis major insertion into the humeral shaft and release using the electrocautery approximately 1 cm from the bone to preserve enough insertion for later repair. After the pectoralis major is fully released from the humerus, retract the muscle medially over the anterior chest wall, preserving its vascular pedicles and exposing the serratus anterior.
  - Development of anterior axillary fascial plane
  - Develop the surgical plane along the clavpectoral fascia, which is a thick, well-defined layer that contains the axillary space and structures.
  - Release of conjoint tendon and pectoralis minor
  - Palpate the conjoint tendon insertion at the coracoid process and release. Protect the musculocutaneous nerve inserting into the muscle belly just distal to the tendon from the underlying brachial plexus by limiting distal retraction. Release of these muscles is key to exposing the vascular sheath and brachial plexus.
Neurologic exploration
- Identify the sheath of the brachial plexus and axillary vessels underneath the detached conjoint tendon. The musculocutaneous nerve comes around the lower border of the coracoid under the pectoralis minor muscle. The axillary nerve comes off deeper from the posterior cord and travels toward the shoulder joint. Both must be identified at this stage.

Vascular exploration
- Completely exposure and control the axillary vessels and brachial plexus proximally by opening the pedicle sheath and placing loops around the major structures; careful dissection is then used to mobilize these structures distally into the arm. Mobilization often is necessary to facilitate adequate exposure prior to tumor resection.

Resection of tumor
- All of the feeding branches entering into the mass are serially ligated and transected. Axillary fat is left around the tumor mass as the only true margin. The tumor is removed, tagged for orientation, and sent to pathology for margins and histologic evaluation.

Resection of Anterior Axillary and Chest Wall Tumors
- Tumors involving the pectoralis and serratus anterior can be resected safely following identification and mobilization of the critical neurovascular structures; these muscles may be elevated directly off the underlying chest wall.
- Resection of high-grade sarcomas may require sacrifice of one or more major branches of the brachial plexus to achieve an adequate oncologic margin. Loss of the median nerve results in the greatest loss of hand function.
- Chest wall involvement requires thoracotomy and resection of contiguous ribs; the underlying lung is deflated before opening the chest cavity to protect it.
- Intrathoracic extent of tumor may be determined by palpation of the pleural surface following thoracotomy; osteotomy of the ribs using a rib cutter under direct visualization permits en bloc removal of the involved chest wall.

Lymphatic involvement, frequently seen in patients with breast cancer extending into the axilla, requires meticulous dissection of the axillary and subclavian vessels proximally; sampling of lymph nodes is crucial in patients with carcinomas or melanoma.

Resection of Posterior Axillary Tumors
- Further exposure of the axilla is achieved by extending the vascular and neurologic exploration further down the arm, widening the area to reach posterior or distal tumors (TECH FIG 2).
- Identify the latissimus insertion into the humerus, which defines the posterior aspect of the axilla distal and posterior to the pectoralis insertion.
- Before performing tendon release, identify and protect the axillary nerve proximal to and the radial nerve distal to the tendon; both nerves serve to tether the brachial plexus and reduce the ability to retract the plexus.
- Tumor involvement of the latissimus may require sacrifice of one or both of these nerves.
- The latissimus muscle may be elevated off the chest wall as necessary for tumor resection.
- Chest wall involvement may require thoracotomy and resection of contiguous ribs; deflate the lung before opening the chest cavity to protect the underlying lung.
- Intrathoracic extent of tumor may be determined by palpation of the pleural surface following thoracotomy. Osteotomy of the ribs using a rib cutter under direct visualization permits en bloc removal of the involved chest wall.

Reconstruction Following Tumor Resection
- Repair and reconstruction of the axilla is necessary following tumor resection.
- Insertion of an epineural catheter into the sheath of the brachial plexus permits postoperative administration of local anesthetics such as bupivacaine (Marcaine) to minimize postoperative pain.
Reattachment of the conjoint tendon and pectoralis minor to the coracoid with the use of mattressed, nonabsorbable sutures covers the brachial plexus and axillary vessels.

Defects of the chest wall can be covered with local rotation flaps using the latissimus dorsi or pectoralis major muscle, which may be tenodesed to the subscapularis tendon as needed.

Careful wound closure over closed suction drains and placement of absorptive padding in the axilla reduce the risk of skin maceration and wound infection. Use of a sling or shoulder immobilizer permits early mobilization of the patient.

Functional deficits resulting from resection of portions of the brachial plexus may require delayed reconstruction after completion of adjuvant treatment.

**PEARLS AND PITFALLS**

**Preoperative angiogram and venogram**
- In addition to mapping out the course of the vessels, loss of flow through the brachial or axillary vein is a worrisome sign that tumor involves the brachial sheath. This often is the first sign of an unresectable tumor (FIG 6) for which forequarter amputation should be considered.

**Axillary incision**
- The axillary incision is not easily extended and severely restricts the ability to dissect out the neurovascular bundle. This incision is rarely indicated.

**Pectoralis major**
- Detachment of the humeral insertion is key to opening up the entire axilla and permits exploration of all important structures. It is not necessary to reattach the pectoralis to its insertion; rotation of this muscle is valuable for reconstruction of defects around the shoulder.

**Musculocutaneous nerve**
- Injury due to over-retraction of the conjoint tendon may occur, leading to loss of elbow flexion and resulting disability. This may be unavoidable for tumors involving the conjoint tendon.

**FIG 6** • Unresectable sarcoma of the axilla. A. Multiple recurrences with a large soft tissue mass. B. Operative view through the anterior incision showing a large tumor surrounding the axillary sheath.
POSTOPERATIVE CARE

- Postoperatively, a sling or shoulder immobilizer is applied to support the arm. Closed suction drains are removed after output slows.
- Patients are mobilized on postoperative day 1, from bed to chair. Ambulation is begun as tolerated to improve pulmonary function.
- A sling is used until the skin wound is sufficiently healed.
- Early shoulder motion with assistance is started as soon as the wound permits.
- Aggressive wrapping of the arm and use of custom-fitted compression gloves is started if there is evidence of lymphedema.

OUTCOMES

- Functional outcome is determined by the amount of muscle resection and loss of particular nerves.
- Loss of shoulder motion results in mild disability, which is easily compensated for by use of the other arm for overhead activities.

COMPLICATIONS

- Although uncommon, the complication most often seen following axillary resection is the accumulation of third-space fluid with secondary wound problems. Previous radiation therapy increases this probability. Use of suction drains and compressive dressings helps mitigate this complication.
- Chronic pain may occur following nerve resection, especially after radiation. Use of nerve sheath catheters with postoperative infusion of local anesthetics may reduce the incidence of neuropathic pain.
- Lymphedema may result in significant disability and chronic pain; early aggressive treatment may lessen the severity or duration of swelling. The risk is greatest following surgery and radiation therapy.
- Infections and flap necrosis following axillary tumor resections rarely occur, because of the substantial network of subcutaneous blood vessels perfusing the shoulder girdle.

REFERENCES

BACKGROUND
Forequarter amputation (interscapulothoracic amputation) entails en bloc removal of the upper extremity together with the scapula and the lateral aspect of the clavicle. This mutilating amputation of the upper extremity traditionally was done for high-grade sarcomas around the proximal humerus and scapula (FIG 1). Tumor response to chemotherapy and radiation therapy and the option of endoprosthetic reconstruction have made these procedures rare, and limb-sparing resections are safe alternatives in 90% to 95% of these cases.

ANATOMY
The upper extremity and scapula are attached to the upper torso and chest wall by soft tissue elements (ie, the rhomboid, levator scapulae, trapezius, pectoralis major and minor, latissimus dorsi, teres major, and serratus anterior muscles) and a single bone (ie, the clavicle). All of these must be transected to allow the performance of a forequarter amputation.

The axillary vessels and infraclavicular portion of the brachial plexus pass just inferiorly to the coracoid process, which is easily palpable, and lie below the deltopectoral fascia. These structures should be evaluated before surgery to determine the segment that can be safely transected and ligated, especially because large tumors may come close to the thoracic outlet.

Large tumors of the periscapular area may easily extend into the posterior triangle of the neck, the adjacent paraspinal muscles, and the underlying chest wall. Tumor extension into these anatomic sites must be evaluated carefully before surgery in case en bloc resection of a chest wall segment or a concomitant neck dissection is required.

INDICATIONS
Large soft tissue tumor around the proximal arm or axilla with neurovascular encasement and compromise and extension across the joint.
Large bone tumor (primary bone sarcoma or metastatic lesion) of the proximal humerus and scapula with and extensive soft tissue component and invasion into the shoulder joint and surrounding muscles.
Extensive locoregional tumor recurrence around the shoulder girdle.
Palliation of intractable pain or tumor fungation, associated with a rapidly enlarging lesion that has not responded to chemo- or radiation therapy (FIG 2).
Forequarter amputation usually is contraindicated when the tumor extends to the chest wall or to the posterior triangle of the neck and paraspinal muscles. This surgery can be considered in selected cases with no metastases, in which concomitant chest wall resection or neck dissection can achieve negative margins and patients can withstand the physiologic impact of these combined major surgeries.

IMAGING AND OTHER STAGING STUDIES
The combined use of CT and MRI allows the extent of bone and soft tissue tumor involvement to be determined and, thus, the potential size of the soft tissue margins to be estimated at the neck, paraspinal muscles, and chest wall (FIG 3).
Angiography is extremely helpful in locating the anatomic position of the axillary and brachial vessels, and in evaluating whether these structures are involved by tumor. Physical anomalies (eg, a duplicate axillary artery) occasionally are identified as well. Angiography also makes it possible to determine accurately the best level of ligation of the axillary vessels.
No imaging studies can distinguish precisely whether the brachial plexus is infiltrated by tumor or whether the vessels and plexus are simply displaced, and they provide only indirect evidence of tumor extension to the nerves. On the other hand, venography of the axillary veins is a simple and accurate method of determining brachial plexus involvement. A brachial venogram will show complete obstruction of the main axillary veins when tumor is infiltrating the brachial plexus, whereas it will show venous patency and displacement when a tumor is adjacent to, but not infiltrating, the plexus.

SURGICAL MANAGEMENT
Position
The patient is placed in a full lateral position and is secured to the operating table at the hips with tape. Alternatively, a VAC pack can be used to secure the torso. An axillary roll is placed under the axilla to allow full excursion of the chest, and a sponge-rubber pad is placed under the hip to prevent ischemic damage to the skin in this area. The skin is prepared in the usual manner, and the tumor-bearing extremity is draped free (FIG 4).

Text continues on page 1837
A. Forequarter amputation entails en bloc removal of the upper extremity together with the scapula and the lateral aspect of the clavicle. B. MRI scan showing an extremely large axillary sarcoma involving the shoulder joint. A forequarter amputation was performed. A forequarter amputation is less commonly performed today than in the past. The most common indications include large sarcomas or carcinomas of the axillary space with involvement of the bony shoulder girdle or tumor fungation through the axilla. Occasionally, metastatic breast carcinoma to the axilla requires forequarter amputation if there is brachial plexus involvement (as a palliative procedure).

A. Surgical illustration. B. Lymphoma of the shoulder girdle and brachial plexus with a non-union pathological fracture and no response to radiation therapy. This patient’s arm was essentially useless and was extremely painful. It is rare for lymphomas to fail to respond to adjuvant therapy. C. Clinical photograph demonstrating tumor fungation through the skin.
FIG 3 • A. Plain radiograph showing destruction of the proximal humerus and the shoulder joint, as well as a non-union fracture. B. Plain radiograph demonstrating very large soft tissue mass in the axillary region caused by extraosseous growth of a Ewing sarcoma. C. CT scan showing a large mass protruding into the axillary space with probable involvement of the brachial plexus. D. Coronal MRI scan of a 63-year-old woman who presented with a fungating sarcoma of the axilla with extension to the proximal arm and scapula. The neurovascular bundle was encased and compressed by the tumor, and the patient had overt edema of the upper extremity and compromised radial and median nerve functions. E. CT scan demonstrating a large Ewing sarcoma. F. MRI scan showing the tumor protruding through the skin, fungating from the axillary area and deep, near the serratus anterior chest wall. G. Axillary venography showing that the axillary vein is almost completely thrombosed from compression by surrounding tumor. This appearance has proven to be an extremely reliable prognostic finding of brachial plexus involvement. If axillary venography shows axillary vein obstruction, a forequarter amputation almost is always required at the time of exploratory surgery.
The patient is placed in a full lateral position and is secured to the operating table at the hips with tape. Alternatively, a VAC pack can be used to secure the torso. An axillary roll is placed under the axilla to allow full excursion of the chest, and a sponge-rubber pad is placed under the hip to prevent ischemic damage to the skin in this area. The skin is prepared, and the tumor-bearing extremity is draped free.

Positioning of a 35-year-old woman with a recurrent sarcoma of the axilla. Note the scar from the previous surgery at the deltopectoral groove. Intraoperative photographs showing a locally recurrent osteosarcoma at the proximal arm and axilla in a 34-year-old patient. A 59-year-old woman with a locally recurrent malignant melanoma extensively involving the arm, axilla, and shoulder that grew rapidly despite chemotherapy, immunotherapy, and radiation. Anterior approach. The first structure transected is the pectoralis major muscle. Posterior approach. The incision starts proximal over the shoulder and extends distally along the axillary border of the scapula and curves toward the midline. A large subcutaneous (or fasciocutaneous) flap is developed. The pectoralis major muscle has been transected; this photograph demonstrates the pectoralis minor over the tumor. A large posterior fasciocutaneous flap following a forequarter amputation for a large fungating tumor of the anterior axillary area. Therefore, a large posterior fasciocutaneous flap has been raised using a component of skin from the posterior two-thirds of the arm. This is a common technique when the usual anterior flap is compromised. This extended posterior fasciocutaneous flap is extremely reliable and can be rotated to close large chest wall and anterior defects as well as the posterior triangle of the neck. Closure of the entire surgical defect. Note the flap has covered the large area extending to the midline anterior, to the base of the neck, and the adjacent chest wall. (A: Courtesy of Martin M. Malawer.)
Incision

- The anterior component of the incision starts over the clavicle about 2 cm lateral to the sternoclavicular joint. Caudally, the incision line is in or near the deltopectoral groove; superiorly, it crosses the tip of the acromion. These two lines meet below the axilla to include the skin-bearing axillary hair and hematoma that results from the biopsy (TECH FIG 1).

- The final shape of the flaps and position of the lines of incision will vary according to the individual tumor extent. Because of the excellent blood supply to the skin in this region, long anterior or posterior flaps generally survive even though they are closed under considerable tension.

**TECH FIG 1**

- **A** The anterior component of the incision starts over the clavicle about 2 cm lateral to the sternoclavicular joint. Caudally, the incision line is in or near the deltopectoral groove; superiorly, the incision line crosses the tip of the acromion. Intraoperative photographs showing the anterior (B) and posterior (C) arms of the incision. These two lines meet below the axilla to include the skin-bearing axillary hair. **D.** The anterior flap is elevated, exposing the clavicle, acromion, and the overlying origin of the pectoralis major muscle. **E.** The origin of the muscle is detached from the clavicle, and an osteotomy is performed. **F.** The underlying brachial plexus and subclavian vessels are identified and clamped.
tension. Occasionally, large tumors extend to the overlying skin and require en bloc resection with a substantial area of skin. This results in a wound defect that cannot be closed primarily and will require a skin graft or be left for a delayed wound closure.

- The anterior skin flap, which can be extended to the mid-sternum, usually is constructed first, with the surgeon standing in front of the patient. The surgeon then switches position to stand behind the patient and constructs the posterior flap to the medial border of the scapula.

### Removal of the Affected Limb and Scapula

- Anterior vascular exploration is performed by detaching the pectoralis major muscle from the clavicle. A clavicular osteotomy is performed at the proximal one-third junction, and the underlying brachial plexus and subclavian vessels are identified. A Statinski clamp can be placed high along the vessels, and surgery can then proceed as planned.

- The posterior approach is used to detach the scapula from the rhomboid, trapezius, levator scapulae, and latissimus dorsi muscles. The scapula is lifted from the chest wall by detaching the serratus anterior muscle from its inner plate and the latissimus dorsi at its lowest point. This exposes the posterior chest wall and allows the surgeon to place his or her hand into the axillary space to check for chest wall or intercostal muscle involvement, whereupon the planned amputation can proceed.

- If the chest wall is involved, a combined chest wall and forequarter amputation can be performed. An axillary incision is made to connect the anterior and posterior incisions. The entire forequarter is removed after ligation and transection of the brachial plexus and subclavian vessels (TECH FIG 2).

### Soft Tissue Reconstruction and Wound Closure

- The area is copiously irrigated. The large posterior flap is closed over the remaining chest wall defect (TECH FIG 3A,B). Marked redundancy of the skin may present an unacceptable cosmetic appearance, so every effort should be made to ensure that the skin flaps are carefully approximated.

- The mid-portion of the long posterior skin flap is approximated to the mid-portion of the anterior flap. Carrying out the closure in this way pleats the longer posterior skin flap and prevents unsightly folds of skin. A two-layered closure, first of superficial fascia and then of skin, is used. Generous suction drainage under the anterior and posterior skin flaps is secured (TECH FIG 3C,D). Suction drains are removed when serous drainage is minimal.

---

**TECH FIG 2 • A,B.** Detachment of the scapular attachments of the rhomboids, trapezius, levator scapulae, and latissimus dorsi muscles. (continued)
**TECH FIG 2** (continued) C, D. The scapula being lifted from the chest wall by detaching the serratus anterior muscle from its inner plate and the latissimus dorsi at its lowest point. E, F. Exposure of the posterior chest wall. This allows the surgeon to palpate the surface of the chest wall and axilla for tumor detection and determine if amputation can proceed as planned or if additional chest wall resection is required. G. The subclavian vessels are ligated and the brachial plexus transected. H. This allows removal of the forequarter. I. Gross findings showing tumor involvement of the brachial plexus as well as the axillary artery and vein. Because this tumor closely approached the neck, the subclavian artery was ligated proximally.
**TECH FIG 3**  
**A.** Illustration showing the exposed chest wall and fasciocutaneous flaps remaining after forequarter amputation. **B.** Intraoperative photograph showing mobilization of the large posterior flap anteriorly over the chest wall. Illustration (C) and intraoperative photograph (D) showing split-thickness graft used to cover the chest wall in tumors with skin infiltration over a wide area.

**PEARLS AND PITFALLS**

| Preoperative | Detailed radiologic assessment of the soft tissue extent of the tumor, its vascular anatomy, and determination of neck and chest wall invasion. If the latter exists and amputation is feasible, make the necessary preparations for concomitant chest wall resection or neck dissection. |
| Intraoperative | Patient is placed in a full lateral position. Clavicular osteotomy and clamping of the subclavian vessels are done first.  
Intraoperative palpation of the chest wall to assess tumor extension.  
Trimming of the posterior flap to avoid redundancy and formation of skin folds.  
Bupivacaine (Marcaine) infusion through an epineural catheter in the nerve sheath in an effort to decrease postoperative pain and causalgia. |
| Postoperative | Assisted postoperative ambulation to avoid loss of balance. Early occupational therapy. |

**POSTOPERATIVE CARE AND REHABILITATION**

- Continuous suction usually is required for 5 to 7 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed. Phantom pain (causalgia) is a major problem following high-level amputations. We use an epineural catheter placed into the axillary sheath at the time of surgery and infuse 0.25% bupivacaine for 3 to 5 days postoperatively. This decreases postoperative pain and may lessen late causalgia syndromes.
- Patients initially have difficulty in keeping their balance because of the acute weight inequality of their upper torso and tend to fall toward the contralateral side. This problem typically resolves itself after a few days of assisted walking.
- It is crucial to have an occupational therapist involved early in the postoperative period to teach the patient how to perform the activities of daily living with a single upper extremity. This is even more critical when the amputated extremity is the dominant one.
- A cosmetic prosthesis can be fitted on wound healing and resolution of wound edema, usually 4 to 6 weeks after surgery.

**OUTCOMES**

- Forequarter amputation is a mutilating procedure that has a profound aesthetic, psychological, and functional impact on patients. Furthermore, it is done for large and aggressive tumors that bear a high risk of metastatic dissemination. Most patients who undergo forequarter amputation gain local con-
Chapter 14  FOREQUARTER AMPUTATION

Pain relief and improved quality of life are pronounced in patients who have undergone palliative amputation to control intractable pain associated with a rapidly enlarging tumor that had not responded to chemo- and radiation therapy. Most patients who undergo forequarter amputation regain reasonable function and are able to perform most daily activities.

For some still undefined reason, phantom limb pain is less common and less disturbing than that associated with high amputation of the lower extremities.

COMPLICATIONS

- Flap ischemia, usually superficial and marginal because of the good blood supply of the shoulder girdle (FIG 5); it usually resolves spontaneously.
- Occasionally, full-thickness necrosis of the posterior flap. A clear demarcation line appears after 4 to 7 days, after which debridement of the necrotic segment and primary closure is carried out.
- Phantom limb pain
- Local tumor recurrence

REFERENCES

BACKGROUND
- Tumors of the upper extremity may cause extensive soft tissue and bone destruction and extend into the main neurovascular bundle. In those extreme situations, limb-sparing may not be feasible, and amputation is required to achieve wide margins of resection and local tumor control.
- Above-elbow amputations may be required for advanced soft tissue and bone sarcomas of the forearm and around the elbow (FIG 1A). Below-elbow amputations are performed for such tumors of the forearm and the hand (FIG 1B).
- Above- and below-elbow amputations rarely are done, because (1) the upper arm, elbow, and forearms are rare location for musculoskeletal tumors and (2) when tumors do occur at one of those sites, they are noticed in relatively early stages and in most cases are resectable. Furthermore, administration of preoperative chemotherapy and availability of isolated limb perfusion have made it possible to achieve control in most patients with a large tumor.
- Nonetheless, above- and below-elbow amputations retain a definitive role in the management of soft tissue and bone tumors of the upper extremity.

ANATOMY
- Above-elbow amputations can be metaphyseal (high), diaphyseal, or supracondylar.
- High above-elbow amputations are those proximal to the deltoid tuberosity. Patients who undergo amputation proximal for musculoskeletal tumors and (2) when tumors do occur at one of those sites, they are noticed in relatively early stages and in most cases are resectable. Furthermore, administration of preoperative chemotherapy and availability of isolated limb perfusion have made it possible to achieve control in most patients with a large tumor.
- Below-elbow amputations should preserve the maximal length of both radius and ulna. Although tumors of the hand are treated by a standard below-elbow amputation, performed through the distal third of the forearm, tumors of the distal forearm require a higher amputation and warrant special consideration. A minimum of 2.5 to 3 cm of bony stump, measured from the radial tuberosity, is required to preserve function. Additional length in a very short stump can be obtained by releasing the biceps tendon; adequate flexion of the stump will be provided by the brachialis muscle.

INDICATIONS
- Extensive soft tissue and bone tumor extension with no option for reconstruction and reasonable function following resection (FIG 2A–E)
- Local recurrence formerly was considered a primary indication for amputation, but the mere presence of a recurrent sarcoma no longer is an immediate indication for an amputation. Whether or not it is possible to resect the recurrent tumor without compromising the function of the extremity is the factor on which the decision to amputate is based (FIG 2F).
- Major vascular involvement
  - The neurovascular bundle within the arm is tightly integrated in a closed anatomic space. The cephalic vein usually provides sufficient collateral flow if the brachial or the axillary vein has to be sacrificed. However, although the tumor mass occasionally can be delicately dissected off the brachial artery, in most cases of vascular involvement the brachial artery is extensively encased and amputation is inevitable.
  - The compact nature of the vascular supply to the wrist makes involvement of the radial and ulnar arteries likely when a large tumor invades the volar aspect of the distal forearm. In such a case, the incidence of morbidity and failure associated with resection and reconstruction using a vascular graft of one of these vessels is prohibitively high.
- Major nerve involvement
  - In general, one nerve around the arm can be sacrificed, and a two-nerve deficit is tolerated. Sacrifice of the three major nerves leaves the patient with a functionless extremity that is better off amputated.
  - Techniques for nerve grafting for replacement of a section of the median, radial, or ulnar nerves have not yet developed to a point at which satisfactory function can be obtained.

IMAGING AND OTHER STAGING STUDIES
- Patients requiring above- or below-elbow amputations for a soft tissue or primary bone sarcoma must undergo complete staging to allow the surgeon to determine the level of amputation and extent of soft tissue resection needed. Complete staging allows determination of full tumor extent and, as a result, the site for skin incision, shape of the flaps, and site of osteotomy.
- The combined use of plain radiography, CT, and MRI is necessary to determine the proximal extent of the intraosseous and soft tissue components of the tumor. In general, the more proximal of the two levels of involvement (ie, bone or soft tissue) determines the level of amputation.
A. Above-elbow amputations are done for advanced soft tissue and bone sarcomas of the forearm. Skin incisions and osteotomy sites for metaphyseal (high), diaphyseal, and supracondylar above-elbow amputations.

B. Below-elbow amputations are done for advanced soft tissue and bone tumors of the forearm and hand. Skin incision and osteotomy site for below-elbow amputation. (Courtesy of Martin M. Malawer.)

FIG 2 • Clinical photograph (A) and plain radiograph (B) showing metastatic carcinoma of lung to the mid-ulna with extensive bone destruction and soft tissue extension, requiring above-elbow amputation to achieve local tumor control and palliate pain. Clinical photograph (C) and plain radiograph (D) showing high-grade sarcoma of the first metacarpus, requiring below-elbow amputation to achieve local tumor control. E. Extensive squamous cell carcinomatosis of the forearm. Above-elbow amputation was done. F. Recurrent high-grade sarcoma of the distal forearm. The recurrent disease is diffused, and wide resection would result in loss of neurovascular structures and all flexor tendons, and would end with an extensive soft tissue defect in a previously irradiated surgical field. Below-elbow amputation was done, therefore following the previously planned incision (outlined).
ABOVE- AND BELOW-ELBOW AMPUTATIONS

- The patient is supine with the ipsilateral shoulder slightly elevated. Standard anterior–posterior “fishmouth” flaps usually are used (TECH FIG 1A). However, medial–lateral flaps occasionally may be needed because of local tumor anatomy. Because of the excellent blood supply to the upper extremity, wound healing is rarely a problem, regardless of flap configuration. The skin and superficial fascia are divided perpendicular to the skin surface.

- Large blood vessels are ligated in continuity and then suture ligated. The nerves are handled delicately. They are pulled approximately 2 cm from their muscular bed, doubly ligated with nonabsorbable monofilament suture, and cut with a knife.

- Muscles are transected according to the flap design, and the humerus or the radius and ulna are cut at the appropriate location, as determined by the preoperative imaging studies (TECH FIG 1B,C). The radius and ulna are transected so that they are the same length.

- For optimal function and mobility of the stump, it is important for muscle groups to be positioned tightly and securely over the cut ends of the bones (TECH FIG 2A,B). Myodesis is reinforced by Dacron tapes, passed through drill-holes made in the cut end of the bone. Superficial fascia and skin are closed over closed suction drains (TECH FIG 2C,D). An epineural catheter, bolused with 0.25 J. bupivicane, is inserted into the nerve sheath (TECH FIG 2E).

TECH FIG 1 • A. Anterior–posterior “fishmouth” flaps are used. The skin and superficial fascia are divided perpendicular to the skin surface. B,C. Osteotomies are performed at the appropriate location, as determined by the preoperative imaging studies. B. Above-elbow amputation. C. Below-elbow amputation. The radius and ulna are transected at equal lengths. (Courtesy of Martin M. Malawer.)
Chapter 15  ABOVE-ELBOW AND BELOW-ELBOW AMPUTATIONS

TECH FIG 2 • Muscle groups are positioned tightly and securely over the transected bone ends. A. Above-elbow amputation. B. Below-elbow amputation. C, D. Superficial fascia and skin are closed over closed-suction drains. C. Final closure for above-elbow amputation. D. Below-elbow amputation with closed-suction drains. E. Closed-over surgical wound. An epineural catheter, which provides continuous flow of local analgesics (specifically 0.25% bupivacaine), was inserted into the nerve sheath to control postoperative pain. (A–D: courtesy of Martin M. Malawer.)

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Preoperative</th>
<th>Detailed preoperative imaging for evaluation of tumor extent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intraoperative</td>
<td>Functional and tight myodesis over the cut ends of the bones</td>
</tr>
<tr>
<td>Postoperative</td>
<td>Rigid dressing and early range-of-motion exercises</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- A rigid dressing is applied immediately postoperatively to decrease pain and edema and facilitate maturation of the stump (FIG 3). Care must be taken to protect the skin that directly overlies the bone.
- Stump edema rarely is a significant problem in the upper extremity, and prosthesis training should begin as soon as possible after surgery.
- Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed.
- Active and passive range-of-motion exercises around the shoulder and elbow (if it exists) are practiced as tolerated.

COMPLICATIONS

- Wound dehiscence
- Deep infection
- Loss of elbow motion (when above-elbow amputation is done)
- Phantom limb pain
BACKGROUND
- Conventionally, curettage or piecemeal excision has been the usual approach to vertebral tumors.
- These approaches have clear disadvantages, however, including high risk of tumor cell contamination to the surrounding structures and residual tumor tissue at the site due to difficulty in demarcating tumor from healthy tissue.
- These contribute to incomplete resection of the tumor as well as high local recurrence rates of the spinal malignant tumor.
- To reduce local recurrence and to increase survival, we have developed total en bloc spondylectomy (TES).10,11,14
- In this method, the entire vertebra or vertebrae containing the malignant tumor are resected, together with en bloc laminectomy, en bloc corpectomy, and bilateral pediculotomy using a T-saw through the posterior approach.9
- Using this technique, we are able to excise the tumor mass together with a wide or marginal margin.

ANATOMY
- The following tissues serve as barriers to spinal tumor progression: the anterior longitudinal ligament (ALL), the posterior longitudinal ligament (PLL), the periosteum abutting the spinal canal, the ligamentum flavum (LF), the periosteum of the lamina and spinous process, the interspinous ligament (ISL), the supraspinous ligament (SSL), the cartilaginous endplate, and the cartilaginous annulus fibrosus. However, both the PLL and the periosteum on the lateral side of the vertebral body are “weak” anatomic barriers. In contrast, the ALL, cartilaginous endplate, and annulus fibrosus are “strong” barriers. In the spine one vertebra could be regarded as a single oncologic compartment and the surrounding tissues as barriers to tumor spread (FIG 1).5

INDICATIONS
- Surgical indication for primary tumors
  - The surgical strategy for primary spinal tumors used at the authors’ institution is based on Enneking’s concept of musculoskeletal tumors5 (Table 1).
- Surgical indication for metastatic tumors
  - Surgical strategy for spinal metastases (Table 2) consists of three prognostic factors: (1) grade of malignancy; (2) visceral metastases; and (3) bone metastases.12
  - The extent of the spinal metastases is stratified using the surgical classification of spinal tumors (Table 3), and technically appropriate and feasible surgery is employed, such as en bloc spondylectomy, piecemeal thorough excision, curettage, or palliative surgery.

IMAGING AND OTHER STAGING STUDIES
- Plain radiography
- CT/MRI
- Bone scan
- Angiography and other studies
- Biopsy

SURGICAL MANAGEMENT
- The TES operation was designed to achieve complete tumor resection en bloc, including main and satellite microlesions in a vertebral compartment to avoid local recurrence.
- The primary candidates for TES are primary malignant tumor (stage 1, 2); aggressive benign tumor (stage 3); and isolated metastasis in a patient with long life expectancy (see Tables 1 and 2).
- From the viewpoint of tumor growth (see Surgical classification; Table 3), TES is recommended for types 3, 4, and 5 lesions; and relatively indicated for types 1, 2, and 6 lesions.
- Type 1 or 2 still can be a candidate for radiation therapy, chemotherapy, corpectomy, or hemivertebrectomy.
- TES is not recommended for type 7 lesions. Systemic treatment or hospice care may be the treatment choice for these lesions.10,11,13 However, the final decision can be made individually based on discussion among the patient and his or her family and doctors.

Preoperative Embolization
- Segmental arteries above and below the feeding artery, as well as the feeding artery itself, should be embolized preoperatively.
- This embolization technique dramatically reduces intraoperative bleeding without compromising spinal cord function.4,8,15

Positioning
- The patient is placed prone over the Relton-Hall four-poster frame for the posterior approach to avoid compression to the vena cava.

Approach
- The surgical approach is decided based on the degree of tumor development or affected spinal level.

Single Posterior Approach
- For TES above L4, a single posterior approach is preferred rather than a postero–anterior combined approach, as long as the tumor does not involve major vessels or segmental arteries.

Anteroposterior Double Approach
- In type 5 or 6 tumors that involve major vessels or segmental arteries, anterior dissection followed by posterior TES is indicated. Currently, a thoracoscopic or mini-open approach is preferred for anterior dissection.

Posteroanterior Double Approach
- Posterior laminectomy and stabilization followed by anterior en bloc corpectomy and placement of a vertebral prosthesis is indicated in spinal tumors at the level of L5 or L4 because of the technical challenge presented by the iliac wing and lumbosacral plexus nerves.
**Chapter 16**

**TOTAL EN BLOC SPONDYLECTOMY**

<table>
<thead>
<tr>
<th>Surgical Strategy for Primary Spinal Tumors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical Staging</td>
</tr>
<tr>
<td><strong>Benign tumor</strong></td>
</tr>
<tr>
<td>1. Latent</td>
</tr>
<tr>
<td>2. Active</td>
</tr>
<tr>
<td>3. Aggressive</td>
</tr>
<tr>
<td><strong>Malignant tumor</strong></td>
</tr>
<tr>
<td>I. Low grade</td>
</tr>
<tr>
<td>II. High grade</td>
</tr>
<tr>
<td>III. With metastases</td>
</tr>
</tbody>
</table>

**Table 2**

**Surgical Strategy for Spinal Metastases**

<table>
<thead>
<tr>
<th>Prognostic Scoring System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>
### Table 2  
**Points for each primary tumor**

1 point = slow growth  
Breast ca.*  
Thyroid ca.*  
Prostatic ca. Testicular ca.

2 points = Moderate growth  
Renal cell ca.*  
Uterus ca. Ovarian ca.  
Colorectal ca

4 points = Rapid growth  
ex. Lung ca.  
Gastric ca. Esophageal ca.  
Nasopharyngeal ca.  
Hepatocellular ca  
Pancreas ca.etc  
Bladder ca.  
Melanoma  
Sarcoma (osteosarcoma, Ewing sarcoma,  
Leiomyosarcoma, etc)  
Primary unknown metastasis  
other rare ca.  
....etc.

*Rare types of the following ca. should be given "4 points” as a rapidly growing cancer:  
1 Breast ca., inflammatory type; 2 Thyroid ca., undifferentiated type; 3 Renal cell ca., inflammatory type.

### Table 3  
**Surgical Classification of Spinal Tumors**

<table>
<thead>
<tr>
<th>Intra-Compartmental</th>
<th>Extra-Compartmental</th>
<th>Multiple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 vertebral body</td>
<td>Type 4 spinal canal extension</td>
<td>Type 7</td>
</tr>
<tr>
<td>Type 2 pedicle extension</td>
<td>Type 5 paravertebral extension</td>
<td></td>
</tr>
<tr>
<td>Type 3 body - lamina extension</td>
<td>Type 6 adjacent vertebral extension</td>
<td></td>
</tr>
</tbody>
</table>
Exposure
- A straight vertical midline incision is made over the spinous processes and is extended three vertebrae above and below the involved segment(s).
- The paraspinal muscles are dissected from the spinous processes and the laminae, and then retracted laterally.
- If the patient underwent a posterior route biopsy, the tracts are carefully resected in a manner similar to that used in limb-salvaging procedures.
- After a careful dissection of the area around the facet joints, a large retractor, the articulated spinal retractor, which has a uniaxial joint in each limb and was designed for this surgery, is applied.
- By spreading the retractor and detaching the muscles around the facet joints, a wider exposure is then obtained.
- The operative field must be wide enough on both sides to allow dissection under the surface of the transverse processes.
- In the thoracic spine, the ribs on the affected level are transected 3 to 4 cm lateral to the costotransverse joint, and the pleura is bluntly separated from the vertebra (TECH FIG 1).
- To expose the superior articular process of the uppermost vertebra, the spinous and inferior articular processes of the neighboring vertebra are osteotomized and removed with dissection of the attached soft tissues, including the ligamentum flavum.

Introduction of the T-saw Guide
- To make an exit for the T-saw guide through the nerve root canal, the soft tissue attached to the inferior aspect of the pars interarticularis is dissected and removed, using utmost care so as not to damage the corresponding nerve root.
- A C-curved malleable T-saw guide is then introduced through the intervertebral foramen in a cephalocaudal direction.
- In this procedure, the tip of the T-saw guide should be introduced along the medial cortex of the lamina and the pedicle so as not to injure the spinal cord and the nerve root (TECH FIG 2).
- After passing the T-saw guide, its tip at the exit of the nerve root canal can be found beneath the inferior border of the pars interarticularis.
- A T-saw is passed through the hole in the wire guide and is clamped with a T-saw holder at each end.
- The T-saw guide is removed, and tension on the T-saw is maintained.

Cutting the Pedicles and En Bloc Laminectomy
- While tension is maintained, the T-saw is placed beneath the superior articular and transverse processes with a specially designed T-saw manipulator. With this procedure, the T-saw placed around the lamina is wrapped around the pedicle.
- With a reciprocating motion of the T-saw, the pedicles are cut, and then the whole posterior element of the spine (the spinous process, the superior and inferior articular processes, the transverse process, and the pedicle) is removed in one piece (TECH FIG 3).
- The cut surface of the pedicle is sealed with bone wax to reduce bleeding and to minimize contamination by tumor cells.1
To maintain stability after segmental resection of the anterior column, a temporary posterior instrumentation ("two above and two below" segmental fixation) is performed.

Blunt Dissection Around the Vertebral Body

- The spinal branch of the segmental artery, which runs along the nerve root, is ligated and divided. In the thoracic spine, the nerve root is cut on the side from which the affected vertebra is removed.
- The blunt dissection is done on both sides through the plane between the pleura (or the iliopsoas muscle) and the vertebral body (TECH FIG 4).
- Usually, the lateral aspect of the body is easily dissected with a curved vertebral spatula.
- Then the segmental artery should be dissected from the vertebral body.
- By continuing dissection of both lateral sides of the vertebral body anteriorly, the aorta is carefully dissected posteriorly from the anterior aspect of the vertebral body with a spatula and the surgeon’s fingers.
- When the surgeon’s fingertips meet with each other anterior to the vertebral body, a series of spatulas, starting from the smallest size, are inserted sequentially to extend the dissection.
- A pair of the largest spatulas is kept in the dissection site to prevent the surrounding tissues and organs from iatrogenic injury and to make the surgical field wide enough for the surgeon to manipulate the anterior column.

Dissection of the Spinal Cord and En Bloc Corpectomy

- Using a cord spatula, the spinal cord (dura mater) is mobilized from the surrounding venous plexus and the ligamentous tissue.
- T-saws are inserted at the proximal and distal cutting levels of the vertebral bodies after confirmation of the disc levels with needles. Recently, a diamond T-saw is now available for corpectomy.
- The teeth-cord protector, which has teeth on both edges to prevent the T-saw from slipping, is then applied.
- The anterior column of the vertebra is cut by the T-saw, together with the anterior and posterior longitudinal ligaments (TECH FIG 5).
- The freed anterior column is rotated around the spinal cord and removed carefully to avoid injury to the spinal cord.
- With this procedure, a complete anterior and posterior decompression of the spinal cord (circumspinal decompression) and total en bloc resection of the vertebral tumor are achieved.

Anterior Reconstruction and Posterior Instrumentation

- An anchor hole on the cut end of the remaining vertebra is made on each side to seat the graft. A vertebral spacer such as a titanium mesh cylinder cage with autograft, allograft, or cement (TECH FIG 6) is properly inserted to the anchor holes within the remaining healthy vertebrae.
- After checking the appropriate position of the vertebral spacer radiographically, the posterior instrumentation is adjusted to slightly compress the inserted vertebral spacer.
- By this "spinal shortening" procedure, the block cylinder is caught tightly and the anteroposterior 360-degree spinal reconstruction is completed. 2,7
- If two or three vertebrae are resected, it is recommended that the connector device be applied between the posterior rods and anterior spacer (artificial pedicle).
Chapter 16  TOTAL EN BLOC SPONDYLECTOMY

**TECH FIG 4**  
A. Schematic drawing of anterior dissection around the vertebral body. Segmental arteries on the right (B) and left (C) sides.  
D,E. Schematic drawings of anterior finger dissection around the vertebral body show the posterior (D) and axial (E) views.  
F. Anterior finger dissection around the vertebral body.  
G. A pair of spatulas is kept around the affected vertebral body to protect the surrounding tissues and organs from iatrogenic injury and to make the surgical field wide enough for manipulation of the anterior column.

**TECH FIG 5**  
A. A temporary posterior instrumentation is performed to maintain stability after segmental resection of the anterior column.  
B,C. The anterior column of the vertebra is cut by the T-saw, together with the anterior and posterior longitudinal ligaments. The teeth-cord protector, which has teeth on both edges to prevent the T-saw from slipping, is then applied.  
D. Schematic drawing of cutting the anterior column.  
E. Diagram of en bloc corpectomy.  
F. Intraoperative photograph of specimen from the resected T7 vertebra. (continued)
TECH FIG 5 • (continued) G. Specimens resected along with the compartment and barrier concept. H, I. Radiographs of resected specimens from metastatic tumor of T7 showing the complete vertebra in horizontal (H) and lateral (I) views.

TECH FIG 6 • A. A vertebral spacer is properly inserted to the anchor holes within the remaining healthy vertebrae. B. Schema of reconstruction (lateral view). C, D. After checking the appropriate position of the vertebral spacer radiographically, the posterior instrumentation is adjusted to slightly compress (10 mm in this case) the inserted vertebral spacer. E, F. Postoperative radiograph after spinal column shortening shows three pairs of preoperative embolization coils. G–I. Resection of two vertebrae. G. Bilateral artificial pedicles are placed. H, I. Postoperative radiographs of reconstruction with artificial pedicle.
Chapter 16  TOTAL EN BLOC SPONDYLECTOMY 1853

POSTOPERATIVE CARE

- Suction drainage is used for 3 to 5 days after surgery.
- The patient is allowed to start walking within 1 week after surgery.
- The patient wears a thoracolumbosacral orthosis for 3 to 6 months until bony union is attained.

OUTCOMES

- From 1989 to 2003, 284 patients with spinal tumors (primary, 86 patients; metastasis, 198 patients) were surgically treated and followed for a minimum of 2 years.
- Total en bloc spondylectomy was performed in 33 of the 86 patients with a primary tumor; 17 patients with malignant tumors (3 osteosarcoma, 3 Ewing sarcoma, 3 plasmocytoma, 2 chondrosarcoma, and 1 case each of 6 other tumors) and 16 patients with aggressive benign tumors (4 patients with giant cell tumor, 3 patients with osteoblastoma, 3 patients with symptomatic hemangioma, and 1 case each of 6 other tumors).
- Five-year survival of the 17 patients with primary malignant spinal tumors (stages 1 and 2) who underwent TES was 67%, and that of the 16 patients with aggressive benign tumors (stages 2 and 3) was 100%.
- In the same periods, TES was performed in 64 of 198 patients with spinal metastases. Of the 64 cases with a metastatic tumor, the primary organs were as follows: kidney, 18 cases; breast, 15 cases; thyroid, 9 cases; lung, 4 cases; liver, 4 cases; and other carcinoma, 14 cases.
- Forty-three patients with the 2, 3, 4 points out of 64 patients who underwent TES resulted in 2-year survival of 66.6% and 5-year survival of 46.6%.

- Ninety-two of 97 patients (95%) had no tumor recurrence until death or last follow-up.
- Five of 97 patients (5%) had local recurrence; the mean length of the recurrence was 22.1 months after operation.
- In all five patients with local recurrence, the recurrence arose from residual tumor tissue.

COMPLICATIONS

- Excessive bleeding
- Injury of the major vessels during blunt dissection of the vertebral body
- Spinal cord injury
- Injury of lung or pleura
- Postoperative hematoma
- Liquorrhea
- Pleural effusion
- Chylothorax
- Instrumentation failure
- Infection, especially after preoperative radiation therapy

REFERENCES


BACKGROUND

- The pelvis is a relatively common anatomic location for metastatic and primary musculoskeletal tumors. Surgical resection is more challenging in the pelvis than in other locations because of the complex anatomy and the proximity to vital abdominal viscera and major blood vessels and nerves. Making decisions about surgical resectability of a tumor involves the assessment of possible osseous or neurovascular involvement, in addition to the possible involvement of adjacent viscera (ie, bowel, ureter, and bladder). Therefore, preoperative evaluation and extensive imaging are critical. Osseous resection and reconstruction usually are carried out adjacent to major nerves, beneath the iliac vessels, or adjacent to the bladder or bowel.

- Tumor surgery around the pelvis has the highest rate of complications, infections, and mechanical failure of all anatomic sites.

ANATOMY (FIG 1)

Pelvic Nerves

Sciatic Nerve
- The sciatic nerve arises from L4, L5, S1, S2, and S3. The nerve emerges from the pelvis through the greater sciatic notch inferior to the piriformis muscle and enters the thigh lateral to the ischial tuberosity. In 10% of patients, the sciatic nerve penetrates the substance of the piriformis muscle. The sciatic nerve is accompanied by the inferior gluteal artery.

- It is essential to protect the sciatic nerve early in most procedures. Inside the pelvis, the nerve should be identified distally at the greater sciatic notch. Proximally, it should be picked up below the psoas muscle. The sciatic nerve is formed at the junction of the lumbar sacral plexus where these two trunks come together.

- Great care must be taken as the nerve exits the pelvis at the level of the greater sciatic notch not to injure the the accompanying inferior and superior gluteal nerves and arteries, because these supply the abductors as well as the gluteus maximus muscle. The gluteus maximus muscle is essential for closure of most pelvic resections.

Femoral Nerve
- The femoral nerve arises from posterior divisions of the ventral rami of L2 and L3 and passes inferolaterally between the psoas and iliacus muscles. It passes over the superficial iliacus muscle to enter the proximal thigh underneath the inguinal ligament, just lateral to the superficial femoral artery.

- This nerve is almost always preserved during pelvic resections. It should be identified early during most procedures. The femoral nerve is identified in the space between the iliacus and psoas muscles as they exit the pelvis. The femoral nerve lies just below the fascia, bridging the interval between the two muscles, lateral to the femoral artery and vein.

<table>
<thead>
<tr>
<th>Obturator Nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>The obturator nerve, formed from the anterior branches of L2, L3, and L4, is the largest nerve formed from anterior divisions of the lumbar plexus. The nerve descends thru the iliopectineus muscle and courses distally over the sacral ala into the lesser pelvis, lying lateral to the ureter and under the internal iliac vessels. It then traverses the obturator foramen into the medial thigh, under the superior pubic ramus, dividing into anterior and posterior branches.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lumbar Plexus Sensory Nerves</th>
</tr>
</thead>
<tbody>
<tr>
<td>The iliohypogastric (L1), ilioinguinal (L1), genitofemoral (L1, 2) and lateral femoral cutaneous nerves, which arises from L2 and L3, travel downward laterally along the iliopsoas muscle, pass underneath the lateral aspect of the inguinal ligament, and pass just distal and medial to the anterior superior iliac crest to innervate the anterolateral thigh.</td>
</tr>
</tbody>
</table>

| This nerve is routinely transected during pelvic floor resections (type 3) due to its intimate proximity to the tumor. |

Pelvic Vessels

Aortic Bifurcation
- Descending the abdomen to the left of the vena cava, the aorta bifurcates at the level of L4 into common iliac vessels at the level of L4-L5. The common iliac bifurcates into internal and external iliac vessels at the level of S1, the ala sacralis. The level of these bifurcations may vary, especially if the vessels are pushed by a large adjacent tumor mass. |

- It is essential to identify two levels of bifurcations prior to any ligation: the aortic bifurcation and the common iliac bifurcation. Even the best surgeons have ligated the wrong vessels due to distorted anatomy. Such a misstep is especially possible with tumors that cross the midline. Preoperative evaluation with angiography is required for evaluation and preoperative to avert such an occurrence. |

Common Iliac Artery
- The common iliac artery must be identified early to correctly identify the aorta as well as the the internal iliac (hypogastric) artery. To the surgeon, the major anatomic features of the common iliac artery are as follows: |
  - No arterial branches arise from the artery (although the common iliac vein does have a major branch joining in, the iliolumbar vein) |
  - The bifurcation of the common iliac artery into the external and internal iliac arteries is at the exact level at which the ureter crosses on the adjacent peritoneal surface. The ureter is routinely identified at this location early in the retroperitoneal dissection. |

External Iliac Artery
- The external iliac artery contributes to the inferior epigastric artery and extends distally, as the superficial femoral artery,
into the femoral triangle, where it is a useful landmark in identifying neighboring structures.

**Internal Iliac Artery**
- The internal iliac (hypogastric) artery descends from the lumbosacral articulation to the greater sciatic notch and branches into several arteries. The internal iliac artery and vein often are difficult to identify or ligate. The internal iliac artery lies on top of its vein, which often is large and is easily injured. The hypogastric vessels are routinely ligated in performing modified hemipelvectomies as well as many pelvic resections.

**Anterior Branches**
- The obturator artery exits the pelvis via the obturator canal (beneath the superior pubic ramus).
- The inferior gluteal artery curves posteriorly between the first and second and third sacral nerves, then runs between the piriformis and coccygeus muscles or through the greater sciatic foramen into the gluteal region below the piriformis muscle.

**Posterior Branches**
- The iliolumbar artery ascends posterior to the obturator nerve and external iliac vessels to the medial border of the psoas. It then divides into the lumbar branch, to the psoas and quadratus lumborum muscles and to the spinal cord, and an iliac branch, to the iliac, gluteal, and abdominal musculature. The iliac branch often is ligated during surgery.
- The superior gluteal artery runs posteriorly between the lumbosacral trunk and first sacral nerve and leaves the pelvis through the greater sciatic foramen superior and posterior to the piriformis muscle. Great care must be taken to preserve the gluteal vessels and nerves when performing types 1 and 2 pelvic resections.

**Ureter**
- The ureter originates from the renal pelvis at the level of L1 and courses in the retroperitoneum to the medial surface of the psoas major muscle, crossed by spermatic or ovarian vessels. The ureter crosses from lateral to medial on the surface of the peritoneum at the level of the common iliac bifurcation. This is a good landmark to identify the ureter during the initial retroperitoneal dissection. The ureter then courses medially at the level of the sciatic notch to insert into the trigone of the bladder.

**Corona Mortis**
- The corona mortis is an anastomosis of the external iliac, inferior epigastric, and obturator vessels located in the retroperitoneal region approximately 3 cm from the symphysis pubis. Laceration during an ilioinguinal approach can lead to extensive bleeding. The retroperitoneal space between pubis and bladder is called the space of Retzius.

**Inguinal Canal**
- The anatomic confines of the inguinal canal are described as 4 cm from the deep inguinal ring to the subcutaneous ring. This “deep ring” is the “direct” inguinal space originating lateral to the epigastric vessels. Hesselbach’s triangle is the “indirect” hernia space originating medial to the epigastric vessels.
- The inguinal contents vary by gender:
  - In males, the spermatic cord contains the ductus deferens, testicular artery, pampiniform plexus, lymphatics, autonomic nerves, the ilioinguinal and genital branches of the genitofemoral nerve, the cremasteric artery and muscle, and the internal spermatic fascia.
  - In females, the inguinal contents include the round ligament and the ilioinguinal nerve.
- The anterior inguinal wall is formed by the aponeurosis of the external oblique and internal oblique (lateral) muscles.
- The posterior inguinal wall runs medial to lateral and is formed by the reflected inguinal ligament, the inguinal falc, and the transversalis fascia.
- The superior or cephalic inguinal wall is formed by arched fibers of the internal oblique muscle and the transverse muscle of the abdomen.
- The inferior or caudal inguinal wall is formed by the inguinal and lacunar ligaments.

**Boundaries**

**Sciatic Notch**
- The sciatic notch should be identified early in surgery, both internally and externally, to protect the sciatic nerve and gluteal pedicles.

**Osseous Boundaries**
- The superior cephalad margin of the pelvis is defined by the ilium and the rim of the great sciatic notch.

**Posterior Margin**
- The posterior margin of the pelvis is bounded by the piriformis muscle and the superior gluteal vessels and nerve. Posterior to the piriformis muscle, the internal pudendal vessels and nerve course medially off the sciatic nerve and the posterior femoral cutaneous nerve, anterior to the piriformis.
Inferior Margin
- The sacrospinous and sactrotuberous ligaments are released during type 1 and 2 pelvic resections.

INDICATIONS
Recurrent Benign Tumors
- Major pelvic resections rarely are performed for benign bony tumors. Occasionally, following multiple recurrence or when tumors are limited to either the superior or inferior pubic rami, pelvic resection is indicated.
- Such benign tumors include large osteochondromas or any osteochondroma associated with multiple hereditary exostosis, due to the high risk of secondary chondrosarcoma.
- Osteoblastoma occurring in the ilium or periacetabulum
- Giant cell tumors or aneurysmal bone cysts have a predilection for the superior pubic ramus and supra-acetabulum.

Primary Malignant Osseous Tumors
- Osteosarcoma
  - Five percent of all osteosarcomas occur in the pelvis. Partial pelvic resection or hemipelvectomy (amputation) is required, usually following induction chemotherapy.
- Ewing sarcoma
  - About 25% of all Ewing sarcomas occur in the pelvis. Surgical resection is required.
  - Radiation therapy remains controversial in treating pelvic Ewing sarcoma.
  - Resection should be performed only following induction chemotherapy.
- Chondrosarcoma
  - Chondrosarcomas are the most common primary malignant bony tumors of the pelvis.

Metastatic Adenocarcinoma: Breast, Prostate, Renal, Lung, Colon
- Metastatic adenocarcinoma most commonly involves iliac or periacetabular sites. Most metastatic tumors to the pelvis are treated adequately with radiation therapy.
- Occasionally, there may be significant acetabular destruction with an impending pathological fracture that requires surgical reconstruction.
- Renal cell carcinoma (hypernephroma) metastases are an exception. These metastases often require surgical removal, either by resection or by curettage and cryosurgery. Preoperative embolization always is required for these vascular tumors to avoid severe bleeding during surgery.

Soft Tissue Sarcomas
- Retroperitoneal soft tissue sarcomas are more common than intraperitoneal sarcomas and must be evaluated for gastrointestinal, genitourinary, vascular or peripheral nerve involvement.

IMAGING AND OTHER STAGING STUDIES
Plain Radiography
- Plain radiography (FIG 2) is of limited value in the assessment of pelvic girdle lesions. Images often are obscure and confusing.
- The pelvis, particularly the sacrum, is a difficult structure in which to recognize early bone lesions, and major bone lesions initially may be overlooked. For these reasons, there

FIG 2 • A. Plain radiographs revealing a large lytic lesion of the right periacetabular region. On the basis of this radiograph, it appears that the cortices are intact. B. AP plain radiograph of the pelvis, read as normal. C. Plain radiographs revealing a cartilage-forming lesion in the left ilium. On the basis of this study alone, it seems that this is an intraosseous lesion. Plain radiographs performed 24 hours after a CT-guided core needle biopsy of a sacral lesion (note the coil) (D) and after 6 weeks (E).
should be a low threshold for performing further imaging, especially for initial screening and the postoperative evaluation of reconstructions.

**CT and MRI**
- CT with intravenous contrast and three-dimensional reconstruction is the optimal technique for assessing the extent of bone involvement and destruction, the osseous anatomy, and the relation between the tumor and the major blood vessels of the pelvis (FIG 3). It is valuable for depicting any distortion of the pelvic anatomy, and aiding in the evaluation of the tumor to decide whether it is resectable. Chest CT is essential for staging purposes in evaluation for pulmonary metastases.
- MRI with contrast is critical for imaging soft tissue (ie, vessels, nerve, muscle) and osseous involvement. MRI is the optimal modality for imaging soft tissue and marrow involvement. It is attractive for assessment of osseous disease and sacral involvement, and may be helpful with the serial assessment of neoadjuvant (induction) therapy.

**Bone Scan**
- Three-phase bone scan is used to rule out systemic metastasis and to assess the focal osseous involvement and tumor vascularity in the initial flow phase. A decrease in vascularity after induction chemotherapy may indicate response to treatment.

**Angiography**
- Angiography is mandatory for determining the vascular anatomy that often is distorted by large pelvic tumors (FIG 4). It is essential to determine the level of the various bifurcations preoperatively and to rule out vascular involvement by the tumor. Embolization of the tumor blood supply before surgery is helpful in minimizing blood loss, especially with vascular tumors and tumors with sacral involvement.

**Venography**
- The pelvic veins always are much larger than their arterial counterparts. Preoperative venography is used to rule out tumor (mural) thrombi, a common finding in chondrosarcomas and osteosarcomas. Their presence may change the planned surgical approach.

**FDG-PET**
- Fluorine-18 2-fluoro-2-deoxy-D-glucose-positron emission tomography (FDG-PET) may be useful in assessing the “grade” of malignancy, evaluating response to neoadjuvant chemotherapy, and monitoring for local recurrence. Positron emission tomography (PET) combined with CT or MR is useful for “co-registered” imaging. PET CT scans are useful in early detection of small recurrences. It plays only a minimal role in preoperative planning in determining the extent of surgical resection.

**Biopsy**
- The purpose of biopsy is to yield a valid tumor diagnosis (benign vs. malignant), tumor grade (high vs. low grade), and tumor subtype (eg, leiomyosarcoma vs. malignant fibrous histiocytoma).
- Biopsies may be performed by either open or needle technique.
- Because open biopsy for pelvic tumors is an extensive procedure, needle biopsy—especially CT-guided needle biopsy—

---

**FIG 3** • A. CT showed extensive bone destruction and extension of the tumor to the pelvis and the right gluteal region. B. CT of the pelvis revealed a large destructive lesion of the sacrum. C. CT shows an extensive tumor on the medial aspect of the ilium with destruction of the inner table and extension of the pelvis. (A,B: Courtesy of Martin M. Malawer; C: Reprinted with permission from Cancer: Principles and Practice of Oncology, 5th ed. Philadelphia: Lippincott Williams & Wilkins, 1997;38.3:1789–1852.)

**FIG 4** • Preoperative angiography and embolization of the metastatic lesion shown in Fig 3A. (Courtesy of Martin M. Malawer.)
always is performed initially for both metastatic and primary pelvic tumors.

- Biopsy technique should follow established guidelines for incision placement within the line of eventual resection, minimize contamination of normal tissues (e.g., achieve adequate hemostasis at biopsy closure), and retrieve an adequate specimen for frozen section diagnosis. The biopsy should avoid the gluteal and groin areas, because they are potential sources for flaps for skin closure after anterior and posterior hemipelvectomy, if necessary.

- Use of the utilitarian surgical incision for open biopsy is recommended.

**Anatomic Considerations**

- Evaluation of the full anatomic extent of a pelvic tumor cannot be based on a single imaging modality. Combined data, gained from two or more imaging modalities, allow a realistic appreciation of the exact anatomic extent. Even when that information is available, however, the full extent of a pelvic tumor often is underestimated preoperatively.

- Review of any imaging study of the pelvis, because of the numerous anatomic details, must be performed very methodically. The authors review the structures from the back (mid-sacral region) and follow the pelvic girdle to the front (symphysis pubis), as described in the following paragraphs.

**Sacrum, Sacral Alae, and Sacroiliac Joint**

- Most patients who undergo extended hemipelvectomy, which necessitates transection of the sacrum through the ipsilateral neural foramina, regain function of the gastrointestinal and genitourinary tracts. Adding a contralateral compromise of the sacral nerve root will create a severe dysfunction. Tumors that penetrate the sacrum and cross the midline are considered unresectable because of the involvement of bilateral neural foramina.

- Bilateral neural foramina for the sciatic nerve extend laterally to the SI joint. Tumors in close proximity to a site in which a major nerve supply is usually located. Clinical evidence of femoral or sciatic nerve dysfunction usually means direct tumor involvement. In most cases the presence and extent of nerve involvement is established only at the time of surgery. Sacral plexus invasion by tumor has the same significance in terms of resectability as tumor invasion of the sacrum; bilateral involvement is an indicator of unresectability.

**Sciatic Notch and Nerve**

- The sciatic notch is the site of pelvic osteotomy in resections of the ilium or periacetabular region and in modified hemipelvectomy. CT establishes tumor extension to the sciatic notch, a tight space through which the sciatic nerve and superior gluteal vessels and nerve pass (FIG 6). The piriformis muscle, which divides the sciatic notch, is a key structure, because the sciatic nerve exits the pelvis underneath it and the superior gluteal artery exits the pelvis above it. The patency of the superior and inferior gluteal arteries, which supply the gluteal vasculature, is established by angiography. Adequate blood supply of the gluteal region is a major consideration in flap design, and the artery must be preserved in any pelvic resection, if oncologically feasible. The artery is located only a few millimeters from the peristeum of the sciatic notch roof, and it should be dissected carefully.

**Ilium**

- The inner aspect of the bone is covered by the iliacus muscle, which originates from the iliac crest. The iliacus is “pushed” by a growing bone sarcoma and serves as a major barrier to direct extension of tumor to the anatomic structures of the pelvis. Therefore, the iliacus can be used as a safe oncologic margin for resection. In contrast, metastatic carcinomas to the pelvis tend to invade the covering muscle layer in their early growth stage, and a surgical plane between the tumor and nearby structures cannot be easily defined (FIG 7).
Although any pelvic organ can be infiltrated by a tumor, structures that are anterior and posterior to the flare of the muscle (ie, sacral plexus, sciatic notch and nerve, femoral vessels and nerve, bladder, and prostate) are at greater risk for direct tumor extension.

**Extension to Pelvic Viscera**

- Direct involvement of a pelvic viscus by a pelvic girdle tumor is rare. Left-sided tumors are more likely to involve a component of the gastrointestinal tract because of its close proximity to the pelvic girdle at that point. A rectal tube is inserted preoperatively during any pelvic resection to facilitate identification of the rectum during dissection.

**Acetabulum and Hip Joint**

- Wide resection of any bone tumor in the periacetabular region, unlike a resection of the ilium or the pubis, imposes a major impairment on the function of the hip joint. It usually necessitates an en bloc resection of the proximal femur and a complex prosthetic reconstruction.

**Pubis**

- The neurovascular bundle passes within the femoral triangle just anterior to the superior pubic ramus. Tumors extending to or arising from the pubic ramus are in close proximity to the femoral artery, vein, and nerve. In addition, the urethra passes straight underneath the symphysis pubis. Vulnerable structures such as a major blood vessel, nerve, or a viscus must be identified and mobilized before resection. By identifying and isolating crucial structures, the surgeon avoids iatrogenic injury during dissection. Establishing the relation of these vulnerable structures to the tumor allows the surgeon to decide whether to proceed with a limb-sparing procedure or perform an amputation, make the necessary preparations for a vascular graft (if needed), and perform a safe resection.

**SURGICAL MANAGEMENT**

**Preoperative Planning**

**Restaging studies**

- Preoperative planning is crucial to obtain an optimal oncologic and functional surgical result.
- Imaging studies are crucial in addressing the following questions: location and extent of the tumor, the type of pelvic resection that is necessary for adequate removal of the tumor, involvement of critical adjacent structures in the tumor mass (ie, ureter, aorta, inferior vena cava, bladder), and the type of reconstruction that can be achieved.
- Plain radiographs, CT scans, MRI scans, bone scans, and 3D-CT angiographs are obtained to access the extent of osseous and soft tissue involvement in all anatomic planes. The status of crucial adjacent structures—bladder, colon, ureter, inferior vena cava, sacral alar, and possible lumbar extent—is reviewed.
- Using angiography and venography, preoperative embolization is considered, and anatomic distortion and vessel occlusion and venous thrombus are assessed.
- Consider possible need for prophylactic ureteral stents if there is evidence of preoperative ureteral obstruction or displacement.
- Medical and anesthesia personnel are consulted to assess medical risk, preoperative laboratory studies, and transfusion needs (eg, prepare red blood cell count, cryo, platelets, and plasma). A risk of major blood loss during surgery is assumed, often equal to one total body transfusion (> 7% body weight in kg).
- Bowel preparation before surgery and ICU reservation also should be considered.
• Orthotic brace is fabricated preoperatively for postoperative use.
• Colostomy planning and training must be considered if there is left colon involvement, or large left-sided pelvic tumors, both of which can be detected preoperatively with contrast-enhanced CT and colonoscopy.
• Appropriate prosthetic implants (eg, total hip replacement vs. saddle prosthesis), bone allograft, or other implants must be ordered.

Positioning
• At the time of surgery all patients should have a Foley catheter and a rectal tube placed. The rectum is sutured closed around the rectal tube to avoid iatrogenic contamination during the operative procedure. During surgery the surgeon may palpate the balloon of the Foley catheter in the bladder and the rectal tube through the wall of the rectum, to assist in proper identification of these structures. This is especially helpful with large pelvic tumors, especially those on the left side.
• Type 1 resection (iliac): the patient is positioned in the lateral decubitus position with an anterior tilt to allow posterior access (FIG 8A–D).
• Type 2 resection (periacetabular): the patient is positioned in the lateral decubitus position for access to both the anterior and posterior pelvis (FIG 8E,F).

FIG 8 • Type 1 pelvic (ilium) resection can be either partial (A), in which only part of the ilium is transected, or complete (B). Partial (C) and complete (D) type 1 resections. E. Type II pelvic (periacetabular) resections. Reconstruction was performed with a saddle prosthesis. F. Type II pelvic resection. G–I. Type III pelvic (pubic) resection. These resections may include the superior pubic ramus (G), inferior pubic ramus, or both rami (H). I. Type III pelvic resection.
Type 3 resection (pelvic floor): The patient is positioned supine with the lower extremity flexed and abducted to provide exposure of the retroperitoneal space, the femoral triangle, the perineum, the symphysis pubis, and the ischiorectal space (FIG 8G–I).

Approach

- The utilitarian pelvic incision is indicated (FIG 9).
- The incision begins at the posterior inferior iliac spine and extends along the iliac crest to the anterior superior iliac spine. It is separated into two arms: one is carried along the inguinal ligament up to the symphysis pubis; the other turns distally over the anterior thigh for one-third the length of the thigh and then curves laterally just posterior to the shaft of the femur below the greater trochanter and follows the insertion of the gluteus maximus muscle. Reflection of the posterior glutus maximus flap exposes the retrogluteal space, the proximal third of the femur, the sciatic notch, the sciatic nerve, the ischium, as well as the supra-acetabular area needed for the superior osteotomy.

Type 1 Resection: Iliac Resection

- The incision for an iliac resection is ilioinguinal, following the iliac crest and curving posteriorly at the level of the sacroiliac joint. It then follows the length of the sacroiliac joint combined with a lateral incision to expose the outer portion of the ilium, sciatic notch, and retrogluteal space.

Type 2 Resection: Periacetabular Resection

- A combination of an anterior retroperitoneal approach and lateral anterior incision along the femur that curves posteriorly is used for a periacetabular resection. A lateral, posterior-based fasciocutaneous flap, called a gluteal flap, is then raised. This permits easy access and visualization of the retrogluteal space; hip joint, sciatic notch, sciatic nerve, and ischium, as well as the supra-acetabular area needed for the superior osteotomy.

Type 3 Resection: Pelvic Floor and Pubic Region

- Three incisions are required for a resection of the pelvic floor and pubic region. The main incision is the retroperitoneal (ilioinguinal) incision to permit retroperitoneal exploration and mobilization of the major vessels and nerves. Two longitudinal incisions are required to develop a distal-based flap of the anterior thigh so as to expose the femoral triangle as well as the adductors attaching to the obturator foramen. One incision follows the perineal crease; the second begins at the lateral portion of the ilioinguinal incision at the level of the anterior superior iliac spine.

Type 1: Iliac Resection

- The patient is placed in the lateral decubitus position with a posterior tilt.
- The utilitarian pelvic incision is used. Its ilioinguinal component is advanced medially to the symphysis pubis, and its posterior arm is brought to the level of the sacroiliac joint (TECH FIG 1A, B).
- All muscle attachments, with the exception of the iliacus and gluteus minimus and portions of the gluteus medius, which are resected en bloc with the tumor, are removed from the iliac crest. The abdominal wall musculature, the sartorius muscle, and the tensor fasciae latae muscle are transected from the iliac crest and reflected away from the ilium. The rectus femoris muscle remains intact. The iliobibial band is transected from its origin from the iliac crest and reflected posteriorly along with the glutus maximus. Large fasciocutaneous flaps are raised and reflected medially and posteriorly.
Chapter 17  OVERVIEW ON PELVIC RESECTIONS: SURGICAL CONSIDERATIONS AND CLASSIFICATIONS

TECH FIG 1 • A. Incision and surgical approach. The entire utilitarian incision is used for type I resection. The posterior fasciocutaneous flap exposes the entire retrogluteal area: the sciatic notch, the sciatic nerve, the abductor muscles, and the hip joint. This approach provides a good exposure of the retroperitoneal space as well as the posterior retrogluteal area and permits a safe resection of the ilium. The ilioinguinal component is advanced medially to the symphysis pubis and posteriorly to the sacrum (B). C. Posterior exposure and muscle releases. The abdominal wall musculature is transected off of the iliac crest. The sartorius and tensor fascia lata muscles are transected from their tendinous insertions and reflected distally. The rectus femoris muscle remains intact. Large fasciocutaneous flaps are raised and reflected medially and posteriorly. The iliotibial band is transected from its origin from the iliac crest and reflected posteriorly along with the gluteus maximus. D. Anterior (retroperitoneal) exposure. The retroperitoneal space is easily exposed and explored through the ilioinguinal component of the incision. The plane between the iliacus and the psoas muscle is developed with caution, because the femoral nerve lies in that space. The psoas muscle and the femoral nerve are reflected medially, and the iliacus muscle is transected through its substance. The femoral nerve is preserved. (continued)
The plane between the iliacus and the psoas muscle is developed cautiously, because the femoral nerve lies in that space. The psoas muscle and the femoral nerve are reflected medially, and the iliacus muscle is transected through its substance (TECH FIG 1C).

The external iliac artery, which lies against the lower margin of the ilium, gives off no major branches along the inner table of the ilium; ligation of large blood vessels is not required, therefore, in type I pelvic resection. Most tumors of the ilium break through the outer table and push the gluteus medius muscle laterally. The gluteus medius muscle is transected through its substance, 2 to 3 cm distal to the inferior border of the tumor (TECH FIG 1D,E). It is important to try to save as much muscle belly as possible because that will be the major component in soft tissue coverage of the pelvic content and will be necessary for reconstruction of the abductor mechanism.

Osteotomy of the ilium is performed using a malleable retractor, which is inserted through the greater sciatic notch, along the inferior border of the inner table, and out just underneath the anterior superior iliac spine, to protect the pelvic viscera. The ilium is transected above the hip capsule, leaving the origin of the rectus femoris muscle and the roof of the acetabulum intact. Care is taken not to enter the hip joint. Insert: The sacroiliac joint is opened from within the pelvis. The iliac vessels must be mobilized and retracted before attempting to open the sacroiliac joint. G. Soft tissue reconstruction. The gluteus medius muscle is sutured to the abdominal wall musculature with the ipsilateral lower extremity in abduction. Dacron tape must be used to reinforce this reconstruction. The suture line also is reinforced by oversewing the tensor fascia lata and sartorius muscles. (Courtesy of Martin M. Malawer.)
anatomically connected, creates a significant tension, which can be reduced by placing the lower extremity in abduction. The suture line is reinforced with the tensor fasciae lata and sartorius muscles with 3-mm Dacron tape (TECH FIG 1G). Closure of the muscle layer must be meticulous, because poor healing and wound dehiscence will expose the abdominal and pelvic contents and will be difficult to manage.

Optional Reconstruction
- It is not necessary to reconstruct the resultant bony defect, although allograft reconstruction has been reported.
- For iliac osseous reconstruction, allograft should be thawed with permanent/tissue culture. Gram stain has a high rate of false positives and should be avoided.
- Cut the allograft after careful sizing and orientation and fix with a 4.5-mm reconstruction plate. Use intraoperative radiographs to confirm screw placement.
- Two deep soft drains (anterior and posterior) are placed deep to the fascial closure.

Type 2: Periacetabular Resection
- The patient is in the lateral decubitus position with posterior tilt to maximize anterior dissection.
- The utilitarian incision is used to expose both the anterior (internal) and posterior (extrapelvic) aspects of the pelvis. The ilioinguinal incision is used to develop the retroperitoneal plane, and the posterior gluteus maximus fasciocutaneous flap is used to develop the retrogluteal space.
- The iliac vessels are mobilized first, and the hypogastric artery is identified and ligated. The sciatic and femoral nerves are identified and protected.
- The level of osteotomy through the ilium is identified from within the pelvis, as are the superior pubic rami. Identification of the superior pubic rami requires mobilization of the external iliac and femoral vessels as they cross the rami (TECH FIG 2).
- A large posterior myocutaneous flap is developed with the gluteus maximus muscle. The gluteus maximus muscle is detached from the iliobibial band and femur to enable it to be retracted posteriorly. This exposes the retrogluteal space: the ilium, sciatic notch, sciatic nerve, and hip joint.
- The ischium is identified through the posterior incision and is osteotomized above the level of the biceps femoris tendon insertion.
- Complete removal of the periacetabulum requires release of the sacrospinous ligament and some of the pelvic floor musculature. An ilioinguinal incision is used with a separate posterolateral hip incision for hip exposure and replacement, posterior column osteotomy, and exposure of the sciatic nerve.
- Three types of osteotomies may be used for periacetabular resection: (1) supra-acetabular osteotomy; (2) superior pubic ramus osteotomy; and (3) ischial osteotomy.

TECH FIG 2 • A. Plain radiograph showing an extremely high-grade malignant fibrous histiocytoma arising from the superior and inferior pubic ramus involving the entire obturator foramen, pelvic floor, and medial and supra-acetabular aspect of the acetabulum (solid arrows). B. Gross specimen following type II/type III pelvic resection. C. Gross specimen following a complete internal hemipelvectomy (type I/type II/type III pelvic resection). D. Radiograph of the resected specimen showing complete involvement of the hemipelvis. The defect superiorly was created by an open biopsy. E. Gross specimen of a combination type II/type III pelvic resection. F. Gross specimen following a type III pelvic resection. A large tumor mass is seen arising from the obturator internus muscle (solid arrows). A, acetabulum; IL, portion of the ilium; IP, inferior pubic ramus and pubis; P, the entire pelvic floor, including the superior and inferior pubic ramus; SP, superior pubic ramus; SY, symphysis pubis. (Courtesy of Martin M. Malawer.)
A total hip exposure is used to identify the sciatic nerve and posterior column. The procedure is begun with dissection of the external rotators and osteotomy of the femoral neck, per total hip procedure.

- Cut the femoral neck at the standard neck length (1.0 cm proximal to the lesser trochanter).
- Incise the hip capsule peripherally with dissection of the sciatic nerve proximally to the sciatic notch.
- The anterior and posterior columns are exposed to allow osteotomy of the acetabulum. Posterior column osteotomy requires careful exposure and retraction of the sciatic nerve and gluteal vessels.

**Reconstruction After Type 2 Resection**

- Several choices are available for reconstruction following a type 2 resection: composite allograft; saddle reconstruction (Link, America); partial pelvic prosthesis (Stryker, Mahwah, NJ); various reconstruction rings with large phalanges; and ischiofemoral arthrodesis. Each has unique techniques, complications, functional deficits, and results.

**Composite Allograft Acetabular Reconstruction**

- Femoral component: ream and place the uncemented femoral component through the posterior lateral approach before proceeding with iliac osteotomy resection.
- Acetabulum: ream the allograft for the acetabular component and place the acetabular component (cement and screws) into the allograft to confirm graft and acetabular orientation in situ with radiography before screw or cement fixation.
- Check acetabulum positioning with radiographs before and after fixation or cementation. Orient the iliac graft before confirming the acetabular orientation, and fix the graft with a reconstruction plate and screws. Use an extended polyethylene acetabular rim and consider a large femoral head (32–36 mm) to improve postoperative stability.
- Closure. Using the inguinal ligaments, reconstruct the abductors, especially if a trochanteric osteotomy was done. Perform pelvic closure at the iliac crest and inguinal canal with wound drainage catheters.

**Type 2: Resection and Reconstruction with Saddle Prosthesis**

**Notchplasty (Tech Fig 3A–C)**

- A notch is created in the remaining ilium using a high-speed burr. The notch should be placed in the thickest region of the remaining bone (usually medial).

**Preparation of the Proximal Femur**

- The proximal femur is prepared as for a standard femoral component. The intramedullary canal of the proximal femur is reamed to accept the largest-diameter stem and allow for a 2-mm circumferential cement mantle. Once reaming is completed, and the appropriate-sized stem (diameter and length) is selected, a distal femoral cement plug is inserted to a depth of 2 cm below the tip of the selected femoral stem. The femoral canal then is irrigated with saline and packed with gauze. Once the cement (polymethylmethacrylate) is prepared, the gauze is removed, and the femoral prosthesis is cemented within the proximal femur.

**Trial Reduction**

- A reduction using trial components is critical in assessing accurate length of the base component (intercalary segment) and determining optimum soft tissue tension (TECH FIG 3D–K). The base component length should be determined by the distance between the ilium and femoral neck cuts, because the length indicated on the base component is the total length from the notch of the saddle to the femoral collar. The base component should be selected so that reduction is barely possible and there is minimum “play” in the reduced joint. The surgeon should be able to reattach the abductor mechanism to its anatomic position on the osteotomized greater trochanter.

- A trial reduction also can determine areas where the saddle component may impinge on the existing notch during intraoperative range of motion. These areas can be further contoured with a high-speed burr to prevent impingement, which may result in limited motion or dislocation. Hip motion (flexion to at least 90 degrees, extension to 30 degrees, abduction to 45 degrees, adduction to neutral, and rotation) should be possible without evidence of impingement or dislocation.

**Abductor Mechanism Reconstruction**

- The osteotomized greater trochanter and abductors are reattached to their original location using cables. If the greater trochanter was included in the resected specimen, the abductor mechanism is reattached to the prosthesis using 3-mm Dacron tapes or a cable system. Soft tissue tension and prosthetic stability are again tested once the abductor mechanism reconstruction is complete. The piriformis and short external rotator muscles are brought forward and reattached to the proximal femur (or prosthesis). The gluteus maximus muscle is then reattached to its insertion using nonabsorbable suture (TECH FIG 3L–N).

- Pelvic closure involves attachment of the inguinal canal and abdominal wall to the symphysis pubis and lateral iliac crest. Soft tissue tension and prosthetic stability are tested again once the abductor mechanism reconstruction is complete. The piriformis and short external rotator muscles are brought forward and reattached to the proximal femur (or prosthesis). The gluteus maximus is then reattached to its insertion using nonabsorbable suture.

- For high type II pelvic resections, reconstruction should be carried out with a partial pelvic prosthesis (Stryker, Mahwah, NJ).

**Type 3 Resection: Pelvic Floor**

- A utilitarian pelvic incision with a perineal extension is used (three-incision approach).
A. Photograph following a periacetabular resection showing the remaining ilium (Il), the sciatic nerve (S), the greater trochanteric osteotomy (G), and the femoral head. B. Intraoperative photograph demonstrating the creation of the deep notch (large arrows). C. Reduction of the saddle prosthesis into the iliac notch (IL). The notch (solid arrows) must be as deep as the saddle and permit approximately 45 degrees of flexion and extension, as well as abduction and adduction. D. Surgical exposure using the utilitarian pelvic incision. E. A large posterior fasciocutaneous flap based medially permits the release of the gluteus maximus. F. Schematic diagram of the mobilization of the periacetabular structures and the three osteotomies that are necessary for a complete resection of the acetabulum. G. Schematic of the “close-up” view of the superior pubic ramus osteotomy. (continued)
The patient is positioned with the ipsilateral hip slightly elevated.

The ilioinguinal component of the utilitarian pelvic incision with a lateral and perineal (medial) extension is used (see Tech Fig 1G). This incision allows exposure and mobilization of the femoral vessels and nerve through a distal-based anterior flap.

Perineal extension of the incision is used to expose the ischium, which is resected through the ischiorectal fossa when the resection is performed for a large pubic lesion.

Large myocutaneous flaps are raised. The spermatic cord is reflected medially. The inguinal ligament is transected from its pubic insertion and reflected laterally.

The neurovascular bundle (ie, the femoral artery, vein, and nerve) is retracted laterally, exposing the origin of the adductor magnus and pectineus muscles, which is transected off the pubis and reflected distally.

Using the lateral component of the incision, the origins of the hamstrings, adductors, and gracilis are transected off the ischium and reflected distally (TECH FIG 4).

The first malleable retractor is placed behind the symphysis pubis, in front of the bladder. The second malleable retractor is placed behind the superior pubic ramus and in front of the inferior pubic ramus, medial or lateral to the ischium, depending on the required oncologic margins (TECH FIG 4C).
Osteotomy through the symphysis pubis and pubic rami is performed. It is important to smooth the sharp bony edges, especially those that lie against the bladder.

Surgical wounds around the groin are notoriously associated with a high incidence of dehiscence and infection. Meticulous wound closure with adequate drainage is, therefore, mandatory. Continuous suction is required for 3 to 5 days. Perioperative intravenous antibiotics are continued until the drainage tubes are removed.

Postoperative mobilization with weight-bearing as tolerated is allowed.

Rarely, reconstruction of the pelvic floor with Marlex (CR Bard, Cranston, RI) mesh is required.

**Type 4 Resection: Hemipelvic**

- Table 1 describes hemipelvic resection, along with other techniques.
- Combined, extended full pelvic dissection from symphysis pubis to sacroiliac joint is required.
- Complete dissection of the sciatic notch, the hip joint, the sciatic nerve, and the femoral vessels is required.
- Pelvic reconstruction is more challenging because of the need for fixation at the sacrum and symphysis pubis and the difficulty in orienting a pelvic graft.
- Some surgeons do not recommend reconstruction but accept 3 inches of shortening and the use of a pelvic long-leg brace.
- A large amount of intraoperative blood loss and hemipelvic graft fixations present significant surgical challenges.
Surgical Vessels

**Technique Position Incision Exposure and Nerves Resection Reconstruction Closure**

**Type 1: Posterior Lateral with Ilioinguinal with External Careful dissection Iliopsoas, Allograft fixation with Abdominal wall ileac resection anterior tilt or without sacral oblique and femoral n. and osteotomy at 4.5-mm plate m. to pelvis with extension abdominal m. vessels; iliac, iliac crest nonabsorbable gluteal vessels sutures and two deep drains (anterior and posterior)**

**Type 2: Lateral Straight Ilioinguinal with External External iliac a. Hip joint, Ream allograft for Attach inguinal acetabular lateral separate posterior oblique off and v., obturator sciatic notch, acetabular placement; canal and resection lateral hip incision superficial n., gluteal external cement and screw abdominal wall lateral crest vessels, sciatic n. rotators, with 4.5-mm plate to symphysis m., expose hip femoral neck pubis and lateral osteotomy iliac crest**

**Type 3: Anterior Supine Ilioinguinal Symphysis Femoral sheath, Between Soft tissue with Inguinal canal with pubis to lateral femoral inferior pubic Martex/fascia allograft with anterolateral posterior cutaneous n., ramus and or Gore-Tex if nonabsorbable extension lateral iliac obturator n., a., ischium, acetabular anterior sutures and deep crest v. depending on column intact. If not drains; prevent tumor location intact, then bony inguinal hernia obturator allograft**

**Hemipelvic Lateral Ilioinguinal Symphysis to External iliac Iliac and hip, Allograft verse saddle Lateral crest and iliac m. obturator with or prosthesis ilioinguinal canal**

**Gluteal Prone Posterior gluteal Gluteal m. Sciatic n., Deep proximal greater trochanter, if inferior to notch and external iliac crest with or without obturator**

**Retroperitoneal Supine Symphysis to Midline if Iliac and gluteal Usually External oblique Reattach (soft tissue) posterolateral bowel is vessels, ureter, respects abdominal wall external oblique ilium involved. femoral vessels iliopsoas reattached to pelvic to pelvic brim Abdominal/ and nerve, musculature brim external sciatic n. iliac crest off**

**Inguinal groin Supine Pubic tubercle to Inguinal Femoral sheath, Inguinal canal Inguinal ligament Lateral iliac crest ligament, inferior epigastric spermatic vessels, umbilical cord,**

---

**Table 1**  
**Summary of Pelvic Resection and Reconstruction Techniques**

<table>
<thead>
<tr>
<th>Surgical Technique</th>
<th>Position</th>
<th>Incision</th>
<th>Exposure</th>
<th>Vessels and Nerves</th>
<th>Resection</th>
<th>Reconstruction</th>
<th>Closure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1: Posterior iliac resection</td>
<td>Lateral with anterior tilt</td>
<td>Ilioinguinal with or without sacral extension</td>
<td>External oblique and abdominal m.</td>
<td>Careful dissection of femoral n. and vessels; iliac, gluteal vessels</td>
<td>Iliopsoas, osteotomy at iliac crest</td>
<td>Allograft fixation with 4.5-mm plate</td>
<td>Abdominal wall m. to pelvis with nonabsorbable sutures and two deep drains (anterior and posterior)</td>
</tr>
<tr>
<td>Type 2: Lateral acetabular resection</td>
<td>Straight lateral</td>
<td>Ilioinguinal with separate posterior lateral hip incision</td>
<td>External oblique off superficial lateral crest m., expose hip</td>
<td>External iliac a. and v., obturator n., gluteal vessels, sciatic n.</td>
<td>Hip joint, sciatic notch, external rotators, femoral neck osteotomy between inferior pubic ramus and ischium, depending on tumor location</td>
<td>Ream allograft for acetabular placement; cement and screw with 4.5-mm plate</td>
<td>Attach inguinal canal and abdominal wall to symphysis pubis and lateral iliac crest</td>
</tr>
<tr>
<td>Type 3: Anterior obturator</td>
<td>Supine</td>
<td>Ilioinguinal incision with anterolateral extension</td>
<td>Symphyseal pubis to posterior lateral iliac crest</td>
<td>Femoral sheath, lateral femoral cutaneous n., obturator n., a., v.</td>
<td>Iliac and hip, with or without obturator</td>
<td>Soft tissue with Martex/fascia allograft or Gore-Tex if acetabular anterior column intact. If not intact, then bony obturator allograft</td>
<td>Inguinal canal with nonabsorbable sutures and deep drains; prevent inguinal hernia</td>
</tr>
<tr>
<td>Hemipelvic</td>
<td>Lateral</td>
<td>Ilioinguinal</td>
<td>Symphysis to lateral crest and external iliac m.</td>
<td>External iliac</td>
<td>Iliac and hip, with or without obturator</td>
<td>Deep proximal posterior greater trochanter, if inferior to notch</td>
<td>Lateral crest and ilioinguinal canal</td>
</tr>
<tr>
<td>Gluteal</td>
<td>Prone</td>
<td>Posterior gluteal</td>
<td>Gluteal m.</td>
<td>Sciatic n., gluteal n., v., a.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retroperitoneal (soft tissue)</td>
<td>Supine</td>
<td>Symphysis to posterolateral ilium</td>
<td>Midline if bowel is involved. Abdominal/external oblique off iliac crest</td>
<td>Iliac and gluteal vessels, ureter, femoral vessels and nerve, sciatic n.</td>
<td>Usually respects iliopsoas musculature</td>
<td>External oblique abdominal wall reattached to pelvic brim</td>
<td>Reattach external oblique to pelvic brim</td>
</tr>
<tr>
<td>Inguinal groin</td>
<td>Supine</td>
<td>Pubic tubercle to lateral iliac crest</td>
<td>Inguinal ligament, spermatic cord, umbilical</td>
<td>Femoral sheath, inferior epigastric vessels</td>
<td>Inguinal canal</td>
<td>Inguinal ligament</td>
<td></td>
</tr>
</tbody>
</table>

---

**PEARLS AND PITFALLS**

**Vascular problems**
- Always have vascular control of the major vessels proximally and distally, both arterial and venous.

**Intraoperative bleeding**
- Severe bleeding usually occurs with venous, not arterial, injuries. Suture and ligate all serious bleeders.

**Thrombosis**
- All patients are at risk to develop an arterial thrombosis during or after surgery and should be evaluated (pulses) carefully during and for the first 72 hours. Always confirm adequacy of hemostasis and distal flow and pulses before leaving the operating room. If there is any question, perform an intraoperative or postoperative angiogram.

**Postoperative bleeding and coagulopathy**
- If bleeding continues, and coagulation factors rule out disseminated intravascular coagulation, strongly consider taking the patient back to the operating room. Alternatively, perform an angiogram with attempt at embolization of the bleeding vessel. The degree and timing of the bleeding are important in determining the correct course of action.
- If massive (≥ 4.0–5.0 L) bleeding occurs during the dissection, pack the wound with local pressure until the patient’s blood pressure stabilizes.
POSTOPERATIVE CARE
- The distal extremity pulses are checked immediately after surgery and every hour for the first 24 hours. Late arterial thrombosis often is due to intimal injuries.
- Persistent wound drainage usually is due to a large retroperitoneal collection. If the wound continues to drain after 4 to 7 days postoperatively, wound irrigation and drainage in the operating room should be considered.
- All postoperative patients should have a pelvic radiograph once a week for the first 2 weeks.
- Postoperative complete blood cell count and laboratory studies daily for the first week then twice per week.
- Postoperative mobilization is highly individualized:
  - Type 1 resection. Abdominal wall to abductors are maintained in abduction for 7 days in bed and then in a pelvic–thigh brace that avoids excessive adduction.
  - Type 2 resection and reconstruction is very variable. Patients with a saddle prosthesis and composite allograft are maintained on partial weight bearing for 3 to 6 months and need a pelvic and thigh brace for 2 to 3 months.
  - Patients with a type 3 resection with or without Marlex reconstructions are kept in bed with the lower extremity in neutral (it is necessary to avoid abduction) to avoid a perineal incision dehiscence. A pelvic and thigh orthosis is used for about 3 months. Full weight bearing can be initiated early if the medial wall of the acetabulum was not involved.

COMPLICATIONS

Early
- Bleeding. Most problems with intraoperative bleeding occur with venous, not arterial, bleeding. Coagulopathy and the need for large blood transfusions are common complications. Coagulation factors, Ca, and Mg should be monitored. Patients should receive packed cells, fresh frozen plasma, platelets, Ca, and Mg as necessary during and after surgery.
- Arterial thrombosis occurs due to intimal flap tear and should be monitored by distal pulse measurement with Doppler, every hour for the first 24 hours. If arterial thrombosis occurs, immediate thrombectomy is required.
- Nerve. Postoperative femoral or sciatic neuropraxia are common and should be observed.
- Ureter/bladder. Patient should be evaluated for intraoperative hematuria or oliguria, which may suggest bladder or ureter injury. Urine output is routinely measured hourly during surgery. The Foley urinary catheter is kept in place for 4 to 7 days.
- Bowel injuries require repair or resection and possible colostomy.
- Major ileus is a common problem following extensive pelvic surgery. The patient should be given nothing by mouth, with a nasogastric tube in place, until appropriate bowel sounds return (usually 3–4 days).

Late Complications
- Infection. Deep infection develops in 20% to 30% of patients following surgery. If such an infection occurs, the patient must be taken back to the operating room, and the prosthesis and allograft must be removed, leaving the limb flail.
- Dislocation. The dislocation rate for a saddle prosthesis is 5% to 10%. This rate may be even higher for “composite” reconstructions.
- Failure of the allograft may take the form of fracture through the allograft or failure of fixation.
- Prosthesis failure includes failure of the reconstruction ring, acetabular cup, screws, and plate.
- Morbidity and mortality after pelvic resection remains high. Hemipelvectomy may be required due to local recurrence, infection, or uncontrolled bleeding.

REFERENCES


BACKGROUND
- For patients with metastatic periacetabular disease confined to the supra-acetabular region, resection and reconstruction avoids hip joint replacement.
- The goal of treatment is to alleviate pain and ensure ambulation as soon as possible after surgery, with minimal perioperative morbidity and mortality.
- Periacetabular lesions may be classified according to Harrington’s classification. Supra-acetabular lesions are categorized as class I.
- Surgical options include extra-articular curettage and fixation versus intra-articular acetabular curettage and reconstruction with an acetabular prosthetic component, known as total hip replacement.
  - The extra-articular approach requires minimal surgical intervention (<1 hour, with minimal blood loss), a shorter postoperative hospital stay, and lower post–hip arthroplasty risk of infection and instability.
  - The intra-articular approach, or total hip replacement, is a more expansive, definitive approach, with a mean blood loss of 1800 mL, mean operative time of 140 minutes, and average hospital stay of 14 days.1

ANATOMY
- Metastatic bone disease usually does not invade into cartilage. Therefore, the acetabular cartilage usually is spared by periacetabular lesions. After curettage, fixation of the lesion provides ample support for the cartilage without violating the joint (analogous to curettage and cementation of giant cell tumors).
- Reconstruction should take into account the concavity of the hip cartilage.

INDICATIONS
- Metastatic periacetabular lesions may present as pain on weight bearing.
- The treatment of choice for most of these lesions is radiation therapy.
- Surgical treatment is reserved for impending pathological fractures and painful lesions resistant to radiation therapy (FIG 1).
  - Harrington class I lesions have extensive tumor invasion without loss of structural integrity of the acetabulum. Minimal medial wall disease is present.
  - Not indicated if the ipsilateral femoral head is involved with tumor.

IMAGING AND OTHER STAGING STUDIES
Imaging
- Plain radiographs and CT scans of the pelvis and hip joint are necessary to define the extent of the lesion accurately.
- Three-dimensional CT reconstructions have been used more recently to show remaining bone stock accurately.
- MRI studies are helpful in defining the continuity of the acetabular cartilage (FIG 2A).
- Bone scan is needed to rule out concomitant metastatic lesions to the ipsilateral femur (FIG 2B).
- Angiography and embolization should be strongly considered in metastases from vascular lesions such as renal cell and thyroid carcinoma.

Biopsy
- For metastatic disease, biopsy is performed at the time of surgery. A frozen section typically provides adequate diagnostic information.

SURGICAL MANAGEMENT
- A CT scan is done preoperatively to access localized tumor to supra-acetabular area with minimal medial wall involvement.
- The patient is placed in the lateral decubitus position.
- The skin incision is made from the posterior third of the iliac crest to the greater trochanter (FIG 3A).
- The gluteus maximus is detached from the iliotibial band and retracted to expose the retrogluteal space. Care is taken not to open the hip joint.
- The sciatic nerve should be picked up as it exits below the piriformis muscle and should be tagged with a vessel loop. The sciatic notch is identified, and the nerve is protected (FIG 3B).
- The iliac bone superior to the acetabulum may then be exposed by retracting the gluteus medius and minimus muscles anteriorly. Care should be taken not to injure the superior and inferior gluteal vessels.
FIG 1 • A. Supra-acetabular metastatic lytic lesion. Joint contour is preserved. B. Supra-acetabular defect in a pelvic model. C. Reconstruction of the defect.

FIG 2 • A. T2-weighted MRI scan showing the preserved cartilage border of the right hip joint. B. Technetium Tc 99m bone scan showing uptake in the supra-acetabular region. No uptake is seen in the ipsilateral femur or medial acetabular wall.

FIG 3 • A. The patient is placed in the lateral decubitus position. The skin incision is carried from the iliac crest to the proximal femur. B. Exposure. The sciatic nerve is tagged and protected, and the sciatic notch is identified. The hip joint is left untouched. The iliac bone is exposed by reflecting the gluteus medius and minimus muscles anteriorly.

CURETTAGE AND RECONSTRUCTION

- The lesion is unroofed and curetted (TECH FIG 1A).
- The acetabular cartilage and the remaining subchondral bone are supported with a highly cross-linked polyethylene tibial liner, chosen for its concave shape. It is cut to size (TECH FIG 1B).
- The remaining defect is then packed with polymethylmethacrylate (TECH FIG 1C,D).
- Additional support may be achieved with Steinmann pins inserted in an antegrade or retrograde fashion between the iliac crest and the area of the lesion if the inner wall of the ilium has been destroyed.
- A perineural catheter is inserted into the sciatic nerve sheath for postoperative pain management. Through this catheter, 0.25% bupivacaine can be administered for up to 72 hours postoperatively.
POSTOPERATIVE CARE
- Immediate weight bearing should be allowed, because the structure should be stable and virtually pain-free.

OUTCOMES
- Full weight bearing permitted
- Minimal blood loss (<300 mL)
- No infections to date
- Avoids the possible complications of total hip replacement
- Rare tumor progression

COMPLICATIONS
- Risk of postoperative infection is minimal due to the minimal extent of the surgery.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>CT and radiographs</th>
<th>Acetabuloplasty is indicated only for supra-acetabular lesions with minimal medial wall involvement.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoid injury to superior gluteal vessels</td>
<td>Identify nerve and artery after release of the gluteus maximus.</td>
</tr>
</tbody>
</table>

REFERENCES
BACKGROUND

- The gluteus maximus (buttock) is a common site for high- and low-grade soft tissue sarcomas. The gluteus maximus is a “quiet area” for soft tissue sarcomas and rarely become symptomatic until they are extremely large. Traditionally low- and high-grade soft tissue sarcomas of the buttock were treated with a posterior cutaneous flap hemipelvectomy. Today, most sarcomas of this muscle can be resected with safe margins; hemipelvectomy is not required. Advances in limb sparing surgical procedures have reduced the need for hemipelvectomy for tumors in this region.
- Tumors of the gluteus maximus are often confined to this muscle and do not extend to the underlying retrogluteal space or involve the sacrum or femur. The most significant structure in the retrogluteal space that must be evaluated is the sciatic nerve. Minimal reconstruction is required. During the postoperative period it is important to take measures to prevent the formation of large postoperative seromas. The functional outcome of a resection of the gluteus maximus is a minimal deficit in hip extension only. The gait is normal.
- A hemipelvectomy rarely is required for a soft tissue sarcoma of the buttock unless it is extremely large or accompanied by fungation, infection, or extension into the ischiorectal space, pelvis, and hip. Direct sacral or iliac bone involvement, which is rare, often necessitates an amputation.
- Today about 90% of soft tissue sarcomas arising in the buttock can be resected and treated adequately by a limb sparing surgery. Low-grade soft tissue sarcomas of the gluteus maximus usually require surgery only; high-grade soft tissue sarcomas in this region, like those in other anatomic areas, are also usually treated with chemotherapy and/or radiation preoperatively and/or postoperatively.
- The authors favor the use of induction chemotherapy followed by a limb-sparing resection when possible for high-grade soft tissue sarcomas. The field is treated with postoperative radiation if required.
- The major indications for an amputation are extremely large sarcomas that involve the adjacent bone, the sciatic nerve, or the ischiorectal fossa.

ANATOMY

- The gluteus maximus arises from the sacral lamina, iliac crest, and ischium. It passes obliquely to its insertion onto the proximal portion of the iliotibial band. This insertion begins above the greater trochanter, passes 4 to 5 cm below the greater trochanter, and then attaches to the adjacent femur. The area underneath the gluteus maximus is termed the retrogluteal space. This area consists of the posterior hip musculature, including the external rotators and portions of the gluteus medius muscle. The sciatic nerve lies in the retrogluteal space. The gluteus maximus does not attach to the retrogluteal structures as it passes over them. This permits easier surgical dissection of the retrogluteal plane and preservation of the sciatic nerve in many situations.
- As it passes from the sacrum to the femur, the gluteus maximus covers the sacroiliac joint and the sacrospinous and sacrotuberous ligaments, as well as a portion of the ischiorectal fossa.
- Most importantly, the sciatic nerve exits the pelvis through the sciatic notch and passes inferiorly to the piriformis muscle. This nerve lies in close proximity to the posterior fascia of the gluteus maximus; therefore, large tumors of the gluteus maximus may involve the sciatic nerve. The sciatic nerve, however, rarely is involved by the tumor; most often it is displaced around the capsule or pseudocapsule. The inferior gluteal vessels pass below the piriformis muscle to enter the midpoint of the gluteus maximus. The inferior gluteal vessels are routinely ligated.

INDICATIONS

- A gluteus maximus resection is indicated for patients with low- and high-grade sarcomas confined to the gluteus maximus.

CONTRAINDICATIONS

- Large tumors that involve the true pelvis or ischiorectal space
- Involvement of the sacrum or ilium
- Sciatic nerve involvement (although, on occasion, the sciatic nerve may be resected)
- Pelvic extension through the sciatic notch

IMAGING STUDIES

Computed Tomography and Magnetic Resonance Imaging

- CT and MRI are most useful in determining the extent of tumor involvement of the gluteus maximus
- Close evaluation determines the involvement of the adjacent sacrum, femur, and sciatic nerve. Attention should be placed on the evaluation of the structures of the retrogluteal space, including the hip joint and sciatic nerve, and ischiorectal fossa. Buttock tumors may extend into the pelvis through the sciatic notch.

Bone Scan

- Tumor involvement may extend to the crest of the ilium, the sacrum, and the proximal femur. These areas should be evaluated by bone scintigraphy.

Angiography

- Angiography is not routinely performed when evaluating tumors of the gluteus maximus. It may be useful in preoperative embolization or preoperative intra-arterial chemotherapy.

Biopsy

- The biopsy site must be in line with the incision for a hemipelvectomy, should one be required. Surgeons performing
a biopsy of tumors of the buttock must, therefore, be familiar with the surgical incisions for both posterior flap and anterior flap hemipelvectomy (see Chaps. ON-21 and ON-22).

The anterior flap hemipelvectomy, as described by Sugarbaker et al., is preferred for large sarcomas of the buttock area. In this procedure the entire musculature and skin are removed with the amputation, and the anterior myocutaneous flap, consisting of the quadriceps muscle, is used to close the defect.

If a posterior flap is used, care must be taken not to contaminate the posterior skin or fascia. The biopsy site must, therefore, be along the lateral aspects of a posterior incision and must avoid the greater trochanter, sciatic nerve, ischiorectal fossa, and greater trochanter.

**BUTTOCKECTOMY**

- A large curvilinear incision is made beginning at the posterior aspect of the crest of the ilium, curving distally following the gluteus maximus muscle along the iliotibial band (TECH FIG 1A,B), passing over the greater trochanter to about 6 cm distal, and then curving posteriorly back toward the inner aspect of the thigh along the gluteal fold. This incision makes it possible to elevate a large posterior flap.

To determine resectability or operability, the sciatic nerve is identified distal to the resection site. It can be identified between the medial and lateral hamstring muscles or just lateral to the ischium before it passes underneath the gluteus maximus muscle. The nerve is palpated below the gluteus maximus muscle toward the piriformis muscle (TECH FIG 1C).

- The gluteus maximus is detached from the iliotibial band throughout its length and from the femur distally. This muscle is then flapped medially to expose the inferior gluteal vessels and nerve, which are then ligated. The sciatic nerve is displaced anteriorly to protect it during the dissection.

- Removal of the gluteus maximus involves detaching this muscle from the sacrotuberous and sacrospinous ligaments, as well as the lamina and sacral alar (TECH FIG 1D).

- To prevent a large postoperative seroma, the large posterior fasciocutaneous flap must be tacked down to the remaining underlying muscle very carefully. Multiple large drains are used (TECH FIG 1E).

- The patient remains supine for 72 hours to prevent the development of a seroma.

---

**TECH FIG 1 • A.** A lateral position is used. The affected extremity is prepped free from the abdominal wall to the foot. The incision extends along the iliac crest and encompasses the biopsy site by 2 to 3 cm and then extends along the greater trochanter and along the gluteus maximus skinfold. The incision permits wide excision of the underlying gluteus maximus muscle and early exploration and preservation of the sciatic nerve. If the tumor is unresectable, an anterior flap hemipelvectomy is required. **B.** A fasciocutaneous flap is elevated and dissected with the electrocautery toward the origin of the gluteus maximus muscle (from the sacrum). This permits exposure of the entire gluteus maximus muscle. The biopsy site is left en bloc with the gluteus maximus muscle. If the tumor is extremely large, only a subcutaneous flap is used, with the deep fascia remaining on the tumor side. **C.** The retrogluteal space, consisting of the hip rotators, abductor muscles, and the sciatic nerve, is seen in this illustration. The gluteus maximus is mobilized from inferior along the deep posterior thigh fascia and released from the iliotibial band up to the iliac crest. It is then dissected to its origin along the sacral alar and the sacrospinous and sacrotuberous ligaments. The sciatic nerve is explored initially by the surgeon placing his hand under the gluteus maximus to ensure that the nerve is free from the tumor. *(continued)*
POSTOPERATIVE CARE

- Postoperative radiation therapy is required for high-grade tumors once the flaps are well healed (4 to 6 weeks after surgery).
- Postoperative chemotherapy is given following the radiation therapy.

OUTCOMES

- The only deficit following gluteus maximus resection is weakness with hip extension. Secondary hip extensors enable some hip extension and the patient’s gait is virtually normal.
- If the sciatic nerve requires resection there is loss of foot and ankle control, so that the patient requires an ankle-foot orthosis.
- Depending on the level of the sciatic nerve resection, the first branch to the biceps femoris may be intact. If that is the case, good knee flexion will be retained. Knee flexion also depends on the sartorius muscle (innervated by the femoral nerve), the gracilis muscle (innervated by the obturator nerve), and the two heads of the gastrocnemius muscle that insert across the knee joint.

COMPLICATIONS

- The most common postoperative complication is the development of a large seroma, because there is a large dead space with only a subcutaneous flap on top. We have used the quadratus femoris muscle rotated over the sciatic nerve for soft tissue coverage of the nerve.
- Similarly, the piriformis is rotated distally. The flap is carefully tacked down throughout its course in its midportion to eliminate “dead” space. One 20-gauge chest tube and two Jackson-Pratt drains are used, and the remaining portion of the flap is closed. A compressive dressing is utilized for 72 hours.
- In the case of recurrent sarcomas of the buttocks, tumor fungation, massive contamination, or extensive tumor involvement of the adjacent structures, an anterior flap hemipelvectomy is recommended (see Chap. ON-22 for a discussion of this procedure).

REFERENCE

BACKGROUND

- Metastatic tumors of the pelvis may cause pain and a major loss of function and weight-bearing capacity. Due to the relatively large size of the pelvic cavity, the elastic nature of the organs it contains, and its surrounding muscles, tumors at that site usually reach considerable size before causing symptoms. While some locations of metastases within the pelvis have no impact on pelvic stability and function (eg, ilium, pubis), tumors of the posterior ilium may pose a threat to lumbosacral integrity, and tumors of the acetabulum may profoundly impair hip function and the weight-bearing capacity of the lower extremity.
- Both primary sarcomas and metastatic tumors usually present with considerable extension into the soft tissues. Due to their inherent sensitivity to radiation therapy, however, the surgical management of metastatic lesions does not require en bloc resection of overlying muscles, and microscopic residua are treated with adjuvant radiation. The complex anatomy of the pelvic girdle mandates detailed preoperative imaging, planning of exposure and reconstruction technique, and careful and meticulous execution of the surgical procedure.
- Pelvic metastases are treated either with curettage and reconstruction with cemented hardware or by wide resections. These procedures are grouped together and termed pelvic resections, the classification of which is attributed to Enneking and is based on the resected region of the innominate bone: type I, ilium; type II, periacetabular region; type III, pubis. En bloc resection of the posterior ilium with the sacral ala is classified as either an extended type I or type IV resection (FIG 1).

ANATOMY

Ilium

- The iliac crest is the attachment site for abdominal wall musculature and quadratus lumborum (FIG 2).
- The iliacus muscle overlies the inner iliac table, and the femoral nerve lies medial to it in the groove between the iliacus and the psoas muscle.
- Gluteal muscles overlie the outer iliac table.

Acetabulum

- The acetabulum provides the upper-medial mechanical support of the hip joint.
- No muscle attachments connect to the acetabulum.

Pubis

- Hip adductors take their origin from the inferior aspect of the pubis.
- The neurovascular bundle runs along the anterior aspect of the pubis.
- The urinary bladder attaches to its posterior wall.

INDICATIONS

- Pathological fracture of the acetabulum
- Impending pathological fractures of the acetabulum, which are defined as lesions that extend to the acetabular roof and are associated with cortical destruction and considerable pain on weight bearing
- Intractable pain associated with locally progressive disease that has shown inadequate response to narcotics and preoperative radiation therapy
- Solitary bone metastasis, in selected patients

IMAGING AND OTHER STAGING STUDIES (FIG 3)

- Plain radiographs and CT of the pelvis and hip joints are mandatory to evaluate the full extent of bone destruction, soft tissue extension, and integrity of the hip joint. MRI rarely adds additional information; rather, it is indicated in lesions that have diffused intramedullary extension, which is commonly underestimated by CT, such as multiple myeloma. Total body bone scintigraphy is done for detecting synchronous metastases elsewhere in the skeleton. At the conclusion of imaging, the surgeon should be able to answer the following questions:
  - What is the full extent of bone destruction and soft tissue extension that are related to the tumor? Is the lesion an impending fracture? If not, it probably should be treated nonsurgically.
  - What incision should be used to obtain optimal exposure?
  - What would be the best technique for resection and reconstruction, if required?
  - Are there additional skeletal metastases and, if so, can they be managed by nonoperative techniques or do they require surgery?
  - Hypervascular lesions (eg, metastatic renal cell or thyroid carcinomas) can bleed profusely and cause life-threatening blood loss within a few minutes upon tumor exposure and curettage. Preoperative embolization of these tumors is strongly advised to reduce intraoperative blood loss.4,5

SURGICAL MANAGEMENT

Positioning

Types I through III Resection

- The patient is placed supine on the operating table with the ipsilateral hip slightly elevated.

Type IV Resection

- The patient is placed in a true lateral position with the affected side of the pelvic girdle uppermost. The operating table is bent with the breakage point just below the contralateral hip: such a position widens the space between the iliac crest and the lower aspect of the chest wall, allowing a comfortable approach and easier maneuvering at that site (FIG 4).
FIG 1 • Metastatic tumors of the ilium, periacetabular region, pubis, and posterior ilium require types I, II, III, and IV pelvic resections, respectively.

FIG 2 • Muscle attachments and relevant structures around the innominate bone.

FIG 3 • Plain radiographs and CT scans with coronal reconstruction showing acetabular metastases with their most pronounced cortical destruction at the lateral acetabular wall (A–C) and medial acetabular wall (D–F). Lesions in the former area are exposed after reflection of the glutei from the outer iliac table; those from the latter area are exposed after reflection of the iliacus from the inner iliac table (see Incision and Exposure: Acetabulum).
Chapter 20  SURGICAL MANAGEMENT OF METASTATIC BONE DISEASE: PELVIC LESIONS

The most useful approach to pelvic resections is the utilitarian pelvic incision (TECH FIG 1A). All or part of the incision can be used for adequate exploration and resection of pelvic girdle metastases. The incision begins at the posterior inferior iliac spine and extends along the iliac crest to the anterior superior iliac spine. It is then separated into two arms: one extends along the inguinal ligament up to the symphysis pubis, and the other turns distally over the anterior thigh for one-third the length of the thigh and then curves laterally just posterior to the shaft of the femur below the greater trochanter and follows the insertion of the gluteus maximus muscle.

Reflection of the posterior gluteus maximus flap exposes the proximal third of the femur, the sciatic notch, the sacrotuberous and sacrospinous ligaments, the origin of the hamstrings from the ischium, the lateral margin of the sacrum, and the entire buttock. Posteriorly, the incision extends along the posterior iliac crest, posterior-superior iliac spine, and ipsilateral hemisacrum (TECH FIG 1B).

**Type I Resection**
- The middle component of the utilitarian incision is used to expose the iliac crest. Using electrocautery, the glutei are detached and reflected from the outer iliac table. The iliacus muscle is similarly detached and reflected from the inner table (TECH FIG 2).

**Type II Resection**
- For lesions with lateral cortical destruction, the middle component of the utilitarian incision, up to the anterior superior iliac spine with a 5-cm extension along the inguinal arm of the incision, is used. Electrocautery is applied to detach and deflect the iliacus from the inner iliac table, exposing the medial wall of the acetabulum (TECH FIG 4).

**Type III Resection**
- For lesions with medial cortical destruction, the middle component of the utilitarian incision, from the anterior superior iliac spine to 2 cm across the

**EXPOSURE**

**Type I Resection**
- The middle component of the utilitarian incision is used to expose the iliac crest. Using electrocautery, the glutei are detached and reflected from the outer iliac table. The iliacus muscle is similarly detached and reflected from the inner table (TECH FIG 2).

**Type II Resection**
- For lesions with lateral cortical destruction, the middle component of the utilitarian incision, up to the anterior superior iliac spine with a 5-cm extension along the lateral thigh arm of the incision, is used. Electrocautery is applied to detach and reflect the glutei from the outer iliac table, exposing the lateral wall of the acetabulum (TECH FIG 3).

**Type III Resection**
- The inguinal component of the utilitarian incision, from the anterior superior iliac spine to 2 cm across the
symphysis pubis, is used for type III resection. The neurovascular bundle is isolated, marked with vessel loops, and mobilized. The retropubic space is exposed, and a pad is inserted between the urinary bladder and the pubis. Muscle attachments are then detached from the inferior aspect of the pubis (TECH FIG 5).

**Type IV Resection**

- The posterior component of the utilitarian incision is used for type IV resections. Electrocautery is applied to detach the glutei from their origin at the posterior iliac crest and to reflect them (TECH FIG 6).
Exposure of an acetabular metastasis that has caused lateral cortical destruction is accomplished using the middle component of the utilitarian incision up to the anterior superior iliac spine, with a 5-cm extension along the lateral thigh arm of the incision. B, C. Using electrocautery, the glutei are detached and reflected from the outer iliac table, exposing the lateral wall of the acetabulum.

Exposure of an acetabular metastasis with medial cortical destruction is achieved by using the middle component of the utilitarian incision up to the anterior superior iliac spine, with a 5-cm extension along the inguinal arm of the incision. B, C. Using electrocautery, the iliacus is detached and reflected from the inner iliac table, exposing the medial wall of the acetabulum.
TECH FIG 5 • A. Exposure of a pubic metastasis is accomplished with the inguinal component of the utilitarian incision, from the anterior superior iliac spine to 2 cm across the symphysis pubis. B. The affected bone is reached after isolation and mobilization of the neurovascular bundle from the anterior aspect of the pubis, reflection of the urinary bladder from its posterior aspect, and detachment and reflection of the adductors origin from its inferior aspect.

TECH FIG 6 • A,B. Exposure of a metastasis at the posterior ilium is achieved by using the posterior component of the utilitarian incision. C. The glutei are detached from their origin from the posterior iliac crest and outer table. D. Reflection exposes the outer iliac table.
TUMOR REMOVAL

Type I Resection
- Type I resections involve an osteotomy of the ilium around the lesion. Margins of 1 to 2 cm are sufficient for resection of metastases at that site (TECH FIG 7). Tumor curettage is neither feasible nor justified at that site, because a resection of the ilium that does not impair acetabular or sacroiliac joint integrity rarely has an impact on function.

Type II Resection
- A wide cortical window is made above the lesion (TECH FIG 8A). Gross tumor is removed with hand curettes (TECH FIG 8B, C). Curettage should be meticulous and leave only microscopic disease in the tumor cavity. It is

TECH FIG 7 • Plain radiograph showing the ilium following a type I resection. The sacroiliac joint and the acetabulum are intact, and function is, therefore, expected to remain unimpaired.

TECH FIG 8 • A. A wide cortical window is created. B, C. Gross tumor is meticulously removed with hand curettes, leaving only microscopic disease. D, E. Curettage is followed by high-speed burr drilling of the tumor cavity.
followed by high-speed burr drilling of the tumor cavity walls (TECH FIG 8D,E).

When the entire acetabulum is destroyed and no cortices are left to contain an internal fixation device and cement, a formal resection is done in the same manner as for primary sarcomas of bone (see Chaps. ON-17 and ON-18). The incision is extended along the upper thigh, the joint capsule is opened, the femur is dislocated, and an acetabular osteotomy and resection are carried out.
Type III Resection

- A longitudinal cortical window with oval edges is made above the lesion, and tumor curettage and high-speed burr drilling are done in the same manner as in a type II resection (TECH FIG 9).
- When the pubis is destroyed and no cortices are left to allow curettage and burr-drilling, the incision is extended to exposed intact cortices from both sides of the lesion, followed by formal resection of the pubic segment.

Type IV Resection

- A longitudinal cortical window with oval edges is made above the lesion, and tumor curettage and high-speed burr drilling are done in the same manner as in a type II resection (TECH FIG 10).
- When the posterior ilium is destroyed and no cortices are left to allow curettage and burr-drilling, wide resection of the posterior iliac segment is carried out. These resections commonly require the en bloc removal of the adjacent component of the sacroiliac joint and potentially can impair stability of the posterior pelvic girdle.

MECHANICAL RECONSTRUCTION

Type I and II Resection

- Type I resections require no reconstruction.
- After completion of tumor removal with burr-drilling, the tumor cavity is reconstructed with cemented Steinmann pins, which are introduced through the iliac crest. Following placement of the pins tips against the subchondral bone, the tumor cavity is filled with cement (TECH FIG 11A–C).

TECH FIG 11 • A,B. Steinmann pins are introduced through the iliac crest into the tumor cavity up to the subchondral bone. Following placement of the pins, the tumor cavity is filled with bone cement. C. Plain radiograph showing the acetabular cavity reconstructed with cements Steinmann pins. D. Deficient articular cartilage may be reconstructed with a polyethylene insert.
Acetabular metastases may destroy the subchondral bone and dissociate the articular cartilage. In such cases, reconstruction of the articulating surface of the acetabulum can be done with a prosthetic polyethylene insert that has been shaped with a high-speed burr to match the convexity of the femoral head (TECH FIG 11D).

Two courses are available following resection of the acetabulum: (1) reconstruction with a saddle prosthesis; or (2) no reconstruction, leaving a flail extremity.

**Type III Resection**

Following curettage, the tumor cavity is filled with cement, which does not contribute to pelvic stability but allows easier determination of tumor extent on the postoperative imaging studies and subsequent planning of radiation fields, as well as early detection of local tumor recurrence at the cement–bone interface. No reconstruction is required if resection of a pubic segment had been performed.

**Type IV Resection**

Following curettage, the tumor cavity is filled with cement, the purpose of which is similar to cementation of a pubic defect.

Small defects of the sacroiliac joints do not require reinforcement. Medium-sized defects, however, require such reinforcement with a plate to prevent dissociation of the joint. Complete resection of the sacroiliac joint compromises stability of the posterior pelvic girdle.

Gradual upward migration of the ilium on weight-bearing as well as limb-length discrepancy is likely to occur (TECH FIG 12). Traction of the lower extremity followed by a protected weight-bearing protocol is implemented to reduce the extent of limb-shortening.

**SOFT TISSUE RECONSTRUCTION AND WOUND CLOSURE**

- The glutei and iliacus are sutured over the innominate bone, and both are then sutured to the abdominal wall musculature (TECH FIG 13). These three muscle groups must be attached properly: correct restoration of muscle origin attachment allows function of the glutei and iliacus muscles; and restoration of abdominal wall continuity prevents herniation of the pelvic viscera to the flank.

- The surgical wound is closed over suction drains, and an abduction pillow is used to enable wound healing with minimal stress at the muscle suture line. In the case of a complete resection of the sacroiliac joint and loss of posterior pelvic continuity, skin traction is used to pull the extremity and avoid limb shortening.
TECH FIG 13 • Plain radiograph (A) and CT scan (B) showing metastatic carcinoma of the left ilium. C. Intraoperative photograph showing the remaining iliac stump following osteotomy (the femoral nerve is lifted with a vessel loop and a clamp is passed through the sciatic notch). D. The glutei are sutured to the iliacus muscle to cover the iliac stump, and both are sutured to the abdominal wall musculature to avoid herniation of the pelvic viscera into the flank.

PEARLS AND PITFALLS
- Detailed preoperative imaging and anatomic tumor classification
- Choice of resection type and extent (curettage vs. resection) and technique of reconstruction, if required
- Preoperative embolization of hypervascular lesions
- Use of the appropriate component of the utilitarian incision for wide tumor exposure
- Tumor removal by curettage and high-speed burr drilling; resection when curettage is not feasible
- Reconstruction with cemented hardware
- Functional reconstruction of muscle groups
- Early ambulation with unrestricted weight bearing, except for patients who had complete resection of their sacroiliac joint
- Postoperative radiation therapy

POSTOPERATIVE CARE
- Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed. Rehabilitation should include early ambulation with unrestricted weight bearing as well as passive and active range-of-motion of the hip joint.
- In complete resections of the sacroiliac joint, skin traction is applied for the first 10 postoperative days, and weight bearing is allowed only after 3 weeks postsurgically have passed. This protocol allows the formation of scar tissue around the sacroiliac defect, which may decrease the extent of iliac migration.
- Once the wound has healed, usually 3 to 4 weeks after surgery, patients are referred to adjuvant radiation therapy.

OUTCOMES
- Most patients who undergo resection of pelvic metastases experience a substantial relief of pain and are able to ambulate with full weight bearing. Most of them do not, however, reach their full functional capability because of a relatively slow recovery and muscle weakness due to their progressing oncologic disease and general wasting.
- Hardware failures rarely are seen if internal fixation devices have been chosen correctly, used properly, and reinforced with
cement. Local recurrence rates are less than 10% as long as there has been adequate tumor removal and if postoperative radiation was administered.\textsuperscript{2,3}

**COMPLICATIONS**

- Deep infection
- Wound dehiscence due to poor nutritional and catabolic states
- Deep vein thrombosis
- Sacroiliac dissociation and upward migration and shortening of lower extremity on weight bearing
- Herniation of pelvic viscera to the flank
- Local tumor recurrence

**REFERENCES**

BACKGROUND

Despite increasingly effective chemotherapy and advances in limb-sparing surgery around the pelvis and hip, hindquarter amputation (hemipelvectomy) often remains the optimal surgical treatment for primary tumors of the upper thigh, hip, or pelvis.

Hemipelvectomy may also be life-saving for patients with massive pelvic trauma or uncontrollable sepsis of the lower extremity, and it can provide significant palliation of uncontrollable metastatic lesions of the extremity. An intimate knowledge of the pelvic anatomy (FIG 1A,B) and a systematic approach to the surgical procedure are required to minimize the intraoperative and postoperative morbidity associated with this demanding procedure.

Early descriptions of the surgical technique of hemipelvectomy emphasized the importance of careful selection of patients and immediate replacement of blood loss. Ligation of the correct pelvic vessels is crucial to a successful outcome. The importance of this fact is indicated by the tumor. Reference to easily palpable and visual landmarks helps identify critical structures.

The advent of limb-sparing pelvic resections has necessitated a distinction between internal and external hemipelvectomy, depending on whether preservation of the ipsilateral limb is performed. Confusion caused by the term “internal hemipelvectomy” can be avoided by use of a standardized classification for pelvic resection.

Sugarbaker and Ackerman and others have shown the utility of a myocutaneous pedicle flap based on the femoral vessels and anterior compartment of the thigh for closure of the wound in patients with tumor involving the posterior buttock structures. This procedure has been termed an “anterior flap hemipelvectomy” to distinguish it from the more common “posterior flap hemipelvectomy.” Anterior flap hemipelvectomy is indicated for tumors that involve the buttock and for selected patients who require a well-vascularized flap for coverage.

There are subtypes of the posterior flap hemipelvectomy. The term “classic hemipelvectomy” is used to refer to amputation of the pelvic ring via disarticulation of the pubic symphysis and the sacroiliac joint, division of the common iliac vessels, and closure with a posterior fasciocutaneous flap (FIG 1C).

Classic hemipelvectomy is typically necessary for large tumors that arise within the pelvis. “Modified hemipelvectomy” refers to a procedure that preserves the hypogastric (internal iliac) vessels and the inferior gluteal vessels supplying the gluteus maximus, permitting creation of a vascularized myocutaneous posterior flap for wound closure. This term also describes variations from the classic operation, including resection through the iliac wing or contralateral pubic rami.

Modified hemipelvectomy is most commonly performed for tumors involving the thigh or hip when a limb-sparing alternative is contraindicated. “Extended hemipelvectomy” refers to a resection of the hemipelvis through the sacral alar and neural foramina, thereby extending the margin for tumors that approach or involve the sacroiliac joint (FIG 2).

Regardless of the type of flap created for closure, the term “compound hemipelvectomy” is used to describe resection of contiguous visceral structures such as bladder, rectum, prostate, or uterus. (Tumor suspected of extending into viscera or extremely large tumors filling the pelvic fossa can be approached through an intraperitoneal incision.)

ANATOMY

The skeletal anatomy and contents of the pelvis are complex and difficult to visualize without direct experience. Major portions of the gastrointestinal tract, the urinary tract, the reproductive organs, and the neurovascular trunks to the extremities all coexist within the confines of the bony pelvis.

Understanding the three-dimensional anatomy is essential to identifying and protecting these structures during a hemipelvectomy (see Fig 1A–C). The normal anatomy may be distorted by the tumor. Reference to easily palpable and visual landmarks helps identify critical structures.

The surgical approach to a hemipelvectomy is based on sequential exposure and identification of these landmarks and structures.

Bony Anatomy

The basic pelvic bony anatomy is best thought of as a ring running from the posterior sacrum to the anterior pubic symphysis. Major joints include the large, flat sacroiliac joints, the hip joints, and the pubic symphysis. The hip joint is easily located by motion of the extremity; the other joints are easily located and identified by palpation. Other easily palpable bony prominences include the iliac crest, the anterior superior iliac spine, the ischial tuberosity, and the greater trochanter of the femur.

These landmarks are essential in creating rational skin incisions during the procedure. Likewise, identification of internal bony landmarks helps localize adjacent structures.

The lumbosacral plexus is found by palpating the sacroiliac joint, the sciatic nerve and gluteal vessels are found under the sciatic notch, and the urethra is found under the arch of the pubic symphysis.

Vascular Anatomy

Ligation of the correct pelvic vessels is crucial to a successful amputation. The importance of this fact is indicated by the
classification scheme, in which the level of ligation determines the type of amputation to be performed. As the abdominal aorta and vena cava descend into the pelvis they bifurcate, creating the common iliac arteries and veins. This bifurcation typically occurs at L4, with the lower bifurcation occurring at S1. The left-sided aorta and the iliac and external iliac arteries remain anterior to the major veins throughout the pelvis. The internal iliac artery (hypogastric artery) bifurcates from the posterior surface of the common iliac artery as it travels down toward the sciatic notch.

- Tumor masses within the pelvis can distort this anatomy, making it mandatory to visualize and isolate each of the vessels before performing a ligation (see Fig 1A).
- The internal iliac (hypogastric) vessels supply the pelvic floor, rectum, bladder, and prostate, as well as the gluteal muscles. Ligation of this vessel will not jeopardize the internal

---

**FIG 2**  •  A. CT scan showing a large chondrosarcoma arising from the left proximal femur. Benign osteochondroma is on the ipsilateral femur. This patient had multiple hereditary osteochondromas. This is one of the more common indications for performing a hemipelvectomy. Chondrosarcoma is the most common malignant tumor of the pelvis.  
B. Pathological fracture (distal location) through an extremely large renal cell carcinoma of the left pelvis. There is a large soft tissue component extending almost to the midline.  
C. Solitary renal cell carcinoma metastasis of the right proximal femur extending into the pelvis. This MRI shows a large extraosseous component with complete destruction of the periacetabular area, and with tumor filling the ischiorectal space. Solitary renal cell carcinoma metastasis is considered to be one of the few indications for radical amputation due to metastatic carcinoma. (continued)
structures because of contralateral blood flow and rich anastomotic vessels; however, it will significantly devascularize the gluteus maximus muscle. Classic hemipelvectomy, in which these branches are divided, has a substantial rate of wound complications as a direct result.

**Pelvic Viscera**
- In addition to the critical vascular structures, major organs of the gastrointestinal and genitourinary tracts are present and exposed during a hemipelvectomy. These structures should be completely evaluated before surgery.
- The bladder and urethra, and the prostate in male patients, are located above and under the pubic symphysis. Placement of a Foley catheter with a large inflated balloon makes these structures easier to palpate during surgery. Care must be taken not to injure the urethra during division of the symphysis. In addition, the venous plexus surrounding the prostate can be a significant source of bleeding that can be difficult to control even with good visualization of the organ. The ureters are at risk of injury as they cross over the iliac vessels from lateral to medial. The peristaltic motion of the ureters helps to identify these structures.
- In female patients the ovaries, fallopian tubes, uterus, cervix, and vagina require identification and protection. Care in taking a complete history of the patient will identify women who have undergone hysterectomies. In female patients who have not undergone such surgery, these organs are found under and adjacent to the bladder. They can be easily and safely retracted out of the operative field.

- Most of the gastrointestinal tract is protected by the peritoneum and is gently retracted out of the operative field. Of particular concern is the sigmoid colon, which must be protected during left-sided amputations. The colon and rectum must also be identified and protected during the division of the sling muscles before completing the amputation. Insertion of a rectal tube before surgery helps to identify both these structures and to decompress them. Because of the possibility of bacterial contamination from these structures, preoperative bowel preparation and the use of appropriate antibiotics are prudent.

**INDICATIONS**

**Unresponsive Sarcomas Involving Multiple Compartments**
- The most common indication for hemipelvectomy is a non-metastatic sarcoma that fails to respond to neoadjuvant chemotherapy or radiation. In addition, patients with extremely large sarcomas involving multiple compartments of the thigh may require an immediate amputation to avoid tumor fungation, hemorrhage, and secondary infection. In each case the type of hemipelvectomy performed is dictated by the anatomic location of the tumor and the expected defect to be created by the resection.
- For example, a posterior tumor involving the buttock and sciatic nerve that cannot be resected by a buttockectomy can be removed and closed with a vascularized pedicle anterior flap hemipelvectomy.
Contamination of Surrounding Structures

- Patients with extensive contamination of compartments from inappropriately placed biopsies or from unplanned intralesional resections of sarcomas around the pelvis, hip, and proximal thigh are candidates for hemipelvectomy. In addition, pathologic fractures of the proximal femur often contaminate unexpectedly large volumes of tissue (Fig 2).
- Traditionally, such fractures have been treated with hemipelvectomy, although some institutions now attempt limb-sparing procedures after aggressive preoperative (neoadjuvant) treatment and spica immobilization.

Nonviable Extremity Precluding Limb Salvage

- Elderly patients with significant peripheral vascular disease and patients with fungating, infected sarcomas that preclude limb-sparing surgery may be candidates for hemipelvectomy.
- Conversely, very young and skeletally immature children with primary sarcomas who are not suitable candidates for limb-sparing procedures because of the inevitable problem of limb-length discrepancy may be treated with hemipelvectomy.
- Typically, the youngest patients adapt most completely to their missing limb and lead extremely active lives. Psychological counseling for the parents and family is essential under such circumstances.

Failure of Previous Resection

- Hemipelvectomy is indicated as a final salvage procedure for patients with local recurrence in the thigh or buttock after aggressive surgical and medical treatment.
- Careful patient evaluation is necessary to rule out metastatic disease in such cases.
- Hemipelvectomy may also be required to control infection after limb-sparing procedures around the hip and pelvis.

Palliation

- The use of radical amputation for palliation of patients with metastatic disease is rare. Palliative indications for hemipelvectomy include uncontrollable pain from tumor involvement of the lumbosacral plexus, sciatic, and femoral nerves.
- Patients with uncontrollable local disease from metastatic carcinoma who have failed to respond to all conventional treatments, including radiation and chemotherapy, may also benefit from amputation.
- Realistic expectations and psychological support for the patient and family are essential in such cases.

Nononcologic Indications

- Modified or anterior flap hemipelvectomy may be required for uncontrolled decubiti and osteomyelitis of the hip and pelvis in patients with longstanding paralytic conditions. Both function and emotional well-being often improve rapidly after the source of chronic sepsis has been surgically removed.
- For patients with partial pelvic amputation and open hemorrhaging fractures of the pelvis, emergency hemipelvectomy may be life-saving. In both circumstances, oncologic margins are not required, making the surgery easier to perform.

IMAGING AND OTHER STAGING STUDIES

- Complete imaging and staging of the patient are essential for proper patient selection and preoperative planning. Routine preoperative staging studies of the patient should include a computed tomography (CT) scan of the chest and a total body bone scan to detect metastatic disease.
- Images of the liver and abdomen may be indicated for patients with certain tumors, such as myxoid liposarcomas that can present with unusual sites of metastases.

Standard Radiographs

- Radiographs remain the gold standard for the detection and diagnosis of bone sarcomas. Evaluation of patients with suspected pelvic and hip or thigh tumors should always include a standard anteroposterior (AP) pelvis view that extends from the top of the iliac crests to below the pubic symphysis.
- Additional views of the pelvis may be helpful, including the iliac and obturator oblique views described by Judet, as well as inlet and outlet views. Given the complexity of pelvic anatomy, cross-sectional images are vital.

CT and Magnetic Resonance Imaging

- CT and magnetic resonance imaging (MRI) both provide the ability to image pelvic anatomy in cross-sectional planes. MRI provides better images in the sagittal and coronal planes. Use of oral, intravenous, and rectal contrast media can greatly improve the ability of CT scanning to image the visceral organs of the pelvis.
- CT is extremely useful in evaluating the sacroiliac joint, the sciatic notch, and the symphysis pubis.
- MRI often provides a better image of the soft tissue and the intramedullary extent of sarcoma. The retroperitoneal lymph nodes can be evaluated with either technique.
- Because of the complementary nature of the information provided by these scans, a complete evaluation may require both imaging modalities.

Angiography

- Preoperative angiography of the pelvis is extremely useful in delineating the relationship of the iliac branches to the tumor. Older patients undergoing anterior flap hemipelvectomy may have silent atherosclerotic disease of the femoral vessels that could jeopardize the success of the flap.
- If a modified hemipelvectomy is being considered, angiography reveals the level of the common iliac bifurcation. Patients undergoing palliative amputation may benefit from preoperative embolization to reduce intraoperative bleeding.

Venography and Other Tests

- Complete evaluation of the visceral structures of the pelvis may require additional studies. Dedicated radiographic evaluation using contrast materials of the colon, rectum, bladder, urethra, and uterus is useful if tumor involvement is suspected. Direct visual inspection by sigmoidoscopy and cystoscopy may be essential in selected patients. Pelvic venography should be performed if there is any clinical suspicion of venous obstruction (ie, distal edema). Venous tumor thrombi often occur with large pelvic chondrosarcomas. Tumor thrombi should be removed during surgery.

Biopsy

- The biopsy of tumors around the pelvis and proximal femur must be extremely well planned to avoid contaminating the
posterior flap, which is the most common type of hemipelvectomy performed. The orthopedic oncologist who will be performing the amputation should be present during the biopsy procedure to ensure that a proper and appropriately placed biopsy is performed (FIG 3).

SURGICAL MANAGEMENT

Positioning

- The patient is placed in a modified semisupine position. Incision of the abdominal wall and retroperitoneal dissection of the iliac vessels are performed first. The common iliac, external iliac, or internal iliac (hypogastric) vessels are selectively ligated according to the type of hemipelvectomy to be performed.

Approach

- Exposure of the pubis, bladder neck, and urethra permits sectioning of the symphysis pubis. The iliac wing, sacroiliac joint, or sacrum is then exposed and divided to complete the amputation. Division of the lumbosacral plexus at the level of the sacrum or pelvis is accomplished at the same time. A fasciocutaneous or a myocutaneous flap (involving the gluteus maximus for posterior flaps or the anterior compartment of the thigh for anterior flaps) is then completed. Flexion and adduction and abduction of the hip then allows the surgeon to divide the muscles and ligaments of the pelvic floor and complete the amputation.

- The classic posterior flap hemipelvectomy can be visualized as consisting of five major surgical components.

ANTERIOR RETROPERITONEAL APPROACH THROUGH THE ILIOINGUINAL INCISION

- Through this incision (TECH FIG 1A), the retroperitoneal space is explored by detaching the abdominal wall musculature from above the ilioinguinal ligament and off the iliac crest (TECH FIG 1B). For large tumors of the ilium the retroperitoneal space is entered laterally, where there is more free retroperitoneal fat. The peritoneum is then reflected off the tumor mass and the retroperitoneal space is developed. The ureter remains on the peritoneal reflection. The iliac arteries or hypogastric vessels are ligated and transected, the psoas muscle and the femoral nerve are transected, and the abdominal wall is released from the iliac crest to the posterior superior iliac spine. All structures are transected or mobilized anteriorly before proceeding to the next steps. It is crucial to identify all of the vascular struc-
B. The retroperitoneal space is easily entered by detaching the abdominal wall musculature from above the ilioinguinal ligament and off the iliac crest. The peritoneum is then reflected off the tumor mass, and the retroperitoneal space is developed. It is crucial to identify all of the vascular structures initially to prevent any mistakes in ligation. C. A modified hemipelvectomy is an amputation preserving a portion of the wing of the ilium and the underlying gluteus maximus muscle and its major pedicle the inferior gluteal vessels.

The second major step is the perineal incision. This incision extends from the symphysis pubis down to the ischium along the inferior pubic ramus. The ischiorectal space is exposed along the inferior pubic ramus to the symphysis pubis. The symphysis pubis is disarticulated. The bladder is retracted with a malleable retractor, and an additional small malleable retractor is placed beneath the symphysis pubis notch to protect the urethra. The urethra is easily palpable and protected with a malleable retractor (TECH FIG 2). A foley catheter is in place. For large tumors of the pelvic floor the urethra may be around the pseudocapsule of the tumor. Therefore, great care must be taken not to enter the tumor or the pericapsular structures of the prostate.

TECH FIG 2 • The perineal incision is then begun prior to abducting or flexing the affected extremity. The symphysis pubis is opened with a small osteotome or a cutting cautery.
POSTERIOR FLAP RETROGLUTEAL AREA EXPLORATION

- The third component of the procedure is the posterior fasciocutaneous or subcutaneous flap that is mobilized along the iliotibial band and the greater trochanter toward the sacroiliac joint. A classic hemipelvectomy involves the removal of all gluteal structures, and only the subcutaneous flap remains (TECH FIG 3). A classic hemipelvectomy consists of a disarticulation of the sacroiliac joint, therefore requiring all of the abdominal muscles to be released up to the paraspinal muscles. The iliolumbar ligament is a good surgical landmark: it inserts onto the ilium posteriorly just above the superior aspect of the sacroiliac joint. This is especially useful in obese patients in whom the sacroiliac joint cannot easily be palpated.

TECH FIG 3 • A. The abdominal wall musculature is released from the crest of the ilium with a 1–2 cm cuff of muscle remaining along the ilium. B. The psoas muscle has a tendency to bleed postoperatively and should therefore be oversewn. Depending on the type of hemipelvectomy to be performed (classical or modified), the level of the abdominal wall musculature release and the level of the posterior osteotomy will vary.

DETACHMENT OF PELVIC FLOOR MUSCULATURE

- This maneuver is performed with the hip abducted and flexed, with the surgeon standing between the two extremities, facing the pelvis. While the assistant abducts the extremity, the pelvic floor musculature is stretched and ligated through Kelly clamps, beginning at the pubic ramus and ending at the sacroiliac joint (TECH FIG 4).

TECH FIG 4 • A. Completion of amputation and release of pelvic floor muscles. The final steps of the amputation involve the release of the sacroiliac joint and the remaining pelvic sling muscles attaching to the ilium and pelvic floor. (continued)
**COMPLETION OF THE AMPUTATION WITH SACROILIAC DISARTICULATION**

- The amputation is completed by transecting the sacroiliac joint with a large osteotome while retracting the peritoneal contents and avoiding the previously transected iliac vessels. The surgical assistant stands on the same side of the table as the surgeon and flexes and abducts the lower extremity to expose the pelvic floor muscles for the surgeon. A sponge on a stick is used to push the rectum off the pelvic sling muscles in the inferior portion of the wound. If a left-sided hemipelvectomy is performed, great care must be taken to mobilize the rectum to avoid injuring it. The sling muscles are clamped with Kelly clamps and transected. The anterior capsule of the sacroiliac joint and occasionally some of the sacrolumbar trunks are the only remaining structures that must be opened and released. The sacroiliac joint is not opened previously due to the potential for bleeding from injury to the perisacral veins.

- If a posterior modified hemipelvectomy is performed, the wing of the ilium is transected from the sciatic notch to the midportion of the ilium. The hypogastric artery is preserved and the external iliac artery is ligated. The choice between a classic hemipelvectomy and a modified posterior flap hemipelvectomy is made preoperatively. In general, modified hemipelvectomies are performed for thigh and groin lesions, whereas classic hemipelvectomy are performed for true pelvic tumors of the muscle or bony structures (TECH FIG 5A).

- A modified hemipelvectomy preserves a portion of the wing of the ilium and the underlying gluteus maximus muscle and its major pedicle, the inferior gluteal vessels. Therefore, an osteotomy is performed through the wing of the ilium starting at the sciatic notch. The iliacus muscle is transected internally and the abductor muscles are transected longitudinally (posteriorly). All of the muscles located anteriorly in the pelvis are transected at this step.

---

**TECH FIG 4** (Continued) **B.** Gross specimen following hemipelvectomy for multiple recurrences of metastatic renal cell carcinoma. Small arrows indicate recurrent tumor; large arrows indicate intramedullary tract site. **C.** This tumor has crossed several anatomical boundaries and involves the anterior, posterior, and medial compartments of the thigh. Large arrow indicates the location of the femur; small arrows indicate intervascular septa. (Courtesy of Martin M. Malawer.)

**TECH FIG 5** **A.** Variation of a posterior flap for a modified posterior flap hemipelvectomy. A modified posterior flap hemipelvectomy is an amputation through the wing of the ilium with preservation of the gluteus maximus and its major pedicle and the inferior gluteus vessels. (continued)
The sacroiliac joint is also identified anteriorly and the vessels are mobilized off the sacroiliac joint in preparation for the sacroiliac disarticulation that is the final step of the operative procedure.

- Closure of the flap is then performed over large 28-gauge chest tubes with suction drainage (TECH FIG 5B).

Marcaine epineural catheters are used for continuous pain relief postoperatively (TECH FIG 5C). Two catheters are used: one is inserted into the lumbosacral plexus and the other into the femoral nerve.

The wound is closed by rotating and suturing the prepared myocutaneous flap to the abdominal wall and flank.

PEARLS AND PITFALLS

Preoperative

- Minimizing the morbidity and mortality associated with hemipelvectomy requires careful physical and psychological preparation of the patient. Patients receiving preoperative chemotherapy or radiation therapy require time to recover from their neutropenia and anemia. Use of supportive growth factors such as erythropoietin and granulocyte colony-stimulating factor may be of significant benefit. Replacing red cell mass by blood transfusion and correcting bleeding abnormalities are essential to reduce the risk of intraoperative mortality.

- Patients with poor nutrition secondary to disease and the nausea and vomiting induced by chemotherapy may require hyperalimentation before and after surgery to reduce problems with wound healing.

Intraoperative

- To reduce the risk of postoperative infection, bowel preparation should be performed for all patients.

- Perioperative antibiotic coverage for aerobic skin flora and anaerobic bowel flora is required.

- If the tumor encases or involves the major vessels, extensive bleeding should be anticipated. Extensive blood loss and replacement in excess of one to two times the patient’s circulatory volume may create life-threatening coagulopathies and pulmonary complications.

- Intraoperative retraction of the peritoneum and use of postoperative narcotics contribute to the development of an ileus that may last for a week or more.

Postoperative

- Postoperative care to prevent hematomas and seromas includes the use of large-bore suction drains and pressure dressings using Ace wraps. A Foley catheter and a nasogastric tube are used to prevent abdominal distention; this reduces pressure on the skin closure. Skin sutures or staples should be retained for 3 to 4 weeks to minimize the risk of wound dehiscence.

- Routine placement of a nasogastric tube and avoidance of oral feeding are required to prevent nausea, vomiting, aspiration, abdominal distention, and wound complications. Early intravenous nutritional supplementation should be considered.

- Patients undergoing hemipelvectomy face a unique combination of psychological stress related to the loss of limb and potential loss of life from the underlying disease. Ongoing psychological support for the patient and family is essential.
POSTOPERATIVE CARE

- The patient should understand that phantom limb sensations are to be expected and that they can be treated with analgesics. The discomfort will lessen over time.
- Although successful rehabilitation depends to a great extent on the patient’s attitude, the physiatrist can help tremendously in these efforts. A positive attitude toward functional recovery augmented by early postoperative ambulation may move the patient rapidly to his or her goals. A positive approach is amplified by contact with other patients who have met some of the rehabilitation challenges. This can provide an immeasurable psychological boost to the patient. The oncologist, rehabilitation therapist, and others involved in the postoperative care must coordinate their efforts carefully.

OUTCOMES

- Most patients can ambulate after appropriate rehabilitation and use of hemipelvectomy prostheses.
- Most patients who survive their disease will go on to enjoy a high quality of life and participate in a multitude of recreational activities (FIG 4).
- Recent reports of series of hemipelvectomy patients have shown that this procedure has a low mortality rate and offers an acceptable survival in carefully selected patients.
- Quality-of-life studies suggest that long-term morbidity in patients who have undergone this radical amputation is not greater than that experienced by patients who have undergone other cancer treatments.
- Elderly and overweight patients may become wheelchair-dependent after this procedure because of the increased workload required to ambulate. Some children and adults find that a prosthesis slows their ability to ambulate with crutches. However, a prosthesis enables the wearer to stand for prolonged periods of time without supports and frees both hands for other activities.

COMPLICATIONS

- All patients undergoing hemipelvectomy will have considerable phantom limb sensation. It may be a more disruptive long-term problem to the patient than the loss of the limb itself. Patient education, aggressive medical treatment, and rigorous physical rehabilitation play a role in minimizing the impact of these sensations. Injection and infusion of local anesthetics into the lumbosacral plexus and stumps of the sciatic and femoral nerves may significantly reduce actual pain and phantom sensation in the immediate postoperative period.
- Another serious postoperative complication is wound necrosis. Ligation of the common iliac vessels during a classic posterior flap hemipelvectomy deprives the flap of its major blood supply; 10% to 50% of patients develop clinically significant ischemia. Pressure from prolonged lying or sitting on the flap may result in ischemic necrosis. Early identification of necrosis...
and surgical revision is essential to minimize additional complications. Meticulous attention to preserving the fasciocutaneous vessels and a portion of the gluteus maximus can reduce the incidence of ischemic necrosis.

- All patients undergoing hemipelvectomy have significant risk factors for infection, such as tumor-related catabolism, chronic malnutrition, and chemotherapy-induced anemia and neutropenia. As a result, it is not surprising that infection is seen in about 15% of patients. Other factors that increase the risk of infection include immunosuppression from surgical stress, transfusions, and psychological depression. Steps to reduce the incidence of infection should include the use of preoperative bowel preparation, use of a purse-string suture to close the anus during surgery, broad-spectrum perioperative antibiotic coverage, and the use of large-bore closed suction drains to prevent retroperitoneal hematomas. Infection may significantly retard wound healing; aggressive surgical débridement and prolonged dressing changes are often necessary.

REFERENCES

BACKGROUND

- The anterior flap hemipelvectomy is a modified version of the classic posterior flap hemipelvectomy. Instead of using the traditional posterior skin flap of the gluteal region, a myocutaneous flap from the anterior thigh is used to close the peritoneum after amputation through the sacroiliac joint and the pubic symphysis. This modification has permitted the treatment of difficult buttock and pelvic tumors where the posterior flap was involved or contaminated by tumor.
- Patients with extensive soft tissue sarcomas of the buttock or bone sarcomas of the pelvis that extend posteriorly, once thought to be incurable by standard posterior flap hemipelvectomy, can often be treated with an anterior flap hemipelvectomy.
- The procedure, which originally entailed use of an anterior skin flap raised off a portion of the superficial femoral vessels, was modified to include a full-thickness myocutaneous flap raised from the anterior thigh.
- The major advantage of anterior flap hemipelvectomy is the creation of a large vascularized myocutaneous flap that is ideal for closure of significant posterior defects (FIG 1). As much of the anterior thigh compartment may be saved as needed, depending on the size of the defect being closed. As always, careful patient selection is critical in ensuring that an acceptable outcome is achieved. For example, elderly patients and diabetics with silent atherosclerotic disease of femoral vessels must be carefully evaluated with preoperative angiography.
- The hemipelvectomy procedures described in Chapter ON-21 required a flap of buttock skin to cover the surgical defect. Anterior flap hemipelvectomy allows sacrifice of the entire buttock and all the overlying skin and soft tissue to the midline. Even patients who have a tumor-contaminated buttock to the midline may have a potentially curative procedure.
- If possible, tumors in this area, especially those of low histologic grade, should be treated with an excision of the gluteus maximus muscle (buttckectomy). However, if tumor extends through the gluteus maximus muscle to involve the gluteus medius or minimus, if tumor encases the sciatic nerve, or if tumor is directly adjacent to the pelvic bones, a radical amputation using an anterior myocutaneous flap is indicated.

ANATOMY

- The surgeon must be familiar with the pelvic anatomy as well as the thigh musculature and femoral vessels. The anatomic key to this procedure is the major vascular pedicle of the pelvis and extremity. Oncologic considerations for tumor involvement of the bone or soft tissues in the pelvis are identical to those discussed in Chapter ON-21 on posterior flap hemipelvectomy.
- The external iliac vessels leave the pelvis and cross through the femoral triangle, where they become the common femoral vessels. A single branch supplying the iliac crest may be encountered along the medial aspect of the external iliac vessel just below the inguinal ligament. The superficial femoral vessels travel underneath the sartorius muscle along most of the length of the thigh; they pass through the adductor hiatus and become the popliteal vessels behind the knee. The major branch in the femoral triangle is the profunda femoris, which arises from the posterior aspect of the superficial femoral vessel and passes deep to the posterior surface of the femur. Ligation of the profunda femoris is required to elevate the anterior flap. The common femoral and superficial femoral vessels are preserved.
- The (four) quadriceps muscles, the adductor muscles, and the sartorius muscle all have a vascular supply that arises from pedicles off the superficial femoral artery. Perforating branches from the profunda are present in the vastus lateralis and may be encountered as they pass through the intramuscular septum.
- The entire anterior and medial compartments can be elevated off the femur by dividing the quadriceps tendon above the patella and peeling the full-thickness myocutaneous flap off the anterior femoral periosteum. To prevent hemorrhage, care must be taken to properly ligate all perforating vessels, as well as the superficial femoral vessels, at the level of the adductor hiatus.
- Division of the skin at the inguinal canal and skeletonization of the external iliac vessels permit the entire flap to be rotated as necessary to cover the defect created by the amputation.
- Use of this flap for closure results in improved cosmesis and facilitates fitting of a prosthesis for an improved functional result. In addition, this flap permits radiation therapy to the remaining pelvis without any wound complications. The nature of the flap available for closure permits greater posterior resection than that possible during a traditional posterior flap hemipelvectomy.
- The entire buttock compartment (ie, the gluteal muscles, sciatic nerve, sacrospinous ligaments, and sacral alar) can be safely removed.
- The anterior myocutaneous flap consists of a portion of or the entire quadriceps muscle group on its vascular pedicle, the superficial femoral artery. This flap covers the entire peritoneal surface and generally heals with minimal problems.

IMAGING AND OTHER STAGING STUDIES

- In addition to the routine radiographic evaluation of the pelvis (radiographs, computed tomography [CT; FIG 2] and magnetic resonance imaging [MRI] scans, and bone scans) necessary to determine the patient’s suitability for a hemipelvectomy, angiography of the femoral vessels is essential for patients undergoing anterior flap hemipelvectomy.
- The variable nature of the profunda femoris, as well as the frequent presence of silent atherosclerosis of the superficial femoral artery in elderly patients or in patients with a history of smoking, can greatly affect the outcome of this procedure. In addition, visualization of the pelvic vessels can help to ensure that they are not involved with the tumor.
- CT and MRI are required to determine whether the tumor involves the sacrum or the vertebra. Spinal involvement is a contraindication to this procedure (Fig 2).
Chapter 22  ANTERIOR FLAP HEMIPELVECTOMY

INDICATIONS

- Anterior flap hemipelvectomy is indicated for tumors involving the buttock that cannot be resected with a less radical procedure. Patients who have failed to respond to prior attempts at limb-sparing surgery, with or without radiation, or who have tumors that primarily involve the posterior thigh and sciatic nerve are also candidates for this procedure.
- This procedure may also be indicated after failed attempts at limb-sparing surgery, as well as for patients with nononcologic indications for amputation (eg, uncontrollable sepsis from sacral or trochanteric osteomyelitis).
- Nononcologic indications include selected paraplegics with uncontrollable chronic osteomyelitis of the pelvis or hip joint.

SURGICAL MANAGEMENT

Preoperative Planning

- Careful presurgical planning is necessary to achieve optimal results. The planned surgical incision is drawn before any cut-
- The planned surgical incision is drawn before any cut-
- The planned surgical incision is drawn before any cut-
- The planned surgical incision is drawn before any cut-

Positioning

- After being placed supine on the operating table, the patient is rolled into the lateral position, with the iliac crest at the flexion point of the table. As the patient is positioned, a cushion is placed beneath the iliac crest and greater trochanter to prevent pressure necrosis of the skin. Padding beneath the axilla is used to allow full excursion of the chest wall and to prevent injury to the brachial plexus.
- The arm is placed on a Krasky arm rest. An elastic wrapping or a support stocking is used to prevent blood from pooling in the contralateral lower extremity.
- The operating room table is flexed to open the angle between the crest of the ilium and the lumbar vertebrae.
- The anus is sutured shut.
- The lower extremity is prepared and draped free, with the skin exposed circumferentially from the knee to the iliac crest.

FIG 1 • Clinical photograph showing a sarcoma recurrence in the posterior thigh with local tumor fungation after surgery and radiation therapy. The old posterior incision is visible (arrow). This is a classic indication for an anterior flap hemipelvectomy, which is used instead of the classic posterior flap hemipelvectomy. (Courtesy of Martin M. Malawer.)

FIG 2 • CT scan showing a large extraosseous chondrosarcoma of the buttock (Tu) with a thin rim of gluteus maximus muscle remaining (G). There is early intrapelvic extension through the sciatic notch. (Courtesy of Martin M. Malawer.)

FIG 3 • Clinical photograph of anterior flap drawn before surgery. The anterior myocutaneous flap consists of a large portion of the anterior thigh skin, subcutaneous tissue, and underlying quadriceps muscle. This flap is based on the common femoral and superficial femoral artery. The profundus artery is ligated when raising this flap. The incision extends along the medial aspect of the thigh below the sartorius so that the superficial femoral artery can be identified and ligated distally to preserve adequate vascularity to the quadriceps. The transverse incision is performed several inches above the knee. B. The posterior incision outlined extends from the anterior flap and follows the sacroiliac joint down to the gluteal crease. It then travels transverse posteriorly to meet the anterior flap. This incision avoids any contamination of the posterior incision. This procedure was developed by Dr. Paul H. Sugarbaker at the National Cancer Institute during the 1980s. C. Intraoperative photograph showing a large myocutaneous quadriceps flap elevated off the femur as the first operative stage during an anterior flap hemipelvectomy. The profundus femoris artery is ligated so that the flap can be raised above the inguinal ligament and the retroperitoneal approach of the hemipelvectomy can proceed. (Courtesy of Martin M. Malawer.)
ANTERIOR AND POSTERIOR SKIN INCISIONS

- Before the operation, the surgeon must ensure that the myocutaneous flap created from the tissue overlying the quadriceps muscle will cover the operative defect created in the buttock. The location of the proposed incision is mapped out with a marking pen and the width and length of the flap are compared with the anticipated defect in the buttock. Once it is ascertained that the flap is adequate to cover the defect, the remainder of the incision is determined (TECH FIG 1).

- First, the location of the incision is drawn medial to the tumor at or near the midline posteriorly above the anus. Superiorly and laterally the incision should parallel the wing of the ilium to the anterior superior iliac spine. It then continues distally along the midpoint of the lateral aspect of the thigh to the junction of the lower and middle thirds of the thigh.

- The medial incision courses 2 to 3 cm lateral to the anus, then anteriorly in the gluteal crease toward the pubic tubercle. It continues along the midpoint of the thigh to the junction of the lower and middle thirds of the thigh.

- The two longitudinal incisions extending along the lateral and medial aspects of the thigh are connected by a transverse incision over the anterior aspect of the thigh. The location of this transverse incision determines the length of the myocutaneous flap. Hence, the transverse incision is positioned so the tip of the flap will extend to the level of the iliac crest.

POSTERIOR DISSECTION IN THE ISCHIORECTAL SPACE

- In excision of buttock tumors, the medial margin of the tumor is usually the closest one to the line of excision. Therefore, the dissection should commence medial to the tumor to allow the surgeon to assess operability before completion of the amputation is required (TECH FIG 2).

- The initial incision is made superficial to the sacrum in the midline, through fascia to the midsacral spines. A cuff of skin 2 to 3 cm long is preserved around the anus.

- The sacral attachments of the gluteus maximus and erector spinae muscles are divided from their origins between the midsacral spines and the dorsal sacral foramina. Biopsies from the medial margin of resection are secured. By removing the outer table from the sacrum, biopsies from sacral nerves may also be obtained if indicated. If by cryostat sectioning and histologic examination these biopsies are negative, the amputation may proceed.
Chapter 22  
ANTERIOR FLAP HEMIPELVECTOMY

**LATERAL INCISION OF THE MYOCUTANEOUS FLAP**
- Abdominal and back muscles that arise on the sacrum and the iliac crest are incised in the plane of attachment of muscle to bone to minimize blood loss. Muscles to be cut include the external oblique, erector spinae, latisimus dorsi, and quadratus lumborum (TECH FIG 3).

**TRANSECTION OF THE SUPERFICIAL FEMORAL ARTERY**
- The extremity is flexed at the hip to place the tissues in the area of the gluteal crease under tension. The perianal incision is extended toward the pubic tubercle along the gluteal crease. The deep dissection is continued lateral to the rectum into the ischiorectal fossa. The remaining origins of the gluteus maximus muscle are now severed from the coccyx and sacrotuberous ligament (TECH FIG 4).

**RELEASE OF THE VASTUS LATERALIS**
- The surgeon now moves from the posterior to the anterior aspect of the patient. The anterior incision at the junction of the middle and lower thirds of the thigh is made and continued down to the femur, transecting the entire quadriceps muscle (TECH FIG 5).
- Laterally, this incision is continued superiorly toward the greater trochanter to the anterior superior iliac spine. The tensor fascia lata muscle is separated from its investing fascia so that it is included with the specimen.

---

**TECH FIG 3** - Release of the back muscles of the iliac crest. (Courtesy of Martin M. Malawer.)

**TECH FIG 4** - Posterior dissection in the ischiorectal space. (Courtesy of Martin M. Malawer.)

**TECH FIG 5** - Lateral incision of the myocutaneous flap. (Courtesy of Martin M. Malawer.)
TRANSECTION OF THE SUPERFICIAL FEMORAL ARTERY

- The fascial covering of the vastus lateralis of the quadriceps femoris muscle is dissected free of the flexor muscles and traced to its insertion on the femur. Then the vastus lateralis is severed from the femur using electrocautery. In performing the dissection from this point on, care must be taken not to separate muscle bundles of the myocutaneous flap from the overlying skin and subcutaneous tissue (TECH FIG 6).

TECH FIG 6 • Release of the vastus lateralis from the femur. (Courtesy of Martin M. Malawer.)

RELEASE OF THE QUADRICEPS MUSCLE FROM THE FEMUR

- The medial skin incision is from the area of Hunter’s canal to the pubic tubercle. The superficial femoral vessels are located at their point of entry into the abductor muscles and are ligated and divided at this level. These vessels course along the deep margin of the myocutaneous flap, and in the subsequent dissection they are traced superiorly to the inguinal ligament. Multiple small branches from the superficial femoral vessels to the abductor muscles must be clamped, divided, and ligated (TECH FIG 7).

TECH FIG 7 • Transection of superficial femoral artery. (Courtesy of Martin M. Malawer.)

RELEASE OF THE MYOCUTANEOUS FLAP FROM THE FEMUR

- Vigorous upward traction on the myocutaneous flap allows the origins of the vastus intermedius and the vastus medialis to be severed from the femur. As the release of the myocutaneous flap continues up toward the pelvis, the profunda femoris vessels are identified. These vessels are ligated and divided at their origin from the common femoral artery (TECH FIG 8).
- The myocutaneous flap is freed from its pelvic attachments by the following procedure. The abdominal muscles and fascia are severed from the iliac crest. The sartorius muscle is transected at its origin on the anterior superior iliac spine. The rectus femoris is transected at its origin on the anterior inferior iliac spine. The femoral sheath overlying the hip joint is divided. The left rectus abdominis muscle is released from the pubic bone.
- By retracting the myocutaneous flap medially, full access to the pelvis is achieved. Blunt dissection along the femoral nerve allows rapid dissection into the pelvis to expose the vessels and nerves to be transected in the subsequent phases of the procedure.
DIVISION OF THE SYMPHYSIS PUBIS

To divide the symphysis pubis, the bladder and urethra are protected and a scalpel is used to locate and divide the cartilaginous joint (TECH FIG 9).

TRANSECTION OF THE ILIAC VESSELS

- The internal iliac artery and vein are divided at their point of origin from the common iliac vessels. Multiple visceral branches of the internal iliac vessels are divided in their course superficial to the sacral nerve roots. Strong medial traction on the viscera will help expose these vessels. When this phase of the dissection is completed, the nerve roots should be clearly visualized throughout their course in the pelvis (TECH FIG 10).
- The common iliac lymph nodes remain with the patient in this procedure, in contrast to a standard hemipelvectomy, in which they are removed.
DIVISION OF THE PSOAS MUSCLES AND NERVE ROOTS

- The psoas muscle is divided near its junction with the ili-acus muscle. The obturator nerve deep to the muscle is also divided. Care is taken to preserve the femoral nerve coursing into the myocutaneous flap. The lumbosacral and sacral nerve roots are ligated and divided close to the ventral sacral foramina (Tech Fig 11).

TECH FIG 11 • Division of the psoas muscle and nerve roots. (Courtesy of Martin M. Malawer.)

DIVISION OF THE PELVIC DIAPHRAGM AND SACRUM

- The leg is elevated to place under tension the individual muscles that constitute the pelvic diaphragm. Care is taken to protect the urethra, bladder, and rectum. The urogenital diaphragm, levator, and piriformis muscles are divided. These muscles are transected near their pelvic attachments (Tech Fig 12).
- The surgeon should again change orientation and move back to the posterior aspect of the patient. Using an osteotome and commencing at the tip of the coccyx, the coccyx and sacrum are divided in a plane that bisects the sacral foramina.
  - Initially, the course of the osteotome should parallel the midsacral spines. The surgeon, being posterior to the patient, reaches around the coccyx with the left hand to locate the S5 neural foramina from within the sacrum. This is at the junction of the sacrum and the coccyx. By holding the osteotome with the right hand, the direction for bone transection can be precisely determined. The assistant drives the osteotome through the bone with the mallet.
  - At the upper portion of the sacrum, care must be taken not to fracture inadvertently through the bone. The lumbosacral ligament is divided to release the specimen.

TECH FIG 12 • A. Division of the pelvic diaphragm. B. Division of the sacrum. (Courtesy of Martin M. Malawer.)
Chapter 22  ANTERIOR FLAP HEMIPELVECTOMY

TECHNIQUES

PEARLS AND PITFALLS

Closure

- Sugarbaker and others have shown the utility of a myocutaneous pedicle flap based on the femoral vessels and anterior compartment of the thigh for closure of the wound in patients with tumors involving the posterior buttock structures.
- The primary advantage of this procedure is that the anterior flap raised from the thigh can be used to reconstruct an enormous posterior defect with little risk of flap necrosis. Patients who are expected to require substantial doses of radiation postoperatively should be considered for this procedure whenever possible, since the well-vascularized myocutaneous flap tolerates radiation well.
- Great care must be taken not to dissect or shear the subcutaneous tissue and skin overlying the quadriceps during the creation of the flap, because this will compromise the cutaneous circulation.
- Occasionally, tumor tissue or heavily irradiated skin overlying the superficial femoral artery may require sacrifice of the skin pedicle. In this instance the island myocutaneous flap should be used.

POSTOPERATIVE CARE

- The patient should understand that phantom limb sensations are to be expected and that they can be treated with analgesics. The discomft will lessen over time.
- Although successful rehabilitation depends to a great extent on the patient’s attitude, the physiatrist can help tremendously in these efforts. A positive attitude toward functional recovery augmented by early postoperative ambulation may move the patient rapidly to his or her goals. A positive approach is amplified by contact with other patients who have met some of the rehabilitation challenges. This can provide an immeasurable psychological boost to the patient. The oncologist, rehabilitation therapist, and others involved in the postoperative care must coordinate their efforts carefully.

OUTCOMES

- The potential for rehabilitation with this procedure is excellent. Patients who are free of disease use a prosthesis regularly. Patients walk with the prosthesis without the use of crutches or a cane.
- Because of the vascular nature of this flap, the surgical wound heals rapidly in the vast majority of patients. Accordingly, the 10% to 30% risk of ischemic necrosis associated with posterior flap hemipelvectomy is not seen with an anterior flap procedure. Likewise, the risk of infection in the postoperative period is markedly reduced.
- Rehabilitative considerations and the risk of phantom pain are similar to those associated with other types of hemipelvec-

REFERENCES

BACKGROUND

- Hip disarticulation is an amputation of the lower extremity through the hip joint capsule. Although most tumors of the lower extremities are amenable to limb-sparing techniques, some tumors of the femur and thigh are so extensive that hip disarticulation is needed for adequate tumor resection.
- With advances in prosthetic design, patients can ambulate with a prosthesis despite the larger energy expenditure needed to ambulate after a hip disarticulation compared to more distal amputations. Even without prosthetic use, most patients are very successful in ambulating and carrying out daily activities.
- Performing a hip disarticulation may be more preferable in some cases instead of leaving a patient with a very short above-knee amputation stump site, which can make prosthesis fitting difficult.

ANATOMY

- The hip joint region is supplied by several major arteries. Familiarity with these structures can minimize intraoperative bleeding if they can be identified and ligated as needed. These arteries include the profunda artery, the medial and lateral circumflex arteries, and the obturator and superior and inferior gluteal arteries.
- The tensor fascia lata, gluteus maximus, and iliotibial band form an outer muscular envelope around the hip, and at least one of these structures usually needs to be split to gain access to the hip.
- The femoral triangle must be identified to access the main neurovascular structures encountered in this procedure. The femoral triangle is bordered superiorly by the inguinal ligament, laterally by the sartorius muscle, and medially by the adductor longus muscle.
- Hip disarticulation involves amputation through the hip joint capsule. This strong fibrous layer covers the anterior hip to the intertrochanteric line but leaves most of the femoral neck exposed posteriorly.
- Tumors can often extend to the ischiorectal fossa; this should be determined preoperatively by examining computed tomography (CT) and magnetic resonance imaging (MRI) scans. The ischiorectal fossa is an area bounded medially by the sphincter ani externus and anal fascia, laterally by the tuberosity of the ischium and obturator fascia, anteriorly by the fascia covering the transversus perinei superficialis, and posteriorly by the gluteus maximus and sacrotuberous ligament. Assessment for tumor extension to this area is particularly important in planning the flaps that will be used.

INDICATIONS

- Proximal tumors not extending above the midthigh
- Femoral diaphyseal tumors with proximal intramedullary extension
- Soft tissue sarcomas of the thigh with extension to the femur or neurovascular structures
- Unresectable local recurrences, particularly after radiation therapy has been used
- Pathological fractures that are not responsive to induction chemotherapy and immobilization
- Palliation of extensive tumors

IMAGING AND OTHER STAGING STUDIES

Computed Tomography and Magnetic Resonance Imaging

- CT is useful in showing the effect of the tumor on the structural integrity of the bone. It may also show extension into the soft tissues, especially in the ischiorectal fossa, hip joint, and groin. MRI shows the intraosseous spread of the tumor within the marrow and therefore is helpful in determining the level of amputation and the appropriateness of the hip disarticulation.

Bone Scan

- A bone scan is helpful in evaluating the bony involvement of the femur, pelvis, and acetabulum. Acetabular involvement is a contraindication to doing a hip disarticulation.

Angiography and Other Studies

- Angiography can help identify the external iliac, common femoral, and profundus arteries when preparing for surgery.

Biopsy

- A biopsy is warranted before most amputations. However, given the potential functional limitations and prosthetic needs of a hip disarticulation, a biopsy is definitely recommended before performing a hip disarticulation.

SURGICAL MANAGEMENT

- Lymph node involvement should be assessed before proceeding with a hip disarticulation. Lymph node involvement is a relative contraindication to performing a hip disarticulation unless the procedure is done for palliation.
- Hip disarticulations are often required after poor chemother-apy response or tumor aggressiveness. These situations increase the likelihood for close surgical margins, which can lead to local recurrences.
- All radiographic studies must be reviewed to ensure that there is no suggestion of tumor proximal to the lesser tuberosity. This would increase the risk of having positive or close margins.
- The development of the flaps is critical for optimal wound closure and healing. It is not uncommon to make flaps of unusual shape in performing a hip disarticulation for tumor of the middle or distal femur or thigh. Previous scars, radiated
fields, and the presence of a tumor mass all determine the best skin to be used. If possible, fasciocutaneous flaps should be constructed to promote wound healing.

Optimizing the patient’s overall health and nutritional status preoperatively is essential in promoting wound healing and decreasing perioperative complications.

Preoperative Planning

- Manipulation of more proximal venous structures can increase the likelihood of the development of deep venous thrombi. Often these more proximal thrombi can embolize and lead to fatal pulmonary emboli. In patients with a prior history of deep venous thrombosis or pulmonary emboli, the surgeon should consider placing a venous filter before surgery to minimize the risk of pulmonary emboli.

- An amputation is a life-altering event; both physical and emotional issues need to be addressed. Many patients find psychological counseling helpful, so the surgeon should ensure that these services are available in the perioperative period.

- Having patients meet with a prosthetist and a functional amputee can help manage expectations and provide answers about daily activities and function.

Positioning

- Since a hip disarticulation involves both anterior and posterior dissections, a semilateral or lateral position is often best.

Approach

- The major portions of the hip disarticulation are done through an anterior approach to the hip and groin. This facilitates exposure of the femoral triangle and muscle origins.

- Recently, Lackman et al3 published their technique using the lateral approach for hip disarticulations. This has the advantage of familiarity and provides access to both anterior and posterior structures.

### INCISION AND INITIAL EXPOSURE

- Bony landmarks to be identified include the pubic tubercle, anterior superior iliac spine, anterior inferior iliac spine, ischial tuberosity, and greater trochanter (TECH FIG 1A).

- The anterior incision starts 1 cm medial to the anterior superior iliac spine and continues distally to the pubic tubercle and over to the pubic bone to 2 cm distal to the ischial tuberosity and gluteal crease.

- If the buttock flap is extremely thick, the anterior portion of the incision should be moved laterally.

- The posterior incision starts about 2 cm anterior to the greater trochanter and extends to the back of the leg distal to the gluteal crease.

- The distance the incision is beyond the gluteal crease is directly proportional to the anteroposterior diameter of the patient’s pelvis.
DIVISION OF ANTERIOR HIP AND GROIN MUSCLES AND ISCHIAL TUBEROSITY RELEASE

- The sartorius muscle is located as it arises from the anterior superior iliac spine. It is dissected free from the surrounding fascia and then transected from its origin on the spine by electrocautery. The femoral sheath and fibroareolar tissue posterior to the femoral vessels are also incised by electrocautery. This dissection exposes the hip joint capsule (TECH FIG 2A).

- With the hip slightly flexed, a finger can be placed in a mediolateral direction under the iliopsoas to isolate the muscle, which can then be freed from its origin at the lesser trochanter (TECH FIG 2B). If an attempt is made to pass the finger beneath the muscle from lateral to medial, the very intimate attachments between the iliopsoas muscle and the rectus femoris muscle prevent this from being easily done. By sharp and blunt dissection the entire iliopsoas muscle is dissected until its insertion on the lesser trochanter is clearly defined. Several vessels of prominent size pass from the anterior surface of this muscle, and care should be taken to secure these vessels before their division. The iliopsoas muscle is severed at the level of its insertion onto the lesser trochanter.

- Next, the adductor muscles are released from the pelvis in a lateral to medial process. To preserve the obturator externus muscle on the pelvis, the surgeon locates its prominent tendon arising from the lesser trochanter. Locating this tendon identifies the plane between the pectineus muscle and the obturator externus; a difference in the direction of the muscle fibers of these two muscles is also apparent. A finger is passed beneath the pectineus muscle, and it is released at the level of its origin from the pubis by electrocautery (TECH FIG 2C). Beneath the pectineus muscle numerous branches of the obturator artery, vein, and nerve can now be visualized. The gracilis, adductor longus, adductor brevis, and adductor magnus are transected at their origins on the symphysis pubis. The obturator vessels and nerves usually bifurcate around the adductor brevis muscle. Branches of the obturator artery must be identified and secured during the dissection to prevent accidental rupture and retraction of the proximal ends up into the pelvis (TECH FIG 2D).

- The extremity is hyperabducted to localize the ischial tuberosity and the retracted cut ends of the adductor muscles. The circumflex femoral vessels should be visible and should be avoided. The semimembranosus, semitendinosus, and long head of the biceps are transected from their origin on the ischial tuberosity while preserving the quadratus femoris and sciatic nerve (TECH FIG 2E).

- Skin, subcutaneous fat, and fascia of Scarpa are incised to expose the aponeurosis of the external oblique.
- Saphenous vein branches are clamped, divided, and ligated.
- A moderate-sized artery, the superficial epigastric, and multiple branches of the external pudendal vessels are secured.
- The spermatic cord in men or the round ligament in women is identified, and care is taken to avoid injuring these structures.
- An incision made just below the inguinal ligament into the fossa ovalis exposes the femoral vein, artery, and nerve (TECH FIG 1B).

Individual silk ties are placed around the femoral vessels; first the artery and then the vein are tied in continuity. Right-angle clamps are placed between the ties, and the vessels are severed. The proximal ends of the vessels are further secured by a silk suture ligature placed proximal to the right-angle clamps. The femoral nerve is placed on gentle traction and ligated where it exits from beneath the inguinal ligament. When the femoral nerve is severed, it retracts beneath the external oblique aponeurosis, so that if a neuroma forms it will not be in a weight-bearing portion of the stump (TECH FIG 1C).

**TECH FIG 2** • A. Division of sartorius muscle and femoral sheath. B. Division of iliopsoas muscle at its insertion. The hip is flexed slightly to relax the iliopsoas muscle. *(continued)*
HIP JOINT CAPSULE INCISION AND DIVISION OF POSTERIOR MUSCLES

- All the anterior and posterior muscle groups have been divided. The joint capsule overlying the head of the femur is incised, and the ligamentum teres is transected by electrocautery (TECH FIG 3A).
- The patient’s torso is tilted from posterolateral to anterolateral. The incision is completed posteriorly through gluteal fascia (TECH FIG 3B). The tensor fascia lata and gluteus maximus muscles are divided in the depths of the skin incision. These are the only muscles not divided at either their origin or insertion in the procedure. Directly beneath these muscles is the rectus femoris muscle, which is transected at its origin on the anterior inferior iliac spine by electrocautery (TECH FIG 3C). The common tendon comprising contributions from the gluteus medius, gluteus minimus, piriformis, superior gemellus, obturator internus, inferior gemellus, and quadratus femoris muscles, is exposed after the division of the gluteus maximus. All these muscles are divided close to their insertions on the greater trochanter (TECH FIG 3D).

TECH FIG 3 • A. Incision of the anterior portion of the hip joint capsule. B. Completion of the skin incision. (continued)
RELEASE OF SPECIMEN AND CLOSURE

- Transection of the hip joint capsule is completed by incising the posterior portion of the capsule. The sciatic nerve is dissected free of surrounding muscle, transected, and allowed to retract beneath the piriformis muscle (TECH FIG 4A).
- The obturator externus and gluteus medius are sutured together over the acetabulum and joint capsule to help provide soft tissue coverage of the bony prominence (TECH FIG 4B).
- The gluteal fascia is elevated and secured to the inguinal ligament and the pubic ramus. Multiple stitches are placed bisecting the fascial edge that gather the gluteal fascia as it is secured to the inguinal ligament. Sutures are individually placed and then tied. Before closure of this posterior myocutaneous flap, suction catheters are placed beneath the gluteal fascia.
- The skin is closed with interrupted sutures. Again, care is taken to make sure that there is equal distribution of the excess tissue of the posterior flap. Not infrequently, additional suction catheters must be used to obliterate space within the subcutaneous tissue when the buttock flap is thick (TECH FIG 4C). Patency of the suction catheters must be maintained until drainage is diminished. Ambulation may proceed if the patient’s hemodynamic status permits on the first postoperative day.

TECH FIG 4 • A. Release of specimen. B. Approximation of obturator externus and gluteus medius over the joint capsule. (continued)
POSTOPERATIVE CARE

- A compressive dressing should be maintained for 3 to 5 days to minimize swelling. After this time the wound should be inspected and redressed.
- Drains should remain until the total daily output is minimal.
- Prosthesis fitting can begin when the wound swelling has decreased and the wound is completely healed. Usually this takes at least 4 to 6 weeks after surgery.

OUTCOMES

- The 5-year survival of patients after hip disarticulation done as the primary treatment is 32%. When done for local recurrence, the 5-year survival is 25%.
- Hip disarticulation has been shown to be very effective as a means of palliation for extensive tumors without other treatment options. It thus improves the quality of life of these patients.
- Prosthetic use in this population is usually lower than that seen in groups with more distal amputations. Use ranges from 5% to 60% of amputees. Problems with artificial limb use and reasons for the lack of limb use have included limb weight and inconvenience with toileting. Despite this, all patients should be offered an artificial limb.

- Many patients with hip disarticulations are very functional, and one study found that most were even able to drive whether or not they used a prosthesis.

COMPLICATIONS

- The local recurrence rate is 2% to 12% and is usually higher in patients whose amputation was done for local recurrences or if there were close margins.
- Wound healing problems can arise from seroma or hematoma development. The use of drains can help decrease the risk of seromas and hematomas.

REFERENCES

BACKGROUND

- The proximal femur and the midfemur are common sites for primary bone sarcomas and metastatic tumors.
- Formerly, patients who were candidates for extensive femoral resection because of malignant tumor were considered a high-risk group for limb-sparing procedures because of the extent of bone and soft tissue resections and the anticipated poor function postoperatively, as well as the deleterious consequences of adjuvant chemotherapy and radiation therapy. Hip disarticulation or hemipelvectomy were, therefore, the classic treatment options for patients with large lesions of the proximal femur or midfemur. Both procedures were associated with a dismal functional, aesthetic, and psychological outcome.
- Today, improved survival of patients with musculoskeletal malignancies, developments in bioengineering, and refinements in surgical technique have enabled these patients to undergo limb-sparing procedures. Local tumor control is good, as is the probability of a functional extremity. Proximal and total femur resection became a reliable surgical option in the treatment of primary bone sarcomas and metastatic bone disease and, more recently, of a variety of nononcologic indications. These latter indications include failure of internal fixation, severe acute fractures with poor bone quality, failed total hip arthroplasty, chronic osteomyelitis, metabolic bone disease, and various congenital skeletal defects.
- Methods of skeletal reconstruction include resection arthrodesis, massive osteoarticular allograft, endoprosthetic reconstruction, and prosthetic allograft composites.
- Osteoarticular allografts, which were popular in the 1970s and 1980s, aim to restore the natural anatomy of a joint by matching the donor bone to the recipient’s anatomy, but they are associated with increased rates of infection, nonunion, instability, fracture, and subchondral collapse and thus ultimate failure.
- Introduced in the mid-1980s, modular prostheses revolutionized endoprosthetic reconstruction. The modular system enables the surgeon to measure the actual bone defect at the time of surgery and select the most appropriate components to use in reconstruction. Components of these interchangeable systems include articulating segments, bodies, and stems of varying lengths and diameters. Design features include extensive porous coating on the extracortical portion of the prostheses for bone and soft tissue fixation and metallic loops to assist in muscle reattachment.

ANATOMY

- The intracapsular location of the femoral neck makes it biologically possible for tumors of the proximal femur to spread into the hip and adjacent synovium, joint capsule, and ligamentum teres. The ligamentum teres provides a mechanism for transarticular skip metastases to the acetabulum. Fortunately, intra-articular involvement is rare and usually occurs after a pathologic fracture. The capsule can be preserved and an intra-articular resection of the femur is usually possible. In the case of capsular or acetabular involvement or both, extra-articular resection of the hip should be considered.
- The greater trochanter, which is removed with the surgical specimen, serves as the attachment site for the hip abductors. The tendon stump should be marked and preserved for reattachment to the prosthesis.
- The lesser trochanter, which is removed with the surgical specimen, serves as the attachment site for the psoas muscle. The tendon stump should be marked and preserved for reattachment to the prosthesis. The combined attachment of the abductors and psoas to the lateral and medial aspects of the prosthesis, respectively, preserves balanced prosthetic range of motion.
- The femoral artery descends the thigh almost vertically within the sartorial canal toward the adductor tubercle of the femur, enters the opening of the canal of Hunter at the adductor magnus muscle, and becomes the popliteal artery. The profunda femoris artery branches to the medial aspect of the femoral artery 4 cm below the inguinal ligament. Occasionally, the profunda femoris is ligated and resected en bloc with large tumors of the proximal femur.

INDICATIONS

- Primary bone sarcomas
- Benign aggressive tumors associated with extensive bone destruction
Metastatic tumors associated with extensive bone destruction (FIG 4B)

Nononcologic indications include failure of internal fixation, severe acute fractures with poor bone quality, failed total hip arthroplasty with segmental bone loss below the level of the lesser trochanter, chronic osteomyelitis, metabolic bone disease, and various congenital skeletal defects (FIG 4C).

Proximal femur resection is performed for metaphyseal-diaphyseal lesions that (1) extend below the lesser trochanter, (2) cause extensive cortical destruction, and (3) spare at least 3 cm of the distal femoral diaphysis. Total femur resection is performed for diaphyseal lesions that (1) extend proximally to the lesser trochanter and distally to the distal diaphyseal-metaphyseal junction and (2) cause extensive bone destruction (FIG 4D).

IMAGING AND OTHER STAGING STUDIES

Proximal and total femur resections are major surgical procedures that necessitate an especially detailed preoperative evaluation. Physical examination and imaging studies are done to determine (1) the extent of bone resection and dimensions of the required prosthesis, (2) the extent of soft tissue...
resection and reconstruction possibilities, and (3) the proximity of the tumor to the femoral vessels, femoral nerve, and sciatic nerve.

- Most complications can be avoided by predicting their likelihood before surgery and modifying the surgical technique accordingly. A full range of imaging studies is needed, including plain radiography, computed tomography (CT), and magnetic resonance imaging (MRI) of the whole femur and the hip and knee joints. CT and plain radiography are used to evaluate the extent and level of bone destruction; MRI is used to evaluate the medullary and extraosseous components of the tumor, the intracapsular tumor extension, and the presence of skip metastases within the femoral canal and in the acetabulum.

- Angiography of the iliofemoral vessels is essential before resection of tumors of the proximal femur. Vascular displacement is common when tumors have a large, medial extraosseous component: the profundus femoral artery is particularly vulnerable to distortion or, less commonly, to direct incorporation into the tumor mass. If the tumor has a large medial extraosseous component and ligation of the profundus femoral artery is anticipated, the presence of a patent superficial femoral artery must be documented by angiography before surgery. Preoperative embolization may be useful to prepare for resection of metastatic vascular carcinomas if an intralesional procedure is anticipated. Metastatic hypernephroma is an extreme example of a vascular lesion that may bleed extensively and cause exsanguination if an intralesional procedure is done without prior embolization.

**SURGICAL MANAGEMENT**

- Limb-sparing surgery that involves endoprosthetic replacement of the proximal or the entire femur is done in three steps: tumor resection, endoprosthetic reconstruction, and soft tissue reconstruction. The technique of proximal femur endoprosthetic replacement is described in the following paragraphs. The additional steps required for total femur resection are described at the end of the appropriate sections.

- In general, surgery for metastatic tumors to the proximal femur is not different from surgery for primary sarcomas of bone. The main differences are that metastatic lesions have a smaller extraosseous component than primary lesions, and the surrounding muscles are usually invaded by the metastatic lesions (as opposed to the “pushing” border of bone sarcomas).
TUMOR RESECTION

Position and Incision
- The patient is placed in a lateral position and a long lateral incision is made extending from 3 to 4 cm proximal to the greater trochanter to the distal two thirds of the thigh (TECH FIG 1A,B). An ilioinguinal extension to that incision is added if the tumor has an extensive, medial soft tissue component along the proximal femur. This approach allows exposure of the proximal third of the femur and the retrogluteal area and allows for identification of the femoral canal, femoral triangle, superficial and profundus femoral artery, and sartorial canal.

- Posterior reflection of the gluteus maximus muscle exposes the retrogluteal area and allows for identification of the femoral canal, femoral triangle, superficial and profundus femoral artery, and sartorial canal.

- The sciatic nerve lies directly posterior to the external rotators. In general, as primary bone sarcomas expand, the external rotators are pushed outward and act as a protective barrier to the sciatic nerve. As such, the sciatic nerve is often not in its usual anatomic location in these patients and must be identified early, isolated, and mobilized posteriorly to prevent injury. The abductors are identified with their anterior and posterior intervals. If there is no tumor involvement, the greater trochanter or small bony attachment is osteotomized; otherwise, the abductors are transected through their tendinous attachments and retracted, exposing the hip joint and acetabulum (TECH FIG 2A,B).

- The sciatic nerve lies directly posterior to the external rotators. In general, as primary bone sarcomas expand, the external rotators are pushed outward and act as a protective barrier to the sciatic nerve. As such, the sciatic nerve is often not in its usual anatomic location in these patients and must be identified early, isolated, and mobilized posteriorly to prevent injury. The abductors are identified with their anterior and posterior intervals. If there is no tumor involvement, the greater trochanter or small bony attachment is osteotomized; otherwise, the abductors are transected through their tendinous attachments and retracted, exposing the hip joint and acetabulum (TECH FIG 2A,B).

Vastus Lateralis Reflection
- The vastus lateralis is transected from its origin at the vastus ridge and reflected distally, and the posterior perforating vessels are ligated (TECH FIG 3A,B). The vastus lateralis must be preserved because of its future role in soft tissue coverage of the prosthesis: it will be advanced proximally and sutured to the abductors (see...
TECH FIG 1 • Illustration (A) and operative photograph (B) showing a long lateral incision used for resection of the proximal or the whole femur. C,D. The incision is brought distally to the anterolateral aspect of the patellar tendon and tibial tuberosity for exposure of the entire femur. If the tumor has medial or posterior soft tissue extensions at the distal femur that require dissection at the medial aspects of the knee and popliteal fossa, the incision is curved medially at its distal part. (A: Reprinted with permission from Clin Orthop Relat Res 2000;375:218–230.)

TECH FIG 2 • The proximal femur after posterior retraction of the gluteus maximus and exposure of the retrogluteal area, external rotators, sciatic nerve, abductors, and posterior capsule. Because of tumor extension into the greater trochanter in the illustrated case, the abductors are identified and transected through their tendinous attachments and retracted, exposing the hip joint and acetabulum. If the greater trochanter is not involved by tumor extension, it is osteotomized and reflected with the abductor tendon. (A: Reprinted with permission from Clin Orthop Relat Res 2000;375:218–230.)
“Soft Tissue Reconstruction” below). Care is taken not to ligate its main pedicle, which crosses anteriorly and obliquely along the rectus femoris fascia.

- The femoral nerve is identified below the fascia (TECH FIG 3A,B). The superficial and profundus femoral artery and vein are identified in the sartorial canal and retracted. If they are invaded by the soft tissue extension of the tumor, the profundus artery and vein may be ligated just distal to their takeoff from the common femoral vessel.

Detachment of Posterior Hip Musculature and Capsule, Dislocation of Femur

- With the retrogluteal area exposed, the rotator muscles are detached en bloc 1 cm from their insertion on the proximal femur. The hip joint capsule has a major role in securing and stabilizing the head of the prosthesis within the acetabulum, and if not invaded by tumor, it should remain intact.

- The capsule is opened longitudinally along its anterolateral aspect and detached circumferentially from the femoral neck. The femur is dislocated anterolaterally. Special care is taken not to fracture the femoral neck, especially if a primary bone sarcoma is being resected. The acetabulum is inspected for evidence of joint involvement (TECH FIG 4A,B). If total femur resection is performed, a tibial osteotomy is carried out in the same manner as a standard knee joint arthroplasty, in which about 1 cm of bone is removed, the cut is perpendicular to the long axis of the tibia, and the insertion of the biceps femoris muscle is retained.

- If delicate dissection around the popliteal vessels is anticipated, an anteromedial arthrotomy should be done and the popliteal fossa should be approached from its medial aspect. The total femur is resected en bloc with the vastus intermedius muscle, but the vastus lateralis, rectus femoris, patella, and patellar tendon are preserved. Because malignant tumors of the distal femur rarely penetrate beyond the vastus intermedius muscle or patellar surface, the patella can be preserved in the large majority of the cases.

Distal Femoral Osteotomy and Release of Medial Structures

- Femoral osteotomy is performed at the appropriate location, as determined by the preoperative imaging studies. In general, 3 to 4 cm beyond the farthest point is appropriate for primary sarcomas and 1 to 2 cm for metastatic carcinomas. An oscillating saw is used for the osteotomy, and a malleable retractor is placed medially to the femoral shaft to prevent inadvertent injury to the soft tissues. The cut should be at a right angle to the shaft (TECH FIG 5).

- It is important not to distract the extremity after removal of the proximal femur to avoid placing tension on the sciatic nerve and femoral vessels. If total femur resection is performed, a bicipital osteotomy is carried out in the same manner as a standard knee joint arthroplasty, in which about 1 cm of bone is removed, the cut is perpendicular to the long axis of the tibia, and the insertion of the biceps femoris muscle is retained.

- After femoral osteotomy or disconnection of the entire femur after bicipital osteotomy, the femur is retracted laterally. The remaining medial structures are now clearly visible: they consist of the psoas and adductor muscles, which should be identified either now or at some point before the femur is osteotomized. The muscles are serially dissected, clamped with Kelly clamps, and tagged with Dacron tapes. Care is taken to dissect the profundus femoral artery.

- If oncologically indicated, the profundus femoral artery may be ligated, but only after patency of the superficial femoral artery has been confirmed.
Chapter 24  PROXIMAL AND TOTAL FEMUR RESECTION WITH ENDOPROSTHETIC RECONSTRUCTION

TECH FIG 4 • Illustration (A) and operative photograph (B) showing detachment of the posterior hip musculature and capsule. Illustration (C) and operative photograph (D) showing the arthrotomy of the knee joint that is required to accomplish total femur resection. An anterolateral arthrotomy using the initial lateral incision is usually feasible. However, if the tumor extends toward the popliteal fossa and delicate dissection of the popliteal vessels is anticipated, anteromedial knee exposure and medial exposure of the popliteal fossa are done as for resection of the distal femur. The femur will be removed with the overlying vastus intermedius; the rectus femoris and patella are spared. (A: Reprinted with permission from Clin Orthop Relat Res 2000;375:218–230; C: Courtesy of Martin M. Malawer.)

TECH FIG 5 • Distal femur osteotomy and removal of the proximal femur. The femoral osteotomy is done 3 to 4 cm beyond the farthest point of tumor extension for primary sarcomas and 1 to 2 cm for metastatic carcinomas. (A: Courtesy of Martin M. Malawer.) (continued)
ENDOPROSTHETIC RECONSTRUCTION

- After resection of the proximal femur, the length of the resected specimen, the size of the femoral head, and the diameter of the distal medullary canal are measured. A trial femoral head prosthesis is used to test the suction fit. The proximal end of the remaining femur should be kept well padded to avoid injuring the superficial femoral artery. A frozen section from the canal is evaluated for evidence of residual tumor before reaming the femoral canal.

Reaming the Intramedullary Canal

- The largest possible stem diameter should be chosen, especially for primary tumors. A 1-mm cement mantle is required around the stem. The intramedullary canal is therefore reamed 2 mm larger than the chosen stem diameter (TECH FIG 6).

Trial Articulation

- Modular trial prosthetic components should be assembled to match the length of the resected specimen. These include body parts, a neck, and prosthetic head (TECH FIG 7A–C). Total femur prostheses are joined to the tibial component with a rotating hinge mechanism (TECH FIG 7D,E). After trial positioning of the prosthesis, the pulses are palpated distally: a shorter prosthesis will be required if they are diminished. The joint capsule is pulled over the femoral head component, and the range of motion of the hip joint is tested. The prosthesis should be stable in flexion, adduction, and internal rotation.
TECH FIG 7 • (continued) C. Trial articulation. Leg length must be measured and the neurovascular bundle evaluated for excessive tension. Schematic (D) and plain radiograph (E) of a total femur prosthesis, which is joined to a tibial component via a rotating hinge mechanism. (C–E: Courtesy of Martin M. Malawer.)

**Prosthetic Assembly and Implantation**

- The modular prosthesis is assembled and cemented into the medullary canal. The orientation of the prosthesis is critical. With the linea aspera as the only remaining anatomic guideline, the prosthesis is placed with the femoral neck anteverted about 5 to 10 degrees with respect to an imaginary perpendicular line from the prosthesis and a line is drawn from the linea aspera through the body of the prosthesis (TECH FIG 8).

- Two bags of bone cement are usually required, and the cementing technique consists of pulsatile lavage, use of an intramedullary cement restrictor, reduction of the cement by centrifugation, use of a cement gun, pressurization of the cement, and enhancement of the prosthesis–cement interface by precoating the proximal portion of the femoral or tibial stem with bone cement. While the bone cement hardens, the surgeons continuously verify the correct positioning of the prosthesis.

**TECH FIG 8** • The prosthesis is positioned in 5 to 10 degrees of anteversion, with the linea aspera being the only remaining anatomic guideline for proximal femur endoprosthetic replacements and the tibial tuberosity for total femur endoprosthetic replacements. (Courtesy of Martin M. Malawer.)

**SOFT TISSUE RECONSTRUCTION**

- Special attention is given to re-establishing hip stability and providing adequate muscle coverage of the prosthesis. The remaining hip capsule is sutured tightly with a 3-mm Dacron tape (Deknatel, Falls River, MA) around the neck of the prosthesis, forming a noose that provides immediate stability (TECH FIG 9A–D). Dacron is a nonabsorbable synthetic polyester (polyethylene-terephthalate) that allows approximation of the cut ends of the joint capsule under considerable tension. It provides the initial mechanical support needed for healing and scar formation throughout the capsule. The surgeon cannot dislocate the prosthesis in a capsule that is
adequately closed. Stabilization of the prosthesis is reinforced by rotating the external rotator muscles proximally and suturing them to the posterolateral aspect of the capsule. The psoas muscle is rotated anteriorly and tenodesed to the anterior capsule as additional reinforcement (TECH FIG 9E,F).

The extracortical component of the prosthesis can be used for additional bone and soft tissue fixation in the form of a noose around the prosthesis. Bone struts, either autografts or allografts, are held circumferentially with Dacron tape to the prosthesis–host bone interface. Theoretically, this procedure will prevent debris from entering the bone–cement interface, thereby reduce the possibility of aseptic loosening.

If the greater trochanter had been resected en bloc with the surgical specimen, the remaining abductor tendon is attached with Dacron tape to the lateral aspect of the prosthesis through a metal loop. If there is a remaining fragment of the greater trochanter, it is fixed to the prosthesis with a cable grip system (TECH FIG 9G). Dynamic reconstruction is obtained by tenodesing the vastus lateralis to overlie the abductor muscle fixation. The remaining muscles are sutured to the vastus lateralis anteriorly and the hamstrings posteriorly (TECH FIG 9H,I).

The wound is closed over a 28-gauge chest tube that is attached to a continuous suction at 20 cmH2O (TECH FIG 9J). The patient is placed in balanced suspension or tibial pin traction with the hip elevated and flexed 20 degrees.

TECH FIG 9 • A–D. The remaining hip capsule is sutured tightly with a 3-mm Dacron tape (Deknatel, Falls River, MA) around the neck of the prosthesis. E. The psoas muscle is rotated anteriorly and tenodesed to the anterior capsule as additional reinforcement. F. Alternatively, a circumferential polyethylene-terephthalate tube may be applied on the prosthesis to which the surrounding muscles and tendons can be sutured. G. Fixation of the greater trochanter to the lateral aspect of the prosthesis with a cable grip system. (continued)
**POSTOPERATIVE CARE**

- The extremity is kept in balanced suspension for at least 5 days. An abduction brace is customized for the patient. Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed.
- Postoperative mobilization with an abduction brace and weight bearing as tolerated are continued for 6 weeks. Active hip abduction is required before the brace can be removed and before unprotected, full weight bearing can be allowed.

**OUTCOMES**

- More than 80% of patients who undergo proximal or total femur resection report good to excellent function.\(^1\) Most of them do not require a walking aid (crutches, walker, or cane), although some abductor insufficiency and Trendelenburg gait are common.
- No differences in function were found between patients who underwent proximal femur replacement and those who underwent total femur replacement.\(^1\)
- Dislocations of the prosthesis have become rare due to the combined use of capsular repair and reconstruction of the abductor mechanism. Because of the excellent blood supply around the proximal thigh and hip joint and the options for prosthetic coverage with viable muscle tissue, flap ischemia, deep infections, and prosthetic loosening are rare.

**COMPLICATIONS**

- Deep infection
- Dislocation
- Abductor insufficiency and Trendelenburg gait
- Local tumor recurrence
- Prosthetic loosening

**REFERENCES**

2. Enneking WF, Shirley PD. Resection-arthrodesis for malignant and potentially malignant lesions about the knee using an in-
BACKGROUND

- Ralph C. Marcove (Memorial Sloan Kettering Cancer Center) and Kenneth C. Francis (New York University Medical Center) introduced limb-sparing resection in the early 1970s for the management of malignant bone tumors, initially for osteosarcoma of the distal femur. The introduction of effective chemotherapy agents (doxorubicin [Adriamycin] and methotrexate) at the same time was a major impetus to the development of these procedures. These surgeons hoped by combining surgery with chemotherapy, either preoperatively or postoperatively (termed adjuvant chemotherapy), limb-sparing surgery would be safe for the patient and would permit a limb-sparing resection.

- Distal femoral endoprosthetic reconstruction has undergone an evolution of surgical techniques and manufacturing changes (initially by Howmedica, Inc., Rutherford, NJ), making it one of the most satisfying orthopaedic oncology procedures available today. Forging of components has greatly diminished mechanical failure problems, and modularity has increased the indications for its use. Muscle-sparing and soft tissue coverage techniques have minimized wound healing problems.

- The three major steps in limb-sparing surgery—wide excision with good oncologic margins, reliable reconstruction of the skeletal defect, and adequate muscle transfer and soft tissue coverage—have formed the basis for reliable and safe limb-sparing resections and reconstruction for both low- and high-grade bone sarcomas. Most clinical experience has been gained in treating osteosarcoma of the bone. The most common site is the distal femur and the proximal tibia. These techniques have subsequently been used for other bony sarcomas and recurrent benign tumors and more recently in the treatment of failed allograft and complicated, multifailed total knee arthroplasties.

- The goal is to have an adequate oncologic resection while maintaining enough muscle to permit a painless functional result. The techniques outlined in this chapter are based on the senior authors’ (MM, JJE) 51 years of combined surgical experience, with approximately 440 distal femoral reconstructions since 1979.

ANATOMY

- The surgeon must be extremely knowledgeable of not only the bony anatomy and the specific endoprosthesis to be used but also the vascular anatomy, soft tissue structures, and potential local muscle flaps and the many techniques involved in a limb-sparing resection (FIG 1).

Sartorial Canal

- The sartorial canal occupies the space between the vastus medialis, sartorius, and adductor magnus muscles in which the superficial femoral artery passes the medial aspect of the thigh (adductor hiatus) and then enters the popliteal space. In patients whose tumors are longer than 13 cm, the sartorial canal is often displaced. The vessels within the canal are usually protected by the deep fascia of the vastus medialis and a tough fascia surrounding the vessels. This fascia border is rarely penetrated by tumor.

Knee Joint

- The knee joint is rarely directly involved by sarcoma. The main mechanisms of knee joint contamination are inappropriate biopsy, extension of tumor along the intra-articular cruciate ligaments, and pathologic fracture. The knee joint can reliably be evaluated by computed tomography (CT) and magnetic resonance imaging (MRI). If the physical examination reveals any evidence of effusion, the knee joint should be aspirated and histologic samples obtained. A hemarthrosis usually indicates tumor involvement of the synovium. This is a rare event but not an indication for amputation.

Popliteal Space

- The popliteal space contains the popliteal artery and vein and the sciatic nerve. The popliteal vessels enter the popliteal space from the medial aspect through the adductor hiatus as the vessels exit the sartorial canal. The popliteal vessels are evaluated by CT with contrast, MRI, and plain angiography.

- It is rare to have direct vessel involvement by tumor. The vessels may be displaced as the tumor grows posteriorly, but usually there is a normal border or margin of popliteal fat.

- Exploration of the popliteal space is the first step in determining the feasibility of a limb-sparing procedure. The popliteal vessels are dissected out and the geniculate vessels are ligated. If the vessels are free of tumor, resection can usually be performed safely.

![FIG 1 • Cross-sectional anatomy of the distal femur.](image-url)
FIG 2 • A. Evolution of the distal femoral endoprosthesis. Composite No. 1: The Waldius knee mechanism, introduced in 1951, had a fixed metal on hinge. No. 2 The Spherocentric distal femoral endoprosthesis was developed by Harry Matthews, MD, in 1975 and first implanted in 1977. A metal ball and polyethylene cupola connected the tibial and femoral components. No. 3: The original kinematic rotating-hinge knee was introduced in 1980. The vitalium hollow body was casted by the lost-wax method, and a custom Zickle nail stem was welded to it. No. 4: Circumferential porous ingrowth beads were introduced in 1985 to allow for bone incorporation. In reality little bone ingrowth occurred, but protective soft tissue ingrowth did. No. 5 Modularity was introduced in 1988. The condyles and femoral stems were forged and were coupled to titanium segments by Morse taper locks. Since its introduction in 1980 by Peter Walker for Howmedica, the kinematic rotating-hinge knee mechanism has remained virtually unchanged except for a slight increase in the diameter of the axle and the polyethylene bushings. The rotating-hinge knee concept has now been universally adopted as the preferred knee mechanism for distal femoral endoprosthetic reconstructions.

B. A Guepar prosthesis (simple hinge) was used in the early 1970s before the development the rotating-hinge prosthesis. C. Custom prosthesis used during the 1980s. The knee joint is a rotating hinge consisting of bushings, axles, and a rotating poly component that is inserted into the tibia. D. The modular replacement system was first used (National Cancer Institute) in 1988 and was approved by the U.S. Food and Drug Administration in 1991. This system consists of a joint component, multiple body segments, and stems of various diameters. This system can replace the proximal femur, distal femur, total femur, or proximal humerus. The original system was developed by the senior author (MM) in conjunction with the engineers (lead engineer George Corsi) at Howmedica (Rutherford, NJ). This system, now known as the Global MRS system, is manufactured by Stryker Orthopedics (Mahwah, NJ).
A frozen section of the popliteal fat or adventitia of the popliteal vessels should be obtained intraoperatively. If there is obvious vascular involvement, the vessels can be replaced by vascular graft.

The popliteal vein is usually not repaired because it rarely stays patent after surgery.

### Anterior and Posterior Cruciate Ligaments

- The cruciate ligaments are occasionally involved by direct tumor extension from the distal femur. This occurs through the bone–tendinous junction of the intercondylar notch of the distal femur. There is no cartilage in this area to act as a barrier to tumor growth.
- MRI is occasionally helpful in determining cruciate ligament involvement.
- Tumor nodules of the anterior and posterior cruciates occasionally present with a hemorrhthrosis. The most common finding at resection is tumor nodule involvement of the cruciates. This does not rule out a limb-sparing procedure. The cruciate ligaments as they attach to the proximal tibial plateau can be resected en bloc with the proximal tibial cut. This is a safe procedure that avoids the need for a true extra-articular resection.

### INDICATIONS

- Endoprostheses were initially used solely for reconstruction after resection of malignant bone tumors. Manufacturing time could be as long as 3 months, an interval that permitted induction chemotherapy. Endoprosthetic reconstructions proved to be enduring, and the designs have evolved ([FIG 2](#)). Modularity, which made for immediate availability, permitted the expansion of the indications for distal femoral endoprosthetic reconstruction to some stage 3 giant cell tumors of bone; metastatic disease where conventional intraleisional procedures cannot reasonably be done, possibly 10% of metastatic cases; complex supracondylar fractures in elderly osteoporotic patients; failed internal fixation of distal femoral fractures; failed allograft or total knee reconstructions; and as a primary knee replacement system in patients with a severe flexion contracture where bone and ligament resection would lead to instability with conventional knee replacement systems.

### PATIENT HISTORY AND PHYSICAL FINDINGS

- The average age of patients with high-grade osteosarcomas is 5 to 30 years; the median is 16 to 21 years. Surface osteosarcomas occur in the third decade and are more common in women.
- Patients with high-grade osteosarcoma almost always initially complain of pain during the day that is not associated with activity. All patients complain of a dull aching pain and only later of night pain.
- Thirty to 40% of patients have a history of local trauma. There is no causal relationship of trauma to the tumor except that it brings the patient to medical attention and the physician orders a radiograph, which always shows the tumor. This has been termed “traumatic determinism.”

Classic high-grade osteosarcoma presents with pain. Parosteal osteosarcoma (surface osteosarcoma) usually presents with a mass and not pain ([FIG 3](#)).

Parosteal osteosarcomas are most common in the posterior aspect of the distal femur. They represent less than 4% of all osteosarcomas. Popliteal fullness is a common finding. Plain radiographs can often distinguish a classic from a parosteal osteosarcoma.

- There may be tenderness on examination. The regional lymph nodes are normal. Osteosarcomas spread hematogenously. Infection is rarely a consideration.
- Pathological fracture occurs in less than 1% of osteosarcomas. Fractures usually occur through the purely osteolytic variant (about 25% of all osteosarcomas), which has minimal mineralized tumor matrix.
- A soft tissue, extraosseous mass occurs in more than 90% of high-grade osteosarcomas.
- An effusion usually indicates tumor involvement of the joint or pathological fracture.
- Distal pulses are usually normal and symmetrical. Decreased pulses may represent tumor involvement.
- Leg edema may represent popliteal vein occlusion or thrombus.
- Enlarged groin lymph nodes may represent lymph node metastasis, but this is rare. Biopsy should be considered.
- Popliteal lymph node enlargement is extremely rare (except for Ewing sarcoma or lymphoma).

### IMAGING AND OTHER STAGING STUDIES

- Diagnostic imaging should include plain radiographs, a technetium-99 bone scan, an MRI of the entire femur, and a CT scan of the distal femur ([FIG 4](#)), as well as angiography. Three-dimensional CT angiograms have recently replaced routine angiography. Preoperative staging studies focus on the four anatomic structures discussed above. This permits the surgical team to determine the type of surgery, placement of the incision, the need for intra- or extra-articular resection, and the biopsy site and technique.
- Plain radiographs correlate very well with the extent of the tumor when a Codman triangle is present.
- A technetium-99 scan shows the extent of the tumor within the femur as well as the presence of skip metastases. Multicentric disease or metastases to other bones can be determined from this test as well. The early and pool phases of the bone scan demonstrate the vascularity of the tumor and tend to correlate with the chemotherapy effect (ie, tumor necrosis).
FIG 4 • A. Schematic illustration depicting the preoperative studies needed for sarcomas of the distal femur. MRIs, CT scans, bone scans, and angiography are required. B,C. AP and lateral radiographs of a patient with a secondary chondrosarcoma arising from an osteochondroma. D. Posterior projection of a technetium-99 bone scan in a patient with a sarcoma of the distal femur. No skip metastases are noted. The uptake on the scan correlates well with the extent of tumor within the bone. E. The CT scan of the patient in Fig. 4B,C clearly shows the medial osteochondroma stalk from which the secondary chondrosarcoma arose. A posterolateral osteochondroma is also noted. Although soft tissue extension of the tumor is apparent, it is less well delineated than on the MRI. F,G. Coronal and cross-sectional MRIs of the patient.
A femoral MRI best shows the extraosseous extent of the tumor as well as its proximal and distal extent within the medullary canal. This study is the most accurate in detecting skip metastases.

CT scans are complementary to MRI scans and can show the quality of the bone stock at the intended level of resection.

Angiography or three-dimensional CT angiography can be used to evaluate the superficial femoral and popliteal arteries. This is especially important if there is a large posterior or medial extraosseous component. The late arterial phase of the angiogram or venous phase will show residual tumor blush. The degree of remaining vascularity correlates well with the tumor necrosis (FIG 5A,B). An unresponsive tumor as shown by a tumor blush requires a wider margin than a good responder (no tumor blush). More recently, three-dimensional CT angiography has replaced traditional angiograms; it shows the vascular anatomy well (FIG 5C–F).

**FIG 5**  
A. Angiography after induction chemotherapy. A. Anteroposterior view. B. Lateral view showing the absence of a tumor blush. This is the most reliable finding of all preoperative staging studies that can predict tumor response. This patient had 100% chemonecrosis. C. Three-dimensional angiography is being evaluated in the treatment of bony tumors. C,D. Lateral and posterior views of the distal sarcoma. The popliteal artery is displaced. The extraosseous component is not visualized because there is no bony formation. E,F. Secondary chondrosarcoma of the proximal tibia. Lateral and posterior views showing excellent visualization of the popliteal artery and its trifurcation (arrows). A 64- or 246-slice CT scanner is required, similar to coronary angiography.
Together these studies help to determine the resectability of the tumor as well as the desired level of the femoral osteotomy. A comprehensive knowledge of prosthetic stem lengths and widths is necessary to be sure that adequate proximal bone stock is available to proceed with endoprosthetic reconstruction.

**SURGICAL MANAGEMENT**

- Surgical guidelines for limb-sparing surgery are as follows:
  - The major neurovascular bundle (popliteal vessels) must be free of tumor.
  - The resection of the affected bone should leave a wide margin and a normal muscle cuff (ie, 1 to 2 cm) in all directions (**Fig 6**).
  - All previous biopsy sites and all potentially contaminated tissues should be removed en bloc. All needle biopsy tracts must be removed (**Fig 7A**).
  - To avoid intraosseous tumor extension, bone should be resected 3 to 5 cm beyond abnormal uptake, as determined by preoperative studies.
  - The adjacent joint and joint capsule should be resected.
  - Adequate motor reconstruction must be accomplished by regional muscle transfers.
  - Adequate soft tissue coverage is needed to decrease the risk of skin flap necrosis and secondary infection. A medial gastrocnemius rotation flap provides excellent coverage of the prosthesis when required.
  - Careful attention to the patient’s general condition is critical in the timing of limb-sparing procedures in cancer patients. Patients undergoing preoperative chemotherapy (**Fig 7B,C**) and radiation therapy (Ewing sarcoma) need an adequate hiatus before surgery. In general, surgery can proceed 2 to 3 weeks after these treatments are completed. The white count and platelet count need to be within a safe range and rising, and the skin must have recovered from the effects of radiation and must be nonerythematous.
  - When the procedure is used for a salvage reconstruction after failed internal fixation, failed total joint arthroplasty, or allograft procedures, a past history of infection can bode poorly if it is not completely eradicated before surgery.

**Preoperative Planning**

- The intended level of resection should be determined before the patient comes to the operating room. A careful review of the diagnostic tests should confirm this location and should
confirm that there is adequate bone stock left to accept the femoral stem, in terms of both length and width. The distal femur should be resected with a safe oncologic margin (3 to 4 cm of normal marrow). The extremity lengths should be equal to within millimeters. To achieve this, intraoperative marks and measurements are made to ensure that the length before resection equals the reconstruction length.

When planning the primary resection and reconstruction, the surgeon should also be planning an amputation or revision. Ideally the level of amputation should be at the same level it would have been had amputation been chosen as the original procedure to achieve local control. The surgeon should plan how he or she will revise this reconstruction in the event of infection or mechanical failure. The real goal would be to retain the patient’s own hip and not go to a total femur replacement unless necessary, as this requires rehabilitating two joints in series, which is always a greater challenge for the patient.

Positioning

- In the preoperative area or as anesthesia is being induced, the patient is given intravenous antibiotics. One gram of vancomycin is slowly infused over 1 hour, and this is repeated every 12 hours until the drains are removed. A single 80-mg dose of gentamicin or tobramycin is also given. An epidural catheter is routinely used for postoperative pain management.
- After anesthesia is induced, a urinary catheter is placed. For the medial approach the patient is placed in the supine position with the entire leg, including the inguinal area, prepared. This provides adequate access to the proximal femoral vessels.
- A tourniquet is not used. A folded sheet placed transversely under the sacrum can elevate the pelvis to permit better access for draping. If the lateral approach is used, then the patient is placed in the lateral decubitus position on a beanbag with an axillary roll. A standard 10-minute preparation is performed, generally iodine-based.

Approach

- The preferred approach is a medial longitudinal approach with exploration of the superficial femoral and popliteal vessels. All vessels that feed the tumor and distal femur are tied off (FIG 8). A lateral approach is used only when access to the proximal femur is needed for cross-pin stem fixation or when little residual proximal femur remains.

RESECTION AND RECONSTRUCTION OF THE DISTAL FEMUR THROUGH A LONGITUDINAL MEDIAL APPROACH AND PREPARATION FOR CEMENTING THE TIBIA, PATELLA, AND FEMORAL COMPONENTS

Position and Dissection

- The patient is in supine position with the leg and inguinal area prepared out (TECH FIG 1A).
- The incision is longitudinal, following the sartorius muscle from proximally in the thigh distal to beyond the tibial tubercle (TECH FIG 1B).
- Any biopsy tract should be kept in continuity with the underlying tumor. Because the routine approach for primary tumors is medial, lateral or anterior open biopsy tracts need to be ellipsed and kept in continuity with the underlying tumor.
- The saphenous nerve is identified and protected (TECH FIG 1C).
- The interval between the sartorius and the vastus medialis is opened, exposing the superficial femoral artery and vein along with the saphenous nerve (TECH FIG 1D,E).
- The vessels and the saphenous nerve are dissected from proximal to distal and are reflected posterior and medial along with the sartorius muscle.
- All vessels (geniculates) are tied off with 2-0 or 3-0 silk ties as they course from the vessels toward the distal femur and tumor (TECH FIG 1F). The surgeon must not ligate the medial or lateral sural vessels, which are the main blood supply to the respective gastrocnemius muscles. These vessels are the basis of a gastrocnemius flap if required.
- The surgeon should be careful at the canal of Hunter because the vessels are just deep to the adductor tendon.
TECH FIG 1  •  A. Right leg with large secondary chondrosarcoma. B. A medial incision follows the sartorius proximally in the thigh to below the tibial tubercle. This allows immediate and very adequate visualization of the femoral and popliteal vessels. C. After the incision through the skin and subcutaneous tissue, a large posteromedial flap is developed deep to the fascia. The first vital structure identified and protected is the saphenous nerve. It accompanies the femoral vessels proximally in the thigh and follows the sartorius into the leg. Cutting the nerve results in numbness over the medial calf and occasionally a painful neuroma. D. In the middle and distal thigh, retracting the sartorius posteromedially exposes the superficial femoral vessels. E. In the proximal thigh, retracting the sartorius anterior and lateral allows exposure of the femoral vessels, all the way to the inguinal ligament if necessary. F. All vessels coursing toward the distal femur and tumor are tied with 2-0 or 3-0 silk sutures before they are cut. This minimizes blood loss, improves exposure, and guarantees the integrity of these structures. G. At the canal of Hunter, the adductor tendon is identified and cut. The main vessels are just beneath this structure, and care and patience at this point in the dissection are necessary. Several collateral vessels come off the femoral vessels at this point, coursing toward the femur and tumor. They need to be tied off. The saphenous nerve is seen accompanying the sartorius muscle.
Distal to the canal of Hunter the popliteal vessels are dissected free and reflected posterior and medially (TECH FIG 1G). The short head of the biceps muscle is now seen coursing proximal to distal to join the long head laterally in the thigh.

The sciatic nerve is exposed and protected.

Proximal and medial in the thigh above the tumor, the junction between the adductors and vastus medialis can be opened to the femur to reflect the quadriceps laterally off the femur (TECH FIG 2A).

Deep to the medial intermuscular septum is the terminal profunda artery and vein, which may be ligated.

The superficial femoral vessels, along with the saphenous nerve and popliteal vessels, are dissected free from the tumor throughout its length to below the joint line (TECH FIG 2B,C).

The medial gastrocnemius muscle can be incised. The surgeon must not ligate the medial sural vessels (TECH FIG 2D,E).

With the femoral vessels completely dissected and reflected, the quadriceps or a portion of it, along with the patella and patellar tendon, are now reflected over the tumor, leaving the vastus intermedialis as a very satisfactory oncologic margin.

Intra-articular resections are usually performed.

The joint capsule is opened and the anterior and posterior cruciate ligaments, the popliteus tendon, and the collateral ligaments are cut with an electrical cautery.

The posterior capsule is incised, with the popliteal vessels kept in direct view or under the operator’s finger to prevent injury.

A. Proximally in the thigh, above the tumor the adductor fascia meets the fascia of the vastus medialis. This interval is opened to permit exposure of the femur. The profunda vessels course just below the adductor fascia and follow the linea aspera. B. Saphenous nerve proximally in the thigh accompanies the superficial femoral vessels as the sartorius has been retracted posteriorly. The adductor tendon has not yet been cut, but the popliteal vessels have been exposed and mobilized to below the knee joint to guarantee their integrity. C. Completed medial dissection. The saphenous nerve follows the sartorius from proximal in the field. The femoral and popliteal vessels have been dissected and accompany the sartorius muscle and the saphenous nerve distally in the thigh. D. Medially at the knee, the medial gastrocnemius muscle is dissected and cut. E. Medial geniculaties are identified and cut. (continued)
TECH FIG 2 • (continued) F. An arthrotomy has been made. The quadriceps had been dissected and mobilized over the tumor mass, leaving the vastus intermedius muscle as an oncologic margin on the tumor. G. Cortical marks have been made on the femur and tibia above and below the planned resection levels to establish the length before resection that should be re-established with the reconstruction. The anterior cortical mark is placed at this time to help with rotation orientation.

- Intra-articular extension of the tumor is rare; when it occurs, it is covered with synovium. Local recurrence, when it occurs, is generally along the neurovascular dissection plane and not anterior in, or in the level of, the knee joint.
- The quadriceps is reflected over the tumor, leaving a cuff of muscle on top of the tumor as the oncologic margin. The vastus intermedius is left as an oncologic margin over the tumor (TECH FIG 2F).
- Cortical marks are as follows:
  - Before dislocating the knee, cortical marks are placed proximally on the femur and on the tibia, and the distance before resection is measured.
  - This distance should be the same after the prosthesis is implanted.
  - An anterior cortex is marked on the proximal femur to help with rotatory alignment during femoral stem insertion. This, along with the linea aspera, is used to determine appropriate rotatory position of the stem (TECH FIG 2G).
- The knee is dislocated and the short head of the biceps and the remaining posterior lateral capsule are cut.

Osteotomy and Preparation of the Femur, Tibia, and Patella

- The femur is cut with a saw at the predetermined level (TECH FIG 3A–C). One more centimeter than the assembled length of the femoral component is removed, and then only 7 mm is taken off the tibia. This 1.7 cm makes up for the distance between the prosthetic condyle and the undersurface of an 8-mm all-poly tibial component when assembled. This ensures leg-length equality (TECH FIG 4A). Alternatively, 17 mm can be taken off the tibia with jigs provided by the manufacturer, and the femur

TECH FIG 3 • A. The femur is cut with a Gigli or oscillating saw at the planned resection level and below the cortical marks. B,C. Anterior and posterior views of the specimen alongside the trial prosthesis.
can be cut exactly at the proximal level of the segmental component. While this may place the patella in a more anatomic location, it makes no difference in functional outcome (TECH FIG 4B).

- The proximal marrow is sampled and sent to pathology for frozen section analysis.
- The femur is reamed to accept the largest stem possible. This concept is “fit and fill.” Curved stems may add to rotatory stability. Stems smaller than 13 mm should be avoided in adults. The cut end is then chamfered (with a facing reamer) and cleaned with an irrigating brush (TECH FIG 4C–E).
- A proximal cement restrictor can be placed at this time if cement fixation is to be used.
- The tibia is osteotomized with an oscillating saw with a very slight posterior slope (TECH FIG 4F,G). This cut can

**TECH FIG 4** • A. With this author’s (JJE) technique, the femur is cut 1 cm longer than the planned femoral replacement. B. Only 7 mm is removed from the proximal tibia. This gives the largest platform for the tibial component. An 8-mm all-polyethylene tibial component is routinely used in primary reconstructions. The distance from the metal condyle to the inferior surface of an 8-mm poly tibial component is 1.7 cm. This ensures extremity-length equality to within millimeters. No effort is made to keep the patella right at the knee joint. Patellar tracking and postoperative function, which is what is important, are routinely excellent. C. After the marrow frozen section report has returned as negative for tumor, reaming the canal can commence, with the femur stabilized with a large locking clamp. Sharp reamers are used and the reaming is done slowly and gently, with copious irrigation to prevent a fat embolus. The canal is reamed to whatever level is necessary to permit the largest stem to fit easily. D. A chamfer reamer is used to prepare the osteotomy site. E. The canal is cleaned again slowly and gently with an irrigating brush. F. A freehand oscillating saw removes 7 mm from the upper tibia. Manufacturers now provide tibial cutoff instrumentation to permit the removal of larger amounts of tibia to keep the patella at the joint line. G. The tibial cut is usually perpendicular when the distal end points to the second metatarsal. The tibial cut should have a slight posterior slope to ensure full extension when the prosthesis is fully extended. If the slope is anterior, the patient will be left with a built-in flexion contracture. (continued)
be done freehand, though instrumentation is now available. Our routine is to take off only 7 mm, just below the cartilage. This leaves the largest surface area to support the reconstruction. An anterior slope will leave the final reconstruction with a knee flexion contracture. The proximal tibia is prepared to receive the tibia component. A distal bone plug or cement restrictor can be placed at this time. A trial all-poly tibial prosthesis is then inserted. An intraoperative radiograph is taken to ensure that the cut is perpendicular to the shaft and not in varus or valgus. The seating of the trial prosthesis is also determined to avoid varus or valgus tilt (TECH FIG 4H).

- The undersurface (50%) of the fat pad is removed to prevent impingement. This can be painful in the immediate postoperative period.

- The patella undersurface is removed and it is prepared (undercut with a burr) to receive the patellar component. One of the senior authors (MM) routinely resurfaces all patellas with a single central peg component. Alternatively, if the patella appears normal (as in most adolescents), there is no need to replace it (TECH FIG 4I–L).

- A trial reduction is made and a measurement is taken to be sure that the post-reconstruction distance is the same as the pre-resection distance (TECH FIG 4M).

- Range of motion is tested: the quadriceps and patella should track nicely without a tendency for lateral dislocation.

- A lateral release should be made at this time if there is a tendency for patellar subluxation or dislocation.

- The tension of the superficial femoral vessels is also checked. The distal pulses at the ankle are checked with a Doppler with the reconstruction in full extension. Overlengthening can cause excessive tension and compression of these structures.

- Overlengthening should be avoided. It is harder to rehabilitate a lengthened extremity. Leg-length inequalities in the growing child can be made up at a later date with an exchange of one of the segmental modules rather than overlengthening at the time of the initial resection. Some adolescent patients never need a lengthening. Overlengthening also increases the risk of sciatic or peroneal nerve palsy.

### Selection and Placement of the Components

- The patellar component should not overhang the cut surface of the patella. A central peg poly component is used and the surface of the bone is undercut to aid in fixation. The rationale for resurfacing the patella is that it allows immediate and vigorous rehabilitation without concern that any knee pain may be due to the patellar cartilage grinding on the metal distal femoral prosthesis. This is more important given that the goal is an active range of motion of 120 to 130 degrees of
flexion, full extension, and no extensor lag. This is routinely achieved. If the expectation of active knee motion is 90 degrees or less, then it probably does not make any difference whether the patella is resurfaced or not.

- The all-poly tibia is almost always 8 mm in primary cases. Metal-backed tibial components are not necessary in primary cases but are routinely used in revisions.
  - The tibial poly is oriented to face the tibial tubercle (slight external rotation).
- The femoral component is picked to maximize the “fit and fill” concept and is oriented anatomically based on the anterior cortical mark and the linea aspera.
- The actual components are assembled on the back table and another trial reduction is performed to check lengths, the tension of the vessels, and distal pulses as well as tracking of the patella. All of the tapers must be dry before impaction, because a “wet” taper will cause unlocking or disassociation.

Cementing of Components

- All components are cemented.
- Before cementing, 100 mg of hydrocortisone (Solu-Cortef) is given intravenously to protect against fat embolism. The deleterious effects of a fat embolism are due to a massive inflammatory response in the lungs. Steroids are the best anti-inflammatory agent.
- Antibiotic-impregnated cement is routinely used.

- The tibial component and the patella are cemented first.
- The cement is injected while it is still fairly liquid, and the femoral canal is pressurized.
- The femoral stem is inserted slowly. Rapid insertion can lead to a fat embolism.
- Once the stem is placed, rotatory changes are avoided because they will lead to poor fixation and early loosening. No last-minute adjustments should be made on the femoral side.
- A final measurement is made once the final components are in place.
- The final reconstruction with and without the resected specimen can be seen in TECH FIG 5A,B.

Closure and Postoperative Care

- Before closure, homeostasis should be meticulous.
- The wound is irrigated copiously with antibiotic solutions, with all final rinses with saline solutions.
- The joint capsular tissue is closed to the remaining capsular tissue about the proximal tibia.
- The sartorius is sutured to the vastus medialis over a deep 10-mm flat drain with a #1 absorbable suture (TECH FIG 6).
- The subcutaneous tissue is closed over a superficial 10-mm flat drain.
- The drains are sutured in place and are kept in place until the 24-hour drainage is less than 30 to 40 cc per hour.
- Skin closure can be with staples or a subcuticular suture.
- Gastrocnemius flaps are necessary in less than 1% of cases but can be useful to cover an endoprosthesis if adequate tissue is not available. More common use of the gastrocnemius flap reflects an individual surgeon’s resection philosophy and technique.
- Sterile dressings and an Ace wrap are applied.
- The patient is placed in the bed with a continuous passive motion machine, flexing to 30 degrees and extending to −5 degrees for 3 days. The range of motion is then advanced rapidly to achieve 90 degrees of flexion before discharge.
- Sequential compression boots are applied to the feet.
- The next technique, from an anterior (transadductor) approach, may be used as an alternative.

Cementing of Components

- All components are cemented.
- Before cementing, 100 mg of hydrocortisone (Solu-Cortef) is given intravenously to protect against fat embolism. The deleterious effects of a fat embolism are due to a massive inflammatory response in the lungs. Steroids are the best anti-inflammatory agent.
- Antibiotic-impregnated cement is routinely used.

- The tibial component and the patella are cemented first.
- The cement is injected while it is still fairly liquid, and the femoral canal is pressurized.
- The femoral stem is inserted slowly. Rapid insertion can lead to a fat embolism.
- Once the stem is placed, rotatory changes are avoided because they will lead to poor fixation and early loosening. No last-minute adjustments should be made on the femoral side.
- A final measurement is made once the final components are in place.
- The final reconstruction with and without the resected specimen can be seen in TECH FIG 5A,B.

Closure and Postoperative Care

- Before closure, homeostasis should be meticulous.
- The wound is irrigated copiously with antibiotic solutions, with all final rinses with saline solutions.
- The joint capsular tissue is closed to the remaining capsular tissue about the proximal tibia.
- The sartorius is sutured to the vastus medialis over a deep 10-mm flat drain with a #1 absorbable suture (TECH FIG 6).
- The subcutaneous tissue is closed over a superficial 10-mm flat drain.
- The drains are sutured in place and are kept in place until the 24-hour drainage is less than 30 to 40 cc per hour.
- Skin closure can be with staples or a subcuticular suture.
- Gastrocnemius flaps are necessary in less than 1% of cases but can be useful to cover an endoprosthesis if adequate tissue is not available. More common use of the gastrocnemius flap reflects an individual surgeon’s resection philosophy and technique.
- Sterile dressings and an Ace wrap are applied.
- The patient is placed in the bed with a continuous passive motion machine, flexing to 30 degrees and extending to −5 degrees for 3 days. The range of motion is then advanced rapidly to achieve 90 degrees of flexion before discharge.
- Sequential compression boots are applied to the feet.
- The next technique, from an anterior (transadductor) approach, may be used as an alternative.
RESECTION AND RECONSTRUCTION OF THE DISTAL FEMUR THROUGH A LONGITUDINAL LATERAL APPROACH AND PREPARATION FOR CEMENTING THE TIBIA, PATELLA, AND FEMORAL COMPONENTS

- Indications for the lateral approach:
  - All revision cases
  - Total femur reconstructions
  - Primary distal femoral tumors that extend so far proximally that cross-pin stem fixation, either at 90 degrees to the shaft or 135 degrees into the femoral neck, is necessary to achieve a stable reconstruction.  
  - Patient preparation for the lateral approach is identical to the medial approach.
  - Once anesthesia is administered, the urinary catheter is placed, and the vancomycin and gentamicin are administered, the patient is rolled to the lateral decubitus position, with all pressure points carefully protected.
  - The entire leg is draped and prepared, from above the iliac crest to the foot.
  - A tourniquet is not used.
  - A longitudinal lateral incision is made from the tibial tubercle to as far proximal as necessary. It can be extended to the tip of the trochanter and then on to the anterior superior iliac spine if a total femur endoprosthesis is planned.
  - The skin and subcutaneous tissues are incised with an electrical cautery knife. The fascia lata is incised in line with its fibers.
  - The lateral intermuscular septum is identified and the entire vastus lateralis can be released from its posterolateral insertion after tying all the perforators before cutting them. Then the entire vastus lateralis can be flipped up over the femur, exposing the entire length of the bone. A cuff of muscle can be left on the tumor as oncologic needs dictate.
  - Because the tibial tubercle is a somewhat laterally placed structure, care needs to be taken to avoid avulsion of the patellar tendon.
  - The remainder of the procedure is identical to the medial approach.

ANTERIOR (TRANSADDUCTOR) APPROACH TO THE DISTAL FEMUR AND POPLITEAL SPACE FOR RESECTION OF TUMORS OF THE DISTAL FEMUR AND ENDOPROSTHETIC RECONSTRUCTION

- The traditional approaches to the distal femur are medial and anteromedial. These techniques facilitate access to the anterior aspect of the femur and allow exploration of the popliteal fossa and mobilization of its neurovascular structures by developing large fasciocutaneous or subcutaneous flaps (TECH FIG 7).
- Because some of the blood supply to the skin and subcutaneous tissue is inevitably compromised during the development of the flaps and because all the geniculate vessels are routinely ligated as part of the resection of the distal femur, the risk for ischemic flap necrosis is increased. In addition, separating the vastus medialis from its fascia and subcutaneous tissue compromises the vascularity of the outer layer of the muscle. Consequently, resection of the inner portion of the vastus medialis, which often is oncologically necessary, compromises the vitality of its residual outer layer and often prevents adequate soft tissue coverage of the endopro-
The distal aspect of the VM is developed. D. The surgical approach shown in A–C. E. The vastus intermedius tendon is opened and the medialis is mobilized. F–H, K. Operative photographs showing the transadductor approach. F. The interval between the RF and VM has been opened and the vastus intermedius has been mobilized. G. The termination of the sartorial canal containing the superficial femoral artery and vein is dissected free. H. The sartorial canal has been opened. I. The remaining attachment of the adductor magnus tendon to the distal femur is released. J. Relationship of the superficial femoral artery to the popliteal space and the adductor magnus tendon. (continued)
If minimal muscle coverage remains a problem after resection and attempted closure, the sartorius muscle can be rotated to cover small defects. In addition, a formal sartorius muscle transfer can be performed through this incision to recreate or to replace either partial or complete vastus medialis loss.

**Position and Incision**
- With the patient in the supine position and the surgeon standing on the medial side of the knee (opposite side of the table), a long, medial paramedian skin incision is made. The incision extends proximally along the junction of the rectus femoris and vastus medialis muscles and curves distally around the medial border of the patella to the level of the pes anserinus.

**Proximal Interval and Creation of Musculocutaneous Flap**
- The interval between the rectus femoris and vastus medialis muscles is identified and opened to expose the underlying vastus intermedius muscle. The fibers of the vastus intermedius are then carefully divided. It is important not to separate the overlying muscle from its fasciocutaneous coverage, which would defeat the purpose of this approach. This can be ensured by suturing the vastus medialis to the overlying skin.

**Exposure of Intermuscular Septum and Adductor Hiatus**
- The plane between the vastus medialis and the medial femoral condyle is identified distally (similar to the subvastus approach). The vastus medialis muscle is dissected off the medial femoral condyle in an extra-articular fashion and retracted medially, away from the knee capsule. By sweeping the fibers of the muscle from the intermuscular septum with a sponge, the intermuscular septum, the adductor hiatus, and the adductor magnus tendon are exposed.

**Identification of the Superficial Femoral and Popliteal Vessels**
- The sartorius muscle, which crosses over the proximal portion of the vastus medialis, is mobilized posteriorly by opening the thin fascia between the vastus medialis and its superior border. The superficial femoral artery and vein are identified proximally at the level of the adductor hiatus. With the surgeon’s finger placed into the adductor hiatus to protect the underlying vessels, the distal portion of the adductor magnus tendon is dissected and released from the distal femur and adductor tubercle, partially exposing the popliteal space. The superficial femoral vessels are carefully dissected and mobilized along their sheath, and vessel loops are placed around them as they enter the popliteal fossa.

**Completion of Popliteal Exposure**
- The knee is placed in 90 degrees of flexion. With the vastus medialis musculocutaneous flap retracted posteriorly, the entire popliteal space is visualized and the popliteal vessels are identified distally between the two heads of the gastrocnemius muscle. After the identification of the
popliteal vessels, the medial head of the gastrocnemius is released from the femoral condyle; this should be performed with the surgeon’s finger placed underneath the muscle, protecting the popliteal artery and vein. In addition, care should be taken to preserve the medial sural artery, which is the sole vascular supply to the medial head of the gastrocnemius (TECH FIG 8).

Mobilization of the Popliteal Vessels and Sciatic Nerve

- Mobilization of the popliteal vessels is facilitated by individually ligating their geniculate branches from the level of the adductor hiatus to the junction of the gastrocnemius muscle. A downward traction maneuver of the vessels allows better identification of the geniculate branches.
- The sciatic nerve is then exposed over the proximal portion of the popliteal fat and followed distally to its bifurcation into the tibial and common peroneal nerves. The popliteal vessels are then covered by a sponge soaked in papaverine to prevent potential vasospasm.

Lateral Structures Release

- After complete exposure of the popliteal space, including release of the medial head of the gastrocnemius and mobilization of the popliteal vessels, the lateral head of the gastrocnemius muscle, the short head of the biceps muscle, and the entire posterior capsule are released.

Anterior (Intra-articular) Release and Distal Femoral Osteotomy

- To complete the soft tissue dissection of the distal femur, the anterior capsule is opened transversely and both cruciate ligaments are divided. With the superficial femoral vessels mobilized, the femoral osteotomy, which is usually made 15 to 20 cm proximal to joint line, above the level of the adductor hiatus, can now be safely performed. The following steps to complete the resection and reconstruction are identical to those discussed above:
  - Intra-articular resections
  - Cortical marks
  - Osteotomy and preparation
  - Trial reduction
  - Selection and placement of the components
  - Cementing
  - Closure

Medial Gastrocnemius Muscle Transfer

- The medial gastrocnemius muscle is the mainstay of muscle transfers of the distal femur. The technique of medial gastrocnemius transfer for difficult and complicated distal...
Femoral resections was initially described by Malawer and Price in 1985 (Tech Fig 9).

- This muscle transfer provides excellent coverage for small and large medial and anterior defects after distal femoral resection. It has been our experience that a free flap has never been required after distal femoral resection and endoprosthetic replacement.

- The medial gastrocnemius muscle is dissected free of its tendinous and midline insertions in the calf after cementing of the prosthesis. It may then be rotated transversely or proximally, depending on the area to be covered. Usually the skin can be closed directly over the transferred muscle, but if there is any skin tension or swelling, the skin flaps are sutured directly to the muscle transfer and the remaining defect is closed with a split-thickness skin graft onto the muscle directly at the time of surgery.

- There is a thick fascia covering both the anterior and posterior surfaces of the medial gastrocnemius muscle. These fascia coverings are routinely removed with a sharp blade. This permits the muscle to expand about 150% larger than normal. The muscle can then be rotated either proximally to cover large medial defects or anteriorly to cover the entire exposed knee joint. The arc of rotation may be increased by releasing the sartorius and the other pes muscles. These muscles are then tenodesed to the transferred gastrocnemius muscle after rotating the gastrocnemius into place.

- The medial gastrocnemius muscle is fed by one major branch: the medial sural artery off the popliteal artery. The origin of this branch is at or below the knee joint line. At the time of popliteal exploration and dissection, it is essential to preserve this branch and not mistake it for a geniculate vessel. Geniculate branches pass anterior from the popliteal artery, whereas the medial sural artery passes posterior and medial. This vessel usually takes off at about the level of the inferior geniculate pedicle. The lateral gastrocnemius is rarely used because it is a much smaller muscle and its arc of rotation is decreased by the peroneal nerve and the fibula.

**Pain Control**

Silastic epineural catheters are routinely placed (MM) in the femoral nerve sheath and a 10-cc bolus of 0.25% bupivacaine is infused before the patient is transferred to the recovery room. Four to 8 cc per hour is administered using an infusion pump for up to 72 hours postoperatively. This provides excellent pain control and decreases systemic narcotic requirements by more than 50% (Tech Fig 10).
POSTOPERATIVE CARE

- In the operating room the patient is placed in the bed with a continuous passive motion machine, flexing to 35 degrees and extending to –5 degrees. That range of motion is maintained until the third day, when it is advanced 10 to 15 degrees a day to achieve 90 degrees before discharge.
- The inpatient stay is generally 7 to 10 days.
- A towel roll is placed under the heel three times a day for 60 minutes to ensure that full extension is achieved and that a flexion contracture is avoided. This practice is continued for the first 4 weeks after surgery.
- The patient is mobilized out of bed on the third postoperative day and ambulated initially with a walker and then crutches and with a knee immobilizer, which is kept on for 4 to 8 weeks when out of bed.
- Before discharge the patient should be able to flex to 90 degrees and do 10 straight-leg raises with the knee immobilizer on, should be in and out of bed independently, and able to go up and down stairs.

- The drains are removed when the drainage in a 24-hour period is less than 30 to 40 cc in each drain; generally this is in 5 to 6 days.
- Intravenous antibiotics are continued until the drains are removed.
- Anticoagulation after surgery is based on the patient’s risk factors.
- A circumferential compression Ace wrap is used for 2 months, and sometime a Neoprene knee brace is used for several months.
- Outpatient physical therapy is begun 4 to 6 weeks after surgery and lasts for 12 weeks. The goals are to maximize knee flexion, motor strength, and gait. Most patients achieve more than 120 degrees of flexion, have full extension without a lag, and walk without a limp. By 4 months the patient should be able to walk down the hall and most observers would not be able to tell that he or she has had surgery.
### PEARLS AND PITFALLS

| Difficulty closing the wound | Difficulty in wound closure usually occurs as a result of significant muscle resection due to the oncologic need for adequate margins. A too-long leg can cause this problem. The level of the patella should be checked. A medial gastrocnemius muscle flap should be used if there is any question about the viability of the medial closure or if a significant amount of the vastus medialis has been resected. Occasionally, the sartorius muscle can be rotated to close a small defect instead of the gastrocnemius muscle. |
| Identifying surgical planes medially and the subvastus interval | The surgeon should carefully identify the vastus medialis and rectus femoris interval and the subsequent vastus intermedius below it. The vastus medialis is mobilized extra-articularly from the femoral condyle. |
| Mobilization of the superficial femoral vessels | These vessels are identified within the sartorial canal and traced to the adductor hiatus. The surgeon places a finger into the hiatus before releasing the adductor fibers and intermuscular septum. |
| Difficulty identifying the popliteal vessels, especially distally | The surgeon should release the medial gastrocnemius muscle within 1 to 2 cm from its insertion onto the medial condyle. The popliteal vessels are found between the two heads of the gastrocnemius muscles. |
| Injury to or ligation of the medial sural artery | The medial sural artery is the main pedicle to the medial gastrocnemius muscle. This branch comes off medial and posterior from the popliteal artery. The geniculates take off anteriorly. The surgeon must not ligate any “geniculate” if it appears to be running medial or posterior. |
| Injury to the sciatic nerve, especially the peroneal branch | The sciatic nerve is easily identified in the popliteal space covered by fat posterior to the popliteal vessel sheath. These two sheaths are separate in the proximal portion of the popliteal space. Only after the sciatic nerve divides does the tibial nerve join the popliteal vessels within a common sheath. The peroneal nerve runs lateral to exit the popliteal space and runs lateral to the lateral gastrocnemius muscle. The nerve can easily be injured at this level, especially when the lateral gastrocnemius is released from the femoral condyle. |
| Injury to the popliteal artery and vein | Although these vessels are initially identified and mobilized, they can be iatrogenically injured later in the procedure. The surgeon must be careful when releasing the posterior capsule. The popliteal vessels are tied down to the capsule at the joint line by the most inferior geniculate vessels. These vessels should be ligated early in the procedure so that the popliteal vessels fall away from the entire femur and capsule. Occasionally the popliteal vessels are punctured by the distal end of the osteotomized femur. The surgeon should pack off the distal femur with a laparotomy pad to avoid this. |
| Absent pulses after closing the wound | This is most common in young patients with small-diameter vessels. It is often due to severe vascular spasm, usually secondary to small vessels, long length of vessels exposed, and exposure to the cold operating room air. It is best to avoid this situation by placing papaverine (vasodilator)-soaked sponges and warm laparotomy pads on the vessels throughout the procedure. If this does occur, the surgeon must ensure that the vessels are intact and not kinked off or thrombosed secondary to traction, intimal damage, or iatrogenic ligation. An intraoperative angiogram and a vascular surgeon consultation should be obtained. In most cases, the wound should be opened and the popliteal vessels quickly explored. The vascular surgeon may choose to pass Fogarty catheters to make sure there is no thrombus, but this technique is also a good means of opening a severely spasmed artery. |
| Unequal leg lengths | Taking careful measurements before resection and after implantation ensures leg-length equality to within millimeters. |
| Fitting and filling the femoral canal | Ream up the femoral canal to maximize fit. |
| Tying vessels before cutting | Tying vessels before cutting minimizes blood loss and improves visibility. |
| Cementing all components, including the patella and all-poly tibia | We have had no patellar or proximal tibia poly failures in 25 years. Cementing permits aggressive rehabilitation. |
| Preventing fat embolism | Ream the canal slowly, insert the stem slowly, and pretreat with 100 mg of hydrocortisone (Solu-Cortef) before cementing. |
| Preventing patellar dislocation | Ensure soft tissue balance; perform a lateral release if necessary before closure. |
| Unwillingness to plan for and do the revisions | A surgeon unwilling to plan for and do revisions should probably not be doing the primary resections and reconstructions. |
OUTCOMES

- In a study by Bickels et al,110 patients diagnosed between 1980 and 1998 with lesions of the distal femur underwent distal femur resection and endoprosthetic reconstructions. Extra-articular resection of the knee occurred in only two of these patients, both of whom were diagnosed with a primary bone sarcoma with tumor extension into the knee along the cruciate ligaments.
- Reconstruction implants included 73 modular prostheses, 27 custom-made prostheses, and 10 expandable prostheses. Only eight patients had a constrained knee mechanism (earlier edition); the remaining patients had reconstruction with a rotating-hinge knee mechanism prosthesis. Twenty-one medial, three lateral, and one bilateral gastrocnemius flaps were used after resection for soft tissue reconstruction. Ten patients with expandable prostheses had 14 lengthening procedures performed.
- Patients who had reconstruction with a rotating-hinge knee mechanism were more likely to have a good to excellent functional outcome (91%) than those who had reconstruction with a constrained knee mechanism (50%).

COMPLICATIONS

- Complications in the above study included six deep wound infections (5.4%), three of which resulted in amputation, two prosthetic revisions, and one wound débridement. Overall, there were 15 revision surgeries; they entailed replacement of a failed polyethylene component in six patients and prosthetic revision in nine patients (aseptic loosening, six; deep infection, two; radiation bone necrosis, one) (FIG 9).
- Two of the polyethylene component failures occurred in the same patient; the first occurred 2.5 years after the initial surgery and the second occurred 3.8 years later. Polyethylene failures occurred after an average of 3.7 years (range 1.25 to 7.25 years) and aseptic loosening occurred after an average of 5.5 years (range 3.2 to 10.3 years).
- During revision of their prostheses, all patients who underwent additional surgery because of a loosened prosthesis were found to have concomitant failure of a polyethylene component.

Local Recurrence

- The risk of local recurrence is surgeon-dependent. It occurs independent of the type of reconstruction (arthrodesis, allograft, or endoprosthesis).

Infections

- Infections are related to the local environment at surgery, bacteremias in the immediate postoperative period, length of the surgery, and soft tissue coverage problems. Infections are also generally independent of the type of reconstruction, though the rate is significantly higher in allograft reconstructions (FIG 10).
- Twenty-five to 30% of deep periprosthetic Staphylococcus aureus or Staphylococcus epidermidis infections can be salvaged.

FIG 9 • Survival of the distal femoral prosthesis. Kaplan-Meier curves of prosthetic survival. A. Custom versus modular prosthesis survival for all anatomic sites. The difference is mostly due to changes in surgical technique and reconstruction of the soft tissues. B. Endoprosthetic survival versus actual patient survival. The prosthesis is extremely reliable over the patient’s lifetime. C. Survival of all distal femoral prostheses. D. Prosthetic survival by various anatomic sites.
if treated early with aggressive and radical débridement, including prosthesis removal, implantation of antibiotic-impregnated cement spacers, and 6 to 8 weeks of intravenous antibiotics, followed by reinsertion of the components if aspirations are negative. Most other bacterial infections and all the gram-negative infections are difficult to cure and can lead to amputation.

- An exposed prosthesis is another cause of infection. Although needed infrequently by one author (JJE), rotation flaps and free flaps have been advocated and used to solve this problem. Their frequent application in primary cases reflects the individual surgeon’s resection philosophy and techniques.3

Fat Embolism

- Fat embolism can result from a number of factors, alone or in combination. Reaming the canal should be done slowly and gently with sharp reamers and frequent irrigation and suction. Although cement restrictors and pressurization of the cement are regularly used, stem insertion is again done gently and slowly. Patients should be well hydrated and oxygenated before insertion of cemented femoral stems.
- Fat emboli cause a massive inflammatory reaction. Because steroids are the best anti-inflammatory medication, 100 mg of hydrocortisone (Solu-Cortef) is routinely administered before cementing and insertion of long intramedullary stems.
- Massive fat emboli can be fatal.

Mechanical Failures

- Mechanical failures includes fatigue fracture of any endoprosthetic metal or polyethylene component, aseptic loosening, disassociation of modular components, and polyethylene wear synovitis (FIG 11).
- Most mechanical failures can be revised. The key to success is to analyze the failure mode and not do the same reconstruction. Although the literature suggests that revisions have a 50% failure rate at 5 years, if you analyze the failure mode and correct it, the revision should last longer than the original reconstruction.13
- The rotating-hinge knee was introduced in December 1980 and has become the international standard knee mechanism for distal femoral knee reconstructions. Anteroposterior stability and mediolateral stability are built into the mechanism, which permits complete resection of all the knee ligaments, a necessity in all tumor resections. The capacity to rotate slightly with loading defuses stress at the bone–prosthesis or the bone–cement–prosthesis interfaces, diminishing aseptic loosening and fatigue fracture.6
The development of modular components with forged stems has greatly reduced the incidence of fatigue fracture, especially of the femoral stems, compared with casted stems. This is unless there is a mismatch between the patient size and the implant size: an 11-mm stem in a 250-pound patient is a recipe for failure.

**Bushing Failures and Pseudomeniscus Formation**

- Bushing failures are heralded by the sudden onset of knee joint pain and a sense of instability to the point that ambulatory aids are necessary. Only on rare occasions, when there is complete disintegration of the bushing and extensor stop, will the radiographs be positive with medial or lateral protrusion of the axle. Surgical exploration, therefore, is done because of a high index of suspicion. This tends to be a late complication: the median time to failure in a series of seven cases was 84 months (range 30 to 112 months; **FIG 12**).

**FIG 12** • **A.** Breakage of medial bushing. **B.** Close-up of residual bushing. **C.** Delamination of a bushing and bumper. **D.** Delamination of a poly bumper removed 17 years after surgery. **E.** Clinical photograph showing gross instability to a varus stress test. This instability is characteristic of worn or broken bushings. **F, G.** Patients with pseudomenisci present with localized pain, lack of full extension, and no effusion. **H.** Gross specimen of a pseudomeniscus. This is formed by thick fibrous collagen without an inflammatory component. Pseudomeniscus rarely occurs before 5 to 7 years after surgery.
Pseudomeniscus and Internal Derangement of the Knee
- The term “pseudomeniscus” refers to scar tissue formation between the moving components of the femoral condyles on the tibial bearing component as well as under this component and the cemented all-poly (within the tibia). Scar tissue over time and with constant motion will form a true fibrocartilage type of scar that takes the shape of a true meniscus.
- Pseudomeniscus formation occurs frequently but is symptomatic in only a few patients. The symptoms are usually subtle, often presenting as an internal derangement of the knee. The most suggestive signs are a feeling of instability, combined with slight valgus instability (more than 5% on a stress test), and with or without a small effusion. There are no real diagnostic tests. Suspicion is the key to diagnosis. These symptoms may mimic those of a bushing failure, but with less instability and a smaller effusion.
- The true incidence of symptomatic pseudomeniscus is 5% to 7%. The treatment is resection of the pseudomeniscus as well as the pseudocapsule in the hope of preventing a recurrence.

Stem Fracture
- The incidence of femoral stem fractures has been reduced significantly with the introduction of forged stems, but they can occur, especially if the stem is undersized compared to the weight of the patient. Stem loosening usually precedes catastrophic fatigue fractures and may present as an actual displaced bone fracture.
- If the stem cracks but does not displace, the patient will have pain at the site of fracture, but the radiographs will remain negative until enough motion exists to cause displacement of the metal fracture pieces. Pain is significant and the patient will seek ambulatory aids. The older casted stems tended to break about 2 cm proximal to the forged junction with the body.

Disassociation of Morse Tapers
- Disassociation of the Morse taper locking mechanism is exceedingly rare and most likely due to failure to impact the components adequately. Surgical exploration and reassembly of the components and full impaction are required.

Aseptic Loosening
- The incidence of aseptic loosening of the femoral stems has been reduced by the incorporation of extramedullary porous ingrowth beads at the junction of the segmental replacement and the stems. Soft tissue ingrowth into these beads in the diaphysis isolates the joint debris from the bone–cement–prosthesis composite, creating a “biologic purse-string” effect. Hydroxyapatite coatings can also enhance fixation.
- Cross-pin stem fixation requires a custom component but permits the use of a short stem or a metaphyseal position that would normally lead to early aseptic loosening.
- On rare occasions patients develop a polyethylene debris synovitis. Exploration of the reconstruction, resection of the “pseudosynovium” or periprosthetic capsule, and exchange of the bushings and extensor stop can manage this. JE never revises the all-poly tibia or poly patellar components if they are well cemented unless there is an infection. If the cemented tibial poly is removed, then at reconstruction a metal-backed tibial component is used. Recementing an all-poly tibia component in revision situations risks early aseptic loosening, as the cementation is never as good as the primary reconstruction.

REFERENCES
BACKGROUND

- Resection of the proximal tibia includes the removal of one half to two thirds of the tibia along with a portion of all muscles that insert on it, as well as the entire popliteus muscle, in combination with an extra-articular resection of the proximal tibiofibular joint. The peroneal nerve is preserved.
- Of all anatomic locations in which major bone resections and prosthetic reconstructions are done, the proximal tibia is considered to be the site in which surgery is the most complicated, where rates of complications are highest, and whose functional outcome is poorest. The major reasons are the lack of muscle coverage along the anteromedial aspect of the tibia, the relatively small caliber of the blood vessels around the leg, and the need to include the insertion site of the extensor mechanism in the removed surgical specimen. In the past, these difficulties made it impossible to perform limb-sparing surgery, and above-knee amputations were the only surgical option for malignant tumors at this site.
- The limb-sparing technique illustrated in this chapter offers a safe approach to the dissection of popliteal vessels and to the resection and replacement of the proximal one third to two thirds of the tibia. Preoperative evaluation of tumor extent requires a detailed understanding of the anatomy and careful evaluation by CT, MRI, bone scintigraphy, and biplane angiography.
- Types of possible reconstructions include primary arthrodesis, prosthetic replacement, and allograft replacement. We prefer prosthetic replacements because of the high rates of nonunion and infections associated with allograft reconstruction and the poor function of an arthrodesed knee. The use of a gastrocnemius rotational flap is a key factor in achieving adequate soft tissue coverage of the prosthesis and in restoring function of the extensor mechanism.

ANATOMY

Knee Joint and Cruciate Ligaments

- The knee joint is seldom directly invaded by tumors of the proximal tibia. When it does occur, invasion is usually the result of a pathologic fracture, contamination due to improper biopsy technique, or tumor extension along the cruciate ligaments. The presence of hemarthrosis is suggestive of intra-articular disease.
- Involvement of the cruciate ligaments is often not determined until the time of surgery, although an MRI is a reliable means of determining cruciate ligament involvement preoperatively. An extra-articular resection (ie, en bloc resection of the proximal tibia, joint capsule, and femoral condyles) should be considered if nodules are identified on the cruciate ligaments.

Extensor Mechanism

- The attachment site of the extensor mechanism at the tibial tuberosity is resected en bloc with the proximal tibia. Reconstruction of this mechanism is essential for a functioning extremity.

Popliteal Trifurcation

- The popliteal artery divides into the anterior tibial artery, the posterior tibial artery, and the peroneal artery at the inferior border of the popliteus muscle. The popliteal trifurcation is actually composed of two bifurcations. The first is found where the anterior tibial artery arises from the popliteal artery, which then continues as the tibioperoneal trunk. The anterior tibial artery, the first branch, arises at the inferior border of the popliteus muscle.
- The second bifurcation is found where the peroneal artery and the posterior tibial artery arise from the tibioperoneal trunk; thus, this bifurcation is distal to the anterior tibial takeoff. It is almost always necessary to ligate the anterior tibial artery at the time of resection, while the other vessels must be identified before ligation.
- A unique and fortuitous anatomic feature is that the popliteus muscle covers the posterior surface of the tibia, which affords an excellent boundary between the posterior soft tissue extension from the tibia and the neurovascular bundle of the lower extremity. This is in contrast to what occurs at the distal femur, in which the posterior aspect is covered solely by the popliteal fat.

Tibiofibular Joint

- The proximal tibiofibular joint is located close to the posterolateral aspect of the proximal tibia. Histologic studies show that tumors involving the proximal tibia have a high incidence of extension and involvement of the periscapular tissues of the tibiofibular joint.
- To obtain a satisfactory surgical margin while performing a resection of the proximal tumor, it is necessary to remove this joint en bloc (ie, perform an extra-articular resection). This is a routine procedure for all high-grade sarcomas of the proximal tibia.

Subcutaneous Location of the Tibia

- The entire medial aspect of the tibia lies in a subcutaneous location and remains there after resection and reconstruction approaches had been carried out. This had been a major source of primary and secondary infections, which, in turn, frequently necessitated above-knee amputation.
- Today, the routine transfer of the medial gastrocnemius muscle anteriorly, to cover the prosthesis, is considered a reliable method of prosthetic coverage and one that also provides a method of extensor mechanism reconstruction. It is a simple and reliable means of decreasing the incidence of infection, flap necrosis, and secondary amputation.

INDICATIONS

- Primary bone sarcomas of the proximal tibia (FIG 1A,B)
- Benign-aggressive tumors associated with extensive bone destruction (FIG 1C-G)
- Metastatic tumors associated with extensive bone destruction
The major contraindications to limb-sparing surgery are neurovascular involvement and compromise as well as extensive soft tissue tumor involvement that precludes adequate prosthetic coverage.

IMAGING AND OTHER STAGING STUDIES (FIG 2)

CT and MRI
- CT and MRI are useful to determine the extent of cortical destruction and intramedullary and soft tissue extensions of the primary tumor. These data are essential for determining the level of tibial resection, which is 3 to 5 cm distal to the area of intramedullary tumor involvement.
- MRI can also reveal skip lesions, which may affect the extent of tibial resection.

Angiography
- Biplane angiography (FIG 3) is used for local arterial evaluation, especially if CT has revealed posterior soft tissue extension. The anteroposterior view is used to evaluate the popliteal bifurcation; of particular relevance is the integrity of the posterior tibial artery, which may be the sole blood supply to the leg after resection.
The lateral view is essential for evaluating the interval between the tibia and the neurovascular bundle. For example, the popliteus muscle often separates a posterior tumor mass from the vessels. This is reflected as a clear interval on the lateral angiogram and serves as an indication that there is an adequate resection margin.

- Ligation of the anterior tibial artery is almost always required.
- The peroneal artery may be involved by tumors that have a large posterior compartment. Two of the major vessels may be ligated in a young patient without jeopardizing the possibility of a viable and functional extremity.

**SURGICAL MANAGEMENT**

- There are three major steps involved in successful resection and reconstruction of tumors of the proximal tibia:
  - Resection of the tumor
  - Prosthetic reconstruction of the skeletal defect and knee joint
  - Reconstruction of the extensor mechanism and soft tissue coverage of the prosthesis with a gastrocnemius flap\(^1,3\)

---

**FIG 2** • AP (A) and lateral (B) plain radiographs, computed tomography (C), and magnetic resonance (MR) imaging (D) showing osteosarcoma of the proximal tibia. These studies show that the tumor is associated with minimal destruction of the cortices and that there is no soft tissue extension. The MR scan also accurately depicts the distal point of the intramedullary tumor extension. These findings will assist in determining the osteotomy level and the amount of surrounding soft tissue to be resected en bloc with the tumor. AP plain radiograph (E) and computed tomography (F) showing osteosarcoma of the proximal tibia with cortical destruction and soft tissue extension of stage IIB osteosarcoma.
**FIG 3** • An angiogram showing a lateral view of the popliteal artery. The space between the tumor in the proximal tibia and the popliteal bifurcation is best visualized by this study. The popliteal artery (P), tibioperoneal trunk (TP), and anterior tibia (AT) arteries are all identifiable. The soft tissue posterior to the tumor mass (curved arrow) must be free of cancer along the popliteal artery and tibioperoneal trunk. The popliteus muscle covers the bone in this interval and usually protects the vessels from tumor invasion. A tumor (T) blush (small arrows) is seen anteriorly. (Reprinted with permission from Clin Orthop Relat Res 1989;239:231–248.)

**INCISION**

- A single anteromedial incision is made, beginning proximally at the distal third of the femur and continuing to the distal third of the tibia. The approach includes excision of biopsy sites with a margin of at least 2 cm. Medial and lateral thick flaps of skin and subcutaneous tissue including the fascia are developed to decrease the likelihood of flap ischemia (TECH FIG 1).

**TECH FIG 1** • Illustration (A) and photograph (B) showing the anteromedial incision used for exposure of the proximal tibia and neurovascular bundle. It begins at the distal third of the femur and continues to the distal third of the tibia, and includes excision of the biopsy site, which remains attached to the underlying bone. C. Thick fasciocutaneous flaps are developed. (A: Reprinted with permission from Clin Orthop Relat Res 1989;239:231–248.)
EXPLORATION OF THE POPLITEAL FOSSA AND DETACHMENT OF THE VASCULAR BUNDLE

- The popliteal trifurcation must be explored early to determine whether the tumor is operable, especially if its soft tissue component extends posteriorly. The popliteal space and trifurcation are exposed by detaching the medial gastrocnemius muscle and by splitting the soleus muscle (TECH FIG 2A–C).

- The popliteal artery can be easily identified and it can be traced distally around the popliteus muscle. Care must be taken to identify and protect all major vascular branches.

- Applying posterior traction proximal to the popliteal artery permits visualization of the takeoff of the anterior tibial artery and its accompanying veins. The anterior tibial vessels are individually ligated, allowing the entire neurovascular bundle to fall away from the posterior aspect of the tibia or tumor (TECH FIG 2D).

- If the mass is a large one, the peroneal artery may need to be ligated as well, leaving the posterior tibial artery as the single blood supply to the leg. Further posterior mobilization of the popliteal vessels is achieved by ligation of the inferior geniculate vessels.

TECH FIG 2 • Illustration (A) and operative photograph (B) showing exploration of the popliteal artery trifurcation, which is required to determine the feasibility of resectability. The medial flap is continued posteriorly, and the medial hamstrings are released 2 to 3 cm proximal to their insertion to expose the popliteal fossa. The popliteal vessels are identified, and the trifurcation is initially explored through the medial approach. The medial gastrocnemius is partially mobilized, and the soleus muscle is split to expose the neurovascular structures. Care is taken to preserve the medial sural artery, which is the main pedicle to the medial gastrocnemius muscle. If the interval between the posterior aspect of the tibia and the tibioperoneal trunk (separated by the popliteus muscle) is free of tumor, resection can proceed. C. Dissection and exposure of the neurovascular bundle is often difficult because the tumor has distorted the normal anatomy. It requires splitting of the soleus muscle for most of its length. Care should be taken to identify and protect all major vascular branches before any ligation. The anterior tibial artery, which is the first takeoff of the popliteal artery, is located at the inferior border of the popliteus muscle. As it passes directly anterior through the interosseous membrane, it tethers the entire neurovascular bundle. D. Ligation of the anterior tibial vessels allows the entire neurovascular bundle to fall away from the posterior aspect of the tibia. (A,C,D: Reprinted with permission from Clin Orthop Relat Res 1989;239:231–248.)
The capsule is transected circumferentially about 1 cm away from the tibia and the patellar tendon to avoid contamination (TECH FIG 3A,B). The cruciate ligaments are carefully examined: if there is any evidence of tumor invasion into the joint space, the femoral condyles are later resected en bloc with the proximal tibia.

The patellar tendon is sectioned 1 to 2 cm proximal to the tibial tubercle, and the entire capsule of the knee is detached circumferentially by electrocautery 1 to 2 cm from the tibial insertion.

The posterior capsule is carefully dissected under direct vision after the popliteal vessels have been mobilized by ligation of the inferior geniculate vessels. The cruciate ligaments are then sectioned close to the femoral attachments. To release the specimen, the tibia is osteomized 3 to 5 cm distal to the lesion, as determined by CT and MR imaging (TECH FIG 3C–E). The intermuscular septum is released under direct vision. An intra-articular resection of the knee joint is then completed.

**EXPOSURE OF THE KNEE JOINT AND REMOVAL OF THE PROXIMAL TIBIA**
Design features of currently used proximal tibia endoprostheses include modular components with an anterior metal loop for the attachment of the patellar tendon, porous coating for soft tissue incorporation, side holes for securing adjacent muscles, and a rotating-hinge knee mechanism (TECH FIG 4).

Uncemented prostheses are preferentially used for reconstruction after resection of a primary bone sarcoma in an adolescent or a young adult, whereas cemented prostheses are used for reconstruction after resection of metastatic tumors.

TECH FIG 4 • Current design features of proximal tibia endoprostheses include modular components with an anterior metal loop for the attachment of the patellar tendon, porous coating for soft tissue incorporation, side holes for securing adjacent muscles, and a rotating-hinge knee mechanism (Howmedica, Mahwah, NJ).
RECONSTRUCTION OF THE EXTENSOR MECHANISM AND MEDIAL GASTROCNEMIUS FLAP

- The remaining patellar tendon stump is advanced distally and secured tightly to the prosthesis with a 3-mm Dacron tape (Deknatel, Falls River, MA), which provides immediate mechanical fixation.
- An autologous bone graft, taken from the cut femoral condyles, is wedged and packed tightly between the porous-coated segment of the prosthesis and the tendon, facing both surfaces (TECH FIG 5). This will create a new bone–tendon junction.
- The soleus muscle is pulled anteriorly to cover the middle segment of the prosthesis and the medial gastrocnemius is used to cover its proximal segment (TECH FIG 6). The medial gastrocnemius muscle is detached at its muscle–tendon junction and interface with the lateral gastrocnemius, mobilized, and rotated anteriorly to cover the prosthesis. At its upper pole, the muscle flap is sutured to the patellar tendon to reinforce the prosthesis and bone graft reconstruction.
- Suction drains are positioned along the muscle envelope, and the fasciocutaneous flaps are pulled and closed, usually leaving a gap over the medial gastrocnemius flap, which necessitates coverage with a split-thickness skin graft taken from the ipsilateral thigh (TECH FIG 7).

TECH FIG 5 * A. Illustration showing reconstruction of the extensor mechanism, which has three components: attachment of the patellar tendon to the prosthesis, reinforcement of the attachment site with bone graft, and overlying medial gastrocnemius flap. B. Intraoperative photograph showing the patellar tendon sutured to the prosthesis and underlying bone graft. C–F. Alternatively, a circumferential polyethylene terephthalate (Trevira) tube may be applied on the prosthesis to which the patellar tendon and surrounding muscles can be sutured.² (A: Courtesy of Martin M. Malawer.)
TECH FIG 6 • Soft tissue coverage around the prosthesis. (A: Reprinted with permission from Clin Orthop Relat Res 1989;239:231–248; B,C: Courtesy of Martin M. Malawer.) (continued)
**TECH FIG 6 • (continued)**

D. The soleus muscle is pulled anteriorly to cover the middle segment of the prosthesis, and the medial gastrocnemius is transposed to cover its proximal segment. The medial sural artery to the medial gastrocnemius muscle is carefully preserved. E. The medial gastrocnemius muscle is detached at its muscle–tendon junction and interfaced with the lateral gastrocnemius, mobilized, and rotated anteriorly to cover the prosthesis. F. It is sutured to the border of the anterior muscles and the patellar tendon, forming a complete soft tissue envelope around the prosthesis.

**TECH FIG 7 • A–D.** Suction drains are positioned along the muscle envelope, and the fasciocutaneous flaps are pulled and closed, usually leaving a gap over the medial gastrocnemius flap that necessitates coverage with a split-thickness skin graft taken from the ipsilateral thigh. E,F. AP and lateral plain radiographs showing a proximal tibia endoprosthetic reconstruction. (A: Reprinted with permission from Clin Orthop Relat Res 1989;239:231–248.)
POSTOPERATIVE CARE

- The extremity is kept elevated and in full extension to avoid tension on the reconstructed patellar tendon for 5 days. Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed.
- If there is no evidence of significant swelling by the end of the fifth day, the patient is allowed to walk with weight bearing as tolerated for 10 to 15 minutes at a time. If the extremity remains free of swelling, a gradual increment in exercise is allowed. The knee is kept fully extended in a knee immobilizer for 6 weeks, by the end of which gradual passive and active flexion of the knee joint are allowed.

OUTCOMES

- Proximal tibia resections are associated with considerably higher rates of flap ischemia, deep infection, and prosthetic loosening than limb-sparing resections at other sites, such as the proximal humerus and the proximal and distal aspects of the femur.
- The lower survival figures for prosthetic replacements at the proximal tibia (about 80% at 10 years compared to 95% for the others) are most likely attributable to the complexity of the surgical procedure and the soft tissue reconstruction, breakage of the polyethylene component, and mechanical failure. Impairment of the extensor mechanism is still the most prominent functional compromise after this resection.

- The incidence of infection has been dramatically decreased by the use of a gastrocnemius muscle flap. Strict adherence to postoperative management guidelines has also decreased the incidence of limb edema, wound problems, and magnitude of extensor mechanism dysfunction.

COMPLICATIONS

- Limb edema
- Flap ischemia to full-thickness necrosis
- Deep periprosthetic infection
- Dysfunctional extensor mechanism and extension lag
- Prosthetic loosening

REFERENCES

BACKGROUND

- The fibula is a rare anatomic location for both primary and metastatic bone tumors. When tumor does occur, it most commonly involves the proximal fibula, followed by the fibular diaphysis and the distal fibula.
- Primary bone sarcomas of the fibula have traditionally been treated with above-knee amputations. Increased use of limb-sparing procedures stimulated an interest in the surgical anatomy in this area and the possibility that tumors of the fibula might be safely resected.

ANATOMY

Proximal Fibula

- The proximal fibula is the attachment site for the lateral collateral ligament (LCL) and biceps femoris tendon and therefore has a role in determining lateral knee joint stability.
- The peroneal nerve turns around the base of the fibular head to enter the peroneus longus tunnel (FIG 1).

Fibular Diaphysis

- The fibular diaphysis is circumferentially surrounded by muscle origins at all aspects and anatomic levels.

Distal Fibula

- The distal fibular is a subcutaneous structure with minimal soft tissue coverage.
- It is the attachment site for the tibiofibular and calcaneofibular ligaments and therefore has a role in determining lateral ankle joint stability.

INDICATIONS

- Benign-aggressive tumors
- Primary sarcomas of bone
- Metastatic lesions of the fibula are usually treated with radiation therapy and rarely require surgery. This is because the fibula is not a major weight-bearing structure and bone destruction at that site does not compromise the mechanical stability of the lower extremity.
- Above-knee amputation is considered when a malignant tumor grossly invades the tibia or there is extensive multi-compartmental involvement, especially the posterior deep compartment.

IMAGING AND OTHER STAGING STUDIES

- In staging fibular tumors, emphasis is placed on the extent of bone destruction, intramedullary involvement, and soft tissue extension. Special attention is also given to the relation of the tumor to the peroneal nerve, blood vessels, and tibia.
- Plain radiographs and computed tomography are required to assess the extent of bone involvement and cortical destruction. These data are completed by magnetic resonance imaging (MRI), which shows the extent of medullary and extraosseous extension (FIG 2).

FIG 1 • A. The lateral collateral ligament and biceps femoris tendon attach to the fibular head and the peroneal nerve turns around the base of the fibula to enter the peroneus longus tunnel. B. Intraoperative photograph showing the peroneal nerve (N) as it enters the peroneus longus tunnel (open arrow). This tunnel has been opened to show the course of the nerve around the base of the fibular head. The biceps tendon (Bi) inserts on the fibular head away from the peroneal nerve. Vessel loops on the peroneal nerve are used to provide gentle traction for the dissection of the nerve branches.
SURGICAL MANAGEMENT

Positioning

- A semisupine position (45-degree elevation of the operated side) is used to permit easy access to the anterior and lateral compartments and allow dissection of the popliteal space. The entire extremity, from the inguinal ligament to the foot, is included in the sterile field to allow evaluation of the distal foot pulses and execution of an above-knee amputation, if indicated.
- The utilitarian fibular incision, which allows exposure and resection of tumors at all levels of the fibula, extends from the biceps above the knee joint, over the midportion of the fibula, anteriorly to the crest of the tibia, and then curves posteriorly and distally to the ankle. This permits the development of large anterior and posterior fasciocutaneous flaps.
- The anterior compartment, the lateral compartment (peroneal musculature), and the superficial posterior compartment consisting of the lateral gastrocnemius and soleus muscle are exposed, and the popliteal space and trifurcation can be explored through this incision. The biopsy site is removed en bloc with the tumor mass (FIG 3).

FIG 2 • A. Computed axial tomography of the proximal fibula shows an intermediate-grade fibrosarcoma with cortical breakthrough and extraosseous extension. B,C. Coronal and axial magnetic resonance images of the proximal fibula, respectively, showing a high-grade osteosarcoma with cortical breakthrough and extension to the anterior and lateral compartments of the leg. (Courtesy of Martin M. Malawer.)

FIG 3 • A. The utilitarian fibular incision extends from the biceps above the knee joint, over the midportion of the fibula, and anteriorly to the crest of the tibia, and then curves posteriorly and distally to the ankle. A component of the incision is used according to the level of resection: the proximal third is used for resection of the proximal fibula (B) and the proximal two thirds are used for intercalary resection (C). (A: Reprinted with permission from Clin Orthop Relat Res 1984;186:172–181.)
Three types of tumor resections are practiced around the proximal fibula: curettage and type I and II resections of the proximal fibula. Tumor curettage is done in benign-aggressive tumors and low-grade sarcomas associated with minimal cortical destruction and extraosseous extension (TECH FIG 1A). The types of proximal fibular resections have been previously described by Malawer. Type I resection includes the proximal fibula, a thin muscle cuff in all dimensions, and the LCL attachment site. The peroneal nerve and its motor branches are preserved and the tibiofibular joint is excised intra-articularly (TECH FIG 1B–D,H). This resection type is used for the management of benign-aggressive tumors and low-grade sarcomas that have caused considerable cortical destruction of the proximal fibula.

Type II resection includes an en bloc removal of the proximal fibula and the tibiofibular joint, the anterior and lateral muscle compartments, the peroneal nerve, and the anterior tibial artery (TECH FIG 1E–H). It is used for the management of high-grade sarcomas, which usually have considerable cortical destruction with extraosseous extension.

All type II resections necessitate anterior tibial artery ligation: in contrast, type I resections usually allow...
TECHNIQUES

Chapter 27  FIBULAR RESECTIONS 1967

TECH FIG 1 • (continued) G. This type of high-grade sarcoma of bone is managed with a type II resection, which includes an en bloc removal of the proximal fibula and the tibiofibular joint, the anterior and lateral muscle compartments, the peroneal nerve, and the anterior tibial artery. H. Cross-sectional anatomy of the proximal leg showing type I and type II resections. (H: Courtesy of Martin M. Malawer.)

preservation of that artery. A type II resection may also require sacrifice of the peroneal artery. Table 1 summarizes the anatomic structures removed en bloc with the various resection types of the proximal fibula.

Exposure

Curettage

- The common peroneal nerve is identified around the inferior border of the biceps femoris. If the nerve is to be preserved, as in tumor curettage or type I resection, its course under the peroneus longus is identified, the peroneus longus tunnel is unroofed, and the nerve is mobilized posteriorly away from the proximal fibula and marked with a vessel loop (TECH FIG 2).
- A longitudinal cortical window with oval edges is made above the lesion.

Type I and II Resections

- Large tumors of the proximal fibula may reach the midline posteriorly and push and distort the popliteal vessels. The major vessels are exposed by reflecting the lateral gastrocnemius muscle through its length and, if necessary, releasing the proximal tendinous origin from the lateral femoral condyle. This exposes the underlying soleus muscle, which is similarly detached through its substance near its fibular origin.
- The neurovascular bundle can be easily identified at the level of the popliteus muscle: the anterior tibial artery is positioned 2 to 3 cm distal to its inferior border. The peroneal artery lies close to the posterior aspect of the tibia and along the flexor hallucis longus muscle.
- The posterior tibial nerve is closest to the surface and the popliteal veins course between the nerve and the posterior tibial artery, which can be identified in the midline. The interval between the posterior fibular head and the posterior tibial and popliteal arteries must be explored

<table>
<thead>
<tr>
<th>Type of Surgery</th>
<th>Lateral Collateral Ligament Attachment Site</th>
<th>Anterior Tibial Artery</th>
<th>Peroneal Nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curettage</td>
<td>Intact</td>
<td>Intact</td>
<td>Intact</td>
</tr>
<tr>
<td>Type I resection</td>
<td>Removed</td>
<td>Intact</td>
<td>Intact</td>
</tr>
<tr>
<td>Type II resection</td>
<td>Removed</td>
<td>Removed</td>
<td>Removed</td>
</tr>
</tbody>
</table>

Table 1: Anatomic Structures Removed with the Various Resection Types of the Proximal Fibula

TECH FIG 2 • The common peroneal nerve is identified around the inferior border of the biceps femoris. The peroneus longus tunnel is unroofed to expose the nerve coursing around the fibular diaphysis.
and evaluated early to determine whether a high-grade sarcoma is resectable or a vascular graft will be required.

- The anterior tibial artery passes directly anteriorly through the interosseous septum, tying down the vascular complex and preventing mobilization. Applying traction on the popliteal artery, a simple maneuver, permits visualization of the anterior tibial artery origin. The anterior tibial artery and the two accompanying veins may then be ligated and transected, allowing the popliteal and posterior tibial arteries to fall away from the posterior surface of the mass. Completion of the vascular dissection proceeds distally.

**Tumor Removal**

**Curettage**

- Gross tumor is removed with hand curettes (TECH FIG 3A,B). Curettage should be meticulous and should leave only microscopic disease in the tumor cavity. Curettage is followed by high-speed burr drilling of the walls of the tumor cavity (TECH FIG 3C,D).

**Type I Resection**

- The LCL and biceps tendon are released at their fibular insertion. Muscle origin is transected by electrocauterization from the proximal shaft of the fibula. The anterior tibiofibular capsule can then be identified: its posterior aspect lies under the popliteus muscle.
- The capsule is incised and the joint opened, after which an intra-articular resection of the proximal fibula is carried out by performing an osteotomy 1 cm below the lower edge of the lesion (TECH FIG 3E).

**Type II Resection**

- The anterior and lateral musculature and the overlying deep fascia are excised. The origin of the anterior muscles from the shaft of the tibia is transected by electrocauterization. The distal level of the transaction is at the musculotendinous junction. The lateral collateral ligament, biceps tendon, and peroneal nerve are released 2.5 cm proximal to their fibular insertion. The anterior tibiofibular capsule can then be identified.
- A semicircular cut is made directly through the popliteus muscle toward the posterior aspect of the lateral tibial condyle. A fibular osteotomy is done 2 to 3 cm below the lower edge of the tumor (TECH FIG 3F). It is important to inspect the condyle after osteotomy and removal of the specimen. If the knee joint capsule had been exposed and opened, it should be repaired to prevent a synovial fistula.

**TECH FIG 3** • A. Macrosopic tumor is removed with hand curettes. B. Curettage of low-grade chondrosarcoma of the proximal fibula. C,D. Curettage is followed with high-speed burr drilling of the walls of the tumor cavity. (continued)
Chapter 27  FIBULAR RESECTIONS

Chapter 27  FIBULAR RESECTIONS

TECH FIG 3 • (continued) E. Type I resection of the proximal fibula. The tibiofibular joint is opened, the peroneal longus tunnel is unroofed to expose the peroneal nerve, muscle origins are transected from the proximal shaft of the fibula, and an osteotomy is performed 1 cm below the lower edge of the lesion. F. Type II fibular resection. The resection of the proximal fibula begins with exploration of the popliteal trifurcation posteriorly. The anterior tibial artery and often the peroneal vessels are ligated if there is a large posterior component to the tumor. A resection then proceeds, with release of all of the muscles attaching to the fibula posteriorly and preservation of the tibial nerve. The peroneal nerve is ligated before it enters the peroneus longus muscles. All of the tibialis muscles are released from the tibial border and are retained on the specimen side. The final step is an extra-articular disarticulation of the tibiofibular joint with a curved osteotome or a high-speed burr drill, removing a portion of the lateral tibial plateau with the joint en bloc. Care must be taken to avoid entering the knee joint. (F: Reprinted with permission from Clin Orthop Relat Res 1984;186:172–181.)

Reconstruction and Wound Closure

Curettage

- The tumor cavity is filled with bone graft or a bone substitute for benign-aggressive lesions in a young patient. Cement is used for reconstruction in adults, especially in low-grade sarcomas or metastatic lesions.

Type I and II Resections

- The LCL stump is attached to the lateral tibial metaphysis using a staple with the knee in 20 degrees of flexion after an osteoperiosteal flap has been formed (TECH FIG 4A–D). Fixation is reinforced with nonabsorbable sutures to the overlying iliotibial band and fascia.

- When the surgical field extends to the lower leg, the authors pull up the peronei and extensor digitorum longus tendons, thereby advancing the foot to a neutral position (to reduce the magnitude of foot drop and possibly avoid the need for an ankle-foot orthosis), and then tenodese the tendons to the tibial shaft using a 3-mm Dacron tape (TECH FIG 4E,F).

- The surgical defect is closed by rotating the lateral gastrocnemius muscle anteriorly to the deep fascia, covering the exposed tibia. The gastrocnemius muscle is sutured to the deep fascia and to the soleus muscle distally, as well as along the lateral capsule of the knee joint. The biceps tendon is then tenodesed to the gastrocnemius muscle (TECH FIG 4G).

TECH FIG 4 • A–D. The stump of the lateral collateral ligament is attached to the lateral tibial metaphysis using a staple with the knee in 20 degrees of flexion after an osteoperiosteal flap has been raised. (continued)
Tumors of the fibular diaphysis, whether benign or malignant, are usually treated with intercalary resection of the affected diaphyseal segment. Tumor curettage is neither feasible nor effective due to the small diameter of the diaphysis. Furthermore, loss of an intercalary segment usually does not affect the stability of knee and ankle joints or the overall function of the lower extremity. Benign tumors require resection of bone only, while high-grade sarcomas require en bloc removal of the surrounding cuff of muscles.

**Exposure**
- Intercalary fibular resections are performed using the middle portion of the utilitarian incision with proximal...
or distal extension, according to anatomic extent of the affected segment.

- To expose the fibular diaphysis, the fascia is opened in line with the utilitarian incision. The plane between the peronei and the soleus is defined by the septum separating the two compartments. The soleus is detached from its fibular origin and, along with the lateral gastrocnemius muscle, is retracted medially and proximally to reveal the posterior crest of the fibula (TECH FIG 5).

- The flexor hallucis longus can be spared or resected, depending on the grade and local extent of the underlying tumor. The peronei are mobilized anteriorly, and retractors are positioned underneath the fibula.

**Tumor Removal**

- Resection is performed at the level that had been determined before surgery. Care must be taken not to damage the peroneal vessels, which are posterior and parallel to the fibula.

---

**TECH FIG 5**  
**A.** Plain radiograph showing fibrous dysplasia of the fibular diaphysis.  
**B.** Operative photograph showing exposure of a benign-aggressive tumor. The soleus (So) is detached from its fibular origin and, along with the lateral gastrocnemius muscle (G), is retracted medially and proximally to reveal the posterior crest of the fibula (arrow). The flexor hallucis longus can be spared or resected, depending on the grade and local extent of the tumor. The peronei muscles (Pe) are mobilized anteriorly, retractors are positioned underneath the fibula, and the resection is performed at the level determined before surgery.  
**C.** Postoperative radiograph.  
**D.** Plain radiographs showing Ewing sarcoma of the fibular diaphysis. (B: Courtesy of Martin M. Malawer.) (continued)
TECH FIG 5 • (continued) E. The tumor is exposed using the upper two thirds of the utilitarian fibular incision. F. Because of the extraosseous tumor extension, the soleus is split to expose and mobilize the neurovascular bundle; the muscle remains attached to the fibula.

Reconstruction and Wound Closure

- Intercalary resections usually do not require osseous reconstruction. Low intercalary resections that leave only a short segment may require reinforcement of the lateral malleolus to preserve lateral ankle stability (TECH FIG 6).
- Distal resections of the fibula, which are rarely done, require reconstruction because of the loss of a component of the ankle joint. Reconstruction with a microvascularized fibula is recommended.
- Alternatively, the ipsilateral fibula can be used for reconstruction. A type I resection of the proximal fibula is performed, and the fibular head and neck are attached to the tibial plafond with a screw and to the fibular shaft with a plate (TECH FIG 6C).

TECH FIG 6 • A,B. Plain radiographs showing reinforcement of the lateral malleolus by means of a screw after low intercalary resection of the fibula. C. A distal fibular defect can be reconstructed with a microvascularized fibula from the contralateral leg or transposition of the ipsilateral proximal fibula.
PEARLS AND PITFALLS

**Proximal fibula resection**

- **Intraoperative**
  - Semisupine position with flexed knee using the utilitarian fibular incision
  - Mobilization and protection of the peroneal nerve
  - Exploration of the popliteal vessels, when required
  - Selection of surgery (curettage/type I or II resection) according to tumor type and anatomic extent
  - Reconstruction of the LCL attachment site after resection of the proximal fibula

- **Postoperative**
  - Specific rehabilitation according to the tumor type, including ankle–foot orthosis for patients who underwent type II resection

- **Fibular diaphysis resection**
  - A utilitarian incision of adequate length for wide exposure of the resected fibular segment
  - En bloc resection of the surrounding cuff of muscles in high-grade sarcomas
  - Mandatory reinforcement of the lateral malleolus in low intercalary resections

**POSTOPERATIVE CARE AND REHABILITATION**

**Proximal Fibula Resection**

- Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed.

**Curettage**

- Early ambulation is encouraged with partial weight-bearing for 3 weeks as well as passive and active range of motion of the knee joint. Unrestricted weight bearing is allowed upon wound healing.

**Type I and II Resections**

- Postoperatively, the extremity is immobilized in a cast for 3 weeks in 20 degrees of knee flexion to allow soft tissue healing. After cast removal, full weight bearing is allowed as well as full active range of motion around the knee.
- An ankle–foot orthosis is required for patients who underwent type II resection and had foot drop because of peroneal nerve dysfunction.
- Patients who have high-grade sarcoma are treated with postoperative chemotherapy.
- Patients with Ewing sarcoma are further treated with radiation therapy consisting of external beam radiation of 6,000 to 7,000 Gy.

**Fibular Diaphysis Resection**

- Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed.
- This is followed by early ambulation with partial weight bearing for 3 weeks, together with passive and active range of motion of the knee joint. Unrestricted weight bearing is allowed after wound healing.

**OUTCOMES**

- Resections of the fibula, even those that require en bloc resection of the muscle cuff, are usually associated with minimal impact on lower extremity function.

- The weight-bearing capacity of the leg is not impaired and its major muscle groups usually remain intact. The only exception is the occurrence of foot drop and the need to use an ankle–foot orthosis after intentional resection of the peroneal nerve in a type II proximal fibular resection.
- Knee stability is similarly preserved when care is taken to adequately reconstruct the LCL attachment site and allow its healing and gradual loading.

**COMPLICATIONS**

- Peroneal nerve injury in curettage or type I resection of the proximal fibula
- Lateral knee instability due to inadequate LCL reconstruction or inadequate postoperative rehabilitation
- Lateral ankle instability because of inadequate fixation of the lateral malleolus in low intercalary resections of the fibular diaphysis
- Chronic swelling of the leg after extensive type II resection, requiring lymphatic drainage
- Deep infections

**REFERENCES**

BACKGROUND

- Wide resection of long-bone tumors can create a large intercalary bone defect requiring reconstruction. Such defects were traditionally reconstructed with prosthetic implants, allografts, and allograft–prosthetic composites, all of which were associated with considerably high rates of complications and failure.
- Distraction osteogenesis provides biologic reconstruction of only small to medium intercalary defects. Moreover, it is a prolonged procedure, requiring up to 2 months for an elongation of 1 cm, complications are frequent, patient compliance is critical, and large soft tissue defects cannot be addressed simultaneously.
- Reported experience regarding safety and efficacy in the oncologic setting is also limited.

Since the introduction of vascularized autogenous graft for long-bone reconstruction after tumor resection in the early 1970s, the use of a free fibular flap has become a viable option for reconstructing large intercalary bone defects after tumor resection or for resection-arthrodesis. Its inherent advantage is based on its ability to exploit the biology of normal fracture healing rather than the creeping substitution that is fundamental to the incorporation of a nonvascularized graft.

- The fibula is an optimal vascularized graft source because of its anatomic accessibility and because removing an intercalary segment while preserving the proximal fibula and lateral malleolus would have minimal impact on knee and ankle stability and would not compromise the weight-bearing capacity and overall function of the lower extremity. It allows reconstruction of large bone defects because of its independent blood supply, which permits graft incorporation into the host bone even when the presence or viability of the surrounding soft tissue is considerably compromised because of previous surgery or radiation therapy.
- The fibular head can also be used for joint reconstruction after intracalary resection of bone tumors. Furthermore, a vascularized fibular graft has the ability to hypertrophy over time in response to continuous pressure load. As a result, vascularized fibula have shown excellent long-term durability.
- In summary, a free fibular graft provides a durable true biologic reconstruction with accommodative and regeneration capabilities and has minimal short- and long-term complications. It requires a combined effort of highly trained and committed teams as well as the patient’s compliance throughout a very long, complex, and demanding rehabilitation period.

ANATOMY

- The fibula is long and narrow and therefore provides a strong cortical strut for reconstruction of long-bone defects. It has a square cross-section in its superior part and is triangular in its inferior end. In the adult, it can reach a width of 1.5 to 2 cm and a length of 35 cm, 25 to 30 cm of which can be harvested for free grafting. Its shape and length can match bone segments of the upper extremity (humerus, radius, and ulna) or can fit the medullary canal of bones of the lower extremity (femur, tibia); it therefore can be used to reconstruct bone defects at these sites.
- The fibula is circumferentially surrounded by muscle groups on its lateral, anteromedial, and posterior aspects and is also the origin of the four intermuscular septa of the leg. The blood supply and drainage of the fibular shaft are related to the peroneal vessels. The peroneal artery, together with the two peroneal venae comitante, follow a course parallel to the fibula and lie between the flexor hallucis longus and tibialis posterior muscles. The fibula is dually vascularized through its endosteal and periosteal vessels.
- The endosteal blood supply is based on the nutrient artery, which stems 6 to 14 cm from the peroneal artery bifurcation, enters the middle third of the diaphysis via the nutrient foramen, and then divides into an ascending and a descending branch. The periosteal blood supply is derived from eight to nine periosteal branches, mostly in the middle third of the diaphysis. The peroneal artery is also the source of four to six fascial vessels that pass through the posterior intercrural septum to the skin territory, lateral to the fibula. It provides numerous muscular branches as well: specifically, it supplies multiple small branches to the muscles of the anterior compartment and a few larger branches to the soleus muscle at the deep posterior compartment of the leg.
- The unique morphologic characteristics and blood supply of the fibula allow considerable versatility in the use of the fibular flap for reconstruction of skeletal, soft tissue, and growth plate defects. The fibular flap can be transferred in various configurations and compositions to suit the needs of individual cases:
  - In its straight configuration, it can be used to reconstruct a relatively narrow bone segment. A longitudinal osteotomy that increases the surface area of the flap can serve as an onlay graft to augment the healing process for partial cortical defects. Based on perforating fasciocutaneous branches at the middle and distal thirds of the pedicle, a skin paddle of up to 20 × 10 cm can be transferred simultaneously to facilitate coverage of concomitant large soft tissue defects and to allow the patency of the pedicle anastomosis to be monitored. Part of the soleus or the flexor hallucis longus muscles can also be included with the flap to reconstruct soft tissue defects and cover exposed bone.
H

A. The blood supply and drainage of the fibula are related to the peroneal artery and two peroneal veins, which follow a course parallel to the fibula. The fibula has a dual blood supply: endosteal and periosteal. The former is based on a nutrient artery that stems 6 to 14 cm from the peroneal bifurcation; the latter is based on multiple periosteal branches along the fibular diaphysis. B. Diaphyseal fibular graft used to reconstruct intercalary bone defects. If a long segment is required and the osteotomy is close to the lateral malleolus, screw fixation to the tibia is advised to prevent valgus deformity and ankle instability. C-G. A skin paddle can be transferred simultaneously to facilitate coverage of concomitant large soft tissue defects and to allow patency of the pedicle anastomosis to be monitored. H. A proximal fibular graft that includes the proximal fibular epiphysis and is based on the anterior tibial vascular pedicle may be used for joint reconstruction and preservation of longitudinal growth in children after intra-articular resection of bone tumors.
Transverse osteotomies can be made through the mid-diaphysis to produce two or more cortical struts on a single pedicle (double or triple barrel) to reconstruct a wide bone segment. When the periosteal vessels are transected, the bone survives on its endosteal system.

The proximal epiphysis may be included in the flap for joint reconstruction and preservation of longitudinal growth potential (in pediatric patients) after intra-articular resection of bone tumors (FIG 1H). This flap is based on the anterior tibial vascular flap or the descending geniculate artery and is most commonly used for reconstructions after resections of the proximal humerus and distal radius.

**INDICATIONS**

- Segmental bone defects larger than 5 cm after resection due to tumor, radiation-induced bone necrosis, or osteomyelitis
- In high-grade sarcomas of bone, we generally use spacers for immediate reconstruction after tumor resection rather than performing the definitive reconstruction with vascularized fibula. The latter is carried out 2 years after tumor resection if there has been no tumor recurrence or lung metastases.

**CONTRAINDICATIONS**

**Systemic and General Conditions**

- Cardiovascular, surgical, or hematologic diseases that may affect peripheral blood flow
- Poor compliance, or if the patient’s physical or psychological state would not allow a prolonged non-weight-bearing period and rehabilitation
- Poor general health

**Donor Site Considerations**

- Fibular deformity after previous injury to the lower extremity
- Vascular injury or compromise after previous trauma to the leg
- Vascular anomalies of the leg or plantar arches (eg, single-vessel foot)

**Recipient Site Considerations**

- Infection around the recipient site
- Suspected tumor recurrence

**IMAGING AND OTHER STAGING STUDIES**

Detailed preoperative evaluation of both the recipient and donor sites is mandatory. Imaging of the recipient site should provide information about the dimensions of bone (length and diameter) and soft tissue defects remaining after tumor resection, thus allowing the selection of the appropriate type and size of fibular flap to be used. Imaging of the donor site should include the entire leg and is aimed at excluding fibular deformity and determining maximal flap length. The surgeon should verify adequate pulses in both posterior tibial and dorsalis pedis arteries.

- The deep and superficial plantar vascular arches are evaluated using an equivalent to the palmar Allen’s test, confirmed by Doppler ultrasound examination. If those studies are inconclusive, angiography or magnetic resonance angiography is performed.

**Recipient Site**

- Plain radiography
- Computed tomography (CT)
- Magnetic resonance imaging (MRI)

**Donor Site**

- Plain radiography
- Magnetic resonance angiography
- Angiography
- Doppler ultrasound

**SURGICAL MANAGEMENT**

**Positioning**

- For treating a bone defect of the lower extremity, the patient is placed supine on the operating table with the thighs spread. The hip and knee of the donor extremity are flexed (FIG 2). The first team, which is responsible for tumor resection (blue team), is positioned along the medial or lateral side of the recipient extremity. If tumor resection is done from the medial side of the extremity, a surgeon can be positioned at that aspect. A second (red) team, responsible for the harvest of the fibular flap from the donor extremity, is positioned along its lateral aspect (Fig 2).
To minimize the duration of surgery, if the patient’s position on the operating table permits, the fibular flap is harvested as the recipient site is being prepared, a procedure that may include resection of the primary bone tumor or removal of a spacer that had been used in a previous surgery for reconstructive purposes.

INTERCALARY RESECTIONS

- As a rule, a vascularized fibula in its straight and simple configuration is sufficient for reconstructing bone defects of the upper extremity because of the relatively narrow cross-sectional diameter of the latter. Reconstruction of such defects of the lower extremity requires graft material of a larger diameter because of the additional mechanical support needed. A double-barrel fibular flap can be used to reconstruct femoral and tibial defects of up to 13 cm.
- Longer defects may require the support of an allograft, which provides the initial stability required for bone healing, graft incorporation, and subsequent fibular hypertrophy. Furthermore, in cases of failed vascular anastomosis, the combined fibular–allograft construct is still comparable to multiple cortical allogenic struts with a relatively good chance of success, especially if reliable fixation is achieved.
- The technique of combined reconstruction with an allograft and the vascularized fibula, as described by Capanna and colleagues, provides such stability and is the preferred method of reconstruction that we use for long intercalary defects of the lower extremities.1,2

RESECTION OF BONE TUMOR

- The bone tumor is removed according to the standard techniques, and the length and diameter of the intercalary bone defect are measured (TECH FIG 1).

TECH FIG 1 • A. Diaphyseal tumor is resected with wide margins, leaving a long intercalary bone defect. B. Plain radiograph of the tibia showing a large diaphyseal low-grade osteosarcoma. C. Intraoperative photograph of the tumor. D. Large intercalary defect remaining after wide tumor resection. E. Plain radiograph of the arm showing considerable bone loss and pathologic fracture associated with acute osteomyelitis of the humeral diaphysis. F. After tissue sampling and cultures, administration of intravenous antibiotics, and resolution of acute manifestations of infection, the patient underwent resection of the infected bone tissue, leaving a long intercalary bone defect.
HARVEST OF A FIBULAR FLAP

- Using an anterolateral incision at the contralateral leg, an intercalary fibular segment that is 6 cm longer than the bone defect is harvested, together with its nutrient vessels and its periosteal cuff (TECH FIG 2A,B). If a large skin defect is anticipated at the tumor resection site, the fibular flap is harvested with an overlying skin island supplied by the same peroneal artery, which allows tension-free skin closure as well as early detection of compromised viability of the flap: arterial or venous compromise would instantly be expressed by ischemic or congestive changes of the skin island (TECH FIG 2C).

- If a long bony segment is required and the osteotomy is close to the lateral malleolus, screw fixation to the tibia is advised to prevent valgus deformity and ankle instability (see Fig 1B). A skin graft, usually taken from the thigh of the donor extremity, is used to cover the skin defect in that leg. The peroneal tendons should be well covered by muscle bulk to enable a safe skin graft take.

PREPARATION OF THE ALLOGRAFT

- The allograft is cut to the same length as the bone defect and a groove is opened longitudinally by removing as much cortical and cancellous bone as needed to allow insertion of the fibular flap into it.

RECONSTRUCTION OF THE RECIPIENT SITE

- The allograft is inserted to fill the bone defect and is fixed to its proximal and distal edges with a side plate and screws (TECH FIG 3A,B). An intramedullary nail is also used if the allograft medullary canal is wide enough to contain both the nail and the fibular graft. Using a high-speed burr, a defect is created in the allograft cortex at the appropriate level to allow the passage of the fibular vascular pedicle toward the vascular bundle of the recipient extremity while avoiding traction on the vascular Anastomosis (Tech Fig 3A,B).

- The fibular graft is inserted 2 to 3 cm into the medullary canal at both ends and fixed with screws (TECH FIG 3C–E). Care is taken to prevent damage to the nutrient vessels of the fibula by those screws. The fibula can be placed in an intramedullary location, inside the allograft or parallel to it. In both options, the fibular osteotomy sites should lie close to the native long-bone resected edges.

- After vascular anastomoses are completed, autologous bone graft, taken from the fibular flap remnants or the ipsilateral iliac crest, is used to reinforce the interface between the fibula and the recipient bone.
Chapter 28  FREE VASCULARIZED FIBULAR GRAFTS FOR RECONSTRUCTION OF SEGMENTAL BONE DEFECTS 1979

**INTRA-ARTICULAR RESECTIONS**

- The proximal fibular epiphysis, with variable lengths of the diaphysis and with the anterior tibial vessels as the vascular pedicle, or alternatively the inferior geniculate artery, is used to reconstruct defects that include one side of the articular surface. After removal of the fibular flap the lateral collateral ligament is secured to the medial tibial metaphysis with a metal staple to preserve lateral knee joint stability (**TECH FIG 4A**).
- The proximal aspect of the fibular flap is fixed to the radial or humeral diaphysis with a side plate and screws, and the biceps tendon stump is used for attachment to the opposing articular surface soft tissue envelope (**TECH FIG 4B–E**).
POSTOPERATIVE CARE

- All patients must be treated and monitored postoperatively according to a strict and constant protocol. They are admitted to the intensive care unit for the first 5 days after surgery, where they are monitored for vital signs and flap viability. A high volume of lactated Ringer solution (1.5 times maintenance) is given to ensure high flow through the anastomosis and prevent thrombus formation. The high volume of fluids is maintained for a total of 3 days, with gradual reduction to normal maintenance volume in the ensuing 2 days.
- Enoxaparin is given to prevent deep vein thromboses. Blood samples are drawn twice daily for blood count and electrolytes. Hemoglobin levels are kept at 9 to 10 g/mL to minimize blood viscosity and further decrease the likelihood of anastomotic thrombus. A technetium methylene diphosphonate bone scan with single-photon emission computed tomography is performed 10 days after surgery to evaluate flap viability.
- Recipient extremities are immobilized for 3 months (upper extremity by a brace, lower extremity by a plaster cast), after which gradual passive range-of-motion exercises are practiced.
- Signs of bone union are evaluated radiologically by serial plain radiographs. Bone unions are usually seen after 4 to 5 months in the upper extremity and after 5 to 7 months in the lower extremity. Partial weight bearing is allowed upon detection of radiologic evidence of bone union. Gradual physical loads on the limb are recommended until full weight bearing is achieved.

OUTCOMES

- Solid bony unions, associated with fibular hypertrophy, full weight bearing, and mechanical load capacities, are achieved in the vast majority of patients. Fibular hypertrophy occurs over years and is the result of pressure transport, microfractures, and callus formation.
- Mild to moderate decreases in range of motion are common and are similar to those seen after other types of reconstructive surgeries. Such decreases result from the extent of resection of bone and soft tissues rather than the mode of reconstruction.
- Deep infections are rare, as is hardware failure requiring revision surgery.

COMPLICATIONS

Recipient Site

- Anastomotic thrombosis and loss of flap viability
- Nonunion
- Infection
- Hardware failure and breakage

Donor Site

- Valgus ankle deformity
- Ankle joint instability
■ Transient or permanent peroneal palsy
■ Transient or permanent peroneal distribution area sensory deficit
■ Skin graft failure and tendon exposure
■ Transient or permanent great toe flexion impairment

REFERENCES
BACKGROUND

- An intercalary reconstruction is defined as replacement of the diaphyseal portion of a long bone after segmental skeletal resection (diaphysectomy).
- Intercalary reconstructions typically result in superior function compared to other limb-sparing procedures because the patient’s own joints above and below the reconstruction are left undisturbed.
- Most intercalary reconstructions are performed with bulk allografts, although various endoprosthetic intercalary prostheses are available.
- Allograft reconstructions require osseous healing for long-term stability; initial allograft stability must be obtained with intramedullary nailing or internal fixation.
- Allografts have a long-term risk of fracture likely related to the size and type of fixation.
- Intercalary allografts are often supplemented with vascularized fibular grafts.
- Endoprosthetic reconstruction has typically been limited to small, central tumors as significant lengths of bone proximal and distal to the lesion are required for successful fixation of traditional prosthetic stems.
- New implant designs have expanded the indication for intercalary prostheses by drastically reducing the length of bone needed to achieve stable fixation.
- Segmental prostheses typically provide immediate stable fixation, allowing early rehabilitation and rapid return of function.
- Vascularized fibular grafts are not required for intercalary implants.
- Although aseptic loosening has been reported after endoprosthetic reconstruction, it is rarely if ever seen with intercalary implants; the lack of bearing surfaces contributing to wear debris formation and the lack of exposure to joint fluid help to protect the implant.

INDICATIONS

- Intercalary reconstructions are indicated for osseous joint-sparing reconstructions.
- Intercalary reconstructions are performed most commonly in the femur, tibia, humerus, and forearm.
- Intercalary reconstructions require adequate remaining bone stock to allow stable fixation; if inadequate bone remains, the procedure should be converted to a joint-replacing reconstruction.
- Intercalary allograft reconstructions require osseous healing for long-term stability, which can be compromised by chemotherapy or radiation during the healing period.
- Intercalary allografts in areas with poor vascularity, with small residual host segments, in heavy or very active patients, or with planned radiation or chemotherapy likely benefit from supplemental vascularized fibular allografts.
- Intercalary endoprosthetic reconstruction is an option if allograft reconstruction is contraindicated due to poor host factors or in patients with prior failed allograft reconstruction.
- Modular intercalary prostheses provide the flexibility to easily convert to a conventional endoprosthetic replacement either at initial surgery or for later revisions by using joint-replacing modules at either end of the implant.

ANATOMY

- Anatomic considerations in the femur include the anterior bow, femoral anteversion, and the proximity of the superficial femoral artery to the distal femur near the adductor hiatus.
- Anatomic considerations in the tibia include the limited soft tissue coverage anteromedially and the proximity of the posterior tibial neurovascular bundle to the posteromedial tibia.
- Anatomic considerations in the humerus include the proximity of the radial nerve to the posterior midhumeral shaft.
- Anatomic considerations in the forearm include the radial bow.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Table 1 outlines methods for examining the patient with a mass or suspected tumor.
- Important aspects of the patient history include:
  - Onset of mass or pain
  - Progression of growth or pain
  - Constitutional symptoms (fevers, chills, night sweats, weight loss)
  - Personal or family history of cancer

IMAGING AND OTHER STAGING STUDIES

- Radiographs are the primary imaging study used in forming a differential diagnosis of bone lesions.
- Radiographs are used to assess the geometry and size of the host bone and the lesion to allow appropriate sizing of the allograft reconstruction.
- Radiographs are helpful in determining the response to chemotherapy, which influences the decision making for limb salvage.
- Bone scan is used to determine if there are additional osseous sites of disease.
- Computed tomography (CT) scanning is used to determine the bone geometry and to assess bone destruction by a lytic lesion.
- Magnetic resonance imaging (MRI) is used to assess the soft tissue extension of a lesion. It is also used to assess the prox-
imity of neurologic and vascular structures, the intraosseous or narrow extent of tumor, and extension into an adjacent joint.

- Sagittal and coronal MRI images are extremely useful in planning the resection length; measurements from the adjacent joints to the planned levels of osteotomy are made to provide a reproducible method of identifying the levels intraoperatively.
- The role of positron emission tomography (PET) scanning has yet to be defined for sarcomas. It likely plays a role in the assessment of metastatic disease.

**SURGICAL MANAGEMENT**

- The main surgical decisions to be made when performing an intercalary resection are the type and length of fixation and the need for supplemental vascularized fibula graft.
- Plate fixation allows for reconstruction with standard osteosynthesis techniques.
- Plate fixation allows for compression across the allograft–host junctions, which likely improves healing.
- Plate fixation results in screw holes in the allograft, which is thought to contribute to late allograft fracture.
- Intramedullary fixation of allografts requires additional incisions but likely provides stronger fixation.
- Intramedullary fixation provides long-term protection of the allograft without placing screw holes in the allograft (FIG 1).
- Intramedullary fixation makes it difficult to obtain compression at the allograft–host junctions, which may impede healing.

- Allograft and host cuts can be transverse or stepped (FIG 2).
- Transverse cuts make rotational adjustments easier and likely result in less periosteal dissection, which may improve healing.
- Stepped cuts are more technically difficult, add surgical time, and may cause more damage to the local periosteum. However, they likely increase host–allograft bone contact, which may improve healing.
- Intercalary implants require careful attention to resection length and canal preparation to ensure optimal fixation of the implant stems.
- Regardless of the method of skeletal reconstruction, careful attention to the soft tissues and use of rotational muscle flaps when indicated are necessary to reduce the risk of wound complications and subsequent infection.

**Preoperative Planning**

- Preoperative planning is extraordinarily critical in these complex reconstructive procedures.
- Multiple imaging techniques should be used to fully assess the tumor, length of resection, and the remaining bone anatomy necessary to support the planned reconstruction.
- Standard instruments for tumor resection are required, including bone saws; equipment for additional procedures such as vascular bypass, vascularized graft, or specialized soft tissue reconstruction should be available.
- Some surgeons prefer to use a separate group of instruments for the resection and the reconstruction.

---

**Table 1 Methods for Examining the Patient with a Mass or Suspected Tumor**

<table>
<thead>
<tr>
<th>Examination</th>
<th>Technique</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palpation</td>
<td>Feel the borders of the mass to evaluate size and whether it is mobile from the surrounding structures.</td>
<td>Lack of mobility suggests adherence to surrounding structures.</td>
</tr>
<tr>
<td>Joint range of motion</td>
<td>Assess range of motion of joints adjacent to mass.</td>
<td>Lack of mobility suggests adherence to surrounding structures.</td>
</tr>
<tr>
<td>Soft tissue evaluation</td>
<td>Assess soft around mass or biopsy to determine resection approach and whether sufficient soft tissue remains to allow primary closure.</td>
<td>Large masses may restrict joint motion.</td>
</tr>
<tr>
<td>Vascular examination</td>
<td>Assess circulation of extremity.</td>
<td>Vascular compromise may complicate limb reconstruction.</td>
</tr>
</tbody>
</table>

---

**FIG 1** Placement of intramedullary nail and compression of junction. **A.** Fluoroscopic view of intramedullary nail through allograft in the proximal femur. The K-wire for rotational reference can be seen. Gaps in the host–graft junction are present without compression of the junction. **B.** Fluoroscopic view after placement and tightening of compression screw in intramedullary nail. Gap at host–allograft junction is minimized.
The allograft needs to be ordered from a bone bank. Some surgeons prefer to size-match allografts used for intercalary reconstructions, requiring radiographs of the allograft to be obtained before ordering.

If a vascularized fibula graft is planned, the timing and host location of the graft must be determined.

Endoprosthetic implants may require customized components, typically requiring a 3- to 4-week lead time to allow for design and manufacturing of the implant.

An examination under anesthesia focusing on the rotational profile of the nonoperative leg can be useful in ensuring proper rotation of the operative leg.

Intraoperative C-arm fluoroscopy is useful to measure and select the levels of planned bone osteotomy.

**Positioning**

- Positioning depends on the tumor location and the surgical approach required for oncologic resection.
- Femoral resections are typically performed either in the supine or lateral position; tibial cases are performed supine.
- Femoral reconstructions may be facilitated by a bump under the buttock, but this may make clinical assessment of rotation more difficult.
- Forearm reconstructions are performed with the patient supine and the arm on a hand table.
- Humeral reconstructions can be performed with the patient in the supine or beach chair position.

**Approach**

- The approach for intercalary reconstructions is determined by the incision needed to perform an adequate resection of the tumor.
- Femoral reconstructions are ideally performed through a lateral or anterolateral approach to the thigh; medial incisions may be necessary to isolate and protect the superficial femoral artery and vein during the resection.
- Tibial reconstructions can be performed through an anterolateral or anteromedial approach.
- An anteromedial approach is more likely to require complicated soft tissue coverage.
- Humeral resections are performed through an extensile anteromedial approach; care must be taken to identify and protect the radial nerve when oncologically possible.
- Forearm reconstructions of the radius are ideally performed through an anterior approach.

**RESECTION**

- The approach is performed as indicated by the location of the tumor and the biopsy.
- Pertinent vascular and neurologic dissection is performed to identify and protect critical structures; soft tissue dissection around the tumor mass is then performed.
- Dissection is performed down to bone at the distal and proximal extent of the planned bone resection.
- Using fluoroscopy or other measurements from preoperative imaging, K-wires placed perpendicular to the shaft of the bone may be used to mark the proximal and distal osteotomy level. Care should be taken to avoid excessive damage to the periosteum adjacent to the planned osteotomy.
- Before osteotomy, the bone should be carefully examined and marked to ensure proper rotational orientation during the reconstruction. The linea aspera of the femur is a convenient anatomic landmark; K-wires or cuts in the bone may be placed proximal and distal to the resection area as well.
- Transverse osteotomy is performed with a power saw. Cooling the saw blade with irrigant prevents excessive heat from causing thermal damage to the host bone.
- The specimen is removed, the length is measured and recorded, and margins are assessed.

**PREPARATION OF THE ALLOGRAFT**

- The allograft is thawed in antibiotic-laden lactated Ringer solution.
- The section of the allograft that most closely matches the shape and size of the resected bone is marked. A few millimeters are added to the resected length to allow additional small cuts to be made to improve the bone contact and alignment with the host bone.
- The proximal and distal allograft cuts are made with a power saw.
- If intramedullary nail fixation is planned, the allograft is then reamed to a diameter 2 mm greater than the planned nail diameter.
- Reaming should be done slowly and progressively to avoid cracking the very brittle allograft.
INTRAMEDULLARY FIXATION (FEMUR)

Following Resection

- A small incision is made approximately 8 cm proximal and slightly posterior to the greater trochanter (TECH FIG 1).
- A guidewire is placed at the appropriate starting point for the type of nail being used, either the piriformis fossa or the tip of the greater trochanter.

Alternatively, if a retrograde nail is planned, a small medial arthrotomy is performed and the guidewire is inserted into the distal femur in the intercondylar notch.

After confirming the wire position with fluoroscopy, an entry reamer is used to open a portal into the proximal (or distal) femur.

TECH FIG 1 • A–D. Osteosarcoma of the femur in a 14-year-old boy reconstructed with an intercalary allograft with plate fixation. A. Preoperative AP radiograph showing diaphyseal lesion. B. Coronal MRI image showing intramedullary and extramedullary extent of the lesion. C. Postoperative AP radiograph showing intercalary reconstruction with medial and lateral locking plates. The most distal medial screw in the epiphysis was later removed to allow continued growth across the distal femoral physis. D. Postoperative lateral radiograph showing the reconstruction with callus formation at the host–allograft junctions. E–G. Customized modular femoral intercalary reconstruction in a patient with Ewing sarcoma. E. Sagittal MRI scan showing length of tumor to be resected. F. Resection specimen and implant; cross-pin fixation is used for improved stability of the short stems. G. Intraoperative view of intercalary implant; surfaces are porous for extraskeletal fixation at the prosthetic bone junctions. H,I. Radiographs of proximal and distal femur showing intercalary implant. (continued)
J–P. Salvage of multiply failed intercalary allograft with conversion to intercalary endoprosthesis. 

J. Chronic painful nonunion of distal allograft–host junction despite repeated surgery and vascularized fibular bone grafting. Patient had been braced for 5 years and unable to bear weight for over 2 years. 

K. Resection of allograft with failed blade plate; cultures of allograft showed infection with methicillin-sensitive Staphylococcus aureus. 

L. Use of high-dose antibiotic spacer for sterilization of soft tissues while preserving limb length and tissue pocket for planned reconstruction. 

M. Preparation of intramedullary canal using facing reamer and (N) use of jigs for anchor plug fixation with bicortical transfusion pins. 

O. Intraoperative view of assembled prosthesis; locking collar and screws are used to hold proximal and distal body segments together. 

P. Radiograph showing final reconstruction. The patient is completely pain-free and ambulatory without braces or crutches.

- A beaded guidewire is inserted into the femur, across the resection bed, and into the femoral segment on the far side of the resection bed. 
- The femur is then progressively reamed to 1.5 mm larger than the planned nail diameter. 
- The beaded guidewire is partially pulled out and the allograft is inserted into the resection bed. 
- The guidewire is then passed back through the allograft into the far femoral segment. 
- A preliminary check of the bone cuts is made by manually compressing the allograft against the host bone and inspecting bone contact and alignment. Small revision cuts may be required on the allograft. 
- The nail is then inserted. With the nail in place, a final inspection of the junctions is made and revision trimming of the allograft is performed to improve bone contact. 
- The nail is fully seated. 
- The locking screws in the “distal” tip of the nail are placed. These may be the screws in the proximal femur if a retrograde nail is being used. 
- The nail is then backtapped to close down any gaps in the host–allograft junctions.
Rotation is checked either clinically or by aligning the previously placed K-wires.

The screws in the “proximal” end of the nail are placed. If a compressible nail is being used, the compression screw is applied after placement of the dynamic locking screw (TECH FIG 2). Because of the extended time often required for healing, two locking screws should be placed proximally and distally.

If compression has been applied with a compression nail and the allograft is rotationally stable, no additional fixation is required.

If the allograft is rotationally unstable around the nail, a short plate can be applied with unicortical screws to improve stability. This can be placed at one or both host–allograft junctions depending on the amount of instability.

Plate and Screw Fixation

The allograft is placed into the resection bed and gross alignment is checked (TECH FIG 3).

If necessary, the plate is contoured to match the alignment of the femoral segment being reconstructed.

A 4.5-mm plate should be used (except in the forearm). The type of plate is dictated by the location. Special plates are available for the proximal and distal femur.

A slight prebend of the plate is performed to maximize compression of the junction on the side opposite the plate.

The plate is positioned and fixed to one side of the host bone with one screw.

The host–allograft segment is aligned and the plate is positioned appropriately (TECH FIG 4).

Rotational alignment is checked clinically or with the previously placed K-wires.

Compression is applied across the host–allograft segments either with a tensioning device or a Verbrugge clamp and a pull screw (TECH FIG 5).

Sagittal and coronal plane alignment is verified with fluoroscopy.

Allograft trimming is performed as necessary to improve bone contact and alignment.
Compression screws are placed into the plate to maximize compression across the host–allograft junctions.

Two screws are placed through the plate into the allograft to prevent dislodgement. If a locking plate is being used, these can be unicortical locking screws. Alternatively, cerclage cables can be placed to avoid holes in the allograft.

In resections resulting in very small residual host segments, large plate fixation may not be possible. In these cases, small hand or foot plates may be beneficial for fixation. Alternatively, oblique compression screws from the host through the allograft may be used.

**Closure**

- Irrigation of the wound is performed and hemostasis obtained.
- If small gaps remain at the host–allograft junctions, grafting can be performed. Usually cancellous bone can be curetted from unused allograft for this purpose.
- The wound is closed in layers over suction drains.
- Efforts should be made to obtain circumferential muscle coverage over the reconstructed bone.
- A gentle compression dressing is placed. Splinting of the knee may improve patient comfort for the first few postoperative days.

**VASCULARIZED FIBULAR GRAFT**

- Vascularized fibular grafts are used to supplement intercalary allografts, improving healing and adding strength and living bone to the reconstruction.
- Vascularized grafts add complexity and time to the operative reconstruction.
- Vascularized graft can be harvested from the ipsilateral or contralateral leg.
- In the femur, vascularized grafts can be placed medial or lateral, bridging across the allograft and affixed to the proximal and distal host segment.
- In the tibia, soft tissue constraints often require the vascularized graft to be placed within the allograft. A groove made in the allograft facilitates placement of the vascular graft.
- For a more complete explanation of this procedure, see Chapter ON-28.

**TIBIA, HUMERUS, AND FOREARM**

- Reconstructions in the tibia, humerus, and forearm are similar.
- Intramedullary fixation may be possible in the tibia and humerus.
- Plate fixation for the humerus and tibia should be done with 4.5-mm plates.
- Plate fixation in the forearm is performed with 3.5-mm plates.
- Special locking plates designed for the proximal tibia are often useful in tibial reconstructions.
- Care must be taken in the radius to recreate the radial bow.

**INTERCALARY ENDOPROSTHETIC RECONSTRUCTION**

- After tumor resection, frozen sections of the remaining medullary contents are performed to ensure margins are free of tumor.
- Careful measurement of the specimen length is necessary to ensure proper selection of components (if using a modular system).
- Preparation of the bone canal is critical to ensure adequate fixation; use of rigid instead of flexible intramedullary reamers is preferred to obtain best fit of the prosthetic stem.
- C-arm fluoroscopy is used to monitor the reaming process to avoid penetration into the adjacent joint.
- Facing reamers are used to machine the proper radius of curvature of the exposed cortical bone to ensure flush fit of the implant's stem–body junction.
- Trial reduction is performed to check length and rotation and to ensure that reduction of the prosthesis bodies is possible; the specific connection between the proximal and distal bodies varies depending on the implant manufacturer.
- For implants with cemented stems, proper canal preparation using cement restrictors, pulsatile lavage, and packing for hemostasis is performed before injection of cement and impaction of the stem.
- Uncemented systems may require further canal preparation; Compress™ implants use a number of interlocked jigs for centralization of the intramedullary anchor plug and placement of transfixion pins through the adjacent cortical bone.
- Final assembly of the prosthesis is performed per implant requirements; care must be taken to ensure that rotation is proper and that all locking mechanisms are tightened or impacted.
- Supplemental bone graft, collected during reaming, is placed at the implant–bone junction (over the porous coated surface) to provide extraskeletal fixation of the implant.
- Soft tissue reconstruction over closed suction drains is then performed. When necessary, local rotation flaps are used to ensure muscular coverage of the implant.
**POSTOPERATIVE CARE**

- Proper wound healing is critical to avoid infection of the reconstruction; use of antibiotics during the perioperative phase is extremely important, particularly with allograft reconstructions.
- Allograft patients are maintained on touch-down weight bearing until healing of the host–allograft junctions is seen radiographically (usually 3 to 12 months).
- Additional bracing is necessary only if a stable construct is not obtained. This can occur in plate reconstructions with small residual host segments after resection.
- Physical therapy should be directed toward range of motion of the hip and knee. Muscle strengthening can be performed with minimal resistance as dictated by the stability of the construct achieved in surgery.
- Intercalary implants permit immediate weight bearing; short-stemmed components around the knee are protected by placing the patient in a knee immobilizer and limiting joint range of motion to gentle assisted exercises under supervision during the initial healing stages.

**OUTCOMES**

- Most studies report combined results for intercalary, osteoarticular, and allograft prosthesis composites.
- Nonunion rates are reported to be 10% to 15%.
- Late fracture rates are reported to be 7% to 20%.
- Union rates with nails and plates are nearly equal, but the late fracture rate is higher with plates.
- Functional outcomes are reported as 78% to 86% good or excellent.
- Graft survival is reported as 79% at 5 years.
- Few reports of intercalary implants have been published; individual institutional experience has been very favorable, with 100% implant survival and near to complete functional restoration of the limb.

**COMPlications**

- Nonunion of the allograft–bone junction frequently occurs and may be treated with secondary bone grafting or allograft revision. Use of vascularized fibular grafts in high-risk patients should be considered to minimize this complication.
Infection is the most common cause of allograft and prosthetic failure and can lead to secondary amputation. Aggressive surgical débridement with removal of all foreign bone or materials is necessary.

Late fracture of massive allografts can lead to chronic pain and loss of function. Use of intramedullary fixation and avoiding screws in the allograft may help to minimize this complication.

Prosthetic loosening rarely if ever occurs for intercalary implants. Implant failure can be revised with use of a new prosthesis.

Degeneration of an adjacent joint after either allograft or intercalary implant reconstruction can be treated with surface-replacing total joint arthroplasty.

REFERENCES

BACKGROUND

The quadriceps muscle group is the most common site for extremity soft tissue sarcomas.

The most common sarcomas at this site are liposarcomas, malignant fibrous histiocytomas, and leiomyosarcomas.

Although tumors of the anterior compartment of the thigh can be extremely large on first presentation, it is possible to perform limb-sparing resections in most patients. By using induction chemotherapy to shrink the lesion and postoperative adjuvant radiation therapy to eradicate possible residual microscopic disease, resections of the anterior compartment of the thigh are often safe and reliable.

In addition, when resection necessitates en bloc removal of a considerable amount of muscle tissue, reconstruction of the extensor mechanism with the sartorius muscle, the hamstring muscles, or both produces good functional results.

The most common indications for amputation (ie, modified hemipelvectomy) are large tumors with extracompartmental extension into the adductor and hamstring musculature, tumors with intrapelvic extension through the femoral triangle and inguinal ligament, large fungating tumors, and massive tumor contamination, with or without infection.

INDICATIONS

Almost all low-grade soft tissue sarcomas of the anterior thigh may be safely resected by a partial muscle group resection. The large majority of high-grade soft tissue sarcomas can be resected by partial or total compartmental removal. The contraindications to limb-sparing resection are as follows:

- Groin involvement. Tumors arising or involving the groin and femoral triangle often cannot be reliably resected and may require amputation.

- Extracompartmental extension. In general, resection of a single muscle group permits a viable extremity. If two muscle groups have to be completely removed, the extremity may not be functionally salvageable. Large tumors of the anterior thigh may involve the adductor group as well as the posterior muscle group by passing through the linea aspera or the intermuscular septum. In this situation amputation might be necessary.

- Intrapelvic extension. On rare occasions, large tumors of the proximal thigh and groin extend below the inguinal ligament into the retroperitoneal space, necessitating amputation.

- Recurrent tumors of the quadriceps, infection, extensive tumor hemorrhage, or extensive tumor contamination from previous surgical procedures may require amputation.

- Neurovascular involvement of the tumor does not necessarily obviate limb-salvage resections. Most tumors of the quadriceps muscle will displace but not invade the superficial femoral or common femoral arteries. If the surgical margins are positive for tumor cells or extremely close, resection of the involved artery and replacement with a vascular graft often allows limb salvage.

- Femoral nerve sacrifice is also not a contraindication for limb-sparing resection; reconstruction techniques often permit knee extension and patellar stabilization, even when the entire quadriceps muscle is resected or paralyzed secondary to femoral nerve resection (Tables 1 and 2).

ANATOMY

The thigh consists of three distinct anatomic compartments, separated by thick fascial layers: the anterior compartment (quadriceps and sartorius muscle), the medial compartment (thigh adductor muscles), and the posterior compartment (the hamstring muscles).

The quadriceps muscle group consists of the vastus medialis, vastus lateralis, rectus femoris, and vastus intermedius muscles. The vastus medialis and lateralis arise from the proximal femur and intermuscular septum. The vastus intermedius arises from the surface of the femur and the linea aspera and covers the entire femoral shaft. The rectus femoris arises from the supra-acetabular tubercle at the superior part of the acetabulum. All four heads merge distally into the quadriceps tendon, which inserts onto the patella.

By covering the anterior aspect of the femur, the vastus intermedius protects the underlying femur from direct tumor extension by tumors of the other components of quadriceps muscle.

The fact that soft tissue sarcomas often remain localized to one muscle belly permits partial muscle group resection for many quadriceps sarcomas (FIG 1).

The medial and lateral intermuscular septum of the thigh separates the anterior thigh muscles from the medial and posterior compartments, respectively. However, the medial intermuscular septum “runs out” proximally, and quadriceps tumors may therefore extend into the posterior and medial compartments and complicate and sometimes obviate a limb-sparing resection. Likewise, tumors arising from the medial and posterior compartments of the thigh may extend into the quadriceps group.

The femoral triangle is the key to resection of the quadriceps muscle group. It is formed by the adductor longus medially, the sartorius muscle laterally, and the inguinal ligament proximally. The pectineus muscle forms the floor of the triangle. A thick fascia covers the roof.

The superficial femoral artery and vein pass from below the inguinal ligament through the femoral triangle and into the sartorial canal at the apex. The femoral nerve enters the canal laterally and quickly branches to innervate the quadriceps muscle components. The superficial femoral artery and vein pass along the medial wall of the sartorial canal throughout the length of the thigh and are separated from the anterior group (vastus medialis) by a thick fascia, which often permits a safe resection.

This fascia forms a good border for quadriceps resections.

Unique Anatomic Considerations

An important criterion for the success of a muscle flap transfer (FIG 2A–D) is maintenance of a pattern of circulation that...
is consistent in location and resistant to the effect of radiation therapy and superficial trauma (FIG 2E). The surgical manipulation of the muscle flap must not interrupt its circulation; therefore, a precise knowledge of the location and pattern of the vascular pedicles is required. The sartorius muscle is supplied by the superficial femoral artery and has a segmental vascular pattern (type IV vascular pattern according to Mathes and Nahai6). Each pedicle provides circulation to a portion of the muscle, and division of more than three pedicles during the elevation of the flap may result in distal muscle necrosis. The hamstring muscles are supplied by branches of the profunda femoris artery and have proximal dominant vascular pedicles and distal minor pedicles (type II vascular pattern). Complete elevation of the muscles is possible when the dominant proximal vascular pedicles are preserved.

IMAGING AND OTHER STAGING STUDIES

Computed Tomography and Magnetic Resonance Imaging
- Magnetic resonance imaging (MRI) and computed axial tomography (CAT) are essential for determining the location and extent of the lesion and its relations to the femoral bone, respectively.
- Tumors may remain within one muscle belly or involve several components of the quadriceps muscle.
- It is important to identify the relationship between the tumor and the underlying femur. Tumors that involve the vastus medialis very often involve the adjacent periosteum as well.

Bone Scan
- A three-phase bone scan is useful to determine the proximity of the tumor to the periosteum. Absence of periosteal uptake indicates a reactive border or a pseudocapsule. This does not make quadriceps tumors unresectable but indicates that the underlying periosteum must be removed during the surgical procedure. Rarely does tumor extend directly into the bone.

Angiography and Other Studies
- Large tumors of the quadriceps muscle often displace the superficial and deep femoral vessels. It is important to determine the anatomic relations of these vessels to the tumor before resection. Large tumors of the proximal thigh may require ligation of the profundus femoris artery and vein; therefore, knowing before surgery whether the superficial artery is patent is essential. This is particularly true in the older patient, in whom the superficial femoral artery may be occluded secondary to peripheral vascular disease. Displacement of the superficial femoral artery usually does not indicate direct tumor extension; however, if the surgical margins are positive, the artery should be resected and replaced with a saphenous or artificial graft.

Biopsy
- The biopsy site should be in line with the planned incision for resection and must be located over the most prominent portion of the tumor. Core needle biopsy has been shown to provide reliable pathologic diagnoses and is our preferred method. Multiple samples can be collected from the same puncture site. Areas that major arteries and veins traverse should be avoided so that the vessels are not penetrated, risking tumor cell contamination.
A. Muscle transfers for type A resection (vastus lateralis with or without vastus intermedius). The long head of the biceps femoris is transferred anteriorly and sutured to the patella, the quadriceps tendon, and the rectus femoris muscle.

B. Muscle transfers for type B resection (vastus medialis with or without vastus intermedius). The sartorius muscle is transferred anteriorly but not detached from its distal insertion and is sutured to the patellar tendon, patella, quadriceps tendon, and rectus femoris muscle.

C. Muscle transfers for type C resection (rectus femoris and vastus intermedius). The sartorius muscle is mobilized anteriorly and sutured to the patella and the remains of the quadriceps tendon.

D. Muscle transfers for type D resection (subtotal resection). The biceps femoris laterally and the sartorius and semitendinosus medially are transferred anteriorly, tenodesed to each other, and sutured to the patella.

E. Vascular anatomy of muscles. There are five patterns of vascular supply to muscles, based on the distribution of major and minor vascular pedicles. The sartorius muscle has a type II vascular pattern and the hamstring muscles have a type IV vascular pattern (represented by the gracilis muscle in the schematic).
POSITION

- The patient is placed in the supine position with a bolster underneath the ipsilateral buttoc. If the tumor is close to or involves the femoral artery, the contralateral leg should also be draped for saphenous vein graft harvesting, in case the femoral artery needs to be resected (TECH FIG 1).

TECH FIG 1 • Type A resection (vastus lateralis and vastus intermedius) and reconstruction with biceps femoris transfer. Preoperative picture of a patient with a large malignant soft tissue sarcoma in the lateral aspect of the anterior compartment of the thigh. Resection includes the vastus lateralis and part of the vastus intermedius and rectus femoris. After completion of the resection, the lateral aspect of the femur is exposed. The long head of the biceps femoris is transferred anteriorly and sutured to the patella and the remains of the quadriceps tendon and rectus femoris.

LIMITED RESECTIONS OF THE QUADRICEPS MUSCLE

- Most tumors of the anterior compartment of the thigh are confined to one part of the quadriceps muscle and can be safely resected with negative margins without the need to sacrifice a considerable amount of muscle tissue.
- A longitudinal skin incision just above the tumor mass is made, encompassing the biopsy site. The tumor mass should be resected en bloc with 1 cm of surrounding healthy tissue.

- For tumors that involve the vastus medialis, vastus lateralis, or rectus femoris, the superficial margins are the skin and subcutaneous tissues and the deep margins may include part of the vastus intermedius. The superficial margins of tumors that involve the vastus intermedius may include part of one of the vasti or rectus femoris. If the deep surface of the tumor is close to the bone, the periosteum should be peeled off and resected and the superficial cortex removed with a high-speed burr (Midas).

PARTIAL OR COMPLETE QUADRICEPS RESECTION

- A long midline incision is made extending longitudinally from the anterior inferior iliac spine to the patella. It should be elliptical and should widely encompass the biopsy site (TECH FIG 2A).
- Flaps composed of skin and subcutaneous tissue are made just superficial to the fascia lata. They extend to the adductor muscle group medially and to the greater trochanter and flexor muscles laterally. The saphenous vein is divided as it enters the fossa ovalis. The inguinal ligament and the femoral triangle are uncovered, exposing the common femoral artery and vein and the femoral nerve (TECH FIG 2B).
- Lateral traction is placed on the quadriceps muscle group so that muscular branches coming from the superficial femoral artery and vein into the quadriceps muscle are exposed. Working from cranial to caudal, these vessels are clamped, divided, and ligated; included are the profunda femoris artery and vein. In the area of the canal of Hunter, while strong lateral traction is placed on the sartorius muscle, muscular insertions from the adductor magnus muscle coursing over the superficial femoral artery are identified. These muscular branches should be divided as they cross the superficial femoral artery (TECH FIG 2C,D).
- A plane beneath the tensor fascia lata muscle and above the gluteus medius and minimus is identified. By electrocautery the tensor fascia lata muscle is released from its origin on the wing of the ilium. Then the origin of the sartorius muscle on the anterior superior iliac spine is identified and divided. The origin of the rectus femoris muscle on the anterior inferior iliac spine is likewise identified and divided through its tendinous portion (TECH FIG 2E).
- The origins of the vastus lateralis, vastus intermedius, and vastus medialis on the femur are transected from the bone using electrocautery. Strong upward traction on the muscle group facilitates this dissection (TECH FIG 2F,G).
- Using strong upward and medial traction on the specimen, the insertions of the vastus lateralis, vastus medialis, and rectus femoris into the patellar tendon are divided on the patella (TECH FIG 2H).
- One cannot avoid transecting both the prepatellar and quadriceps (postpatellar) bursae. The insertion of the vastus medialis into the medial collateral ligament is likewise divided, and the specimen is then free. The dissection site is copiously irrigated, and any bleeding points are secured with ligatures or electrocautery.
TECH FIG 2 • A. The incision extends longitudinally from the anterior inferior iliac spine to the patella. It should be elliptical and should widely encompass the biopsy site. If physical examination or tomography shows that the tumor encroaches on the patella, this bone and its tendon should also be excised. If this clinical situation arises, the incision should be continued over the knee to the tibial tubercle. B. Cross-sectional anatomy. C. Flaps composed of skin and subcutaneous tissue are made just superficial to the fascia lata. They extend to the abductor muscle group medially and to the greater trochanter and flexor muscles laterally. The saphenous vein is divided as it enters the fossa ovalis. The inguinal ligament and the femoral triangle are uncovered, exposing the common femoral artery and vein and the femoral nerve. D. Dissection of the superficial femoral vessels. Lateral traction is placed on the quadriceps muscle group so that muscular branches coming from the superficial femoral artery and vein into the quadriceps muscle are exposed. Working from cranial to caudal, these vessels are clamped, divided, and ligated; included are the profunda femoris artery and vein. In the area of the canal of Hunter, when strong lateral traction is placed on the sartorius muscle, muscular insertions from the abductor magnus muscle coursing over the superficial femoral artery are identified. These muscle fibers should be divided as they cross the superficial femoral artery. E. Transection of muscle origins on the pelvis. A plane beneath the tensor fascia lata muscle and above the gluteus medius and minimus is identified. By electrocautery the tensor fascia lata muscle is released from its origin on the wing of the ilium. Then the origin of the sartorius muscle on the anterior superior iliac spine is identified and divided. The origin of the rectus femoris muscle on the anterior inferior iliac spine is likewise identified and divided through its tendinous portion. F. Resection includes the vastus lateralis and part of the vastus intermedius and rectus femoris. (continued)
G. Transection of muscle origins on the femur. Origins of the vastus lateralis, vastus intermedius, and vastus medialis on the femur are transected from bone by using electrocautery. Strong upward traction on the muscle group facilitates this dissection. H. Transection of the muscle insertions of the quadriceps muscle. Using strong upward and medial traction on the specimen, the insertions of the vastus lateralis, vastus medialis, and rectus femoris into the patellar tendon are divided on the patella bone. The insertion of the vastus medialis into the medial collateral ligament is likewise divided, and the specimen is then free. The dissection site is copiously irrigated, and any bleeding points are secured with ligatures or electrocautery. I. To facilitate rehabilitation by helping to provide stability to the knee, the gracilis muscle medially and the short head of the biceps muscle laterally are transected at their insertions on the medial and lateral collateral ligaments. This transection should be as far distal as possible so that a tendinous portion of the muscle is retained. Then, using heavy nonabsorbable sutures, these two muscles are transplanted onto the patellar tendon. The prepatellar and quadriceps bursae are closed within these sutures. The muscles are approximated in the midline to cover the distal third of the femur. J. After completion of the resection, the lateral aspect of the femur is exposed. K. Suction catheters are placed beneath the skin flaps and the subcutaneous tissue is approximated. The skin is closed and the incision is covered with povidone–iodine ointment and a loose dry sterile dressing. The patient may begin ambulation when the suction catheters have been removed and edema of the leg has resolved. Because the lymphatics along the superficial femoral artery and within the buttock remain intact, prolonged swelling is not usually a problem, serous drainage from transected muscle bundles does not occur in large amounts. The patient is ambulated initially with crutches and a touch-down gait.
If the tumor is close to the underlying femoral bone (TECH FIG 2I), the periosteum can be removed and the underlying bone exposed using a high-speed burr (Midas). Several millimeters of the outer cortex can be removed; however, the outer cortex itself should not be removed en bloc.

Suction catheters are placed beneath the skin flaps and the subcutaneous tissue is approximated with interrupted absorbable sutures. We recommend using 28-gauge chest tubes to drain the surgical space (TECH FIG 2K).

SOFT TISSUE RECONSTRUCTION OF RESIDUAL LARGE DEFECTS

If a significant amount of quadriceps muscle is resected or if the femoral nerve must be sacrificed, we routinely reconstruct the extensor mechanism to restore strength and balance patellar tracking. The long head of the biceps femoris muscle is used to reconstruct the lateral aspect of the quadriceps muscle (TECH FIG 3), and the sartorius muscle, the semitendinosus muscle, or both are used to reconstruct the medial aspect of the quadriceps muscle.

Another technique that can be used to functionally reconstruct large defects (which is not within the scope of this textbook) is latissimus dorsi microvascular transplantation. We believe it should be used whenever muscle transfers cannot be performed.

BICEPS FEMORIS TRANSFER FOR FUNCTIONAL RECONSTRUCTION OF LARGE LATERAL SOFT TISSUE DEFECTS

After completion of the resection, the long head of the biceps is transected from its insertion on the head of the fibula. This transection should be as far distal as possible to retain a tendinous portion of the muscle. The muscle is transferred anteriorly to the midline so that it will have an almost direct line of pull. Only a few deep perforating branches need to be ligated during this procedure. Due to the type II vascular pattern of the hamstring muscles, ligation of distal branches does not jeopardize its vitality. Then, using heavy, nonabsorbable sutures, the muscle is transplanted onto the patella and the remains of the quadriceps tendon and rectus femoris.

SARTORIUS AND SEMITENDINOSUS MUSCLE TRANSFER FOR FUNCTIONAL RECONSTRUCTION OF CENTRAL AND MEDIAL SOFT TISSUE DEFECTS

The sartorius, the semitendinosus, or both can be used to functionally reconstruct large medial defects. Large central defects are reconstructed with the sartorius muscle.

Semitendinosus Muscle Transfer

The muscle is transected as far distal as possible from its insertion to the proximal tibia and transferred anteriorly so that it will have an almost direct line of pull. Since the semitendinosus has a type II vascular pattern, ligation of its distal vascular branches for its mobilization does not compromise the vitality of the muscle. The muscle and its tendinous part are then sutured to the patella and the remains of the quadriceps.

Sartorius Muscle Transfer

After completion of the resection, the sartorius muscle is released, but not transected, from its distal insertion on the medial aspect of the proximal tibia. The aim is to transfer the muscle anteriorly to the midline to achieve a straight line of pull between its origin on the anterior superior iliac spine and the patella. After ligating only two or three distal vascular branches, the sartorius can easily be transferred toward the midline and sutured to the patellar tendon, the patella, and the remains of the quadriceps tendon. Since the sartorius muscle has a type IV vascular pattern, care should be taken not to ligate more than three vascular branches to prevent distal flap necrosis (Table 3).
POSTOPERATIVE CARE AND REHABILITATION

- Continuous suction is required for 3 to 5 days and perioperative intravenous antibiotics are continued until the drainage tubes are removed. If muscle transfer reconstruction was performed, a knee extension brace is initially used and an intensive physical therapy program for muscle strengthening and knee range of motion is started 3 to 4 weeks postoperatively. Weaning off the brace proceeds gradually, in accordance with the patient’s functional improvement.

- No immobilization is required if only resection was carried out, and patients may gradually begin ambulation when the suction catheters have been removed. Because the lymphatics along the superficial femoral artery and within the buttock remain intact, prolonged swelling is not usually a problem.

OUTCOMES

- Patients who undergo limited resections of the quadriceps muscle usually do not have any residual functional limitations. There are limited data regarding the functional outcomes of patients who undergo extensive resections of the quadriceps muscle with or without reconstruction.

- Markhede and Stener\(^5\) evaluated the postoperative function in 17 patients who underwent quadriceps muscle resections. They found that the isometric strength of the muscle decreased by 22%, 33%, 55%, and 76% when one, two, three, or more components of the quadriceps muscle were resected, respectively.

- Capanna et al\(^1\) reported on the functional effect of quadriceps resection combined with distal femoral resection and prosthetic reconstruction in patients with malignant bone tu-

---

### Table 3

**Clinical Data on the Type and Size of Resection and Functional Results of 15 Patients Who Underwent Muscle Transfer Reconstruction of the Extensor Mechanism**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Patient Age</th>
<th>Resection Type</th>
<th>Resection Size (cm(^3))</th>
<th>Extensor Lag (degrees)</th>
<th>Active Flexion (degrees)</th>
<th>Strength</th>
<th>MSTS Functional Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>67</td>
<td>C</td>
<td>480</td>
<td>0</td>
<td>135</td>
<td>5</td>
<td>Excellent</td>
</tr>
<tr>
<td>2</td>
<td>57</td>
<td>C</td>
<td>560</td>
<td>0</td>
<td>120</td>
<td>5</td>
<td>Excellent</td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td>B</td>
<td>648</td>
<td>0</td>
<td>100</td>
<td>5</td>
<td>Excellent</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>B</td>
<td>720</td>
<td>20</td>
<td>135</td>
<td>4</td>
<td>Excellent</td>
</tr>
<tr>
<td>5</td>
<td>55</td>
<td>B</td>
<td>768</td>
<td>0</td>
<td>130</td>
<td>5</td>
<td>Excellent</td>
</tr>
<tr>
<td>6</td>
<td>36</td>
<td>A</td>
<td>810</td>
<td>0</td>
<td>110</td>
<td>5</td>
<td>Excellent</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>B</td>
<td>828</td>
<td>0</td>
<td>130</td>
<td>5</td>
<td>Excellent</td>
</tr>
<tr>
<td>8</td>
<td>27</td>
<td>A</td>
<td>872</td>
<td>0</td>
<td>100</td>
<td>4</td>
<td>Excellent</td>
</tr>
<tr>
<td>9</td>
<td>54</td>
<td>A</td>
<td>1220</td>
<td>30</td>
<td>90</td>
<td>3</td>
<td>Fair</td>
</tr>
<tr>
<td>10</td>
<td>45</td>
<td>B</td>
<td>1430</td>
<td>10</td>
<td>70</td>
<td>4</td>
<td>Good</td>
</tr>
<tr>
<td>11</td>
<td>70</td>
<td>D</td>
<td>1912</td>
<td>20</td>
<td>90</td>
<td>3</td>
<td>Fair</td>
</tr>
<tr>
<td>12</td>
<td>54</td>
<td>B</td>
<td>2200</td>
<td>0</td>
<td>120</td>
<td>5</td>
<td>Excellent</td>
</tr>
<tr>
<td>13</td>
<td>60</td>
<td>A</td>
<td>3600</td>
<td>0</td>
<td>130</td>
<td>5</td>
<td>Excellent</td>
</tr>
<tr>
<td>14</td>
<td>41</td>
<td>A</td>
<td>4930</td>
<td>0</td>
<td>115</td>
<td>4</td>
<td>Good</td>
</tr>
<tr>
<td>15</td>
<td>38</td>
<td>F.N.</td>
<td>n/a</td>
<td>25</td>
<td>90</td>
<td>3</td>
<td>Good</td>
</tr>
</tbody>
</table>

F.N., femoral nerve.
mors. They concluded that the degree of quadriceps resection has a strong impact on functional outcome.

- Malawer performed a gait electromyographic analysis on a patient who underwent distal femoral resection, endoprosthetic replacement, and extensor mechanism reconstruction with the sartorius and biceps femoris muscles. Six months after the operation, both muscles were recruiting in phase with the rectus femoris of the same limb.
- According to our experience, most patients who undergo muscle transfer functional reconstruction have good to excellent functional outcomes and satisfactory active range of motion. Reported results of latissimus dorsi functional transplantation are likewise encouraging.

### COMPLICATIONS

- Wound dehiscence is usually associated with recent or ongoing postoperative radiation therapy and is easily managed by débridement and skin grafting.
- Vascular injuries rarely occur.
- Knee stiffness is the most common problem and is easily treated by physical therapy.

### REFERENCES

BACKGROUND

- The adductor compartment of the thigh is the second most common site for soft tissue tumors of the thigh, preceded by the anterior (quadriceps) compartment. Although resecting the muscular elements of this compartment does not considerably affect overall function of the lower extremity, the proximity of the major neurovascular bundle of the lower extremity requires special attention in the preoperative evaluation process and during tumor resection.
- Tumors arising within the adductor compartment are often extremely large at presentation. As they enlarge they often displace the superficial femoral and profundus vessels, and they may involve the extrapelvic floor musculature (obturator fascia) and bone (superior and inferior pubic rami and ischium) and even extend extracompartmentally to the medial hamstrings or the psoas muscle and the adjacent hip joint. These anatomic characteristics often make resection extremely difficult. Such large tumors were traditionally treated with amputation (i.e., hemipelvectomy). However, effective chemotherapy and radiotherapy regimens have allowed limb-sparing resections to be performed at that site with low rates of local tumor recurrence.
- Lipomas and low-grade liposarcomas, which are the most common tumor type at that site, are usually removed easily with their enveloping capsule without having to manipulate the vascular bundle. High-grade soft-tissue sarcomas, however, may grossly adhere to and surround the vascular bundle and require partial or complete resection of the involved bundle segment. Therefore, a limb-sparing tumor resection at that site begins with dissection and preservation of the superficial femoral vessels.
- Large high-grade sarcomas usually necessitate ligation of the profundus femoris artery. The surrounding adductors are then detached from their origin along the inferior and superior pubic rami and ischium and removed en bloc with the tumor. The soft tissue defect remaining after tumour resection is usually reconstructed by transferring the sartorius muscle and the remaining medial hamstrings.

ANATOMY

- The adductor compartment of the thigh consists of the adductor magnus, brevis, and longus, the gracilis muscles, and the major vascular bundle of the lower extremity. Compartmental muscles arise from the pelvic floor and the medial aspect of the ipsilateral pelvic ring (symphysis pubis, inferior pubic ramus, ischium, and obturator fascia) and attach distally to the linea aspera and the medial aspect of the distal femur.
- The superficial femoral artery passes along the anterior and lateral margins of the entire compartment and forms the lateral border. This compartment is best thought of as an inverted funnel, with the base being the obturator ring and fascia, the lateral border being the femur and linea aspera, and the tip of the cone being the adductor hiatus (FIG 1A,B).

- The bony structures of the pelvic floor are the closest margins for large sarcomas that arise within this muscle group. Occasionally, tumors arising from the pelvic ring require resection of the pelvic floor (type III pelvic resection) if negative margins are to be obtained in conjunction with a formal adductor group resection. Rarely, proximal adductor tumors may extend as a dumbbell around the ischium into the ischiorectal fossa. The possibility of such extension must always be evaluated preoperatively (FIG 1C).
- The medial hamstrings also take their origin from the ischium. There is no intermuscular septum separating the adductor group from the posterior hamstrings proximally; therefore, extracompartmental extension may occur between the adductor muscles and the medial hamstrings as these tumors enlarge proximally. Adequate resection may require partial medial hamstring resection.

INDICATIONS

- Benign soft tissue tumors of the adductor compartment
- Soft tissue sarcomas of the adductor compartment

CONTRAINDICATIONS

- In general, a combination of several contraindications is required, most of which are related to extremely large tumors. In those cases, we recommend induction chemotherapy or isolated limb perfusion and repeated staging studies before a definitive decision is made regarding amputation.2,3
- Contraindications to limb-sparing surgery include the following:
  - Major neurovascular involvement
  - Pelvic floor involvement
  - Extensive extracompartmental extension

IMAGING AND OTHER STAGING STUDIES

- Preoperative staging studies must evaluate the sartorial canal, pelvic floor, medial hamstrings, ischium, psoas muscle, and hip joint to determine the full extent of bone and soft tissue involvement.
- Plain radiographs, computed tomography (CT), and magnetic resonance (MR) imaging of the affected thigh, ipsilateral hip joint, and hemipelvis are indicated.
- Most adductor tumors displace the superficial femoral vessels but rarely directly involve these structures (FIG 2). The profundus femoris artery, on the other hand, is often involved and must be ligated as it passes through the adductor brevis. The obturator artery and nerve, which pass through the obturator fascia, are routinely ligated.
- In light of the above, preoperative vascular evaluation of the patient should include direct questioning about intermittent claudication, limb swelling, and deep vein thrombosis. Vascular evaluation should include, in addition to physical examination, ankle–brachial pressure index and duplex ultrasound scanning.
FIG 1 • A. Anatomic structures of the adductor compartment. B. Cross-sectional anatomy of the adductor group. The sartorial canal is opened. C. Coronal section showing a dumbbell-shaped extension around the ischium into the pelvic cavity.

FIG 2 • A. Axial MRI showing a sarcoma of the adductor compartment. B. CT showing a large sarcoma of the proximal adductor compartment with displacement of the common femoral vascular bundle. Although the vessels are considerably displaced, a plane of dissection is evident between them and the tumoral mass.
of the femoral arteries and veins in the affected leg and of the greater saphenous vein in both legs.

- Underlying chronic obstructive arterial disease should prompt liberal use of angiography, CT angiography or MR angiography. Biplanar angiography, especially in patients older than 40, should be done to evaluate the patency of the superficial femoral artery: ligation of the profundus artery without a patent superficial femoral artery will lead to a non-viable extremity.

- In the past, angiography was also used preoperatively to outline the course of the vascular bundle within the affected thigh and to assess the likelihood of vascular reconstruction. High-definition MR scans provide the same useful information.

### INCISION AND EXPOSURE

- The incision extends from the proximal border of the inguinal region just inferior to the sartorius muscle and parallels the muscle to the posteromedial aspect of the knee to include the previous biopsy site (TECH FIG 1A). This incision permits large anterior and posterior flaps to be developed to visualize the vastus medialis, the sartorial canal, and the entire adductor compartment. The incision can be extended to expose the popliteal space medially if required. The superior extent may have to be T’d along the border of the inferior pubic ramus if there is a large soft tissue component extending to the obturator fossa and ischium.

- Large anterior and posterior fasciocutaneous flaps are elevated and retracted anteriorly to expose the vastus medialis and the sartorial canal and posteriorly to the lower edge of the adductor muscle group (TECH FIG 1B). The biopsy site is left en bloc with the underlying adductor muscles.

- The sartorius muscle is the key to the dissection of the entire muscle group. The sartorial canal is opened proximally to identify the common femoral artery before ligating the profundus vessels. The muscles are detached from their origin (superior and inferior pubic rami) and along the obturator foramen. The dissection continues from proximal to distal: the obturator vessels, then the profundus femoral vessels, are ligated and transected (TECH FIG 1C).

![TECH FIG 1 • A. The incision extends from the proximal border of the inguinal region just inferior to the sartorius muscle and parallels the muscle to the posteromedial aspect of the knee, to include the previous biopsy site. B. Large anterior and posterior fasciocutaneous flaps are elevated and retracted anteriorly to expose the vastus medialis and the sartorial canal and posteriorly to the lower edge of the adductor muscle group. C. Release of the adductor muscles from their insertions. The adductor magnus and longus are detached from their insertions on the femur throughout its length to the adductor hiatus. The adductor magnus tendon is then transected distally. A finger is inserted into the adductor hiatus to guide the cautery and protect the underlying vessels. (Courtesy of Martin M. Malawer.)](image)

### TUMOR RESECTION

- Low- and high-grade sarcomas, require en bloc removal of an overlying cuff of adductor musculature (TECH FIG 2A–C). Vascular involvement without a plane of dissection necessitates en bloc resection of the involved vascular segment (TECH FIG 2D–F).
VASCULAR AND SOFT TISSUE RECONSTRUCTION

- Resection of only a portion of the circumference of the artery for a short segment may be repaired by autologous vein patch. End-to-end anastomosis of a full circumferential resection is likely to be associated with considerable tension, and an interposition graft is required in those cases. Such reconstructions should be carried out with autologous tissue, primarily the greater saphenous vein (TECH FIG 3).
- It is best to use the vein from the contralateral thigh to preserve venous drainage as much as possible around the primary surgical site. This is particularly important if the femoral vein has to be ligated because of tumor extension around it or because of inadvertent injury. If the greater saphenous vein is inadequate or has been previously removed, the use of a prosthetic conduit is acceptable.
- An arm vein graft, although more time-consuming, is a better long-term solution. If the superficial femoral artery is chronically occluded, removal of the occluded segment is of no direct consequence. Careful intraoperative and postoperative evaluation of the profunda collaterals is mandatory; construction of a femoral...

TECH FIG 2 • A. Axial MRI of the midthigh showing a well-differentiated liposarcoma of the adductor compartment. B. The tumor is well encapsulated and can be safely removed with a narrow cuff of adductor musculature. C. Completion of tumor removal. The remaining structures to be transected are the insertions onto the distal femur, as well as portions of the gracilis muscle if required. The entire tumor is then removed and the wound is inspected. The superficial femoral artery and vein are inspected for any leaks. The cut edge of the muscles along the femur may be oversewn for hemostasis. If there is a large adductor tumor, occasionally a portion of the proximal medial hamstrings must also be removed en bloc. D. High-grade sarcoma of the adductor compartment extending into the superficial femoral vessels. Note the metal clip over the profundus femoral artery stump at the tumor bed. E. Blood vessels are suture-ligated and removed en bloc with the tumor. F. Gross surgical specimen. (C: Courtesy of Martin M. Malawer.)
Preoperative imaging of the entire adductor compartment and pelvic floor as well as detailed vascular evaluation

Full exposure of the vascular bundle before tumor resection

En bloc resection and reconstruction of affected vascular segments

Prophylactic calf fasciotomy if arterial reconstruction and venous ligation were done

Postoperative care

Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed. Full weight bearing is allowed as tolerated.

Outcomes

Resections around the adductor compartment are usually associated with minimal loss of function. Limb edema, however, may occur in patients who had vascular reconstruction and venous ligation. Adjuvant radiation therapy also increases the likelihood of chronic limb edema, which can be managed with lymphatic drainage.

Patients who require a vascular reconstruction have similar rates of local tumor control and systemic relapse compared with patients who have not. However, these patients have higher chances of wound complications and deep vein thromboses.1

Complications

Deep wound infection

Vascular insufficiency

Deep vein thrombosis

Flap ischemia

Local tumor recurrence

References


BACKGROUND

- The posterior thigh (hamstring musculature) is the least common of the three compartments of the thigh for sarcomas to arise within. About 15% to 20% of the soft tissue sarcomas of the thigh arise within the posterior hamstring musculature. There is great variation in the size of tumors that occur in the posterior thigh, and the location varies from a proximal location near the ischium to a distal location involving the popliteal space. The posterior thigh is a quiet surgical area; the most significant structure is the sciatic nerve. Almost all low-grade sarcomas can be resected safely. Most high-grade sarcomas can be resected by either a complete or partial muscle group resection. The sciatic nerve is rarely involved, either because of direct tumor extension or because of a primary nerve tumor.
- En bloc resection of the sciatic nerve with a malignant tumor of the posterior thigh rarely is done; this has traditionally been considered an indication for amputation. This approach was based on the belief that the expected motor and sensory loss around the leg and foot would result in an intolerable functional deficit and the development of pressure sores and, therefore, high rates of secondary amputation. However, it has been shown that limb-sparing resection of the sciatic nerve is associated with a good functional outcome in most patients who have this procedure. Most patients were ambulatory; all used a short-leg brace because of the peroneal nerve palsy, but only half required a walking aid (crutches or a cane).  

ANATOMY

- The posterior compartment consists of the semimembranosus, the semitendinosus, and the long and short heads of the biceps muscles. All of these muscles originate at the ischium and the linea aspera. No major artery is involved with this compartment.
- The sciatic nerve is the most significant structure. It runs from the sciatic notch into the compartment from lateral to the ischium and divides the medial and lateral hamstrings. A thick sheath surrounds the nerve, acting as a barrier to direct tumor extension. Often tumors arise within one of the individual muscles of the posterior thigh or between the muscles. In most cases the sciatic nerve is displaced around an adjacent muscle.

INDICATIONS

- Almost all low-grade sarcomas of the posterior thigh can be treated by partial or total resection of the involved muscle. High-grade sarcomas are treated by complete myomectomy of the muscle involved. If the tumor is extramuscular but still remains within the compartment, a partial muscle group resection is performed (FIG 1). Multiple muscles or the entire compartment can be resected instead of an amputation.
- Contraindications for limb-sparing resections of the posterior compartment include:
  - Extension into ischiorectal space: This makes the resection more difficult and may indicate the need for an amputation.
  - Extension into the popliteal space with vascular compromise
  - Femoral involvement with cortical destruction

IMAGING AND OTHER STAGING STUDIES

- Preoperative evaluation must include the ischium, the ischiorectal space, the retrogluteal area, and the popliteal space for tumor extension. The most useful imaging studies are computed tomography (CT) and magnetic resonance imaging (MRI). Angiography is required only if tumor extends distally into the popliteal space (FIG 2).

FIG 1 • Cross-sectional anatomy of the midthigh showing the extent of compartmental resection of the posterior thigh. The proximity of the sciatic nerve to large sarcomas within the posterior compartment is clearly indicated. (Courtesy of Martin M. Malawer.)
FIG 2 • Axial (A) and coronal (B) MR images of a myxoid liposarcoma of the posterior thigh. The tumor is extramuscular, arising in the space between the medial and lateral hamstrings. Clinical picture (C) and axial MR image (D) of a high-grade neurofibrosarcoma of the posterior thigh in a patient with an underlying neurofibromatosis. Café-au-lait spots are present on the patient’s thigh. This is a primary tumor of the sciatic nerve and must be removed to obtain wide margins of resection.

POSITION AND DISSECTION

- The patient is placed in a prone position. A long midline incision is used. An ellipse of skin is outlined so that there is a 2-cm margin of skin around the old biopsy site. The skin flaps are dissected, with care being taken to taper the flaps as one encounters the lateral margins of the dissection. The medial extent of the dissection is the gracilis muscle, and the lateral extent is the iliotibial tract (TECH FIG 1A,B).

TECH FIG 1 • Illustration (A) and clinical photograph (B) showing the surgical incision. The extent of the tumor is outlined. (continued)
SKIN FLAPS AND EXPOSURE

- The medial (semitendinosus and semimembranosus) and lateral (long and short heads of biceps femoris) muscles are exposed (TECH FIG 1C). The extent of the dissection is determined by the location of the tumor, but it generally involves the long head of the biceps femoris, the semimembranosus, and the semitendinosus (TECH FIG 1D–F). It is possible for part of the lateral quadriceps mechanism to be included with the specimen.

- Likewise, one or more muscle bundles of the adductor muscle group may be included if this will afford a more generous margin. The three muscles mentioned, which originate from the ischial tuberosity, are superficial to the sciatic nerve. With a tumor-free margin of resection on a tumor-free plane superficial to the posterior limits of this compartment, it is clear that the next adjacent structure is the sciatic nerve itself.

TUMOR REMOVAL

- Benign and low-grade extramuscular tumors can be removed with their enveloping capsule (TECH FIG 2A). High-grade sarcomas or tumors that involve muscles of the posterior compartment, however, require en bloc muscle resection.

- Dissection begins by exposing the ischial tuberosity. It is easily identified on the skin surface. The hamstring muscles are released at their origin from the ischial tuberosity (TECH FIG 2B). Traction is then placed on the muscle group, which is secured with a clamp. Blood ves-
A. The extramuscular liposarcoma shown in Techniques Figure 1F can be safely removed without adjacent muscle tissue. B. Dissection and release of the hamstrings origin is the first stage of tumor removal. C. Tumor mass and enveloping muscles are elevated from the sciatic nerve and the base of the compartment by blunt and sharp dissection. D. Tendinous insertion of the biceps femoris muscle on the lateral aspect of the thigh is transected. E. Sciatic nerve is grossly surrounded by high-grade sarcoma of the posterior compartment. No plane of dissection exists, and resection of the sciatic nerve is mandatory to achieve wide margins of resection. F. Tendinous insertion of the medial hamstrings is transected. (B–D,F: Courtesy of Martin M. Malawer.) (continued)
G. Photograph of the posterior thigh after resection of an extramuscular liposarcoma. Posterior thigh musculature is preserved and retracted, and the tibial and common peroneal nerves are seen underneath. H. Posterior thigh after en bloc resection of a high-grade sarcoma with the overlying muscles and the sciatic nerve; only the semimembranosus muscle is left in the surgical field.

By blunt and sharp dissection, the sciatic nerve, the short head of the biceps laterally, and the adductor muscles medially are elevated from the base of the dissection (TECH FIG 2C). The lateral muscle insertion is then transected. The long head of the biceps femoris muscle is transected through its tendinous portion on the lateral aspect of the thigh. Care should be taken to avoid injury to the common peroneal nerve (TECH FIG 2D).

If tumor grossly involves the sciatic nerve with no plane of dissection, the nerve is then resected (TECH FIG 2E). The insertions of the semimembranosus and semitendinosus muscles are then divided through their tendinous portion medially. The medial head of the gastrocnemius muscle is exposed (TECH FIG 2F–H).

The superficial fascia and skin are meticulously closed. Generous suction drainage is applied. The suction drains should not exit through the skin flaps, but just above the gluteal crease (TECH FIG 3).

The superficial fascia and skin are meticulously closed. Generous suction drainage is applied. The suction drains should not exit through the skin flaps, but just above the gluteal crease (TECH FIG 3).

PEARLS AND PITFALLS

| Preoperative | Imaging of the posterior compartment, ischium, and ischiorectal space |
| Intraoperative | Long midline incision |
| Postoperative | Use of short-leg brace and passive range-of-motion exercises |

A short-leg brace is applied and passive range-of-motion exercises are practiced immediately after surgery to avoid Achilles tendon shortening. Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed. Full weight bearing is allowed as tolerated.

OUTCOMES

Function after posterior thigh resection is almost normal: knee flexion is maintained by the remaining sartorius, gracilis, and gastrocnemius muscles.

Most patients who underwent en bloc resection of the sciatic nerve with a tumor of the posterior thigh were ambulatory; only half required a walking aid. All used a short-leg
brace because of the loss of the peroneal nerve. Padded shoes are used to prevent pressure sores.

Although all patients have an anesthetic ipsilateral foot, phantom limb pain, causalgia, pressure sores, and secondary amputation have not been documented. It seems that patients who had resection of the nerve at a lower anatomic level have better functional outcomes than patients whose resections involved a higher level. A possible explanation is that the innervation to the semimembranosus, semitendinosus, and long head of the biceps femoris is preserved in lower-level resections.

**COMPLICATIONS**

- Deep infection
- Flap ischemia and necrosis
- Sciatic nerve partial to complete dysfunction
- Local tumor recurrence

**REFERENCES**

Chapter 33

Overview of Surgical Resection of Space Sarcomas

Amir Sternheim, Tamir Pritsch, and Martin M. Malawer

BACKGROUND

- The three main extracompartmental spaces of the lower extremities are the femoral triangle, the sartorial canal, and the popliteal space. Each of these spaces is defined by the bordering compartments of the lower extremity.
- All extracompartmental spaces have walls comprising the muscles and their fascia of the neighboring compartment, lumen, that is filled with fat, fibrous tissue, and vessels that transverse the space, mainly arteries, veins, and nerves.
- The distinction between intracompartmental and extracompartmental spaces was introduced by Enneking in his classification of soft tissue tumors as part of the Musculoskeletal Tumor Society (MSTS) surgical staging system more than two decades ago. Enneking borrowed the term “extracompartmental” from his classification of bone tumors. In that context, it refers to tumors that originate in the bone and then breach the cortex and have a soft tissue component.
- Extracompartmental tumors were considered to be more aggressive than their intracompartmental counterparts and therefore harder to treat and with a worse prognosis, although this has changed in recent years.
- The original soft tissue sarcoma (MSTS) staging system had three prognostic criteria: metastasis, grade, and compartmentalization.
- The term “compartmentalization” divides soft tissue sarcomas into intracompartmental and extracompartmental tumors. Intracompartmental lesions are bound in all directions by natural barriers such as bone and muscle. These tumors arise within a structure—thigh: anterior, adductor, posterior; leg: anterior, peroneal, posterior superficial, posterior deep.
- In contrast, extracompartmental tumors either arise in spaces that are not bound by tight muscle fascia as compartments are (ie, popliteal space, sartorial canal, femoral triangle, axilla, antecubital fossa, paraspinal, intrapelvis, thigh, midfoot, and hindfoot) or develop secondary to the extension of an intracompartmental tumor beyond the confines of a compartment.
- Extracompartmental tumors have unique characteristics. They can extend a considerable distance with less anatomic restraint. They tend to be larger than their intracompartmental counterparts and frequently arise close to the neurovascular bundle. For these reasons, space tumors were initially considered to have a poorer prognosis than those confined to a compartment at diagnosis. Newer prognostic studies of soft tissue sarcomas do not support the assumption that space tumors have a worse prognosis due to their location but rather due to their size.
- Space tumors have been poorly addressed in Enneking’s classification and in the later American Joint Committee on Cancer (AJCC) classification. The classification of an intracompartmental lesion was based on tumor biology. Extracompartmental tumors were originally tumors that grew from within a compartment outward and into an adjacent compartment. Only later was the definition broadened to include space tumors. Since then, these space tumors have been poorly discussed in terms of their anatomy, biology, and surgical approach.
- The newer version of the AJCC classification for the staging of soft tissue sarcomas does not use compartmentalization as a staging criteria but rather tumor grade, size, and depth.
- Resection goals for soft tissue sarcomas of the extremities are wide resection of the lesion with negative resection margins and satisfactory extremity function.
- With intracompartmental tumors, these goals are achieved by resecting the tumor with the muscle that surrounds it. Space tumors lie in proximity to vessels and nerves, so achieving wide resection of the tumor without resecting the vessels is a delicate task.
- Some tumors, although in intimate proximity to the vessels, may still be resected with negative margins, whereas other tumors behave differently and invade the vessels. Vessel invasion dictates vascular resection. This biologic difference in tumor behavior is dictated by tumor grade, size, and histology and the anatomic location in the space from which it arises.
- Different tumors, due to their different biology, dictate different surgical resection techniques. Unlike intracompartmental tumors, space tumors differ vastly from one tumor to the next in the amount and technique of resection needed. Guidelines for resecting the different types of space tumors are lacking.

ANATOMY

Femoral Triangle Space

- The femoral triangle can be depicted as a three-dimensional pyramid. The base is the inguinal ligament, bound laterally by the sartorius and medially by the medial edge of adductor longus or the anterior border of gracilis (FIG 1).
- The floor of the femoral triangle is the iliopsoas laterally and the pectineus and adductor longus medially. Its apex is where the sartorius crosses over to the adductors.
- The main vessels traversing the canal are, from medial to lateral, the femoral vein, artery, and nerve. They enter the femoral triangle from the abdomen under the inguinal ligament and exit it distally from the tip of the pyramid into the sartorial canal.

Sartorial Canal

- The sartorial canal lies between the anterior (quadriceps) compartment and the medial adductor compartment, connecting the tip of the femoral triangle in the proximal thigh to the popliteal fossa in the distal posterior aspect of the thigh. The cross-section of the sartorial canal is shaped like an inverted triangle (FIG 2).
- The roof of the canal is made up of the sartorius muscle, which lies anterior and medial to the canal. The adductor longus makes up the floor of the canal. The lateral border is the thick fascia of the vastus medialis. Posteriorly, the border...
FIG 1 • Cross-sectional anatomy of the lower extremity spaces. A. Femoral triangle anatomy follows the general outline of a three-dimensional pyramid. The vessels within the space from medial to lateral are the femoral vein, artery, and nerve. The femoral triangle has as its base the inguinal ligament; it is bound laterally by the sartorius and medially by the medial edge of adductor longus and the anterior border of gracilis. The floor of the femoral triangle is the iliohypogastric laterally and the pectineus and adductor longus medially, and its apex is where the sartorius crosses over to the adductors. B. Popliteal space anatomy follows the general outline of a three-dimensional diamond shape. The biceps femoris, semimembranosus, lateral gastrocnemius, and medial gastrocnemius muscles form the four walls of the space. The popliteal artery and vein lie deep in the space, while the sciatic nerve is more superficial. The deep fascia serves as a barrier between the space and the superficial tissue.

Popliteal Space
- The popliteal space is shaped like a three-dimensional diamond. On its proximal lateral side is the biceps femoris muscle. On the proximal medial side are the semitendinosus and semimembranosus muscles. On the distal side of the space are the lateral and medial heads of the gastrocnemius muscles (see FIG 1B).
- Anterior to the space is the posterior capsule of the knee joint. Posterior to the space is a thick popliteal fascia.
**Vessels of the popliteal space are the popliteal artery and vein, which enter proximally through the adductor hiatus and exit distally between the two heads of the gastrocnemius.**

**The sciatic nerve enters the space through the proximal tip and divides into the peroneal and tibial nerve branches.**

**INDICATIONS**

A set of surgical guidelines is a helpful clinical conceptual tool in resecting lower extremity soft tissue sarcomas from the three anatomic spaces. Using preoperative MRIs and initial intraoperative impressions, tumors may be divided into three groups.

Tumors are divided according to their location of origin.

- Type 1 tumors arise from within the space. Typically they originate from fat or fibrous tissue within the space. These tumors are termed “luminal” because they may approximate but do not adhere to the walls of the space or any of the arteries, veins, and nerves in the space. They lie within the lumen.
- Type 2 tumors arise from one of the walls that border the space. These tumors arise from within a muscle or the muscle fascia that borders the space.
- Type 3 tumors invade the arteries, veins, or nerves and are termed vessel lesions. These lesions either originate from or invade the vessels walls.

The surgical planes of resection differ for each of the three types:

- Type 1 (luminal) lesions are resected with a thin cuff of healthy tissue that surrounds the tumor. At times these tumors almost deliver themselves once the space is opened. Tumor margins, although negative, are often close.
- Type 2 (wall) lesions are essentially resected with the muscle from which they originate. Wide surgical resection is achieved by resecting the tumor with its muscle of origin and the fascia covering that muscle.
- Tumors that approximate the vessels and are adherent to the vessel sheath are resected with the vessel sheath as an oncologic barrier and should be approached in the following manner. On approaching the tumor area, if the sheath appears free and separates easily from the wall of the artery, the surgeon continues the dissection, leaving the sheath attached to the surface of the specimen by making an incision in the sheath on the side away from the tumor and extricating the artery (and vein if possible) from its sheath.
- The fibrous sheath surrounding the vessels is inspected carefully on frozen section after it has been removed en bloc with the tumor. Even when the tumor does not adhere to the vessel sheath, it should be removed separately from the tumor so that it can be examined to rule out tumor invasion through the sheath, thus ensuring safe resection margins.
- Type 3 (vessel) tumors are imbedded in the vessel wall. When it is clear that the vessels are involved, the surgeon establishes vessel control proximally and distally and works around the tumor widely all the way around until the soon-to-be specimen is tethered by the vessels proximally and distally. The surgeon then chooses the grafts to be used, administers heparin, and applies vascular clamps proximally and distally. The specimen is removed, followed by reconstruction.

- This circumferential freeing of the tumor and the normal tissue margin is the essential difference between space tumors involving the vessels and those not involving them, a difference in surgical strategy.
- After the artery is resected it must be reconstructed with a synthetic graft or a reverse saphenous vein graft. Venous resection does not need to be reconstructed as long as the ipsilateral saphenous vein is intact. Potential morbidity from venous resections arises from the risk of edema in the affected limb. Nerves invaded by tumor must be resected en bloc (namely, sciatic, femoral, tibial, and peroneal). These nerve resections do not dictate a need for amputation but can be treated with limb-sparing surgery. As the tumor is resected en bloc with the vessel, these resections, while challenging surgically in their reconstructive aspects, are relatively straightforward in their tumor resection aspects and can achieve wide surgical margins.

**IMAGING AND OTHER STAGING STUDIES**

Plain Radiography

Plain radiography studies are performed to rule out local invasion of the bone by the tumor.

Computed Tomography and Magnetic Resonance Imaging

These studies are used to assess the anatomic location and size of the tumor and its relation to surrounding structures. These studies are particularly important since the tumor often distorts the normal anatomy in these small, tight spaces. Arterial contrast and three-dimensional reconstruction enhance these studies even further.

MRI is useful in assessing the tumor’s invasion into neighboring anatomic structures, namely the muscles bordering the canal and the vessels traversing the canal.

Bone Scan

Bone scan is used to rule out distant metastatic disease and may give a clue to the malignancy of the tumor, as high-grade tumors show a strong tumor blush in the late arterial flow phase of the three-phase technetium scan.

Angiography and Other Studies

Angiography is used to assess the vascularity of the tumor, tumor blush, the location of the vessels feeding the tumor, and the relation between the tumor and the major artery and vein, giving vital information as to whether the tumor has displaced or invaded the vessel.

Venography of the limb is used to rule out venous thrombus, tumor thrombus, or direct tumor involvement.

**Biopsy**

- Core needle and open incisional biopsy give vital information about the tumor. The proximity of these tumors to major vessels adds an additional risk factor for both iatrogenic damage to the vessels and contamination of the space with tumor cells due to hematoma. We prefer a small needle biopsy and a fine-needle aspiration. It is most important to determine whether the tumor is a lymphoma or a mesenchymal tumor (soft tissue sarcoma).
- Lymphomas do not require surgical resection. The exact histogenesis is not required if it is a soft tissue sarcoma, because
resection margins are usually more defined by the anatomy than the actual surgical procedure. However, it is important to determine the grade (high or low) because neoadjuvant chemotherapy may be recommended.

SURGICAL MANAGEMENT
- Wide exposure of the space is critical. The space must be unroofed by retracting and at times detaching the overlying muscle.
- Initially critical vessels should be identified and controlled proximally and distally to the tumor, where the anatomy has not been distorted.
- Tumor is resected in a circumferential manner with wide margins when possible. When the lesion is in intimate proximity to the vessels, the sheath of fibrous tissue surrounding the vessels should be resected en bloc with the tumor unless it is evident that it has not been invaded. The vessel sheath should be opened from the opposite side of the tumor to assess whether tumor that adheres to the sheath has invaded the vessel wall as well.
- Tumor that invades the vessels must be resected with the vessels, which then need to be reconstructed.
- When the tumor does not seem to grossly invade the vessels, the sheath that has been resected en bloc with the tumor should be examined on frozen section to rule out microinvasion.
- Soft tissue reconstruction is done by moving adjacent muscle to cover the vessels. This is essential. If there is later wound breakdown, the vessels must have good vascularized soft tissue coverage.

Preoperative Planning
- Preoperative MRI and CT and possible three-dimensional CT angiography are useful to identify the exact size and location of the tumor. This will help in classifying the type and thus in choosing the type of surgery that is required.
- Angiography is extremely important to determine accurately the position of the artery within the specific space. Often the artery is greatly displaced from the normal anatomic relationships. In the popliteal space, the artery is often displaced anterior to the tumor, whereas the sciatic nerve (tibial and peroneal branches) is often displaced in the opposite direction (ie, posteriorly and or laterally). In addition, the decrease in tumor blush from the initial angiogram and the final one after induction chemotherapy (for high-grade sarcomas) correlates well with the percentage of tumor necrosis. If there is a good angiographic response, then a marginal resection is very reasonable.

- Venography: The major veins may be occluded due to pressure of the soft tissue mass or invasion of the vascular sheath, and therefore by inference the major artery or nerves may be involved by tumor. Venous grafts are not performed because most will not remain patent.
- Neurologic examination: Involvement of a major nerve within a space often presents with severe pain or motor weakness. This should suggest to the surgeon that the major nerve may have to be sacrificed. In general, femoral nerve (femoral triangle) or sciatic nerve (popliteal space) involvement is not a sole indication for amputation.

Positioning
- Femoral triangle (space): A supine position is used. The abdomen and the thigh must be prepared together. It is often necessary to begin the exploration of the femoral vessels retroperitoneally to identify and to place a vascular loop around the external iliac artery and vein for proximal control.
- Sartorial canal: The patient is placed supine and the lower extremity is flexed and rotated externally at the hip. The entire thigh, lower pelvis, and leg are prepared so that the distal pulses can be palpated (or assessed using Doppler).
- Popliteal space: The patient is placed prone. The posterior thigh from above the gluteal crease to the foot is prepared free. This provides good exposure to the retrogluteal area, the posterior thigh (if the tumor extends proximal from the space), the popliteal space, and the leg (calf) if the tumor extends distal to the popliteal space, specifically below or between the gastrocnemius muscles.

Approach
- Femoral triangle: The incision begins proximal to the inguinal ligament as a gentle S and crosses the inguinal ligament. It then proceeds distal to the tip of the femoral triangle to the proximal portion of the sartorial canal. The incision somewhat parallels the medial border of the sartorius muscle. The major vessels are located proximal and distal before any attempted resection.
- Sartorial canal: The incision follows the sartorius muscle from the apex of the femoral triangle to the level of the adductor hiatus. If necessary, the incision may be extended to include the popliteal space (if the tumor is distal in the canal) or proximal (if the tumor is located proximal in the canal and extends into the femoral triangle). The sartorius muscle is mobilized either anteriorly or posteriorly along its borders (as long as the sartorius is not involved with tumor). Segmental pedicles to the sartorius muscle may be ligated. If the sartorius muscle is involved, then the muscle is transected proximal and distal to the tumor for exposure before resection.

TUMORS OF THE FEMORAL TRIANGLE
- The femoral triangle is exposed through a longitudinal incision that curves over the inguinal ligament and extends to the sartorial canal. The external iliac vessels (retroperitoneal) are exposed and a vessel loop is placed around them (TECH FIG 1).
- Wide subcutaneous skin flaps are made above the femoral triangle fascia to permit identification of the tumor, sartorius muscle, and adductor fascia.
- The proximal end of the sartorial canal is opened and the superficial femoral artery and vein are located to gain distal control.
- The deep fascia of the canal is opened, exposing the tumor.
- The tumor is explored and its surgical type is determined. Its relationship to the femoral nerve and femoral vessels is assessed. This will define which structures need to be resected and which can be preserved. If a vascular graft is required, either Gore-Tex or contralateral saphenous
vein can be used. If the femoral nerve is resected, medial and lateral hamstring transfers are performed at a second stage after wound healing or radiotherapy.

- The tumor is resected with surrounding fat, lymphatics, and any necessary muscle.
- Hemoclips are placed around the surgical bed.

TUMORS OF THE SARTORIAL CANAL

- The incision follows the course of the sartorius muscle. It may be extended proximally (femoral triangle) or distally (popliteal space) as required (TECH FIG 2).
- Wide subcutaneous flaps are elevated off the deep fascia to expose the anterior and posterior borders of the sartorius muscle.
- The sartorius muscle is then mobilized either along the anterior interval with the vastus medialis muscle or posteriorly along the adductor interval.
- If the sartorius muscle is not involved by tumor (based on the preoperative MRI), the muscle is usually preserved. The sartorial canal is explored both proximal and distal to the tumor mass to identify the superficial femoral artery and vein. If the saphenous nerve is encountered, it may be sacrificed.
- Tumor resection is then performed according to the type of tumor. Type 1 (intraluminal) tumors usually require only a simple marginal excision. If the tumor approaches the vessels, then the sheath is removed and sent for a frozen section examination. If no tumor is present at this margin, the sartorius flap is then closed.
- The sartorius muscle is routinely detached from the anterior superior iliac spine and rotated to cover the remaining defect and neurovascular structures. The sartorius muscle is tenodesed to the inguinal ligament and the remaining adjacent musculature. The skin flaps are then closed. A flat drain is placed deep to the muscle transfer.

TECH FIG 1 • Intraoperative image of a type 3 resection of a leiomyosarcoma arising from the femoral vessels. Proximal and distal control of the involved vessel is crucial. A vessel loop is placed on the external iliac artery (marked vessel). The spermatic cord is tagged and mobilized. A. The skin incision and the surgical approach follow the line of the inguinal ligament and sartorius muscle. B. The sartorius muscle is detached proximally to allow better exposure and soft tissue reconstruction. C. Soft tissue is reconstructed by fanning out the sartorius muscle, thus achieving a muscle barrier between the femoral vessels and the skin.

TECH FIG 2 • Type 2 resection of a tumor of the sartorial canal arising from the wall (vastus medialis) that comes in close proximity of the vessels. Even so, the tumor was resected and the vessels were spared, as it did not penetrate the fascial sheath surrounding the vessels. A. The skin incision is carried along the sartorius muscle. The sartorius is resected with the tumor if necessary from an oncologic point of view. If the tumor is not connected to the sartorius muscle it may be disconnected distally for exposure. B. Soft tissue reconstruction with a gracilis muscle transfer affords good soft tissue coverage of the vessels of the sartorial canal and is considered crucial. The distal end of the gracilis muscle is disconnected and rotated anteriorly. The muscle is then spread out like a fan and reattached anteriorly.
TECH FIG 3 • Large popliteal type 1 resection of a luminal tumor. Intraoperative picture shows wide exposure of the popliteal space. The tumor is in close proximity to the sciatic nerve above it and the popliteal artery and vein just below it (vessel loops). As it is a luminal tumor, resection with negative margins was achieved without resection of the surrounding vessels. A. Skin incision and subcutaneous flaps necessary to permit exposure. Care should be taken not to open the popliteal fascia while developing the flaps to reduce the risk of neurovascular injury. B. Release of the gastrocnemius heads, which are then reflected distally for maximal exposure. The popliteal vessels are identified distally between the gastrocnemius heads. C. Tenodesis of the heads of the gastrocnemius and the hamstring muscles, forming a muscular coverage over the popliteal vessels and nerves.

TUMORS OF THE POPLITEAL SPACE

- A “lazy S” incision is made over the popliteal space. The medial arm is always made along the medial border of the medial hamstrings because the popliteal vessels come into the space medially from the adductor hiatus (TECH FIG 3).
- The lateral arm of the incision is made along the lower border of the biceps femoris muscle because the peroneal nerve is initially picked up just below the deep fascia as a satellite of the biceps muscle.
- Wide subcutaneous flaps are made exposing the deep popliteal fascia. Great care is taken not to penetrate this fascia early because it is easy to get lost in the popliteal fat.
- The peroneal nerve is first identified just medial to the biceps muscle, just under the deep fascia.
- The deep fascia is then opened longitudinally and the sciatic nerve is identified between the medial and lateral hamstrings.
- The four muscles that make up the “diamond” of the popliteal space are now identified: the medial and lateral hamstrings proximally and the medial and lateral gastrocnemius muscles distally.
- The midline of the gastrocnemius muscles is identified. The popliteal vessels and the tibial nerve are mobilized and a vessel loop is placed around them for distal control.
- The sciatic nerve is then mobilized, both the peroneal and the tibial nerve components.
- The popliteal artery and vein are identified proximally near the medial hamstrings deep in the fossa as they enter from the adductor foramen. The surgeon can easily feel the pulse (a tourniquet should not be used), and a finger can be safely placed into the adductor hiatus for localization.
- Careful dissection and mobilization of the vascular and nerve structures are then performed.
- The medial or lateral head, or both, of the gastrocnemius muscles may be released from their origins on their respective femoral condyles to help in the exposure. Similarly, the semimembranosus or biceps femoris muscle may be released for better exposure.
- If the tumor extends proximally (between the hamstrings or distally between the gastrocnemius muscles), then the corresponding muscle must be released to obtain a wide excision.
- The popliteal vessels are usually displaced and not involved by tumor, unless a leiomyosarcoma is arising from them. In this situation a vascular graft is required.
- The tumor is resected only after all of the above structures are identified and mobilized. Sheaths of the adjacent nerves or vessels are removed and sent for frozen section examination to determine whether further resection is required.
- Soft tissue closure is necessary to cover and fill the popliteal space to prevent wound problems. The medial and lateral gastrocnemius heads are tenodesed to each other, covering the distal portion of the popliteal space and the neurovascular structures. Similarly, the medial hamstrings are tenodesed to the biceps femoris muscle to close over the proximal popliteal space. Both the gastrocnemius and the hamstrings are then sutured together to make a nice muscle closure of the entire popliteal space.
POSTOPERATIVE CARE
- Pulses are checked hourly for the first 24 hours.
- Drains are removed on postoperative day 2 or 3.
- Full weight bearing is permitted within 1 to 2 days.
- Minimal rehabilitation is required. Motion is limited according to the anatomic space for 7 to 10 days to permit complete wound healing. Popliteal incisions are protected with a bent-knee brace until the wound is well healed.
- Postoperative radiation therapy is started only after the wound is well healed, between 2 and 4 weeks.

OUTCOMES
- We have treated 53 patients with space tumors. Malignant fibrous histiocytoma and liposarcomas are the most common. A classification system was developed as described above. Most sartorial tumors tend to be of low grade and involve the wall; the sartorius muscle is most often involved.
- Liposarcomas and secondarily malignant fibrous histiocytomas were the most common histologic types. Tumors involving the wall of the space were more common than those that are intraluminal or those that arise from the major neurovascular structures. Tumors arising from the major vessels were leiomyosarcomas.
- Popliteal tumors, often high grade, can be dissected with negative margins and followed by radiation therapy. Sciatic nerve resection is very unusual.
- Amputation for all space tumors is needed in less than 10% of cases and is usually reserved for tumors that locally recur.
- The overall survival depends on the grade. Local recurrence is less than 10% for all sites. Radiation therapy is used for all high-grade sarcomas after wound healing.
- The surgical classification has been implemented on 53 patients with soft tissue tumors of the lower extremity spaces (femoral triangle, sartorial canal, and popliteal fossa).

COMPLICATIONS
- The most common problem is wound or flap necrosis. This is more common in the popliteal space. Incisions of the femoral triangle or the sartorial canal heal well.
- Neuropraxia, especially of the peroneal nerve, is common but, function almost always returns.
- Infection is unusual.
- Preoperative radiation is not used due to the risk of wound dehiscence or necrosis.
- Secondary amputations occur in less than 5% to 10% of patients, often after local tumor recurrence.

REFERENCES
Chapter 34

Popliteal Resections

Jacob Bickels and Tamir Pritsch

BACKGROUND

- Soft tissue sarcomas of the popliteal fossa are rare, accounting for less than 5% of all soft tissue sarcomas of the extremities. Surgery in this anatomic area is challenging: performing a good resection with wide surgical margins is often difficult because of the periarticular location and the proximity to neurovascular structures.3,6,9
- Such tumors formerly were treated with amputations4; however, better understanding of tumor biology and advances in chemotherapy and radiation therapy now allow limb-sparing procedures to be performed in most of these cases.

ANATOMY

- The popliteal space is diamond-shaped; on its superior aspect it is bounded by the semimembranosus and semitendinosus muscles medially and by the biceps femoris muscle laterally. Its inferior boundaries are the two heads of the gastrocnemius muscle. The roof of the fossa is the thin popliteal fascia; the floor is the posterior aspect of the distal end of the femur, the posterior capsule of the joint, and the popliteus muscle, which overlies the proximal tibia.
- The popliteal artery and vein enter the popliteal space from its medial aspect through the adductor hiatus and lie directly behind the posterior capsule of the knee joint.
- They run obliquely through the fossa and branch into two superior, a single middle, and two inferior genicular branches. After exiting the popliteal fossa the popliteal artery divides into its terminal branches: the anterior tibial, posterior tibial, and peroneal arteries. The popliteal vein lies between the tibial nerve and the popliteal artery. The short saphenous vein pierces the popliteal fascia to join the popliteal vein within the fossa.
- The tibial nerve enters the popliteal fossa lateral to the popliteal artery and approximately in the middle of the fossa. It crosses the artery to its medial aspect and remains at that location. The common peroneal nerve slopes down the suprolateral border of the popliteal fossa toward the medial aspect and along the biceps femoris tendon, where it enters a tunnel within the substance of the peroneus longus muscle.

IMAGING AND OTHER STAGING STUDIES

Magnetic Resonance Imaging

- MRI is the imaging modality of choice for the diagnosis of popliteal soft tissue sarcomas. The typical finding is a soft tissue mass with a solid component, no communication to the knee, and central or irregular nodular gadolinium enhancement. Conversely, the classic presentation on MRI of popliteal cysts, which are the most frequently encountered masses in the popliteal fossa, is a well-defined, unilocular, fluid-filled cyst in direct communication with the knee joint; its peripheral walls are normally enhanced with gadolinium.
- MRI is also used to evaluate the size of the tumor and its relation to the neurovascular structures, the posterior knee joint capsule, and surrounding musculature and to assess local lymph node involvement (FIG 1A–C).

Plain Radiography and Computed Tomography

- Plain radiography and CT scans are performed to rule out invasion of the tumor into the adjacent bones.

Angiography

- Angiography (FIG 1D) is routinely used to assess the relation of the tumor to the popliteal artery, patterns of possible vascular displacement, the presence of vascular anomalies, and arterial and venous patency.

SURGICAL MANAGEMENT

Positioning

- The patient is placed in the prone position (FIG 2) and both lower limbs are draped. The contralateral leg is prepared for saphenous vein harvesting, which will be necessary for arterial reconstruction if the popliteal artery must be resected.
FIG 1 • MRI of a typical popliteal sarcoma. A. Normal MRI of the distal section of the popliteal (diamond) space through the medial and lateral gastrocnemius muscle insertions onto the femoral condyles. B. Large popliteal soft tissue sarcoma. C. Sagittal view showing the relationship of a popliteal sarcoma to the adjacent femur and knee joint (not involved in this case). D. Angiogram of an extremely vascular popliteal sarcoma. Arterial embolization may be useful. All of the small pedicles to the tumor must be ligated at the time of resection. The popliteal artery is rarely involved directly and is often preserved.

FIG 2 • Clinical photograph of a large popliteal sarcoma. A prone position is routinely used for surgical resection.

EXPOSURE

- An S-shaped incision is made, crossing from proximal-medial to distal-lateral at the level of the knee joint (TECH FIG 1A). The medial-proximal arm of the incision allows the popliteal vessels to be identified as they exit the adductor hiatus, and the lateral distal arm enables easy exposure of the peroneal nerve, posterior to the fibular head. In addition, making the distal arm of the incision lateral avoids damaging the greater saphenous vein, which runs on the medial aspect of the leg (TECH FIG 1B).
- The very thin and friable popliteal fascia lies in close proximity to the neurovascular bundle (especially the peroneal nerve, which lies just deep to the popliteal fascia at the level of the fibular head), making it a critical landmark. To identify the popliteal fascia, subcutaneous flaps are made. The landmarks and various structures of the popliteal fossa can often be palpated through the fascia, which is then cautiously incised accordingly. Failure to realize that the dissection is underneath the fascia and that only a few millimeters separates the blade from the vessels and nerves of the popliteal fossa can easily result in injury of those structures.
TECH FIG 1 • A. Incision used for resection of popliteal sarcomas. A wide exposure of the popliteal (diamond) space must be obtained to avoid inadvertent injury to important neurovascular structures. B. The medial and lateral hamstrings are mobilized and retracted with a wide self-retainer retractor. Similarly, the medial and lateral gastrocnemius heads are detached from the femoral condyles, retracted, or both. The two heads of the gastrocnemius muscles are split at the midline, taking care not to injure the now more superficial tibial nerve and vessels (located just anterior to the nerve).

TUMOR RESECTION

- The initial step of a popliteal fossa resection is exposure and identification of the neurovascular bundle. This allows the surgical team to mobilize the vulnerable structures before resection. Mobilization is usually accomplished by exposing the structures in the distal thigh and proximal leg and following them to the popliteal fossa (TECH FIG 2A,B). If the popliteal vessels are difficult to expose, an intraoperative Doppler ultrasound device can be helpful.
- After mobilizing the neurovascular bundle, the tumor is resected with a cuff of normal tissue if possible. Not uncommonly, however, the vessels, the nerves, or both are

TECH FIG 2 • A. The sciatic nerve is identified, as well as its two major branches, the tibial and peroneal nerves. B. Exposure and identification of the popliteal space and a large soft tissue sarcoma. The tumor has arisen between the sciatic nerve and the popliteal vessels. The nerve is easily seen and identified posteriorly and the popliteal vessels were found anterior to the tumor. (continued)
TECH FIG 2 • (continued) 

C. Lateral intraoperative view of the popliteal sarcoma. D. Surgical resection site after tumor removal. The sciatic nerves and the popliteal vessels were preserved.

In close proximity to the tumor mass or adherent to its pseudocapsule. In such cases, the structures are dissected free and the nerve sheath and adventitia are removed and pathologically examined using frozen sections to determine the surgical margins (TECH FIG 2C,D).

- Vessels and nerves of the popliteal fossa must be resected if they are embedded in the tumor mass. The popliteal artery can be reconstructed with a saphenous vein graft taken from the contralateral leg. We consider reconstructing the popliteal vein to be unnecessary because the ipsilateral saphenous vein can compensate for its loss. Nerve involvement or vascular involvement is not an indication for primary amputation if these features can be adequately resected.1,2,5

SOFT TISSUE RECONSTRUCTION

- After the tumor is resected, the two heads of the gastrocnemius are sutured to each other and to the hamstring muscles to form a uniform muscle layer that covers the popliteal space (TECH FIG 3A). This wound closure technique minimizes the occurrence of deep wound infection by forming a muscular barrier between the skin incision and the popliteal space. The resected tumor specimen is shown in (TECH FIG 3B,C).

TECH FIG 3 • A. Closure of popliteal space. The medial and lateral heads of the gastrocnemius muscles are tenodesed below the sciatic nerve to cover the popliteal vessels. The medial (semimembranosus muscle) and the lateral hamstrings (biceps femoris muscle) are similarly tenodesed proximally to close the popliteal space and are also tenodesed to the gastrocnemius repair. This closure closes off all the dead space as well as protecting the popliteal vessels and provides a nice muscle base if a skin graft is needed. B. Gross specimen of the popliteal sarcoma. C. The tumor transected.
PEARLS AND PITFALLS

- Soft tissue sarcomas of the popliteal fossa commonly displace the usual anatomic landmarks. To locate the components of the neurovascular bundle, one must expose regions that are proximal and distal to the popliteal fossa, identify the major nerves and vessels, and follow them to the popliteal fossa.

- The sciatic nerve is proximally identified between the medial and lateral hamstrings; distally, the peroneal nerve is carefully identified posterior to the fibular head, immediately below the thin popliteal fascia, and the tibial nerve is found between the two heads of the gastrocnemius.

- The popliteal vessels are identified proximal to the popliteal fossa as they exit the adductor hiatus and distally between the two heads of the gastrocnemius muscle. We routinely detach the origin of the medial and lateral hamstrings and both heads of the gastrocnemius muscle to achieve a wide exposure. In the popliteal space the nerves are usually found posterior to the tumor mass and the vessels are usually anterior to it.

- While running through the popliteal fossa the popliteal artery branches into two superior, a single middle, and two inferior genicular arteries. The inferior genicular vessels pull the popliteal artery toward the joint capsule and usually must be ligated to allow its mobilization. The popliteal vein, which runs more superficial to the artery, lies between the popliteal artery and the tibial nerve.

- The two main venous tracts responsible for the venous drainage of the leg are the popliteal vein and the greater saphenous vein. During tumor resection, excision of the popliteal vein may be unavoidable; for this reason, care should be taken not to damage the greater saphenous vein, which might be the only remaining venous tract. Moreover, if the popliteal artery and vein are resected, the contralateral greater saphenous vein should be harvested to reconstruct the popliteal artery. Ligation of both the popliteal vein and the ipsilateral greater saphenous vein may lead to severe venous insufficiency.

POSTOPERATIVE CARE AND REHABILITATION

- After surgery, the patient is placed in a long, posterior splint in 15 to 30 degrees of knee flexion to relieve tension from the neurovascular bundle and skin incision.

- Physiotherapy for muscle strengthening and range of motion is not started until the skin incision is completely healed.

OUTCOMES

- Only four case series of soft tissue sarcomas were identified in the English literature.3,7,8,10 All of the studies found that the prognosis was equivalent to that of soft tissue sarcomas in other locations and the limb salvage rate was high.

- In a recently published case series of 29 patients with popliteal sarcomas with a median postoperative follow-up of 79 months, of the 16 patients with high-grade tumors 3 (19%) had local recurrences and 4 (25%) had distant metastases; of these, 2 died.8 None of the patients with low-grade tumors had local recurrences or distant metastases. The overall limb salvage rate was 86.2%; for the patients with high-grade tumors it was 75%.8

COMPLICATIONS

- Superficial wound dehiscence is the most common complication. It usually occurs during adjuvant radiation therapy and sometimes necessitates local surgical débridement.

- Peroneal palsy is most commonly due to neuropraxia and usually resolves after several weeks.

- Knee range-of-motion limitation is usually secondary to adjuvant radiation therapy to the popliteal fossa. In our series of 29 patients with popliteal sarcomas, 14 of the 26 patients (53.8%) who underwent primary resections had full range of motion of the knee joint, 12 patients (46.1%) had mild to moderate limitations in knee flexion (120 to 90 degrees), and 4 patients (15.3%) had mild flexion contractures (5 to 15 degrees).8 No patient in our series required knee manipulation or contracture release.

REFERENCES


BACKGROUND

- Malignant tumors of the soleus and gastrocnemius muscles are rare and have been traditionally treated with above-knee amputation. During the past 20 years, the treatment of soft tissue sarcoma of the lower extremities has undergone a dramatic shift toward limb-salvage procedures.
- Better understanding of the biologic behavior of these tumors, the availability of effective neoadjuvant chemotherapy (which often decreases the tumor size and facilitates a more conservative resection), and the recognition that close negative surgical margins in conjunction with postoperative radiation therapy often provide good local control now allow tumor resection instead of amputation in most cases.

ANATOMY

- The soleus and gastrocnemius muscles form a tripartite muscle sometimes referred to as the triceps surae muscle. Together with the plantaris muscle they form the superficial posterior muscle group of the leg. These muscles act together in plantarflexing the foot and ankle joint.
- The gastrocnemius muscle is the most superficial in the superficial posterior compartment and forms most of the prominence of the calf. It has two heads of origin. Its medial head is slightly larger and extends a little more distal than its lateral head. The two heads converge at the inferior margins of the popliteal fossa, where they form the inferolateral and inferomedial boundaries. The lateral head originates from the lateral surface of the lateral femoral condyle and the medial head arises from the posterior surface of the femur, superior to the medial condyle.
- The soleus muscle is a broad fleshy muscle that lies deep to the gastrocnemius muscle. It arises from the posterior aspect of the head and superior fourth of the fibula, the soleal line, and the middle third of the medial border of the tibia. It also arises from the tendinous arch between the tibia and fibula, which arches over the tibial vessels. The soleus muscle and both heads of the gastrocnemius converge to form the Achilles tendon, which inserts into the posterior surface of the calcaneus.

INDICATIONS

- Tumors that arise from and are completely within the soleus muscle
- Most low-grade and some high-grade sarcomas

IMAGING AND OTHER STAGING STUDIES

Computed Tomography and Magnetic Resonance Imaging

- Careful examination of the CT and MRI is essential in determining resectability. Tumors that extend to and around the popliteal trifurcation or into the gastrocnemius muscles usually require an amputation (FIG 1).
- The popliteal space must also be evaluated. Proximal tumors arising within the soleus muscle often extend into the popliteal space and may involve the popliteal vessels, the sciatic nerve, or both.

Bone Scan

- Bone scans may show involvement of the adjacent tibia, fibula, or both.
- Areas of uptake should lead to close examination of the corresponding cuts of the MRI and CT scans.

Angiography and Other Studies

- Biplane angiography is very useful in determining vascular displacement or encasement.
- Careful analysis of the popliteal trifurcation is necessary before surgery and may indicate tumor involvement and thus the need for an amputation.

Biopsy

- The biopsy site should be in line with the planned incision for resection and must be located over the most prominent portion of the tumor.
- Core needle biopsy has been shown to provide reliable pathologic diagnoses and is our preferred method. Multiple samples can be collected from the same puncture site.
- Areas where major arteries and veins traverse should be avoided so as not to penetrate the vessels and risk tumor cell contamination.

SURGICAL MANAGEMENT

Positioning

- Resection is performed with the patient in a prone position. General or epidural anesthesia is used.
This patient with an alveolar soft part sarcoma of the soleus muscle was treated with induction chemotherapy followed by limb-salvage surgical resection and reconstruction with a Gore-Tex vascular graft. A, B. The axial and coronal T2-weighted MRIs show a large tumor arising within the soleus muscle. Arrows show the extension of the tumor.

**RESECTION OF SOLEUS MUSCLE WITH OR WITHOUT ADJACENT GASTROCNEMIUS MUSCLE**

- The initial incision is made longitudinally on the posterior aspect of the leg and shifted medially or laterally, depending on the anatomic location of tumor (TECH FIG 1A). A lateral incision is used if resection of the lateral gastrocnemius is planned. A midline posterior incision is used for resections of the medial gastrocnemius, soleus, and deep posterior compartment.
- The fascia is dissected with the subcutaneous tissues, and large fasciocutaneous flaps are raised. The peroneal nerve is first identified and placed within a vessel loop; this is followed by careful dissection to identify the sciatic and tibial nerves.
- The popliteal vessels are identified by opening up the deep fascia overlying the two heads of the gastrocnemius. Radical excision of the medial or lateral heads of the gastrocnemius is achieved by ligation of their main pedicle (medial or lateral sural artery and vein, respectively) and transection of their femoral origin and insertion to the Achilles tendon.
- Exposure for resection of the soleus muscle is achieved by partial or complete Achilles tenotomy and reflection of the medial and lateral heads of the gastrocnemius muscle proximally (TECH FIG 1B).
- By blunt dissection the soleus is separated from the transverse intermuscular septum, which outlines the deep posterior compartment (TECH FIG 1C, D). The soleus can then be detached from its tibial and fibular origins and calcaneal insertion.
- Residual defects in the Achilles tendon should be reconstructed. The wound is then closed over closed suction drains.

**TECH FIG 1** • A. Anatomy and a utilitarian approach to the posterior compartment of the leg. B. Exposure of the tumor and identification of the posterior vessels requires the release of the medial and lateral heads of the gastrocnemius muscle from the Achilles tendon. (continued)
Chapter 35  SOLEUS RESECTION

TECH FIG 1 • (continued)  C,D. Completion of tumor removal.  C. The massive defect created by wide resection of a soleus muscle sarcoma or carcinoma.  D. This intraoperative photograph shows the anatomic defect after tumor resection. The medial and lateral gastrocnemius muscles (MG, LG) were both mobilized and retracted proximally.

FUNCTIONAL RECONSTRUCTION AFTER RESECTION

- Functional reconstruction is usually necessary after resection of soleus tumors because of the complete resection of the proximal part of the Achilles tendon. It consists of tenodesing the medial and lateral heads of the gastrocnemius muscle and incorporating them with a Gore-Tex vascular graft. The length of the vascular graft depends on the size of the tumor and the gap between the resected stump and the Achilles tendon.
- The Gore-Tex vascular graft is sutured to the stump of the Achilles tendon with a 3-mm Dacron tape and #0 Ethibond sutures (TECH FIG 2A–D).
- The retracted gastrocnemius and soleus muscle stump is pulled out and sewn with the Gore-Tex aortic graft under moderate tension with a 3-mm Dacron tape and #0 Ethibond sutures.
- After resection of the tumor, the surgical specimen consists of the biopsy tract, the tumor, and the entire soleus muscle belly (TECH FIG 2E).
- The foot is kept in the neutral position during these reconstructive procedures. A posterior splint is used to maintain the foot in neutral position and the knee in 15 degrees of flexion.

TECH FIG 2 • A. The Gore-Tex vascular graft was sutured to the stump of Achilles tendon. Insert shows a close-up of the graft stump junction.  B. Suturing the medial and lateral heads of the gastrocnemius muscle and their incorporation with the Gore-Tex vascular graft.  C. This intraoperative photograph shows the anatomic defect reconstructed with the Gore-Tex vascular graft (arrows), which was anastomosed to the remaining gastrocnemius muscle (MG, LG) and the stump of the Achilles tendon (AT) with #0 Ethibond and 3-mm Dacron tape. (continued)
D. Postoperative MRI shows the Gore-Tex graft extending from the insertion of gastrocnemius muscle to the remaining stump of the Achilles tendon.

E. After tumor resection, the surgical specimen consists of the biopsy tract (BX), the tumor, and the entire soleus muscle belly (arrow).

**Table 1**

**Clinical Demographic Data and Functional Outcomes**

<table>
<thead>
<tr>
<th>Case</th>
<th>Sex, Age (yr)</th>
<th>Diagnosis</th>
<th>Size of Tumor</th>
<th>Location</th>
<th>Follow-up (months)</th>
<th>Result (total scores out of 1000 points)</th>
<th>Load Bearing (out of 400 points)</th>
<th>Pain at Rest (out of 300 points)</th>
<th>Function (out of 300 points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F, 12</td>
<td>High-grade synovial sarcoma</td>
<td>5×3 cm</td>
<td>Soleus muscle</td>
<td>8</td>
<td>861</td>
<td>326</td>
<td>300</td>
<td>235</td>
</tr>
<tr>
<td>2</td>
<td>M, 45</td>
<td>Metastatic hypernephroma</td>
<td>8×10 cm</td>
<td>Soleus muscle</td>
<td>11, deceased</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>3</td>
<td>M, 27</td>
<td>Malignant fibrous histocytoma</td>
<td>8×7 cm</td>
<td>Gastrocnemius and soleus muscles</td>
<td>9, deceased</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>4</td>
<td>M, 69</td>
<td>Liposarcoma</td>
<td>11×6 cm</td>
<td>Gastrocnemius and soleus muscles</td>
<td>32</td>
<td>867</td>
<td>362</td>
<td>255</td>
<td>250</td>
</tr>
<tr>
<td>5</td>
<td>F, 15</td>
<td>Alveolar soft part sarcoma</td>
<td>7×4 cm</td>
<td>Soleus muscle</td>
<td>36</td>
<td>890</td>
<td>340</td>
<td>300</td>
<td>250</td>
</tr>
</tbody>
</table>

NA — Not available.
PEARLS AND PITFALLS

Preoperative
- Large tumors of the soleus muscle may extend further than anticipated.
- Preoperative evaluation of the popliteal space and vessels is mandatory.

Intraoperative
- Reconstruction with a Gore-Tex graft after resection is recommended for large soleus defects.
- The surgeon should carefully mobilize the popliteal vessels before attempting to resect the tumor.
- An intraoperative Doppler scan may be useful.

POSTOPERATIVE CARE AND REHABILITATION
- Postoperatively, the leg is immobilized in a long-leg splint, followed by a short-leg walking cast for a total of 3 to 4 weeks, depending on the extent of the soft tissue resection.
- Patients who underwent reconstruction of the Achilles tendon with Gore-Tex graft should be immobilized in an ankle-foot orthosis for an additional 8 weeks.
- Rehabilitation includes leg strengthening, balance, and gait training (FIG 2).

OUTCOMES
- There have been only a few reported cases of soleus muscle resections for sarcomas. Reconstruction with a Gore-Tex graft allows the patient an almost normal gait (heel-toe, pushoff) and an almost normal range of motion of the ankle (Tables 1 and 2).
- Local recurrence may require an amputation.

COMPLICATIONS
- The most common complications are flap necrosis and tumor recurrence.
- Vascular occlusion of the posterior tibial artery is rare.
- Radiation therapy should be deferred a few weeks to permit the Gore-Tex graft to heal.

---

**Table 2**

**Score Template For The Outcome of Surgical Management of Achilles Tendon Ruptures Described by Merkel et al.**

<table>
<thead>
<tr>
<th>Category for Load- (Weight-) Bearing Capacity</th>
<th>Point Assignment</th>
<th>Maximum Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing continuously on both toes</td>
<td>1.33 points for each second</td>
<td>40</td>
</tr>
<tr>
<td>Standing continuously on toes of ruptured tendon side</td>
<td>2 points for each second</td>
<td>60</td>
</tr>
<tr>
<td>Number of times can stand on toes (starting with the heel on the floor) on the side with ruptured tendon</td>
<td>3 points for each time the patient can stand on toes</td>
<td>60</td>
</tr>
<tr>
<td>Difference in maximum torque between normal side and side with ruptured tendon</td>
<td>Deduct 14 points for each 10% difference</td>
<td>140</td>
</tr>
<tr>
<td>Difference in work performance between the normal side and the side with the ruptured tendon</td>
<td>10 points for each 10% difference</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category for Pain</th>
<th>Point Assignment</th>
<th>Maximum Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain at rest</td>
<td>No pain 90 points; pain from time to time 45 points; intense pain 0 points</td>
<td>90</td>
</tr>
<tr>
<td>Pain on weight bearing</td>
<td>Yes 0 points; no 60 points</td>
<td>60</td>
</tr>
<tr>
<td>Pain at the end of maximal dorsal or plantar flexion by the examiner</td>
<td>Yes 0 points; no 60 points</td>
<td>60</td>
</tr>
<tr>
<td>Distance to first appearance of pain while walking over uneven ground</td>
<td>&lt; 1 km 0 points; 15 km 45 points; &gt; 5 km 90 points</td>
<td>90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category for Functional Capacity</th>
<th>Point Assignment</th>
<th>Maximum Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference in active dorsal flexion between the normal side and the side with the ruptured tendon</td>
<td>Deduct 3 points for each degree of difference</td>
<td>45</td>
</tr>
<tr>
<td>Difference in active plantar flexion between the normal side and the side with the ruptured tendon</td>
<td>Deduct 3 points for each degree of difference</td>
<td>45</td>
</tr>
<tr>
<td>Difference between active and passive dorsal flexion on the side with the ruptured tendon</td>
<td>Deduct 5 points for each degree of difference</td>
<td>45</td>
</tr>
<tr>
<td>Difference between active and passive plantar flexion on the side with the ruptured tendon</td>
<td>Deduct 5 points for each degree of difference</td>
<td>45</td>
</tr>
<tr>
<td>Difference in the maximum kinetic movement dimension between the normal side and the side with the ruptured tendon</td>
<td>Deduct 25 points for each 10% difference</td>
<td>120</td>
</tr>
</tbody>
</table>

**Total score = (points for weight bearing) + (points for pain) + (points for functional capacity)**

**Interpretation:**
- Minimum total score: 0
- Maximum total score: 1000
- The higher the score, the more normal the function on the side with the ruptured tendon.
**BACKGROUND**

- Tumors of the sartorial canal are a unique group of tumors: they are extracompartmental space tumors with close proximity to the superficial femoral artery and vein.
- The sartorial canal, synonymous with the subsartorial canal, canal of Hunter, and femoral and adductor canal, runs from the femoral triangle proximally to the popliteal fossa on its distal end.
- Soft tissue sarcomas of the sartorial canal are rare, accounting for less than 2.5% of all soft tissue sarcomas.
- In the extremities, the distinction is made between intracompartmental and extracompartmental tumors because the two behave differently (Enneking stage Ia versus IIb).3,7 Tumors arising in the extracompartmental spaces may spread rapidly longitudinally far beyond their intracompartmental counterparts, and wide resection of these tumors is more demanding due to their proximity to major neurovascular structures.3,5,6
- Space tumors are a subgroup of tumors of the extracompartmental spaces. Such extracompartmental spaces are namely the sartorial canal, popliteal space, femoral triangle, and axilla.1-3
- A common assumption is that intracompartmental tumors are more amenable to control by local procedures (ie, easier to evaluate preoperatively and easier to resect surgically, with lower recurrence rates) compared with extracompartmental tumors.3 The only tumor factors proven to have a real prognostic effect are size, malignancy grade, depth, histotype, and local recurrence.4,7 Anatomic space or compartmental space has not been shown to have a significant prognostic impact. The surgical assumption is that treatment of space tumors is difficult, has more complications and a higher local recurrence rate, and may require primary amputation.

**ANATOMY**

- The canal lies between the anterior (quadriceps) compartment and the medial adductor compartment, connecting the tip of the femoral triangle in the proximal thigh to the popliteal space in the distal posterior aspect of the thigh. All three are considered “spaces” of the thigh, and each carries its own unique soft tissue tumors, presentation, treatment options, and hazards.
- Cross-section of the sartorial canal is shaped like an inverted triangle. The roof of the canal is the sartorius muscle, which lies anterior and medial to the canal. The adductor longus makes up the floor of the canal. The lateral border is the thick fascia of the vastus medialis. Posteriorly the border of the canal is the adductor compartment, namely the adductor magnus. Both the posterior and lateral borders are covered with thick fascia. The superficial femoral artery and the femoral vein enter the canal through the tip of the femoral triangle. These structures lie deep in the canal, where they are surrounded throughout its length with very thick fascial sheath. The vessels exit the canal at the distal medial end, through the adductor hiatus, a foramen in the distal part of the adductor magnus.

**INDICATIONS**

- Tumors of the sartorial canal are often malignant and should all be removed as soon as possible. Tumors of the canal are all deep tumors that are in intimate proximity with the main vessels to the lower limb. Small tumors are as suspicious as large tumors because they may be high-grade tumors about to invade the vessels. Early resection avoids vessel involvement and thus lessens the need for arterial resection and reconstruction and most likely lowers the risk of metastatic disease with high-grade tumors. Tumors of the sartorial canal should not undergo core needle biopsy but rather excisional biopsy with frozen section during surgery.
- Patients present initially with a painless mass in the medial thigh. Some of the masses may be larger than 20 cm and may have been growing slowly for years. There is no clear correlation between the size of the tumor at presentation and its malignancy.

**IMAGING AND OTHER STAGING STUDIES**

**Plain Radiography**

Plain radiography studies are performed to rule out local invasion of the femur by the tumor and to rule out soft tissue calcifications (pathognomonic of synovial sarcoma and hemangiomas).

**Computed Tomography and Magnetic Resonance Imaging**

- CT with 3D reconstruction and arterial contrast has been used to assess the anatomic relation between the main vessels of the limb and the tumor. Due to the small space in the canal and the proximity to the vessels, tumors distort the normal anatomy early in their growth and may displace the vessels. Therefore, good imaging is crucial.
- MRI is used to assess the tumor’s anatomic relation to the vessels and to evaluate the tumor’s size and invasion of neighboring anatomic structures, namely the muscles bordering the canal and the proximal and distal extent, the femoral triangle, and popliteal spaces (FIGS 1, 2A).
- MRI often identifies the specific structure from which the tumor arises and invades the canal (sartorius, vastus medialis, and adductor muscles).

**Bone Scan**

Bone scan is used to rule out distant metastatic disease and may give a clue about the malignancy of the tumor: high-grade tumors show a strong tumor blush in the late arterial flow phase of the three-phase technetium bone scan.
Angiography and Other Studies
- Angiography is used to assess the vascularity of the tumor, tumor blush, the location of the vessels feeding it, and the relation between the tumor and the femoral artery, which indicates whether the vessel was displaced by the tumor or is invading the vessels (FIG 2B).
- Venography of the limb is used to rule out venous thrombus, tumor thrombus (mural thrombus), or direct tumor involvement.

Biopsy
- Core needle biopsy and open incisional biopsy are problematic in the sartorial canal. Therefore, biopsy should be done using frozen section at the time of definitive surgery. Most tumors within the sartorial canal are malignant, so all should be removed. The risk of a biopsy with either an inaccurate diagnosis or local contamination warrants the consideration of primary resection.
- The proximity of the tumor to the vessels carries several disadvantages when considering biopsy:
  - Hematoma from the biopsy site may spread along the vessels, thus contaminating the extremity and necessitating an amputation.

SURGICAL MANAGEMENT
- Tumors such as leiomyosarcomas may arise from the vessel walls; therefore, the main vessels may be punctured at the time of biopsy, causing significant bleeding.

FIG 1 • Axial (A) and sagittal (B) MR image of a sartorial canal tumor that approximates the vessels. The tumor is a low-grade liposarcoma. SF A&V, superficial artery and vein.

FIG 2 • A. Axial MR image of a tumor of the sartorial canal that arises from the muscle wall and encroaches on the vessels. B. Angiogram of the same lesion showing tumor blush from the late arterial phase.
wide exposure. Proximal and distal control of the vessels should be achieved before beginning to resect the tumor.

- There are two main venous tracts that drain blood from the limb, the popliteal vein and the greater saphenous vein. Care must be taken not to damage the saphenous vein because resection of the femoral vein may be unavoidable due to tumor invasion. Ligation of both veins would lead to severe venous insufficiency of the limb.

- A thick fascial sheath covers the superficial femoral artery and vein throughout its length. This fascia often separates the tumor from these major vessels and provides a safe plane of dissection. This fascia is routinely analyzed under frozen section during surgery to confirm the adequacy of resection. In these extracompartmental resections, achieving 1 cm of normal tissue borders is often not possible. Sarcomas are known to respect fascial boundaries; therefore, dissecting an intact adventitia off the vessels that is free of tumor on pathologic inspection should provide sufficient resection margins.

Preoperative Planning

- Tumors of the sartorial canal may be divided according to their anatomic and surgical location into three types of resections. This classification is designed to serve as a guideline for the surgeon. By analyzing preoperative imaging and the initial intraoperative surgical impression, the surgeon can assess the structures from which the tumor arises and the appropriate plane of resection. These guidelines correlate with the surgical margins and, in general, the higher the number the more difficult the surgical resection and reconstruction will be.

- Tumors are classified according to the location from which they originate (FIG 3):
  - Type 1 (luminal) tumors arise from within the space. Typically they originate from fat or fibrous tissue within the space and lie loose in the space. We call these tumors “luminal” because they may approximate but are not adherent to the walls of the space or any of the arteries, veins, and nerves in the sartorial canal.

---

FIG 3 • Systematic resection of extracompartmental space tumors of the sartorial canal. The left column shows axial MR images of the three different types of tumors in the sartorial canal. The middle column shows a schematic of the tumor location and the right column shows the recommended planes of surgical resection (dotted line). Resection types from 1 to 3 are presented in the rows from top to bottom. Type 1 (luminal) tumors lie within the space and are resected with a thin cuff of tissue that surrounds them. Type 2 (wall) tumors arise from the muscles surrounding the space and are resected as a typical muscle resection. Type 3 (vessel) tumors invade the vessels and are therefore resected en bloc with the vessels.
- Type 2 (wall) tumors arise from one of the walls that border the sartorial canal (sartorius, vastus medialis, adductor magnus or adductor longus muscles). These tumors arise from within a muscle or the muscle’s fascia that borders the space.
- Type 3 (vessel) tumors involve arteries, veins, or nerves. These lesions originate from the vessel wall and are not simply juxtaposed to it.
- Tumors are classified into one of these three types according to the preoperative imaging and the surgeon’s intraoperative impression. Each type of tumor should be resected with different plane of resection:
  - Type 1 tumors are resected with a thin layer of normal tissue that abuts the tumor. This normal tissue is typically the thick encasing fascia over the vessel. Vascular resection is not required. At times these tumors almost deliver themselves once the space is opened. Tumor margins, although negative, are often close. The fibrous sheath surrounding the vessels is inspected by carefully resecting it and examining the sheath on frozen section to rule out tumor invasion.
  - Type 2 tumors are essentially resected with the muscle from which they originate. Wide surgical resection is achieved by resecting the tumor with a large cuff of muscle of origin, the fascia covering that muscle, and adjacent fat from within the canal.
  - For type 3 tumors, there is no safe way to resect the lesion and guarantee negative margins without resecting the vessel itself. The vessel and the lesion must be resected en bloc with adjacent muscle or fascia as required. If the artery is resected it must be reconstructed with a synthetic graft or a reverse saphenous vein graft. Venous resections do not need reconstruction as long as the ipsilateral saphenous vein is intact. Because the tumor is resected en bloc with the vessel, these resections, although challenging surgically in their reconstructive aspects, are relatively simple in their tumor resection aspects and in achieving wide surgical margins.

**Positioning**

- The patient is placed in the supine position and the leg is prepared and draped. The contralateral leg should be prepared and draped as well in case a saphenous vein graft is needed for vascular reconstruction.

**Approach**

- The skin incision is made along the sartorius muscle throughout its length as necessary. Fasciocutaneous flaps are raised anteriorly and posteriorly for wide exposure (FIG 4).
- The sartorius muscle is disconnected at its distal end and the inferior border of the muscle is retracted anteriorly. The canal is carefully dissected open.
- At this point it is important to identify and control the major vessels at both ends of the canal, near the adductor hiatus and the femoral triangle. Small perforating vessels connecting the tumor to the main vessels are ligated.
- The surgical classification for tumors of anatomic spaces helps dictate the type of resection needed for each type of tumor.

**FIG 4** - Surgical approach to resecting a tumor of the sartorial canal. Skin incision is carried along the sartorius muscle. Fasciocutaneous flaps are raised anteriorly and posteriorly for wide exposure. The sartorius muscle is either resected with the tumor if necessary from an oncologic point of view or disconnected distally for wide exposure. The adductor hiatus is opened to better expose the vessels as they pass from the canal into the popliteal space (inset).
**Techniques**

- The femoral vein may be sacrificed if the tumor is in intimate contact with it. If the saphenous vein is intact, there is no need to reconstruct the femoral vein.
- The wound is marked with hemoclips for postoperative radiation therapy.
- After tumor resection, the femoral vessels are covered with muscle flaps comprising either the sartorius muscle or, if that was excised with the tumor, the adjacent gracilis muscle. A gracilis muscle transfer (TECH FIG 1C) is done by dissecting the distal end of the gracilis free and rotating the muscle anteriorly to cover the canal. This provides good soft tissue coverage.

**Pearls and Pitfalls**

| Tumor may involve the vessels and necessitate resection of vessels. | **A vascular surgeon should be on call for reconstruction if needed.** |
| Loss of both the femoral and saphenous vein in the same leg will cause symptomatic edema. | **Injury to the saphenous vein is avoided during dissection, as the femoral vein may have to be resected due to tumor involvement.** |
| **If both veins are nonfunctional, the femoral vein is reconstructed with a saphenous vein graft.** | **The soft tissue of the canal is reconstructed with sartorius remnants and a gracilis muscle transfer.** |
| **Cover vessels with muscle to protect them in case of postsurgical superficial wound infection or wound dehiscence after radiation.** |  |

**Postoperative Care**

- Physiotherapy for full range of motion of the hip and knee joint may commence as soon as the wound has healed and skin sutures have been removed. Full weight bearing is permitted after surgery.
- Leg edema should be monitored after venous resection. The leg should be kept elevated.
- Radiation therapy may be started as soon as the wound has healed; this is typically no sooner than 3 weeks after surgery. In patients with arterial graft reconstruction, we believe it is safe to begin radiation therapy 3 weeks after surgery.

**Outcomes**

- Functional outcome is excellent. Because the surgical resection and postoperative radiation do not cross a joint line, there is no restriction in range of motion.

**Complications**

- Complications of tumor surgery in the sartorial canal occur mainly when there is involvement of the vessels and reconstruction. These complications include deep infection, arterial occlusion, and deep vein thrombosis.

**References**

BACKGROUND

- The femur is the most common site for metastatic bone disease requiring surgery. Because it is a major weight-bearing bone with minimal space for surgical errors, the operative procedure must be carefully planned and meticulously executed, with the aim of achieving durable reconstruction. Detailed preoperative clinical and imaging evaluation is essential to define the morphologic characteristics of the lesion that validate surgical intervention and to distinguish between lesions that can be managed with curettage and cemented fixation and those that require resection with endoprosthetic reconstruction.\(^1,6,7\)

- Unlike primary sarcomas of the femur, metastatic tumors usually have a small soft tissue component, even in the presence of extensive bone destruction. This feature allows the sparing of extracortical structures, such as the joint capsule, overlying muscles, and muscle attachments, and the possibility of applying them for reconstruction and preservation of function.

- Because of distinctive differences in anatomic and surgical considerations, surgeries around the proximal femur, femoral diaphysis, and distal femur will be discussed separately (FIG 1).

ANATOMY

Proximal Femur

- A thick joint capsule encircles the femoral head and neck and attaches to the base of the neck.
- Key elements at the lateral aspect: The greater trochanter is the insertion site for the gluteus medius muscle (lateral stabilizer and hip abductor) and the origin for the vastus lateralis muscle.
- Key elements at the medial aspect: The minor trochanter is the insertion site for the psoas muscle (medial stabilizer and hip flexor).

Femoral Diaphysis

- The femoral diaphysis is encircled by two muscle layers:
  - First layer: the vastus intermedius muscle
  - Second layer: The rectus femoris and vastus medialis muscles intersect at the anteromedial aspect, and the rectus femoris and the vastus lateralis muscles intersect at the anterolateral aspect.

Distal Femur

- The medial femoral condyle is positioned below the insertion site of the vastus medialis muscle.
- The lateral femoral condyle is positioned below the insertion site of the vastus lateralis muscle.

INDICATIONS

- Pathologic fracture
- Impending pathologic fracture (FIG 2)

FIG 1 • Metastatic tumors at the proximal femur, femoral diaphysis, and distal femur.

FIG 2 • AP and lateral plain radiographs showing an impending fracture of the femoral diaphysis due to metastatic lesions.
Intractable pain associated with locally progressive disease that has shown inadequate response to narcotics and radiation therapy

Solitary bone metastasis in selected patients and tumor types (eg, those with breast cancer and renal cell carcinoma)

**IMAGING AND OTHER STAGING STUDIES**

Plain radiographs of the entire femur are mandatory to rule out coexisting metastases that may influence the extent and technique of surgery. CT of the lesion will clearly define the extents of soft-tissue component and bone destruction. Total body bone scintigraphy is done to detect coexisting metastases elsewhere in the skeleton (FIG 3). The results of imaging should provide the surgeon with answers to the following questions:

- Is the lesion an impending fracture? (If not, it should probably be treated nonoperatively).
- Are there additional femoral metastases? If so, can they be managed by nonoperative techniques or do they also require surgery?
- What is the appropriate surgical approach? As a rule, tumor curettage with cemented fixation is indicated for lesions in which the remaining cortices allow containment of the fixation device. Otherwise, surgery consists of resection of the affected bone segment with prosthetic reconstruction.

![FIG 3](image-url)

A. Plain radiograph showing a metastatic lesion of the proximal femur. The surrounding cortices are intact. Surgery consisted of curettage and reconstruction with a cemented intramedullary nail.

B. Metastatic lesion at the same site with extensive circumferential bone destruction. Surgery in this case entailed resection of the proximal femur and reconstruction with an endoprosthesis.

C. AP plain radiograph (C) and computed tomography (D) of the distal femur showing a metastatic lesion at the left medial femoral condyle. The lateral condyle and articular cartilage are preserved and form an anatomic continuum, which allows the fixation of a cemented reconstructive device.

D. AP (E) and lateral (F) plain radiographs and computed tomography (G) of the distal femur showing a large metastasis with destruction of the entire anterior aspect of the bone and considerable thinning of the posterior cortex. Surgery included resection of the distal femur and reconstruction with an endoprosthesis.
PROXIMAL FEMUR

Position and Incision

- The patient is placed supine on the operating table, with the buttock of the affected side close to its edge. The operating table is positioned in a 30-degree tilt away from the surgeon.

  - A straight longitudinal incision is made along the tip of the greater trochanter and femoral diaphysis (TECH FIG 1). It should begin 5 cm proximal to the greater trochanter to allow the introduction of a femoral nail and 5 cm below the lower edge of the lesion to enable adequate tumor curettage.

Exposure

- The fascia lata is divided longitudinally and retracted to expose the lower edge of the gluteus medius muscle and its insertion site at the greater trochanter muscle, the vastus ridge, and the upper part of the vastus lateralis muscle (TECH FIG 2A,B).

  - Using electrocautery, the vastus lateralis muscle is detached from the vastus ridge and the lower aspect of the proximal diaphysis and reflected anteriorly to expose the diaphyseal cortex (TECH FIG 2C–E). A longitudinal cortical window with oval edges is made below the vastus ridge (TECH FIG 2F).

Tumor Removal

- Gross tumor is removed with hand curettes (TECH FIG 3A,B). Curettage should be meticulous and should leave only microscopic disease in the tumor cavity. It is followed by high-speed burr drilling of walls of the tumor cavity (TECH FIG 3C,D).

TECH FIG 1 • A straight longitudinal incision is made along the tip of the greater trochanter and femoral diaphysis.

TECH FIG 2 • A,B. The fascia lata is divided longitudinally and retracted to expose the lower edge of the gluteus medius muscle and its insertion site at the greater trochanter muscle, the vastus ridge, and the upper part of the vastus lateralis muscle. C–E. The vastus lateralis muscle is detached from the vastus ridge and femoral diaphysis. (continued)
TECH FIG 2 • (continued) F. A cortical window is made below the vastus ridge.

TECH FIG 3 • A,B. Gross tumor is removed with hand curettes. C,D. Curettage is followed by high-speed burr drilling of the walls of the tumor cavity. E. The gluteus medius muscle is detatched and reflected from its insertion site at the greater trochanter muscle. (continued)
When a proximal femur resection is done, the gluteus medius muscle is detached and reflected from its insertion site at the greater trochanter muscle (TECH FIG 3E), the joint capsule is opened and the femoral head is dislocated from the acetabulum, the medial aspect of the proximal femur is freed of muscle attachments, and then an osteotomy is performed below the lower aspect of the tumor (TECH FIG 3F–H).

**Mechanical Reconstruction**

Reconstruction begins with the introduction of an intramedullary nail. After proper positioning and length are verified, the nail is partially withdrawn and the entire tumor cavity is filled with cement (TECH FIG 4A). The nail is then pushed back into the medullary canal and fixed with interlocking screws (TECH FIG 4B,C). Alternatively, a side plate and a sliding screw can be sim-
Chapter 37  SURGICAL MANAGEMENT OF METASTATIC BONE DISEASE: FEMORAL LESIONS

TECHNIQUES

TECH FIG 4D  Similarly used for reconstruction. After resection of the proximal femur, a cemented tumor prosthesis is used to reconstruct the bone defect.

Soft Tissue Reconstruction and Wound Closure

- The origin of the vastus lateralis muscle is reattached to the vastus ridge (TECH FIG 5A). If endoprosthetic reconstruction had been carried out, the remaining hip capsule is sutured tightly with a 3-mm Dacron tape around the neck of the prosthesis, forming a noose that provides immediate stability. The capsule is reinforced by rotating the external rotator muscles proximally and suturing them to its posterolateral aspect. The remaining abductor tendon is attached to the lateral aspect of the prosthesis through a metal loop, and the psoas muscle is attached to the medial aspect of the prosthesis at the level where the lesser trochanter had been (TECH FIG 5B).
- It is important to attach these two muscles to the prosthesis so that balanced function will be achieved. The surgical wound is then closed over suction drains and the patient is placed in balanced suspension or in tibial pin traction with the hip elevated and flexed 20 degrees. An abduction pillow can also achieve the correct positioning.

Postoperative Care

- Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed. If tumor curettage had been done, rehabilitation should include early ambulation with unrestricted weight bearing as well as passive and active range of motion of the hip joint.
- After wound healing, usually 3 to 4 weeks after surgery, the patient is referred for adjuvant radiation therapy. Adjuvant radiation therapy is usually not required in patients who underwent proximal femur resection with endoprosthetic reconstruction.
- If endoprosthetic reconstruction had been done, the extremity is kept in balanced suspension for at least 5 days. Postoperative mobilization with total hip replacement precautions with or without an abduction brace and weight bearing as tolerated are continued for 6 weeks.

FEMORAL DIAPHYSIS

Position and Incision

- The patient is placed supine on the operating table, with the buttock of the affected side close to its edge. The operating table is positioned in a 30-degree tilt away from the surgeon.
- A diaphyseal lesion with a lateral cortical breakthrough is approached using a longitudinal incision along the anterolateral aspect of the thigh at the level of the interface between the rectus femoris and vastus lateralis muscles, with the lesion located at the center of the incision.
- A lesion with medial cortical destruction is similarly approached using an anteromedial incision at the level of the interface of the rectus femoris and vastus medialis.
Exposure
- The interval between the rectus femoris and vastus lateralis muscles is opened, and the muscles are retracted to expose the vastus intermedius overlying the femoral diaphysis. The vastus intermedius is split longitudinally to expose the femoral diaphysis, and retractors are placed behind it (TECH FIG 6). This approach allows wide exposure of the affected bone with minimal injury to the overlying muscles. A longitudinal cortical window with oval edges is made above the lesion.

Tumor Removal
- Gross tumor is removed with hand curettes (TECH FIG 7A,B). Curettage should be meticulous and should leave only microscopic disease in the tumor cavity. This is followed by high-speed burr drilling of the walls of the tumor cavity (TECH FIG 7C,D).

Mechanical Reconstruction
- Reconstruction begins with the introduction of an intramedullary nail either antegrade or retrograde, depending on the location of the lesion along the diaphysis. After proper positioning and length have been verified, the nail is partially withdrawn and the entire tumor cavity is filled with cement (TECH FIG 8). The nail is then pushed back into the medullary canal and fixed with interlocking screws.

Soft Tissue Reconstruction and Wound Closure
- A suction drain is positioned along the femoral diaphysis muscle, and the vastus lateralis muscle is sutured to the rectus femoris muscle.
Chapter 37  SURGICAL MANAGEMENT OF METASTATIC BONE DISEASE: FEMORAL LESIONS

TECH FIG 8 • An intramedullary nail is introduced and adequate positioning is verified. The nail is then partially withdrawn, the tumor cavity is entirely filled with cement, and the nail is reintroduced through the cement and secured with interlocking screws.

Postoperative Care

- Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed. Rehabilitation should include early ambulation with unrestricted weight bearing as well as passive and active range of motion of the knee joint.
- When wound healing is complete, usually 3 to 4 weeks after surgery, the patient is referred for adjuvant radiation therapy.

DISTAL FEMUR

Position and Incision

- The patient is placed supine on the operating table, with the affected knee flexed 30 degrees.
- A medial condyle lesion is approached using a longitudinal incision along the anteromedial aspect of the distal thigh at the level of the interface between the rectus femoris and vastus medialis muscles and 1 cm away from the medial border of the patella (TECH FIG 9).
- A lesion of the lateral condyle is similarly approached using an anterolateral incision at the level of the interface of the rectus femoris and the vastus lateralis and lateral to the patella.

Exposure

- The interval between the distal aspect of the vastus medialis and rectus femoris muscles is opened and the insertion of the vastus medialis to the quadriceps tendon, patella, and joint capsule is detached (TECH FIG 10A,B). The vastus medialis muscle is retracted posteriorly, exposing the underlying vastus intermedius muscle and the distal femur (TECH FIG 10C,D).

Tumor Removal

- A lesion at the lateral femoral condyle is approached using similar detachment and posterior reflection of the vastus lateralis muscle. This approach allows wide exposure of the affected bone with minimal injury to the overlying muscles. A longitudinal cortical window with oval edges is made above the lesion.
- Curettage. Gross tumor is removed with hand curettes (TECH FIG 11A,B). Curettage should be meticulous and should leave only microscopic disease in the tumor cavity. It is followed by high-speed burr drilling of walls of the tumor cavity (TECH FIG 11C,D).
- Distal femoral resection (see Chap. ON-25). TECH FIG 11E,F show the release of the vastus medialis and the popliteal exposure. TECH FIG 11G,H show the release of all soft tissues around the distal femur and the femoral osteotomy. The cavity is reconstructed by a combination of intramedullary and plate fixation followed by cement (PMMA). See TECH FIG 12A.
TECH FIG 10 • A,B. The vastus medialis muscle is detached from its attachment to the rectus femoris muscle and inserted into the quadriceps tendon, patella, and joint capsule. C,D. The vastus medialis muscle is retracted posteriorly, exposing the vastus intermedius muscle and distal femur.

TECH FIG 11 • A,B. Gross tumor is removed with hand curettes. (continued)
Tech Fig 11 (continued) C, D. Curettage is followed by high-speed burr drilling of the walls of the tumor cavity. E, F. The medial gastrocnemius muscle is detached and reflected, exposing the popliteal fossa. The posterior femur is isolated by ligation and transection of the geniculate vessels. G. The joint capsule is opened and released circumferentially from the femur. H. A distal femur osteotomy is done 1 to 2 cm beyond the point of proximal tumor extension.
A distal femur osteotomy is carried out at the appropriate location as determined by the preoperative imaging studies: 1 to 2 cm beyond the point of proximal tumor extension is generally appropriate for metastatic tumors (TECH FIG 11H–J). A tibial osteotomy is then done to allow the introduction of the prosthetic tibial component.

### Mechanical Reconstruction
- A combination of a cemented intramedullary nail and a condylar plate achieves optimal stability and is preferred for reconstruction (TECH FIG 12A–C). After resection of the distal femur, a cemented tumor prosthesis is used for reconstruction (TECH FIG 12D–F).

### Soft Tissue Reconstruction and Wound Closure
- Suction drains are positioned along the femoral diaphysis, and the vastus medialis muscle is sutured to the rectus femoris muscle and its insertion sites along the quadriceps and patella. The medial gastrocnemius muscle is pulled up and sutured to the vastus medialis muscle (TECH FIG 13).

### Postoperative Care and Rehabilitation
- Continuous suction is required for 3 to 5 days, and perioperative intravenous antibiotics are continued until the drainage tubes are removed. If tumor curettage had been done, rehabilitation should include early
ambulation with unrestricted weight bearing as well as passive and active range of motion of the knee joint.

When the wound is healed, usually 3 to 4 weeks after surgery, the patient is referred for adjuvant radiation therapy. In the case of distal femur resection, the lower extremity is elevated for 3 days, until the first postoperative wound check, to prevent wound edema. Knee motion is restricted in an immobilizing brace for 2 to 3 weeks to allow healing of the surgical flaps and until the extensor mechanism is again functional. During that time, isometric exercises are carried out and weight bearing is allowed. Adjuvant radiation therapy is usually not required in patients who underwent distal femur resection with endoprosthetic reconstruction.

PEARLS AND PITFALLS

Proximal femur
- Adequate imaging of the entire femur: allows the surgeon to decide whether to perform tumor curettage or resection with endoprosthetic reconstruction
- Wide exposure of the tumor cavity, using an adequately positioned and large cortical window
- Meticulous curettage and burr drilling
- Reconstruction with hardware and cementation of the entire volume of the cavity
- Proximal femur resection: reconstruction with cemented implant, suturing of the joint capsule, and reattachment of the gluteus medius and psoas muscles
- Early ambulation and range-of-motion exercises; weight bearing as tolerated

Femoral diaphysis
- Exposure through the interval between the rectus femoris and vastus lateralis or medialis
- Wide exposure of the tumor cavity using an adequately positioned large cortical window
- Meticulous curettage and burr drilling
- Reconstruction with hardware and cementation of the entire volume of the cavity
- Early ambulation and range-of-motion exercises; weight bearing as tolerated

Distal femur
- Intraoperative
  - Exposure through the interval between the vastus medialis and lateralis and the rectus femoris
  - Wide exposure of the tumor cavity using an adequately positioned large cortical window
  - Meticulous curettage and burr drilling
  - Reconstruction with a cemented intramedullary nail and a condylar plate
  - When distal femur resection is indicated, the gastrocnemius origin is detached to expose the popliteal fossa.
  - Reconstruction is done with a cemented tumor prosthesis.

- Postoperative
  - Early ambulation and weight bearing as tolerated
OUTCOMES AND COMPLICATIONS

- Functional outcomes and common complications of prosthetic replacements for metastatic bone disease are no different from those with the same operations for primary sarcomas of bone (see Chaps. ON-25 and ON-26). 2–5,8 Because of the short life expectancy of most patients with metastatic bone disease, however, the problems seen at long-term follow-up, such as aseptic loosening, the wearing down of polyethylene components, and fatigue prosthetic fractures, are rarely seen.

- The real concerns in the setting of metastatic bone disease are local tumor recurrence and failure of reconstruction. Meticulous tumor removal, proper selection and use of fixation devices, and adjuvant radiation therapy have made these complications rare: local recurrence and reconstruction failures are seen in less than 5% of the patients.

REFERENCES

BACKGROUND

- Malignant tumors of the foot present a significant and formidable challenge to the orthopaedic oncologist due to the foot’s unique function and anatomic peculiarities.
- The foot is uniquely adapted for bipedal motion and as such is essentially a tripod. The tripod is basically formed by the first ray, the fifth ray, and the calcaneus and is supported by the osseous configuration of bones in the midfoot that form a Roman arch, which in and of itself is inherently stable.
- Both bone and soft tissue contribute to the structure and function of the foot. Furthermore, the foot is composed of compact compartments that are interconnected by nerves and vascular structures. Complete resection (wide local excision) of osseous structures of the foot is difficult because of the interruption of these complex anatomic relationships, which afford stability to the foot, in addition to the interconnected compartments. Malignant tumors of bone are rare in the foot and rarer still in locations distal to the metatarsophalangeal joints.
- Many of these tumors are treated with amputations.
- In the senior author’s experience of 153 foot and ankle tumors in 153 cases, 31 amputations were performed (FIG 1A). Fortunately, tumors distal to the metatarsophalangeal joint can be treated by amputation through the metatarsophalangeal joint with minimal disruption to function. The only exception is the first ray, which typically bears 50% of the weight with toe-off during each gait cycle. Therefore, preservation of as much proximal phalanx as possible is important to optimize this important structure.

INDICATIONS

- Tumors involving the toe or metatarsal bone are rare. Primary tumors affecting the foot, including osteosarcomas, have a low incidence. Metastatic tumors of the foot are also rare. The most common sites of primary tumors are lung, kidney, and colon.
- In the senior author’s experience of 153 foot and ankle tumors, 73 cases were bony (FIG 1B); of these, 7 cases involved the metatarsals (FIG 1C). The indications for ray resections are tumors involving the toe or metatarsal bone. Benign tumors make up the majority of these lesions.
- **FIGURE 1D** shows the distribution of benign versus malignant diagnoses. The malignant lesions include metastatic disease, primary bony tumors, and soft tissue tumors.

ANATOMY

- The tripod is basically formed by the first ray, the fifth ray, and the calcaneus and is supported by the osseous configuration of bones in the midfoot that forms a Roman arch, which in and of itself is inherently stable.
- These bones are supported by ligamentous structures as well as tendons that help preserve the arch and support foot function. For this reason, resections of the first and fifth rays typically result in significant alterations in function, especially the first ray. The resulting forces after resection of the first ray result in transfer to the lesser metatarsals, which are ill adapted to structurally support the weight of the body, resulting in transverse metatarsalgia.
- These structural alterations can be mitigated in part by the judicious use of orthotics, such as a medial heel wedge to transfer the forces farther lateral or the use of a metatarsal bar, which will more evenly distribute the weight across the lesser metatarsals. Resection of the fifth ray is relatively easily compensated for by creating an orthosis that transfers the forces medially; thus, a lateral heel wedge is beneficial.
- Resection of the middle rays results in insignificant loss of function and acceptable cosmesis. The only net result is narrowing of the forefoot, which can be easily compensated for with shoe modifications.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with tumors of the toe or metatarsal present with pain and mass. The mass may be small and chronic. It may appear with an injury.
- Physical examination (Table 1) will reveal a tender mass localized to the toe or metatarsal. There may be associated swelling. If a sensory nerve overlies the mass, there may be paresthesia.

IMAGING AND OTHER STAGING STUDIES

- Preoperative studies include plain radiographs of the foot, including anteroposterior, lateral, and oblique views. If the ankle joint is involved, then anteroposterior and mortise views are obtained.
- MRI is important to evaluate the amount of involvement of the metatarsals to determine the level of amputation. The case in **FIGURE 2** shows cortical thickening of the second metatarsal. The clinical photographs show increased space between the metatarsals. MRI shows the soft tissue involvement. The lesion was found to be benign.

SURGICAL MANAGEMENT

- The goal of the surgical procedure is to remove the tumor with adequate margins.
- A long plantar flap is important for a sturdy end-bearing stump.
- The bony edges should be smooth and beveled if possible.
- Myodesis is helpful to pad the end of the stump.
- **Figure 2** shows pigmented villonodular synovitis (PVNS) localized to the plantar aspect of the first metatarsal head. The clinical photographs show the mass. MRI shows the soft tissue involvement. Intraoperative photograph shows resection of the tumor.
FIG 1 • A. Distribution of types of amputations for 153 tumors of the foot and ankle (n = 31). B. All diagnoses of bony tumors of the foot and ankle (n = 73). C. Diagnoses of metatarsal tumors (n = 7). D. Distribution of bony tumors of the foot and ankle by diagnosis and site (n = 73).

Table 1 Physical Examination Methods

<table>
<thead>
<tr>
<th>Examination</th>
<th>Technique</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection</td>
<td>Evaluate the lower extremity with the patient undressed from the knees.</td>
<td>Examination of both extremities allows for comparison to identify abnormalities.</td>
</tr>
<tr>
<td>Palpation</td>
<td>Gentle and deep palpation of the mass or area of pain</td>
<td>Evaluates tenderness of the mass; evaluates whether the mass is mobile or fixed.</td>
</tr>
<tr>
<td>Range of motion</td>
<td>Observe passive and active range of motion of the foot and ankle.</td>
<td>Identifies joint involvement with tumor.</td>
</tr>
<tr>
<td>Vascular examination</td>
<td>Palpate dorsalis pedis and posterior tibia arteries.</td>
<td>Evaluates vascularity of the extremity and whether there is tumor involvement.</td>
</tr>
<tr>
<td>Neurologic examination</td>
<td>Evaluate motor strength and sensation to light touch.</td>
<td>Evaluates involvement of muscles and sensory nerves.</td>
</tr>
</tbody>
</table>
Preoperative Planning

- Preoperative planning is crucial for a good outcome. The preoperative radiographs and CT and MRI studies are important to determine the amount of tumor involvement. They also show the extent of soft tissue tumors and may be helpful in distinguishing benign from malignant tumors. The biopsy results will determine the level of amputation.
- The level of amputation is an important part of preoperative planning. The length of the residual stump is as important as the quality of soft tissue. There must be adequate padding of skin, subcutaneous fat, muscle, and tendons to cover the end of the bones.

Positioning

- The patient is placed supine on the operating table. A thigh tourniquet is placed over adequate cotton padding. A bump may be placed proximal to the sciatic notch on the ipsilateral hip to limit external rotation of the extremity during the procedure.

Approach

- The surgical approach is planned preoperatively. It is important to maintain as much plantar skin as possible because this skin is thicker and has specialized columns of plantar fat for weight bearing.
RAY RESECTION

- In performing a ray resection, an incision is made longitudinally and dorsally in line with the involved metatarsal (TECH FIG 1A,B). At the metatarsophalangeal joint, the incision is carried plantarly in a curvilinear fashion around the joint. This tissue is then used to reconstruct the resulting web space between the adjacent digits.
- The sensory nerves are identified just beneath the skin and are pulled distally and transected sharply with a scalpel. The extensor tendon is also transected sharply at and proximally near the tarsometatarsal joint.
- The common digital nerve is identified along with the vascular bundle. If they are involved or closely adherent to the tumor pseudocapsule, they are ligated proximally. The lumbrical and interosseous muscles are transected proximally, exposing the base of the metatarsal. It is preferable to preserve the base of the metatarsal if possible because this does not cause any disruption in the arch formed by the tarsal–metatarsal articulation.
- An oscillating saw is used to transect the metatarsal, or the metatarsal is disarticulated at the tarsometatarsal joint and elevated. The resection then is performed from proximal to distal. The flexor tendon is identified and transected. The entire metatarsal is then excised along with the adjacent soft tissue (lumbricals, intrinsics, and flexor extensor tendons). The dissection is then carried distally and plantarward. The capsular structures of the metatarsophalangeal joint are then separated from the underlying dermis, and the ray is removed.
- A suture is placed through the capsular structures of the adjacent metatarsal heads. Pressure is then applied to the tibial and fibular aspect of the foot to close the defect between the adjacent metatarsals, and a 0 nonabsorbable suture is used to anchor the capsular structures between the adjacent metatarsals to bring the metatarsals together and narrow the defect between the adjacent rays. A small drain is placed in the defect and brought out through a separate puncture wound distally. The subcutaneous tissue is then closed with 3-0 absorbable sutures placed in interrupted fashion. The skin is closed with 4-0 nylon sutures placed in interrupted fashion.
- A bulky dressing is applied, maintaining even compression across the foot and compressing the adjacent metatarsals to decrease tension on the capsular stitch maintaining the metatarsal heads in close proximity. If the flexor or extensor tendons are not involved with tumor, they can be woven through the metatarsal heads to create a sling to anchor the metatarsal heads in close proximity and maintain the close space between the metatarsal heads.

First Ray Resection with Reconstruction with Autogenous Fibular Graft

- TECH FIG 2 shows a recurrent giant cell tumor of the first metatarsal that was treated successfully with a fibular strut graft. The lateral radiograph shows the healed graft 7 years postoperatively.
- Under epidural anesthesia an incision is made over the first metatarsal. Anterior and posterior fasciocutaneous flaps are made extending to the level of the second metatarsal anterior and posterior. The proximal limb of the incision extends beyond the metatarsal cuneiform joint, and the distal incision extends to the web space.
- Resection consists of the following planes between the first and second metatarsals following the bone in the second metatarsal through the metatarsal cuneiform joint and posteriorly and around the first metatarsal the flexor longus muscle tendon. The distal metatarsal is osteomized at the condyles and proximally just distal to the joint. The tumor mass is removed; the anterior tibial tendon, peroneal tendons, and anterior tibial vessels are preserved.
- Reconstruction is performed with a fibular graft from the midshaft of the fibula of the ipsilateral limb. This is placed within the defect, measuring about 8 cm between the cuneiform and the metatarsal head. Fixation is achieved with two small cortical interfragmentary screws proximally and distally. The hallux is maintained in neutral position.

**TECH FIG 1** • **A.** Skin incision location in a metatarsal ray resection. **B.** Dorsal incision. **C.** Plantar incision. **D.** The plantar flap is longer. It is brought dorsally to cover the bony end of the stump.

**TECH FIG 2** • This example shows a recurrent giant cell tumor of the first metatarsal that was treated successfully with a fibular strut graft. The lateral radiograph shows the healed graft 7 years postoperatively.
PEARLS AND PITFALLS

Indications
- A careful and complete history and physical examination are essential. Preoperative studies are necessary to plan the resection and reconstruction.

Surgical incision
- A long plantar flap results in a better end-bearing stump. The natural cascade of metatarsal lengths should be maintained.

Wound healing complications
- Local wound care with dressings and oral antibiotics are usually sufficient for healing.

Deep infection
- Parenteral antibiotics and surgical débridement may be necessary to treat deep infections. Early diagnosis and treatment can affect outcome.

Contractures
- Postoperative splinting can help prevent contractures. Once a contracture occurs, it is treated with stretching if mild. Serial casting may be needed.

Painful stump
- The end of the bones should be contoured to be smooth. A rasp is effective. Adequate soft tissue coverage will help prevent bony prominence, which may become symptomatic.

POSTOPERATIVE CARE
- After a ray resection, the patient is placed in a well-padded splint. Crutches are used until the sutures are removed. The patient may begin range-of-motion exercises and weight bearing as tolerated.
- Toe amputation patients may ambulate in a postoperative shoe immediately. The sutures are removed at 2 to 3 weeks. A wide comfort shoe is worn and activities are progressed as tolerated.

OUTCOMES
- After a toe amputation at the level of the metatarsophalangeal joint, full preoperative function is regained.
- A cosmetic toe prosthesis may be used if the patient desires one, but it has no functional purpose.
- Ray resection outcomes depend on the number of rays amputated and whether the first ray is involved. A ray resection of the second, third, fourth, or fifth metatarsal does not need shoe modification with a molded insert or filler. Generally, ordinary store-bought shoes that are wide and have adequate cushioning are worn.
- A first ray resection affects the remaining foot function because of loss of the windlass mechanism. Reconstruction of the first ray would prevent this problem.
- Removal of two central rays will leave a narrower foot and shoewear problems.
- Patients with a metatarsal ray or transmetatarsal amputation have better outcomes than patients with a Syme amputation.

COMPLICATIONS
- Wound healing complications are treated with local wound care, elevation, and non-weight bearing. Oral antibiotics may be indicated. If there is skin flap necrosis, débridement with a skin graft may be necessary.
- Superficial infection can be treated with a short course of oral antibiotics.
- Deep infection may require immediate operative débridement of devitalized tissue. Parenteral antibiotics are important to treat this limb-threatening problem. At the time of the débridement, a bone culture should be ordered to help determine the appropriate antibiotic.

REFERENCES


Orthopaedic oncology has made dramatic advances in the past 25 years by developing limb-sparing surgery to the point where 85% to 95% of the patients can be treated with complete resection of their disease while preserving the limb and its function. Despite these recent advances in limb-sparing surgery, approximately 10% of all femoral sarcomas are not amenable to limb-salvage techniques and require an amputation. Disarticulation of the hip for malignant tumors is a rare operation, but it is still needed instead of an above-knee amputation if the tumor cannot be resected using a limb-salvage procedure due to proximal transosseous skip metastases, pathologic fractures, extensive diaphyseal extension, and adjacent large soft tissue masses combined with poor response to adjuvant chemotherapy.

Functional outcome after hip disarticulation is problematic. Jain et al published their results of 80 hip disarticulations. Function on the whole was poor, with only one surviving patient regularly using an artificial limb. Patients after hip disarticulation are left without a leg and without a fulcrum to move an artificial limb. They are likely to suffer loss of self-esteem as well as loss of function and mobility, and they may well suffer from phantom pains. The energy expenditure during mobility after an amputation is much greater than that without an amputation and increases as the amputation level becomes more proximal. In comparison, the energy expenditure after a long below-knee amputation is only about 10% more than that required by a non-amputee. When a patient with a hip disarticulation attempts to use a prosthesis, the energy requirements can then be as much as twice that of a normal ambulator. Those who cannot overcome these significant energy requirements must adapt to the use of crutches, canes, or a wheelchair. Given these factors, any intervention that can reduce the energy expenditures required of amputees might increase their likelihood of prosthetic use.

The stump prosthesis provides a lever arm for hip joint motion. This dramatically lowers the energy consumption of ambulating with a prosthetic limb and thus increases the likelihood of prosthetic use. The first attempt to improve the functional status of patients requiring hip disarticulation for malignant bone tumors was published by Marcove, McMillian, and Nasr in 1979. They used an Austin-Moore prosthesis (Smith and Nephew, Memphis, TN) to convert a hip disarticulation to an above-knee amputation. Over the years, the senior author has used this basic idea and made modifications to develop a technique that involves complete tumor removal and resection of the entire femur (hip disarticulation) followed by reconstruction of a proximal thigh stump (similar to an above-knee amputation stump) using a custom modular “stump” endoprosthesis.

**INDICATIONS**

- Indications for stump prosthesis reconstructive surgery after tumor resection are as follows (FIG 1):
  - Skip metastasis to proximal femur from a primary distal femur osteosarcoma
  - Inability to achieve safe osseous margins with a typical wide resection or above-knee amputation due to tumor extension (the most common indication)
  - Tumor contamination of the proximal medullary canal after pathologic fracture due to tumor in the distal femur and retrograde intramedullary fixation
  - A prerequisite for the operation is uncontaminated soft tissues around the hip, retrogluteal region, and proximal thigh.

**IMAGING AND OTHER STAGING STUDIES**

**Plain Radiography**

- Hip and pelvic imaging to rule out pelvic involvement
- Radiographic analysis of the entire femur

**Computed Tomography and Magnetic Resonance Imaging**

- Pelvic and hip CT scans are done to locate and define the tumor margins. CT helps rule out tumor involvement of the acetabulum.

**Bone Scan**

- A bone scan of the femur is done to determine the extent of the skip metastasis.

**Angiography and Other Studies**

- MRI of the soft tissue of the pelvis and proximal femur is a crucial part of the decision as to whether enough soft tissue...
can be safely spared to reconstruct the proximal thigh stump with adequate soft tissue coverage.

**SURGICAL MANAGEMENT**

- Unique anatomic considerations:
  - Arterial blood supply to the soft tissues must be preserved. The superficial femoral artery should be ligated within the sartorial canal as distally as oncologically possible.
  - The prosthesis must be secured to the hip capsule to avoid dislocation aggravated by gravity pulling on the prosthesis. This requires capsular reconstruction and reinforcement.
  - Modular prosthetic design allows use of a large bipolar cup, modular body length with porous coating to aid in soft tissue ingrowth, and a distal rounded tip designed to avoid tissue penetration with distal muscle fixation holes (FIG 2).
  - Muscle groups of the thigh must be connected distally to the prosthesis with tension balanced properly to avoid the excessively strong pull of the hip flexors and abductors.

**FIG 1** • Indications for hip disarticulation and reconstruction with a stump prosthesis. **A.** Proximal skip metastasis without soft tissue extension. **B.** Corresponding resected pathology gross specimen as seen in (C). **C.** Plain radiograph of a distal femoral nonunion after a pathologic fracture that was treated with a long retrograde intramedullary nail. **D.** Distal femoral synovial sarcoma with a proximal femoral head skip metastasis.

**FIG 2** • A modular stump prosthesis consists of a proximal bipolar head, porous coating, and holes to reconnect the hip capsule and abductor mechanism. The prosthesis body comes in different lengths. The distal tip is rounded to avoid penetration of tissues. Distal holes are used to anchor down the distal muscle ends.
Sufficient soft tissue coverage of all the prosthesis, and specifically its distal part, is critical.

Phantom pain and stump pain should be addressed initially by placing an epineural catheter in the transected sciatic nerve and using multimodal analgesia.

**Preoperative Planning**

- MRI and CT are done to determine the extent of the tumor in the proximal femur.

**HIP EXPOSURE AND VASCULAR DISSECTION**

- The patient is placed supine on the operating table. A two-armed incision is made starting medially and extending distally along the medial side of the distal femur. This incision should be relatively posterior so that the sartorial canal and the superficial femoral artery are accessed through their posterior aspect, leaving the anterior branches to supply the anterior flap and quadriceps muscle (similar to an anterior flap hemipelvectomy). The lateral portion of the incision is directed toward the greater trochanter and extends down the lateral portion of the femur in line with the course of the fascia lata.

- The incision and approach to the hip may vary depending on the type of flap. The initial incision is carried down through the subcutaneous fat and fascial layer to reveal the external oblique aponeurosis using large anterior myocutaneous flaps (TECH FIG 1). Multiple branches of the saphenous vein are usually encountered; these should be clamped, divided, and ligated.

- Once the superficial femoral artery is identified, it is clamped, divided, and ligated as distally as oncologically possible. The accompanying vein and nerve are also ligated. The sartorius is identified at its origin at the anterior superior iliac spine and divided from its origin. Next the hip is flexed to relax the iliopsoas muscle, which is identified and dissected from its origin.

**Anterior Flap Dissection**

- Large anterior and posterior flaps are developed. The fascia lata is incised along its entire length. The vastus lateralis is released from its origin.

- With the fascia lata exposed, the hip girdle muscles are visualized with internal rotation of the hip.

- The sciatic nerve is identified and a Penrose drain is placed around the nerve. The next steps involve dissecting the bone away from the musculature distally.

- Distally, the quadriceps muscles, the adductor muscles, and the hamstring muscles are sequentially clamped using large Kelly clamps and divided according to a predetermined anatomic level of the above-knee amputation. They are marked with Dacron tape (Deknatel, Mansfield, MA).

**Hip Disarticulation**

- A trochanteric osteotomy is made with the abductors detached with the osteotomy fragment. The osteotomy is recommended as long as there is no tumor involving the greater trochanter and surrounding area. An appropriate angle should be maintained while the osteotomy is being performed to ensure that an adequate amount of bone remains attached to the abductor musculature.

- The short external rotators are divided at their bony insertions.

- The hip capsule is identified and divided at the base of the femoral neck using a standard T-type incision. The base of the T runs along the anterior part of the neck. The T itself is circumferential along the base of the neck.

- The hip capsule is tagged for later reconstruction.

- The sciatic nerve is located at the level of the hamstring. It should be cut 2 cm proximal to where the hamstrings are cut. By maintaining the proximal sciatic branches, innervation to the hamstrings is maintained and thus hip extension is preserved. The hip is disarticulated at the acetabular level at this point and the entire femur is removed (TECH FIG 2).

**Creating a Femoral Stump with a Proximal Femoral Modular Prosthesis**

- The proximal femoral modular prosthesis comprises a proximal bipolar part, a body, and a distal rounded tip. The proximal bipolar part has holes and porous coating around the base of the neck that is intended for reattaching the hip capsule and the greater trochanter. This prevents sliding of the transferred muscles.

- The prosthesis body has variable length options. The correct length is chosen according to trial measurements.

- The distal conical tip is custom-made to fit the prosthetic body. It has a rounded bullet-shaped tip to avoid pene-
The whole proximal femur is exposed, disconnected from the hip capsule, and removed. Muscle ends and hip capsule are tagged as they are disconnected.

A trial proximal femoral prosthesis can be assembled based on an approximation of the required length. The resected femoral head should be measured to help approximate the head cup size that is required. The trial prosthesis should be placed into the acetabulum and the soft tissues should be released from their retracted positions to simulate closure and demonstrate whether the trial prosthesis will allow adequate soft tissue closure (TECH FIG 3). Once the desired prosthesis is determined, the prosthesis is assembled and the Morse tapers are impacted.

To strengthen the capsular closure, we use 3-mm Dacron tape, which acts as a noose around the prosthesis to prevent dislocation. This step is often easier if done just before the actual prosthesis placement.

The Dacron tape is sewn circumferentially around the cut capsule (TECH FIG 4). Putting too much tension on the Dacron tape may cause difficulty in reducing the prosthesis. Once the Dacron is in place, the assembled prosthesis is reduced into the acetabulum and the Dacron is snugly tightened and tied, forming a noose around the femoral neck. In our experience this has helped to prevent dislocations.

The hip joint should be put through functional range of motion to ensure a successful outcome.

Once the surgeon is satisfied with the prosthesis and range of motion, the previously detached iliopsoas muscle is pulled over the anterior hip capsule and sutured to it with Ethibond. The short external hip rotators are pulled anteriorly and sutured to the posterior capsule.
Reconstruction of the Adductor and Abductor Mechanism

- The hip abductors with the osteotomized greater trochanter are repositioned and reconnected with cables and a greater trochanter grip (TECH FIG 5A). The adductors are reconnected to the stump stem (TECH FIG 5B, C).
- The remaining proximal portion of the sciatic nerve is identified. Its epineural sheath is opened carefully using a fine right-angle clamp, and a standard epidural catheter is placed and threaded proximally for at least 5 to 10 cm within the sheath. The catheter is then sutured to nearby adipose or muscular tissue to help secure it using a 4-0 chromic suture. A 14-gauge angiocatheter is placed at the desired exit point for the catheter, with the needle passing beneath the subcutaneous and muscular layers. The epineural catheter is threaded through the angiocatheter to its desired position at the skin level and the angiocatheter is removed with the epineural catheter now outside the skin. The catheter should be infused with 4 to 8 cc 0.25% bupivacaine without epinephrine to aid in postoperative pain control.

Soft Tissue Reconstruction and Wound Closure

- Dacron tapes are sutured into all cut distal stumps of the quadriceps, adductors, and hamstrings (TECH FIG 6).
- The posterior muscle groups are tenodesed to the stump prosthesis using the holes made into the distal portion of the prosthesis with the hip in complete extension. The quadriceps muscle is tenodesed to the anterior portion of the stump prosthesis in a similar fashion through the preformed holes, also with the hip in extension. The adductor group is connected in a similar fashion. By setting the prosthesis in neutral position and pulling all three groups and tenodesing them at once, muscle balance is achieved.
- The surgeon should avoid hip flexion and adduction.
- The ends of the muscles are sutured to each other, forming a continuous fascial border covering the distal stump. Appropriate muscle tensioning and balancing are imperative to prevent muscle contractures, particularly abduction and adduction or flexion contractures.
- The reconstructed stump should lie in neutral position. The origin of the vastus lateralis is reattached to the greater trochanter proximally. The vastus lateralis fascia is tenodesed to the fascia lata.
- We favor the use of two Jackson-Pratt drains to drain the wound at the deep layers of the hip joint and the distal stump (TECH FIG 6D).
- The fascia lata is reapprroximated along its entire length. The subcutaneous and skin layers are then closed using standard techniques.
- A compressive dressing is recommended to prevent excessive swelling. The stump should remain in neutral position if the tissue tension is balanced correctly.
Fasciocutaneous flaps to supply adequate cover
- An anterior flap is preferred, but if this is not possible then a posterior flap is used.

Sparing the abductor mechanism with a greater trochanter osteotomy
- As long as no disease involves the area of the greater trochanter, this should be osteotomized and used in reconnecting the abductor mechanism.

Trial prosthesis
- Measurements should be made intraoperatively for the bipolar head size and body length of the prosthesis.

Hip capsule
- Hip joint capsule should be preserved and tagged. After resection the capsule should be reconnected to the prosthesis around the base of the neck. The hip capsule is then reinforced by connecting the distal end of the psoas muscle to the anterior capsule and the short external rotators to the posterior capsule.

Muscle tension
- The quadriceps, hamstrings, and adductor muscles should be reconnected at equal tension while the prosthesis is in neutral position.

Sciatic epineural catheter
- Postoperative analgesia is crucial. We believe pain should be treated perioperatively by inserting an epineural catheter into the transected tip of the sciatic nerve.
POSTOPERATIVE CARE

- Drains may be removed about 3 days after surgery. Compressive dressings are used for the first few weeks after surgery. A prosthesis may be fitted as soon as the wound has healed. Full weight bearing is permitted.
- Physiotherapy may begin promptly after surgery and should focus on achieving range of motion.

OUTCOMES

- We have used this procedure in six patients over a 30-year period for osteosarcoma (n = 2), malignant fibrous histiocytoma of bone (n = 2), and synovial sarcoma (n = 2), with very good results. Five of the six patients ambulated with an above-knee prosthesis (FIG 3). The only patient who did not ambulate with his prosthesis died within several months of the surgery due to complications from his disease.
- There were no infections, no dislocations, and no local recurrences; no secondary procedures were required in any of these patients.
- Three patients died of their disease and three patients remain alive. Of the three remaining patients, one has been ambulating with his stump prosthesis for 15 years.

COMPLICATIONS

- A possible complication is deep infection involving the prosthesis. Stump reconstruction should be undertaken only when it is evident there is no infection of the limb. If there is doubt about infection, a two-stage procedure is recommended.
- To avoid hip dislocation, the hip joint capsule must be reconstructed. The reconstructed hip is then reinforced with the psoas anteriorly and the short external rotators posteriorly. Stability should be assessed intraoperatively.
- There is a natural tendency for the stump toward flexion and abduction due to the muscle strength of the quadriceps and abductors. It is therefore crucial to achieve muscle balance of the quadriceps, adductors, hamstrings, and abductors during reconstruction.

REFERENCES

BACKGROUND

- Although many bone and soft tissue sarcomas of the femur and thigh can be treated with limb-sparing techniques, some aggressive tumors are complicated by neurovascular involvement or extensive soft tissue contamination and thus require an above-knee amputation (AKA) (FIG 1).
- An AKA is a transfemoral amputation of the lower extremity. AKAs are usually classified by level: high (just below the lesser trochanter), standard or midfemur (diaphyseal), or low distal femur (supracondylar).
- In general, transfemoral amputations with 50% to 70% of the residual bone length (measured from the greater trochanter to the lateral femoral condyle) are optimal. However, when amputations are done in an oncologic setting, the amount of femur remaining is determined by the extent of the tumor.
- Generally if 3 to 5 cm of bone distal to the lesser trochanter remains, a standard AKA prosthesis can still be used.

ANATOMY

- The surgeon must be familiar with the major neurovascular structures of the thigh because these structures will need to be identified and ligated. The femoral artery is the main artery of the thigh and femur. Its course changes throughout the length of the femur, and therefore its location varies depending on the level of amputation (FIG 2).

High AKA

- Proximally, the femoral artery lies beneath the sartorius muscle, anterior to the adductor longus muscle and anterior to the femur. The profunda femoris artery lies posterior to the adductor longus muscle. At this level the femoral artery is lateral to the femoral vein. The sciatic nerve lies posterior to the adductor magnus and anterior to the long head of the biceps.

Midfemur AKA

- The femoral artery lies between the vastus medialis and the adductor magnus and is medial to the femur in the mid thigh area. In this region, the femoral vein is lateral to the artery. The sciatic nerve lies between the short head of the biceps and the semimembranosus.

Supracondylar AKA

- The femoral artery is directly posterior to the femur. After passing the canal of Hunter, the femoral artery joins the sciatic nerve in the popliteal fossa. The artery is deep and medial to the sciatic nerve.

INDICATIONS

- Local recurrence of malignant carcinoma or sarcoma where limb salvage would not yield a functional limb or effectively remove the disease (FIG 3).
Chapter 40  ABOVE-KNEE AMPUTATION  2061

- Tumors with major vascular involvement with invasion of major blood vessels, which usually have poor outcomes and a poor prognosis
- Soft tissue contamination, such as after a pathologic fracture
- Tumors of the distal lower extremity with major nerve involvement, as with tumors of the popliteal space (FIG 4A,B)
- A poorly planned and executed biopsy, which can cause extensive contamination
- Infection, particularly in the case of biopsy, which can cause extensive contamination
- Skeletal immaturity, which often leads to significant limb-length discrepancies when limb-sparing procedures are done on skeletally immature patients
- Extensive tumor involvement that prohibits adequate soft tissue coverage of a prosthesis (FIG 4C–E)

IMAGING AND OTHER STAGING STUDIES

Plain Radiography
- Plain radiographs often provide the first indication for the need for amputation and an initial estimate of the necessary amputation level.
- Orthogonal views of the femur, tibia, and fibula can be helpful in showing tumor involvement and the extent of bony destruction, although generally up to 30% of the bony architecture has to be destroyed before radiographic findings are apparent (FIG 5A).

Computed Tomography and Magnetic Resonance Imaging
- CT and MRI are the most helpful in determining the level of intramedullary tumor involvement and the extraosseous extent of the tumor, which is used to determine the amputation level (FIG 5B).
- MRI is also useful for showing tumor involvement of neurovascular structures, which often necessitates amputation. MRI is the most reliable imaging study in determining the presence of skip metastases, which may alter the level of amputation.

FIG 2 • Level of osteotomy and cross-sectional anatomy for supracondylar, diaphyseal, and high above-knee amputation. (Courtesy of Martin M. Malawer.)

FIG 3 • A. A 45-year-old patient initially presented with a dedifferentiated, high-grade osteosarcoma of the fibula. After neoadjuvant chemotherapy the patient underwent intercalary fibular resection. Approximately a year after the surgery the patient presented with a rapidly enlarging, extensive tumor recurrence. B. As shown on MRI, the tumor extensively invaded the superficial posterior, deep posterior, and lateral compartments of the leg. Wide excision of the tumor would necessitate removal of the neurovascular bundle and all three compartments. Above-knee amputation was therefore performed.
FIG 4 • A, B. A 77-year-old patient presented with a high-grade soft tissue sarcoma that invaded the popliteal space and destroyed the proximal and midshaft areas of the tibia and fibula, resulting in the loss of peroneal function. C. A 23-year-old patient with a few years’ history of a neglected benign giant cell tumor of the distal femur with an extensive soft tissue component. D. A plain radiograph of the distal femur showing extensive bone destruction. The knee joint is in flexion contracture due to intractable pain. E. CT shows that only a thin rim of muscles is left. Adequate soft tissue coverage of a prosthesis was therefore not feasible, and above-knee amputation was performed. (C–E: Courtesy of Martin M. Malawer.)

FIG 5 • A. Plain radiograph of the knee showing extensive destruction of the proximal tibia and fibula. B. CT scan showing a large tumor that displaced the popliteal artery posteriorly and obliterated branches of the popliteal artery more distally.
Bone Scan
- Bone scans are useful in determining the intraosseous extent of the tumor; findings correlate well with the MRI.

Angiography and Other Studies
- Angiography is useful in determining the patency of the major vessels. In the older population, the superficial femoral artery is often obliterated.

Biopsy
- A biopsy is necessary before determining the final level of amputation. In general, transmedullary amputation is now performed for bony sarcomas of the distal femur, although historically a hip disarticulation was recommended. A failed limb-sparing procedure of the distal femur can still be treated with a high AKA.

Surgical Management
- When AKAs are done for oncologic indications, the tumor extent ultimately determines the level of amputation. Beyond that consideration, retaining as much length as possible that is closest to the ideal stump length will facilitate prosthetic fitting. The types of flaps may vary depending on the extent of the distal femoral tumor; medial-lateral flaps may be required instead of the more traditional fish-mouth incision. The quality of the skin, prior radiation, and old scars must all be considered. In general we do not use immediate-fit prostheses after amputation for tumors.
- When planning the types of flaps that will be used for the amputation, the surgeon should consider the soft tissue extent of the tumor, prior radiation fields, and previous incisions.

Preoperative Planning
- Having patients meet with a prosthethist, a functional amputee, or both can help manage expectations and answer specific questions about daily activities and function.

Positioning
- Patients are placed supine on the operating table with the operative extremity in flexion and abduction (Fig 6).

Approach
- Most amputations are done initially using an anterior approach to the femur. The leg can then be placed in a figure-4 position and then flexed and adducted to facilitate the posterior work.

Incision and Transection of Muscle, Neurovascular Structures, and Bone
- The most common type of flap is the anterior and posterior fish-mouth flap. This type of incisional line should be drawn before starting the procedure. The initial incision is made through the skin, superficial fascia, and subcutaneous tissue vertical to the skin edges (Tech Fig 1A).
- The major muscles should be carefully transected using electrocautery to reduce bleeding and tacked for later use in soft tissue reconstruction. The level of the amputation will determine the muscles that are transected, but portions of the quadriceps, hamstrings, and adductors are cut at almost all levels (Tech Fig 1B).
- The deep femoral artery and vein are dissected, suture-ligated, and transected.
- Nerves should be pulled gently about 2 cm, ligated with nonabsorbable sutures, and transected with a knife. The sutures can be used later to identify the femoral and sciatic nerves if epineural catheters are to be placed. If the catheters are not placed, the nerves should be allowed to retract back to the muscle mass.
- The bone is cut using an oscillating or Gigli saw. A malleable retractor placed posterior to the femur can prevent damage to the posterior soft tissue and flap. Once the bone is cut, frozen section analysis from the remaining intramedullary canal is performed to ensure that there is no tumor remaining.
- The femoral edge is beveled using a saw or rasp to smooth the remaining edge and to leave a less prominent point of contact for the prosthesis (Tech Fig 1C, D).

Placement of Epineural Catheter and Myodesis
- A small opening is made using a 15-blade scalpel into the epineural sheath. An epineural catheter, which has previously been flushed with 0.25% bupivacaine, is introduced into the epineural space and advanced proximally for 5 to 7 cm. The neural sheath is then closed with 4-0 chromic suture (Tech Fig 2A, B).
- A 16-gauge angiocatheter is introduced into the skin at the desired site of exit for the epineural catheter. The epineural catheter is threaded through the angiocatheter until it is visible beyond the skin. The angiocatheter, encasing the epineural catheter, is carefully brought through the subcutaneous tissue to exit at the skin.
- To prevent flexion and abduction of the femoral stump, drill holes can be made in the femur using a standard drill, and then the sutures used to tag the adductor musculature can be threaded through the femoral holes to tenodese the adductors to the femur. This also helps restore some of the muscular strength (Tech Fig 2C).
Part 5 ONCOLOGY • Section IV LOWER EXTREMITIES

TECH FIG 1 • A. Incision. The skin flaps are marked. The main factors that determine the type of flaps are the extent of the soft tissue tumor, areas of prior radiation, and previous scars. The highest priority is to avoid local recurrence, and no attempt is made to adhere to standard flaps; at this level a skin or muscle flap of almost any length will heal primarily in a young patient. It is not necessary to use equal flaps; long posterior, anterior, and medial flaps will heal. B. Transection of muscle and bone. Incision is performed through the skin, superficial fascia, and subcutaneous tissue vertical to the skin edges. Using electrocautery, muscles are beveled in their transection down to bone. Large vessels are dissected, suture-ligated in continuity, and transected in a bloodless fashion. Nerves should be gently pulled down from their muscular bed approximately 2 cm, ligated with nonabsorbable monofilament sutures, transected with a knife, and allowed to retract back to the muscle mass. The bone is transected with an oscillating or Gigli saw without traumatizing the soft tissues. C. The femoral edge should be beveled and smooth. D. A sharp edge can become extremely painful, especially when pressure from a prosthesis is applied. (Courtesy of Martin M. Malawer.)

- We recommend excising some of the adductors before myodesis to shape the stump into a nice conical shape. Additional muscle may be resected from the lateral aspect of the thigh if necessary.
- A plug of polymethylmethacrylate (PMMA) or Gelfoam is placed in the distal canal to prevent large hematomas from occurring due to continuous intraosseous bleeding after surgery. This is more common in young adults and children.
- The remaining quadriceps and hamstring muscles are myodesed to each other to cover the end of the femur.

Drain Placement and Closure
- Closed suction drains placed beneath the fascial layer should be brought out of the medial and lateral aspects of the incision (TECH FIG 3A).
- The superficial fascia should be tightly closed. As the skin edges are closed, the surgeon should take care to avoid having excess tissue and large skin folds, which can later interfere with optimal prosthesis fitting.
- A rigid dressing should be applied at the completion of the amputation to reduce swelling and prevent the development of a flexion contracture (TECH FIG 3B).
**TECH FIG 2** • A. An epidural catheter, flushed with bupivacaine 0.25%, is introduced into the epineural space. The catheter is advanced 5 to 7 cm proximally, and the neural sheath is sutured over the catheter with absorbable sutures. B. An epineural catheter in the femoral nerve after above-knee amputation. Contrast dye was bolus injected to show the distribution of local anesthetics within the epineural space. C. A two-layer myodesis is used over the end of the femur. Muscle stabilization of the femur is essential if the strength of the limb is to be retained. The quadriceps and hamstring muscles are myodesed to each other to cover the bony end of the femur, and the adductors are tenodesed to these muscles and the femoral stump using drill holes. This is especially important if there is a short proximal femoral stump, which tends to go into flexion and abduction. (Courtesy of Martin M. Malawer.)

**TECH FIG 3** • A. Closed suction drains are brought out of the medial and lateral aspects of the incision. It is important not to stitch these catheters to the skin, because they will be removed from inside the rigid dressing. B. Application of a rigid dressing. (Courtesy of Martin M. Malawer.)
PEARS AND PITFALLS

Postoperative flexion contracture  ■ Flexion contractures can be prevented with the use of proximal casting or immobilization to the groin level, suspended in place with a belt, if necessary.

Adductor myodesis  ■ After AKA the iliopsoas and hip abductors can cause the stump to go into flexion and abduction. Tenodesing the adductor magnus prevents this deformity and helps prevent the loss of hip abduction power, which has been estimated to be up to 70% less without myodesis. Myodesis acts as an insertion site and facilitates muscle contraction and function.

Muscle balance  ■ Managing muscle group imbalances through myoplasty also improves the function of the amputee. Because the hip flexors are stronger than the extensors, the hamstrings should be cut longer than the quadriceps and attached to one another.

Neuroma  ■ Nerves should be cut as proximally as possible and buried within muscular tissue to prevent neuroma formation.

Phantom pain  ■ The use of epineural catheters in the femoral and sciatic nerves can decrease the incidence and severity of phantom pain.

Skin pressure from bone edges  ■ The distal anterior cortical edge of the femur should be beveled to prevent pressure arising from the bone, particularly with prosthetic use.

POSTOPERATIVE CARE

■ A compressive dressing applied to the stump site diminishes postoperative swelling at the stump site.
■ Proximal extension of the postoperative immobilizer or splint, prone positioning, and physical therapy help to prevent flexion contracture.
■ Fitting for an initial or temporary prosthesis soon after wound healing and swelling resolution is most often associated with increased prosthetic use.
■ Because the energy requirements of AKAs are about 60% to 100% times greater than that required for non-amputees, many amputees require the use of assistive devices for ambulation.
■ Phantom limb pain and sensations can diminish after surgery. However, when phantom pain persists, narcotics and drugs with effects on nerves such as gabapentin (Neurontin) may be helpful.

OUTCOMES

■ Through effective multidisciplinary care, most patients are able to ambulate and return to normal daily activities, including driving. Some are also able to participate in sporting activities.
■ Outcome studies comparing patients treated with amputations versus those treated with limb salvage found that AKA amputees were more limited in their mobility and community activities compared to those with limb salvage, but they reported less muscle weakness. In general, AKA amputees have approximately the same overall quality of life compared to patients undergoing limb-sparing surgery when assessed by numerous psychological measures.
■ AKA amputees have also been shown to be more likely to walk with a limp.

COMPLICATIONS

■ Wound healing problems can arise but are not as common as in amputations performed for vascular or ischemic problems. Wound problems after amputations performed for tumors are most likely due to preoperative host factors such as comorbidities and nutritional status. Therefore, the patient’s preoperative status should always be optimized where possible.
■ Phantom pain or causalgia syndromes may occur and are difficult to predict, although patients with significant preoperative pain complain of postoperative pain more often. Attempts at preventive anesthesia (eg, serial epidurals before surgery) have produced mixed results. It is important to identify and diagnose these painful syndromes early and manage them aggressively.

REFERENCES
BACKGROUND

- Extensive tumors of the distal leg, ankle, and foot often require a below-knee amputation (BKA) as the primary form of surgical treatment. With such extensive tumors in these locations, attempts at limb salvage often leave patients with a limb with very limited function. Conversely, advances in prosthetic design and engineering allow for BKA amputees to be very active in a variety of activities, often more active than patients who have had limb-sparing procedures for similar tumors.
- In general, we recommend BKAs for most high-grade and many low-grade sarcomas of the foot, especially when they occur in the plantar aspect. About 1% of bone sarcomas occur in the foot; these are usually treated with a BKA (FIG 1).

ANATOMY

- The main anatomic focus of a BKA is identification and ligation of the tibial neurovascular structures.
- The anterior tibial artery and vein and deep peroneal nerve lie deep to the anterior tibialis muscle and lateral to the tibia. These structures must be identified and individually ligated.
- As the dissection progresses posteriorly, the posterior tibial artery and vein and tibial nerve are found posterior to the tibia and tibialis posterior muscle and anterior to the soleus muscle.
- The peroneal artery and veins also lie posterior and lateral to the tibia. They lie between the tibialis posterior and the flexor hallucis longus.
- The superficial peroneal nerve is identified within the lateral compartment of the leg and also must be transected. It usually exits the fascia of the anterolateral leg approximately 12 cm proximal to the tip of the lateral malleolus. It should be identified and transected.

INDICATIONS

- Tumor recurrence in the distal tibia, ankle, and foot not amenable to limb-salvage techniques (FIG 2)
- Infiltrative high-grade soft tissue sarcomas or other malignant tumors of the lower extremities.
- Extensive involvement of bone sarcomas of the lower extremities
- Palliation
- Failed attempt of radiation therapy for dorsal and plantar foot tumors

IMAGING AND OTHER STAGING STUDIES

Plain Radiography

- Although plain radiographs are poor at identifying soft tissue tumors of the foot and ankle, they can be useful for the initial diagnosis of bone tumors such as enchondromas, giant cell tumors, and primary sarcomas of bone (FIG 3A).

Computed Tomography and Magnetic Resonance Imaging

- CT and MRI are helpful in determining the level of intramedullary tumor involvement and the extraosseous extent of the tumor, which is used to determine the amputation level. MRI is also useful for showing tumor involvement of neurovascular structures, which often necessitates amputation (FIG 3B).

Bone Scan

- Bone scans are required if the tumor is located at or above the ankle. This study correlates well with the MRI. In general, amputation is performed 4 to 7 cm above abnormal findings on a bone scan.

Angiography and Other Studies

- Angiography is very helpful in determining the extent of involvement of the anterior tibialis and posterior tibialis arteries. Tumor involvement of either of these structures determines the type of flap that should be used. This planning is important in minimizing wound healing problems.

Biopsy

- As with an amputation at any level, a biopsy should be done to confirm the diagnosis before performing a BKA.

SURGICAL MANAGEMENT

- The ideal level of surgical resection for a BKA is at the musculocutaneous junction of the gastrocnemius muscle. This provides better soft tissue padding and usually a more reliable blood supply for the posterior flap.
- The recommended length for a BKA stump for optimal prosthetic fitting is 12.5 to 17.5 cm. However, tumor extent and margins will ultimately determine the length of the stump.
- Careful flap selection is important in achieving a functional BKA stump. Because of the subcutaneous location of the tibia and sparse musculature of the anterior leg compartment, use of a long posterior flap is preferable to a fish-mouth flap.
- Prevention of hematoma and seroma development with the use of drains is critical. These complications can delay wound healing and in some cases delay adjunctive treatments such as chemotherapy and radiation therapy.

Preoperative Planning

- Preoperative referrals to a psychologist and prosthetist are often useful in helping patients prepare for their upcoming life adjustments.

Positioning

- The patient is supine on the operating table with the operative extremity slightly elevated.

Approach

- The initial approach is made anteriorly in most cases. Then the knee can be flexed and abducted and adducted or an assistant can elevate the leg to gain exposure for the posterior work.
FIG 1 • Below-knee amputation is performed for malignant tumors of the distal leg, ankle, and foot. (Courtesy of Martin M. Malawer.)

FIG 2 • A. Locally recurrent carcinoma of the foot. This local recurrence, the patient’s fifth, occurred only a few months after the previous resection within the irradiated field. B. Extensive high-grade angiosarcoma of the dorsal aspect of the foot. (Courtesy of Martin M. Malawer.)

FIG 3 • A. Angiosarcomatosis of the leg and foot. There are multiple lytic lesions of the distal third of the tibia, fibula, and talus. B. T2-weighed MR image of the foot, showing extensive high-grade malignant fibrous histiocytoma of almost the entire plantar aspect of the foot, with extension to the dorsal aspect of the foot.
Incision and Flap Selection, Soft Tissue Dissection, and Bone Transection

- Because of the subcutaneous location of the tibia and the minimal musculature of the anterior leg compartment, a long posterior flap is preferable to the classic fish-mouth flap. In the initial incision, the skin, superficial fascia, and subcutaneous tissue are cut perpendicular to the skin surface (TECH FIG 1A).
- The muscles of the anterior, lateral, and deep compartments of the leg are transected using the electrocautery to minimize bleeding.
- The skin, superficial fascia, and subcutaneous tissue are cut perpendicular to the skin surface. The muscles are transected with electrocautery. Vascular structures are ligated in continuity and divided. Major blood vessels are suture-ligated (TECH FIG 1B). Nerves are meticulously dissected and gently pulled 2 cm out of their surrounding muscle mass. They are double-ligated with monofilament nonabsorbable suture. The large muscle groups are tapered so that they can be secured over the cut ends of the bone. If the amputation is performed for a primary bone sarcoma, intramedullary content from the edge of the stump should be sent for frozen section to verify that it is free of tumor. If the amputation is performed for a soft tissue sarcoma, soft tissues from the surgical margins should be assessed in a similar manner. After transection, the tibial edge is beveled (TECH FIG 1C,D).
- The tibia is osteotomized using an oscillating or Gigli saw. The fibula is resected several centimeters proximal to the tibial osteotomy to create a more tapered stump. The cut edge of the tibia is beveled using a saw or rasp to smooth the edges and contour the bone for a better prosthetic fit (TECH FIG 1C).
- A sample from the remaining intramedullary canal of the tibia should be sent for frozen section analysis to verify that the remaining bone is free of tumor.
- To form a nice conical stump, we recommend excising the fibula about 4 to 5 cm above the tibial osteotomy, in addition to removing some of the peroneal musculature at the same level. This permits easier stump shrinking and prosthetic fit.

Placement of Epineural Catheter and Myodesis

- A small opening is made using a 15-blade scalpel into the epineural sheath. The epineural catheter, which has previously been flushed with 0.25% bupivacaine, is intro-
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Stump contour</th>
<th>■ Rounding the contour of the distal end of the tibial stump and resecting the fibula a few centimeters shorter than the tibia can promote better fit and ease with prosthesis use.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myodesis</td>
<td>■ Functional myodesis of the major muscle groups of the leg to the distal tibia provides good soft tissue coverage for the stump while allowing functional range of motion.</td>
</tr>
<tr>
<td>Wound healing problems</td>
<td>■ Healing can be compromised by preoperative chemotherapy. The use of drains and attention to detail with wound closures can help avoid these problems as well as hematoma and seroma development, which can delay other adjunctive treatments.</td>
</tr>
<tr>
<td>Postoperative flexion contracture</td>
<td>■ The use of a knee immobilizer or custom splint can prevent the development of a flexion contracture.</td>
</tr>
<tr>
<td>Phantom pain and causalgia</td>
<td>■ Perineural catheter flow rate, dose should be titrated, typically 4 to 8 mL of 0.25% bupivacaine per hour for about 72 hours.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- Once the initial postoperative dressing is removed, a stump-shrinker sock can be worn to minimize swelling.
- Patients should be counseled that the transition to prosthesis use will be slow and gradual and will occur over about 3 to 6 months. Once an initial prosthesis can be fitted, wear time is gradually increased to build tolerance.

OUTCOMES

- Similar to other lower extremity amputations, BKAs have been shown to be effective in palliation and improving the quality of life in cancer patients.
- As might be expected, patients after BKAs report less limitations than their AKA counterparts and are less likely to ambulate with walking aids or a limp.
- The vast improvements in prosthetic design for BKA amputees allow them to be extremely functional. They can participate in almost any desired recreational activity.

COMPLICATIONS

- Hematoma and seroma develop can cause major wound healing problems that sometimes require additional surgeries. This is a major problem when the amputation has been done for a primary bone or soft tissue sarcoma and adjuvant chemotherapy is needed. Such wound problems can delay the start of these very important treatments and ultimately also delay prosthetic fitting. The use of closed suction drains can minimize the risk of such complications.

REFERENCES

Foot and Ankle Amputations: Lisfranc/Chopart

Loretta B. Chou, H. Thomas Temple, Yvette Ho, and Martin M. Malawer

BACKGROUND

- Tumors of the foot and ankle are rare. In the senior author’s experience, 153 cases were treated.
- FIGURE 1A shows all anatomic sites, FIGURE 1B shows the distribution of malignant and benign cases, and FIGURE 1C shows the distribution of all types of surgical procedures.
- Patients with tumors of the metatarsals complain of pain with an associated mass. The mass may be small and chronic. It may be first noticed after a minor injury. The patient may have difficulty with weight-bearing activities, including walking and standing. Shoe wear, particularly fashionable shoes, may be limited.
- Physical examination often shows a tender mass localized to the metatarsal with some swelling. If a sensory nerve overlies the mass, there may be paresthesias. If the mass is large, there may be loss of motion, or discomfort with active range of motion of the foot and ankle.
- For extensive disease of the forefoot involving the first and second interspace in adjacent metatarsals or multiple metatarsals, a Lisfranc amputation or a transmetatarsal amputation is indicated (FIG 2A–C). These amputation levels are highly functional with minor shoe-wear modifications and forefoot fillers. If the metatarsal bases can be preserved using a transmetatarsal amputation, the functional outcome is improved.
- Careful preoperative evaluation is necessary, and MRI is especially important to assess the extent of marrow change in the metatarsals to ascertain the appropriate level of amputation.
- For tumors extending to the tarsometatarsal joint with soft tissue extension, a Chopart amputation is a consideration. The Chopart amputation is a transtarsal amputation that preserves the talus and calcaneus. The disadvantage of the Chopart amputation is the loss of the dorsiflexors of the foot, which allows unopposed action of the Achilles tendon, resulting in an equinus contracture.
- To circumvent this problem, the tibialis anterior is used. It is detached from the tarsal navicular with a cuff of soft tissue, preferably periosteum. A drill hole is made through this bone tunnel and sewn to itself or soft tissue as it exits through the tunnel. The repair may be augmented with bone anchors placed near the dorsal opening of the tunnel. The residual foot is maintained in maximal dorsiflexion (FIG 2D,E).
- The advantage of a Chopart amputation over a Syme amputation is the maintenance of hindfoot height. This is an end-bearing residual limb and the patient can negotiate short distances without modified shoe wear or prosthetic fitting.

ANATOMY

- The Lisfranc joint is the tarsometatarsal joint. An amputation at this level will preserve the dorsiflexors and plantarflexors.
- The Chopart joint is also known as the transverse tarsal joint. It includes the talonavicular and calcaneocuboid joints. An amputation at this level preserves the plantarflexors but sacrifices the dorsiflexors, often resulting in an equinus contracture.

INDICATIONS

Lisfranc

- Extensive tumor involving the first and second interspace in adjacent metatarsals or multiple metatarsals

Chopart

- Tumors extending to the tarsometatarsal joint with soft tissue extension. FIGURE 3 shows the pathology specimen after wide resection of a chondrosarcoma involving multiple small bones of the foot.

IMAGING AND OTHER STAGING STUDIES

- Preoperative studies include plain radiographs of the foot, including anteroposterior, lateral, and oblique views. If there is involvement of the ankle joint, then anteroposterior and mortise views are obtained as well. MRI is important to evaluate the amount of involvement of the metatarsals to determine the level of amputation. It also shows the extent of soft tissue tumors and may be helpful in distinguishing benign from malignant tumors.
- MRI is helpful for assessing soft tissue involvement. FIGURE 4A,B shows a chondrosarcoma of the calcaneus, and the MRI shows extension into the soft tissue. It was treated with cryosurgery but recurred, and a below-the-knee amputation was performed.
- FIGURE 4C,D shows an example of a unilateral calcaneal brace (UCB). The radiograph shows the typical expansile appearance of the UCB. The CT scan shows greater bony detail. The lesion was treated with curettage, graft, and polymethylmethacrylate (PMMA).

SURGICAL MANAGEMENT

- The goal of the surgical procedure is remove the tumor with adequate margins. FIGURE 5 illustrates a case of osteosarcoma of the calcaneus. Osteosarcoma is usually treated with wide resection, but in this case the tumor was confined to the calcaneus. The patient had a good response to adjuvant chemotherapy, with 100% tumor necrosis, and was treated with the only calcaneal prosthesis reported in the world.
- A long plantar flap is important for a sturdy end-bearing stump.
- The quality of the tissue is more important than the quantity. The bony edges should be smooth and beveled if possible. An example is the Lisfranc amputation, in which the cuneiforms...
FIG 1 • A. All anatomic sites of tumors of the foot and ankle (n = 153). B. Distribution of malignant and benign tumors of the foot and ankle (n = 153). C. Distribution of surgical procedures for tumors of the foot and ankle (n = 153).

A

FIG 2 • Chopart amputation has a poor reputation because many patients develop an equinus contracture. With transfer of the tibialis anterior to the neck of the talus, this problem can be avoided. This case is an example of synovial sarcoma involving the forefoot. A. This patient’s radiographs showed radiodensity surrounding the second metatarsal, a typical radiographic appearance of a synovial sarcoma. B,C. MRI shows extensive soft tissue mass. The patient was treated with a Chopart amputation. (continued)
FIG 2 • (continued) D. Postoperative photograph shows good dorsiflexion function. E. Chopart amputation can be successful with the transfer of the tibialis anterior into the talar neck. This patient also had a bupivacaine catheter placed for postoperative pain control (A).

FIG 3 • Chondrosarcoma can spread to involve multiple sites. This photograph shows the pathology specimen after a below knee amputation of a chondrosarcoma involving multiple small bones of the foot.

FIG 4 • Chondrosarcoma of the calcaneus. A,B. MRI shows extension into the soft tissue. It was treated with cryosurgery but recurred, and a below-knee amputation was performed. C,D. UCB of the calcaneus. The radiograph shows the typical expansile appearance of the UCB. The CT scan shows greater bony detail. The lesion was treated with curettage, graft, and polymethylmethacrylate.
should be contoured to a rounded end. In a Chopart amputation, the talus and calcaneus should be cut and contoured to fit a prosthesis.

- Myodesis is helpful to pad the end of the stump.
- Reconstruction of the anterior tibialis tendon insertion into the neck of the talus in the Chopart amputation will help prevent an equinus contracture.

**Preoperative Planning**

- Preoperative planning is crucial for a good outcome. The preoperative radiographs and CT and MRI studies are important to determine the amount of tumor involvement. The results of the biopsy will determine the level of amputation.

**Positioning**

- The patient is placed supine on the operating table. A thigh tourniquet is placed over adequate padding, such as Webril. A bump may be placed proximal to the sciatic notch on the ipsilateral hip to limit external rotation of the extremity during the procedure.

**Approach**

- Lisfranc and transmetatarsal amputations are performed through a midfoot incision, with a long plantar flap. This is the same approach with the Chopart amputation. The plantar skin is thicker and has specialized columns of plantar fat to provide for a weight-bearing stump.

**TRANSMETATARSAL AMPUTATION**

- A transverse incision is made either at the middle or proximal third of the metatarsals, extending through skin into the subcutaneous tissue (**TECH FIG 1A,B**).
- The cutaneous branches of the terminal portions of the peroneal nerve are identified. Traction is applied, pulling the nerve distally. The nerve is transected sharply to allow it to retract proximally.
- The terminal branch of the dorsalis pedis is preserved if possible to maintain continuity of the anastomosis with the posterior tibial terminal arterial branch, thus maintaining the dorsalis pedis contribution of arterial flow through the arch.
- The extensor tendons are placed on a stretch, and this is best accomplished by flexing the forefoot and sharply dividing the tendons at the level of the skin incision, allowing the tendons to retract proximally.
- A beveled cut is made in the metatarsal heads by angling an oscillating saw 30 degrees from the perpendicular...
with the foot placed in neutral position on the operating table. A plantar flap is then fashioned by extending the incision through the skin approximately 45 degrees from the transverse dorsal incision obliquely across the medial and lateral foot to the level of approximately the metatarsal heads and then transversely across the skin just proximal to the metatarsal heads.

- The sensory nerve to the first ray is identified, traction is placed, and the nerve is transected sharply. The terminal branches in the medial plantar nerve are identified as well, placed on stretch, and sharply divided. The terminal branches of the medial plantar artery are identified, ligated, and divided.

- The superficial and deep flexor tendons are placed on stretch by dorsiflexing the forefoot through the metatarsal osteotomies and sharply dividing them, allowing them to retract proximally. No attempt is made to suture the extensor tendons to the flexor tendons.

- If there is a significant plantar extension of the tumor, a long plantar flap cannot be used. In this case, a fish-mouth configuration is preferable. To achieve this, equal dorsal and plantar flaps are constructed and the same operation is carried out as indicated above.

- The tourniquet is deflated and meticulous hemostasis is obtained. Excessive use of cautery to obtain hemostasis is discouraged to limit dysvascularity of the plantar flap.

- The plantar flap is brought up and myodesed to the residual metatarsals or tarsal bones. Alternatively, the plantar fascia can be sewn into the periosteum overlying the residual metatarsal heads or capsular structures in and around the tarsal bones.

- The skin is closed with 4-0 nylon sutures. A Penrose drain is placed deep to the flap and brought out either medially or laterally through the incision.

---

**TECH FIG 1 • A,B.** Surgical technique for transmetatarsal amputation. Dorsal and plantar skin incisions. Bone cuts are made with a sagittal saw.

---

**LISFRANC AMPUTATION**

- A transverse incision is made either at the middle or proximal third of the metatarsals, extending through skin into the subcutaneous tissue (TECH FIG 1C,D).

- The cutaneous branches of the terminal portions of the peroneal nerve are identified. Traction is applied, pulling the nerve distally. The nerve is transected sharply to allow it to retract proximally.

- The terminal branch of the dorsalis pedis artery is ligated and divided as it enters the first dorsal interspace and courses in the plantar fascia.

- The extensor tendons are placed on a stretch; this is best accomplished by flexing the forefoot and sharply dividing the tendons at the level of the skin incision, allowing the tendons to retract proximally.
- The Lisfranc joint is disarticulated sharply. A plantar flap is fashioned by extending the incision through the skin approximately 45 degrees from the transverse dorsal incision obliquely across the medial and lateral foot to the level of the distal metatarsals.
- The sensory nerve to the first ray is identified, traction is placed, and the nerve is transected sharply. The terminal branches in the medial plantar nerve are identified, placed on stretch, and sharply divided.
- The terminal branches of the medial plantar artery are identified, ligated, and divided. The superficial and deep flexor tendons are placed on stretch by dorsiflexing the forefoot through the Lisfranc joint and sharply dividing them, allowing them to retract proximally. No attempt is made to suture the extensor tendons to the flexor tendons.
- If there is a significant plantar extension of the tumor, a long plantar flap cannot be used. In this case, a fishmouth configuration is preferable. To achieve this, equal dorsal and plantar flaps are constructed and the same operation is carried out as indicated above.
- The tourniquet is deflated and meticulous hemostasis is obtained. Excessive use of cautery to obtain hemostasis is discouraged to limit dysvascularity of the plantar flap.
- The plantar flap is brought up and myodesed to the tarsal bones. Alternatively, the plantar fascia can be sewn into the periosteum overlying the capsular structures in and around the tarsal bones. The skin is closed with 4-0 nylon sutures, and a small drain is placed deep to the flap and brought out either medially or laterally through the incision.

**TECH FIG 1 • C,D. Surgical technique for Lisfranc amputation. Skin incisions on the dorsal and plantar aspects of the foot. The plantar skin flap is longer. Dissection and removal of the metatarsals. Wound closure with sutures.**

**CHOPART AMPUTATION**

- The Chopart amputation is performed through a transverse incision that is dorsally based at or just distal to the talonavicular joint (**TECH FIG 1E,F**).
- The dorsalis pedis artery and accompanying nerve are identified. The dorsalis pedis artery is ligated and divided, and the sensory nerve is placed on stretch and transected sharply, allowing it to retract proximally.
- The capsule of the talonavicular joint is circumferentially divided, along with release of the posterior tibial tendon. This tendon is tagged for later use as it is brought

**TECH FIG 1 • E,F. Surgical technique for Chopart amputation. Skin incisions with dorsal and plantar flaps. Dissection and removal of bones. Attachment of tibialis anterior tendon into the neck of the talus through drill holes. Wound closure with sutures.**
through the interosseous membrane and reattached to
the neck of the talus with suture anchors or through a
hole drilled in the talus as described above.

- An alternative solution is to place the posterior tibial
tendon through the interosseous membrane with the
medial half of the Achilles tendon. The Achilles tendon is
then suture-anchored to the neck of the talus and used
to augment the tibialis anterior or posterior tibial ten-
don. Achilles lengthening is also a helpful technique be-
cause it reduces the stress on the tibialis anterior. The
Achilles tendon is not necessary for normal ambulation
due to the lack of forefoot.

- A long plantar flap is preferred, but if the tumor extends
into the plantar base and soft tissues, a fish-mouth inci-
sion is made with equal-length dorsal and plantar flaps.

- To help prevent equinus contracture, the tibialis anterior
is detached from the tarsal navicular with a cuff of soft
tissue, preferably periosteum. A drill hole is made
through the neck and head of the talus in an oblique
fashion from dorsolateral to plantar-medial. The tendon
is then routed through this bone tunnel and sewn to it-
self or soft tissue as it exits through the tunnel. This re-
pair may be augmented with bone anchors placed near
the dorsal opening of the tunnel.

- The residual foot is maintained in maximal dorsiflexion
during this repair. Figure 2E shows the position of the
ankle after the amputation and reconstruction of the
tibialis anterior into the talus. Several additional proce-
dures are required for a functional Chopart amputation.
Contracture prevention is critical and ensured through
transfer of the extensor tendons to the dorsum of the
foot and lengthening of the Achilles tendon.\(^5\)

- The posterior tibial tendon and the flexor hallucis longus
and brevis tendons are divided; the tendons are allowed
to retract proximally unless the posterior tibial tendon is
used to augment the dorsiflexion repair.

- The plantar branch of the posterior tibial artery is lo-
cated, ligated, and divided. The flaps are maintained
with sufficient soft tissue to keep them as thick as possi-
able to prevent devitalization of the skin.

- If the head of the talus is prominent, a portion of this
bone can be removed in a beveled fashion by using an
oscillating saw and angling the blade 30 degrees from
distal proximal to plantar distal. The calcaneocuboid
articulation is generally divided, but if part of the cuboid
can be maintained, this is preferable. Contouring the dis-
tal talus and calcaneus will help to decrease the size of
the stumps, and this will help with prosthetic fitting.

- The repair of the plantar soft tissue to the dorsal soft tis-
sue is tenuous as there is no stout tissue dorsally to anchor
the plantar flap. For this reason, a myodesis is preferred;
it is performed by drilling holes in the distal talus and
residual cuboid and anchoring the plantar fascia to the
dorsal residual bone with 0 nonabsorbable suture. The
subcutaneous tissue is approximated with 3-0 absorbable
sutures and the skin repaired with 4-0 nylon suture.

- The residual foot must be maintained in as much dorsi-
flexion as possible. To help achieve this, a rigid dressing
is applied by binding the residual foot from a proximal-
plantar to distal-dorsal direction and applying gentle but
firm compression on the residual foot. This rigid dressing
is applied and extended up to the proximal leg, main-
taining the residual foot and ankle in a maximally dorsi-
flexed position to protect the repair.

---

**CURETTAGE AND CRYOSURGERY OF THE CALCANEUS**

- A sciatic nerve catheter is used for intraoperative and
postoperative pain control. General anesthesia is used for
the procedure. The patient is placed into the lateral decu-
bitus position with the affected side up. A tourniquet is
placed on the upper thigh. After sterile surgical prepara-
tion and draping, an L-shaped incision is made from the
tip of the fibula posteriorly and anterior to the Achilles
tendon. The incision is parallel to the fibula, extending
distally and making a curve at the border between the
dorsal and plantar skin of the calcaneus laterally.

- The initial skin is incised using the scalpel and dissection
is carried down through the subcutaneous tissue. The
incision and approach are inferior to the peroneal ten-
dons, which remain safely superior to the dorsal fasciocu-
taneous flap. The sural nerve is also more superior and
away from the operative field. The lateral wall of the cal-
caneus is exposed.

- A corticotomy is made using a drill to open the lateral
wall of the calcaneus. The tumor is opened, which allows
for the curettage. Large curettes are used to remove the
obvious tumor material. This is followed by inspecting
and burring the edges of the remaining calcaneal wall.
Once the resection is completed, the cavity is irrigated to
again inspect the cavity for remaining tumor.

- To do the cryosurgery, the tourniquet is inflated to 350
mm Hg. Gelfoam is used to line the skin edges and subcu-
taneous tissue around the wound site. The retractors are
placed over the Gelfoam, and laparoscopic tape sponges
are placed around the skin to cover the skin. The foot is
placed into a basin of warm water to try to keep the foot
warm to prevent any problems that the decreased tem-
perature from the cryosurgery may cause in the unin-
volved portions of the foot. Normal saline is poured into
the tumor cavity. Endocare cryosurgery probes are pre-
pared on the back table. Ice balls are formed and noted at
the tip of each of the probes. Three- and 5-mm probes are
used for the cryosurgery. The cryoprobes are placed into
the tumor cavity and left in to complete a 10-minute cycle.
The skin is monitored for necrosis, and warm saline is used
to keep the skin warm and supple. The cavity is allowed
to thaw and the tourniquet is deflated.

- The reconstruction portion of the procedure consists of
an allograft cancellous bone block from the bone tissue
bank that is cut and contoured and placed against the
subchondral surface adjacent to the subtalar joint.
Two small Rush rods are cut, contoured, and placed
within the calcaneus to extend from the subtalar joint,
abutting and holding the allograft in place. PMMA is
mixed with 1 g vancomycin on the back table and prepared by hand mixing. This is placed into the tumor cavity to fill the cavity, completing the reconstruction. The midfoot and forefoot are taken through gentle range of motion to ensure normal movement of these joints and to make sure that there was no iatrogenic extrusion of cement, which could compromise the motion of these joints. Also, the calcaneus is gently axially loaded with hand pressure to ensure that the reconstructed calcaneus moves as a single unit. A drain is placed, and the wound is closed in layers. A plaster splint is used.

SYMES AMPUTATION

- The incision extends from the anterior aspect of the lateral malleolus to the anterior aspect of the medial malleolus, continuing to the plantar skin. The incision at the plantar flap is made to the level of the calcaneocuboid joint. The soft tissues, including tendons, are incised and allowed to retract; the neurovascular bundle is identified and ligated. The talus and calcaneus are dissected sharply and removed.
- The surgeon must be cautious at the point of the Achilles tendon insertion site: the skin is thin and adherent and must be protected.
- The flares of the malleoli are removed with a sagittal saw. The plantar fat pad is fixed to the end of the stump with nonabsorbable sutures into drill holes of the distal tibia and fibula.
- A drain is placed and the wound closed in layers; 3-0 nylon suture is used to repair the skin. A well-padded soft dressing is applied.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>A careful and complete history and physical examination are essential. Preoperative studies are necessary to plan the resection and reconstruction.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical incision</td>
<td>A long plantar flap results in a better end-bearing stump. The natural cascade of metatarsal lengths should be maintained.</td>
</tr>
<tr>
<td>Wound healing</td>
<td>Local wound care with dressings and oral antibiotics are usually sufficient to allow for healing.</td>
</tr>
<tr>
<td>complications</td>
<td>Parenteral antibiotics and surgical débridement may be necessary to treat deep infections. Early diagnosis and treatment can affect outcome.</td>
</tr>
<tr>
<td>Deep infection</td>
<td>Postoperative splinting can help prevent contractures. Once a contracture occurs, it is treated with stretching if mild. Serial casting may be needed.</td>
</tr>
<tr>
<td>Contractures</td>
<td></td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Postoperative pain control will allow early mobilization of the patient. Wound healing without complications and prevention of contractures, particularly equinus contractures, are vital.¹
- For the Lisfranc and transmetatarsal amputations, a rigid postoperative dressing is used. The wound is dressed with nonadherent dressing gauze. A gauze roll is used to bind the residual foot. Cotton padding is then placed in strips from the hindfoot to the forefoot from plantar to dorsal in an attempt to reduce the tension on the suture line. The heel is well padded with cotton padding, and then a plaster cast is applied. The cotton padding may have elastic in it for built-in stretch. The plaster is also applied from proximal and plantar to distal and dorsal to reduce the tension on the suture line. The plaster application should be firm but not tight. It should be placed in closed-toe fashion and should extend up to the proximal leg, maintaining the residual foot in the neutral position to a slightly dorsiflexed position. ²
- This initial dressing is changed after 3 to 5 days and the Penrose drain is removed with the first dressing change. A similar plaster is applied for an additional 2 weeks. At the time of plaster removal, the sutures are removed. The patient is given a prescription for a shoe filler.
- After 2.5 weeks, the patient’s foot is placed in a buckle-wedge shoe for an additional 3 to 4 weeks. After that, shoe wear and progressive ambulation are encouraged.
- After a Chopart amputation, the cast is removed after 5 days and the drain is removed. A second dressing and cast are applied for about 3 weeks. The second cast is removed and the sutures are removed at the end of the 3 weeks. A third cast is applied and maintained for 6 to 8 weeks. After the final cast is removed, the patient begins physical therapy to begin range of motion, in particular dorsiflexion and plantarflexion excursion of the residual foot. A prosthetic measurement is taken.

OUTCOMES

- Patients with a Lisfranc, transmetatarsal, or Chopart amputation have good overall function compared with patients with a Syme amputation.³⁴ However, patients with an equinus contracture after a Chopart amputation have inferior results.⁵⁶ A Chopart amputation in a young patient is inferior in function to a Syme amputation due to the lack of ability to replace forefoot function when the space between the floor
and the plantar surface is reduced significantly in a Chopart amputation.

- The Chopart procedure provides an excellent level of amputation for a patient with limited activities and goals. The main advantage to this level is that little is lost between the distal end of the residual limb and the floor. This allows ease of ambulation without the need for a prosthetic device. For persons requiring short trips to the bathroom in the middle of the night or stability for transfers, the Chopart level is perfect. Unfortunately, the lack of anatomic structure and minimal distance from the plantar surface to the floor makes the Chopart amputation a poor choice for the active amputee.

- Ambulation is achieved with a foot spacer. For the Chopart stump, a clamshell type of prosthesis allows good weight-bearing function and restores the effective foot length. Generally, patients are able to ambulate 3 months after amputation using a simple shoe prosthesis.

- Gait analysis shows that abnormality and asymmetry of ground-reaction forces were less with a greater preserved stump length.

**COMPLICATIONS**

- Wound healing complications are treated with local wound care, elevation, and non-weight bearing. Oral antibiotics may be indicated. If there is skin flap necrosis, debridement with a skin graft may be necessary.

- Superficial infection is often resolved with a short course of oral antibiotics.

- Deep infection may require immediate operative débridement of devitalized tissue. Parenteral antibiotics are important to treat this limb-threatening problem. At the time of the débridement, a bone culture should be ordered to help determine the appropriate antibiotic.

- Equinus contracture is most easily treated by prevention. However, stretching with a therapist may be helpful. Serial casting may be required to correct the deformity.

**REFERENCES**


Chapter 1
Anatomy and Surgical Approaches of the Forearm, Wrist, and Hand 2093

Chapter 2
Anesthetic Considerations for Surgery of the Upper Extremity 2102

Chapter 3
Arthroscopy of the Hand and Wrist 2114

Chapter 4
Open Reduction and Internal Fixation of Diaphyseal Forearm Fractures 2127

Chapter 5
Reduction and Stabilization of the Distal Radioulnar Joint Following Galeazzi Fractures 2139

Chapter 6
Corrective Osteotomy for Radius and Ulna Diaphyseal Malunions 2149

Chapter 7
Operative Treatment of Radius and Ulna Diaphyseal Nonunions 2156

Chapter 8
K-Wire Fixation of Distal Radius Fractures With and Without External Fixation 2162

Chapter 9
Arthroscopic Reduction and Fixation of Distal Radius and Ulnar Styloid Fractures 2172
Chapter 41
Arthroscopic Evaluation and Treatment of Scapholunate and Lunotriquetral Ligament Disruptions 2459

Chapter 42
Open Scapholunate Ligament Repair and Augmentation 2467

Chapter 43
Capsulodesis for Treatment of Scapholunate Instability 2472

Chapter 44
Tenodesis for Treatment of Scapholunate Instability 2480

Chapter 45
Bone–Ligament–Bone Reconstruction of the Scapholunate Ligament 2488

Chapter 46
Reduction and Association of the Scaphoid and the Lunate for Scapholunate Instability 2495

Chapter 47
Lunotriquetral Ligament Repair and Augmentation 2501

Chapter 48
Operative Treatment of Lesser and Greater Arc Injuries 2513

Chapter 49
Arthroscopic and Open Triangular Fibrocartilage Complex Repair 2520

Chapter 50
Intra-articular Radioulnar Ligament Reconstruction 2528
Chapter 51
Extra-articular Reconstructive Techniques for the Distal Radioulnar and Ulnocarpal Joints 2535

Chapter 52
Arthroscopic Dorsal Radiocarpal Ligament Repair 2544

Chapter 53
Distal Biceps Tendon Disruptions: Acute and Delayed Reconstruction 2550

Chapter 54
Repair of Acute Digital Flexor Tendon Disruptions 2555

Chapter 55
Tenolysis Following Injury and Repair of Digital Flexor Tendons 2561

Chapter 56
Staged Digital Flexor Tendon Reconstruction 2570

Chapter 57
Repair Following Traumatic Extensor Tendon Disruption in the Hand, Wrist, and Forearm 2577

Chapter 58
Tendon Transfer and Grafting for Traumatic Extensor Tendon Disruption 2587

Chapter 59
Extensor Tendon Centralization Following Traumatic Subluxation at the Metacarpophalangeal Joint 2594

Chapter 60
Flexor and Extensor Tenosynovectomy 2603

Chapter 61
Tendon Transfers Used for Treatment of Rheumatoid Disorders 2608
Chapter 72
Primary Repair and Nerve Grafting Following Complete Nerve Transection in the Hand, Wrist, and Forearm 2691

Chapter 73
Surgical Treatment of Nerve Injuries in Continuity 2699

Chapter 74
Tendon Transfers forMedian Nerve Palsy 2706

Chapter 75
Tendon Transfers for Ulnar Nerve Palsy 2715

Chapter 76
Tendon Transfers for Radial Nerve Palsy 2722

Chapter 77
Metacarpophalangeal Joint Synovectomy and Extensor Tendon Centralization in the Inflammatory Arthritis Patient 2729

Chapter 78
Proximal Interphalangeal and Metacarpophalangeal Joint Silicone Implant Arthroplasty 2736

Chapter 79
Proximal Interphalangeal and Metacarpophalangeal Joint Surface Replacement Arthroplasty 2744

Chapter 80
Distal Interphalangeal, Proximal Interphalangeal, and Metacarpophalangeal Joint Arthrodesis 2752
Chapter 91
Resection Arthroplasty of the Distal Radioulnar Joint 2831

Chapter 92
Sauvé-Kapandji Procedure for Distal Radioulnar Joint Arthritis 2840

Chapter 93
Ulnar Head Implant Arthroplasty 2849

Chapter 94
Arthroscopically Assisted Triangular Fibrocartilage Complex Débridement and Ulnar Shortening 2857

Chapter 95
Ulnar Shortening Osteotomy 2864

Chapter 96
Surgical Decompression of the Forearm, Hand, and Digits for Compartment Syndrome 2875

Chapter 97
Surgical Treatment of Injection Injuries in the Hand 2882

Chapter 98
Revascularization and Replantation of the Digits 2888

Chapter 99
Surgical Treatment of Vasospastic and Vaso-occlusive Diseases of the Hand 2900

Chapter 100
Surgical Treatment of Acute and Chronic Paronychia and Felons 2906
Chapter 101
Surgical Treatment of Deep Space Infections of the Hand 2912

Chapter 102
Surgical Treatment of Septic Arthritis in the Hand and Wrist 2917

Chapter 103
Nail Matrix Repair, Reconstruction, and Ablation 2924

Chapter 104
Soft Tissue Coverage of Fingertip Amputations 2932

Chapter 105
Skin Grafts and Skin Graft Substitutes in the Distal Upper Extremity 2941

Chapter 106
Rotational and Pedicle Flaps for Coverage of Distal Upper Extremity Injuries 2950

Chapter 107
Surgical Treatment of Thermal and Electrical Injury and Contracture Involving the Distal Upper Extremity 2961

Chapter 108
Release of Post-Traumatic Metacarpophalangeal and Proximal Interphalangeal Joint Contractures 2972

Chapter 109
Surgical Treatment of Dupuytren’s Disease 2983
Chapter 110
Surgical Treatment of Vascular Tumors of the Hand 2992

Chapter 111
Excision and Coverage of Squamous Cell Carcinoma and Melanoma of the Hand 3004

Chapter 112
Open and Arthroscopic Excision of Ganglion Cysts and Related Tumors 3010

Chapter 113
Surgical Treatment of Nerve Tumors in the Distal Upper Extremity 3022

Chapter 114
Treatment of Enchondroma, Bone Cyst, and Giant Cell Tumor of the Distal Upper Extremity 3029
Anatomy and Surgical Approaches of the Forearm, Wrist, and Hand

Asif M. Ilyas, Neal C. Chen, and Chaitanya S. Mudgal

Chapter 1

Unique to the hand, wrist, and forearm is the complex relationship of not only the muscles overlying bone but also the close proximity and delicate balance of accessory anatomic structures, including tendons, vessels, and nerves.

ANATOMY

The anatomy of the hand, wrist, and forearm is intricate and can be discussed in many ways and in extensive detail. For the discussion in this chapter, anatomy will focus on the compartments of the hand and forearm, and their relevance to surgical approaches (Table 1).

Table 1 Compartments of the Hand and Forearm

<table>
<thead>
<tr>
<th>Compartments</th>
<th>Origin</th>
<th>Insertion</th>
<th>Innervation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thenar</td>
<td>Trapezium/scaphoid</td>
<td>Radial base of thumb P1</td>
<td>Median (recurrent motor branch)</td>
</tr>
<tr>
<td></td>
<td>Trapezium</td>
<td>Base of thumb P1</td>
<td>Median (recurrent motor branch)</td>
</tr>
<tr>
<td></td>
<td>Trapezium</td>
<td>Radial base of thumb P1</td>
<td>Median (recurrent motor branch)</td>
</tr>
<tr>
<td>Adductor</td>
<td>Capitate/third metacarpal</td>
<td>Ulnar base of thumb P1</td>
<td>Ulnar</td>
</tr>
<tr>
<td>Hypothenar</td>
<td>Pisiform</td>
<td>Ulnar base of small P1</td>
<td>Ulnar</td>
</tr>
<tr>
<td></td>
<td>Hook of hamate</td>
<td>Base of small P1</td>
<td>Ulnar</td>
</tr>
<tr>
<td></td>
<td>Hook of hamate</td>
<td>Ulnar base of small P1</td>
<td>Ulnar</td>
</tr>
<tr>
<td>Interosseous (4)</td>
<td>#2, 3, 4, 5 metacarpals</td>
<td>Radial or ulnar base of P1</td>
<td>Ulnar</td>
</tr>
<tr>
<td></td>
<td>#2, 4, 5 metacarpals</td>
<td>Radial or ulnar base of P1</td>
<td>Ulnar</td>
</tr>
<tr>
<td>Carpal Tunnel</td>
<td>Flexor digitorum</td>
<td>Lateral bands</td>
<td>Median and ulnar</td>
</tr>
<tr>
<td></td>
<td>profundus tendons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superficial Volar Forearm</td>
<td>Medial epicondyle</td>
<td>Mid third of radius</td>
<td>Median</td>
</tr>
<tr>
<td></td>
<td>Medial epicondyle</td>
<td>Base of #2 metacarpal</td>
<td>Median</td>
</tr>
<tr>
<td></td>
<td>Medial epicondyle</td>
<td>Palmar fascia of hand</td>
<td>Median</td>
</tr>
<tr>
<td></td>
<td>Medial epicondyle</td>
<td>Pisiform/base of #5</td>
<td>Median</td>
</tr>
<tr>
<td></td>
<td>Medial epicondyle</td>
<td>Base of #2, 3, 4, 5 P2</td>
<td>Median</td>
</tr>
<tr>
<td>Deep Volar Forearm</td>
<td>Ulna/interosseous membrane</td>
<td>Base of #2, 3, 4, 5 P3</td>
<td>Median (ant. interosseous branch)</td>
</tr>
<tr>
<td></td>
<td>Distal third of radius</td>
<td>Base of thumb P2</td>
<td>Median (ant. interosseous branch)</td>
</tr>
<tr>
<td></td>
<td>Distal third of ulna</td>
<td>Distal third of radius</td>
<td>Median (ant. interosseous branch)</td>
</tr>
<tr>
<td>Dorsal Forearm</td>
<td>Medial epicondyle</td>
<td>Radial base of thumb MC</td>
<td>Radial (post. interosseous branch)</td>
</tr>
<tr>
<td></td>
<td>Mid-third dorsal radius</td>
<td>Dorsal base of thumb P1</td>
<td>Radial (post. interosseous branch)</td>
</tr>
<tr>
<td></td>
<td>Mid-third dorsal radius</td>
<td>Dorsal base of thumb P2</td>
<td>Radial (post. interosseous branch)</td>
</tr>
<tr>
<td></td>
<td>Mid-third dorsal radius</td>
<td>Dorsal base of #2, 3, 4, 5 P3</td>
<td>Radial (post. interosseous branch)</td>
</tr>
<tr>
<td></td>
<td>Dorsal ulna</td>
<td>Dorsal base of #2 P3</td>
<td>Radial (post. interosseous branch)</td>
</tr>
<tr>
<td></td>
<td>Dorsal ulna</td>
<td>Dorsal base of #5 P3</td>
<td>Radial (post. interosseous branch)</td>
</tr>
<tr>
<td></td>
<td>Dorsal ulna</td>
<td>Dorsal base of #5 MC</td>
<td>Radial (post. interosseous branch)</td>
</tr>
<tr>
<td></td>
<td>Dorsal ulna</td>
<td>Proximal third of radius</td>
<td>Radial (post. interosseous branch)</td>
</tr>
<tr>
<td>Mobile Wad</td>
<td>Lat. condyle humerus</td>
<td>Distal radius styloid</td>
<td>Radial (post. interosseous branch)</td>
</tr>
<tr>
<td></td>
<td>Brachioradialis</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extensor carpi radialis longus</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extensor carpi radialis brevis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DEFINITION

Safe surgical dissection and exposure require an in-depth knowledge of anatomy. In no place is this more relevant than in the surgical approaches to the hand, wrist, and forearm.

The critical aspect of successful surgical approaches is the use of internervous planes.

These planes lie between muscles that are innervated by different nerves.

This allows extensive mobilization and exposure without risk of muscle denervation.
Surgical Management
- All surgical approaches to the hand, wrist, and forearm warrant sound understanding of surface and deep anatomy, internervous planes, and surgical technique.
- Planning the surgical approach begins by identifying reliable surface anatomy.

Preoperative Planning
- Arrangements for instruments, sutures, microscope, imaging support, implants, and assistants should be made before the day of surgery.
- Anatomy, radiographic templating, surgical approach, procedure, and alternatives should be reviewed.

Positioning
- Most approaches to the hand, wrist, and forearm can be performed with the patient supine and the operative extremity extended on a hand table and the surgeon and assistants seated.
- The hand table should be stable and well secured and should allow adequate space for both the operative limb and the surgeon’s elbow and forearm to minimize fatigue and enhance stability.
- The stool should be stable and comfortable, with the height set such that the knees are level with the hips and the feet are resting flat on the ground.
- The lights should be angled directly over the hand table, and not from behind the surgeon or assistant’s shoulder, to prevent shadows on the operative field.
- The use of a pneumatic tourniquet is advised to maintain a bloodless field and clear visualization of all anatomic structures.

Approach
- Multiple approaches to the hand, wrist, and forearm exist and are best divided into the anatomic site and direction of exposure.
- The approach should be chosen based on the indication for surgery.

Skin Incisions of the Hand
- Incisions in the hand can be placed almost anywhere as long as certain principles are respected.
- Incisions should be outlined by sterile surgical markers before making the actual incision to confirm appropriate position, to confirm the adequacy of skin bridges should multiple incisions be used, and to help guide closure.
- Incisions can be made in skin creases on the volar aspect of the hand but incisions in deep creases should be avoided due to the thin subcutaneous tissue, tendency for maceration due to moisture, and tendency toward poor apposition of skin edges on closure.
- Incisions perpendicular to a volar flexion crease should be avoided to prevent scar formation and secondary skin contractures that can lead to loss of motion and functional impairment (TECH FIG 1A,B).
- Incisions on the dorsal surface of the hand can be smaller due to the more mobile and loose nature of the dorsal skin (TECH FIG 1C).

TECH FIG 1 • Examples of volar (A,B) and dorsal (C) incisions for the hand and digits.
Vertical, horizontal, and curved incisions can all be used with good facility as long as adequate skin bridges are maintained. 
- Fingers can be exposed dorsally, volarly, or midaxially. 
- Dorsal incisions can be longitudinal or curvilinear. 
- Volar incisions are best facilitated by a zigzag pattern that crosses creases laterally and at angles. 
- Midaxial incisions are best placed at the junction of glabrous and nonglabrous skin, with attention being paid to the neurovascular bundle that sits in the plane of the flexor sheath. The neurovascular bundle can be taken volarly with the volar flap or can be left in place by carrying the dissection superficial to it.

**APPROACH TO THE INTERPHALANGEAL JOINTS**

- Straight dorsal longitudinal incisions can be made or a variety of curved incisions can be used, including an S-type and a chevron style (TECH FIG 2A).
- In the distal interphalangeal joint, caution must be paid to the germinal matrix, which is about 1 mm distal to the attachment of the extensor tendon.
- At the proximal interphalangeal joint, there is no internervous plane and the extensor mechanism should be immediately evident (TECH FIG 2B).
- The integrity of the central slip inserting in the middle phalanx guides exposure of the proximal interphalangeal joint.
- Three techniques can be employed to approach the joint: 
  - The lateral bands can be freed and gently retracted dorsally, allowing a lateral approach into the joint. 
  - When more exposure is required, the lateral bands can be incised in line with the extensor mechanism and repaired later. 
  - Lastly, to maximize exposure of the joint, the extensor mechanism is cut dorsally in a long distally based V-shaped flap, raised, and later repaired. 
- It is critical not to detach the central slip distally and to maintain continuity of the extensor mechanism through the lateral bands on each side (TECH FIG 2C).

**APPROACH TO THE METACARPOPHALANGEAL JOINT**

- With the metacarpophalangeal joint flexed, identify the apex of the joint, which is the metacarpal head, and the extensor tendon. 
- Make a straight dorsal longitudinal incision centered over the metacarpophalangeal joint. 
- If multiple joints are being approached, a transverse incision centered dorsally connecting each of the joints may be used (TECH FIG 3A). 
- There is no internervous plane. The extensor mechanism should be immediately evident. Sensory branches of
TECH FIG 3 • A. Examples of metacarpophalangeal skin incisions. A straight longitudinal incision can be placed over each joint. If multiple joints are being approached, a single straight transverse incision can be used. B. Extensor mechanism overlying the metacarpophalangeal joint. A, extensor tendon; B, ulnar sagittal band. C. The ulnar sagittal band is incised in line with the extensor mechanism revealing the metacarpophalangeal joint. A, extensor tendon; B, reflected ulnar sagittal band; C, metacarpophalangeal joint. D. The metacarpophalangeal joint is arthrotomized dorsal to the collaterals.

TECH FIG 4 • Incision for approaching multiple metacarpals.
Chapter 1 ANATOMY AND SURGICAL APPROACHES OF THE FOREARM, WRIST, AND HAND

**APPROACH TO THE CARPAL TUNNEL**

- The carpal tunnel is an enclosed fibro-osseous tunnel that contains nine flexor tendons and the median nerve. Its borders include the transverse carpal ligament (the roof), the carpal bones (the floor), the hook of hamate (ulnar wall), and the scaphoid (radial wall).
  - The proximal extent of the tunnel lies at the level of the distal wrist crease.
- Identify the interthenar depression, which lies between the thenar eminence radially and the hypothenar eminence ulnarily (TECH FIG 5A).
- Palpate the hook of hamate and pisiform bone along the ulnar base of the hand.
- Determine the cardinal line of Kaplan, the estimated distal extent of the transverse carpal ligament.\(^4\) The cardinal line of Kaplan runs from the base of the first web space (with the thumb abducted in the plane of the palm) parallel to the proximal palmar crease toward the hook of hamate.
- Multiple incisions can be used depending on the surgeon’s preference, ranging from a limited approach (TECH FIG 5B) to an extensile one.
  - The incision should be centered within the interthenar depression and in line with the third web space to avoid injury to the palmar cutaneous branches of the median and ulnar nerves.\(^8\)
  - The internervous plane occurs between the palmar cutaneous branches of the ulnar and median nerves.
- Incise the subcutaneous fat in line with the skin incision. Deep to the fat lies the longitudinally oriented superficial palmar fascia (TECH FIG 5C).
  - Incise this fascia in line with the incision.
  - Avoid raising flaps radially or ulnarily to prevent skin devitalization and injury to branches of the palmar cutaneous branch of the median and ulnar nerves.
  - Deep to the superficial palmar fascia lies the thick transverse carpal ligament.
  - Release this ligament in line with the skin incision, paying attention to the median nerve lying deep to it as well as being cautious of the recurrent motor branch of the median nerve, which could cross through or across the transverse carpal ligament (TECH FIG 5D).
  - Distal to the transverse carpal ligament, confirm release of the ligament both proximally and distally.
    - Distal release is confirmed on visualization of the “sentinel” pad of fat, which has a distinct yellow color different from that of the subcutaneous fat.
    - Proximal release is confirmed both visually and by feel and usually corresponds to the confluence of the transverse carpal ligament with the deep forearm fascia, generally located at the level of the distal wrist crease.

**TECH FIG 5** • **A.** Surface anatomy of the volar hand. A, radial artery; B, flexor carpi radialis tendon; C, flexor carpi ulnaris tendon; D, pisiform; E, hook of hamate; F, distal pole of scaphoid; G, cardinal line of Kaplan. **B.** Incision for the limited incision carpal tunnel approach. **C.** Superficial palmar fascia of the hand. **D.** Partial release of the transverse carpal ligament with the median nerve lying deep to it. A, retracted superficial palmar fascia; B, partially released transverse carpal ligament; C, median nerve.
PROXIMAL RELEASE IS CONFIRMED BOTH VISUALLY AND BY FEEL AND USUALLY CORRESPONDS TO THE CONFLUENCE OF THE TRANSVERSE CARPAL LIGAMENT WITH THE DEEP FOREARM FASCIA, GENERALLY LOCATED AT THE LEVEL OF THE DISTAL WRIST CREASE.

APPROACH TO CANAL OF GUYON

- The canal of Guyon is an enclosed fibro-osseous space at the ulnar base of the hand through which the ulnar neurovascular structures travel before innervating and perfusing the intrinsic structures of the hand.
  - Its borders include the volar carpal ligament (the roof), the transverse carpal ligament (the floor), the pisiform (ulnar wall), and the hook of hamate (radial wall).
- Palpate the pisiform bone, which lies subcutaneously at the ulnar base of the hand immediately distal to the wrist flexion crease in line with the flexor carpi ulnaris (see TECH FIG 5A).
- Palpate the hook of hamate, which lies about 2 cm distal and 2 cm radial to the pisiform bone.
  - This may be difficult to palpate in patients with large hands or those with well-developed hypothenar musculature.
- Palpate the flexor carpi ulnaris tendon, which runs along the ulnar aspect of the forearm and inserts into the pisiform upon crossing the wrist flexion crease.
- Make a zigzag or curved incision between the pisiform and hook of hamate and extend it proximally (TECH FIG 6A).
- Avoid crossing the wrist flexion crease perpendicularly. Extend it proximally along the radial border of the flexor carpi ulnaris tendon (TECH FIG 6B).
- Identify the flexor carpi ulnaris proximal to the wrist flexion crease and mobilize it ulnarily by releasing the fascia along its radial border. The ulnar artery and nerve will lie just deep and radial to the tendon, with the nerve more superficial and ulnar to the artery.
- Follow the ulnar artery and nerve distally into the hand.
  - In the hand, the flexor carpi ulnaris tendon will insert into the pisiform and the ulnar artery and nerve will dive deep to the volar carpal ligament.
- Releasing the volar carpal ligament radial to the pisiform opens the roof of the canal of Guyon and decompresses the ulnar artery and nerve. In the canal of Guyon, the nerve splits into its motor and sensory branches. The motor branch of the ulnar nerve dives below a fibrous arch formed by the hypothenar musculature originating from the hook of hamate (TECH FIG 6C).
- There is a high frequency of anatomic variations of the ulnar neurovascular structures within the canal of Guyon, and a release of the canal must include not only the roof but also the distal extent of it as it enters below the fibrous arch below the hypothenar muscles.5

TECH FIG 6 • A. Surface anatomy and incision for the approach to the canal of Guyon. A, pisiform; B, hook of hamate. B. The ulnar neurovascular structures in the base of the hand after release of the volar carpal ligament. A, ulnar nerve; B, ulnar artery and vein; C, pisiform with origin of the hypothenar muscles. C. Fibrous arch formed by the hypothenar muscles over the motor branch of the ulnar nerve. A, ulnar nerve; B, sensory branch of ulnar nerve; C, motor branch of ulnar nerve.

VOLAR APPROACH TO THE RADIUS

- Identify the flexor carpi radialis at the wrist flexion crease distally and follow it subcutaneously proximally (TECH FIG 7A).
  - Its tendinous nature will give way to muscle at roughly the middle of the forearm.
- Identify the brachioradialis, which originates along the lateral epicondylar ridge of the distal humerus and is the most superficial muscle mass along the lateral forearm. Distally and laterally it has a broad insertion along the flare of the radial border of the radius.
- Identify the biceps tendon, which is the broad and taut extension of the biceps tendon that crosses anterior to the elbow joint and dives toward its insertion into the radius medial to the brachioradialis.
Identify the radial artery at the wrist. It is found between the flexor carpi radialis and brachioradialis tendons.

With the forearm supinated, begin the incision proximal to the wrist flexion crease and immediately radial to the flexor carpi radialis tendon and extend the incision proximally parallel to the tendon.

The incision can end lateral to the biceps tendon and distal to the elbow flexion crease.

The incision can be extended as shown by the dotted extensions in Techniques Figure 7A.

The length of the incision depends on the extent of bone that needs to be exposed.

As described by Henry, the internervous plane distally occurs between the flexor carpi radialis (median nerve) and the brachioradialis (radial nerve). Proximally it occurs between the pronator teres (median nerve) and the brachioradialis (radial nerve).

Distally the interval between the flexor carpi radialis and the brachioradialis is developed (TECH FIG 7B).

The radial artery lies just ulnar to the brachioradialis tendon and lies underneath the brachioradialis in the middle of the forearm. Dissection should not drift ulnar to the flexor carpi radialis, for the median nerve lies just deep and ulnar to this tendon.

The superficial radial sensory nerve exits from under the brachioradialis at the middle of the forearm, about 8 to 10 cm proximal to the radial styloid, and travels adjacent to the tendon distally. The nerve arborizes proximal to the wrist joint.

Proximally the interval between the pronator teres and brachioradialis is developed.

An alternative to the volar approach of Henry is the trans–flexor carpi radialis approach.

In this approach, the incision is placed directly over the flexor carpi radialis tendon.

The flexor carpi radialis sheath is opened sharply in line with the tendon.

The tendon is retracted ulnarly and the floor of the tendon sheath is opened sharply, leading directly into the deep layer between the finger flexors and the pronator quadratus, also known as the space of Parona.

Several muscles lie over the radius in the deep layer. Distally, the pronator quadratus and flexor pollicis longus cover the radius (TECH FIG 7C). On the middle third of the radius lie the flexor carpi radialis and pronator teres.

To expose the radius, these muscles are released along the volar radial aspect of the radius and are raised in a subperiosteal fashion ulnarly.

Proximally, the supinator muscle covers the radius. Through its substance travels the posterior interosseous nerve as it travels to the dorsal compartment of the forearm.

To expose the radius proximally, the forearm must be fully supinated and the supinator is released along the ulnar border of the radius and raised radially. The forearm must be kept fully supinated to protect the posterior interosseous nerve.

**DORSAL APPROACH TO THE RADIUS**

Identify the tubercle of Lister at the distal and radial aspect of the radius. It is the most prominent bony protuberance on the dorsal distal radius, and the extensor pollicis longus tendon curves around it (TECH FIG 8A).

Identify the “mobile wad of three,” which is the common muscle mass composed of the brachioradialis and the extensor carpi radialis longus and brevis.

Identify the lateral epicondyle of the distal humerus, which is the bony prominence most easily palpable proximal to the radial head along the lateral aspect of the elbow.

With the forearm pronated, make the incision from the tubercle of Lister and extend it proximally along the medial border of the “mobile wad” toward the lateral epicondyle.
The length of the incision depends on the extent of bone that needs to be exposed (TECH FIG 8A).

As described by Thompson, the internervous plane distally occurs between the extensor carpi radialis brevis (radial nerve, posterior interosseous nerve, or both) and the extensor pollicis longus (posterior interosseous nerve).^7^ Proximally it occurs between the extensor carpi radialis brevis (radial nerve; inconsistent innervation) and the extensor digitorum communis (posterior interosseous nerve).

Distally, develop the interval between the extensor carpi radialis brevis and the extensor pollicis longus with the tubercle of Lister positioned between them (TECH FIG 8B).

Exposing proximally, the interval between the extensor carpi radialis brevis and the extensor digitorum communis is identified by the emergence of the outcropping abductor pollicis longus and the extensor pollicis brevis (TECH FIG 8C).

Distally the radius sits immediately below the superficial extensor tendons.

To expose the distal radius, the extensor retinaculum and the sheath of the extensor pollicis longus tendon is opened and the tendon is retracted radially.

The floor of the tendon sheath is incised longitudinally and the extensor tendons are raised subperiosteally, with the extensor carpi radialis longus and brevis taken radially and the finger extensors taken ulnarly.

Proximally, the abductor pollicis longus and extensor pollicis brevis cover the middle third of the radius.

To expose the radius, these muscles are released along their radial border, to avoid denervation, and raised ulnarly.

The proximal third of the radius is covered by the supinator. Within its substance and between its two heads runs the posterior interosseous nerve.

Exposure of the dorsal radius proximally requires exposure and protection of this nerve before elevating the supinator off the radius.

First, identify the nerve as it exits between the two heads of the supinator.

Follow the nerve proximally through the substance of the supinator’s superficial head while taking care to preserve all its branches.

Once the nerve is identified along its entire course, the supinator can be released along its radial border and raised ulnarly.

**TECH FIG 8 • A.** Surface anatomy and incision of the dorsal forearm. A, tubercle of Lister; B, ulnar border of the “mobile wad of three”; C, lateral epicondyle. B. Superficial exposure of the dorsal distal radius. A, tubercle of Lister; B, extensor carpi radialis longus and brevis; C, extensor pollicis longus; D, reflected extensor retinaculum. C. Musculature of the dorsal forearm. A, extensor digitorum communis; B, extensor carpi radialis brevis; C, abductor pollicis longus and extensor pollicis brevis.

**APPROACH TO THE ULNA**

- Identify the ulnar head and styloid distally with the forearm in neutral rotation (TECH FIG 9).
- Identify the subcutaneous border of the ulna.
- Identify the tip of the olecranon proximally.
- With the forearm in neutral rotation, begin the incision at the level of the head of the ulna but proximal to the styloid. Extend the incision across the subcutaneous border of the ulna proximally toward the olecranon. The length of incision depends on the extent of the bone that needs to be exposed.

Distally, the internervous plane occurs between the flexor carpi ulnaris (ulnar nerve) and the extensor carpi ulnaris (posterior interosseous nerve).

Proximally, at the level of the olecranon, the internervous plan occurs for a short length between the flexor carpi ulnaris (ulnar nerve) and the anconeus (radial nerve).

Distally, the interval between the flexor carpi ulnaris and the extensor carpi ulnaris occurs along the subcutaneous border of the ulna.
TECH FIG 9 • Surface anatomy and incision for the ulnar shaft. A, ulnar head and styloid; B, subcutaneous border of ulna.

- Both muscles can be raised volarily and dorsally off the ulna, respectively, in a subperiosteal fashion.
- The ulnar artery and nerve travel deep and radial to the flexor carpi ulnaris. The nerve is protected by careful subperiosteal elevation of the flexor carpi ulnaris.

PEARLS AND PITFALLS

Approach to the interphalangeal joints (proximal and distal)

- Protect the germinal matrix and terminal tendon at the base of the distal phalanx.
- Protect the central slip at the base of the middle phalanx.

Approach to the metacarpophalangeal joints

- If necessary, release the ulnar sagittal band at the joint. Avoid releasing the radial sagittal band.

Approach to the carpal tunnel

- Protect branches of the palmar cutaneous branch of the median and ulnar nerves in the subcutaneous tissue by centering the incision in the interthenar eminence.
- Remain vigilant for a transligamentous recurrent motor branch of the median nerve.

Volar approach to the radius

- Dissection should not drift ulnar to the flexor carpi radialis tendon to protect the median nerve and its cutaneous branches.

Dorsal approach to the radius

- The posterior interosseous nerve ends at the level of the wrist dorsally in line with the fourth metacarpal and is easily approached for denervation for postoperative pain relief.

REFERENCES

6. Parona F. Dell’oncotomia negli accessi profundi diffuse dell’avambrachio. Annali Universali di Medicina e Chirurgia Milano, 1876.
ORTHOPAEDIC SURGERY MAKES UP A CONSIDERABLE PORTION OF THE 70% OF PROCEDURES DONE ON AN AMBULATORY BASIS IN THE UNITED STATES.9

Several factors have fueled this growth in outpatient orthopaedic surgery, including less invasive surgical approaches, changes in practice patterns, and the introduction of anesthetic agents associated with fewer postoperative side effects.

Percutaneous pain management represents a particular challenge with ambulatory surgery, as 40% of patients experience severe pain despite treatment.5

Regional anesthesia techniques have been used to solve this problem. Anesthetic techniques incorporating peripheral nerve blocks are associated with superior analgesia and a lower incidence of postoperative nausea and vomiting.12,15

Regional anesthetic techniques result in increased patient satisfaction and fewer unanticipated hospital admissions.23

Peripheral nerve blocks administered with a single dose of long-acting local anesthetic (bupivacaine or ropivacaine) have frequently been used to provide postoperative pain control. However, patients and surgeons alike are frustrated when these blocks dissipate in the middle of the night, resulting in the return of severe pain. In these situations, the pain state is longer than the duration of the block.

Despite the selection of long-acting local anesthetics (14 to 24 hours of analgesia), about 20% of patients after orthopaedic surgery have significant pain requiring opioids after 7 days.14

Continuous regional analgesia, using an indwelling nerve catheter and local anesthetic pump, can maintain analgesia until the pain state dissipates.

The frustration with the limited analgesia provided by a single dose of local anesthetic causes some physicians to avoid nerve blocks altogether. They choose instead to use an opioid strategy begun preoperatively with sustained-release analgesics (oxycodone SR).

This approach is associated with increased side effects such as urinary retention, pruritus, ileus, nausea, and vomiting.

If continuous regional analgesia is selected, it may be used for anesthesia and postoperative analgesia.

The continuous peripheral nerve catheter offers prolonged analgesia and minimal side effects and eliminates the problem of block resolution and the return of severe pain. The nerve block is maintained with a continuous infusion of local anesthetic agents.

Pumps have been developed allowing outpatient infusions, and these elastometric pumps are ideal because they are compact, simple to operate, and designed to provide safe infusion rates of local anesthetic in the uncontrolled home environment.

Regional anesthetic techniques result in increased patient satisfaction and fewer unanticipated hospital admissions.23

Continuous regional analgesia, using an indwelling nerve catheter and local anesthetic pump, can maintain analgesia until the pain state dissipates.

The frustration with the limited analgesia provided by a single dose of local anesthetic causes some physicians to avoid nerve blocks altogether. They choose instead to use an opioid strategy begun preoperatively with sustained-release analgesics (oxycodone SR).

This approach is associated with increased side effects such as urinary retention, pruritus, ileus, nausea, and vomiting.

If continuous regional analgesia is selected, it may be used for anesthesia and postoperative analgesia.

The continuous peripheral nerve catheter offers prolonged analgesia and minimal side effects and eliminates the problem of block resolution and the return of severe pain. The nerve block is maintained with a continuous infusion of local anesthetic agents.

Pumps have been developed allowing outpatient infusions, and these elastometric pumps are ideal because they are compact, simple to operate, and designed to provide safe infusion rates of local anesthetic in the uncontrolled home environment.

Regional anesthetic techniques result in increased patient satisfaction and fewer unanticipated hospital admissions.23

Continuous regional analgesia, using an indwelling nerve catheter and local anesthetic pump, can maintain analgesia until the pain state dissipates.

The frustration with the limited analgesia provided by a single dose of local anesthetic causes some physicians to avoid nerve blocks altogether. They choose instead to use an opioid strategy begun preoperatively with sustained-release analgesics (oxycodone SR).

This approach is associated with increased side effects such as urinary retention, pruritus, ileus, nausea, and vomiting.

If continuous regional analgesia is selected, it may be used for anesthesia and postoperative analgesia.

The continuous peripheral nerve catheter offers prolonged analgesia and minimal side effects and eliminates the problem of block resolution and the return of severe pain. The nerve block is maintained with a continuous infusion of local anesthetic agents.

Pumps have been developed allowing outpatient infusions, and these elastometric pumps are ideal because they are compact, simple to operate, and designed to provide safe infusion rates of local anesthetic in the uncontrolled home environment.

Regional anesthetic techniques result in increased patient satisfaction and fewer unanticipated hospital admissions.23

Continuous regional analgesia, using an indwelling nerve catheter and local anesthetic pump, can maintain analgesia until the pain state dissipates.

The frustration with the limited analgesia provided by a single dose of local anesthetic causes some physicians to avoid nerve blocks altogether. They choose instead to use an opioid strategy begun preoperatively with sustained-release analgesics (oxycodone SR).

This approach is associated with increased side effects such as urinary retention, pruritus, ileus, nausea, and vomiting.

If continuous regional analgesia is selected, it may be used for anesthesia and postoperative analgesia.

The continuous peripheral nerve catheter offers prolonged analgesia and minimal side effects and eliminates the problem of block resolution and the return of severe pain. The nerve block is maintained with a continuous infusion of local anesthetic agents.

Pumps have been developed allowing outpatient infusions, and these elastometric pumps are ideal because they are compact, simple to operate, and designed to provide safe infusion rates of local anesthetic in the uncontrolled home environment.

Regional anesthetic techniques result in increased patient satisfaction and fewer unanticipated hospital admissions.23

Continuous regional analgesia, using an indwelling nerve catheter and local anesthetic pump, can maintain analgesia until the pain state dissipates.

The frustration with the limited analgesia provided by a single dose of local anesthetic causes some physicians to avoid nerve blocks altogether. They choose instead to use an opioid strategy begun preoperatively with sustained-release analgesics (oxycodone SR).

This approach is associated with increased side effects such as urinary retention, pruritus, ileus, nausea, and vomiting.

If continuous regional analgesia is selected, it may be used for anesthesia and postoperative analgesia.

The continuous peripheral nerve catheter offers prolonged analgesia and minimal side effects and eliminates the problem of block resolution and the return of severe pain. The nerve block is maintained with a continuous infusion of local anesthetic agents.

Pumps have been developed allowing outpatient infusions, and these elastometric pumps are ideal because they are compact, simple to operate, and designed to provide safe infusion rates of local anesthetic in the uncontrolled home environment.

Regional anesthetic techniques result in increased patient satisfaction and fewer unanticipated hospital admissions.23

Continuous regional analgesia, using an indwelling nerve catheter and local anesthetic pump, can maintain analgesia until the pain state dissipates.

The frustration with the limited analgesia provided by a single dose of local anesthetic causes some physicians to avoid nerve blocks altogether. They choose instead to use an opioid strategy begun preoperatively with sustained-release analgesics (oxycodone SR).

This approach is associated with increased side effects such as urinary retention, pruritus, ileus, nausea, and vomiting.

If continuous regional analgesia is selected, it may be used for anesthesia and postoperative analgesia.

The continuous peripheral nerve catheter offers prolonged analgesia and minimal side effects and eliminates the problem of block resolution and the return of severe pain. The nerve block is maintained with a continuous infusion of local anesthetic agents.

Pumps have been developed allowing outpatient infusions, and these elastometric pumps are ideal because they are compact, simple to operate, and designed to provide safe infusion rates of local anesthetic in the uncontrolled home environment.
whether the intubation is performed with the patient awake or asleep.

- General anesthesia is frequently used for orthopaedic trauma. Factors that influence this decision include surgery on more than one extremity, unknown duration of procedure, the need to assess postoperative neurologic function, and surgeon or patient preference.
- Nerve blocks with concentrated local anesthesia (bupivacaine or ropivacaine 0.5% or higher) can mask symptoms of compartment syndrome and should be avoided in patients at risk.
- Advantages of regional anesthesia for upper extremity trauma surgery include:
  - Increased blood flow in anesthetized area
  - Lower incidence of deep venous thrombosis with neuraxial blocks
  - Decreased blood loss
  - Decreased postoperative nausea and vomiting
  - Avoidance of difficult endotracheal intubation
  - Decreased phantom limb pain following amputation by preventing pain centralization

### Pediatrics

- General anesthesia is often used in pediatric surgery because children lack the emotional and intellectual maturity to be conscious during the procedure (FIG 1).
- Regional anesthesia may be performed in a child during general anesthesia, but the loss of patient feedback regarding pain and paresthesia increases the risk of neural injury.
- Regional anesthesia decreases anesthetic and opioid requirements, resulting in shorter wake-up times with general anesthesia.
- Caudal and spinal blocks have been the most commonly used regional techniques due to the anesthesiologist familiarity and their relative safety when performed in the anesthetized patient.
- Nerve blocks may provide preemptive analgesia by blocking painful stimuli and lead to lower stress hormone levels and less overall pain.
- Nerve blocks done while the patient is under anesthesia have caused severe injury in adults, but these injuries are much less common in children.
- Ultrasound-guided nerve blocks during general anesthesia may reduce the risk of nerve injury, allowing direct visualization of neural targets.
- Pediatric regional techniques require smaller needles, which have only recently become available, but continuous blocks are done with adult equipment, a less-than-optimal situation.
- Pediatric patients require cautious local anesthetic selection and administration to avoid toxicity.
- Epinephrine is typically added to enable the diagnosis of an intravascular injection of local anesthetic and to decrease its systemic absorption.
- Fasting guidelines for children up to 3 years old are given in Table 2.
- Pediatric doses of local anesthetics are summarized in Table 3.
- Continuous peripheral nerve catheters offer the same advantages in pediatric patients as in adults.
- Recommended infusion rates begin at 0.15 mL/kg per hour of bupivacaine 0.25%.
- Continuous peripheral nerve catheters may be dosed with dilute local anesthetics (bupivacaine or ropivacaine 0.1%) because of incomplete myelinization of neural fibers, permitting greater local anesthetic penetration. This will decrease the risks of local anesthetic toxicity.

### Table 2

<table>
<thead>
<tr>
<th>Age</th>
<th>Fasting Time (hr)</th>
<th>Milk and Solids</th>
<th>Clear Liquids</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;6 mo</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>6–36 mo</td>
<td>6</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>&gt;36 mo</td>
<td>8</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3

**Pediatric Doses of Clinical Characteristics of Commonly Used Local Anesthetics**

<table>
<thead>
<tr>
<th>Local Anesthetic</th>
<th>Usual Concentration (%)</th>
<th>Usual Doses (mg/kg)</th>
<th>Maximum Dose, Plain† (mg/kg)</th>
<th>Maximum Dose with Epinephrine† (mg/kg)</th>
<th>Latency (min)</th>
<th>Duration of Effects (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lidocaine</td>
<td>0.5–2.0</td>
<td>5</td>
<td>7.5</td>
<td>10</td>
<td>5–15</td>
<td>0.75–2.0</td>
</tr>
<tr>
<td>Prilocaine</td>
<td>0.5–1.5</td>
<td>5</td>
<td>7.0</td>
<td>10</td>
<td>15–25</td>
<td>0.75–2.0</td>
</tr>
<tr>
<td>Mepivacaine</td>
<td>0.5–1.5</td>
<td>5–7</td>
<td>8.0</td>
<td>10</td>
<td>5–15</td>
<td>1–1.25</td>
</tr>
<tr>
<td>Bupivacaine</td>
<td>0.25–0.5</td>
<td>2</td>
<td>2.5</td>
<td>3</td>
<td>15–30</td>
<td>2.5–6.0</td>
</tr>
<tr>
<td>Ropivacaine</td>
<td>0.2–10.0</td>
<td>3</td>
<td>3.5</td>
<td>NA</td>
<td>7–20</td>
<td>2.5–5.0</td>
</tr>
</tbody>
</table>

*Data are not applicable to spinal anesthesia or intravenous regional anesthesia.

†Maximum doses vary; free and unbound local causes toxicity, not total dose. Do not apply if previously injected or local anesthetic infusion maintained.
ANESTHESIA SELECTION FOR UPPER EXTREMITY PROCEDURES

- Anesthesia for arm and hand surgery may be general, regional, or a combination of techniques.
- The potential benefits of an upper extremity nerve block are less nausea, a shorter recovery, and faster discharge from the hospital, in part due to improved postoperative analgesia, requiring fewer narcotics for pain.8
- The anesthetic plan may also be based on factors unrelated to evidence-based medicine, such as anxiety, extended case duration, or the need for immediate neurologic examination after surgery.

General Anesthesia
- Easier to apply and no anesthetic failures
- Provides unconsciousness for the long procedure or uncomfortable position
- Pediatric and mentally retarded patients are easier to manage.
- Cadaveric conditions when the surgery requires no movement
- Procedure and graft harvest can be in different anatomic locations.
- Nerve function can be immediately assessed.
- Efficient anesthesia recovery with anesthetics such as propofol, sevoflurane, or desflurane

Regional Anesthesia
- Increases operating room efficiency: nerve blocks are done before entering the operating room, eliminating the time needed for induction and emergence from anesthesia
- Simplified perioperative management with conditions such as malignant hyperthermia, cardiomyopathy, and obstructive or restrictive lung conditions
- Continuous nerve blocks may provide anesthesia and be used for postoperative pain control.
- Propofol may be administered with regional blocks for light or heavy sedation.
- Less postoperative nausea and vomiting
- Faster recovery from anesthesia and earlier discharge
- Less postoperative cognitive dysfunction than from general anesthesia due to superior pain control, fewer sleep disturbances, and fewer unplanned admissions to the hospital
- By avoiding unplanned admissions to the hospital, the incidence of postoperative cognitive dysfunction is lowered from 9.8% to 3.5%.9
- American Society of Regional Anesthesia and Pain Medicine guidelines on anticoagulation are given in Table 4.

REGIONAL ANESTHESIA FOR UPPER EXTREMITY SURGERY

- Nerve blocks for upper extremity surgery are summarized in Table 5.
- Shoulder Surgery
  - Because of the intense perioperative pain, particularly with arthroplasty or open rotator cuff operations, general anesthesia is rarely the sole technique for shoulder surgery.
  - Performing regional anesthesia for shoulder surgery requires knowledge of the anatomy and the surgical approach.
- The shoulder is innervated primarily by the brachial plexus, with minor contributions of sensory innervation from the superficial cervical plexus (FIG 2).

### Table 4: American Society of Regional Anesthesia Guidelines for Anticoagulation

<table>
<thead>
<tr>
<th>Medication</th>
<th>Discontinuation Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbal medications: ginkgo, ginseng, and garlic (greatest effect)</td>
<td>No discontinuation</td>
</tr>
<tr>
<td>Nonsteroidal anti-inflammatories and acetaminophen</td>
<td>No discontinuation</td>
</tr>
<tr>
<td>Ticlopidine and clopidogrel</td>
<td>14 days</td>
</tr>
<tr>
<td>Heparin</td>
<td></td>
</tr>
<tr>
<td>SQ</td>
<td>No discontinuation</td>
</tr>
<tr>
<td>IV</td>
<td>Stop and 1 hour after block</td>
</tr>
<tr>
<td>Low-molecular-weight heparin</td>
<td>12 hours after last dose</td>
</tr>
<tr>
<td>Coumadin</td>
<td>Discontinue 4 days</td>
</tr>
<tr>
<td>Thrombolytics</td>
<td>Avoid regional</td>
</tr>
</tbody>
</table>

### Table 5: Nerve Blocks for Surgery

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder surgery</td>
<td>Interscalene</td>
</tr>
<tr>
<td>Elbow surgery</td>
<td>Interscalene, supraclavicular, or infraclavicular</td>
</tr>
<tr>
<td>Forearm and hand surgery</td>
<td>Intraclavicular, axillary or IV regional (short procedures &lt;1 hour)</td>
</tr>
</tbody>
</table>

- No contraindication
- Carpel tunnel syndrome
- Multiple sclerosis (spinal anesthesia contraindicated)
- Stroke
- Diabetes mellitus

**Contraindications**
- Absolute
  - Acute or resolving nerve injury in the regional block distribution
  - Progressive peripheral neuropathy
  - Infection at the puncture site for the block
  - Patient refusal
  - Bleeding disorder: full anticoagulation, thrombolytic therapy, and hemophilia
- Relative
  - Stable nerve impairment
  - Interscalene blocks with severe chronic obstructive pulmonary disease
  - Fever, bacteremia
The interscalene block is done at the level of the trunks and blocks the superior and middle trunks along with the superficial cervical plexus.

Identification of superficial landmarks and the needle puncture site is done by palpating the space created by the trunks between the anterior and middle scalene muscles at the level of the cricoid cartilage (FIG 3A).

The nerves can be localized using paresthesia, nerve stimulator, or ultrasound (FIG 3B).

Once the needle is in approximation to the brachial plexus trunks, local anesthetic is incrementally injected, resulting in anesthesia of the shoulder and proximal arm.

Interscalene blocks with bupivacaine or ropivacaine provide perioperative analgesia.

Interscalene blocks cause a sympathectomy and resultant redistribution of blood away from the surgical site, decreasing intraoperative blood loss.

Incisions and port holes are occasionally outside the block’s anesthetic distribution, requiring local anesthetic to be injected by the surgical team into the affected area.

Intra-articular local anesthetic and narcotic infusions may be helpful but must be combined with interscalene blocks for maximum postoperative analgesia.

The semisitting position is often selected for the surgery, and the table must be equipped with a head piece securing the patient’s head with a padded strap at the forehead.

The semisitting and lateral decubitus positions place the operative site above the heart, rarely resulting in air embolism.

Head and neck positioning is crucial to avoid spinal cord compression and neurologic deficits. However, the anesthesiologist may be hampered by this position because the proximity of the surgical incision allows little access to the head.

It may be very difficult to convert to general anesthesia without disrupting the sterile surgical field when a patient with a regional anesthetic must be put to sleep in the middle of the procedure. General anesthesia can be administered without endotracheal intubation either by holding a mask on the face or by inserting a laryngeal mask airway while the patient remains in the semisitting position.

Although this does not provide protection from stomach content aspiration, it offers some control of the airway without putting the patient supine and taking down the drapes for endotracheal intubation.

Because of this potential problem, many anesthesiologists and surgeons alike prefer to use general anesthesia with an endotracheal tube in combination with an interscalene block.

This combined anesthetic would also be chosen with complicated reoperations or where induced hypotension is needed.

Continuous interscalene blocks may be done to provide analgesia for a prolonged period.

Typically 48 hours of postoperative pain is adequate, and catheters are then removed.

Prolonged interscalene analgesia may be required in acute surgical shoulder pain in the chronic pain patient or in a patient with a frozen shoulder requiring mobilization therapy.

Continuous interscalene blocks have been associated with enhanced physical rehabilitation after shoulder surgery due to superior pain control.

Interscalene block side effects include phrenic nerve, recurrent laryngeal nerve, and stellate ganglion blockade.

These may result in transient loss of ipsilateral diaphragm function, weak voice, miosis, ptosis, and anhidrosis (Horner syndrome).

Elbow Surgery

Surgical procedures at the elbow, whether for arthroplasty or the reattachment of a biceps brachii tendon, frequently require general anesthesia despite the advantages of regional anesthesia.
The proximity of nerves to the surgical incision is concerning to surgeons who may wish to examine neurologic function in the immediate postoperative period, which is not possible with a nerve block.
- Regional techniques are often performed in the recovery area after nerve function is assessed.
- Functional outcomes after elbow surgery often depend on early rehabilitation using continuous passive motion devices.
- This therapy can be facilitated with continuous brachial plexus analgesia. The infraclavicular and the axillary approaches to the brachial plexus are options for catheter placement.
- The infraclavicular block is performed by placing the needle 1 inch distal to the midclavicle, with the needle advanced toward the axillary pulsation until twitch or paresthesia is obtained (FIG 4).
- Continuous infraclavicular blocks are ideal as they cover the brachial plexus, including the musculocutaneous nerves, providing anesthesia of the entire arm.
- Continuous axillary nerve blocks cover the brachial plexus, with the exception of the musculocutaneous nerve. This may result in pain during continuous passive motion and it may need to be separately blocked.
- Surgery with brachial plexus blocks may require supplementation at the musculocutaneous and intercostobrachial nerves.

Hand Surgery
- Hand procedures are frequently done with nerve blocks because of the ideal operating conditions and early discharge times postoperatively.
  - General anesthesia is reserved for extremely long cases and is combined with brachial plexus analgesia.
  - Carpel tunnel release surgery is one of the most common hand procedures and may be done with an intravenous regional block (Bier block).
  - Bier blocks are impractical for the efficient outpatient practice. Local infiltration by the surgeon combined with intravenous sedation is a more common and efficient anesthetic approach.
- The axillary approach to the brachial plexus is ideal for more extensive hand procedures (FIG 5A).
  - The block may be placed easily, sets up quickly, covers all of the nerves of the hand, and is associated with low complication rates.
  - The nerves in the axilla have a predictable anatomic relationship to the axillary artery.
  - The block may be done with paresthesia, nerve stimulation, or transarterial approaches.
  - Ultrasound guidance more recently has been used to provide real-time visualization of both the needle and the neural targets (FIG 5B,C).
  - The success of the block can be predicted by confirming circumferential spread of local anesthetic around the nerves.
  - Continuous peripheral nerve catheters may be placed if the procedure is prolonged, a sympathectomy is needed, or significant pain is expected.
  - Brachial plexus anesthesia with an intercostobrachial nerve block will prevent tourniquet pain, unlike general anesthesia.

Supplementing Nerve Blocks
- It is preferable to place blocks outside the operating room so that block efficacy can be evaluated.
  - Often a “failed” block is simply the result of inadequate time for local anesthetic distribution to nerve targets.
  - Insufficient blocks can be supplemented, and again ultrasound offers a safe option for this.
  - Propofol infusions will allow control of anxiety and can turn an incomplete block into an intraoperative success.
Continuous Nerve Blocks

- Postoperative pain control after a single injection of local anesthesia is limited to 16 hours, and this limits its usefulness for postoperative pain management.
  - In a procedure associated with moderate to severe postoperative pain, patients experience significant pain when the block resolves.
  - Undertreated pain may result in more refractory pain states, such as chronic pain or complex regional pain syndromes.
- Because of the anatomic relationships of the upper extremity, a single catheter may provide continuous analgesia in the distribution of surgical pain.
  - The catheter is placed and local anesthetic administered preoperatively and combined with other analgesic interventions.
  - The surgical pain is not amplified at the tissue level or centrally in the spinal cord, so the pain is less intense and of shorter duration.20
- Continuous blocks may be maintained in the hospital as well as at home using disposable infusion pumps. To ensure success with home-going regional anesthesia, instructions and teaching must begin in the preoperative period.
  - Patients must be counseled about the danger of injury in the absence of normal pain responses. They are instructed to avoid working with extreme heat or cold and to avoid driving.
  - Patients are educated about symptoms of local anesthetic toxicity, and phone numbers are provided with instructions to call in the event of problems.
  - When continuous peripheral nerve catheters are part of a multimodal pain therapy consisting of nonsteroidal anti-inflammatory medications, acetaminophen, cryotherapy, and weak opioids, greater analgesia and patient satisfaction may be achieved.

- The efficacy of continuous interscalene blocks was demonstrated in patients treated with ropivacaine 0.2% after open rotator cuff surgery; they achieved pain scores averaging 1 out of 10 compared to placebo.13
  - Similar results were achieved with outpatient shoulder patients sent home with continuous interscalene blocks.11
  - The efficacy of continuous infraclavicular blocks was demonstrated when ropivacaine 0.2% was administered to outpatients with moderately painful orthopaedic procedures; they achieved pain scores of 2 versus 6 in the placebo control group. The blocks were associated with less pain, resulting in fewer sleep disturbances, less opioid consumption, and fewer side effects.10
  - Infusion pumps maintain the block by infusing dilute local anesthetic (bupivacaine 0.1% and ropivacaine 0.2%) at 10 cc/hr.
  - Local anesthetic toxicity resulting from the continuous infusion is very rare. Local anesthetic toxicity is most likely during the initial injection (bolus with 30 to 40 cc of bupivacaine or ropivacaine 0.5%).

Local Anesthetics and Additives

- Local anesthetics produce anesthesia by inhibiting excitation of nerve endings and blocking conduction in peripheral nerves due to the binding and inactivation of both sodium and potassium channels. This prevents the sodium influx through these channels that is necessary for the depolarization of nerve cell membranes and propagation of impulses along the course of the nerve.
- There are two classes of local anesthetics, named for their linkage between the carbon chain and aromatic chain.
  - The amino amides have an amide link between the chain and the aromatic end, and amino esters have an ester link between the chain and the aromatic end.
  - The amino esters are metabolized in the plasma via pseudocholinesterases, and amino amides are metabolized in the liver.
Amino esters are eliminated rapidly compared with amides, decreasing the possibility of toxicity.

Amino esters are much more likely than amino amides to cause true allergic reactions due to metabolites like para-aminobenzoic acid.

Varying the concentration of local anesthetics will produce a differential block. Higher concentrations produce an intense motor and sensory block. More dilute locals result in a sensory block with little motor blockade.

Toxicity from local anesthesia occurs when a peak plasma level is reached, typically from inadvertent intravascular administration of anesthetic.

Toxicity from rapid absorption is also possible, especially in vascular areas (intercostal, epidural, or interscalene), and epinephrine is added to the local anesthetic to signal intravascular injection and decrease the vascular absorption of the local anesthetic.

The inadvertent intravascular injection of bupivacaine or ropivacaine may result in cardiovascular collapse (ventricular tachycardia or fibrillation).

Because of their potent binding to the heart, these arrests can be difficult to treat.

Cardiotoxicity from bupivacaine has been successfully treated with 2 mL/kg of 20% lipid emulsion in a case report. The mechanism of the lipid emulsion is the binding of bupivacaine in the plasma and tissues. In other cases patients have required cardiopulmonary bypass until the conduction blockade resolved.

Recommended doses of local anesthetics are given in Table 6.

The use of additives with local anesthetics has increased as regional analgesia has become a standard method for managing postoperative pain.

Some additives prolong the duration of the block and therefore the postoperative pain control (Table 7).

### EQUIPMENT

#### Airway Management

- For 30 minutes after a nerve block, patients must be closely monitored for signs of systemic toxicity.
- Medications to treat seizures and to establish general anesthesia must be immediately available.
- Induction drugs such as propofol and succinylcholine and airway equipment, including oxygen, an Ambu-bag with mask for positive-pressure ventilation, and a laryngoscope with assorted endotracheal tubes, should be nearby.

#### Monitoring

- The rare occurrence of local anesthetic toxicity mandates full monitoring in the operating room and in areas where blocks may be done before surgery.
- Pulse oximetry measures blood oxygen saturation in response to sedatives and analgesics, and the electrocardiogram is required to diagnose rhythm changes in the unlikely event of cardiac toxicity.
- Observation of the patient for early signs of central nervous system excitation is perhaps the best monitoring practice.

#### Regional Equipment

- The practice of regional anesthesia requires special equipment designed for peripheral nerve blockade.
- The nerve stimulator allows confirmation of the needle position adjacent to the nerve when a motor response is seen with low current output (0.5 mA; FIG 6).
- In today’s clinical practice, continuous nerve blocks for pain control are commonly placed using nerve stimulation.
- A newer technique uses ultrasound to visualize the nerve to be blocked.
- With ultrasound, it is possible to visualize, in real time, images of the nerve, the needle approaching the nerve, and

### Table 6  Local Anesthetic Dosages

<table>
<thead>
<tr>
<th>Local Anesthetic</th>
<th>Usual Concentration (%)</th>
<th>Usual Doses (mg/kg)</th>
<th>Maximum Dose Plain † (mg/kg)</th>
<th>Maximum Dose with Epinephrine † (mg/kg)</th>
<th>Latency (min)</th>
<th>Duration of Effects (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lidocaine</td>
<td>0.5–2.0</td>
<td>5</td>
<td>7.5</td>
<td>10</td>
<td>5–15</td>
<td>0.75–2</td>
</tr>
<tr>
<td>Mepivacaine</td>
<td>0.5–1.5</td>
<td>5–7</td>
<td>7.5</td>
<td>10</td>
<td>5–15</td>
<td>1–1.25</td>
</tr>
<tr>
<td>Bupivacaine</td>
<td>0.25–0.5</td>
<td>2</td>
<td>2.5</td>
<td>3</td>
<td>15–30</td>
<td>2.5–6.0</td>
</tr>
<tr>
<td>Ropivacaine</td>
<td>0.2–10.0</td>
<td>3</td>
<td>3.5</td>
<td>NA</td>
<td>10–20</td>
<td>2.5–5.0</td>
</tr>
</tbody>
</table>

†Epinephrine is 1:200,000 concentration.

### Table 7  Additives to Local Anesthetics

<table>
<thead>
<tr>
<th>Additive</th>
<th>Dosage</th>
<th>Effect on Intermediate Local Anesthetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epinephrine</td>
<td>2.5 μg/mL</td>
<td>Prolonged</td>
</tr>
<tr>
<td>Clonidine</td>
<td>1.0 μg/kg</td>
<td>Prolonged</td>
</tr>
<tr>
<td>Opioids (alfentanil, sufentanil, morphine)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Buprenorphine</td>
<td>0.3 mg</td>
<td>None</td>
</tr>
<tr>
<td>Neostigmine</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Ketamine</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Sodium bicarbonate</td>
<td>1.0 mEq/10.0 mL</td>
<td>Faster onset</td>
</tr>
</tbody>
</table>
the local anesthesia or catheter being placed in the space around the nerve.

**PAIN MANAGEMENT**

**Preemptive Analgesia**
- Preemptive analgesia is implemented before a painful stimulus, which limits the sensitization of the nervous system to the pain. This should result in less intense pain of shorter duration.
- A dense, sustained nerve block inhibits the transmission of noxious afferent stimuli from the operative site to the spinal cord and brain.
- Multimodal pain control uses multiple analgesics affecting multiple pathways to maximize analgesia (Table 8).
- These interventions complement each other and often allow smaller individual drug doses to be used, thereby minimizing side effects.

![Image of regional anesthesia equipment](image)


<table>
<thead>
<tr>
<th>Analgesic</th>
<th>Dosage</th>
<th>Interval</th>
<th>Route</th>
<th>Maximum Dose</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oral</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspirin</td>
<td>300–600 mg</td>
<td>q4–6h</td>
<td>PO</td>
<td>3600 mg</td>
<td>Avoid in liver disease and glucose-6-phosphate deficiency.</td>
</tr>
<tr>
<td>Acetaminophen</td>
<td>500–1000 mg</td>
<td>q4–6h</td>
<td>PO</td>
<td>4000 mg/d</td>
<td>Avoid in renal insufficiency.</td>
</tr>
<tr>
<td>Ibuprofen</td>
<td>200–400 mg</td>
<td>q4–6h</td>
<td>PO</td>
<td>3200 mg</td>
<td>Avoid in renal insufficiency.</td>
</tr>
<tr>
<td>Naproxen</td>
<td>250–500 mg</td>
<td>q12</td>
<td>PO</td>
<td>1000 mg</td>
<td>Lower dosing in renal and hepatic disease</td>
</tr>
<tr>
<td>Celecoxib</td>
<td>400 mg initial; 200 mg</td>
<td>q12h</td>
<td>PO</td>
<td>800 mg</td>
<td></td>
</tr>
<tr>
<td>Tramadol</td>
<td>50–100 mg</td>
<td>q6h</td>
<td>PO</td>
<td>400 mg</td>
<td></td>
</tr>
<tr>
<td>Gabapentin</td>
<td>600 mg initial; 300 mg</td>
<td>q8h</td>
<td>PO</td>
<td>2400 mg</td>
<td></td>
</tr>
<tr>
<td><strong>Parenteral</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ketorolac</td>
<td>15 mg</td>
<td>q4–6h</td>
<td>IM/IV</td>
<td>&lt;65 yr, 90 mg; &gt;65 yr, 60 mg</td>
<td>Avoid in renal insufficiency.</td>
</tr>
</tbody>
</table>
The primary goal is to avoid hyperalgesia, allodynia, and increased pain.

Acetaminophen is a weak analgesic, but it should be given preoperatively and postoperatively (1 g every 8 hours) unless contraindicated.

The drug acts on prostaglandin synthesis centrally, so there are no concerns with hyper- or hypo-coagulation side effects perioperatively.

Celecoxib is currently the only available cyclooxygenase inhibitor available for clinical use.

It is an ideal nonsteroidal anti-inflammatory as it has no platelet and few gastrointestinal effects.

Caution should be exercised with chronic administration: strokes and myocardial infarctions have been reported after 18 months of regular use.

Gabapentin has been shown to reduce pain and analgesic requirements when given preoperatively.

The drug is an N-methyl-D-aspartic acid antagonist, and it reduces hyperexcitability of dorsal horn neurons induced by tissue trauma.

Gabapentin is active only where there is tissue trauma and sensitization of nociceptive pathways, which distinguishes it from other analgesics.

Mild side effects include slight dizziness and somnolence.

Multimodal Analgesia Perioperative Pain Control

Table 9 covers equianalgesic dosages of opioids.

Table 10 summarizes multimodal postoperative pain control methods.

**Table 9** Narcotic Dosage Comparison

<table>
<thead>
<tr>
<th>Drug</th>
<th>Oral Dose (mg)</th>
<th>Parenteral Dose (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fentanyl</td>
<td>—</td>
<td>0.1</td>
</tr>
<tr>
<td>Meperidine</td>
<td>300</td>
<td>100</td>
</tr>
<tr>
<td>Morphine</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>Hydromorphone</td>
<td>7.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Methadone</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Tramadol</td>
<td>100</td>
<td>—</td>
</tr>
<tr>
<td>Codeine</td>
<td>200</td>
<td>130</td>
</tr>
<tr>
<td>Oxycodone</td>
<td>25</td>
<td>15</td>
</tr>
</tbody>
</table>

**Chronic Pain**

- Patients with chronic pain can be expected to have higher analgesic requirements after surgery.
- These patients are tolerant to the effects of opioids and tend to have very low thresholds for pain.
- Plans for pain management, in consultation between the surgeon, anesthesiologist, and patient, should be made preoperatively to optimally manage this acute-on-chronic pain state.
- The patient’s chronic narcotic therapy should be continued and increased 30% to 40%, depending on the expected severity of the postoperative pain.
- Multimodal analgesia should be implemented before the procedure.
- Continuous peripheral nerve blocks are critical in the treatment of this population of patients.
- Reasonable expectations for analgesia should be discussed by the care team with the patient, and the goal for pain control should be to reach his or her average pain score.

The concept of pain as the “fifth vital sign” (postoperative pain score of 3 or less out of 10) will not apply to these patients.

**INFORMED CONSENT**

- The anesthesiologist must separately articulate both the risks and benefits of regional and general anesthetic options.
- Patients are most often accepting of a regional technique once it has been explained properly and they understand the benefits of superior pain management and the avoidance of postoperative nausea and vomiting.
- The patient may make the final decision, but it is important for the surgical and anesthesia staff to recommend techniques associated with positive outcomes.
- The clinical impression is that regional anesthesia is safer than general anesthesia.
- Numerous studies have examined the complication rate for general and regional anesthesia.
- These studies have compared long-term outcomes between both techniques and have found no difference between regional and general anesthesia in terms of nonfatal myocardial infarction, unstable angina, or 6-month mortality.
- This is reassuring, but there are other outcomes important when choosing an anesthetic plan.

**Table 10** Multimodal Postoperative Pain Management

<table>
<thead>
<tr>
<th>Drug</th>
<th>Mild Postoperative Pain</th>
<th>Moderate Postoperative Pain</th>
<th>Severe Postoperative Pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaminophen</td>
<td>Preop: 1000 mg</td>
<td>Preop: 1000 mg</td>
<td>Preop: 1000 mg</td>
</tr>
<tr>
<td></td>
<td>Postop: 1000 mg q8h</td>
<td>Postop: 1000 mg q8h</td>
<td>Postop: 1000 mg q8h</td>
</tr>
<tr>
<td></td>
<td>Preop: 400 mg</td>
<td>Preop: 400 mg</td>
<td>Postop: 400 mg</td>
</tr>
<tr>
<td></td>
<td>Postop: 200 mg q12h</td>
<td>Postop: 200 mg q12h</td>
<td>Postop: 200 mg q12h</td>
</tr>
<tr>
<td></td>
<td>600 mg</td>
<td></td>
<td>600 mg/300 mg q8h</td>
</tr>
<tr>
<td>Oxycodone SR Pt &lt; 65 yr</td>
<td>Preop: 10 mg</td>
<td>Preop: 10 mg q12h</td>
<td>Preop: 20 mg</td>
</tr>
<tr>
<td></td>
<td>Postop: 10 mg q12h</td>
<td>Assess pain score (0–10)</td>
<td>Postop: 20 mg q12h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 or 5: 5 mg q4h</td>
<td>Assess pain score (0–10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6–10: 10 mg q4h</td>
<td>4 or 5: 5 mg q2h</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6–10: 10 mg q2h</td>
</tr>
<tr>
<td>Oxycodone IR Pt &gt; 65 yr</td>
<td>Assess pain score (0–10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 or 5: 5 mg q4h</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6–10: 10 mg q4h</td>
<td></td>
</tr>
</tbody>
</table>
COMPLICATIONS

General Anesthesia

- The perceived efficiencies of general anesthesia may not be evident in the postoperative period where more complications must be managed, and the level of postoperative care with general anesthesia will be dictated by these complications.

Postoperative Nausea and Vomiting

- Avoiding postoperative nausea and vomiting (PONV) is a high priority because of the expense resulting from treatments and subsequent delays.
  - PONV may not respond to treatment, leading to an unplanned hospital admission.
  - Patient satisfaction surveys have determined that patients often find PONV more unpleasant than postoperative pain.
- Postoperative nausea and vomiting risk is related to age.
  - There is a low risk in children less than 2 years old, but the risk increases until puberty and then drops as aging occurs.
- Patients with prior PONV or who have motion sickness have a higher risk of PONV with general anesthesia.
  - Women have a higher incidence of PONV.
  - Nonsmokers have a higher risk of PONV.
- The risk of PONV varies with the type of surgery.
  - Ear, nose, and throat and dental procedures have a high incidence of PONV, followed by orthopaedic and plastic surgery.
  - Procedures such as strabismus, peritoneal, testicular, and middle ear surgeries are associated with PONV.
- The risk of PONV is higher with general anesthesia than regional anesthesia.
  - General anesthetics such as the inhalational gasses (nitrous oxide, sevoflurane, and desflurane) increase the incidence of PONV compared to propofol.
  - Droperidol (0.625 mg) has been a PONV treatment mainstay because of its efficacy and low cost.
  - However, as a result of isolated cardiac events with large doses of droperidol (1.25 to 2.5 mg) in the presence of prolonged Q-T syndrome, the U.S. Food and Drug Administration has issued a black box warning for its clinical use.
- Table 11 summarizes factors related to patient and surgery and lists treatment guidelines.

Urine Retention

- Vomiting difficulty is common after spinal anesthesia and in patients with prostatic hypertrophy as well as in urology, inguinal hernia, and genital procedures.
- The use of parenteral opioids to control significant pain will increase the incidence of urine retention.
- For procedures associated with a low risk of urine retention, patients may be discharged without demonstration of voiding.
- Patients must be instructed to return for evaluation if they have not voided in a specified time frame.

Postanesthetic Injuries

- Corneal abrasion
  - Corneal abrasion may occur due to drying of the cornea or incidental trauma during mask ventilation or intubation or as a result of the patient rubbing the eyes after the procedure.
- Nerve injuries
  - Nerve injuries may occur due to improper positioning and padding during the procedure.
  - Injury may occur from compression or stretch of the neural tissue.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient</td>
<td>Monitored anesthesia care or regional anesthesia</td>
</tr>
<tr>
<td></td>
<td>No treatment required</td>
</tr>
<tr>
<td>Two factors</td>
<td>Dexamethasone 8 mg at induction of anesthesia</td>
</tr>
<tr>
<td></td>
<td>Odansetron (Zofran) 4 mg at end of surgery</td>
</tr>
<tr>
<td>Three or four factors</td>
<td>Droperidol 0.625 mg at induction of anesthesia (Q-T interval less than 440 msec)</td>
</tr>
<tr>
<td>Five factors</td>
<td>Dexamethasone 8 mg at induction of anesthesia</td>
</tr>
<tr>
<td></td>
<td>Odansetron (Zofran) 4 mg at end of surgery</td>
</tr>
<tr>
<td></td>
<td>Total intravenous anesthesia with propofol</td>
</tr>
</tbody>
</table>

The symptoms of corneal abrasion include redness, tearing, photophobia, decreased visual acuity, and pain.
- They are usually self-limited, resolving in 24 to 48 hours, and artificial tears and an eye patch are standard treatments.
- Severe abrasions may warrant ophthalmologic consultation as they may lead to cataract formation.

Pharyngeal injuries

- Endotracheal intubation may cause a sore throat in 20% to 50% of patients, depending on the amount of trauma during laryngoscopy or oropharyngeal suctioning.
- Local anesthetic ointments during anesthesia, once thought to prevent sore throats, may also result in airway irritation. This may present as pain or an unquenchable thirst.
- Mucosal trauma may also be the result of the laryngeal mask airway, despite the impression that they are less invasive and traumatic than endotracheal tubes.
- Dental damage may occur during the induction or emergence from anesthesia.
  - Any dental damage should be carefully documented, and dental consultation may be needed depending on the extent of the injury.
  - Lip, gum, or tongue damage may be treated with ice to manage the pain and inflammation.

Table 11

| Postoperative Nausea and Vomiting Prophylaxis and Treatment |
|----------------------------------------------------------|---------------------------------------------------------|
| Factors                                                  | Treatment                                               |
| Patient                                                  | Monitored anesthesia care or regional anesthesia        |
| Premenopausal female                                      | No treatment required                                   |
| History of motion sickness                               | Dexamethasone 8 mg at induction of anesthesia            |
| History of PONV                                          | Odansetron (Zofran) 4 mg at end of surgery              |
| Nonsmoker                                                | Droperidol 0.625 mg at induction of anesthesia (Q-T interval less than 440 msec) |
| Surgical                                                 | Dexamethasone 8 mg at induction of anesthesia            |
| Laparoscopic/laparotomy                                   | Odansetron (Zofran) 4 mg at end of surgery              |
| Plastic surgery                                          | Total intravenous anesthesia with propofol              |
| Otolaryngology                                           |                                                        |
| Strabismus surgery                                       |                                                        |
| Otolaryngology                                           |                                                        |
| Plastic surgery                                          |                                                        |
| Laparoscopic/laparotomy                                   |                                                        |
| Nonsmoker                                                |                                                        |
| Premenopausal female                                      |                                                        |
| History of motion sickness                               |                                                        |
| History of PONV                                          |                                                        |
| Nonsmoker                                                |                                                        |
| Premenopausal female                                      |                                                        |
| History of motion sickness                               |                                                        |
| History of PONV                                          |                                                        |
| Nonsmoker                                                |                                                        |
| Premenopausal female                                      |                                                        |
| History of motion sickness                               |                                                        |
| History of PONV                                          |                                                        |
| Nonsmoker                                                |                                                        |
| Premenopausal female                                      |                                                        |
| History of motion sickness                               |                                                        |
| History of PONV                                          |                                                        |
| Nonsmoker                                                |                                                        |
Nerve injury is usually thought to be associated with regional anesthesia, but the incidence of nerve injury is higher with general anesthesia (ulnar nerve).

Regional Anesthesia

Nerve Injury

The incidence of nerve injury was evaluated in a large retrospective European study involving over 150,000 regional anesthetics.1

The anesthetics were administered over a 10-month period; over 50,000 were peripheral nerve blocks. The incidence of peripheral nerve injury was 0.04% (4/10,000). Peripheral nerve injury occurred in 12 patients, and the symptoms were present after 6 months in 7 patients.

Much has been written about the risks of nerve injury after peripheral nerve blocks, but it is only recently that the positive merits of these techniques have been discussed.

Peripheral nerve injury with regional anesthesia may be the result of direct needle or catheter trauma, local anesthetic toxicity, or vasoconstrictors added to the local solution.

Severe injuries occurred, in adult patients under general anesthesia, when local anesthetic was inadvertently injected into the spinal cord. This resulted in irreversible paralysis.2

Short-beveled needles do not result in fewer cases of nerve injury compared with long-beveled needles, as had previously been believed.

The neural repair appears more rapid after injury from a long-beveled needle according to animal data, although there are no clinical data to support this.

Patient factors increasing the risk of nerve injury include diabetes mellitus, pre-existing nerve injury, male sex, and older age.

Surgical factors associated with a higher rate of nerve injury include trauma, stretch, positioning, tourniquet ischemia, and cast compression.

Neurologic changes should be evaluated urgently so that treatable causes such as hematoma, constrictive dressings, and abscess formation may be diagnosed and treated, limiting the extent of injury.

If significant nerve injury is suspected, documentation of neurologic status and neurology consultation with early and late electromyography are advisable.

Infectious Complications

Infection may result after a nerve block from the contamination of the needle or local anesthetics as well as from bacteremia.

This would be less likely with a single injection block because the local anesthetics used in regional anesthesia are bactericidal (bupivacaine at a concentration of at least 0.25%).

Infection is more likely with a continuous block as the catheter is a track for bacteria and dilute local anesthetics are less bactericidal.

Local infection at the site of the block is a clear contraindication to a regional anesthetic, especially catheter placement.

Bacterial colonization of continuous nerve blocks was examined by Capdevila et al.4

In the 969 catheters that were cultured, bacterial colonization was found to be present in 28.7% (278), but only 3% of the patients had signs of local inflammation at the site.

The bacteria most often identified were coagulase-negative staphylococci (Staphylococcus epidermidis; 61%), gram-negative bacillus (21.6%), and Staphylococcus aureus (17.6%).

Localized inflammation or infection at the site is associated with factors such as catheter duration greater than 48 hours, male sex, absence of antibiotic prophylaxis, and postoperative monitoring in the intensive care unit.4

It is our practice to limit the peripheral nerve catheter and infusion to 48 hours.

Catheters are tunneled under the skin for prolonged analgesia, preventing bacteria from migrating to deeper tissue planes.

Hemorrhagic Complications

The risk of bleeding during regional anesthesia, although rare, is always present because of the anatomic relationships of nerves and vascular structures.

Hematoma formation has been reported with almost every nerve block approach, and superficial bruising is very common.

A high index of suspicion will allow early diagnosis and treatment, avoiding permanent injury.

Patients at particularly high risk for hemorrhagic complications are those receiving low-molecular-weight heparins, antiplatelet drugs such as clopidogrel (Plavix), therapeutic Coumadin levels, and antithrombotic drugs.

Hematomas should be considered in the setting of an evolving neural deficit and obviously if vascular injury occurred during the technique.

Acute hematoma formation may be handled conservatively by holding pressure for at least 5 minutes and continued observation.

A large hematoma that continues to expand or is causing acute neural deficits will require surgical drainage to preserve nerve function.

Imaging such as ultrasound or CT scanning may confirm the diagnosis before surgery if there is doubt.

Local Anesthetic Toxicity

Local anesthetics in the proper concentration and dosage are safe. When local anesthesia is inadvertently injected intravascularly, seizures may occur.

Seizures result due to high concentration of local anesthesia in the plasma despite binding by albumin and alpha-1 acid glycoprotein.

The seizures tend to be short with the prompt administration of benzodiazepines and positive-pressure ventilation.

When a significant portion of a bupivacaine dose becomes intravascular, death has occurred as a result of the cardiac conduction being blocked, which resulted in cardiovascular collapse.

Factors affecting toxicity of local anesthetics

Location of block (intercostal, epidural, or interscalene)

Patient characteristics (extremes of age, parturients, hypoalbuminemia)

Pharmacologic factors

Toxicity: bupivacaine> ropivacaine >> mepivacaine>> lidocaine

Perioperative Considerations

The proper selection of anesthetic techniques for orthopaedic surgery begins with the consideration of surgical and patient factors. Additionally, factors such as safety, cost-effectiveness, and efficiency are considered.
A well-organized surgical and anesthetic practice allows patients to receive nerve blocks before going to the operating room.

Peripheral nerve blocks need not delay surgery or fail if proper utilization of the induction room occurs.

Operating room efficiency and turnover are increased in this manner. The patient will be sedated and have monitors, intravenous access, and a functional regional block in place when he or she enters the operating room.

The regional patient will also bypass the postanesthesia care unit and may move to the outpatient or regular nursing area without delay.

The upper extremity is uniquely suited for regional anesthesia because the brachial plexus may be anesthetized with one injection, and continuous blocks may be maintained postoperatively, providing extended analgesia.

Whether general, regional, or a combination is selected for anesthesia, patients' perioperative experiences are improving.

In the past, regional anesthesia was selected for safety reasons, and now regional anesthesia is being administered for its superior pain control.

In the future, anesthetics may be selected based on the patient's genotype, and the patient may have surgery and postoperative pain control without needles, catheters, or even a general anesthesia. Until then, regional techniques, in conjunction with multimodal analgesic protocols, will continue to be the care standard after orthopaedic surgery.

REFERENCES

BACKGROUND

- Since its inception, wrist arthroscopy has continued to evolve. The initial emphasis on viewing the wrist from the dorsal aspect arose from the relative lack of neurovascular structures as well as the familiarity of most surgeons with dorsal approaches to the radiocarpal joint.
- Anatomic studies provided a better understanding of both the interosseous ligaments as well as carpal kinematics, which led to the development of midcarpal arthroscopy.
- Innovative surgeons continue to push the envelope through the development of techniques for treating intracarpal pathology, which in turn has culminated in a plethora of new accessory portals.

ANATOMY

- The standard portals for wrist arthroscopy are dorsal (FIG 1A–C). This is in part due to the relative lack of neurovascular structures on the dorsum of the wrist as well as the initial emphasis on assessing the volar wrist ligaments. The dorsal portals that allow access to the radiocarpal joint are so named in relation to the tendons of the dorsal extensor compartments.
- The 1–2 portal lies between the first extensor compartment tendons, which include the extensor pollicis brevis and the abductor pollicis longus, and the second extensor compartment, which contains the extensor carpi radialis brevis and longus (FIG 1D).
- The 3–4 portal is named for the interval between the third dorsal extensor compartment, which contains the extensor pollicis longus tendon, and the fourth extensor compartment, which contains the extensor digitorum communis (EDC) tendons.
- The 4–5 portal is located between the EDC and the extensor digiti minimi (EDM).
- The 6R portal is located on the radial side of the extensor carpi ulnaris (ECU) tendon; the 6U portal is located on the ulnar side.
- The midcarpal joint is assessed through two portals, which allows triangulation of the arthroscope and the instrumentation.
- The midcarpal radial portal is located 1 cm distal to the 3–4 portal and is bounded radially by the extensor carpi radialis brevis and ulnarly by the EDC.
- The midcarpal ulnar portal is similarly located 1 to 2 cm distal to the 4–5 portal and is bounded by the EDC and the EDM.
- The triquetrohamate portal enters the midcarpal joint at the level of the triquetrohamate joint ulnar to the ECU tendon. The entry site is both ulnar and distal to the midcarpal ulnar portal. Branches of the dorsal cutaneous branch of the ulnar nerve are most at risk (FIG 2A).
- The dorsal radioulnar joint portal lies between the ECU and the EDM tendons. Transverse branches of the dorsal cutaneous branch of the ulnar nerve are the only sensory

FIG 1 • Dorsal portal anatomy. A. Cadaver dissection of the dorsal aspect of a left wrist demonstrating the relative positions of the dorsoradial portals. EDC, extensor digitorum communis; EPL, extensor pollicis longus; SRN, superficial radial nerve; *, tubercle of Lister. B. Relative positions of the dorsoulnar portals. EDM, extensor digiti minimi; DCBUN, dorsal cutaneous branch of the ulnar nerve. (continued)

FIG 2 • A. Ulnar aspect of a left wrist demonstrating the relative positions of the triquetrohamate (T-H) portal and the 6U portal. DCBUN, dorsal cutaneous branch of the ulnar nerve; UN, ulnar nerve. B, C. Dorsal distal radioulnar joint (DRUJ) portal anatomy. B. Relative position of the proximal (PDRUJ) and distal (DDRUJ) portals. C. Close-up with the dorsal capsule removed demonstrating the position of the needles in relation to the dorsal radioulnar ligament (*). AD, articular disc; UC, ulnocarpal joint; UH, ulnar head. D, E. Volar DRUJ portals. D. Volar aspect of a left wrist demonstrating the relative positions of the volar ulnar (VU) and volar DRUJ (VDR) portals in relation to the ulnar nerve (*) and ulnar artery (UA). FDS, flexor digitorum sublimis; FCU, flexor carpi ulnaris. E. Close-up view after the volar capsule is removed showing position of needles in relation to the volar radioulnar ligament (*). Tr, triquetrum; UH, ulnar head. (From Slutsky DJ. Wrist arthroscopy portals. In Slutsky DJ, Nagle DJ, eds. Techniques in Hand and Wrist Arthroscopy. Philadelphia: Elsevier, 2007.)
nerves in proximity to the dorsal radioulnar portal, at a mean of 17.5 mm distally (range 10–20 mm) (FIG 2B,C).

- There are two volar portals that can be used to access the radiocarpal joint.
  - The volar radial portal is accessed through the floor of the flexor carpi radialis tendon sheath at the level of the proximal wrist crease.5,7,9
  - Anatomic studies revealed that there is a safe zone free of any neurovascular structures, equal to the width of the flexor carpi radialis tendon plus at least 3 mm in all directions.
  - The volar aspect of the midcarpal joint can be accessed through the volar radial midcarpal portal. The same skin incision is used but the capsular entry point is about 1 cm distal.
  - The volar ulnar portal is located underneath the ulnar border of the flexor tendons at the level of the proximal wrist crease.6

- The volar aspect of the distal radioulnar joint (DRUJ) can be accessed through the volar distal radioulnar portal using the same skin incision, but the capsular entry point for the volar distal radioulnar portal lies 5 mm to 1 cm proximal to the ulnocarpal entry point (FIG 2D,E).

**AUTHOR’S EXPERIENCE**

- The volar radial portal has been used in 111 patients since 1998.4
  - Additional pathology was evident in 61 of the patients that was not visible from any standard dorsal portals. This included 1 case of hypertrophic synovitis of the dorsal capsule (FIG 3A), 1 patient with an avulsion of the radioscapopholunate ligament that exposed the volar scapholunate cleft (FIG 3B), 2 patients with tears restricted to the palmar region of the scapholunate interosseous ligament (SLIL), and 57 patients with tears of the dorsal radiocarpal ligament (DRCL). In 16 patients an isolated DRCL tear alone was responsible for chronic dorsal wrist pain (FIG 3C,D).
- The midcarpal joint was accessed from the volar radial portal in three cases. In one patient with Preiser disease, the use of the volar radial midcarpal portal allowed a more complete assessment of the distal articular surface of the

---

**FIG 3**

scaphoid. Another patient had unrecognized chondromalacia of the palmar capitate following a perilunate dislocation (FIG 3E). The volar radial midcarpal portal admirably demonstrated the intact dorsal portion of the SLIL in the patient with the palmar tear (FIG 3F).

- The volar ulnar portal has been used in 61 patients since 1998.8

- The ulnar-sided pathology included 21 tears of the lunotriquetral interosseous ligament (LTIL) (FIG 4A), 19 triangular fibrocartilage complex (TFCC) tears, and 2 ulnolunate ligament tears. In one patient a TFCC tear was found to extend into the dorsoulnar ligament (FIG 4B,C). The volar ulnar portal facilitated débridement of the palmar region of the LTIL ligament through the 6R or 6U portals. In three of these

---

**FIG 3 • (continued)** Volar midcarpal portal. **E.** Chondromalacia of the palmar capitate (C). Probe is in the midcarpal radial portal (MCR). L, lunate. **F.** Tear of the palmar region of the scapholunate interosseous ligament (SLIL), as viewed from the volar radial midcarpal portal. Note the intact dorsal fibers of the SLIL. S, scaphoid; L, lunate; H, hamate; DC, dorsal capsule. (A,B: From Slutsky DJ. Wrist arthroscopy through a volar radial portal. Arthroscopy 2002;18:624–630, with permission.)

**FIG 4 • A.** Lunotriquetral ligament tear as viewed from the volar ulnar portal. Note the tear of the lunotriquetral ligament (*). T, triquetrum, L, lunate. **B,C.** Volar ulnar portal view. **B.** Triangular fibrocartilage (TFC) tear extending into the dorsal radioulnar ligament. Probe inserted through the dorsal 4–5 portal. **C.** Palpation of the dorsal radioulnar ligament tear with the hook probe. (continued)
patients unrecognized chondromalacia of the palmar aspect of the lunate was identified (FIG 4D), and one patient had chondromalacia of the palmar triquetrum. One patient was found to have a loose body in the ulnocarpal joint (FIG 4E).

The volar aspect of the DRUJ was accessed in eight of these patients to rule out a peripheral TFCC tear. The DRUJ was well visualized, demonstrating an intact articular disc in four and a full-thickness tear with undersurface fibrillation in one (FIG 4F). The foveal attachment of the TFCC was seen to be intact in each case (FIG 4G,H).

NONOPERATIVE MANAGEMENT

- In general, wrist arthroscopy is indicated as a diagnostic technique in any patient with persistent wrist pain that has not responded to an appropriate trial of conservative measures:
  - Nonsteroidal anti-inflammatory and activity modification
  - Cortisone injection
  - Wrist arthroscopy is used as an adjuvant procedure for the treatment of acute fractures of the distal radius or scaphoid, or for staging degenerative disorders involving the carpus.

Indications

- The indications for the use of the standard dorsal portals are intertwined with the indications for wrist arthroscopy and depend largely on the condition that is being treated.
  - A typical arthroscopic examination of the wrist will include variable combinations of the 3–4 portal, the 4-5 portal, and the 6R and 6U portals.
Arthroscopic Wrist Procedures

- The 3–4 and 4–5 portals are the main viewing portals for the radial aspect of the radiocarpal joint and for instrumentation.
- The 4–5 and 6R portals are used to access the ulnocarpal joint.
- The 6U portal is typically used for outflow.
- The volar radial portal is indicated for the evaluation of the DRL and the palmar portion of the SLIL. The volar radial portal also facilitates arthroscopic reduction of intra-articular fractures of the distal radius fractures by providing a clear view of the dorsal rim fragments.
- The volar ulnar portal is indicated for visualizing and débriding palmar tears of the lunotriquetral ligament. It also aids in the repair or débridement of dorsally located TFCC tears since the proximity of the 4–5 and 6R portals makes triangulation of the instruments difficult.
- Midcarpal arthroscopy through the dorsal midcarpal portals is essential in making the diagnoses of scapholunate and lunotriquetral instability.
- The grading scale reported by Geissler and colleagues provides a means for staging the degree of instability and provides an algorithm for treatment.
- Midcarpal arthroscopy is likewise employed for the assessment and treatment of chondral lesions of the proximal hamate.
- The triquetrohamate joint can also be accessed through another special-use midcarpal portal.
- The volar radial midcarpal portal is occasionally used as an accessory portal for visualizing the palmar aspects of the capitohamate joint.
- This portal facilitates visualization of the palmar aspect of the capitohamate interosseous ligament, which is important in minimizing translational motion and has an essential role in providing stability to the transverse carpal arch.
- The volar distal radioulnar portal is useful for assessing the deep foveal attachment of the TFCC, which would normally require an open capsulotomy.
- It may be employed if the suspicion of a peripheral TFCC detachment remains despite the absence of any visible TFCC tears through the standard ulnocarpal portals.
- The dorsal DRUJ portals may be used in concert with the volar distal radioulnar portal to more completely assess the status of the articular cartilage of the ulnar head and sigmoid notch as well as for instrumentation.
- The number of conditions amenable to arthroscopic treatment continues to grow. Many arthroscopic procedures are now common, while others await clinical validation. Table 1 provides a list of the more standard procedures.

**Contraindications**
- Contraindications to the use of dorsal or volar portals would include marked swelling, which distorts the topographic anatomy; large capsular tears, which might lead to extravasation of irrigation fluid; neurovascular compromise; bleeding disorders; or infection.
- Unfamiliarity with the regional anatomy is a relative contraindication.

**SURGICAL MANAGEMENT**
- It is useful to have a systematic approach to viewing the wrist.
- The structures that should be visualized as a part of a standard examination include the radius articular surface; the proximal scaphoid, lunate, and triquetrum; the SLIL and LTIL, both palmar and dorsal; the radioscaphocapitate ligament; the long radiolunate ligament; the radioscapholunate ligament; the ulnolunate ligament; the lunotriquetral ligament; and the radial and peripheral TFCC attachments.
- It is my practice to establish the dorsal portals first but then to start the arthroscopic examination with the volar radial portal to visualize the palmar SLIL and the DRCL ligament to minimize any error from iatrogenic trauma to the dorsal capsular structures.
- In patients with ulnar-sided wrist pain, the volar ulnar portal is used to assess the palmar LTIL and dorsal radioulnar ligament, the region of the extensor carpi ulnaris subsheath, and the radial TFCC attachment.
- The scope is then inserted in the 3–4 portal followed by various combinations of the 4–5 portal and 6R portal. The 6U portal is mostly used for outflow, but it may be used for instrumentation when débriding palmar LTIL tears.
- Midcarpal arthroscopy is then performed to probe the SLIL and LTIL joint spaces for instability, the capitohamate interosseous ligament, and to look for chondral lesions on the proximal capitohamate ligament and loose bodies (FIG 5).
- The special-use portals such as the dorsal and volar DRUJ portals and the 1–2 portal are used as needed.

**Preoperative Planning**
- A 2.7-mm, 30-degree-angled scope along with a camera attachment is used.
- Table 2 describes the typical field of view as seen through a 2.7-mm arthroscope under ideal conditions.
- A 1.9-mm scope is sometimes beneficial, especially for evaluation of the DRUJ.
- A fiberoptic light source, video monitor, and printer have become the standard of care.
- Digital systems allow direct writing to a CD and superior video quality as compared to analog cameras.
- A 3-mm hook probe is needed for palpation of intracarpal structures.

### Table 1

<table>
<thead>
<tr>
<th>Arthroscopic Wrist Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ganglion resection: volar and dorsal</td>
</tr>
<tr>
<td>Release of wrist contracture</td>
</tr>
<tr>
<td>Arthroscopic synovectomy</td>
</tr>
<tr>
<td>Staging of degenerative arthritis (scapholunate advanced collapse or scaphoid nonunion advanced collapse, Kienbock disease)</td>
</tr>
<tr>
<td>Radial styloidectomy</td>
</tr>
<tr>
<td>Proximal pole of hamate resection</td>
</tr>
<tr>
<td>Dorsal radiocarpal ligament repair</td>
</tr>
<tr>
<td>Evaluation and treatment of carpal instability: scapholunate, lunotriquetral, midcarpal</td>
</tr>
<tr>
<td>Triangular fibrocartilage tears: repair vs. débridement</td>
</tr>
<tr>
<td>Arthroscopic wafer resection</td>
</tr>
<tr>
<td>Arthroscopic reduction and internal fixation of distal radius fractures</td>
</tr>
<tr>
<td>Arthroscopic-guided fixation of scaphoid fractures</td>
</tr>
</tbody>
</table>

![FIG 5](image-url)
Ligament repairs can also be facilitated by use of a Tuohy needle, which is generally found in any anesthesia cart.

Positioning
- The patient is positioned supine on the operating table with the involved arm abducted on an arm table.
- A tourniquet is placed as far proximal on the arm as feasible.
- Traction is useful:
  - A shoulder holder along with 5- to 10-lb sand bags attached to an arm sling
  - A commercially available traction tower such as the Linvatec tower (Conmed–Linvatec Corporation, Utica, NY) or the ARC traction tower (Arc Surgical LLC, Hillsboro, OR)
- For the dorsal portals the surgeon faces the dorsum of the wrist and is seated by the patient’s head. For the volar portals the surgeon faces the palm and is seated in the patient’s axillary region.

Approach
- Portals are established by palpating and identifying anatomic landmarks and then inserting a 22-gauge needle into the joint space. The joint is then injected with 5 cc of saline.
  - The ability to draw the saline back into the syringe serves as evidence that the needle is in the joint.

A motorized shaver or diathermy unit such as the Oratec probe (Smith & Nephew, NY) is useful for débridement.
- Ancillary equipment is largely procedure-dependent.
- A motorized 2.9-mm burr is needed for bony resection.
- There are a variety of commercially available suture repair kits, including the TFCC repair kit by Linvatec (Conmed–Linvatec Corporation, Largo, FL).

Table 2

<table>
<thead>
<tr>
<th>Portal</th>
<th>Radial</th>
<th>Central</th>
<th>Volar</th>
<th>Dorsal/Distal</th>
<th>Ulnar</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–2</td>
<td>Scaphoid and lunate fossa</td>
<td>Proximal and radial scaphoid, proximal lunate</td>
<td>Oblique views of RSC, LRL, SRL</td>
<td>Oblique views of DRCL</td>
<td>TFCC poorly visualized</td>
</tr>
<tr>
<td>3–4</td>
<td>Scaphoid and lunate fossa</td>
<td>Proximal scaphoid and lunate, dorsal and membranous SLIL</td>
<td>RSC, RSL, LRL, ULL</td>
<td>Oblique views of DRCL insertion onto the dorsal SLIL</td>
<td>Poorly seen</td>
</tr>
<tr>
<td>4–5</td>
<td>Lunate fossa, volar rim of radius</td>
<td>Proximal lunate, triquetrum, dorsal and membranous LTIL</td>
<td>RSL, LRL, ULL</td>
<td>Poorly seen</td>
<td>Poorly seen</td>
</tr>
<tr>
<td>6R</td>
<td>Poorly seen</td>
<td>Proximal triquetrum, dorsal and membranous LTIL</td>
<td>Oblique views of ULL, ULT</td>
<td>Oblique views of DRCL</td>
<td>Poorly seen</td>
</tr>
<tr>
<td>6U</td>
<td>Sigmoid notch</td>
<td>Proximal triquetrum, membranous LTIL</td>
<td>Oblique views of ULL, ULT</td>
<td>Oblique views of DRCL</td>
<td>Poorly seen</td>
</tr>
<tr>
<td>Volar radial</td>
<td>Scaphoid and lunate fossa</td>
<td>Scaphoid and lunate fossa, dorsal rim of radius</td>
<td>Palmar scaphoid and lunate, palmar SLIL</td>
<td>Oblique views of RSL, LRL, ULL</td>
<td>Oblique views of DRCL insertion into the radial insertion, central disc, ulnar attachment, PRUL, DRUL</td>
</tr>
<tr>
<td>Midcarpal radial</td>
<td>Scaphotrapezotrapezoidal joint, distal scaphoid pol</td>
<td>SLL joint, distal scaphoid, distal lunate</td>
<td>Radial limb of arcuate ligament (ie, continuation of the RSC ligament)</td>
<td>Proximal capitate, CHIL, oblique views of proximal hamate</td>
<td>LTIL joint, partial triquetrum</td>
</tr>
<tr>
<td>Midcarpal ulnar</td>
<td>Distal articular surface of the lunate and triquetrum and partial scaphoid</td>
<td>SLL joint</td>
<td>Volar limb of arcuate ligament (ie, continuation of the triquetro-capito-lunate)</td>
<td>Oblique views of proximal hamate, CHIL, proximal hamate</td>
<td>LTIL joint, triquetrum</td>
</tr>
<tr>
<td>Dorsal distal radioulnar joint</td>
<td>Ulnar head</td>
<td>Ulnar head</td>
<td>Palmar radioulnar ligament</td>
<td>Proximal surface of articular disc</td>
<td>Limited view of deep DRUL</td>
</tr>
<tr>
<td>Volar distal radioulnar joint</td>
<td>Ulnar head</td>
<td>Ulnar head</td>
<td>Dorsal radioulnar ligament</td>
<td>Proximal surface of articular disc</td>
<td>Foveal attachment of deep fibers of TFCC (ie, DRUL, PRUL)</td>
</tr>
</tbody>
</table>

CHIL, capitohamate ligament; DRCL, dorsal radiocarpal ligament; DRUL, dorsal radioulnar ligament; LRL, long radiolunate ligament; LTIL, lunotriquetral interosseous ligament; PRUL, palmar radioulnar ligament; PSR, prestyloid recess; PTO, piso-tiquetal orifice; RSC, radioscaphocapitate ligament; RSL, radioscapholunate ligament; SLIL, scapholunate interosseous ligament; SRL, short radiolunate ligament; TFCC, triangular fibrocartilage complex; ULL, ulnolunate ligament; ULT, ulnotriquetral ligament.

Shallow incisions avoid injury to sensory nerve branches and tendons. Soft tissues are dissected using a blunt mosquito clamp or a pair of small curved scissors. The dorsal capsule is pierced with these same instruments, providing access to the joint.

- A blunt trocar is used to introduce the scope cannula, which will house the scope and the inflow.

Routinely, an 18-gauge needle is placed in the 6U portal for outflow.

- Synovitis, fractures, ligament tears, and a tight wrist joint may limit the field of view and necessitate the use of more portals to adequately assess the entire wrist.

3–4 PORTAL

- The concavity overlying the lunate between the extensor pollicis longus and the EDC is located just distal to the tubercle of Lister, in line with the second web space.

- The radiocarpal joint is identified with a 22-gauge needle that is inserted 10 degrees palmar to account for the volar inclination of the radius.

- The vascular tuft of the radioscapholunate ligament is directly in line with this portal. Superior to the radioscapholunate ligament is the membranous portion of the SLIL.

- Routinely, an 18-gauge needle is placed in the 6U portal for outflow.

4–5 PORTAL

- The 6R portal is identified on the radial side of the ECU tendon, just distal to the ulnar head.

- The scope should be angled 10 degrees proximally to avoid hitting the triquetrum. The TFCC is immediately below the entry site.

- The LTIL is located radially and superiorly, whereas the ulnar capsule is immediately adjacent to the scope.

- By rotating the scope dorsally while looking in an ulnar direction, the insertion of the dorsal capsule onto the dorsal aspect of the SLIL can often be visualized. This is a common origin for the stalk of a dorsal ganglion.

- The radioscapholunate ligament and the long radiolunate ligament are radial to the portal and can be probed with a hook in the 4–5 portal.

- The LTIL, TFCC, and ulnolunate ligament are ulnar to the portal.

6R AND 6U PORTALS

- The 6R portal is identified on the radial side of the ECU tendon, just distal to the ulnar head.

- The scope should be angled 10 degrees proximally to avoid hitting the triquetrum. The TFCC is immediately below the entry site.

- The LTIL is located radially and superiorly, whereas the ulnar capsule is immediately adjacent to the scope.

- The 6U portal is found on the ulnar side of the ECU tendon. Angling the needle distally and ulnar deviation of the wrist helps avoid running into the triquetrum.

- This portal can be used to view the dorsal rim of the TFCC or for instrumentation when débriding the palmar LTIL.
1–2 PORTAL

- The relevant landmarks in the snuff box are palpated and outlined, including the distal edge of the radial styloid, the abductor pollicis longus, extensor pollicis brevis, and extensor pollicis longus tendons, and the radial artery in the snuff box.
- To minimize the risk of injury to branches of the superficial radial nerve and the radial artery, the 1–2 portal should be no more than 4.5 mm dorsal to the first extensor compartment and within 4.5 mm of the radial styloid (TECH FIG 1).
- A blunt trocar and cannula are inserted with the wrist in ulnar deviation to minimize damage to the proximal scaphoid.

![TECH FIG 1](image1)

1. Cadaver dissection demonstrating the placement of the 1–2 portal. SR, superficial radial nerve branches; EPL, extensor pollicis longus; EPB, extensor pollicis brevis; APL, abductor pollicis longus.

MIDCARPAL RADIAL PORTAL

- The midcarpal radial portal is found 1 cm distal to the 3–4 portal.
- Flexing the wrist and firm thumb pressure helps identify the soft spot between the distal pole of the scaphoid and the proximal capitate.
- The scaphotrapezial trapezoidal joint lies radially and can be seen by rotating the scope dorsally.
- The scapholunate articulation can be seen proximally and ulnarly; it can be probed for instability or step-off.
- Further ulnarly, the lunotriquetral articulation is visualized.
- Moving the scope superiorly yields oblique views of the proximal surface capitate and hamate as well as the capitohamate interosseous ligament.
- The continuation of the radioscapohamate ligament, which forms the radial arm of the arcuate ligament (ie, the scaphocapitate ligament) can occasionally be seen across the midcarpal space.
MIDCARPAL ULNAR PORTAL

- The midcarpal ulnar port is found 1 cm distal to the 4–5 portal and 1.5 cm ulnar and slightly proximal to the midcarpal radial portal, in line with the ring metacarpal axis.
- This entry site is at the intersection of the lunate, triquetrum, hamate, and capitate with a type I lunate facet and directly over the lunotriquetral joint with a type II lunate facet. This portal provides preferential views of the lunotriquetral articulation.
- Directly anteriorly, the ulnar limb of the arcuate ligament (ie, the triquetro-hamate-capitate ligament) can be seen as it crosses obliquely from the triquetrum, across the proximal corner of the hamate to the palmar neck of the capitate.
- This is especially important in midcarpal instability.
- Normally there is very little step-off between the distal articular surfaces of the scaphoid and lunate.
- Direct pressure from the scope combined with traction may force the carpal joints out of alignment.
- The traction should be released and the scapholunate joint should be viewed with the scope in the midcarpal ulnar portal, whereas the lunotriquetral joint should be viewed with the scope in the midcarpal radial portal.

VOLAR RADIAL PORTAL

- A 2-cm transverse or longitudinal incision is made in the proximal wrist crease overlying the flexor carpi radialis tendon. The portal is established in the usual manner (TECH FIG 2).
- It is not necessary to specifically identify the adjacent neurovascular structures, provided that the anatomic landmarks are adhered to.

**VOLAR RADIAL MIDCARPAL PORTAL**

- The volar aspect of the midcarpal joint can be accessed through the same skin incision as the volar radial portal.
- The capsular entry site through the volar radial midcarpal portal is entered by angling the trocar 1 cm distally and about 5 degrees ulnarward to the radiocarpal site.
- A hook probe can be inserted dorsally in the midcarpal radial portal for palpation.
- With tears of the palmar SLIL one can see the intact dorsal fibers and the volar surface of the capitate.

**VOLAR ULNAR PORTAL**

- The volar ulnar portal is established via a 2-cm longitudinal incision centered over the proximal wrist crease along the ulnar edge of the finger flexor tendons (TECH FIG 3).
- The tendons are retracted to the radial side and the radiocarpal joint space is identified with a 22-gauge needle.
- Care is taken to situate the portal underneath the ulnar edge of the flexor tendons and to apply retraction in a radial direction alone to avoid injury to the ulnar nerve and artery.
- The median nerve is protected by the interposed flexor tendons.
- The palmar region of the LTIL can usually be seen slightly distal and radial to the portal.
- A hook probe is inserted through the 6R or 6U portal.

**TECH FIG 3** • Technique for volar ulnar portal. **A.** Skin incision for volar ulnar portal. **FCR,** flexor carpi radialis tendon; **FDS,** flexor digitorum sublimis. **B.** FDS retracted, saline injection of radiocarpal joint. **C.** Insertion of cannula through capsule deep to FDS tendons. (From Slutsky DJ. The use of a volar ulnar portal in wrist arthroscopy. Arthroscopy 2004;20:158–163.)
**VOLAR DRUJ PORTAL**

- The volar DRUJ portal is accessed through the volar ulnar skin incision.
  - The joint is entered by angling the 22-gauge needle 45 degrees proximally.
    - It is useful to leave a needle or cannula in the ulnocarpal joint for reference.
  - Alternatively, a probe can be placed in the distal DRUJ portal and advanced through the palmar incision to act as a switching stick over which the cannula can be threaded.

- Initially, the space appears quite limited, but over the course of 3 to 5 minutes the fluid irrigation expands the joint space, which improves visibility.

- A 3-mm hook probe is inserted through the dorsal distal DRUJ portal for palpation.
  - A burr or thermal probe can be substituted as necessary.

- Direct visualization of the foveal attachment prevents accidental injury to this structure.
- The articular disc is seen superiorly.
- Proximal surface tears of the TFCC, which are usually caused by severe axial load, may be detected through this portal.
- The dome of the ulnar head lies inferiorly.
- The TFCC attachment to the sigmoid notch can be palpated with a hook probe in the distal dorsal DRUJ portal as it penetrates the dorsal DRUJ capsule.
- The deep attachments of the dorsal radioulnar ligament can be seen as it inserts into the fovea.

**DORSAL DRUJ PORTALS**

- The dorsal aspect of the DRUJ can be accessed through proximal and distal portals.
  - The proximal DRUJ portal is located in the axilla of the joint, just proximal to the sigmoid notch and the flare of the ulnar metaphysis.
    - This portal is easier to penetrate and should be used initially to prevent chondral injury from insertion of the trocar.
    - The forearm is held in supination to relax the dorsal capsule, to move the ulnar head volarly, and to lift the central disc distally from the head of the ulna.
    - Reducing the traction to 1 to 2 pounds permits better views between the ulna and the sigmoid notch by reducing the compressive force caused by axial traction.
    - The joint space is entered by inserting a 22-gauge needle horizontally at the neck of the distal ulna.
      - Fluoroscopy facilitates needle placement.

- The distal dorsal DRUJ portal is identified 6 to 8 mm distally with the 22-gauge needle, and just proximal to the 6R portal.
  - This portal can be used for outflow drainage or for instrumentation.
  - It lies on top of the ulnar head but underneath the TFCC and so is difficult to use in the presence of positive ulnar variance.
  - The TFCC has the least tension in neutral rotation of the forearm, which is the optimal position for visualizing the articular dome of the ulnar head, the undersurface of the TFCC, and the proximal radioulnar ligament from its attachment to the sigmoid notch to its insertion into the fovea of the ulna.
  - Because of the dorsal entry of the arthroscope, the course of the dorsal radioulnar ligament is not visible until its attachment into the fovea is encountered.
  - Entry into this portal provides views of the proximal sigmoid notch cartilage and the articular surface of the neck of the ulna.

**PEARLS AND PITFALLS**

- Use shallow skin incisions.
- Use the wound spread technique to protect surrounding sensory nerves.
- If the trocar does not insert easily, reposition to avoid chondral injury.
- Wrist traction often diminishes during the procedure and should be readjusted as needed to avoid scraping the articular surface.
- Use of a standard methodologic approach ensures a complete and thorough examination.

**POSTOPERATIVE CARE**

- The postoperative rehabilitation depends on the specific procedure that is performed.
  - After diagnostic arthroscopy, with or without débridement, the patient is splinted for comfort for a brief period of 4 to 7 days.

- Active wrist motion is encouraged after this period and patients are allowed activities of daily living, followed by gradual strengthening.
  - If a ligament repair or TFCC repair has been performed or if there is interosseous pinning, the protocol is adjusted as necessary and typically involves an initial period of immobilization before instituting wrist motion.
COMPLICATIONS

- Most of the complications related to use of the dorsal portals are related to injury to the sensory branches of the superficial radial nerve and the dorsal cutaneous branch of the ulnar nerve.
  - The palmar cutaneous branch of the ulnar nerve is at risk with the volar radial portal, although the interposed flexor carpi radialis tendon mitigates this risk.
  - There is no true internervous plane when using the volar ulnar portal; hence, sensory branches of the palmar cutaneous branches of the ulnar nerve or nerve of Henle are always at risk. Thus, proper wound spread technique is paramount.
  - The ulnar neurovascular bundle is also potentially at risk with overzealous retraction or poor portal placement.
  - Venous bleeding, loss of wrist motion (especially forearm supination), complications related to fluid extravasation, and infection are general risks attendant to any arthroscopic procedure.
  - These can be minimized by fastidious surgical technique, aggressive rehabilitation as necessary, and diligent follow-up in the early postoperative period.

REFERENCES

DEFINITION

- Motion in the human forearm is a complex interaction between the radius and ulna produced by the combination of multiple muscles working coherently and hinged at the proximal and distal radioulnar joints.
- Surgical reconstruction of diaphyseal forearm fractures requires precise realignment of both radius and ulna to minimize complications and maximize function.
- Ingenious surgical approaches have been described that allow the surgeon to follow defined internervous planes to the bones for internal fixation. The design of the forearm allows near 180-degree rotation combining with considerable elbow flexion-extension and wrist circumduction. To achieve this, the ulna is enlarged proximally, making it a principal bone of the elbow, and is smaller distally, while the reverse is true for the radius, with the enlarged radius being the primary articulation with the carpus. The result for the diaphysis of each bone is that the proximal ulna is metaphyseal for about 25% to 30% of its length but distally less than 10%, with the reverse holding true for the radius. Implant design has taken these differences into account, with many whole systems available for metaphyseal distal radius and proximal ulna fractures.
- The importance of maintaining the radial and ulnar heads has only recently been understood. New developments are taking place, therefore, for the management of distal ulna and proximal radius fractures.
- This chapter discusses ulna fractures distal to the junction of the proximal and middle thirds to the distal margin of the pronator quadratus (PQ) and radius fractures distal to the biceps tuberosity down to the distal flare of the radius.
- Pediatric fractures, distal radius and ulna fractures, olecranon and radial head fractures are not covered.
- Diaphyseal forearm fractures usually are classified according to the AO classification.

ANATOMY

- The surgical approaches to the forearm bones for fracture osteosynthesis involve five steps:
  - Finding an interval between longitudinally oriented superficial muscles
  - Finding and preserving vessels and nerves
  - Understanding the anatomy of deeper muscles that cross the forearm obliquely or transversely
  - Knowing where to lift these muscles to expose the bone
  - Understanding the shape of the bones themselves and their relation to one another

Radius and Ulna

- Motion of the forearm involves a complex interaction between the radius and ulna.
  - The radius rotates around a longitudinal axis that passes through the center of the radial head at the proximal radioulnar joint and through the center of the ulnar head distally.
  - With rotation, the radius rotates around the ulna, and the ulna moves in a varus–valgus direction about 9 degrees at the elbow. This allows the ulnar head to move out of the way of the rotating radius distally.
  - At the distal radioulnar joint (DRUJ), motion between 50 degrees pronation and 50 degrees supination is almost pure rotation, but at the extremes the radius translates in a dorsal direction during pronation and a palmar direction during supination.
  - Movement at the proximal radioulnar joint (PRUJ) is primarily rotation.
  - The radius and ulna have two bows that assist in getting out of the other’s way. Schemitsch and Richards quantified the importance of the distal of the two bows in the radius. Restoration of this bow is the single most important step in reconstruction of the forearm after diaphyseal fracture.
  - To determine whether the bow has been restored after osteosynthesis, draw a line from the biceps tuberosity to the sigmoid notch. A perpendicular line from the apex can then be measured (FIG 1). The normal range of bow is 15.3 ± 0.3 mm at a point at 60% of the radius measured between the bicipital tuberosity and the distal radius at the sigmoid notch.
  - At the apex of this bow on the convex side is the insertion of the pronator teres. This provides a biomechanical advantage for pronation.
  - The biceps insertion is at the apex of a smaller proximal bow. As a result, the biceps needs to be much larger to overcome the disadvantage of insertion into a small bow for balanced supination.
  - The arrangement in the ulna is the converse of the radius: a longer shallower proximal bow (the anconeus inserts into the apex for valgus of the elbow), and a small distal bow for the insertion of the PQ.
  - The radius and ulna are bound together essentially throughout their length, with the annular ligament at the PRUJ, the interosseous ligament through the middle 75%, and the ligaments of the triangular fibrocartilage complex.
Muscles and Ligaments

- The forearm is criss-crossed with longitudinal, oblique, and transversely directed musculotendinous units. These muscles are in layers, with longitudinal muscles more superficial and crossing muscles deeper.

- Most activities performed by the forearm, wrist, and hand occur from the midpronation position, with the wrist moving into extension and radial deviation, then in an arc accelerating past neutral again, to flexion and ulnar deviation (FUD, end of deceleration) before returning to wrist neutral. The forearm is designed to maximize the ability to perform this motion. This wrist motion is commonly known as the “dart thrower’s motion” or primary wrist motion.

- The extensor carpi radialis longus (ECRL), the cocking or lifting muscle of primary wrist motion, originates proximal to the lateral epicondyle on the supracondylar ridge, is positioned “above” the forearm, and inserts into the radial and dorsal aspect of the index metacarpal.

- On either side of the ECRL is the brachioradialis (BR), which originates high on the lateral supracondylar ridge, inserting on the radial styloid deep to the first dorsal compartment, and the extensor carpi radialis brevis (ECRB), which originates more distally just above the lateral epicondyle and inserts into the long finger metacarpal. ECRL and ECRB share the second dorsal compartment at the wrist.

- Together the BR, ECRL, and ECRB form a mobile wad above the forearm (in the functional position). They are innervated directly by the radial nerve and are best palpated just distal to the elbow.

- In a posterior approach to the radius, which is performed in pronation, after incising the deep fascia, the dissection interval is between the ECRB and the extensor digitorum communis (EDC) muscle. The EDC originates from the lateral epicondyle (where it shares a common origin with the extensor digiti minimi) and passes essentially in a straight line down the forearm, then through the fourth dorsal compartment at the wrist, just ulnar to Lister’s tubercle.

- In an anterior approach, which is performed in supination, the deep fascia is incised along the medial border of the BR. The BR is then mobilized radially and the interval between it and flexor carpi radialis is developed. The FCR, like the EDC, has a straight course in the forearm from the medial epicondyle to the scaphoid tubercle (where it passes en route to the index metacarpal).

- The muscle of utmost importance in approaches to the ulna is the flexor carpi ulnaris (FCU). It is the primary accelerator of the wrist, and thus has a large tendon (equal to the mechanical strength of the ECRL and ECRB combined), which originates from two heads, one from the medial epicondyle and one from the ulna. It proceeds straight down the forearm along the ulna border and inserts into the pisiform. From the distal tip of the lateral epicondyle originates the extensor carpi ulnaris, which runs down the forearm on the extensor side of the subcutaneous border of the ulna, sharing a septum with the FCU.

- The ulna is approached along this septum. The anterior surface and posterior aspects of the ulna can be approached this way. The true anterior approach to the ulna is along the radial edge of the FCU, mobilizing the ulna neurovascular bundle and going between the FCU and the flexor digitorum profundus (FDP). The FDP occupies the floor of most of the flexor compartment of the forearm.

- Crossing the forearm in its deepest parts are a series of obliquely oriented muscles. The supinator plays a role in both the anterior and posterior approaches to the radius. It has two heads of origin and probably can be thought of as two muscles, because the fibers of each head traverse in different directions.

- The ulnar head attaches to the supinator crest on the radial side of the ulna. Its fibers are transverse (like those of the PQ distally) and attach to the most proximal part of the radius, deep to the posterior interosseous nerve (PIN).

- The humeral head attaches to the lateral epicondyle, deep to the ECU and anconeus. Its fibers slope down the forearm more longitudinally, and wrap over the deep or ulnar head to attach to the radius distal to the ulnar head of the supinator and proximal to the insertion of the pronator teres.

- In an anterior approach to the radius, the forearm is supinated, protecting the PIN, and the humeral head of the supinator is lifted from its most ulnar attachment.

- The pronator teres originates mainly from the medial supracondylar ridge, arches obliquely across the ulnar artery and median nerve, and inserts into the apex of the larger bow of the radius. Distally, it is superficial, but distally, where it must be lifted from the radius, it is deep to the BR muscle (FIG 2). It must be lifted from the most radial aspect of the radius in the anterior approach.

- Distally in the floor of the anterior compartment the PQ muscle comes into play in anterior approaches to the radius and ulna. It must be lifted from the radial border in an approach to the radius and the ulna border in an approach to the ulna.

- In a posterior approach to the radius, the abductor pollicis longus muscle drapes across the radius just distal to its midpoint. It can be lifted to allow plate fixation to this part of the radius. Its ulnar origin is always left intact.

- Cross-shaped muscles are especially the flexor digitorum superficialis and flexor digitorum profundus, the superficialis being crossed over the deepis.
Nerves
- The forearm is traversed longitudinally with three major nerves plus an additional three sensory nerves, only one of which is of surgical importance. Once the interval between muscles is breached, care is taken to find these nerves. Each nerve enters the forearm from a predictable place, and each gives off key branches that must be protected.
- Although the radial nerve supplies all the extensor muscles of the arm and forearm, it is an anterior structure after it pierces the lateral intermuscular septum 10 cm above the elbow.
- At the elbow the radial nerve lies between the BR and the brachialis and gives off the PIN.
- The radial sensory nerve continues deep to the BR muscle, on its undersurface. Here, the nerve generally lies close to the radial artery. The anterior approach to the radius is through the interval between the nerve and artery.
- The posterior interosseous branch leaves the main nerve just distal to the elbow and passes through the supinator muscle, between its two heads, to enter the dorsal or extensor compartment of the forearm.
- As it leaves the supinator, it fans into multiple variable branches to supply the EDC, EDM, and ECU, with the majority of the nerve continuing distally deep to the interval between EDC and ECRB.
- The course of the ulnar nerve is represented by a line drawn from the medial epicondyle to the pisiform. Throughout the forearm the nerve is deep to the FCU muscle and lies deep and slightly radial to the tendon of this muscle at the wrist. Throughout most of the forearm the nerve is between the FCU and the FDP.
- The median nerve enters the forearm between the brachial artery and the tendon of the biceps brachii. It lies deep to the pronator teres, then passes deep to the fibrous arch of the FDS. The nerve is closely associated with the undersurface of the FDS as it travels distally.

Blood Supply
- The vascular anatomy is of critical importance in the flexor compartment.
- The brachial artery enters the forearm deep to the lacer-tus fibrosus, next to the median nerve. It almost immediately branches into radial and ulnar arteries.
- The ulnar artery passes deep to the arch of origin of the FDS to lie next to the ulnar nerve throughout the distal two thirds of the forearm.
- The radial artery is pushed more superficial by the bulk of the FDS and the pronator teres lying just deep to the fascia along the medial border of the BR muscle.

PATHOGENESIS
- The degree of injury and specifics of the fracture are directly related to the magnitude, direction, and duration of energy.
- Both-bone forearm fractures are common in motor vehicle trauma.
- Industrial trauma often is associated with a high level of soft tissue injury.
- Forearm fractures occur relatively commonly in some sports, eg, rugby in all its forms and wrestling.
- The most common mechanism of injury is a direct blow to the mid-forearm. If this blow is directed primarily at the ulna, an isolated ulna shaft fracture results ("nightstick" fracture).
- An isolated radius fracture often is associated with a fall onto an outstretched hand.

NATURAL HISTORY
- Normal function of the human forearm requires the radius to rotate around the ulna.
- Matthews showed in a cadaveric study that 10 degrees of angulation of one or both bones of the forearm results in a loss of 20 degrees of pronation and supination. Thus, the natural history is highly dependent on the position of healing of the two forearm bones.
- It is reasonable to consider nonoperative treatment of an isolated ulna fracture with less than 10 degrees angulation, but nonoperative treatment of both-bone forearm fractures has a poor outcome.

PATIENT HISTORY AND PHYSICAL FINDINGS
- In most cases, the initial presentation of a radius or ulna diaphyseal fracture makes the diagnosis obvious. Most fractures are displaced due to the high-energy nature of the traumatic event and, therefore, deformity is common. Patients with nondisplaced fractures usually have considerable pain and swelling in the forearm.
- Despite the ease of initial diagnosis, the treating physician must be on guard for significant associated injuries and complications, not only of the bone and joint but also of soft tissue.
- A systems approach to these associated injuries is as follows:
  - Skin: Look at the skin for any evidence of laceration or abrasion. A laceration may communicate with the fracture site; therefore, a contaminated abrasion at the site of surgical incision should be allowed to heal before surgery.
  - Fascia: Tense tissues to palpation over the flexor or extensor compartments and pain with passive finger extension are evidence of compartment syndrome, and compartment release must be considered.
  - Vascular: Radial and ulnar pulses distal to the site of injury must be palpated and compared to the uninjured side. These pulses can be difficult to palpate due to the proximity of the fractures, so checking capillary refill in the digits is the next step. In the multiply injured patient, the peripheries are shut down, making capillary refill and pulses difficult to perform. In such a situation, a needle stick to the digit should reveal bright red blood.
  - Nerve: Assessment of nerve injury is summarized later in this chapter.
  - Bone: The joints above and below the fracture must be palpated for associated joint disruption.
- For any upper extremity injury, a history of the causative event is essential to understand the degree of energy that the limb has had to absorb. Given the common association with high energy, the patient must be assessed according to an appropriate trauma checklist protocol.
- The patient must be questioned specifically regarding elbow or wrist pain, and neurologic symptoms of numbness, tingling, or unusual sensation in the hand. Severe pain should suggest the possibility of compartment syndrome or vascular injury.
- Palpation of the mid-forearm should be gentle, step by step feeling along the radius and ulna. A tense forearm may indicate a compartment syndrome.
Palpation should then proceed over the DRUJ and ulnar head plus PRUJ and radial head. Palpation should be performed of the medial and lateral epicondyles, of the scaphoid in the snuff box, and over carpal bones and the carpometacarpal joints.

A systematic examination of the median, ulnar, and radial nerves involves examination of sensory and motor aspects (Table 1).

- The sensory examination involves static two-point discrimination of the digital nerves and light touch over the autogenous zones of each nerve.
- Motor examination is graded by Medical Research Council (MRC) grading and is done by stressing the appropriate joint and palpating the affected muscle.

### IMAGING AND OTHER DIAGNOSTIC STUDIES

- High-quality plain radiographs of the forearm, wrist, and elbow are the mainstay of diagnosis of diaphyseal radius and ulna fractures.
- Mino16 described a technique to interpret the lateral wrist radiograph whereby the radial styloid is aligned with the center of the lunate, and an assessment of the overlap of the radius and ulna is made. The head of the ulna should be completely obscured by the radius. If only part of the ulnar head is obscured by the radius, then there is subluxation of the head; if the ulnar head is clearly seen, there is dislocation. Any shift in the ulnar head is a subluxation and, when combined with a radius fracture, represents a Galeazzi fracture-dislocation.9
- A CT scan in neutral, pronation, and supination is useful in interpreting the degree of DRUJ congruity. This is rarely used in the acute setting.

### DIFFERENTIAL DIAGNOsis

- Pathologic fracture may result from a number of causes.
- **Metabolic causes:** osteoporosis, estrogen deficiency, renal transplantation, vitamin D deficiency, parathyroid disease, Cushing disease, hyperthyroidism, hypogonadism, hypophosphatasia
- **Primary tumors:** osteosarcoma, Ewing sarcoma and primitive neuroectodermal tumors, chondrosarcoma, myeloma, fibrous histiocytoma, desmoplastic fibroma, hemangioma, intraosseous lipoma, acute myeloid leukemia, Langerhans’ cell histiocytosis, fibrous dysplasia, chondroblastoma
- **Metastatic tumors:** breast, thyroid, lung, prostate, melanoma
- **Infection:** osteomyelitis, tuberculosis
- **Congenital disorders:** Turner syndrome, neurofibromatosis, pseudoarthrosis, osteogenesis imperfecta
- **Iatrogenic fracture:** post–plate/screw removal; post–osteocutaneous radial forearm flap; post–elbow, forearm, and wrist manipulation
- **Stress fracture**

### NONOPERATIVE MANAGEMENT

- Slight deviations in the spatial orientation of the radius and ulna will significantly decrease the forearm’s ability to rotate, impairing hand function.

### Table 1  Methods for Neurologic Examination After Radius and Ulna Fracture

<table>
<thead>
<tr>
<th>Examination</th>
<th>Technique</th>
<th>Grading</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median nerve autogenous zone</td>
<td>Light palpation over the palmar aspect of the index MP joint crease</td>
<td>Compare sides: can be considered normal, absent, or altered.</td>
<td>If altered or absent, consider median nerve palsy. Examine median nerve distribution two-point discrimination. If altered or absent, consider median nerve palsy. Examine median nerve distribution two-point discrimination. If altered or absent, consider median nerve palsy. Examine median nerve distribution two-point discrimination.</td>
</tr>
<tr>
<td>Ulnar nerve autogenous zone</td>
<td>Light palpation over the palmar aspect of the small finger MP joint crease</td>
<td>Compare sides: can be considered normal, absent, or altered.</td>
<td>If altered or absent, consider ulnar nerve palsy. Examine ulnar nerve distribution two-point discrimination. If altered or absent, consider ulnar nerve palsy. Examine ulnar nerve distribution two-point discrimination. If altered or absent, consider ulnar nerve palsy. Examine ulnar nerve distribution two-point discrimination.</td>
</tr>
<tr>
<td>Radial nerve autogenous zone</td>
<td>Light palpation over dorsal first interosseous space</td>
<td>Abduction of first dorsal interosseous against resistance</td>
<td>MRC muscle grading</td>
</tr>
<tr>
<td>First dorsal interosseous muscle test</td>
<td>Abduction of thumb against resistance with palpation of thenar space</td>
<td>MRC grading</td>
<td>If weak, consider median nerve lesion.</td>
</tr>
<tr>
<td>Abductor pollicis brevis muscle test</td>
<td>Extensor pollicis longus muscle test</td>
<td>MRC grading</td>
<td>If weak, consider radial nerve palsy.</td>
</tr>
<tr>
<td>Extensor pollicis longus muscle test</td>
<td>Extend the interphalangeal joint of the thumb against resistance and hyperaduct thumb while palpating the extensor pollicis longus tendon.</td>
<td>If weak, consider radial nerve palsy.</td>
<td></td>
</tr>
<tr>
<td>Flexor pollicis longus muscle test</td>
<td>Flex interphalangeal joint of thumb against resistance.</td>
<td>MRC grading</td>
<td>If weak, consider palsy to anterior interosseous branch of median nerve. Consider intracompartmental pressure monitoring.</td>
</tr>
<tr>
<td>Passive stretch test</td>
<td>Severe pain may indicate compartment syndrome.</td>
<td>Severe pain may indicate compartment syndrome.</td>
<td></td>
</tr>
</tbody>
</table>

MRC, Medical Research Council system.
Fractures of the radius and ulna can be regarded as articular fractures in the sense that functional restoration requires anatomic reduction.

The only indication for nonoperative treatment is a nondisplaced fracture of the ulna,14,21 or if the patient’s general condition makes operative treatment ill advised.

In the case of a displaced fracture, closed reduction and cast immobilization sometimes is possible but is unreliable. Loss of initial satisfactory reduction is common.3,8,12,13

The treatment of choice for adult diaphyseal forearm fractures is open reduction and internal fixation.1,7,20

SURGICAL MANAGEMENT

The most common scenario is fractures of the radius and ulna in the middle third of both bones. The most common questions confronting the surgeon are considered here.

Which approach should be used?

- The anterior surface of the radius and ulna is the best location for a plate. This surface is broad and flat on both bones, and a plate on this surface is covered with muscle, resulting in less plate irritation for the patient.
- Consequently, I prefer the anterior approach to both the radius and the ulna. In addition, the patient is positioned supine for these approaches, reducing the need to reposition the patient during the procedure.
- Should one or two incisions be used?
  - Use of two incisions markedly decreases the risk of synostosis, decreases the length of the incision, and reduces tension on the skin and soft tissue by retractors.
  - Which bone should be stabilized first?
    - The fracture with the least comminution should be approached first and stabilized. This allows for length to be restored in the forearm, allowing easier judgment of length in the more comminuted bone.

Where there is equal comminution or no comminution, the radius is generally approached first.

Should fixation be completed on one bone before approaching the other?

- I recommend not completing fixation but stabilizing one bone before proceeding to the next. This allows reduction of the second bone.
- In a stable, non-comminuted fracture, “temporary stability” may mean a plate and one screw through two cortices on each side of the fracture. In a comminuted fracture, it may mean four cortices and two screws on each side.
- Completion of fixation should occur after the second bone is reduced and stabilized.
- What implant and what length of implant should be used?
  - The plate must span the fracture complex and provide six cortices of fixation in stable bone, both proximally and distally.
  - Non-comminuted transverse fractures require at least a six-hole small fragment limited contact–dynamic compression (LC-DC) or locking plate.
  - Oblique fractures and comminuted fractures require a longer plate. Oblique fractures are treated with an interfragmentary screw or screws at right angles to the fracture line and a seven-hole plate.
  - A unicortical locked screw can be considered “bicortical,” but practically speaking, this rule is used only for the screw hole furthest from the fracture. In almost all situations there must be three screw holes in the plate over stable bone away from the fracture complex.
  - In distal metaphyseal, diaphyseal fractures of the ulna, it often is impossible to get six cortices of fixation. In this situation, two mini fragment plates (with 2.7-mm screws) applied at a 90-degree angle to each other provides excellent fixation.

Anterior and posterior approaches can be used to treat fractures along the entire length of each bone. The anterior approach to the radius is preferred when possible.

- This location allows for excellent soft tissue coverage, reducing the need for plate removal.
- Most diaphyseal forearm fractures are best stabilized by plates and screws, but other implants sometimes are indicated.
- External fixation may be used in the following settings:
  - Open fractures with severe soft tissue damage, as a temporizing measure until reconstruction can safely be undertaken
  - Maintenance of length in fractures with severe bone loss (this usually occurs in open fractures)
  - Patients with multiple injuries (“damage control” surgery)
  - The Ilizarov technique is useful in segmental fractures, especially when the fractures are very close to the wrist and elbow joints.
  - Intermedullary nailing is used in the following settings:
    - Young women who desire a better cosmetic result
    - Segmental fractures
    - Re-fracture at the bone plate interface in a contact athlete or following plate removal

Preoperative Planning

- The surgeon must develop a strategy to achieve satisfactory alignment of the radius and ulna with congruency of the PRUJ and DRUJ.

FIG 3 • The Bado classification of Monteggia lesions lists four types, depending on the direction of the radial head. In type I lesions the head is anterior to the distal humerus. In type II lesions it is posterior, and in type III lesions it is lateral. Type IV fracture-dislocations involve a dislocation of the radial head associated with a fracture of both the radius and the ulna.
Factors that must be considered include the following:
- Operating room time and availability (ideally within 7 days of the injury)
- Implant and equipment availability (eg, a distraction device)
- Patient factors and patient support factors (in outpatient surgery a supportive family or friend is needed in the early postoperative period)
- Regional versus general anesthesia
- Standard AO planning18 consists of drawing the fragments on transparent paper; superimposing the transparent sheets to align the bones; adding a chosen implant template; and drawing the final outcome corresponding to the expected postoperative radiograph. With experience in fracture management, these steps are intuitive.
- AO principles of internal fixation using plates and screws should be reviewed by the surgeon before attempting internal fixation.

Positioning
- Generally, the patient is positioned supine and the hand table is attached to the main table so the midpoint of the hand table is directly opposite the patient’s shoulder. The shoulder is directly over the adjoining point of the hand and main tables. The arm is abducted to 90 degrees at the shoulder, so the entire arm lies across the midpoint of the hand table.
- In the case of a posterior approach to the proximal ulna, the patient is positioned supine and a pillow is placed across his or her chest and secured with broad paper tape to the operating table. A hand table is used to rest the instruments rather than support the upper extremity. If other forearm fractures are present, however, the arm table may then be available.
- A non-sterile tourniquet is applied to the upper arm before prepping and draping the patient.
- The surgeon usually is seated on the side of the hand table closest to the bone being reduced and stabilized.
- For the anterior approach to the radius, the surgeon is on the side of the table closest to the patient’s head. The forearm is supinated and the elbow extended. For a posterior approach to the radius, the forearm is pronated and the elbow extended.
- For a posterior or subcutaneous approach to the ulna, the elbow is flexed, and the forearm is in a neutral position.

Approach
- The anterior approach to the radius is the standard approach for a radius fracture, but the posterior approach is useful when soft tissue lesions are posterior or the anterior approach is compromised in some way.
- The posterior or subcutaneous approach to the ulna is the common approach. I prefer an anterior approach, however, because the anterior border of the ulna is flat, and, therefore, the plate fits better and is buried deep to the FCU and FDP muscles, reducing plate irritation.
- In general, the incision is 2 cm longer than the implant to be utilized.

ANTERIOR APPROACH TO THE RADIUS
- The anterior approach to the radius, first described by Henry,17 is one of the classic approaches in orthopaedic surgery.
- A straight metallic instrument is placed on the forearm skin, and a C-arm image is taken to judge the position of the fracture. The skin is marked (TECH FIG 1A).
- The biceps tendon and radial styloid are found and marked. The diathermy cord is extended between these points (TECH FIG 1B), and the skin incision is marked centered on the fracture site (TECH FIG 1C).
- The skin is incised, and the superficial tissues are carefully dissected, looking for the lateral antebrachial cutaneous nerve (lateral cutaneous nerve of the forearm) (TECH FIG 1D).
- At the level of the deep fascia, a Raytech (Raytech Industries, Middletown, CT) is used to sweep the soft tissues so that the ulnar edge of the BR can be seen (TECH FIG 1E).
- The deep fascia is incised along the ulnar edge of the BR, and the BR is mobilized and lifted (TECH FIG 1F). The radial nerve and radial artery are found deep to the BR.
- The interval between the radial artery and nerve is opened (TECH FIG 1G,H), exposing the radius.
- The radial aspect of the pronator teres insertion is dissected off the radial shaft, in this case exposing the distal fragment (TECH FIG 1I).
- For more proximal exposure, follow the radial sensory nerve proximally to the place where it and the posterior interosseous nerve bifurcate (TECH FIG 1J).
- The supinator is dissected off the ulnar aspect of the radius to protect the PIN, thus exposing the proximal fragment (TECH FIG 1K).
- The fracture is then reduced and held following AO principles. I prefer six cortices of screw fixation on either side of the fracture and currently use the Synthes Small Fragment Locking Compression Plates as fixation.
TECH FIG 1 • (continued) B. The estimated level of the fracture is marked. The radial styloid and biceps tuberosity are marked, and the diathermy cord is placed between these two points to align the incision. C. The incision is centered on the fracture. The length of the incision depends on fracture comminution, the primary determinant of implant length. The most common implant used is a seven-hole 3.5-mm small fragment plate, and the incision is 2 cm longer than the implant. D. The incision is made and the lateral cutaneous nerve of the forearm is isolated in the superficial fat and preserved. E. The incision is continued to the deep fascia, and the fascia is swept with a Raytech sponge (Raytech Industries, Middletown, CT). The fascia is incised at the ulnar edge of the brachioradialis. F. The brachioradialis muscle and tendon are mobilized. G. The radial artery and radial nerve are located, and the dissection is continued through the fascia between these structures. H. The radius is exposed over the length of the incision. I. The pronator teres insertion is dissected off the radial shaft from the radial aspect of the bone, in this case exposing the distal fragment. J. In this image, the elbow is at the top. For proximal exposure of the radius, the superficial radial nerve is traced proximally to the posterior interosseous branch. K. The elbow is to the right in this image. The supinator is dissected from the ulnar aspect of the radius to protect the posterior interosseous branch of the radial nerve, exposing the proximal fracture fragment.
POSTERIOR APPROACH TO THE RADIUS

- The posterior approach to the radius also is known as the dorsolateral approach or Thompson’s approach.24
- Lister’s tubercle is palpated at the dorsal aspect of the distal radius and marked. The lateral epicondyle of the humerus is palpated and marked.
- The diathermy cord is extended between these bony prominences, and the skin incision is centered on the fracture site.
- A straight metal instrument is placed transverse to the forearm, and fluoroscopy is used to find the level of the fracture site, which is marked with a transverse line.
- The approach uses the theoretical internervous plane between the ECRB (radial nerve) and the extensor digitorum (PIN; TECH FIG 2A).
- The ECRB is part of the mobile wad of Henry,10 which also includes the BR and the ECRL. This usually can be palpated and can help guide placement of the skin incision.
- After the skin incision and superficial dissection are performed, the interval between the ECRB and EDC is opened distally where the abductor pollicis longus transversely spans the forearm (TECH FIG 2B).
- Extending the interval proximally reveals the PIN as it leaves the supinator. Here, it is always accompanied by a leash of vessels, the posterior interosseous artery, and its venae communicantes.
- The surgeon must be cautious at this stage, because as it leaves the supinator, the PIN quickly gives off small branches to the EDC and ECU. The main nerve at

TECH FIG 2 • Posterior approach to the radius. A. After incising the deep fascia, the interval between the extensor carpi radialis brevis and the extensor digitorum communis muscles is identified. B. The interval between the extensor carpi radialis brevis and extensor digitorum is developed. C. Further dissection of the interval proximally with splitting of the aponeurotic origin of the extensors reveals the supinator and the posterior interosseous nerve as it leaves the arcade of Frohse. D. Development of the interval between extensor carpi radialis brevis and extensor pollicis longus reveals the radius distal to the extensor pollicis brevis. Proximally, the nerve can be mobilized where it exits the supinator if required. The posterior interosseous nerve should be identified and protected throughout the whole procedure.
this stage can become relatively small, taking on the appearance of a branch.
- Branches to the long muscles to the thumb also can come off relatively high, giving a fan-like appearance to the nerves and branches (TECH FIG 2C).
- The PIN must be mobilized from the deep head of supinator. The deep head is then split to reach the radius proximally. Fibers of the pronator teres encroach into the field over the middle radius, and distally the abductor pollicis longus must be carefully lifted from the radius to provide room for the plate (TECH FIG 2D).
- The fracture is then reduced and held with a plate and screws. I prefer a locked small fragment plate (Synthes) with six cortices on either side of the fracture.
- The deep fascia is closed, followed by the skin.

**ANTERIOR APPROACH TO THE ULNA**

- The anterior approach is my preferred approach for fixation of the distal two thirds of the ulna, because the plate is buried deep to the FCU and FDP muscles and the anterior surface of the ulna is flat, much like the anterior surface of the radius. This allows for minimal contouring of the plate and minimal overhang of the plate over the borders of the bone.
- The bony landmarks for the incision are the medial epicondyle of the humerus and the ulnar aspect of the pisiform at the wrist.
- As with the radius approach, the diathermy cord can be extended between these two points, a straight metal instrument can be placed on the patient transverse to the long axis of the forearm, and a C-arm image taken to confirm that the incision is centered on the fracture site (TECH FIG 3A).
- The skin incision should be through skin and dermis only.
- If the fracture is relatively distal, care should be taken to avoid injuring the dorsal branch of the ulnar nerve, which exits between the FCU and the ulna about 4 cm proximal to the ulnar head.
- The dissection continues directly deep down to the fascia overlying the FCU muscle. The epimysium and fascia are incised in the line of the incision (TECH FIG 3B), and the

**TECH FIG 3 • Anterior approach to the ulna. A.** The radial incision has been temporarily closed with staples. The medial epicondyle and ulnar aspect of the pisiform are marked. Using a similar technique to that described in Tech Fig 1A, with C-arm fluoroscopy and diathermy lead, the incision is centered on the fracture. **B.** The deep fascia and epimysium of the flexor carpi ulnaris are opened. The fascia is mobilized off the FCU and followed around the ulnar border of the muscle. **C.** The interval between the flexor carpi ulnaris and extensor carpi ulnaris is incised, and the ulna exposed subperiosteally at the level of the fracture site. A Hohmann retractor lifts the FCU. **D.** The flexor digitorum profundus and distally the pronator quadratus are lifted, the fracture is reduced, and a locked small fragment plate applied. (The elbow is to the left and the wrist to the right.)
dissection continues superficial to the FCU muscle ulnarly around onto the ulna (TECH FIG 3C).

- Dissection is continued proximally and distally in the interval between the FCU and ECU, and the fracture is reduced and held with a locked small fragment plate (Synthes; TECH FIG 3D).

- I prefer to use six cortices of fixation on either side of the fracture, but this is not possible within 3 cm of the ulnar head. In this situation, two 2.7-mm mini-fragment plates are placed at right angles to each other.

- The fascia and epimysium are closed together, and skin closure follows.

### POSTERIOR APPROACH TO THE ULNA

- The posterior approach is preferred for fractures of the proximal third of the ulna diaphysis but can be used to expose the entire ulna.
- Distally, the dorsal branch of the ulna nerve is at risk where it exits between the FCU and the ulna, but it usually passes distal to the head of the ulna where it crosses the ECU tendon sheath and the extensor retinaculum.
- The interval for the approach is between the ECU and FCU, which share a short fascial septum along most of the length of the ulna.
- The olecranon and ulnar head can be palpated on all patients, and marked. In slim individuals, the fracture and the entire subcutaneous border of the ulna can be palpated.
- The incision is centered on the fracture, over the subcutaneous border or in line with the olecranon and ulnar head.
- The incision is deepened down to the fascia, and in most cases the epimysium over the ECU is opened. The ulna is exposed in the interval between the ECU and FCU distally and between the FCU and anconeus proximally.
- The fracture is reduced and held following AO principles with a locked small fragment plate. The plate usually is placed on the lateral surface of the ulna.

### FRACTURE REDUCTION AND FIXATION

- Once the bone is reached by an anterior or posterior approach, reduction and fixation are performed.
- Bone-holding clamps allow delivery of the fracture ends into the wound (TECH FIG 4A).
  - For an oblique fracture, a lobster claw bone reduction clamp is placed on either side of the fracture site and angled about 30 degrees to the longitudinal axis of the bone. This allows control of both fracture fragments.
- The fracture fragments are completely cleaned of all soft tissue debris (TECH FIG 4B).
- The fracture fragments are reduced using longitudinal traction and rotation (TECH FIG 4C).
- Once this is accomplished provisional stability is obtained using a bone clamp across the fracture site (TECH FIG 4D).

- The clamp is then lifted and the plate slid beneath and the clamp replaced (TECH FIG 4E).
  - The two screw holes closest to the fracture are filled first, followed by placement of an interfragmentary screw (TECH FIG 4F).
- In both-bone fractures, the second bone is now approached and stabilized in a similar manner before final fixation of the first fracture.
- Locking (TECH FIG 4G) or non-locking screws are placed in the remaining open screw holes, and fixation is complete (TECH FIG 4H).
Chapter 4  ORIF OF DIAPHYSEAL FOREARM FRACTURES

**TECH FIG 4 (continued)**

C. Fracture reduction is obtained using longitudinal traction, and rotation applied through the lobster clamps. D. The lobster-claw bone clamp temporarily secures the fracture site. E. The clamp is lifted and the plate slid beneath. F. One screw on each side of the fracture and closest to the fracture is placed first, followed by an interfragmentary screw. G. Locking guides attached to the proximal two holes allow placement of the locking screws in this Synthes plate. H. Fixation is complete.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Plate irritation on the subcutaneous border of the ulna</th>
<th>- Use an anterior approach on the distal half to two thirds of the diaphysis and place the plate on the anterior (volar) surface. Be very diligent about screw length, because long screws can be felt dorsally. Place the plate more proximally on the lateral surface.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal exposure of the radius and the posterior interosseous nerve</td>
<td>- When in doubt, find the nerve. This is mandatory in a posterior approach, but in an anterior approach follow the superficial radial nerve to its bifurcation proximally.</td>
</tr>
<tr>
<td>The wound is tight and difficult to close.</td>
<td>- Leave the wound open, admit the patient to the hospital for strict elevation, and revisit the operating room in 48 to 72 hours. The wound usually will have closed at that time. This scenario is far more predictable and easier to deal with than a compartment problem and a wound slough.</td>
</tr>
<tr>
<td>Should the fascia be closed?</td>
<td>- In most patients, the fascia can be safely closed, but when it is tense, leave open and consider the above.</td>
</tr>
<tr>
<td>Distal radioulnar joint and forearm rotation</td>
<td>- Always examine the DRUJ for stability at the end of the case, and put the forearm through a range of motion. Then obtain radiographs of the wrist.</td>
</tr>
<tr>
<td>DRUJ instability can be subtle and may not be picked up until late.</td>
<td>- DRUJ problems can occur in the presence of an ulna fracture.</td>
</tr>
<tr>
<td>If the forearm is not able to complete a full ROM (compare opposite forearm), that usually means the radial bow has not been preserved.</td>
<td></td>
</tr>
<tr>
<td>Proximal radioulnar joint</td>
<td>- As with the DRUJ an elbow AP and lateral should be performed at the end of the case.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- The key points in immediate postoperative care are splinting, pain relief, elevation of the extremity, and watching for signs of complications.
- The patient usually receives axillary block anesthesia, which allows him or her to return home pain-free.
- A sugartong splint is placed at the time of surgery and is worn for 2 weeks, at which time the patient returns to the office for a removal of splint and sutures.
- Narcotic pain relief usually is ceased at 2 weeks.
- Radiographs of the wrist, elbow, and forearm are ordered at the 2-week visit.
- At the 2-week visit the patient is referred for physical therapy and rehabilitation to work on ROM of the elbow, forearm, and wrist using active and gentle active assisted exercises.
- From 2 to 6 weeks, the patient is given a 5-pound weight lifting restriction and is placed on restricted work duty, including no repetitive forearm twisting, until union occurs.
- At 6 weeks, simple two-part fractures usually are united and all lifting and twisting restrictions are removed. If there is no evidence of union, the patient is placed on a 20-pound weight restriction until union has occurred.

OUTCOMES

- In two-part fracture of the radius and ulna, patients can expect over 95% problem-free consolidation before 6 months. In a study by Hertel,11 out of 132 patients there were two delayed unions and two non-unions that required reoperation. Plates were removed from 70 patients (53%) at a mean of 33.1 months (range 8–122 months) after the first operation. In this group, there were three refractures (4.3%) occurring at a mean of 8.7 months (range 0–14) after plate removal. In another study by Chapman,9 98% of the fractures united, and 92% of the patients achieved an excellent or satisfactory functional result.
- Nonunion rates are much higher in comminuted fractures, approximately 12%, but it has been shown that bone grafting primarily does not lead to improved outcomes.19

COMPLICATIONS

- Complications of forearm fractures include compartment syndrome,6 malunion,23 nonunion,5 and radioulnar synostosis.4 The rate of infection is about 2%.7
- In a study by Stern23 of 64 adult patients with 87 diaphyseal forearm fractures treated by plating, 18 patients (28%) had a major complication. There was a nonunion rate four times higher for bones plated with four screws than six screws, and screws loosened in three fractures, all involving the ulna. Radioulnar synostosis occurred in seven forearms, and in five of these the forearm injuries were associated with multiple-system trauma involving head injury. Two patients had osteomyelitis.
- The surgeon must be aware of the DRUJ and PRUJ dislocation associated with either an isolated or both-bone forearm fracture.
- With attention to detail, using the appropriate anatomic approach, accurate reduction, and the use of hardware that provides adequate bone stability, outcomes from diaphyseal fractures of the forearm are as good as any in orthopaedic surgery.

REFERENCES

DEFINITION
- In 1934 Galeazzi described a fracture of the junction of the middle and distal thirds of the radius and called attention to the associated dislocation or subluxation of the distal radioulnar joint (DRUJ).
- Garcia-Elias and Dobyns divided DRUJ dislocations into three types:
  - Type I: Pure soft tissue dislocations
  - Type II: Intra-articular fracture dislocations where there is a fracture involving the joint surface of the sigmoid notch of the radius
  - Type III: Extra-articular DRUJ fracture dislocations for subdivided
- Type III fracture-dislocations can be subdivided as follows:
  - IIIa: abnormal joint surface orientation; usually involve fractures of the distal two thirds of the radius without complete longitudinal disruption of the forearm
  - IIIb: radioulnar length discrepancy; fractures of the distal two thirds of the radius with complete longitudinal disruption of the forearm; also known as Essex-Lopresti injuries
- In this chapter, the term Galeazzi fracture-dislocation refers to a type IIIa (extra-articular) fracture of the distal two thirds of the radius with any disruption at all of the congruency of the DRUJ due to soft tissue injury.
- Management of the fractured radius is discussed elsewhere (see Chaps. HA-8 to HA-13). A fracture of the ulna styloid commonly is associated with a distal radius fracture. Reduction and fixation of this fracture is covered in Chapter HA-14.

ANATOMY
- During forearm rotation a complex interaction occurs between the radius and the ulna.
- From about 50 degrees pronation to 50 degrees supination there is a nearly pure rotation of the radius around the ulna, with the center of rotation through the middle of the ulna head. The ulna head moves out of the way of the radius by virtue of a 9-degree varus-valgus motion that occurs at the elbow.
- At 50 degrees supination or pronation, a translational slide of the radius occurs on the ulna at the DRUJ.
- In full pronation the radius slides volar, making the ulna head prominent dorsally. The opposite takes place in full supination.
- The head of the ulna is the keystone of the DRUJ. It is flattened distally adjacent to the triangular fibrocartilage disc and rounded radially articulating with the sigmoid notch of the radius. The sigmoid notch of the radius is only mildly concave but is functionally deepened by a horseshoe-shaped labrum. A flimsy, somewhat loose capsule attached to this labrum allows the nearly 180 degrees of rotation required of the forearm.
- The capsule is relevant only when it is thickened, causing a contracture and limitation in forearm motion.
- Considerable incongruity exists between the curvature of the sigmoid notch and the radius. The sigmoid notch of the radius is only mildly concave but is functionally deepened by a horseshoe-shaped labrum. A flimsy, somewhat loose capsule attached to this labrum allows the nearly 180 degrees of rotation required of the forearm.
- The triangular fibrocartilage is a specialized structure, part meniscus (to allow compression accommodating the relative shortening of the radius in pronation) and part ligament. It has palmar and dorsal fibrous thickenings known as the palmar and dorsal radioulnar ligaments. These attach to the distal palmar and dorsal rims of the sigmoid notch as separate bundles, and have superficial fibers that attach to the ulna styloid and deep fibers that criss-cross to form a weave as they attach to the foveal fossa of the distal ulna adjacent to the head. These ligaments, along with the distal aspect of the interosseous membrane, are the most important primary stabilizers of the DRUJ.
- During rotation, the deep interdigitating fibers create a screw home mechanism, similar to the cruciate ligaments of the knee.
- In pronation the deep fibers of the dorsal radioulnar ligament are taut and the superficial fibers are lax, whereas the superficial fibers of the palmar radioulnar ligament are taut and the deep fibers are lax.
- The opposite is true in supination. Avulsion of the foveal attachment is common in Galeazzi injuries.

PATHOGENESIS
- The most common mechanism of injury is an axial load in pronation, associated with wrist hyperextension.
- Acute dislocations of the DRUJ also can occur in supination. This usually happens after a fall with a rotating body on an outstretched hand, but also can occur in the workplace when the forearm is twisted by rotating machinery.
- The direction of force is radial to ulnar and proximal to distal, through the radius fracture down the interosseous membrane, and through the DRUJ.
- The DRUJ zone of injury includes the capsule, avulsion of the foveal attachment of the palmar and dorsal radioulnar ligament, and tear of the extensor carpi ulnaris (ECU) subsheath.

NATURAL HISTORY
- Hughston, in 1957, brought attention to the poor outcome of these fracture-dislocations without surgical intervention. The criteria used for a perfect result were very strict, leading to a judgment of poor results in 92% of cases. This injury complex has been termed “the fracture of necessity,” meaning open reduction and internal fixation of the radius is necessary for a good result.
- Milic drew attention to the significance of the DRUJ injury. He advocated reduction and percutaneous K-wire fixation, noting poor results otherwise.
Experiments have shown that with an artificial osteotomy of the radius, up to 5 mm of radial shortening occurs. Shortening of more than 10 mm does not occur unless both the interosseous ligament and the triangular ligament are sectioned. Alexander and Lichtman added another subcategory of Galeazzi injury, those in which closed reduction cannot be achieved. The natural history of injuries in this subcategory depends on the recognition and appropriate management of neurologic and vascular complications, in addition to the adequacy of reduction and the degree of DRUJ instability. The DRUJ component of Galeazzi fracture dislocations, after anatomic reduction and fixation of the radius, can be considered simple (ie, able to be reduced closed) or complex (ie, requiring open reduction). Once reduced, the DRUJ is re-examined and judged stable or unstable.

PATIENT HISTORY AND PHYSICAL FINDINGS

Lister stated “nothing influences the eventual recovery of hand function more than the mechanism and the force of the injury.” This is certainly true for forearm injuries. Accurate anatomic bone anatomy is required for perfect functioning of the forearm during rotation. Patients with a Galeazzi fracture-dislocation usually present acutely to an emergency department due to the severity of the pain. Three common mechanisms lead to Galeazzi injuries: falls, industrial accidents, and motor vehicle trauma.

It is important to elicit information regarding the degree of energy associated with the injury. A fall off a ladder from a height or from a roof is associated with much greater energy than a ground-level fall. In industrial accidents, the worker will tend to use technical jargon in referring to machinery, but the examiner must obtain a layman’s description of the machinery and get an accurate idea of the force the machinery will generate. Any motor vehicle accident is associated with high energy. Any crushing component to the injury must be elicited. Initially, the fracture pain may overwhelm both the patient and the examiner. Reassessment of the patient following a radiograph showing a radius fracture in the presence of an intact ulna should direct the examiner to the DRUJ as a site of pathology. The patient must be asked about neurologic symptoms in the hand, in particular numbness and tingling in the median nerve distribution. Acute carpal tunnel syndrome and forearm and hand compartment syndromes must be ruled out in the Emergency Department. Forearm swelling and tenderness with dorsal prominence of the distal ulna (ie, caput ulna deformity) will be observed. The entire carpus and the elbow should be palpated to rule out any longitudinal forearm injury (ie, Essex Lopresti injury). Forearm, wrist, and digital motion often are extremely limited due to pain.

FIG 1 • Intraoperative distal radioulnar joint (DRUJ) shuck test. The head of the ulna is held with a chuck pinch grip, and the wrist and distal radius are held with a span grasp with the thumb extended across the wrist joint. The radius is held firmly and the ulna is moved back and forth in a palmar-dorsal direction. The test is done first in neutral (A), then in supination (B) and in pronation (C).
A sensory examination using static two-point testing is the most reliable Emergency Department examination for sensation. Vascularity is best assessed by examination of radial and ulnar pulses together with capillary refill in the fingers.

- Often the fingers are pale in this situation. A needle stick to the digital pulp should cause bright red bleeding.
- The fingers must be passively extended to rule out a forearm compartment syndrome. Inability to extend the fingers combined with tense forearm swelling are the best indicators of a compartment syndrome, which if present, necessitates urgent surgery.
- Patients presenting late, in the office, usually complain of ulnar-sided wrist pain, pain with activities requiring pronopronation, and DRUJ instability. In these situations the radius often is malunited or there is unrecognized bowing of the ulna.
- The DRUJ is examined initially by direct observation, looking for a caput ulna deformity. Palpation begins at the radial head, along the intersosseous membrane to the ulnar head. Tenderness at the DRUJ proper is elicited by palpating the head of the ulna with the examiner’s thumb and sliding the thumb off the head in a radial direction. Tenderness just distal to the head dorsally is associated with a dorsal tear of the triangular fibrocartilage complex (TFCC). A volar tear of the TFCC is tender on palpation of the ulnar head between the FCU and ECU and when the examiner slides his or her thumb distally over the head.
- The fingers must be passively extended to rule out a forearm compartment syndrome. Inability to extend the fingers combined with tense forearm swelling are the best indicators of a compartment syndrome, which if present, necessitates urgent surgery.
- Patients presenting late, in the office, usually complain of ulnar-sided wrist pain, pain with activities requiring pronopronation, and DRUJ instability. In these situations the radius often is malunited or there is unrecognized bowing of the ulna.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Imaging of the patient with a suspected Galeazzi injury consists of plain radiographs of the elbow, forearm, and wrist.
- The forearm views help in preoperative planning for fixation of the radius fracture.
- The wrist views help to determine the degree of disruption to the DRUJ. On a posteroanterior (PA) view of the wrist, the degree of ulna shortening has been shown to differ depending on which structures are torn at the DRUJ. Less than 5 mm of positive variance of the ulna indicates that TFCC disruption is unlikely; more than 1 cm indicates intersosseous membrane disruption.
- Mino et al described a technique for interpreting the lateral wrist radiograph whereby the radial styloid is aligned with the center of the lunate and an assessment of the overlap of the radius and ulna is made. The head of the ulna should be completely obscured by the radius. If only part of the ulna head is obscured by the radius, then there is subluxation of the head, and if the ulnar head is clearly seen, then the joint is dislocated. In the operating room a C-arm image in neutral forearm rotation is obtained with the radial styloid in the mid-lunate position to interpret DRUJ subluxation.
- A CT scan is very useful in measuring the degree of subluxation or dislocation of the DRUJ. A CT scan in the acute situation can be useful in interpreting the degree of DRUJ congruity, but the test is more often performed in the setting of a chronic injury.
- This is most reliably interpreted by the radioulnar ratio (FIG 2), calculated as follows:
  - The center of the ulnar head is found using concentric circles.
  - A line similar to that used in the epicenter method is drawn from the dorsal and volar margins of the sigmoid notch (line A-B).
  - A line perpendicular to this line is drawn to the center of the ulnar head (line C).
  - The AD:AB ratio is the radioulnar ratio. The normal ratios are 0.5 to 0.71 for pronation, 0.42 to 0.58 for neutral, and 0.19 to 0.55 for supination.

---

**Table 1**  
**Shuck Test**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
<th>Pathogenesis/Diagnosis</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>&lt;0.5 cm motion at extremes; firm endpoint</td>
<td>Probable intrasubstance tearing of either the PRUL or DRUL</td>
<td>Cast in neutral rotation</td>
</tr>
<tr>
<td>II</td>
<td>&gt;0.5 cm motion at extremes; soft endpoint but no dislocation</td>
<td>Usually associated with foveal avulsion of the TFCC; can be confirmed by arthroscopy of the DRUJ and repaired. No rupture of the distal intersosseous membrane.</td>
<td>Cast in midpronation</td>
</tr>
<tr>
<td>III</td>
<td>Reduced joint seen before stress, with dislocation of the DRUJ at extremes</td>
<td>Rupture of distal aspect of intersosseous membrane</td>
<td>Repair foveal avulsion as for grade II; pin DRUJ in midsupination.</td>
</tr>
<tr>
<td>IV</td>
<td>Dislocated joint</td>
<td>“Mushy” feeling on stressing joint</td>
<td>Reducible with rotation, consider malposition of radius fragments if easily dislocatable. If truly mushy throughout forearm rotation, there is interposition of soft tissue, and open treatment is required.</td>
</tr>
</tbody>
</table>

DRUJ, distal radioulnar joint; DRUL, distal radioulnar ligament; PRUL, proximal radioulnar ligament.
The DRUJ is unstable:

- The following information is considered in deciding whether fixation of the radius are discussed later in this chapter.
- Options for nonoperative management of the DRUJ after fixation of the radius are discussed later in this chapter.

NONOPERATIVE MANAGEMENT

- The only time the radius is not internally fixed is when other patient factors make such surgery unsafe.
- In the Emergency Department, the longitudinal injury to the forearm should be reduced and held in a splint.
- The reduction maneuver is performed under conscious sedation with the thumb and index fingers placed in finger traps and 10 pounds of traction applied.
- A sugar tong or long-arm splint with an interosseous mold is applied.
- Radiographs must be obtained to confirm reduction.
- If the DRUJ is reduced, then surgery can be delayed for up to 2 weeks. If the DRUJ remains dislocated, surgery should be performed within 72 hours.
- This interval allows an MRI or CT scan to be ordered and interpreted to plan for the operative procedure.
- Options for nonoperative management of the DRUJ after fixation of the radius are discussed later in this chapter.

SURGICAL MANAGEMENT

- The key to the management of a Galeazzi fracture is determination of the degree of injury to the DRUJ. It can be classified
- Triangular fibrocartilage complex injury. Any of the following structures may be injured: fibrocartilage disc, palmar and dorsal radioulnar ligaments, ulnotriquetral ligament, ulnolunate ligament, ECU subsheath.
- Lunotriquetral ligament: isolated and as part of either a perilunate dislocation or a longitudinal wrist
- Essex-Lopresti injury
- Monteggia fracture-dislocation
- Elbow fracture-dislocation
- Stress and pathologic fractures of the radius

DIFFERENTIAL DIAGNOSIS

- The differential diagnosis of ulnar wrist pain in the presence of a radius fracture includes:
- Fracture of the ulna: shaft, metaphysis, head, styloid
- Triangular fibrocartilage complex injury. Any of the following structures may be injured: fibrocartilage disc, palmar and dorsal radioulnar ligaments, ulnotriquetral ligament, ulnolunate ligament, ECU subsheath.
- Lunotriquetral ligament: isolated and as part of either a perilunate dislocation or a longitudinal wrist
- Carpal fractures: triquetrum, hamate, lunate
- Essex-Lopresti injury
- Monteggia fracture-dislocation
- Elbow fracture-dislocation
- Stress and pathologic fractures of the radius

NONOPERATIVE MANAGEMENT

- The only time the radius is not internally fixed is when other patient factors make such surgery unsafe.
- If the DRUJ is reduced, then surgery can be delayed for up to 2 weeks. If the DRUJ remains dislocated, surgery should be performed within 72 hours.
- This interval allows an MRI or CT scan to be ordered and interpreted to plan for the operative procedure.
- Options for nonoperative management of the DRUJ after fixation of the radius are discussed later in this chapter.

SURGICAL MANAGEMENT

- The key to the management of a Galeazzi fracture is determination of the degree of injury to the DRUJ. It can be classified
- As stable, unstable but reducible, or unstable and irreducible.
- The following information is considered in deciding whether the DRUJ is unstable:
- If, on the initial pre-reduction PA radiograph, the ulna variance is more than 5 mm positive
- If frank dislocation remains after evaluation of the post-reduction lateral radiograph using the Mino technique (discussed under Imaging And Other Diagnostic Studies)
- In the Emergency Department, the longitudinal injury to the forearm should be reduced and held in a splint.
- The reduction maneuver is performed under conscious sedation with the thumb and index fingers placed in finger traps and 10 pounds of traction applied.
- A sugar tong or long-arm splint with an interosseous mold is applied.
- Radiographs must be obtained to confirm reduction.
- If the DRUJ is reduced, then surgery can be delayed for up to 2 weeks. If the DRUJ remains dislocated, surgery should be performed within 72 hours.
- This interval allows an MRI or CT scan to be ordered and interpreted to plan for the operative procedure.
- Options for nonoperative management of the DRUJ after fixation of the radius are discussed later in this chapter.

SURGICAL MANAGEMENT

- The key to the management of a Galeazzi fracture is determination of the degree of injury to the DRUJ. It can be classified
- As stable, unstable but reducible, or unstable and irreducible.
- The following information is considered in deciding whether the DRUJ is unstable:
- If, on the initial pre-reduction PA radiograph, the ulna variance is more than 5 mm positive
- If frank dislocation remains after evaluation of the post-reduction lateral radiograph using the Mino technique (discussed under Imaging And Other Diagnostic Studies)
- A foveal avulsion of the TFCC is noted on the preoperative MRI scan.
- Intraoperative fluoroscopic examination of the DRUJ after fracture fixation
- Intra-operative C-arm assessment includes PA and lateral views in neutral rotation. In most cases the DRUJ should be reduced following fixation.
- If increased ulna variance, joint diastasis, or subluxation of the ulna head is seen, the first possibility to consider is a malreduction of the radius fracture.
- Most importantly, instability is determined by intraoperative physical examination after fracture fixation.
- Grade I: less than 0.5 cm motion at extremes, with a firm endpoint. Probable intrasubstance tearing of either the proximal radioulnar ligament or the DRUJ. Management is in a cast in neutral rotation.
- Grade II: more than 0.5 cm motion at extremes, with a soft endpoint but no dislocation. This injury usually is associated with foveal avulsion of the TFCC, which can be confirmed by arthroscopy of the DRUJ and repaired. The distal interosseous membrane is not ruptured. Cast in mid-supination.
- Grade III: reduced joint prior to stress with dislocation of the DRUJ at extremes. Requires rupture of the distal aspect of the interosseous membrane. Repair the foveal avulsion as in grade II and pin the DRUJ in mid-supination.
- Grade IV: dislocated joint. “Mushy” feeling with stressing joint. This joint may be reducible with rotation; consider malposition of radius fragments if easily dislocatable. If truly mushy throughout forearm rotation, then there is interposition of soft tissue, and open treatment is required.

POSITIONING

- The patient is positioned supine on the operating table with a hand table, and the affected extremity is abducted at the shoulder and extended across the table.
- The hand table is positioned so that it adjoins the main table at the level of the shoulder. When the extremity is abducted 90 degrees, it lies in the mid portion of the table.
- A tourniquet is applied at the mid-humerus level, and a layer of towels is placed between the humerus and the arm. A layer of padding is placed on the upper arm just proximal to the elbow, and the arm is taped firmly to the hand table. This allows traction to be applied along the axis of the forearm for arthroscopy.
- Following fixation of the radius, finger traps are applied to the long and index fingers, and 10 to 12 lb of traction is applied.

APPROACH

- The DRUJ can be approached using arthroscopy, a mini-open technique, or an open dorsal approach.

ARTHROSCOPICALLY ASSISTED REPAIR OF FOVEAL TFCC AVULSIONS

Arthroscopy of the Distal Radioulnar Joint

- A 1.9-mm scope and 2.0-mm shaver are the working instruments for DRUJ arthroscopy.
- Two principal portals are used.
- The dorsal-proximal DRUJ (PD-DRUJ) portal is located in the axilla of the joint, just proximal to the sigmoid notch of the radius and the flare of the metaphysis of the ulna. It is easily palpated with the wrist supinated, which relaxes the dorsal capsule and facilitates introduction of the trocar and scope sheath.
- The joint is insufflated with about 3 mL of saline (which helps as a direction guide), the skin is incised with a no. 15 blade, and a hemostat pierces the deep fascia and capsule, followed by scope sheath insertion.
After initial joint penetration, the scope is withdrawn slightly until the sigmoid notch and neck of the ulna are brought into view.

Systematically, the steps of a diagnostic arthroscopy are as follows:
- Evaluate the sigmoid notch while in supination.
- Look down into the axilla of the joint (loose bodies sometimes hide here).

The scope is then swept distally over the head of the ulna and pushed anteriorly between the disc of the TFCC and the seat of the head while relaxing the rotation of the forearm to neutral.

Rotate into pronation and visualize the anterior compartment of the DRUJ.

Then slightly withdraw the scope and visualize the foveal region.

The distal DRUJ (DDRUJ) portal is located just distal to the seat of the ulna between the fifth and sixth dorsal compartments. It is about 5 mm proximal to the 6R portal.
- The DDRUJ portal allows entry of the scope between the disc of the TFCC and the head of the ulna.
- A 21-gauge hypodermic needle is inserted as a direction finder with the scope in the PDRUJ portal.
- A probe can be inserted to stress the undersurface of the TFCC disc and ligament insertion into the fovea.
- A shaver and other instruments also can be introduced through the DDRUJ portal.

**Repair of Foveal TFCC Avulsion**
- Diagnostic arthroscopy of the radiocarpal joint may reveal a peripheral tear in the TFCC.
- Mid-carpal arthroscopy is performed primarily to evaluate the integrity of the lunotriquetral ligament.
- DRUJ arthroscopy shows the status of the proximal surface of the TFCC and confirms a foveal tear of the TFCC (TECH FIG 1A).
- A shaver is introduced through the DDRUJ portal to débride this area (TECH FIG 1B), and the mini C-arm is brought in to confirm position over the fovea.
- A curette is used to freshen the ulna at the foveal insertion.
- Using a C-arm and arthroscopic guidance, a 1.8-mm drill hole is made (TECH FIG 1C–E).
- The DDRUJ portal is then enlarged to about 1 cm in size with the drill bit in place (TECH FIG 1F).
- The deep fascia and capsule are opened in line with the incision. A Mitek Mini QuickAnchor (Mitek Products, Norwood, MA) is inserted into the drill hole (TECH FIG 1G).
- Each suture end is placed through the TFCC, and the needle is brought out the 6R window made in the radiocarpal capsule.
- The suture is then tied, pulling the TFCC back to its anatomic position.
- A DRUJ shuck test is performed to ensure restoration of stability, the wounds are closed, and a long-arm splint is added in mid-supination.

**TECH FIG 1** • Diagnostic arthroscopy and distal radioulnar joint (DRUJ) arthroscopy-assisted repair of the triangular fibrocartilage complex (TFCC). A. Foveal avulsion tear. B. Hand placement and portal position using 1.9-mm scope and 2.0-mm shaver. C. Hand placement for drilling before Mitek anchor insertion. D. Position of the mini–C-arm, which is brought in to confirm placement of the drill bit in the fovea for insertion of the Mitek anchor. E. C-arm image confirming placement of the drill bit at the foveal insertion of the TFCC. F. The distal DRUJ portal is opened to about 1 cm, and dissection is carried down through the deep fascia in line with the incision. Care is taken to avoid the dorsal branch of the ulnar nerve. (continued)
ARTHROSCOPICALLY ASSISTED REPAIR OF FOVEAL TFCC AVULSION WITH RADIOCARPAL ARTHROSCOPY AND OPEN TECHNIQUES

Mini-Open Approach

- In the mini-open approach, a diagnostic arthroscopy of the radiocarpal joint is carried out.
- The 6R portal should be made in a longitudinal orientation. This is a guide for creation of a longitudinal 2- to 3-cm incision incorporating the 6R portal.
  - The incision usually is about 5 mm distal to the 6R portal and 2 cm proximal.
  - The dorsal branch of the ulnar nerve is found in the soft tissues at the distal end of the incision and is preserved.
- The deep fascia is incised in line with the incision.
- A 21-gauge needle is inserted through the capsule of the DRUJ into the interval between the head and the proximal edge of the TFCC.
- The joint capsule is incised from just proximal to the TFCC disc to the metaphysis of the ulna.
- A 21-gauge needle is then inserted just distal to the TFCC disc into the radiocarpal joint.
- The radiocarpal joint capsule is incised transversely about 6 or 7 mm (not quite to the lunate).

- The 6R portal also can be enlarged to see the distal aspect of the TFCC disc. This gives the surgeon good visualization of both surfaces of the TFCC disc and associated ligaments.

Repair of Foveal TFCC Avulsion

- The avulsed TFCC is identified and débrided.
- The ulnar fovea is roughened with a curette and drilled with a 1.8-mm bit, after which a single Mitek Mini QuickAnchor (Mitek Products, Norwood, MA) is inserted into the drill hole.
- The torn ulnar border of the TFCC is then advanced and sutured down to the ulnar fovea (TECH FIG 2). The suture on the Mitek Quick Anchor is double ended. Each needle is passed from a proximal to distal direction about 5 mm apart, and then the needles are cut off and the sutures tied within the radiocarpal joint. I use a one-handed suture-tying technique. No additional suturing is necessary.
- The capsule, retinaculum, and skin are closed, and a sterile dressing and long-arm splint are applied.

TECH FIG 1 (continued) G. C-arm image confirming placement of the Mitek anchor.

TECH FIG 2 • Sotereanos triangular fibrocartilage complex repair. The technique involves a 3-cm incision centered on the distal aspect of the head of the ulna. Small windows are created in the capsule of the DRUJ and the radiocarpal joint, and the foveal tear of the TFCC is identified. (continued)
**TECH FIG 2** (continued) C. The TFCC is lifted and the fovea cleared of soft tissue debris. A bone anchor (usually a 2-0 suture mini-Mitek) is placed in the head of the ulna at the fovea. D. The sutures are passed through the TFCC. E. The sutures are tied, repairing the TFCC back to its foveal insertion.

---

**OPEN DRUJ ARTHROTOMY AND TFCC REPAIR**

**Two-Window Exposure of the DRUJ**

- The forearm is pronated and extended at the elbow.
- A dorsal incision is made beginning 3 cm distal to the ulnar styloid.
  - The incision is carried proximally at 45 degrees to the long axis of the forearm in a radial direction until it reaches the dorsal aspect of the radius at the sigmoid notch.
  - At this point it is continued proximally, longitudinally down the forearm for about 7 cm ([TECH FIG 3A](#)).
- The soft tissues are spread, taking care to preserve the dorsal sensory branch of the ulnar nerve, which passes onto the dorsum of the hand about 1 to 2 cm distal to the ulna styloid.

- At the level of the deep fascia the soft tissues are swept off the fascia in the region of the ulna head ([TECH FIG 3B](#)).
- The distal aspect of the antebrachial fascia and the proximal 50% of the extensor retinaculum are incised longitudinally between the EDM and ECU tendons, and an ulnarly based flap is created ([TECH FIG 3C](#)).
- A 21-gauge needle can be inserted to assess the proximal and distal margins of the TFCC disc.

**TECH FIG 3** Open dorsal DRUJ approach.

A. Marker of initial incision. The incision is made 3 cm distal to the ulnar styloid at a 45-degree angle toward the sigmoid notch, then continued parallel to the interosseous interval proximally up the forearm. B. The dissection is taken down to the deep fascia. On the fascia, the fifth compartment is clearly visualized. C. The deep fascia is opened with an L shape along the border of the fifth compartment and the proximal edge of the extensor retinaculum. (continued)
The capsule of the DRUJ is incised proximal to the TFCC disc to the point where it blends with the periosteum over the metaphysis of the ulna (TECH FIG 3D).

The ulnocarpal joint capsule is opened to the lunotriquetrum.

Both capsular incisions are in line with retinaculum–fascial incision.

The TFCC disc and associated ligaments, the DRUJ, and ulnar aspect of the radiocarpal joint can be inspected.

A second, more ulnar window to the distal ulna can be made by sharp dissection to the ulna styloid and carried proximally parallel with the ECU sheath (TECH FIG 3E).

Care is taken to avoid opening the EDM and ECU sheaths.

TFCC Repair

The peripheral foveal avulsion is débrided, and the fovea freshened with a curette.

Two drill holes are made with 0.045-inch K-wires at a 45-degree angle about 1 cm from the articular surface of the head of the ulna, directed from the medial cortex of the ulna and exiting at the ulnar fovea.

The holes are parallel, beginning 1 cm apart, and converge toward the fovea.

A transverse arthrotomy is made in the radiocarpal capsule at the distal edge of the TFCC disc.

Three separate loops of a 3-0 braided nylon suture are passed through one hole, through the peripheral TFCC, and back out the other hole, and tied individually over the medial ulna.

The capsulotomy incisions are closed first, then the retinaculum is closed, and finally the skin is closed.

Two 0.062-inch K-wires are placed through the ulna and into the radius in neutral position (TECH FIG 4).

The capsule, retinaculum–fascia, and skin are closed in layers.

Open DRUJ Arthrotomy and TFCC Reconstruction Using a Palmaris Graft

Rarely, the TFCC can be completely shredded in a high-energy injury. In this instance the TFCC is excised and reconstructed using a palmaris graft.
PEARLS AND PITFALLS

Assessment of DRUJ instability
- The initial PA view of the wrist will show more than 5 mm of ulna shortening. The initial lateral radiograph will show dorsal subluxation of the ulna. A preoperative MRI scan will show increased signal (white) in the TFCC and an avulsion of the TFCC at the fovea. A positive shuck test will be present intraoperatively (this is the most important test). A subluxed ulna will be seen in the lateral intraoperative C-arm view.

Irreducible DRUJ after radial fixation
- Consider lack of anatomic reduction of the radius. Radial bow will not have been fully restored. This is especially prevalent in the segmental or comminuted radius. If convinced the radius is anatomic, then explore the DRUJ with open technique. The ECU and the extensor digitis minimi of the ulnar styloid are commonly in the joint.

Difficulty interpreting DRUJ shuck test
- Ensure forearm is in full supination or pronation. There should be no motion at the DRUJ between the radius and the ulna. If there is any motion then there is likely to be instability, and at the very least, a long-arm cast in mid-supination should be applied.

Difficulty in getting into the joint for DRUJ arthroscopy
- Reduce traction to about 5 lb. Use a 1.9-mm scope, and use a 21-gauge needle and saline to insufflate the joint. Place the forearm in supination. Push the trocar into the neck of the ulna (ie, between the radius and ulna).

POSTOPERATIVE CARE
- All of the following protocols assume that rigid and stable fixation of the radius fracture has been obtained.
  - Stable DRUJ
    - The patient is placed in a sugar-tong splint for 2 weeks, and is given a Carter block arm pillow for strict elevation and encouragement of finger and thumb motion.
    - At 2 weeks, the patient returns to the office for suture and splint removal.
    - The patient is referred to a hand therapist for active, passive, and gentle resisted motion up to 10 lbs resistance.
    - Motion of all joints from the elbow distally is encouraged.
    - Further resistance and weight bearing depend on union of the radius.
    - Usually, union occurs by 6 weeks and restrictions are lifted.
    - Return to work status depends on the level of repetition and lifting required by the patient’s job.
  - Rehabilitation following bone anchor fixation of a foveal avulsion of the TFCC and full palmaris graft reconstruction
    - Long-arm splint, elbow at 90 degrees, forearm in mid-supination, wrist neutral; fingers not included.
    - At 2 weeks the patient returns to the office for suture removal and the arm is placed in a cast in the same position.
    - Four weeks later (ie, 6 weeks postoperatively), the cast is removed and active gentle passive motion is begun to all joints from the elbow distally.
    - At 12 weeks postoperatively, graduated lifting activity is begun, and continues for 6 more weeks.
    - At week 18 all restrictions are removed.
    - Open foveal repair and K-wire
      - At 6 weeks, K-wires are removed.
      - Begin protocol as for bone anchor fixation.

OUTCOMES
- The key to a successful outcome of acute Galeazzi fracture dislocations is accurate reduction and rigid fixation of the radius along with recognition and appropriate repair or reconstruction of the disrupted DRUJ. Conservative management seems to be successful only in children.
  - In a classic article by Mikic, conservative management in adults resulted in failure in 80% of cases. The results of operative treatment were much better, and the conclusion was that rigid internal fixation is necessary for the dislocation as well as the fracture.
  - So-called “isolated” fractures of the radial diaphysis, where there is less than 5 mm of positive ulna variance, are more common than true Galeazzi fractures. Fractures without identifiable radioulnar disruption can be treated without specific treatment of the DRUJ and with immediate mobilization. In this situation, patients with anatomic fracture reduction have minimal sequelae and better or equal functional results than patients with imperfect reduction.
  - In a series of 50 Galeazzi fracture dislocations treated by early open reduction and internal fixation, Mohan et al found, at 1 year, 40 good, 8 fair, and 2 poor results. Their conclusion was that early open reduction and rigid internal fixation re-establishes the normal relation of the fractured fragments and the DRUJ without repair of the ligaments. Thus, in many situations, ligament repair is unnecessary. (However, in Mohan et al’s series, 1 in 5 had a less than good result.)
  - Rettig and Raskin, in a more recent series, found that the more distal the fracture the greater the likelihood of DRUJ disruption. In this series, 12 out of 22 fractures within 7.5 cm of the midarticular surface of the distal radius had intraoperative DRUJ instability, whereas only one of 18 more proximally were unstable. Their conclusion was that a high index of suspicion, early recognition, and acute treatment of DRUJ instability will avoid chronic problems in this complex injury.
  - This high index of suspicion will lead to the recognition that dislocations of the DRUJ associated with fractures of the forearm often are irreducible. These have been termed “complex” DRUJ dislocations: dislocations characterized by obvious irreducibility, recurrent subluxation, or “ mushy” reduction caused by soft tissue or bone interposition.
  - With the advent of internal fixation of the radius, most Galeazzi fractures are predictably reduced. It is mandatory that the DRUJ be evaluated and managed according to the degree of instability to the joint. A high index of suspicion means the outcome is associated more with the degree of energy involved in the injury than with any inability on the part of the surgeon to care for the DRUJ appropriately.

COMPLICATIONS
- The most common complication of a Galeazzi fracture is malunion of the radius and residual DRUJ instability, due to
malrotation and residual angulation of the radial shaft. In most cases a DRUJ-stabilizing tenodesis cannot restore the joint, and a corrective osteotomy is required.

- A preoperative three-dimensional CT reconstruction of the bones of the entire forearm is very helpful in this situation.
- Management of a missed dislocation depends on the timing of presentation.
  - If less than 10 weeks after the injury, open reduction and repair usually is possible.
  - After 10 weeks, reconstruction with ligament grafting is required.
- The incidence of radius nonunion is directly related to the number of screws used: the rate is four times higher for bones plated with four screws compared to those plated with five or more screws.
- Radioulnar synostosis may be seen, particularly in patients with multiple system trauma involving head injury.
- Osteomyelitis may develop in open and crush injuries.
- Nerve palsies, including the anterior interosseous and ulna nerves, have been associated with Galeazzi fractures, and acute carpal tunnel syndrome is a common complication, particularly in crush and high-energy injuries.
- Compartment syndrome of the forearm also is a known complication.
- Osteoarthritis of the DRUJ is a long-term complication and can be managed by arthroscopy, interposition arthroplasty, ulna shortening, ulna head replacement, or total joint arthroplasty, depending on severity of the injury and age of the patient.
- Complications in Galeazzi fracture-dislocations can be minimized with attention to detail, in particular accurate anatomic reduction of the radius fracture, thorough assessment and repair of instability of the DRUJ, and appropriate postoperative rehabilitation.

REFERENCES

11. Kleinman WB. Repair of chronic peripheral tears/avulsions of the tria
18. Moore TM, Lester DK, Sarmiento A. The stabilizing effect of soft
25. Stahl S, Freeman S, Volpin G. Anterior interosseous nerve palsy asso
DEFINITION
- Malunion of the radial or ulnar shaft can lead to pain, loss of motion, loss of strength, and instability at the level of the wrist or elbow.
- Malrotation, angulation (with narrowing of the interosseous space between the radius and ulna), shortening, and loss of the radial bow have been shown in various studies to lead to decreased functional outcomes.4,5,9,10,12
- Arthritis has been reported at the level of the proximal radioulnar joint (PRUJ) with longstanding malunions, although the distal radioulnar joint (DRUJ) is most commonly affected by forearm malunions.11

ANATOMY
- The forearm can be thought of as a ring, connected at the PRUJ, the interosseous membrane, and the DRUJ (FIG 1).
- Force transmission occurs through the interosseous membrane from the radius distally to the ulna proximally.
- Radius
  - The radius lies parallel to the ulna in supination. With pronation, it rotates around the ulna while the ulna maintains its position throughout forearm rotation.
  - The radius shaft is triangular in cross section, with the apex toward the attachment of the interosseous membrane.
  - It contains three surfaces: anterior, lateral, and posterior.
- The shaft possesses a gentle bow, with the volar surface concave and the dorsal and lateral surfaces convex.1
- Schemitsch and Richards5 devised a formula that locates the apex and defines the magnitude of the radial bow for each individual (FIG 2).
- Ulna1
  - The ulna is a long bone that has a triangular cross section in the proximal two thirds and a circular cross section distally.
  - It possesses three surfaces: anterior, posterior, and medial.
  - The proximal half of the shaft is slightly concave volarly. The distal half is relatively straight.
- The PRUJ consists of the radial head, the radial notch, the annular ligament, and the quadrate ligament.
- The DRUJ consists of the sigmoid notch, the ulnar head, the dorsal and volar radioulnar ligaments, the extensor carpi ulnaris (ECU) subsheath, and the triangular fibrocartilage complex (TFCC).

PATHOGENESIS
- Both-bone forearm fractures occur through a variety of mechanisms, including indirect trauma (such as falls on an outstretched arm or motor vehicle accidents) and direct trauma (such as blows to the forearm).

FIG 1 • Lateral projection of the radius and ulna. Relationship of the interosseous membrane to the radius and ulna during forearm rotation. The fibers of the interosseous membrane are longest with the forearm in neutral position and shorten in both pronation and supination.

FIG 2 • Measurement of the location and magnitude of the radial bow. The distance y represents the length of the radius as measured from the bicipital tuberosity to the ulnar aspect of the radius. Line a, drawn perpendicular to y from the point of greatest curvature of the radius, represents the magnitude of the radial bow (expressed in millimeters). The distance x represents the length of the radius from the bicipital tuberosity to the point where a intersects y. The location of the radial bow is calculated by \( \frac{x \times y}{100} \). (Adapted from Schemitsch EH, Richards RR. The effect of malunion on functional outcome after plate fixation of fractures of both bones of the forearm in adults. J Bone Joint Surg Am 1992;74A:1068–1078.)
Acute fractures treated closed or with intramedullary nailing techniques are more likely to heal malunited.\(^7,^8\)
Radius malunions have a greater effect on forearm rotation than ulna malunions.\(^10,^12\)
A torsional deformity of greater than 30 degrees in the radius leads to significant loss of forearm motion.\(^4\)
Changes in the length–tension curve of the interosseous membrane may also account for loss of rotation.\(^12\)

**NATURAL HISTORY**
Fifty degrees of supination and 50 degrees of pronation are needed for activities of daily living.\(^6\)
Patients with untreated forearm malunions may experience loss of forearm rotation, PRUJ or DRUJ instability, wrist pain, loss of strength, and arthritis at the PRUJ.\(^11\)
The severity of the symptoms depends on the degree of malunion and the corresponding alteration in degree and location of the bow of the radius.

- Malunions of 10 degrees or less lead to less than a 20-degree loss of forearm rotation and hence are clinically insignificant.\(^7\)
- Angular malalignment of more than 20 degrees in the radius or ulna results in clinically significant loss of motion. Greater than 15 degrees of malalignment leads to inability to perform activities of daily living.\(^5,^7,^10\)
- Patients with greater than 15 degrees of malalignment or loss of the radial bow will have clinically significant loss of motion and strength if left untreated.

**PATIENT HISTORY AND PHYSICAL FINDINGS**
The preoperative evaluation for patients with forearm malunions includes a detailed assessment of the patient’s functional limitations as well as documentation of elbow and wrist range of motion, the supination–pronation arc of the forearm, and the stability of the PRUJ and DRUJ.

**Physical examination**
- The skin is inspected for scarring or previous incision sites.
- Muscle bulk and tone are examined.
- The wrist, elbow, and malunion site are palpated for tenderness.

**Range of motion**
- The flexion–extension arc of the elbow is measured with the shoulder at 30 degrees of forward flexion.
- Rotation of the forearm is ascertained with the humerus stabilized against the chest wall and the elbow at 90 degrees of flexion.
- Wrist flexion and extension are determined with the forearm in neutral rotation.
- Joint loss of motion may indicate location of pathology.
- A high degree of motion loss will lead to functional deficits.

**PRUJ and DRUJ**
- Stability of the PRUJ is assessed by palpation during passive pronation and supination.
- The DRUJ is evaluated by stressing the ulna volarly and dorsally while stabilizing the radius.
- Subluxation of the ulnar head or the ECU is evaluated during passive range of motion (ECU subluxation test).
- The piano key test can also be used to assess for an unstable DRUJ. Patients with a positive piano key sign will have an ulnar head that shifts volarly with a minimal volarily directed force and then rebounds dorsally once that force is removed, much like a key in a piano.
- Pain with compression of the radius and ulna at the level of the DRUJ may also be indicative of DRUJ instability or arthritis (DRUJ compression test).
- Neurovascular examination
  - The examiner should check for anterior interosseous nerve (OK sign), posterior interosseous nerve (thumb extension), and ulnar nerve (abduction–adduction of fingers) function.
  - Inability to perform tasks identifies nerve injury.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- AP and lateral radiographs of both forearms should be obtained (FIG 3A,B).
- Both the bicipital tuberosity and the radial styloid should be visualized for the film to be adequate.
- The degree of angulation and comminution can be calculated from these films.
- Contralateral forearm films provide a comparison for the amount of shortening as well as for the location and angle of the radial bow.\(^9\)

**FIG 3 • A,B.** AP and lateral radiographs demonstrate a segmental radius shaft fracture resulting in a malunion both proximally and distally despite open reduction and internal fixation. Note the loss of radial bow in both direction and magnitude, narrowing of the interosseous space between the radius and ulna, dorsal positioning of the distal ulna, and nonunion of the basilar ulnar styloid fracture. The patient was unable to supinate to neutral and demonstrated instability at the distal radioulnar joint. C. CT scan demonstrates narrowing of the interosseous space with heterotopic bone formation.
A CT (Fig 3C) scan or MRI can also be obtained to assess for malrotation.2

DIFFERENTIAL DIAGNOSIS
- DRUJ injury or instability
- PRUJ injury or instability
- Injury to the interosseous membrane
- Synostosis
- Nonunion

NONOPERATIVE MANAGEMENT
- Nonoperative treatment of malunions depends on the patient’s symptoms and includes occupational therapy for strengthening and range of motion, removable off-the-shelf braces, non-narcotic medications, and custom molded DRUJ orthoses.

SURGICAL MANAGEMENT
- Operative intervention for forearm malunions depends on the functional limitations of the patient, not the degree of deformity apparent on radiographs.
- Indications for surgery include loss of forearm rotation that leads to a functional deficit (rotational arc less than 100 degrees), DRUJ instability, unacceptable cosmetic, and painful nonunion.
- Risks to the patient include vascular injury, nerve injury or paresthesias (specifically the superficial radial nerve), infection, nonunion, delayed union, need for iliac crest bone graft, synostosis, loss of motion, and DRUJ instability.
- Patients treated within 1 year of the initial injury may be more likely to improve functionally and have a lower surgical complication rate.11
- Malunions of the radius and ulna are generally treated with an open approach, corrective osteotomy of one or both bones, compression plating, and bone grafting as necessary.
  - Generally, the more deformed bone is corrected first. If after correction of the first bone forearm rotation is still lacking, an osteotomy is performed on the second bone.
  - If both bones are equally deformed, the ulna is osteotomized and provisionally plated first to provide a working length for the radius.
- Restoration of the radial bow in large part determines functional outcome.
  - Patients whose radial bow is restored within 1.5 mm of magnitude and located within 4.3% of the contralateral forearm regain 80% of normal motion.
  - Eighty percent of grip strength is regained if the radial bow is located within 5% of the contralateral side.9
  - Anatomic realignment of the radius and ulna will not improve functional deficits if a synostosis or significant scarring and contracture involving the soft tissues has occurred.
  - Occult injury to or contracture of the DRUJ and PRUJ must be identified and treated at the time of surgery.

Preoperative Planning
- Radiographs of the affected and contralateral extremity should be reviewed.
  - A CT scan is helpful to assess for rotational deformity.
  - A corrective three-dimensional osteotomy is planned using standard AO technique (Fig 4).
  - The need for corticocancellous iliac crest bone graft should be determined by the degree of shortening.
  - The surgeon should be familiar with techniques for reconstruction or stabilization of the DRUJ should it remain unstable after correction of the malunion.

Positioning
- The patient is positioned supine on the operating table. A radiolucent hand board is attached to the table, centered on the patient’s axilla. The affected extremity is then extended and can be positioned for either a volar or dorsal approach to the radius by rotating through the shoulder.
- The subcutaneous border of the ulna can be visualized by flexing the arm at the elbow or by placing the arm across the chest.
- A nonsterile tourniquet may be used on the arm.

Approach
- Radius shaft malunions may be approached either volarly or dorsally.
  - The volar (Henry) approach is best suited for midshaft and distal radius shaft malunions.
  - The proximal radius shaft can be approached volarly in this manner; however, injury to the posterior interosseous nerve (PIN) can occur when dissecting the supinator muscle off the radius.
  - The approach is extensile and can be used to expose not only the entire length of the radius but also the wrist joint.3
  - The dorsal (Thompson) approach to the radius is used most commonly for proximal malunions.
  - It provides access to the PIN, allowing the surgeon to isolate the nerve and retract it out of harm’s way for the remainder of the procedure.
  - This approach may be of value for midshaft exposure of the radius, especially in the case of a midshaft segmental malunion (see Fig 3A,B).
  - The entire dorsal surface of the radius can be exposed through this approach.3
  - The ulna is approached along its subcutaneous border.
  - The entire length of the ulna can easily be exposed through this approach.

FIG 4 Preoperative planning using AO technique for correction of the malunion of the case in Figure 3. A. The malunion is first sketched out from the preoperative radiographs. B. Each fragment is then drawn out separately. C. The osteotomy sites are noted on both the AP and lateral views. The radius is then realigned through the planned osteotomy sites and bone graft (yellow) is inserted to restore the normal magnitude and location of the radial bow.
**VOLAR APPROACH TO THE RADIUS**

- **Landmarks:** biceps tendon, brachioradialis (BR), radial styloid
- **Center the skin incision over the malunion site and follow a line that begins lateral to the biceps tendon, continues over the medial edge of the BR, and ends distally at the level of the radial styloid.**
  - The length of the incision depends on the amount of exposure needed to take down the malunion and plate the osteotomy.
- **To expose the midshaft, dissect between the BR and the pronator teres (PT) proximally (TECH FIG 1).**
  - The superficial radial nerve lies on the undersurface of the BR and must be protected.
- **Ligate the recurrent radial artery to retract the BR laterally.**
- **Pronate the forearm and release the PT insertion.**
- **Dissect the PT muscle subperiosteally from a lateral to medial direction to expose the volar surface of the radius.**
- **To expose the distal radius, the surgical interval lies between the flexor carpi radialis (FCR) and the radial artery.**
- **Retract the FCR medially and the radial artery laterally to expose the flexor pollicis longus (FPL) and the pronator quadratus (PQ).**
- **Retract the FPL medially.**
- **Release the PQ from its radial insertion and dissect the muscle belly from the volar distal radius.**

**DORSAL APPROACH TO THE RADIUS**

- **Landmarks:** lateral epicondyle, tubercle of Lister
- **The skin incision is centered over the malunion and follows a gently curved line starting just anterior to the lateral epicondyle and ending just distal and ulnar to the tubercle of Lister at the wrist (TECH FIG 2A).**
- **Incise the fascia in line with the skin incision.**
- **Dissect between the extensor digitorum communis (EDC) and the extensor carpi radialis brevis (ECRB) proximally.**
- **Pronate the forearm.**
- **Identify the PIN as it emerges from the supinator 1 cm proximal to the distal edge of the muscle (TECH FIG 2B).**
- **Follow the nerve in a distal to proximal direction through the supinator, carefully preserving its motor branches.**
- **Once the nerve is fully mobilized and protected, supinate the arm and release the supinator from the anterior surface of the radius in a medial to lateral direction.**
- **To expose the midshaft of the radius dorsally, the abductor pollicis longus (APL) and the extensor pollicis brevis (EPB) must be mobilized as they cross radially over the dorsal shaft of the radius.**
- **Incise the fascia along the inferior and superior borders of the two muscles and lift them off the radius.**
- **Retract them distally or proximally as needed for exposure of the malunion.**
Chapter 6  CORRECTIVE OSTEOTOMY FOR RADIUS AND ULNA DIAPHYSEAL MALUNIONS

**TECHNIQUES**

**Exposure of the radius through the dorsal approach.** This approach is best for proximal shaft malunions.

A. Skin incision on dorsal surface, running from tip of lateral epicondyle toward radial styloid. B. The posterior interosseous nerve is followed through the supinator, with its branches preserved.

**TECH FIG 2**

**APPROACH TO THE ULNA**

- Landmark: subcutaneous border of the ulna
- Make a longitudinal incision along the subcutaneous border of the ulna (TECH FIG 3A).
- Incise the fascia in line with the skin incision.
- Dissect between the extensor carpi ulnaris (ECU) dorsally and the flexor carpi radialis (FCU) volarly (TECH FIG 3B).
  - Take care to avoid disrupting the ECU subsheath distally over the ulna head.

**TECH FIG 3**

**REDUCTION, PLATING, AND BONE GRAFTING**

- Based on the preoperative scheme, perform the planned osteotomy at the site of malunion using a combination of a water-cooled saw and osteotomies.
- Bring the radius out to length and insert bone graft as necessary (TECH FIG 4A).
- Make a template for plate contouring so as to match the radial bow (TECH FIG 4B, C).
- Plate the malunion using a 3.5-mm compression plate and AO compression plating techniques (TECH FIG 4D–G).
  - Obtain a minimum of six cortices of fixation proximal and distal to the malunion.
  - In smaller patients, a 2.7 DC plate may be used instead.

**TECH FIG 4**

A. Reduction after osteotomy of the midshaft segmental radius malunion through a volar exposure in the patient in Figures 3 and 4. Because of the segmental nature of this malunion, fixation was accomplished by plating both volarly and dorsally. B. A metal template is placed on the volar surface of the corrected radius. C. The template is used to precisely contour the plate so that when applied, the normal curvature of the radius is restored. (continued)
After fixation, take the forearm through a full supination–pronation arc.
- Blocks to motion result from an uncorrected ulnar malunion, DRUJ incongruency or instability, failure to restore the radial bow, synostosis, and soft tissue or interosseous membrane scarring and contracture.
- If an ulna osteotomy is required, the plate can be placed on the volar surface of the ulna or on its subcutaneous border in the manner detailed above.
- If the DRUJ is unstable, consider palmar capsular reefing, reconstruction with tendon graft, fixation of an ulnar styloid base nonunion, or pinning of the joint in full supination.

If the joint is incongruent or arthritic, consider ulna shortening, matched resection arthroplasty, Darrach resection, or the Sauve-Kapandji procedure.
- Reapproximate tendon insertions. For example, in the case of a volar exposure to the distal radius, repair the PQ to its radial insertion using absorbable suture.
- Close the subcutaneous tissues and skin.
- To minimize the risk of compartment syndrome, do not close the fascia.
- Apply a volar splint.
- In patients with concomitant DRUJ instability, a sugar-tong splint with the forearm in full supination is placed.

PEARLS AND PITFALLS

Indications
- Assess DRUJ stability.
- Determine that lack of motion is not due to soft tissue contracture, synostosis, or interosseous membrane scarring, for which realignment of the malunion would not improve motion.

Osteotomy
- Obtain contralateral forearm films to determine location and magnitude of radial bow.
- Obtain CT or MRI if concerned for rotational malunion.
- Perform detailed preoperative drawings to determine the ideal location for the osteotomy, the degree and direction of correction required, and the need for bone graft.
- Obtain consent for bone graft.

Approach
- If a volar approach to the proximal radius is chosen, avoid injury to the PIN by careful subperiosteal stripping of the supinator from the radius and gentle retraction of the supinator laterally to prevent a traction neurapraxia. Avoid placing a retractor around radial neck as this can compress the PIN (or cause a traction injury of the nerve). Gently retract the superficial radial nerve and radial artery.
- Protect the PIN during dissection when approaching the proximal radius dorsally. The nerve lies directly on bone dorsally, opposite of the bicipital tuberosity in 25% of patients. Avoid trapping the nerve between the plate and bone when placing a plate proximally.

DRUJ
- Determine the cause of instability of the DRUJ once malalignment is restored.
- Perform a procedure that addresses the precise cause of the DRUJ instability.
POSTOPERATIVE CARE
- In a compliant patient with secure fixation, the splint may be removed 5 to 7 days after surgery and range-of-motion exercises initiated.
- A removable orthosis is worn for the next 4 to 5 weeks.
- Strengthening exercises are begun 6 weeks after surgery.
- Resistive strength training is delayed until radiographic evidence of healing is present (usually 8 to 12 weeks postoperatively).
- Normal activities are resumed when a solid union is present.
- Plates are generally not removed in adults.
- If concomitant DRUJ instability is present:
  - A Munster cast is applied at the first postoperative visit. The forearm is held in full supination for 6 weeks.
  - Finger range-of-motion and elbow flexion–extension exercises are begun at the first postoperative visit.
  - At 6 weeks, any pins in the DRUJ are removed, and supination–pronation exercises are initiated.

OUTCOMES
- Trousdale and Linscheid retrospectively reviewed 27 patients with corrective osteotomies for forearm malunions. Indications for surgery included loss of rotation (20 patients), unstable DRUJ (6 patients), and cosmesis (1 patient).11
  - Of the six patients with DRUJ instability, five had stable wrist joints at follow-up. Three patients were stabilized with correction of the deformity alone, and three required reefing of the palmar capsule and temporary pinning of the DRUJ with Kirschner wires (K-wires).
  - The patient who underwent the procedure for cosmesis lost 10 degrees of rotation but was happy with the overall appearance and function.
  - The age of the patient at the time of injury, location of the malunion, and involvement of one or both bones were not associated with the final outcome.
  - Shorter time from injury to corrective surgery (less than 12 months) was associated with improved forearm rotation and a lower complication rate.

COMPLICATIONS
- A 48% complication rate was noted in Trousdale and Linscheid’s study.11
  - Infection
  - Wrist pain
  - Loss of motion
  - Heterotopic ossification
  - DRUJ instability
  - Delayed union or nonunion
  - Superficial radial nerve paresthesias

REFERENCES
DEFINITION
- A diaphyseal forearm fracture is generally considered to be a nonunion if healing has not taken place within 6 months.
- Nonunions are generally classified as hypertrophic or atrophic, an important distinction in treatment selection.
  - Hypertrophic nonunions have abundant callus and a rich blood supply and result from inadequate stability of fracture fixation. This type of nonunion is rare in the forearm and constitutes less than 10% of nonunion cases.9
  - Atrophic nonunions are characterized by poor blood supply and little or no callus formation.
- Nonunion of the forearm diaphysis is rare because of the success of current techniques of plate and screw fixation. Nonunion rates of only 2% in the radius and 4% in the ulna are reported.2

ANATOMY
- The forearm consists of the radius and ulna, joined at either end by the proximal and distal radioulnar joints (PRUJ and DRUJ, respectively) (FIG 1).
- The ulna is straight, while the radius has both an apex radial and apex dorsal curvature.
- It can help to think of the forearm as a joint rather than a pair of long bones.
  - Pronation and supination are achieved by rotation of the curved radius about the straight ulna.
- Both the curvature of the radius and the integrity of the interosseous space and interosseous membrane (IOM) must be maintained for the forearm “joint” to function optimally.
- The diaphyseal portions of the radius and ulna are surrounded by complex anatomy, including neural and vascular structures, that must be considered during any surgical approach. Both radius and ulna are covered by muscle proximally, while the ulna emerges distally to be subcutaneous.

PATHOGENESIS
- Nonunions of the diaphysis of the forearm are rare and result most commonly from incorrect or inadequate treatment.
  - Inadequate fixation, generally less than six cortices of screw fixation proximal and distal to the fracture, will increase the rate of nonunion.
  - Lack of attention to critical surgical principles such as creating compression across the fracture site (either with the use of an interfragmentary screw or a compression plate) also leads to nonunion.
- Nonoperative treatment results in markedly increased rates of nonunion and other complications.2 With the exception of isolated, minimally displaced ulnar shaft fractures, all adult diaphyseal forearm fractures require operative management.
  - Comminution increases the risk of nonunion, with 12% of comminuted, diaphyseal fractures going on to develop nonunion after treatment with dynamic compression plates.11
  - Fracture characteristics that increase the risk of nonunion include extensive devascularization and periosteal stripping, bone loss, and infection.
    - Open, comminuted fractures with bone loss have the highest rate of nonunion.7
  - Patient comorbidities known to increase rates of nonunion include diabetes mellitus, steroid use, malnutrition, and renal dysfunction.

NATURAL HISTORY
- Once a nonunion of the forearm is established, it will not go on to heal spontaneously.
  - If significant shortening of either the radius or ulna occurs, the intricate anatomy of the entire forearm “joint” can be disrupted. Malalignment of the DRUJ secondary to such shortening can cause pain and lead to loss of motion at the wrist.
  - Loss of motion secondary to pain, particularly pronation and supination, can lead to shortening and fibrosis of the IOM. This can lead to permanent loss of rotational motion in the forearm.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients with nonunion of the diaphysis of the radius or ulna most commonly present with pain.
  - This pain frequently worsens with attempts to use the extremity for lifting or pushing, but may also occur at rest.
Resisted rotational movements are frequently painful, such as turning a key in a lock.

It is important to explore whether infection could be the cause of the nonunion. Important history includes whether or not the original fracture was open, whether postoperative complications or drainage developed, and whether the patient has received antibiotics.

During the physical examination, the examiner should do the following:

- Palpate the nonunion site for pain.
- Grasp the bone on either side of the nonunion and attempt to flex and extend the nonunion to assess fracture stability and healing. Palpable motion and increased pain indicate lack of union.
- Loss of flexion–extension in the elbow may result from pain. Loss of pronation and supination indicates deranged forearm anatomy or pain.
- Loss of flexion or extension at the wrist may indicate pain or scarring of muscle and tendons around the nonunion. Loss of radioulnar deviation may indicate DRUJ abnormality secondary to shortening at the nonunion site.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs are essential for diagnosis. This should include AP and lateral views of the forearm, elbow, and wrist.
- Comparative views of the contralateral forearm, elbow, and wrist are also essential for preoperative planning.
- Plain radiographs will allow the surgeon to determine if the nonunion is hypertrophic (FIG 2A) or atrophic (FIG 2B).
- CT is helpful in identifying synostosis, assessing rotational deformity, and evaluating the size of the gap between bone ends at the nonunion site. CT also allows assessment of the DRUJ and PRUJ.
- The metal suppression CT technique minimizes the bright scatter created by retained hardware.

**DIFFERENTIAL DIAGNOSIS**

- Malunion
- Infection
- IOM injury
- Painful hardware

**NONOPERATIVE MANAGEMENT**

- The goal of treatment is to alleviate pain and restore function to the forearm. This can rarely be accomplished without surgical intervention.
- In rare circumstances (if the patient is a high risk for surgery due to comorbidities, for example), an external bone stimulator can be used.
- A minority of patients develop a stable, fibrous nonunion that is painless and allows good function. Nonoperative management can be considered in such patients.

**SURGICAL MANAGEMENT**

- In all nonunions of the forearm, the first considerations are the patient’s level of pain and function.
- The surgeon should not elect to operate based on radiographic findings alone.
- All patients with nonunions should undergo a workup to determine if the cause of the nonunion is infection, particularly after open fractures.
- The workup should include careful history of open fracture, drainage, or postoperative complications after initial surgery.
- Blood should be obtained for a complete blood count, erythrocyte sedimentation rate, and C-reactive protein.
- Nuclear medicine imaging should be performed if the suspicion of infection is high.

**Preoperative Planning**

- All imaging studies should be reviewed and pathoanatomy recognized.
- Plain radiographs should be reviewed for presence or absence of callus in order to categorize the nonunion as hypertrophic or atrophic.
- If a nonunion of the forearm is hypertrophic (which is rare), it may be treated by simple revision of hardware, creating compression across the fracture site with either a compression screw or a compression plate. This is the same technique that should be used for initial management of radius or ulna fractures (see Chap. HA-4).
- If any possibility of infection at the nonunion site exists, plans must be made to search for infection when the nonunion site is opened, and to have an alternative treatment plan if infection is encountered.
- Preoperative antibiotics may be held until cultures are obtained from the nonunion site (ensuring the tourniquet is not inflated if antibiotics are administered later in the case).

**FIG 2** A. Radiograph showing an infected, hypertrophic nonunion. The abundant callus formation indicates a biologically active nonunion. B. Radiograph showing an atrophic nonunion. There is complete absence of callus at the fracture site. The problem in an atrophic nonunion is lack of biologic activity. (Courtesy of Thomas R. Hunt III, MD.)
Intraoperative culture swabs and tissue for aerobic, anaerobic, and fungal cultures should be obtained from sites within the nonunion.

Patients should be made aware that if severe infection is encountered, the planned procedure may need to be altered. For example, if frank purulence is encountered, the nonunion repair may be abandoned in favor of débridement and irrigation with possible antibiotic bead placement and even external fixation if stability is compromised.

Template the radiographs to ensure selection of proper plate size and length.

DCP, LCDCP, and combination locking plates are all appropriate.

A minimum of six cortices of screw purchase proximal and distal to the nonunion is critical. This may require plates longer than those available in a standard plating set.

In osteoporotic bone, the use of locking plates should be considered.

If bone graft will be required, the type of graft should be determined preoperatively. While autograft is still considered the gold standard, a vast array of bone graft substitutes are now available. The surgeon’s preference and familiarity with various bone graft substitutes may guide this choice. It is important to determine if a structural graft will be required, as this may necessitate the use of autograft.

Patients should be counseled regarding the possible need for (and risks associated with) various types of autograft, including the possible need for a tricortical iliac crest or fibula graft if significant bone loss is encountered.

A vascularized fibula graft may be used to fill large defects, especially those associated with infection.

A complete examination of range of motion of the elbow and wrist, including pronation and supination, should be performed under anesthesia.

**Positioning**
- The patient should be positioned supine with the operative arm extended on a radiolucent arm table.
- A nonsterile or sterile tourniquet may be applied, but full access to the elbow is necessary.
- Because restoration of the radial bow is a critical component in restoring forearm motion, intraoperative radiographs showing the entire radius are essential. For this reason, use of the mini C-arm should be avoided in favor of regular fluoroscopy, with its much larger field of view.
- The selected site for harvest of autograft should also be prepared and draped.

**Approach**
- The approach to either the radius or ulna should generally be through the original surgical incisions.
- Approach to the radius is most commonly volar through the standard Henry approach. Proximal nonunions of the radius may be more easily accessed via a dorsal Thompson approach, particularly in muscular individuals.
- Care should be taken to identify and protect the posterior interosseous nerve during this approach.
- The ulna is accessed along the subcutaneous border in the interval between the flexor carpi ulnaris and the extensor carpi ulnaris.
- Care should be taken to identify and protect the dorsal cutaneous branch of the ulnar nerve distally.
- In all cases, preservation of blood supply is key to healing of a nonunion. Therefore, periosteal stripping should be kept to a minimum and the use of cautery should be restricted to vessel coagulation.

**Techniques**

**PLATE FIXATION FOR TREATMENT OF FOREARM NONUNIONS**

**Preparation of the Nonunion**
- Determine the correct length of the radius or ulna by measuring the corresponding contralateral bone.
- Expose the nonunion site and search for evidence of infection. If found, send specimens for Gram stain and culture and abort the planned procedure. Perform a two-stage reconstruction.
  - Thoroughly débride all necrotic and infected bone and soft tissue. Remove all hardware.
  - Place antibiotic-loaded PMMA beads in the gap.
  - Begin a multiweek course of antibiotics before proceeding with definitive nonunion repair.
- If infection is considered unlikely, after removal of all hardware, thoroughly débride the nonunion site of all necrotic and inflammatory tissue, synovial membranes, and sclerotic or avascular bone.
  - Tools such as curved curettes, small rongeurs, and a small high-speed burr (with copious irrigation to prevent thermal injury to the bone) are helpful.
  - Flatten the bone ends to allow for excellent fragment-to-fragment contact with compression.
- Open the sclerotic bone ends using sequentially larger diameter drills.
  - Pass these drills proximally and distally as far as possible to open the medullary canals (TECH FIG 1B).
  - Restrict elevation of muscle and periosteum to only what is needed to thoroughly débride the nonunion and to realign the bone.
  - Realign the bone and restore length by manipulating fragments with bone-holding forceps.
  - Use of a small skeletal distractor, small external fixator, or lamina spreader aids in restoration of length.
  - Measure the length of the residual bone defect directly and, taking into consideration the preoperative plan, determine the appropriate bone graft to use.

**Compression Plating Without Bone Graft**
- In rare cases with minimal or no bone loss at the nonunion site, the bone may be plated in situ without causing shortening. Because the bone remains at normal
Chapter 7  OPERATIVE TREATMENT OF RADIUS AND ULNA DIAPHYSEAL NONUNIONS

TECHNIQUES

length, the relationship of the radius and ulna at both the DRUJ and the PRUJ is not disrupted and rotation will be preserved.

- This technique may also be used if there is nonunion of both the radius and the ulna. Both bones may then be shortened a symmetrical distance.

- After bone preparation as detailed above, anatomically align the bone ends and precisely apply a compression plate using the same technique employed for acute forearm fractures.

- Ensure that compression of the bone ends is achieved.

- If a small bone gap exists after compression, the other forearm bone may then be shortened to restore the length relationship.

- Because this approach involves surgery on a normal bone, this strategy should be used with caution.

Cancellous Bone Grafting

- Cancellous bone grafting is generally used for small defects up to 3 cm that can be effectively stabilized with a plate.

- Gaps of up to 6 cm have been successfully treated using cancellous bone for grafting.9

- Firmly pack the cancellous autograft into the residual nonunion defect after the plate is applied.

- Ensure the graft does not escape from the nonunion site and come to lie on the IOM (TECH FIG 2).

Structural Corticocancellous Autograft Bone Grafting

- Structural autograft harvested from the anterior or posterior iliac crest is used for larger defects.

- Expose the superior crest and define the inner and outer tables.

- Utilize a water-cooled sagittal saw and osteotomes to harvest a tricortical block of bone from the iliac crest. Additionally, harvest cancellous bone to fill defects that may present.

- The graft should be slightly larger than that required based on preoperative planning.

- Precisely contour the graft to fit snugly into the defect. Square the ends of the graft to match the ends of the bone fragments.5

- Alternatively, cut both the bone ends of the radius or ulna and of the bone block chamfered, or on the bias, to increase the area of bony contact.3 This also allows the graft to be wedged securely in place.

- Insert the graft before plate fixation and fill any residual gaps with cancellous bone after plate application.

TECH FIG 1  •  A. Complete débridement of the nonunion site is the essential first step. Any fibrous or necrotic material must be removed and the bone ends delivered. B. Medullary canals are opened using increasing-diameter drill bits to allow vascular ingrowth.

TECH FIG 2  •  The nonunion gap is distracted if necessary to recreate the normal anatomic bone length. A 3.5-mm plate with a minimum of three screws proximal and distal should be used. Cancellous bone graft is inserted and packed in the nonunion gap.
**Nonvascularized Structural Fibula Autograft With Cortical Allograft Bone Grafting**

- An appropriate-length segmental graft is harvested from the fibula and placed into the defect.
- The fibula is approached laterally, via the intramuscular plane between the peroneal muscles and the soleus.
- A cuff of muscle 2 to 3 mm in thickness should be left to protect the periosteum.
- The IOM is incised longitudinally, taking care to avoid the posterior neurovascular bundle.
- The fibula is osteotomized proximally and distally to create an appropriate-length graft.
- Complications of fibular harvest are rare but include transient motor weakness, peroneal nerve palsy, and flexor hallucis longus (FHL) contracture.
- A minimum of 6 cm of the distal fibula must be retained to avoid adversely affecting the distal tibiofibular syndesmosis and ankle joint function.
- Insert the fibula graft into the defect and then apply the plate as described below, first placing the two screws just proximal and just distal to the nonunion to gain initial compression.
- Select a cortical allograft several centimeters longer than the defect.

**TECH FIG 3** • Combined intercalary autograft and allograft strut technique described by Moroni et al.8 After débridement of the nonunion site, an intercalary graft of appropriate length is harvested from the patient’s fibula and placed in the gap. A cortical allograft is placed opposite to the plate, and screws are placed passing through the plate, the patient’s radius or ulna, and finally the allograft strut.

**COMPRESSION PLATE FIXATION**

- Select a 3.5-mm (small fragment) compression plate of adequate length to ensure a minimum of three or four screws (six to eight cortices) on either side of the nonunion.
- Always err on the side of a longer plate.
- Thinner locking plates may be considered when structural fibular autografts are combined with cortical allograft struts.
- Fix the plate to the bone in compression (ensuring that proper length is maintained) with one screw proximal and one screw distal to the nonunion, then use full-length fluoroscopic views or radiographs of the forearm to ensure restoration of length, bow, and joint alignment.
- Compare with the contralateral forearm.
- Insert the remaining screws.
- Ideally, screws are not placed into the graft itself and the graft is stabilized by the compression created by the plate (TECH FIG 4).
- Close the wound routinely and apply an above-elbow or sugartong splint.

- Tibial allograft is recommended due to its suitable thickness and mechanical characteristics, which provide excellent screw purchase.8
- Place the cortical allograft along the outer cortex of the bone, opposite the plate, spanning beyond the length of the fibula allograft.
- Insert the remainder of the screws so that they pass through the plate and then the patient’s bone and finally into the cortical allograft on the opposite side (TECH FIG 3).
Débridement of all necrotic, sclerotic, and avascular tissue from the nonunion site is essential. Bone graft substitutes may offer alternatives to autograft, but no comparative studies exist at this time. Compression must be created across all structural grafts. An intraoperative infection workup, including Gram stain and culture, should be performed and an alternative plan should be available if infection is encountered. Differentiation should be made between hypertrophic and atrophic nonunions, as treatment differs. A negative preoperative workup does not rule out infection. Opening the sclerotic bone ends and gentle reaming of the medullary canals promotes ingrowth of medullary blood vessels. Periosteal stripping and cautery must be minimized to preserve periosteal blood supply. Anatomic restoration of length and bow is necessary to allow full rotational motion of the forearm. Contralateral radiographs must be used to determine the appropriate length of the forearm bones and degree of radial bow. Anatomic restoration of length and bow is necessary to allow full rotational motion of the forearm. A complete preoperative infection workup should be done for all patients with a nonunion. Defects up to 3 cm are successfully managed with cancellous autograft and appropriate fixation. Careful evaluation of the patient’s pain and functional limitations must be done before surgical management is planned. Postoperative care is delayed after surgery, the greater the chance the patient will develop stiffness. Therefore, early active range of motion (ROM) should be initiated at the first postoperative visit, except in cases with more tenuous fixation. Use of the arm for activities of daily living is encouraged. If the patient has difficulty in achieving satisfactory ROM with active, active-assisted, and gentle passive ROM, static progressive splints may be used. Having the patient sleep in a static extension splint may significantly improve elbow extension. Heavy lifting, pushing, and weight bearing are delayed until radiographic evidence of healing is present, often 3 to 6 months after the index procedure. When precise surgical techniques are used, such as creating stable compression across structural grafts, high rates of union are expected. Rates of healing from 95% to 100% are reported for all of the methods described in this chapter. Failure of union is related to recurrence of previous infection in nearly all cases. The prognosis for infected nonunions should be guarded. Patient satisfaction does not correlate directly with bony healing. In multiple studies only two thirds of patients achieved good or excellent results. Unsatisfactory results are associated with poor postoperative motion in the majority of cases. Other injuries to the upper extremity (common in high-energy trauma associated with nonunions) contributed to unsatisfactory overall function in a minority of patients. Because nonunion of the forearm diaphysis is a rare condition, no comparative studies of treatment methods exist, including the use of bone graft substitutes. Recurrent nonunion and hardware failure. Loss of motion. Synostosis. Pain or other complications at the autograft harvest site.

Pearls and Pitfalls

<table>
<thead>
<tr>
<th>Indications</th>
<th>Careful evaluation of the patient’s pain and functional limitations must be done before surgical management is planned.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiographs</td>
<td>Differentiation should be made between hypertrophic and atrophic nonunions, as treatment differs. Contralateral radiographs must be used to determine the appropriate length of the forearm bones and degree of radial bow. Anatomic restoration of length and bow is necessary to allow full rotational motion of the forearm.</td>
</tr>
<tr>
<td>Diagnosis of infection</td>
<td>A complete preoperative infection workup should be done for all patients with a nonunion. A negative preoperative workup does not rule out infection. An intraoperative infection workup, including Gram stain and culture, should be performed and an alternative plan should be available if infection is encountered.</td>
</tr>
<tr>
<td>Nonunion site preparation</td>
<td>Débridement of all necrotic, sclerotic, and avascular tissue from the nonunion site is essential. Opening the sclerotic bone ends and gentle reaming of the medullary canals promotes ingrowth of medullary blood vessels. Periosteal stripping and cautery must be minimized to preserve periosteal blood supply.</td>
</tr>
<tr>
<td>Graft selection</td>
<td>Defects up to 3 cm are successfully managed with cancellous autograft and appropriate fixation. Bone graft substitutes may offer alternatives to autograft, but no comparative studies exist at this time.</td>
</tr>
<tr>
<td>Compression of structural grafts</td>
<td>Compression must be created across all structural grafts.</td>
</tr>
</tbody>
</table>

Postoperative Care

- The longer motion is delayed after surgery, the greater the chance the patient will develop stiffness. Therefore, early active range of motion (ROM) should be initiated at the first postoperative visit, except in cases with more tenuous fixation.
- Use of the arm for activities of daily living is encouraged.
- If the patient has difficulty in achieving satisfactory ROM with active, active-assisted, and gentle passive ROM, static progressive splints may be used.
- Having the patient sleep in a static extension splint may significantly improve elbow extension.
- Heavy lifting, pushing, and weight bearing are delayed until radiographic evidence of healing is present, often 3 to 6 months after the index procedure.

Outcomes

- When precise surgical techniques are used, such as creating stable compression across structural grafts, high rates of union are expected.
- Rates of healing from 95% to 100% are reported for all of the methods described in this chapter.
- Failure of union is related to recurrence of previous infection in nearly all cases. The prognosis for infected nonunions should be guarded.
- Patient satisfaction does not correlate directly with bony healing. In multiple studies only two thirds of patients achieved good or excellent results.
- Unsatisfactory results are associated with poor postoperative motion in the majority of cases.
- Other injuries to the upper extremity (common in high-energy trauma associated with nonunions) contributed to unsatisfactory overall function in a minority of patients.
- Because nonunion of the forearm diaphysis is a rare condition, no comparative studies of treatment methods exist, including the use of bone graft substitutes.

Complications

- Infection
- Graft displacement

References

DEFINITION
- Distal radius fractures occur at the distal end of the bone, originating in the metaphyseal region and often extending to the radiocarpal and distal radioulnar joints.
- Distal radius fractures can be classified as stable or unstable and extra- or intra-articular to assist in treatment decisions.
- Fractures may angulate dorsal or volar and may have significant comminution, depending on the energy of the injury and the quality of the bone.
- Percutaneous pins or K-wires, typically 0.062- or 0.045-inch, can be used for unstable intra-articular or extra-articular fractures with mild comminution and no osteoporosis.
- Percutaneous pins can aid reduction and stabilize the fragments in a minimally invasive manner.
- Percutaneous pins can support the subchondral area of the distal radius and maintain the articular reduction in highly comminuted fractures, which is useful in combined fixation methods.
- Smooth percutaneous pins may also be placed across the physis to maintain a reduction in children without causing a growth arrest.
- Highly comminuted fractures are more difficult to fix rigidly and often require internal and external fixation to maintain alignment during healing.
- External fixators can be hinged or static, and may or may not bridge the wrist joint.

ANATOMY
- The distal radius consists of three articular surfaces: the scaphoid fossa, the lunate fossa, and the sigmoid notch.
- Ligamentotaxis aids in the reduction of intra-articular and comminuted fractures.
  - Volar ligamentous attachments include the radioscapohamate, long radiolunate, and short radiolunate ligaments.
  - Dorsal ligamentous attachments include the dorsal intercarpal and radiocarpal ligaments.
- Dorsal and radial to the second metacarpal lie the first dorsal interosseous muscle and the terminal branches of the radial sensory nerve.

PATHOGENESIS
- Distal radius fractures are the most common fractures of the upper extremity in adults, representing about 20% of all fractures seen in the emergency room.17
- Mechanism of injury typically is a fall on an outstretched hand with axial loading, but other common histories include motor vehicle accidents or pathologic fractures.
- Higher-energy injuries cause increased comminution, angulation, and displacement.
- Osteoporosis, tumors, and metabolic bone diseases are risk factors for sustaining pathologic distal radius fractures.
- In children, fractures typically occur along the physis due to its relative weakness compared to the surrounding ligaments.

NATURAL HISTORY
- Distal radius fractures needing no reduction and those that are stable after reduction typically recover functional range of motion with minimal long-term sequelae.
Three parameters that affect outcome include articular congruity, angulation, and shortening.\(^{16,20}\)
- 1 to 2 mm of articular surface incongruity of the distal radius can lead to degenerative changes, pain, and stiffness.
- Dorsal angulation can lead to decreased range of motion and increased load transfer to the ulna.
- Radial shortening can lead to decreased range of motion, pain, and ulnar impaction of the carpus.

**PATIENT HISTORY AND PHYSICAL FINDINGS**
- The history of a fall on an outstretched hand is the most common presentation for a patient with a distal radius fracture.
- Motor vehicle or motorcycle accidents and osteoporosis account for most comminuted fractures.
- It may be clinically indicated to implement a workup for osteoporosis.
- Pain, tenderness, swelling, crepitus, deformity, ecchymosis, and decreased range of motion at the wrist are typical symptoms and warrant radiographic evaluation.
- Physical examination should include the following:
  - Inspection: Evaluate the integrity of the skin, cascade of the digits, direction of displacement, and presence of any swelling.
  - Identify points of maximal tenderness to differentiate between distal radius injuries and carpal or ligamentous injuries.
  - Touch or press specific areas of the wrist and hand to differentiate distal intra-articular, DRUJ, and carpal injuries.
  - Two-point discrimination: Higher than normal (5 mm) results in the form of progressive neurologic deficit may signify an acute carpal tunnel syndrome or ulnar neuropathy.
  - Passive finger stretch test to assist with diagnosis of compartment syndrome.
  - EPL tendon function should be evaluated.
  - EPL assessment: Assess the resting position of the thumb interphalangeal joint and the patient’s ability to lift the thumb off of a flat surface to determine the continuity of the EPL tendon.
  - Palpation of forearm and elbow to assess for concomitant injury proximally.
  - The DRUJ must be assessed for displacement.
  - The bony anatomy must be carefully evaluated to avoid missing minimally displaced fractures, which may displace without treatment.
  - Skin should be assessed to avoid missing an open fracture.
  - Swelling should be monitored to allow for early diagnosis of compartment syndrome.
  - Sensory examination should be monitored for progressive changes, which may represent acute carpal tunnel syndrome.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Radiographic evaluation should include posteroanterior (PA), lateral, and oblique views to assess displacement, angulation, comminution, and intra-articular involvement, and allow for radiologic measurements.\(^{14,17}\)
- Lateral articular (volar) tilt is the angle between the radial shaft and a tangential line parallel to the articular margin as seen on the lateral view (FIG 2A). The normal angle is 11 degrees.
- Radial inclination, measured on the PA view (FIG 2B), is the angle between a line perpendicular to the shaft of the radius at the ulnar articular margin and the tangential line along the radial styloid to the ulnar articular margin. The normal angle is 22 degrees.
- Ulnar variance, also measured on the PA view (see Fig 2B), is the distance between the radial and ulnar articular surfaces. Ulnar variance is compared to the contralateral side.
- Traction radiographs help assess intra-articular involvement, intercarpal ligamentous injury, and potential fracture reduction through ligamentotaxis.
- CT scans are useful in fully elucidating the anatomy of the fracture, including impaction, comminution, and size of the fragments.
- CT scans often significantly alter the original treatment plan.\(^{11}\)
- MRI is rarely performed acutely but can diagnose concomitant ligamentous injuries, triangular fibrocartilage complex injuries, and occult carpal fractures.

**DIFFERENTIAL DIAGNOSIS**
- Bony contusion
- Radiocarpal dislocation
- Scaphoid or other carpal fracture
- Perilunate or lunate fracture dislocation
- Distal ulna fracture
- Wrist ligament or triangular fibrocartilage complex injury
- DRUJ injury

**NONOPERATIVE MANAGEMENT**
- Conservative treatment consists of splinting or casting for stable fracture patterns using a three-point mold.
- Fractures amenable to nonoperative treatment include fractures that are stable after reduction with minimal metaphyseal comminution, shortening, angulation, and displacement.
Evaluation for secondary displacement weekly for 2 to 3 weeks is critical as the swelling subsides.
- Unstable patterns will displace if not surgically stabilized.
- There is little role for nonoperative treatment in highly comminuted fractures.
- The physiologic age, medical comorbidities, and functional level of the patient should be considered in determining the need for surgical treatment.
- Early range of motion of the nonimmobilized joints is essential in the nonoperative treatment of all fractures near the wrist to prevent contracture.
- The cast or splint must not extend past the metacarpophalangeal joints so as to allow digital motion.

**SURGICAL MANAGEMENT**

- Surgical treatments are indicated to prevent malunion and improve pain control, function, and range of motion.
- Surgery is reserved for unstable fractures, including displaced, intra-articular, comminuted, or severely angulated injuries and fractures that displace following attempted closed management.
- Percutaneous pinning can assist in obtaining and maintaining reduction of displaced fractures with limited comminution in a minimally invasive manner.
- External fixators maintain radius length but cannot always control angulation and displacement; therefore, supplementation with percutaneous pins is typically performed.²
- Conversely, external fixators may augment percutaneous pins and plate fixation when extensive comminution is present.
- Supplemental external fixation should be considered for fractures with comminution of over 50% of the diameter of the radius on a lateral view.
- External fixation may be used as a neutralization device, because the distraction forces decrease soon after fracture reduction.
- External fixators also are useful for “damage control or-thopaedics” to temporarily stabilize wrist fractures, especially for complex, combined, open injuries.
- For nonbridging external fixation, there must be at least 1 cm of volar cortex intact and adequate fragment sizes to allow proper pin placement.
- A relative contraindication to pin fixation with or without external fixation is a volar shear injury, which should be reduced and stabilized using a volar plate and screws.

**Preoperative Planning**

- All radiographs should be reviewed before surgery and brought into the operating room.
- Analysis of the pattern and presumed stability of the fracture fragments determines whether percutaneous fixation, with or without external fixation, is suitable.
- For intra-articular fractures, the specific fragments to be reduced and fixed must be identified preoperatively to avoid incomplete reduction of the joint surface.
- The surgeon must be prepared to change his or her management decision intraoperatively if the fracture behavior is different than anticipated. A variety of fixation devices should be available in the operating room.

**Positioning**

- The patient is positioned supine on the operating table with a radiolucent arm board.

**FIG 3 • Positioning of patient supine on the hand table with tourniquet in place.**

- A tourniquet is applied near the axilla with the splint still in place (FIG 3).
- Fluoroscopy should be used for reduction confirmation and fixation throughout the procedure.
- There must be enough range of motion of the shoulder and elbow to allow standard AP, lateral, and oblique images.

**Approach**

- Various approaches can be used in the application of external fixators and the insertion of percutaneous pins.
- Distal external fixator half-pins may be placed directly into the second metacarpal or into other carpal bones (for injuries including the second metacarpal). Wires and half-pins, which are non-bridging fixators, may be placed in the distal radius itself.
- Percutaneous pins can be inserted through the radial styloid between the first and second dorsal compartments, through Lister’s tubercle, through the interval between the fourth and fifth dorsal compartments, and across the DRUJ (FIG 4).
- Caution is taken to avoid skewering tendons and nerves and to avoid penetrating the articular surface.

**FIG 4 • Areas for K-wire insertion at the distal radius.**
CLOSED REDUCTION OF A DISTAL RADIUS FRACTURE

- Closed reduction should be performed before fixation using distraction and palmar translation of the distal radius fragment and carpus.\(^1\)
- Use of a padded bump or towel roll will aid in the reduction (TECH FIG 1).
- Overdistraction will cause increased dorsal angulation due to the intact short, stout volar ligaments.\(^1\)
- Excessive palmar flexion of the wrist can restore volar tilt but leads to an increased incidence of stiffness and carpal tunnel syndrome.\(^7\)
- Overdistraction can be assessed by measuring the carpal height index, measuring the radioscaphoid and midcarpal joint spaces, checking full finger flexion into the palm, or evaluating index finger extrinsic extensor tightness.\(^8\)

CLOSED REDUCTION OF A DISTAL RADIUS FRACTURE

- Closed reduction is obtained using a bump, and the reduction is confirmed using fluoroscopy.
- This technique should be employed in patients younger than 55 years of age with minimal comminution. It should not be used in osteoporotic, elderly patients or those with comminution secondary to a higher loss of reduction. External fixation should be used to supplement pinning in these populations.\(^2\)

KAPANDJI TECHNIQUE FOR PERCUTANEOUS PINNING

- A stab incision is made radially, and a 0.062-inch pin is manually inserted into the fracture site, taking care to protect the sensory nerve branches and the first dorsal compartment tendons (TECH FIG 2A).
- The pin is angled distal, levering the bone back into its normal position and restoring the radial inclination (TECH FIG 2B). The pin is advanced through the far cortex using power, acting as a buttress to prevent loss of radial inclination (TECH FIG 2C).

**TECH FIG 1** • Closed reduction over a towel bump using traction and palmar translation.

**TECH FIG 2** • **A.** An incision is made over the radial styloid and a K-wire is manually inserted into the fracture site. **B.** The wire is levered distally to correct the radial inclination. **C.** The wire is advanced proximally, using power, into cortical bone. **D.** An incision is made over Lister’s tubercle, and a wire is inserted into the fracture site. **E,F.** The wire is levered distally to correct the dorsal angulation and advanced proximally using power into cortical bone.
A second stab incision is placed dorsally, and a second pin is manually inserted into the fracture (TECH FIG 2D). The pin is angled distal, levering the bone back into its normal position and restoring the volar tilt (TECH FIG 2E). The pin is advanced through the volar cortex using power, acting as a buttress to prevent loss of volar tilt (TECH FIG 2F). Using the modified technique, a third pin is placed retrograde using power, starting at the radial styloid and proceeding into the ulnar cortex of the radius proximal to the fracture line. The pins are buried and cut just below the skin, and the skin is sutured. Alternatively, the pins may be bent using two needle drivers and left outside the skin. The pins are then cut and covered with pin caps or antibiotic gauze. A sterile dressing is applied, followed by a splint.

**AUTHOR’S PREFERRED TECHNIQUE FOR PERCUTANEOUS PINNING**

- Closed reduction is obtained using a bump, and the reduction is confirmed using fluoroscopy (TECH FIG 3A,B).
- A small incision is placed over the bare spot on the radial styloid between the first and second dorsal compartments (TECH FIG 3C).
- Two 0.062-inch smooth K-wires are placed retrograde from the radial styloid across the reduced fracture, engaging the opposite cortex in a divergent fashion (TECH FIG 3D,E).
- A small incision is placed over the interval between the fourth and fifth dorsal compartments.
- One or two K-wires are placed retrograde from the dorsal ulnar corner of the distal radius across the reduced fracture, engaging the opposite cortex in a divergent fashion (TECH FIG 3F–H).
- The pins are cut just beneath the skin, which is closed with a 5-0 nylon suture. Alternatively, the pins are bent and cut and left outside the skin (TECH FIG 3I).
- A dressing and splint are then applied.

**TECH FIG 3 • A,B.** PA and lateral views demonstrating reduction of distal radius fracture. **C.** The incision is made over the radial styloid. **D.** A pin is inserted retrograde into the radial styloid. **E.** PA radiograph demonstrating the course of the radial styloid wire. **F.** Two radial styloid wires and two dorsoulnar wires are in place. *(continued)*
Distal Pin Placement

- A 3-cm incision is made over the dorsal index metacarpal, exposing the proximal two thirds.
- The distal sensory nerve branches are retracted, and the first dorsal interosseous muscle is elevated from the metacarpal to identify the insertion of the ECRL (TECH FIG 4A).

BRIDGING EXTERNAL FIXATOR APPLICATION

- The index metacarpophalangeal joint is flexed to protect the sagittal band and first dorsal interosseous aponeurosis.
- The metacarpal drill guide is placed on the radial base of the index metacarpal at the flare of the metaphysis. Partially threaded 3- to 4-mm pins are used, with or without predrilling.
A long threaded pin is placed through the index and long metacarpal bases, obtaining three cortices of fixation. Care is taken not to enter the carpometacarpal joint. The double drill guide is then placed over the first pin, and the distal short threaded pin is placed through both cortices of the index metacarpal shaft (TECH FIG 4B,C). Fluoroscopy confirms placement and length of the pins.

**Proximal Pin Placement and Frame Construction**

A 4- to 5-cm incision is made over the radial forearm, proximal to the first dorsal compartment musculature, through skin and subcutaneous tissue, avoiding the lateral antebrachial cutaneous nerve branches. The fascia overlying the interval between the brachioradialis and the ECRL is divided, and the radial sensory nerve is identified and retracted (TECH FIG 5A). The interval between the ECRL and ECRB also may be used to avoid the radial sensory branch.

The double drill guide is placed onto the diaphysis of the radius between the brachioradialis and the radial wrist extensors or between the ECRL and ECRB (TECH FIG 5B). Threaded 3- to 4-mm pins are placed, with or without predrilling. The fracture should be reduced, and the pins placed parallel to the metacarpal pins to facilitate alignment of the fracture. The proximal pin should be placed bicortically, just distal to the tendon of the pronator teres. The distal pin is then drilled bicortically through the double drill guide. Pin placement is confirmed using fluoroscopy. The incisions are closed using nylon suture, ensuring no tension is on the skin at the pin sites. Clamps and rods or adjustable fixators may then be applied to the pins to achieve and maintain final reduction (TECH FIG 5C). Supplementary K-wire fixation is added before or after external fixation (TECH FIG 5D).

**Nonbridging External Fixator Application**

Fracture reduction can be performed after insertion of the distal pins, allowing direct control of the distal fragment. The wrist is placed for a lateral fluoroscopic view, and a marker is used to determine the level of incision halfway between the radiocarpal joint and the fracture. A short transverse skin incision is made just proximal to the radiocarpal joint. A longitudinal incision is then made through the retinaculum on either side of Lister’s tubercle, and the EPL is protected. The first distal pin is drilled using power, parallel to the radiocarpal joint on the lateral view, halfway between the fracture and the joint surface (TECH FIG 6A).
The second distal pin is placed between the second and third dorsal compartments, between the radial wrist extensors and the EPL tendon.

This pin should be placed parallel to the first pin in both planes, with the starting point halfway between the radiocarpal joint and the fracture.

The two proximal radius pins are placed using the technique described for placement of a bridging external fixator.

The incisions are closed, after which the clamps are applied but not tightened.

Reduction is achieved by manipulation of the distal pins and clamps.

Pushing the pins in the dorsal/volar plane corrects dorsal tilt.

Adjusting the pin clamp can correct radial inclination.

Reduction is confirmed using fluoroscopy, and the clamps are tightened (TECH FIG 6B).

PEARLS AND PITFALLS

**Indications**
- Determine stability.
- Determine comminution and supplement fixation with external or internal fixation as necessary.

**Surgical approach**
- Make skin incisions for pin placement to avoid sensory nerves, tendons, and crossing veins.
- Obtain adequate exposure of the radial sensory branch at forearm and hand to avoid injury.

**Hardware placement**
- Choose pins of appropriate diameter.
- Supplement fixation with pins, using external or internal fixation as necessary.
- Do not leave pins more than 1 to 2 mm out of the cortex, and keep all pins extra-articular.
- If placing the proximal metacarpal pin in metaphyseal bone, ensure that three cortices are penetrated.
- Do not back out conical pins, because fixation will be lost.
- Evaluate the DRUJ after fixation to determine stability.
- Subcutaneous pins are more costly to remove, because that requires a second procedure, but they have a lower infection rate. Therefore, if fixation is needed for an extended period, bury the pins.
- Overdistraction of the carpus must be avoided, because it is associated with chronic pain-mediated syndromes and nonunion.

**Postoperative management**
- Allow for adequate immobilization.
- Encourage early range of motion of the fingers, elbow, and shoulder whenever possible.
- Educate the patient regarding appropriate pin care.
- Begin strengthening only after healing is complete and range of motion is maximized.

POSTOPERATIVE CARE

- After fixation with percutaneous pins, alone the wrist is immobilized in a short-arm splint to allow for swelling but provide stability. A cast is applied after the swelling goes down.
- Isolated radial styloid fractures fixed with pins can be placed in a volar wrist splint.

- External fixation devices typically require no additional immobilization, although a volar forearm-based Orthoplast (Johnson & Johnson, Langhorne, PA) splint may be used for support and patient comfort.
- The splint or cast is continued for 4 to 8 weeks, until healing occurs and the pins are removed.
OUTCOMES

A prospective randomized trial comparing percutaneous pinning and casting versus external fixation with augmentation (eg, pins, screws, bone graft) found no difference in clinical outcomes for fractures with minimal articular displacement.9

In patients over 60 years of age, percutaneous pinning has been shown to provide only marginal radiographic improvement over cast immobilization alone, with no correlation with clinical outcome.4

Ebraheim et al5 reported excellent outcomes for restoration of radiographic parameters and functional outcomes with intrafocal pinning and trans-styloid augmentation.

An evaluation of percutaneous pinning outcomes found the best results for metaphyseal fractures. Good results were found for intra-articular fractures. The worst results were seen in fractures with associated unlar styloid fractures and fractures in elderly persons.15

A retrospective review of radiographic and clinical outcomes of open reduction internal fixation (volar and dorsal) versus external fixation revealed no significant differences, except that palmar tilt was more effectively restored with dorsal plating.22

A meta-analysis found no evidence for the use of internal fixation over external fixation for unstable distal radius fractures.12

Women over 55 years of age with unstable intra-articular distal radius fractures treated with external fixation have a high rate of secondary displacement but can have acceptable functional outcomes.10

Patients over the age of 55 years have better results with external fixation and pinning than with pinning alone. Younger patients with two or more sides having comminution also have better results with supplemental external fixation.21

Nonbridging external fixation has been shown to maintain volar tilt and carpal alignment better than bridging external fixation while having significantly better function during the first year.13

Nonbridging external fixation was shown to have no clinical advantage in patients over 60 years of age with moderately or severely displaced distal radius fractures.3

A prospective, randomized comparison of bridging versus nonbridging external fixation revealed more complications in the nonbridging fixators and better outcomes in the bridged fixator group.18

A prospective study compared unrepaird ulnar styloid fractures to those without ulnar styloid fractures and found no significant differences in clinical outcome. However, DRUJ instability was not evaluated.19

COMPLICATIONS

Infection (pin tract or deep). Pin tract infections occur in 10% to 30% of patients.8,9

Finger, elbow, and shoulder range of motion are begun immediately, and wrist range of motion is begun as the fracture heals.

K-wires and half pins should be inspected and cleaned regularly using either soap and water or half-strength hydrogen peroxide and water.

Injury to tendons, vessels, and nerves due to percutaneous technique. Stiffness may result if tendons are inadvertently skewed, and the radial sensory branch can be injured.

Loss of range of motion

Posttraumatic arthritis

Weakness in grip or pinch

Tenosynovitis and tendon rupture

Malunion or nonunion

Compartment syndrome

Carpal tunnel syndrome

Hardware failure

Nonunion (associated with overdistraction with an external fixator)

Complex regional pain syndrome type I (associated with overdistraction with an external fixator)

REFERENCES


DEFINITION

- A bimodal age distribution exists for patients with distal radius fractures (ie, young adults vs elderly persons), and they frequently have a different mechanism of injury.
- Patients 65 years of age or older have an annual incidence of 8 to 10 fractures of the distal radius per 1000 person-years.
  - The incidence is seven times higher in women than in men.
  - Sixteen percent of white women and 23% of white men will sustain a fracture of the distal radius after the age of 50 years.
- Fractures of the distal radius are one of the most common skeletal injuries treated by orthopaedic surgeons.
- These injuries account for one-sixth of all fractures that are evaluated in the Emergency Department.
- Displaced intra-articular fractures of the distal radius are a unique subset of radius fractures.18
  - These fractures are a high-energy injury.
  - This high-energy injury results in comminuted fracture patterns.
  - These fractures are less amenable to traditional closed manipulation and casting.
  - The prognosis for these fractures depends on the amount of residual radius shortening, both radiocarpal and radioulnar articular congruity, and associated soft tissue injuries.22,24

ANATOMY

- The distal radius serves as a plateau to support the carpus.
- The distal radius has three concave articular surfaces: the scaphoid fossa, the lunate fossa, and the sigmoid notch.
- The distal articular surface of the radius has a radial inclination averaging 22 degrees and palmar tilt averaging 11 degrees.
- Radial-based volar and dorsal ligaments arise from the distal radius to support the wrist.
- The sigmoid notch of the distal radius articulates with the ulnar head about which it rotates.
  - The distal radioulnar joint (DRUJ) is primarily stabilized by the triangular fibrocartilage complex (TFCC).
  - The sigmoid notch angles distally and medially at an average of 22 degrees.

PATHOGENESIS

- The biomechanical characteristics of each fracture type depend on the mechanism of injury.
- Fernandez and Geissler4 developed a classification based on the mechanism of injury. They noted that the associated ligamentous lesions, subluxations, and associated carpal fractures are related directly to the degree of energy absorbed by the distal radius.
  - Type I fractures are bending fractures of the metaphysis in which one cortex fails to tensile stress and the opposite one undergoes a certain degree of comminution (eg, extra-articular Smith or Colles’ fractures).
  - Type II fractures are shearing fractures of the joint surface (eg, radial styloid fractures, Barton’s fracture).
  - Type III fractures are compression fractures of the joint surface with impaction of the subcondral and metaphyseal cancellous bone (ie, intra-articular comminuted fractures).
  - Type IV fractures are avulsion fractures of ligamentous attachments, including radial styloid and ulnar styloid fractures, and are associated with radiocarpal fracture-dislocations.
  - Type V fractures are high-energy injuries that involve a combination of bending, compression, shearing, and avulsion mechanisms or bone loss.
- Several studies have shown that a high incidence of associated soft tissue injuries is seen with displaced intra-articular distal radius fractures.9,11–13,17,19,20
  - Arthroscopic studies demonstrate a high incidence of injury to the triangular fibrocartilage complex, followed by the scapholunate interosseous ligament, and then the lunotriquetral interosseous ligament (which is the least injured).
  - A spectrum of injury occurs to the interosseous ligament in which it attenuates and eventually tears and the degree of rotation between the carpal bones increases.
- Geissler et al defined an arthroscopic classification of interosseous ligament tears that helps define the degree of ligament injury and secondary instability as well as proposes treatment (Table 1; see also Chap. HA-41).

NATURAL HISTORY

- Intra-articular fractures of the distal radius have two pathologies: the associated global injury to the soft tissues and the injury to the bone itself.
- The natural history for an intra-articular fracture of the distal radius depends on restoration of anatomy as well as detection and management of any associated soft tissue injuries.1,4
  - Knirk and Jupiter13 documented the importance of articular restoration over extra-articular orientation in predicting outcomes for fractures of the distal radius.
    - They showed solid evidence that the largest tolerable articular step-off is 2 mm.
    - They demonstrate that the better the restoration of the articular surface, the better the outcome.
  - A loss in radius length of 2.5 mm will shift the normal load transmitted across the ulna from 20% to 42%, which may lead to various stages of ulnar impaction syndrome.
Table 1  Geissler Arthroscopic Classification of Carpal Instability

<table>
<thead>
<tr>
<th>Grade</th>
<th>Definition</th>
<th>Arthroscopic Findings</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Attenuation/hemorrhage of interosseous ligament as seen from the radiocarpal joint.</td>
<td>There is a loss of the normal concave appearance between the carpal bones, and the interosseous ligament attenuates and becomes convex as seen from the radiocarpal space. In midcarpal space, the interval between the carpal bones will still be tight and congruent, with no step-off.</td>
<td>Immobilization</td>
</tr>
<tr>
<td>II</td>
<td>Attenuation/hemorrhage of the interosseous ligament as seen from the radiocarpal joint. Incongruency/step-off as seen from the midcarpal space. A slight gap between the carpal bones may be present.</td>
<td>A slight gap (less than the width of a probe) between the carpal bones may be present. The interosseous ligament continues to become attenuated and is convex as seen from the radial carpal space. In the midcarpal space, the interval between the involved carpal bones is no longer congruent, and a step-off is present. In scapholunate instability, palmar flexion of the dorsal lip of the scaphoid will be seen as compared to the lunate. In lunotriquetral instability, increased translation between the triquetrum and lunate will be seen when palpated with a probe.</td>
<td>Arthroscopic reduction and pinning</td>
</tr>
<tr>
<td>III</td>
<td>Incongruency/step-off of carpal alignment is seen in both the radiocarpal and midcarpal spaces.</td>
<td>The interosseous ligament has started to tear, usually from volar to dorsal, and a gap is seen between the carpal bones in the radiocarpal space. A probe often is helpful to separate the involved carpal bones in the radiocarpal space. In the midcarpal space, a 2-mm probe may be placed between the carpal bones and twisted.</td>
<td>Arthroscopic/open reduction and pinning</td>
</tr>
<tr>
<td>IV</td>
<td>Incongruency/step-off of carpal alignment is seen in both the radiocarpal and midcarpal spaces. Gross instability with manipulation is noted.</td>
<td>A 2.7-mm arthroscope may be passed through the gap between the carpal bones. The interosseous ligament is completely detached between the involved carpal bones. This is the “drive-through” sign, when the arthroscope may be freely passed from the radiocarpal space through the tear to the midcarpal space.</td>
<td>Open reduction and repair</td>
</tr>
</tbody>
</table>

Untreated complete tears of the scapholunate interosseous ligament, which are highly associated with radial styloid fractures, may progress to a wrist with scapholunate advanced collapse.

PATIENT HISTORY AND PHYSICAL FINDINGS

A thorough history should be obtained, including the circumstances surrounding the injury as well as any additional injuries.

- Neurologic basis
- Cardiac basis
- Patients’ level of independence, dominant hand, status with assisted devices, work, activity level, and support structure should be determined.
- Physical examination, while concentrating on the wrist, should also include the hand, elbow, and shoulder to check for concomitant injuries.
- The hand, wrist, arm, and shoulder must be carefully inspected for open injury so that tetanus and antibiotic prophylaxis may be initiated if necessary.
- Thorough distal sensory and motor function examination should be carried out in an organized manner.
- Vascular examination should include palpation of both the radial and ulnar pulses and determination of capillary refill time.
- Precise palpation is used to define areas of potential trauma.

Diminished sensibility, pallor, altered capillary refill, increased tensesness of the soft tissues, and pain out of proportion should raise suspicion for significant soft tissue injury, including compartment syndrome.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Posteroanterior (PA), oblique, and lateral radiographs are the primary radiographic workup for distal radius fractures.
- Contralateral radiographs of the uninvolved extremity are useful to compare radial inclination, ulnar variance, and sigmoid notch anatomy.
- PA projections are useful to evaluate the radial inclination, radius height, presence of ulnar styloid fractures, widening of the DRUJ, widening of intracarpal spaces, and intra-articular involvement (FIG 1A).
- Standard radiographic parameters of the distal radius include radial inclination of 23 degrees (range 13–30), radius length of 12 mm (range 8–18 mm), and volar tilt of 12 degrees (range 1–21 degrees).
- Ulnar variance should be measured with the shoulder in 90 degrees of abduction, the elbow at 90 degrees of flexion, and the wrist in neutral pronation-supination.
- A lateral projection is used to assess volar and dorsal tilt of the distal fragment, dislocation or subluxation of the DRUJ or carpus, lunate angulation, and dorsal comminution (FIG 1B).
A modified lateral radiograph with the beam angulating 10 to 30 degrees proximally improves visualization of the articular surface and evaluation of the volar rim of the lunate facet represented by the anterior teardrop. An additional 30-degree anteroposterior (AP) cephalic projection is useful to evaluate the dorsal ulnar margin of the distal radius. Oblique radiographs are very helpful, because major fracture fragments may be rotated out of their anatomic planes. CT evaluation, particularly three-dimensional CT, can further delineate fragment location, joint compression, and rotation. MRI evaluation is useful in assessing for associated soft tissue injuries such as TFCC tears, interosseous ligament injuries, and carpal fractures.

Radiographic signs that demonstrate that the distal radius fracture is likely unstable and closed reduction would be insufficient include13:

- Lateral tilt greater than 20 degrees dorsal
- Dorsal comminution greater than 50% of the width
- Initial fragment displacement greater than 1 cm
- Volar translation greater than 2 mm
- Initial radius shortening more than 5 mm
- Intra-articular step-off greater than 2 mm
- Associated ulna fracture
- Severe osteoporosis.
- Age greater than 60 years

**DIFFERENTIAL DIAGNOSIS**

- Carpal bone fracture
- Metacarpal or phalangeal fracture
- DRUJ disruption
- Essex-Lopresti lesion
- Interosseous ligament tear
- Carpal dislocation (perilunate)

**NONOPERATIVE MANAGEMENT**

- Displaced fractures of the distal radius are reduced using an adequate anesthetic agent.
- Knowledge of the mechanisms of injury helps facilitate manual reduction. Force is applied opposite the force that caused the fracture.
- Gentle traction is necessary to disimpact the fracture fragments, followed by palmar translation of the hand and carpus in respect to the radius.
- The radius articular surface will rotate around the intact volar cortical lip to restore volar inclination with palmar translation.
- Care must be taken to avoid trauma to the skin during the reduction maneuver, particularly in elderly patients where the skin may be fragile.
- A splint is supplied following the reduction. No consensus has been established regarding wrist or forearm position, long-arm versus short-arm immobilization, or splint versus cast.
- Extreme positions of wrist flexion and ulnar deviation should be avoided.
- Postreduction radiographs are taken in plaster.
- Depending on stability of the fracture, most patients treated nonoperatively require weekly visits for the first 3 weeks to monitor fracture reduction.
- In patients older than 65 years, one third of initially undisplaced fractures subsequently collapsed to some degree.
- One study of elderly patients with moderately displaced fractures of the distal radius found that two thirds of the correction obtained by closed manipulation was lost at 5 weeks.
- Patients with minimally displaced or nondisplaced fractures of the distal radius treated nonoperatively must be made aware of possible complications, including rupture of the extensor pollicis longus tendon, carpal tunnel syndrome, and compartment syndrome.

**SURGICAL MANAGEMENT**

- Distal radius fractures without extensive metaphyseal comminution are ideal candidates for arthroscopic-assisted fixation with K-wires or cannulated screws.7,8
  - Radial styloid fractures
  - Impacted fractures
  - Die punch fractures
  - Three-part T-type fractures and four-part fractures with metaphyseal comminution are best treated with a combination of volar plate stabilization. Wrist arthroscopy is used as an adjunct to fine-tune the articular reduction and evaluate for associated soft tissue lesions.
  - Distal radius fractures that may be minimally displaced, and fractures with strongly suspected associated soft tissue injury, also are candidates for arthroscopic-assisted fixation to stabilize the fracture but, more importantly, to evaluate and treat the acute associated soft tissue injury.
  - Stabilization of associated ulnar styloid fragments is controversial.11 Wrist arthroscopy provides a rationale as to when to stabilize an ulnar styloid fragment.

**Preoperative Planning**

- All radiographic studies are reviewed.
- Equipment needed for arthroscopic treatment and for open stabilization is made available.
  - Small joint instrumentation is essential for arthroscopic-assisted fixation of distal radius fractures. The small joint arthroscope is approximately 2.7 mm in diameter, and even
smaller scopes may be used if desired. In addition, a small joint shaver (3.5 mm or less) is useful to clear fracture debris and hematoma.

- The ideal timing for arthroscopic-assisted fixation of distal radius fractures is 3 to 10 days following injury.6
- Earlier attempts at fixation may be complicated by soft tissue swelling and troublesome bleeding, obscuring visualization.
- After 10 days, the fracture fragments start to become sticky and more difficult to percutaneously elevate and reduce.

### Positioning

Arthroscopic-assisted fixation of distal radius fractures may be performed with the arm suspended vertically in a traction tower, horizontally in a traction tower, or with finger traps applied attached to weights hanging over the edge of the hand table.

- Wrist arthroscopy in the horizontal position may make it easier to simultaneously monitor the reduction fluoroscopically and place hardware. However, it does not allow for simultaneous volar access to the wrist.
- Suspending the wrist in a vertical position with a traction tower allows simultaneous access to both the volar and dorsal aspects of the wrist. This is particularly useful when wrist arthroscopy is used as an adjunct to volar plate fixation of the distal radius fracture.
- A new traction tower has been designed to allow simultaneous evaluation of the intra-articular reduction of the distal radius arthroscopically and fluoroscopically (FIG 2A).
- The surgeon may stabilize a comminuted fracture of the distal radius with a plate and simultaneously evaluate the articular reduction arthroscopically.
- The traction tower allows for traction of the wrist in either the vertical or horizontal planes, depending on the surgeon’s preference (FIG 2B).

### Approach

- The wrist is suspended in a traction tower, and the standard dorsal 3/4 viewing portal, 4/5 or 6R working portal, and 6U inflow portal are made.
- It is difficult to palpate the normal extensor tendon landmarks for traditional wrist arthroscopy in patients who sustain a fracture of the distal radius because of swelling.10 However, the bony landmarks usually can still be palpated. These bony landmarks include the bases of the metacarpals, the dorsal lip of the radius, and the ulnar head.
- The 3/4 portal is made in line with the radial border of the long finger. It is very useful to place a no. 18 needle into the proposed location of the 3/4 portal before making a skin incision.
- If the portal is placed too proximal, the arthroscope may be placed within the fracture pattern itself. If it is placed too distal, it can injure the articular surface of the carpus.
- Once the precise ideal location of the portal is located, the portal is made by pulling the skin with the surgeon’s thumb against the tip of a no. 11 blade. Blunt dissection is carried down with a hemostat, and the arthroscope, with a blunt trocar, is introduced into the dorsal 3/4 portal.
- This technique decreases potential injury to cutaneous nerves.
- Thorough irrigation of the joint is necessary to wash out fracture hematoma and debris and improve visualization. Inflow may be provided through the arthroscopy cannula or separately through a no. 14 needle into the 6U portal.
- Use of a separate 6U inflow portal is recommended. The small-joint arthroscopy cannula does not allow as much space between the cannula and the arthroscope, limiting the amount of flow through the cannula.
- Outflow to the wrist is provided through intervenous extension tubing connected to the arthroscopy cannula.
- The 4/5 working portal is made in line with the mid-axis of the ring metacarpal. Alternatively, the 6R working portal is made just radial to the palpable extensor carpi ulnaris tendon.
- A no. 18 needle is placed into the joint and should lie just distal to the articular disc.
- A 4/5 or 6R portal usually is located just proximal to the 3/4 portal because of the natural radial slope of the distal radius.

![FIG 2](image-url) • A. This traction tower (Acumed, Hillsboro, OR) uses a suspension bar at the side rather than at the center of the wrist. This allows easy fluoroscopic evaluation of the fracture reduction, with simultaneous full access to the volar and dorsal aspects of the wrist. B. The tower can be flexed into a horizontal position for surgeons who prefer to treat distal radius fractures in that position.
RADIAL STYLOID FRACTURES

- An isolated fracture of the radial styloid is an ideal fracture pattern to manage arthroscopically, especially for the surgeon beginning to gain experience in arthroscopic-assisted fixation of distal radius fractures.
- In addition, radial styloid fractures have a high incidence of associated injury to the scapholunate interosseous ligament, which is best assessed arthroscopically.
- Insert one or two guidewires from a cannulated screw system percutaneously into the radial styloid—not across the fracture site—using a wire driver in oscillation mode.
  - Evaluate the position of the wires under fluoroscopy to ensure they are centered in the radial styloid fragment.
- Suspend the wrist in a traction tower and establish the standard arthroscopic portals.
- Insert the scope in the dorsal 3/4 portal and clear the joint of debris and hematoma.
- Transfer the arthroscope to the 6R or 4/5 portal to look across the wrist and effectively judge rotation and reduction of the radial styloid fragment.
- Using the previously placed guidewires as joysticks, manipulate and anatomically reduce the fracture fragment under direct arthroscopic observation.
  - A trocar can be inserted through the 3/4 portal to help further guide the reduction of the radial styloid fragment (TECH FIG 1A,B).
- Once the fracture is judged to be absolutely anatomic, the guidewires are advanced across the fracture site into the radius shaft and evaluated under fluoroscopy (TECH FIG 1C).
  - In many cases, the fracture reduction may look anatomic under fluoroscopy, but when viewed arthroscopically, the radial styloid fragment is seen to be slightly rotated.³
- Guidewires alone can be used to stabilize the fracture, but cannulated screws (with or without heads) are recommended (TECH FIG 1D,E).
  - Cannulated screws decrease soft tissue irritation and potential pin track infection as compared with K-wires.

TECH FIG 1 • A. Arthroscopic view of the patient whose radiographs are seen in Figure 1. The arthroscope is in the 6R portal looking across the wrist, and a blunt trochar is in the 3/4 portal. The displaced radial styloid fragment is well visualized. B. A combination of joysticks inserted into the radial styloid fragment and a trochar inserted into the 3/4 portal allows anatomic reduction of the displaced radial styloid fragment and radiocarpal joint. C. The radial styloid fragment is anatomically reduced (with no residual rotation) and stabilized. D. PA view demonstrating anatomic reduction to the radial styloid fragment. Headless cannulated screws are used, if possible, to avoid soft tissue irritation. E. Lateral view showing anatomic restoration to the radial styloid fragment and restoration of the carpus in line with the radius.
THREE-PART FRACTURES

- Three-part fractures that involve a displaced fracture of the radial styloid and a lunate facet fragment without metaphyseal comminution are ideal for arthroscopic-assisted reduction (TECH FIG 2A,B).
- Reduce and provisionally stabilize the radial styloid fragment with guidewires under fluoroscopic guidance.
  - The radial styloid serves as a landmark to which the depressed lunate facet fragment is reduced.
- Suspend the wrist in the traction tower, establish portals, and evacuate the fracture debris and hematoma.
  - The depressed lunate facet fragment is best seen with the arthroscope in the 3/4 portal (TECH FIG 2C,D).
- Percutaneously place a no. 18 needle directly over the depressed fragment as viewed arthroscopically.
- Insert a large K-wire about 2 cm proximal to the previously placed no. 18 needle to percutaneously elevate the depressed lunate facet fragment.
  - Use a bone tenaculum to further diminish the gap between the radial styloid and lunate facet fragments.
  - Place guidewires transversely under the subchondral surface of the radius from the radial styloid into the anatomically reduced lunate facet fragment.
  - It is important to pronate and supinate the wrist following placement of the transverse pins to ensure the guidewires have not violated the DRUJ. The concave nature of the DRUJ makes radiographic assessment difficult.
  - Consider insertion of bone graft to support the reduced lunate fragment and avoid late settling.
  - Make a small incision between the fourth and fifth dorsal compartments.
  - Use cancellous allograft bone chips or bone substitutes.
  - If feasible, place headless cannulated screws to stabilize both the radial styloid and the impacted lunate facet fragments (TECH FIG 2E–H).

TECH FIG 2 • A. PA view showing a impacted scaphoid facet fracture fragment with an obvious injury to the scapholunate interosseous ligament. B. Lateral view showing a dorsal rim fracture fragment. C. The arthroscope is in the 6R portal, demonstrating the impacted scaphoid facet fracture fragment. This would be quite difficult to view through an open arthrotomy, but is well visualized arthroscopically under bright light and magnified conditions. D. The impacted scaphoid facet fragment is elevated back to the volar rim, using the rim as a landmark to judge rotation. E,F. Geissler grade III tear involving the scapholunate interosseous ligament as seen through the 3/4 portal (E) and the radial midcarpal portal (F). (continued)
THREE- AND FOUR-PART FRACTURES WITH METAPHYSEAL COMMINUTION

- A combination of open surgery, using a volar plate for stability, and arthroscopy, as an adjunct to assist the articular reduction, is used if metaphyseal comminution is present (TECH FIG 3).
- Volar plate stabilization is very stable and allows for early range of motion and rehabilitation as compared to K-wires or headless screws alone.

Open Reduction and Stabilization

- Perform a standard volar approach and do not open the radiocarpal joint capsule (TECH FIG 4A).
- The radial styloid fragment and the volar ulnar fragment are reduced to the shaft under direct visualization. The radial styloid fragment is provisionally pinned.
- Apply a volar distal radius locking plate to stabilize the volar bone fragments (TECH FIG 4B).
  - Place a screw in the proximal portion of the plate first, to reduce the plate to the shaft.
- Provisionally pin the distal fragments through the plate.
- Manipulate the articular fragments under fluoroscopy to obtain as anatomic a reduction as possible (TECH FIG 4C,D).
- Suspend the wrist in the traction tower and reduce the articular fragments arthroscopically (TECH FIG 4E,F).
  - If articular reduction is not anatomic, remove the pins and fine-tune the reduction.
- Once the fracture reduction is thought to be anatomic, place the distal screws through the plate (TECH FIG 4G–I).
  - It is important that the fracture be reduced to the plate, with no gap between the plate and the bone. This can be achieved by flexion of the wrist in the tower and by insertion of a non-locking screw first, before the insertion of standard locking screws.
  - Place the remaining proximal and distal screws if the reduction is anatomic under both fluoroscopy and arthroscopy.
TECH FIG 4 • A. A standard volar approach is made, centered over the flexor carpi radialis tendon, and the fracture site is exposed. B. A volar distal radius locking plate (Acumed, Hillsboro, OR) is applied. The initial screw is placed through the proximal plate to secure the plate to the shaft. C. The intra-articular reduction is viewed under fluoroscopy and provisionally pinned. A displaced intra-articular fracture fragment can still be identified. D. The arthroscope is in the 3/4 portal, showing the volar capsule blocking reduction of the radial styloid fragment. E. Joysticks previously inserted into the radial styloid fragment are then used to control and anatomically reduce the radial styloid fragment. F. The arthroscope is in the 6R portal looking across the wrist. Anatomic reduction of the radial styloid fragment is documented. G. Once the anatomic restoration of the articular surface is evaluated both arthroscopically and fluoroscopically, the distal screws are placed in the plate. H. Fluoroscopic view showing anatomic restoration to the articular surface of the distal radius. I. The patient had an associated osteochondral fracture of the lunate, not visible on plain radiographs. The displaced fragment is arthroscopically removed.
Reduction and Stabilization of a Dorsal Die Punch Fragment

- It is not possible to see the reduction of a dorsal die punch fragment through the volar approach when stabilized with a plate. Arthroscopy can be helpful in this scenario.
- Insert the volar plate as previously described and provisionally fix the device to the radius.
- Frequently, the dorsal fragment may still be slightly proximal in relation to the radial shaft.

ULNAR STYLOID FRACTURES

- Following anatomic reduction of the distal radius fracture, insert the arthroscope in the dorsal 3/4 portal and the probe in the 6R portal. Palpate the tension of the articular disc.
  - Good tension indicates that the majority of the peripheral TFCC fibers are intact or still attached to the proximal ulna.
  - A peripheral tear of the articular disc is repaired arthroscopically when detected.
- Stabilization of a large ulnar styloid fragment is considered when the articular disc is lax by palpation and no peripheral TFCC is identified (TECH FIG 5).
  - In this instance, the majority of the fibers of the TFCC are attached to the displaced ulnar styloid fragment.
- Make a small incision between the extensor carpi ulnaris and the flexor carpi ulnaris tendons and identify the fracture site.
- Retrieve the distal fragment, which often displaces in a distal and radial direction.
- Mobilize the styloid fragment using a no. 15 blade, taking care to protect the TFCC insertion.
- Reduce the fragment anatomically, under direct visualization, and insert a guidewire in a retrograde manner for provisional stability.
- Stabilize the ulnar styloid fragment using either a tension band technique (with wire and two K-wires) or, preferably, using a micro headless cannulated screw.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Timing of reduction</th>
<th>Arthroscopically assisted reduction of distal radius fractures is most ideal between 3 and 10 days following injury. Assisted fixation before 3 days usually is complicated by bleeding that can obscure visualization. Percutaneous fracture reduction more than 10 days after the injury is exceedingly difficult and often unsuccessful.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arthroscopic visualization</td>
<td>It is important to take the time to thoroughly irrigate and débride the joint of hematoma and debris. This especially helps visualization of fragment rotation. Irrigation through a separate 6U inflow portal is helpful. A Coban wrap (3M, St. Paul, MN) may be wrapped around the forearm to limit fluid extravasation into the soft tissues.</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>Large-joint instrumentation will damage the articular cartilage and is not appropriate. A mobile traction tower is extremely helpful in arthroscopic-assisted management of distal radius fractures.</td>
</tr>
<tr>
<td>Fixation</td>
<td>Do not substitute poor fixation for an arthroscopically assisted procedure. Fixation should be chosen to fit the personality of the fracture. For example, K-wires should not be used to stabilize a volar Barton’s fracture when volar plate stabilization is the obvious choice. While K-wires are easy to insert, they hinder rehabilitation and have the potential for pin track infections.</td>
</tr>
</tbody>
</table>
Cannulated screws are recommended when arthroscopically stabilizing a fracture of the distal radius without metaphyseal comminution.

Volar plate fixation is recommended when metaphyseal comminution is present.

Arthroscopic evaluation of the wrist while the distal screws are being placed offers the advantage of seeing the screws penetrate into the fracture fragments, thereby ensuring stability. Arthroscopic evaluation is helpful in variable-angle volar locking plates to ensure the screws do not violate the joint.

POSTOPERATIVE CARE

- The degree of postoperative immobilization depends on numerous factors, including the mode of fracture stabilization, the quality of the bone for internal fixation, the stability of the fixation, and the management of any associated soft tissue injuries that were addressed during the arthroscopic evaluation.
- Immediate range of motion of the digits and wrist is initiated in patients with volar plate fixation with good bone stock and solid fixation.
- In patients with soft osteopenic bone with volar plate fixation, digital range of motion exercises are initiated immediately, but wrist range of motion is delayed approximately 3 to 4 weeks to permit some fracture healing.
- Soft bone may collapse around the rigid plate.
- In patients without metaphyseal comminution treated by arthroscopically assisted stabilization with cannulated screws, range of motion is initiated as the patient tolerates.
- In patients treated with percutaneous K-wires, the wrist is immobilized until the wires are removed, usually 4 to 6 weeks after surgery.
- A patient with an unstable DRUJ treated by TFCC repair or ulnar styloid reduction and fixation is restricted from pronation and supination for 2 to 4 weeks.

OUTCOMES

- The literature is relatively sparse regarding the results of arthroscopically assisted fixation of displaced intra-articular distal radius fractures.
- A comparison study of 12 open and 12 arthroscopic reductions of comminuted AO type VII and VIII fractures of the distal radius found that the arthroscopic group had increased range of motion as compared to the open stabilization group.\(^{23}\)
- A second comparison study of 38 patients who underwent arthroscopically assisted fixation compared to open reduction found the arthroscopically assisted group had better results and improved range of motion.\(^{2}\)
- One study compared 15 patients with arthroscopically assisted fixation to 15 patients who underwent closed reduction and external fixation.\(^{21}\) In this study, there were 10 tears of the triangular fibrocartilage complex in the group that underwent arthroscopic reduction, of which seven were peripheral and repaired. There were no signs of distal radioulnar joint instability at final follow-up visit. In the 15 patients who underwent stabilization by external fixation alone, four patients had continued complaints of instability of the distal radial joint, very possibly the result of undiagnosed and untreated TFCC tears.

COMPILATIONS

- Failure of fixation
- Late settling of the fracture despite fixation
- Flexor and extensor tendon irritation
- Painful metal requiring removal
- Neuromas of the dorsal sensory branch of the radial and ulnar nerves
- Carpal tunnel syndrome
- Reflex sympathetic dystrophy
- Wrist and hand stiffness

REFERENCES

DEFINITION

- Fragment-specific fixation is a treatment approach in which each major fracture component is identified and fixed independently using low-profile implants with a certain degree of "spring-like" elasticity.
- Each fracture component has a unique implant specifically designed for that particular fracture element (FIG 1).
- Surgical planning is extremely important to determine whether a single approach or a combination of surgical approaches is needed to visualize and fix each of the main fracture components present in a particular injury.
- At the start of surgery, a complete set of implants should be available to address fractures of the radial column, ulnar corner, volar rim, dorsal wall, and free impacted articular fragments. In addition, identification and treatment of distal radioulnar joint (DRUJ) disruptions or unstable fractures of the ulnar column may be required.
- As a rule, this technique avoids creating large holes in small distal fragments, with fixation based and often triangulated to the stable ipsilateral cortex of the proximal fragment.

- The goal of fragment-specific fixation is to create a multi-planar, load-sharing construct that anatomically restores the articular surface and has enough stability to allow immediate motion after surgery.

ANATOMY

- The radial column fragment is formed from the pillar of bone along the radial border (FIG 2). This fracture component is important to maintain radial length to support the carpus in its normal spatial position. The brachioradialis inserts on the base of the radial column and may result in shortening of the radial column fragment, leading to impaction of the carpus into remaining fragments. Metaphyseal comminution may also contribute to radial column instability.
- The volar rim of the lunate facet is a primary load-bearing structure of the articular surface. Instability of the volar rim occurs in two patterns:
  - In the volar instability pattern, shortening and volar translation of the volar rim result in secondary volar subluxation of the carpus.

FIG 1 • Fragment-specific implants.
In the axial instability pattern of the volar rim, axial impact of the carpus drives the volar rim into dorsiflexion, resulting in secondary axial and dorsal subluxation of the carpus.

- The ulnar corner fragment involves the dorsal half of the sigmoid notch. Typically a result of impaction of the lunate into the articular surface, this fragment migrates dorsally and shortens proximally. Residual displacement of the ulnar corner can result in instability of the DRUJ as well as restriction of forearm rotation.
- Dorsal wall fragmentation typically occurs with either dorsal bending injuries or axial loading injuries and may contribute to fracture instability.
- Free articular fragments may be impacted within the metaphyseal cavity and result in incongruity of the articular surface.

**PATHOGENESIS**
- Dorsal bending injuries result in extra-articular fractures with dorsal displacement. Comminution of the metaphyseal cavity or dorsal wall usually suggests a dorsally unstable fracture pattern.
- Volar bending injuries result in extra-articular fractures with volar displacement. Fractures with significant volar displacement are nearly always unstable and require some type of intervention to obtain and hold a reduction until union.
- Dorsal shearing injuries present as fractures of the dorsal rim and are often associated with dorsal instability of the carpus. (FIG 3C). Volar shearing injuries present as displaced fractures of the volar rim and result in volar instability of the carpus. (FIG 3D). Often, this pattern is comminuted and highly unstable and not suited to closed methods of treatment.
- Simple three-part fractures are usually the result of low-energy injuries that combine an axial loading and dorsal bending mechanism. This pattern is characterized by the presence of an ulnar corner fragment that involves the dorsal portion of the sigmoid notch, a main articular fragment, and a proximal shaft fragment.
- Unstable fractures with complex involvement of the articular surface to simplify complex articular fractures. In addition to articular comminution, this pattern may often generate a significant defect in the metaphyseal cavity or complete disruption of the DRUJ (FIG 3F).
The avulsion and carpal instability pattern is primarily a ligamentous injury of the carpus that has associated osseous avulsions of the distal radius (FIG 3G).

Extremely high-energy injuries present as complex fractures involving comminution of the articular surface as well as extension into the radial or ulnar shaft (FIG 3H).

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Posteroanterior (PA), standard lateral (FIG 4A,B), and 10-degree lateral views are routine views for radiographic evaluation of the distal radius. The 10-degree lateral view (FIG 4C,D) clearly visualizes the ulnar two thirds of the articular surface from the base of the scaphoid facet through the entire lunate facet. Oblique views may also be helpful for evaluating the injury.

- The radiographic features of distal radius fractures include the following:
  - Carpal facet horizon (FIG 5A,B). This is the radiodense horizontal landmark that is used to identify the volar and dorsal rim on the PA view. If the articular surface is in palmar tilt, the x-ray beam is parallel to the subchondral bone of the volar half of the lunate facet and the carpal facet horizon identifies the volar rim. However, if the articular surface is in dorsal tilt, the x-ray beam is parallel to the subchondral bone of the dorsal half of the lunate facet and the carpal facet horizon identifies the dorsal rim (not shown). The carpal facet horizon is the portion of the articular surface that is visualized on the 10-degree lateral x-ray projection.
  - Teardrop angle (normal 70 ± 5 degrees; FIG 5C,D). The teardrop angle is used to identify dorsiflexion of the volar rim of the lunate facet. Depression of the teardrop angle to a value less than 45 degrees indicates that the volar rim of the lunate facet has rotated dorsally and impacted into the metaphyseal cavity (axial instability pattern of the volar rim). This may be associated with axial and dorsal subluxation of the carpus. Restoration of the teardrop angle is necessary to correct this type of malreduction.
  - Articular concentricity (FIG 5E,F). The subchondral outline of the articular surface of the distal radius is normally congruent and concentric with the subchondral outline of the base of the lunate; a uniform joint interval should be present between the radius and lunate along the entire articular surface. When these articular surfaces are

FIG 5 • A. Carpal facet horizon (arrows). Used to differentiate between the volar and dorsal rim on the PA projection. B. Origin of carpal facet horizon. The carpal facet horizon is formed by that part of the articular surface that is parallel to the x-ray beam and depends on whether the articular surface is in volar or dorsal tilt. C. Normal teardrop angle. D. Depressed teardrop angle, in this case caused by axial instability of the volar rim. (continued)
Clinical and radiographic evaluations of the carpus, interosseous membrane, and elbow are used to identify the presence of other associated injuries that may affect the decision for a particular treatment.

SURGICAL MANAGEMENT

Operative Indications
- General parameters:
  - Shortening of more than 5 mm
  - Radial inclination of less than 15 degrees
  - Dorsal angulation of more than 10 degrees
  - Articular stepoff of more than 1 to 2 mm
  - Depression of teardrop angle of less than 45 degrees
  - Volar instability
  - DRUJ instability
  - Displaced articular fractures
  - Young, active patients are generally less tolerant of residual deformity and malposition.

Preoperative Planning
- Extra-articular fractures: multiple options:
  - Volar plating through a volar approach
  - Dorsal plating through a dorsal approach
  - Fragment-specific fixation
    - Radial pin plate (TriMed, Inc., Valencia, CA) and volar buttress pin (TriMed, Inc.) fixation through a limited incision volar or standard volar approach
    - Radial pin plate and either an ulnar pin plate dorsally or a dorsal buttress pin through a dorsal or combined approach
  - Intra-articular fractures: surgical approach is based on the fragmentation pattern
    - Unstable volar rim fragments require a standard volar or ulnar-volar approach for adequate visualization.
Fixation of the radial column can be done through either a limited-incision volar-radial approach, a volar approach with a radial extension combined with pronation of the forearm, or a dorsal approach with radial extension combined with supination of the forearm. Fixation of dorsal, ulnar corner, and free intra-articular fragments can be done through a dorsal approach.

**Positioning**
- The patient is supine.
- The affected arm is on an armboard out to the side.
- C-arm
  - If the armboard is radiolucent, the C-arm can be brought in from the end of the armboard and images taken directly with the wrist on the armboard.
  - If the armboard is not radiolucent, the C-arm is brought in along the side of the table from the foot, and the arm is brought off the armboard for each image.

**Operative Sequence**
- Radial column length is restored first with traction; a transstyloid pin is inserted to hold the reduction if needed.
- The volar rim is reduced and fixed.
- The dorsal ulnar corner is reduced and fixed.
- Free intra-articular fragments and the dorsal wall if needed are reduced and stabilized.
- Bone graft is applied if the metaphyseal defect is large.
- Fixation is completed with a radial column plate.

**Approach**
- The repair is undertaken by means of one of the following approaches:
  - Limited-incision volar approach
  - Dorsal approach
  - Extensile volar approach
  - Volar-ulnar approach

---

**LIMITED-INCISION VOLAR APPROACH**

- Make a longitudinal incision along the radial side of the radial artery.
- Proximally, insert the tip of a tenotomy scissors over the surface of the first dorsal compartment sheath and sweep distally to elevate a radial skin flap.
- Pronate the forearm and sharply expose the bone over the radial styloid in the interval between the first and second dorsal compartments (TECH FIG 1A).
- Leaving the distal 1 cm of sheath intact, open the first dorsal compartment proximally and mobilize the tendons.

Reflect the insertion of brachioradialis to expose the radial column (TECH FIG 1B).
- If needed, the dissection can be continued through the floor of the incision to expose the volar surface. Detach the insertion of the pronator quadratus radially and distally and reflect it to the ulnar side. Alternatively, create an ulnar skin flap superficial to the artery and continue the exposure through a standard volar approach.
- This approach cannot be used to access the ulnar side of the volar rim.
DORSAL APPROACH

- Make a longitudinal skin incision dorsally along the ulnar side of the tubercle of Lister (TECH FIG 2A).
- Identify the extensor digitorum communis (EDC) tendons visible proximally through the translucent extensor sheath. Incise the dorsal retinacular sheath.
- Develop the interval between the third and fourth compartment tendons for access to dorsal wall and free, impacted articular fragments. Resect a segment of the terminal branch of the posterior interosseous nerve (TECH FIG 2B).
- Transpose the extensor pollicis longus (EPL) from the tubercle of Lister if required for additional exposure.
- Develop the interval between the fourth and fifth extensor compartments to gain access to the ulnar corner fragment.
- A dorsal capsulotomy can be done to visualize the articular surface and carpus if necessary.
- To gain access to the radial column through a dorsal exposure, extend the incision as needed and elevate a radial subcutaneous flap and supinate the wrist.
- To gain access to the distal ulna, extend the incision as needed and elevate an ulnar subcutaneous flap.

EXTENSILE VOLAR APPROACH

- Start the skin incision at the distal pole of the scaphoid and angle it toward the radial border of the flexor wrist crease, then extend it proximally along the flexor carpi radialis (FCR) tendon (TECH FIG 3A).
- Open the FCR tendon sheath both proximally and distally and continue in the plane between the FCR tendon and the radial artery (TECH FIG 3B).
- Use blunt dissection with a finger or sponge to separate the interval between the contents of the carpal tunnel and the surface of the pronator quadratus. Retract the FCR, median nerve, and flexor tendons to the ulnar side.
- Divide the radial and distal attachment of the pronator quadratus and reflect it to the ulnar side. Limit the distal dissection to no more than 1 or 2 mm beyond the distal radial ridge to avoid detachment of the volar wrist capsular ligaments (TECH FIG 3C).
- Reflect the brachioradialis from its insertion on the distal fragment if needed. Bone graft can be applied through the radial fracture defect.
- If access to the radial column is needed, elevate a radial subcutaneous flap superficial to the radial artery and first dorsal compartment tendon sheath. Pronate the wrist and retract the radial skin flap to expose the radial column.
VOLAR-ULNAR APPROACH

- Make a longitudinal skin incision along the ulnar border of the flexor carpi ulnaris (FCU) tendon (TECH FIG 4A).
- Reflect the FCU tendon and the ulnar artery and nerve to the ulnar side (TECH FIG 4B).
- With blunt finger or sponge dissection, develop the plane on the superficial surface of the pronator quadratus.
- Retract the contents of the carpal tunnel to the radial side (TECH FIG 4C).
- Reflect the pronator quadratus from its ulnar and distal attachment. Do not dissect more than 1 to 2 mm beyond the distal radial ridge to avoid detaching the volar wrist capsule.

RADIAL COLUMN FIXATION WITH RADIAL PIN PLATE

- Expose the radial column with any of the approaches previously described. Sharply expose the interval between the first and second dorsal compartments over the tip of the radial styloid. Release the tendon sheath of the first dorsal compartment proximally, leaving the last 1 cm of tendon sheath intact.
- Retract the tendons of the first dorsal compartment dorsally or volarly as needed. Release the terminal insertion
of the brachioradialis to complete exposure of the radial column.

- After the initial fracture exposure, restore radial length with traction and ulnar deviation of the wrist. If needed, structural bone graft can be inserted through the radial fracture defect.

- Insert a 0.045-inch transstyloid Kirschner wire angled to engage the far cortex of the proximal fragment (TECH FIG 5A). When the advancing tip of the Kirschner wire hits the far cortex, place a drill sleeve over the Kirschner wire to use as a drill stop to limit penetration of the far cortex to 1 to 2 mm.

- Once the radial column is temporarily fixed with a transstyloid Kirschner wire, reduce and stabilize other volar, dorsal, and articular fracture elements before completing fixation of the radial column.

- Select a distal pin hole and slide a radial pin plate over the transstyloid Kirschner wire. Proximally, guide the plate under the tendons of the first dorsal compartment and secure it initially with a single 2.3-mm bone screw.

- Insert a second transstyloid Kirschner wire through a non-adjacent distal pin hole. Use the previous technique to limit penetration of the Kirschner wire through the far cortex to 1 to 2 mm.

- Mark a reference point where the Kirschner wire crosses the surface of the plate. Withdraw the Kirschner wire 1 cm and cut it 1 cm or more above the reference mark (TECH FIG 5B).

- Position the reference mark between the lower two posts of a wire bender and create a hook (TECH FIG 5C). The bend should start at the reference mark to make a Kirschner wire of proper length when completed.

- Complete the bend with a pin clamp, overbending slightly to allow the hook to snap into an adjacent pin hole or over the edge of the plate. With a free 0.045-inch Kirschner wire, predrill a hole to accept the end of the hook (TECH FIG 5D).

- Impact the Kirschner wire with a pin impactor and fully seat the hook (TECH FIG 5E). Repeat the procedure with the second Kirschner wire.

- Complete proximal fixation with 2.3-mm cortical bone screws (TECH FIG 5F,G).

**TECH FIG 5** - Radial column fixation. **A.** Insertion of transstyloid Kirschner wire. **B,C.** Creation of pin hook. **D,E.** Completion and impaction of pin hook. **F,G.** Completed radial column fixation.
ULNAR CORNER AND DORSAL WALL FIXATION

**Ulnar Pin Plate**
- Through a dorsal approach, expose and reduce the dorsal ulnar corner fragment, dorsal wall fragment, or both.
- Insert a 0.045-inch Kirschner wire through the fragment (TECH FIG 6A), angled proximally and slightly radially to purchase the far cortex of the proximal fragment.
- Insert structural bone graft into the metaphyseal defect if present to support the subarticular surface.
- If the plate is aligned over the ulnar half of the shaft, add a 15-degree torsional bend to the plate (twist the proximal end of the plate into slight supination). Often, a little extra extension can be contoured at the distal end of the plate (TECH FIG 6B).

**Dorsal Buttress Pin**
- Through a dorsal approach, expose and reduce the dorsal ulnar corner fragment, dorsal wall fragment, or both.

- Slide the plate over the Kirschner wire and fix it proximally with a 2.3-mm bone screw (TECH FIG 6C).
- Insert a second Kirschner wire if the fragment is large enough. Create and impact hooks as described for the radial pin plate (TECH FIG 6D–E).
- If the Kirschner wire tips protrude beyond the volar cortex, they can be cut flush to the bone surface through a volar incision.

TECH FIG 6 • Ulnar corner fixation with an ulnar pin plate. A. Insertion of the interfragmentary Kirschner wire. B. Contouring the plate. C. Application of the plate and insertion of the initial fixation screw. D. Fixation completed. E,F. Radial and ulnar pin plate fixation of a three-part articular pattern (radial column and ulnar corner fragment).
Insert structural bone graft into the metaphyseal defect if present to support the subarticular surface.

Insert two 0.045-inch Kirschner wires through the dorsal cortex and behind the subchondral bone; check the position with the C-arm (TECH FIG 7A). The Kirschner wires should be separated by about 1 cm and should be transverse to the longitudinal axis of the shaft. Initially placing a dorsal buttress pin upside-down on the bone is helpful to use as a template to visualize the proper position and insertion angle of the Kirschner wires (TECH FIG 7B).

Ensure that the leading tips of the legs of the dorsal buttress pin are straight and cut to the required length (TECH FIG 7C). Leave the ulnar leg 2 to 3 mm longer than the radial leg so one leg can be engaged at a time.

Place the ulnar leg of the buttress pin adjacent to the insertion site of the ulnar Kirschner wire, and then withdraw the Kirschner wire and immediately engage the leg in the hole. Repeat with the radial Kirschner wire to engage the radial leg of the buttress pin. Impact and seat the buttress pin (TECH FIG 7D).

Fine-tune the reduction and complete the fixation proximally with one or two 2.3-mm cortical bone screws and washers (TECH FIG 7E,F). If needed, a blocking screw can be placed just proximal to the end of the buttress pin to prevent shortening of the fragment.

**TECH FIG 7** Dorsal buttress pin fixation. A. The position of the Kirschner wires is checked with a C-arm before inserting the implant. B. Placing an implant upside-down on bone to template the trajectory of the Kirschner wires. C. Inserting the dorsal buttress pin. D. Buttress pin fixation completed. E,F. Fixation of a three-part articular fracture with radial column and ulnar corner fragment with radial column plate and dorsal buttress pin.

**VOLAR RIM FRAGMENT**

**Small-Fragment Plate Fixation**

Small-fragment volar plate fixation may be indicated for treatment of a volar instability pattern of the volar rim. The fragment must be of adequate size to allow buttressing on the volar surface by the plate (TECH FIG 8A,B).

If volar rim fragmentation is associated with an axial instability pattern, the fragment must be of adequate size and strength to allow distal locked screw purchase to obtain angular correction of the dorsiflexion deformity.

An appropriate volar approach is used to expose the volar rim fragment. If a shortened radial column fragment is present, first restore radial length and provisionally hold it with a transstyloid Kirschner wire to unload the lunate facet.
Reduce the volar rim fragment; this should restore normal carpal alignment.
- Apply a small-fragment volar plate and fix it proximally with cortical bone screws. If needed, secure the distal fragment with standard or locking bone screws (TECH FIG 8C,D).

**Volar Buttress Pin Fixation**
- Volar buttress pin fixation is indicated for unstable volar rim fragments and can be a particularly effective technique when faced with small distal fragments or axial instability patterns of the volar rim (depressed teardrop angle; TECH FIG 9A,B).
- Use an appropriate volar approach to expose the volar rim fragment. If necessary, restore radial length and provisionally hold it with a transstyloid Kirschner wire to unload the lunate facet (TECH FIG 9C).
- Continue exposure for up to 1 to 2 mm beyond the distal radial ridge. Reduce the volar rim fragment as much as possible and note the orientation of the teardrop on the 10-degree lateral view.
- Insert two 0.045-inch Kirschner wires transverse to one another starting at an entry site 1 to 2 mm beyond the distal radial ridge. They should be placed within the center of the teardrop on the lateral view. Confirm the position of the Kirschner wires with C-arm.
- If necessary, the volar buttress pin may be contoured with a wire bender to match the flare of the volar surface of the distal radius. Adjust the trajectory of the legs of the implant to make a 70-degree angle with the base of the wire form. Cut the legs to appropriate length, leaving the ulnar leg 2 to 3 mm longer than the radial leg (TECH FIG 9D,E).
- Noting the entry site of the Kirschner wire, carefully remove the ulnar Kirschner wire and engage the ulnar leg of the volar buttress pin. Repeat the procedure with the radial leg. Impact and seat the implant into the volar rim fragment (TECH FIG 9F).
- Fine-tune the reduction and fix it proximally with a minimum of two screws and washers (TECH FIG 9G,H).
FREE ARTICULAR FRAGMENT SUPPORT WITH A BUTTRESS PIN

- Free articular fragments impacted into the metaphyseal cavity require both a buttress to support the subchondral surface and circumferential peripheral cortical stability to prevent displacement (TECH FIG 10A).
- In some cases, impacted free articular fragments may be adequately supported by a properly applied locking plate that provides subchondral support.
- An alternative method is to use structural bone graft to support the free articular fragment in combination with fragment-specific fixation of the surrounding cortical shell, resulting in containment of the graft within the metaphysis.
- The dorsal buttress pin can also be used for direct subchondral support of impacted articular fragments. The legs of the implant are cut to length and inserted through the dorsal defect, slid distally directly behind the articular fragment, and then fixed proximally with a screw and washer (TECH FIG 10B). The articular fragment is sandwiched between the base of the lunate and the legs of the implant (TECH FIG 10C).
**POSTOPERATIVE CARE**

- At the end of the surgical procedure, confirm the stability of fixation as well as the stability of the DRUJ.
- If stable, apply a removable wrist brace and instruct the patient to initiate gentle range-of-motion exercises of the fingers, wrist, and forearm twice or more daily as tolerated. For non-compliant patients or injuries with tenuous fixation, use a cast for 2 to 3 weeks postoperatively.
- Avoid resistive loading across the wrist until signs of radiographic healing are present; typically this occurs by 4 weeks postoperatively. Specifically instruct older patients not to push up out of a chair or lift heavy objects after surgery.

---

**PEARLS AND PITFALLS**

**Determining whether a fragment is volar or dorsal on the PA view**
- Correlate the carpal facet horizon with the lateral view to determine whether a fragment is dorsal or volar.
- If the articular surface is tilted dorsally, the carpal facet horizon identifies the dorsal rim.
- If the articular surface is tilted volarily, the carpal facet horizon identifies the volar rim.

**Reduction of unstable fracture pattern**
- Identify and start reduction with the fragment that stabilizes the carpus to its normal spatial relationship. Often, initial reduction of the radial column with a provisional transstyloid Kirschner wire will restore carpal length. Alternatively, when this fragment is comminuted, fixation of the volar rim is often successful for reduction of the carpus.
- Adding structural bone graft, either through the fracture line at the base of the radial column or through a dorsal defect, can help stabilize the reduction during operative fixation.

**Widening of the DRUJ or carpal translation**
- Make sure the distal articular fragments are translated toward the ulna before completing volar fixation.
- An elastic, slightly overcontoured radial column plate can help close sagittal fracture gaps and seat the sigmoid notch against the ulnar head.
- Assess the clinical stability of the DRUJ and consider TFCC repair or suture or fixation of the ulnar styloid if needed.

**Small or dorsally rotated volar rim fragment; loss of fixation of small volar-ulnar fragment**
- Ensure adequate fixation of volar-ulnar corner fragment.
- Consider volar buttress pin fixation for an extremely distal or dorsally rotated volar rim fragment.
- Avoid release of the volar wrist capsule. When necessary, the legs of the implant can be inserted through the capsule.
- If needed, the volar buttress pin can be contoured as needed to match the arc of curve of the flare of the volar shaft.

**Unrecognized carpal ligament injury**
- Maintain a high index of suspicion for ligamentous injuries of the carpus. Consider arthroscopic injury evaluation, particularly in the context of radial or dorsal shear fractures, carpal avulsion and instability patterns, or articular fractures associated with a significant longitudinal stepoff between the scaphoid and lunate facets.

**Complications**

**Missed fragment: fracture displacement after surgery**
- Careful analysis of radiographic features both before and during reduction; CT scan when needed.
- Preoperative planning to select approaches that allow complete visualization of all major fragments.
- Complete set of implants and instruments available before surgery.

**Loss of radial length: proximal migration of articular surface**
- Graft the metaphyseal defect when needed with structural bone graft.
- Use implants that buttress the subchondral bone.

**DRUJ dysfunction: pain, instability, or limitation of forearm rotation**
- Assess clinical stability of DRUJ at end of procedure.
- Use radial column plate to push distal fragment against ulna to seat sigmoid notch against ulnar head.
- Evaluate and repair TFCC and capsular tears when necessary.
- Reduce and fix ulnar corner and volar rim fragments to restore congruity of sigmoid notch.
- Ensure that radial length is restored.

**Stiffness: slow, restricted return of movement of wrist, forearm, and fingers, often associated with pain**
- Early range of motion and mobilization of soft tissues.
- Avoidance of constricting bandages and postoperative swelling.

**Tendinitis or rupture: pain with resisted motion, loss of tendon function, clicking and pain**
- Use implants that have a low distal profile.
- Avoid placing sharp, bulky edges of hardware in proximity to tendons.
- Cover plates distally with retinacular flap when needed.
- Consider use of buttress pins (which have a very low profile) when possible.
- Remove any pins or hardware that back out or become prominent postoperatively.
- Ensure that volar plates do not extend up beyond distal volar ridge into soft tissues.
- Avoid long screws or pins, particularly when placed from volar to dorsal. Distal screws should normally be 2 to 4 mm shy of the dorsal cortical margin.
If there is persistent stiffness after 4 weeks, initiate physical and occupational therapy.

OUTCOMES

Konrath and Bahler\(^4\) reported 27 patients with at least 2 years of follow-up:
- One fracture lost reduction.
- Patient satisfaction was high (average DASH scores 17 and PRWE scores 19 at follow-up).
- In only three cases was hardware removed; no tendon ruptures occurred.
- Schnall et al\(^7\) reported on two groups of patients: group I had sustained high-energy trauma and group II had lower-energy injuries.
  - Group I patients averaged return to work in 6 weeks, with all fractures uniting without loss of position or deformity.
  - Two patients in group I required removal of painful hardware.
  - Group II patients averaged 2 degrees of loss of volar tilt, a 0.3-mm change in ulnar variance, and no loss of joint congruity at follow-up.
  - Grip strength in group II patients was 67% of the contralateral side.
- Benson et al\(^2\) reported on 85 intra-articular fractures in 81 patients with a mean follow-up of 32 months.
  - There were 64 excellent and 24 good results, with an average DASH score of 9 at final follow-up.
  - Flexion and extension motion was 85% and 91% of the opposite side at final follow-up.
  - Grip strength was 92% of the opposite side at final follow-up.
  - Sixty-two percent of patients had a 100-degree arc of flexion–extension and normal forearm rotation by 6 weeks postoperatively.
  - Postoperative radiographic alignment was maintained at follow-up.
  - There were no cases of symptomatic arthritis.

COMPLICATIONS

Stiffness: common early, uncommon at follow-up
- Recovery can be accelerated by anatomic fixation that is stable enough to start motion immediately after surgery. The relative degree of trauma to the bone and soft tissues, combined with underlying physiologic factors, is also a critical factor that can lead to slow recovery of motion or residual stiffness.
- Malunion or nonunion: rare
  - Loss of reduction may occur, particularly if a major fracture component is missed and left untreated. In addition, osteoporosis, failure to graft the metaphyseal defect, and associated DRUJ injuries may contribute to loss of reduction or malunion.
- Pin plates are able to resist translational displacements but are less effective for preventing loss of length; they require osseous contact between the proximal and distal fragments or additional support by a secondary implant that will buttress the subchondral surface.
- Nonunions are extremely rare.
- Tendinitis or tendon rupture: uncommon
  - If pins are noted postoperatively to back out, they should be removed. Leaving the distal 1 cm of tendon sheath of the first dorsal compartment intact helps avoid tendon contact with hardware.
  - Using low-profile implants dorsally, covering the distal ends with a strip of retinacular sheath, or both is also helpful.
  - The surgeon should avoid leaving screws or pins protruding from the dorsal or volar surfaces of the bone.
- Painful hardware: rare
  - Painful hardware can be related to migration of a pin or settling of the fracture proximally. Overbending pin hooks and using bone graft or buttressing implants can help avoid this problem.
  - Remove hardware when painful.
- Late arthritis is uncommon and probably related to the quality of the articular restoration.
- Infections, bleeding, carpal tunnel syndrome, and other nerve injuries are uncommon and often related to the primary injury.
- Complex regional pain syndrome is rare and may be related to initiation of early motion after surgery.

REFERENCES

DEFINITION
- Distal radius fractures typically originate in the radial metaphysis and occasionally enter the radiocarpal joint and distal radioulnar joint.
- These fractures may be stable or unstable, intra-articular or extra-articular, and can be associated with various other bony and soft tissue injuries about the wrist.
- Distal radius fractures are most commonly dorsally displaced or angulated (apex volar).
- Treatment is based on fracture stability, comminution, articular segment displacement, articular surface displacement, and the functional demand of the patient.
- Stability is related to initial dorsal angulation, residual dorsal angulation after closed reduction, dorsal comminution, age of the patient, and associated distal ulna fracture and intra-articular fracture extension.7,8

ANATOMY
- The distal radius has articulations at the scaphoid fossa, lunate fossa, and sigmoid notch.
- The normal bony anatomy includes volar tilt of 10 degrees, radial height of 11 mm, and radial inclination of 22 degrees.
- Ulnar variance (the length of the radius relative to the ulnar head at the sigmoid notch) is variable and patient dependent.
- Dorsal ligamentous structures include the dorsal intercarpal ligament and the dorsal radiocarpal ligament.
- The dorsal radiocarpal ligament originates from the dorsal lip of the radius and attaches on the ulnar carpus.
- The dorsal intercarpal ligament represents a capsular thickening on the dorsum of the carpus, with fiber alignment perpendicular to the long axis of the radius.
- Volar ligamentous origins include the radioscaphocapitate ligament, the long radiolunate ligament, and the short radiolunate ligament, among others.
- The triangular fibrocartilage complex (TFCC) consists of the triangular fibrocartilage and volar radioulnar and dorsal radioulnar ligaments.
- The volar radioulnar and dorsal radioulnar ligaments originate form the volar and dorsal edges of the sigmoid notch respectively, and become confluent and insert at the base of the ulnar styloid.
- The extensor retinaculum lies superficial to the extensor tendons and deep to the subcutaneous tissues. It has septations creating six dorsal compartments (FIG 1).
  - The first compartment lies over the radial styloid and contains the abductor pollicis longus and the extensor pollicis brevis tendons (each may have multiple slips).
  - The second compartment, containing the extensor carpi radialis longus and extensor carpi radialis brevis, lies radial to the tubercle of Lister.
  - The third compartment, containing the extensor pollicis longus, lies ulnar to the tubercle of Lister.
- The fourth compartment, containing the extensor indicis proprius and extensor digitorum communis, lies over the dorsal-ulnar distal radius.
- The fifth compartment, containing the extensor digiti minimi, lies over the distal radioulnar joint.
- The sixth compartment, containing the extensor carpi ulnaris, lies over the distal ulna.

PATHOGENESIS
- Distal radius fractures typically occur due to a fall on an outstretched hand.
- Fractures occur when the force of axial loading exceeds the failure strength of cortical and trabecular bone.9
- The fracture pattern is determined by the magnitude and direction of the force applied and the position of the hand during impact.3
- Dorsally displaced or angulated fractures occur when the wrist is neutral or extended and an axial or dorsally directed force is applied to the carpus.
- Osteoporosis, metabolic bone diseases, and bony tumors are risk factors for fracture.

NATURAL HISTORY
- Distal radius fractures are either stable or unstable.
- Stable fractures, treated nonoperatively, historically have excellent outcomes in terms of range of motion, pain, strength, and function.1
  - Nonoperative management consists of immobilization with either a cast or a splint, molded to prevent dorsal displacement.
  - Displaced, unstable, and comminuted fractures often require operative treatment.
- The goals of surgical treatment are to provide stability and improve bony alignment in order to achieve pain control, improve range of motion, and increase function.1,6

FIG 1 • Anatomy of the distal radius. The six dorsal extensor compartments at the level of the extensor retinaculum.
One to 2 mm or more of displacement of the articular surface of the distal radius leads to degenerative changes in young adults.6

Dorsal angulation of more than 20 degrees from normal (10 degrees dorsal tilt) can lead to pain, decreased range of motion, and decreased grip strength.10

Radial shortening can decrease range of motion and cause pain with ulnar impaction of the carpus.10

PATIENT HISTORY AND PHYSICAL FINDINGS

A history of trauma is the most common patient presentation.

Pathologic fractures may occur with minimal stress or trauma.

Patients complain of localized pain and present with swelling, decreased range of motion, and ecchymosis about the fracture.

A history of previous fractures in an older patient should alert the physician to the possibility of underlying osteoporosis.

The skin should be carefully examined to rule out the presence of an open fracture and to assess swelling before surgery or casting. If the wrist is markedly swollen or if swelling is anticipated, casting should be delayed and a splint should be placed.

Neurologic symptoms in the form of numbness, tingling, and radiating pain into the digits should alert the physician to the possibility of acute carpal tunnel syndrome. Careful neurologic assessments should be performed to rule out the presence of a progressive neurologic deficit.

Acute carpal tunnel syndrome represents a surgical emergency.

■ Examination:
  - Remove splints and dressings to visualize all areas of skin.
  - Palpate for areas of tenderness or deformity. Palpate anatomic snuffbox.
  - Visualize and palpate the elbow for swelling, ecchymosis, tenderness, crepitis, and deformity.
  - Visualize and palpate the hand and fingers for swelling, ecchymosis, tenderness, crepitus, and deformity.
  - Use two-point tool or paper clip bent to 5 mm and touch radial and ulnar aspects of all fingers with one or two points. Greater than normal (5 mm) two-point testing in the form of progressive neurologic deficit may signify an acute or chronic carpal tunnel syndrome.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Posteroanterior (PA), lateral, and oblique radiographic views are critical in evaluating all suspected distal radius fractures.

Consider imaging the uninjured wrist for comparison and to serve as a template for surgical reconstruction.

Radiographs of the elbow should be obtained in almost all cases, especially if any tenderness, swelling, or deformity is detected clinically.

Radiographic measurements taken from the PA view (FIG 2A) include\(^9,13\):

- Radial inclination, which is the angle between a line perpendicular to the shaft of the radius at the articular margin and a line along the radial articular margin
  - Normal angle = 21 degrees
- Radial length, which is the distance from a line tangent to the ulnar articular margin to a line drawn perpendicular to the long axis of the radius at the radial styloid tip
  - Normal length = 11 mm
- Ulnar variance, which is the distance from a line perpendicular to the long axis of the radius at the sigmoid notch and a line tangent to the ulnar articular surface
  - Ulnar variance is variable, so to establish a normal value, radiographs of the normal contralateral side should be obtained.

Lateral articular (volar) tilt is the angle between a line for the articular surface of the radius and a perpendicular line to the long axis of the radius.

- Normal angle = 11 degrees volar tilt (FIG 2B)\(^9,13\)
- CT scans can fully elucidate the anatomy of the fracture, particularly articular disruption or incongruity, and also help to determine the necessary surgical approach based on the location and extent of comminution.
  - CT scans increase the interobserver reliability of treatment plans and may actually alter the initial treatment plan based on plain radiographs.5
- MRI can be useful in evaluating for concomitant ligamentous injuries, TFCC injuries, stress fractures, and occult carpal fractures.

FIG 2 • A. PA radiograph demonstrating radial inclination, (black lines), ulnar variance (red), and radial height (white bracket). B. Lateral radiograph of the wrist demonstrating volar tilt (black lines).
DIFFERENTIAL DIAGNOSIS
- Bony contusion
- Wrist dislocation
- Scaphoid or other carpal fracture
- Carpal instability or dislocation
- Distal ulna fracture
- Wrist ligament or TFCC sprain or tear

NONOPERATIVE MANAGEMENT
- Closed reduction should be performed in the emergency department with longitudinal axial traction followed by volar displacement of the carpus. A bivalved, short-arm, well-molded cast or sugar-tong splint should be applied.
- Casting is the most commonly used method to definitively treat distal radius fractures and is preferred for nondisplaced or minimally displaced fractures and those that are stable after a reduction maneuver (ie, restored volar tilt with minimal dorsal comminution). A precise three-point mold is required to maintain fracture reduction.
- Removable splinting can be considered when treating completely nondisplaced stable fractures in young adults.
- If nonoperative treatment is chosen, repeat radiographs should be taken on a weekly basis for the first 3 weeks to ensure that the reduction is maintained. The physician should have a low threshold for changing the cast.
- Any sign of dorsal migration indicates instability, and operative stabilization should be considered.
- Finger range of motion is begun immediately and wrist range of motion can be started as the fracture heals and is managed in a removable splint.

SURGICAL MANAGEMENT
- Open reduction and internal fixation with a dorsal plate can be used successfully in the treatment of displaced, unstable, comminuted fractures of the distal radius that fail to respond to closed treatment.
- Dorsal plating buttresses the fracture to correct deformity and maintain fracture reduction.
- New intramedullary implants have been designed to alleviate some of the complications associated with traditional dorsal plates and allow a less invasive option for fixation of dorsally displaced fractures (FIG 3A,B).
- Indications for dorsal plating include:
  - Severe initial dorsal displacement (>20 degrees from normal, 10 degrees dorsal tilt)
  - Marked dorsal comminution (greater than or equal to 50% of the diameter of the radius shaft on the lateral radiograph)
  - Residual (after reduction) dorsal tilt greater than 10 degrees past neutral
  - 10 mm of radius shortening
  - Dorsal intra-articular fragments displaced more than 1 mm
- Stabilization using an intramedullary device is indicated for distal radius fractures without extensive articular involvement in which a limited incision and shorter procedure are desired (see Tech Fig 4E).
- Comminution of the volar metaphysis is a relative contraindication for the use of a dorsal intramedullary implant.
- The surgeon should be prepared to change management intraoperatively and must have additional stabilization options available, if necessary, such as percutaneous pins or an external fixator.

Preoperative Planning
- All radiographic imaging must be reviewed before surgery.
  - It is helpful to compare radiographs of the injured wrist to the uninjured wrist.
  - Displaced intra-articular fragments must be identified.
  - Dorsal comminution must be evaluated to determine fracture stability and the need for bone grafting.
  - The distal extent of the fracture must be determined to enable the buttress plate to function properly.
- Bone should be evaluated for osteopenia, osteoporosis, and tumors.

Positioning
- The patient is placed supine on a regular operating table.
- A tourniquet is placed near the axilla with the splint in place.

![FIG 3](image-url) • PA radiograph (A) and lateral radiograph (B) of a healed distal radius fracture fixed with an intramedullary plate. C,D. PA and lateral radiographs showing an unstable metaphyseal distal radius fracture. (C,D: copyright Thomas R. Hunt III, MD.)
After anesthesia has been administered, the arm is placed on a radiolucent hand table (FIG 4).
Motion of the shoulder and elbow should be adequate to allow adequate reduction and positioning.
Image intensification using fluoroscopy should be performed throughout the procedure to assess fracture reduction and the position of the hardware.

**Approach**
- The dorsal approach to the distal radius through the third dorsal compartment with subperiosteal elevation of the compartments provides the exposure needed to place a dorsal plate while protecting the extensor tendons from the plate and screws.
  - This approach helps to minimize adhesions and the risk of tenosynovitis and tendon rupture.
- The approach used to place an intramedullary device depends on the nature of the implant and the location and extent of the fracture.
  - Dorsal intramedullary implants are placed through a limited dorsal approach through the third extensor compartment.
  - Radial intramedullary implants are placed through a small radial incision with careful protection of the radial sensory nerve.

**DORSAL PLATE FIXATION OF DISTAL RADIUS FRACTURES**

**Incision and Dissection**
- The skin incision is centered over the tubercle of Lister (TECH FIG 1A).
- The subcutaneous tissues are dissected down to extensor retinaculum, with care to preserve any sensory nerve branches while obtaining hemostasis with bipolar electrocautery (TECH FIG 1B).
- The extensor retinaculum is incised just ulnar to the tubercle of Lister, exposing the extensor pollicis longus (EPL) tendon (TECH FIG 1C).
- The hematoma is evacuated and the EPL tendon is freed proximally and distally by incising the septa of the third compartment (TECH FIG 1D).
- The EPL tendon can then be removed from the third compartment and protected for the rest of the surgical procedure.
- The extensor compartments are subperiosteally elevated using a scalpel in radial and ulnar directions to expose the dorsal cortex of the distal radius (TECH FIG 1E,F).
- If properly maintained, the periosteum of the extensor compartments can be repaired after placement of the fixation device and will serve as a barrier between the dorsal plate and the extensor tendons.
- The tubercle of Lister is almost invariably involved in the fracture and should be completely removed using a rongeur (TECH FIG 1G).
The radius shaft is exposed with a periosteal elevator (TECH FIG 1H).

**Reduction and Plate Fixation**

- Reduction is obtained and confirmed using axial traction and palmar translation of the hand (TECH FIG 2A).
- If reduction of articular fragments is needed, the radial portion of the origin of the dorsal radiocarpal ligament can be elevated sharply off the radius to evaluate the articular surfaces.
- Kirschner wires can be used for temporary fixation.
- Bone graft is inserted to support reduced articular fragments.
- The dorsal plate is applied directly on the radius (TECH FIG 2B).
- The plate is secured beginning with a bicortical screw in the oval sliding hole.
- Fracture reduction and placement of the plate are confirmed using fluoroscopy.
- The plate is secured to the distal fragment with one or two cancellous screws. The surgeon should avoid placing...
the distal, ulnar screw if possible as this may irritate the overlying digital extensor tendons in the fourth dorsal compartment.

- Additional cortical screws are added in the radius shaft.
- Reduction and stability are confirmed (TECH FIG 2C,D).

**Wound Closure**

- The wound is copiously irrigated.
- The retinaculum is closed deep to the transposed EPL tendon, incorporating the periosteal layer that forms the floor of the extensor compartments (TECH FIG 3A).
- The skin is closed with nylon suture (TECH FIG 3B).
- A volar splint is applied.

**FIXATION OF DISTAL RADIUS FRACTURES USING A DORSAL INTRAMEDULLARY DEVICE (TORNIER)**

- The fracture is exposed using a limited version of the incision detailed for placement of a dorsal plate (TECH FIG 4A).
  - The extensor retinaculum is incised just ulnar to the tubercle of Lister, exposing the EPL tendon.
  - The EPL tendon is freed proximally and distally by incising the septa of the third compartment.
  - The EPL tendon can then be transposed for the rest of the surgical procedure.
  - A scalpel is used to subperiosteally elevate the fourth and portions of the second extensor compartment in radial and ulnar directions.
  - The dorsal cortex of the distal radius is exposed and room is created for seating of the extramedullary portion of the device.
  - The tubercle of Lister is removed and an awl is used to create an entry point in the dorsal cortex (TECH FIG 4B).
  - This usually involves a portion of the fracture line.
  - The canal is rasped until the rasp may be fully seated (TECH FIG 4C).
  - The implant is placed using the insertion device to control rotation (TECH FIG 4D).
  - Fracture reduction is typically achieved as the device is inserted and seated due to its buttress effect and three-point fixation in the canal.
  - Lag screws are inserted as required, followed by a cover lock to create fixed angle stability.
  - Reduction and stabilization are confirmed radiographically (TECH FIG 4E,F).
  - Wound closure and splinting are as described above.
A 2- to 3-cm incision is made over the radial styloid, between the first and second extensor compartments. Care is taken to protect branches of the radial sensory nerve. A cannulated drill is used to penetrate the cortex 2 to 3 mm proximal to the radiocarpal joint line to create the entry point. After insertion of a starter awl, the canal is broached sequentially under fluoroscopic guidance to fit the medullary canal. The implant is then inserted with the insertion jig, making sure the implant is countersunk into the radial styloid. The proximal interlocking screws are then placed using the insertion jig, using small incisions of the dorsal aspect of the forearm. The distal interlocking screws are placed last using the insertion jig. Small adjustments to radial height and tilt can be made at this time. Reduction and stabilization are confirmed radiographically. Wound closure and splinting are as described above.

**PEARLS AND PITFALLS**

**Indications**
- Determine the direction of fracture stability.
- Determine the area and extent of comminution.
- Ensure that an acute carpal tunnel syndrome does not exist.

**Surgical approach**
- Incise the extensor retinaculum sharply to allow easier repair.
- Expose only the third dorsal compartment.
- Remove the tubercle of Lister to allow better plate contouring.

**Hardware choice and placement**
- Choose a low-profile implant system that offers the flexibility needed to stabilize the fracture.
- Place the plate distally to ensure buttress effect.
- Place the oval plate hole screw initially.
- Do not place the plate distal to the dorsal lip of the distal radius.
- Avoid placing the distal, ulnar screw.
- Although titanium implants and their particulate debris have been implicated in the development of tenosynovitis and other tendon pathology, there is no clear scientific evidence to substantiate these claims.

**Postoperative management**
- Avoid casting for long periods.
- Encourage early active range of motion of the wrist and fingers.
- Avoid using a sling to prevent unnecessary shoulder and elbow stiffness.
- Do not begin strengthening until range of motion is restored.
POSTOPERATIVE CARE
- Postoperatively the patient is placed in a bulky dressing that allows motion of the digits, elbow, and shoulder. A volar resting splint may be used to support the wrist if there is any concern about fixation strength.
- The patient is encouraged to begin finger range-of-motion exercises immediately after surgery.
- Seven to 10 days after surgery the sutures are removed, Steri-Strips are applied, and the incision is allowed to get wet.
- The patient is evaluated by an occupational therapist, who provides a thermoplastic splint, and can start active and active-assisted range-of-motion exercises depending on fracture stability.
- When the fracture heals at about 6 weeks, gentle passive range of motion and strengthening may be started.

OUTCOMES
- Dorsal plating has recently been shown biomechanically to be stronger and stiffer than volar plating for dorsally unstable fractures.\(^\text{12}\)
- Dorsal plating has been associated with a higher complication rate than other means of stabilization.\(^\text{2,9,10}\)
- Extensor tenosynovitis and tendon rupture have been prevalent in the past, mainly due to bulky implants.
- There has been renewed interest in dorsal plating of the distal radius as it has been shown to have a low rate of tendon-related complications with the use of low-profile, anatomic implants.\(^\text{4,10,11}\)
- Clinical reports have suggested that low-profile systems are more important in satisfactory outcomes for dorsal plating, with a much lower rate of complications.\(^\text{10}\)
- Fixation with low-profile dorsal plates can result in at least 80% of contralateral wrist range of motion, about 80% to 90% of grip strength, and over 90% pinch strength, with minimal risk of tendon rupture.\(^\text{4,11}\)

COMPLICATIONS
- Infection (pin tract or deep)
- Injury to tendons, vessels, and nerves
- Stiffness
- Posttraumatic arthritis
- Weakness in grip or pinch
- Tenosynovitis and tendon ruptures
- Malunion or nonunion
- Compartment syndrome
- Carpal tunnel syndrome
- Late tendon rupture, potentially related to implant design and material
- Hardware failure
- Complex regional pain syndrome type I

DISCLOSURE
Dr. Beredjiklian is a stockholder with and consultant for Tornier, Inc.

REFERENCES
DEFINITION
- Distal radius fractures are defined by their involvement of the metaphysis of the distal radius.
- They are assessed on the basis of fracture pattern, alignment, and stability:
  - Articular versus nonarticular
  - Reducible versus irreducible
  - Stable versus unstable
- Irreducible or unstable fractures require surgical reduction and stable fixation.
- Volar plating historically has been the method of choice for volar shear-type fractures.
- Recently developed fixed-angle plates have now made it a preferred method of fixation for most types of distal radius fractures.

ANATOMY
- The distal radius serves as a buttress for the proximal carpus, transmitting 75% to 80% of its forces into the forearm.
- The remaining 20% to 25% of force is transmitted through the distal ulna and the triangular fibrocartilage complex (TFCC).
- Dorsally
  - The distal radius is the origin for the dorsal radiocarpal ligament.
- Volarly
  - The distal radius is the origin for the extrinsic ligaments of the carpus, including the radioscaphocapitate ligament.
  - It also is the origin of the pronator quadratus.
- Distally
  - It is the floor of the fibro-osseous extensor tendon compartments and includes Lister’s tubercle, assisting in extensor pollicis longus function (FIG 1A).
  - The extensor tendons are in immediate contact with the dorsal surface of the distal radius.
- Volarly
  - The distal radius is the origin for the extrinsic ligaments of the carpus, including the radioscapohocapitate ligament.
  - It also is the origin of the pronator quadratus.
  - The flexor tendons are separated from the distal radius by the pronator quadratus.
- Ulnarly
  - The distal radius is the origin for the radial triangular fibrocartilage (FIG 1A).
  - It also contains the sigmoid notch, which articulates with the head of the distal ulna, contributing to forearm rotation.
- Distally
  - The surface is divided into a triangular, radiocapitate fossa and a square, radiocapitate fossa articulating with the respective carpal bones (FIG 1B).
- The distal articular surface is inclined approximately 22 degrees ulnarly in the coronal plane and 11 degrees volarly in the sagittal plane (FIG 1C,D).
- The metaphysis is defined by the distal radius within a length of the articular surface that is equivalent to the widest portion of the entire wrist.

FIG 1 • A. Axial MR image of the wrist at the level of the distal radius. Lister’s tubercle is marked with an asterisk. Dotted lines represent dorsal and volar borders of the triangular fibrocartilage that helps stabilize the distal radioulnar joint. The dorsal distal radius acts as an attachment for dorsal extensor compartment sheaths. B. The distal articular surface of the radius is divided into a triangularly shaped scaphoid fossa (SF) and a square-shaped lunate fossa (LF). The distal ulna and the triangular fibrocartilage complex (TFCC) act as ulnar buttresses for the wrist. C. MR coronal cut of the distal radius. The articular surface of the distal radius is inclined about 22 degrees relative to the forearm axis (dotted lines). The ulnar aspect of the distal radius (ie, the lunate fossa) usually is distal to the end of the distal ulna (ie, negative ulnar variance). Note the solid lines marking ulnar variance. D. MR sagittal cut of the distal radius. The articular surface of the distal radius is inclined approximately 11 degrees palmar relative to the forearm axis (dotted lines). Proximally, there exists relatively thinner dorsal cortical bone versus the thicker volar bone.
The dorsal cortical bone is less substantial than the volar cortical bone, contributing to the characteristic dorsal-bending fracture pattern of distal radius fractures.

PATHOGENESIS
- The mechanism of injury in a distal radius fracture is an axial force across the wrist, with the pattern of injury determined by bone density, the position of the wrist, and the magnitude and direction of force.
- Most distal radius fractures result from falls with the wrist extended and pronated, which places a dorsal bending moment across the distal radius.
  - Relatively weaker, thinner dorsal bone collapses under compression, whereas stronger volar bone fails under tension, resulting in a characteristic “triangle” of bone comminution with the apex volar and greater comminution dorsal.
- Other possible mechanisms form a basis for some fracture classifications such as the one proposed by Jupiter and Fernandez.5

- Bending
- Compression
- Shear
- Avulsion
- Combinations
- Articular involvement and its severity are the basis of some fracture classifications, such as the AO9 and Melone8 classifications.
- Articular involvement splits the distal radius into distinct fragments separate from the radius shaft (FIG 2):
  - Scaphoid fossa fragment
  - Lunate fossa fragment. Further comminution can split the lunate fossa fragment into dorsal and volar segments, creating the so-called four-part fracture.

NATURAL HISTORY
- Clinical outcome usually, but not always, correlates with deformity.
- Variable residual deformity can be tolerated best by individuals with fewer functional demands.
- As wrist deformity increases, physiologic function is progressively altered.
  - Intra-articular displacement of 1 to 2 mm results in an increased risk of osteoarthritis.3,6
  - Radial shortening of 3 to 5 mm or more results in increased loading of the ulnar complex.1,12
  - Dorsal angulation greater than 10 degrees shifts contact forces to the dorsal scaphoid fossa and the ulnar complex, causing increased disability.13,16
  - The incidence of associated intracarpal injuries increases with fracture severity. Such injuries can account for poor outcomes. These injuries often are not recognized at first, with the result that treatment is delayed.4,14
  - Triangular fibrocartilage (TFC) tears
  - Scapholunate and lunotriquetral ligament tears
  - Chondral injuries involving the carpal surfaces
  - Distal radioulnar joint injury
  - Distal ulna fractures

By predicting the stability of a distal radius fracture, deformity and its complications can be minimized. Several risk factors have been suggested by LaFontaine et al7 and others. The presence of three or more indicates instability:
- Dorsal angulation greater than 20 degrees
- Dorsal comminution
- Intra-articular extension
- Associated ulna fracture
- Patient age over 60 years

PATIENT HISTORY AND PHYSICAL FINDINGS
- The mechanism of injury should be sought, to assist in assessing the energy and level of destruction.
- Associated injuries are not uncommon and should be carefully ruled out.
  - Injuries to the hand, carpus, and proximal arm, including other fractures or dislocations
  - Injuries to other extremities or the head, neck, and torso
  - Establish the patient’s functional and occupational demands.
  - Document co-existing medical conditions that may affect healing, such as osteoporosis or diabetes.
  - Determine possible risk factors for anesthesia and surgery, such as cardiac disease.
- The physical examination should document the following:
  - Condition of surrounding soft tissues (ie, skin and subcutaneous tissues)
  - Quality of vascular perfusion and pulses
  - Integrity of nerve function
  - Sensory two-point discrimination or threshold sensory testing
  - Motor function of intrinsic, thenar, and hypothenar muscles of the hand
- Examination of the distal ulna, TFCC, and distal radioulnar joint should rule out disruption and instability.
- Reliable physical examination of the carpus often is difficult, making radiographic review even more critical and follow-up examinations important.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Imaging establishes fracture severity, helps determine stability, and guides the operative approach and choice of fixation.
Plain radiographs should be obtained before and after reduction: PA, lateral, and two separate oblique views.

- Oblique views, in particular, help evaluate articular involvement, particularly the lunate fossa fragment (FIG 3A,B).
- The lateral view should be modified with the forearm inclined 15 to 20 degrees to best visualize the articular surface (FIG 3C; see Tech Fig 5BC).

- Fluoroscopic evaluation can be useful, because it gives a complete circumferential view of the wrist and, with traction applied, can help evaluate injuries of the carpus.
- CT helps define intra-articular involvement and helps detect small or impacted fragments, which may not be apparent on plain radiographs, particularly those involving the central portion of the distal radius (FIG 3D,E).

**DIFFERENTIAL DIAGNOSIS**

- Diagnosis is directly confirmed by radiographs.
- Associated and contributory injuries should always be considered.
  - Pathologic fracture (eg, related to tumor, infection)
  - Associated injuries to the carpus (eg, scaphoid fracture, scapholunate ligament injury)

**NONOPERATIVE MANAGEMENT**

- Nonoperative treatment is reserved for distal radius fractures that are reducible and stable based on the criteria previously discussed.
- The goal of nonoperative treatment is to immobilize the wrist using a method that will maintain acceptable alignment until the fracture is healed.
  - Radial inclination greater than 10 degrees
  - Ulnar variance less than 4 mm positive
  - Palmar tilt less than 15 degrees dorsal or 20 degrees volar
  - Articular congruity less than 2-mm gap or step-off

**SURGICAL MANAGEMENT**

- The goal of operative treatment is to achieve acceptable alignment and stable fixation.
- Various methods of fixation are available: pins, external fixators, dorsal plates, intramedullary devices, and volar plates.

**Preoperative Planning**

- The standard preoperative medical and anesthesia evaluation for concurrent medical problems is done.
- Discontinue blood thinning medications (anticoagulants and nonsteroidal anti-inflammatory drugs).
- Request necessary equipment, including fluoroscopic and power equipment.
- Confirm the plate fixation system to be used and check the equipment before beginning surgery for completeness (ie, all appropriate drills, plates, and screws).
- Have a contingency plan or additional fixation (external fixator, bone graft, or bone graft substitute).
- Review previous radiographic studies.
- Consider use of a regional anesthetic for postoperative pain control.

**Positioning**
- Place the patient in the supine position with the affected extremity on an arm table.
- Apply an upper arm tourniquet, preferably within the sterile field.
- Incorporate weights or a traction system to apply distraction across the fracture (FIG 4).
- The surgeon is seated on the side, toward the patient’s head, particularly if he or she is right-hand dominant.
- The assistant is seated opposite the surgeon.
- The fluoroscopy unit is brought in from the end or corner of the table.

**Approach**
- Dorsal exposure allows for direct visualization of the articular surface when necessary.
- Fracture comminution is more severe dorsally, making overall alignment more difficult to judge.
- The thicker volar cortex is less comminuted, allowing for more precise reduction and buttressing of bone fragments.
- Sometimes both dorsal and volar exposures may be necessary to achieve articular congruency and volar reduction and fixation, respectively.
- An extended volar–ulnar exposure may be necessary to perform a carpal tunnel release if indicated.
- The techniques described in this chapter use the volar approach to distal radius, as described by Henry (FIG 5).

**FIG 4** • Traction is applied over the arm table with finger traps and hanging weights. The surgeon sits on the volar side, and the assistant on the dorsal side. Fluoroscopy can be brought in from any direction, but preferably from the side adjacent or the opposite surgeon.

**FIG 5** • The volar incision is represented by the dotted line just proximal to the wrist flexion creases and radial to the flexor carpi radialis longus. Care is exercised to avoid dissection ulnar to the flexor carpi radialis, because the palmar cutaneous nerve branch of the median nerve (arrow) is at risk.

### VOLAR FIXED-ANGLE PLATE FIXATION OF THE DISTAL RADIUS

#### Incision and Dissection
- Palpate the flexor carpi radialis tendon and make a 4- to 8-cm longitudinal incision from the proximal wrist flexion crease, extending proximally along the radial border of the flexor carpi radialis tendon.
  - If the incision must cross the wrist flexion creases, use a zigzag incision in that area.
- Carefully avoid the palmar cutaneous branch of the median nerve along the ulnar side of the flexor carpi radialis within 10 cm of the wrist flexion crease.
- Branches of the dorsal radial sensory nerve and lateral antebrachial cutaneous nerve sometimes appear along the path of the incision and also need to be protected.
- At the distal end of the incision, protect the palmar branch of the radial artery to the deep arch.
  - It usually is not necessary to dissect out the radial artery (TECH FIG 1A).
- Incise the anterior sheath of the flexor carpi radialis tendon and retract the tendon ulnarly to help protect the median nerve (TECH FIG 1B).
- Incise the posterior sheath of the flexor carpi radialis tendon.
- The deep tissues likely will bulge out from the pressure of swelling and fracture hematoma.
- The median nerve lies within the subcutaneous tissues along the ulnar portion of the wound (TECH FIG 1C,D).
- The flexor pollicis longus tendon sits along the radial margin of the wound.
- Using blunt dissection with a gauze-covered finger, sweep the tendons and the nerve ulnarly.
- A self-retaining retractor is carefully placed between the radial artery radially and the tendons and median nerve ulnarly.
TECH FIG 1 • A. The interval between the radial artery (arrow) and the flexor carpi radialis tendon (*) is seen. B. The posterior sheath (*) of the flexor carpi radialis is visible after retracting the flexor carpi radialis ulnarly (arrow). Be careful during deeper dissection, because swelling and hematoma may distort the position of the median nerve beneath the sheath. C. Following incision in the flexor carpi radialis posterior sheath, the deep tendons are visible, including the flexor pollicis longus (FPL) and the flexor digitorum superficialis of the index finger (FDS). The median nerve also is visible (*). D. The palmar cutaneous nerve branches of the median nerve (arrow) and median nerve (asterisk) are both at risk for injury during this approach. Be careful regarding placement of retractors and during dissection and plate placement. E. The pronator quadratus (PQ) is incised distally, radially, and proximally and then reflected ulnarly after dissection off the volar distal radius. F. The brachioradialis (arrow) can be a deforming force, especially in comminuted fractures and in those for which treatment has been delayed. This tendon can be released if necessary.

- The pronator quadratus is now visualized at the floor of the wound.
- Incise the pronator quadratus at its radial insertion, leaving fascial tissue on either side to aid in closure. Also, determine the proximal and distal extent of the muscle, and make horizontal incisions at both of those points (TECH FIG 1E).
- The distal margin of the pronator quadratus attaches along the distal volar lip of the distal radius, along the “teardrop.”
- The radial margin is in proximity to the tendons of the first dorsal compartment and the brachioradialis.
- Subperiosteally dissect the pronator quadratus off the volar surface of the distal radius as an ulnarly based flap with a knife or elevator.
- Retract the pronator ulnarly with the flexor tendons and median nerve.
- Particularly if significant shortening of radial-sided fracture fragments has occurred, incise the broad insertion
of the brachioradialis to eliminate the deforming force (TECH FIG 1F).
- Release the first dorsal compartment and retract the tendons before releasing the brachioradialis.
- Alternatively, Z-lengthen the brachioradialis tendon to allow for repair at the completion of the case.

**Fracture Reduction and Provisional Fixation**

- Apply a lobster-claw clamp around the radius shaft at a perpendicular angle to the volar surface at the most proximal portion of the wound (TECH FIG 2A).
  - This allows for excellent control of the proximal shaft for rotation and translation.
  - It also provides an excellent counterforce when correcting the dorsal angulation collapse.
- With the fracture now exposed, apply traction distally to distract and disimpact the fragments.

- Carefully clean the fracture of any interposed muscle, fascia, hematoma, or callus while maintaining the bony contours.
- In the case of significant volar comminution, reduce and provisionally stabilize the fragments with K-wires.
- Take plate positioning into account when placing these K-wires.
- The articular surface is first reduced, if necessary.
- Under fluoroscopic guidance, manipulate the articular fragments through the fracture with a periosteal elevator, osteotome, or K-wires (TECH FIG 2B,C).
- Longitudinal traction is important during this reduction phase. It can be performed by an assistant or using cross-table weights and finger-traps.
- A dorsal exposure is performed at this stage if there is significant impaction, particularly centrally, that cannot be corrected using the extra-articular technique described here.

**TECH FIG 2**

- **A.** A lobster-claw clamp (double arrow) is applied to the radius shaft well proximal to the fracture. This instrument helps the surgeon control the radius during reduction and define the lateral margins of the radius. A Freer elevator is inserted into the fracture to help disimpact the fragments and assist in their reduction. **B.** The brachioradialis (white arrow) is released, and the first compartment extensor tendons are visible in the background (black arrow). An instrument can now be placed to assist in the reduction (arrow). **C.** The Freer elevator is used to reduce the fragments. In this case, the intra-articular step-off is being corrected, and the radial length and inclination are being restored. **D.** K-wires are placed across the radial styloid into the reduced ulna fossa fragment. An assistant usually applies traction, and the lobster-claw clamp can be used for powerful leverage. If there is no articular involvement, this K-wire can be placed into the radius metaphysis or diaphysis proximally. **E.** The K-wire should be placed as close as possible to the subchondral bone, avoiding areas of comminution. **F.** The K-wire should maintain the articular reduction without any support.
- Place K-wires from the radial styloid fragment into the lunate fossa fragment to maintain the articular reduction (TECH FIG 2D).
  - The K-wires should be placed as close as possible to the subchondral plate (TECH FIG 2E,F).
- Once the distal articular reduction is complete, reduce the distal radius as a single unit to the radius shaft.
- Insert K-wires as required to maintain the provisional reduction between the distal fragments and the proximal shaft fragment.
  - If radial collapse and translation are prominent, a large K-wire can be introduced into the radial portion of the fracture and advanced proximally and ulnarly to behave like an intrafocal pin and provide a radial buttress by pushing the distal fragment ulnarly.
  - A similar technique can be applied through the dorsal fracture to assist in maintaining the palmar tilt correction.

**Plate Application**

- Apply a fixed-angle volar plate to the volar surface of the distal radius and shaft. Position the plate to accommodate for the unique design characteristics of the plating system as well as the location of the fracture fragments.
  - Each plating system has unique characteristics that determine its optimal placement.
  - Ideally, the plate should be placed as close to the articular margin as possible without the distal locking pegs or screws penetrating the joint.
  - If the fracture has not yet been fully reduced, this must be taken into account when placing the device.
- Clamp the previously applied lobster claw to the proximal portion of the plate to keep the plate centralized on the radius shaft.
- Place provisional K-wires through the plate to maintain position (TECH FIG 3). Then fluoroscopically confirm proper plate position in both the distal-proximal and radioulnar directions.
  - Proper alignment of the plate can be determined only using a true anteroposterior (AP) image in which the distal radioulnar joint is well visualized.
- The K-wires allow for fine adjustment in plate position before committing to insertion of a screw.
- Drill and insert a provisional screw in the oblong hole in the plate.
- If the bone is osteopenic, a screw longer than the initial measurement should be placed to ensure that both cortices are engaged. Otherwise, the plate may not be held securely, and the reduction will be compromised. After the remaining screws have been secured, this screw can be replaced with one of the appropriate length.
- Insert at least one additional proximal screw and remove the provisional K-wires holding the plate in place.

**Distal Fragment Reduction**

- Once the proximal plate has been secured, execute any additional reduction needed.
  - A well-designed plate serves as an excellent buttress for correction of the palmar tilt (TECH FIG 4A).
- Apply counterforce through the lobster-claw clamp in a dorsal direction while the distal hand and wrist are translated palmarly and flexed (TECH FIG 4B).
- This maneuver reduces the distal radius to the plate, effectively restoring volar tilt by pushing the lunate against the volar lip of the distal radius (TECH FIG 4C,D).
- Additional distraction and ulnar deviation correct radial collapse and loss of radial inclination.

**TECH FIG 3** • Keep the plate centered on the radius and as distal as possible. The lobster-claw clamp helps keep the plate centered. K-wires (arrows) are helpful as provision fixation until alignment can be confirmed radiographically and screws placed.

**TECH FIG 4** • A. The final reduction is performed with traction on the hand and with the radius held proximally with a clamp. Once the reduction is confirmed radiographically, the assistant places the distal screws or K-wires. B. The hand is translated (not appreciably flexed) palmarly while the radius shaft is held with the clamp. (continued)
Plate Fixation

- While the reduction is held, drill the holes in the distal plate (TECH FIG 5A).
  - Some plate systems allow for provisional fixation using K-wires placed through the distal plate.
  - Do not penetrate the dorsal distal radius with the drill, to protect the dorsal extensor tendons.
  - Drill and place the distal ulnar screws first and then proceed radially and proximally.
  - Judge the placement of all distal screws or pegs precisely using fluoroscopic imaging in multiple planes.
  - Perform a “true” lateral view of the wrist with the x-ray beam at a 20-degree angle to the radius shaft (TECH FIG 5B,C). This is facilitated by lifting the wrist off the table with the elbow maintained on the table and the forearm at a 20-degree angle to the table (TECH FIG 5D,E).
  - Lister’s tubercle can be mistaken for the dorsal cortex, resulting in screws that are too long.
  - The extensor pollicis longus is at greatest risk of injury from a protruding screw.
  - Sequentially insert the remaining distal screws or pegs, followed by the remaining proximal plate screws (TECH FIG 5F).
  - If necessary, add bone graft or bone graft substitute around the plate into the fracture site or through a small dorsal incision.

(TECH FIG 5A). The remaining holes can now be drilled and screws placed where needed. B. This screw (arrow) looks as though it has penetrated the joint when in reality it is simply the angle of the radiographic beam that throws its projection into the joint. C. A true lateral view of the distal radius is necessary to judge placement of the radial screws. D. A radiograph is being taken with the wrist perpendicular to the x-ray beam (arrow). This is not a true lateral image, because the distal surface of the radius is inclined 20 degrees radially. (continued)
Precisely assess the stability of the construct after the plate has been applied. If appropriate, remove the provisional K-wires. If the K-wires are deemed critical for fracture stability, they can be left in place and removed 4 to 8 weeks later. If residual instability exists, add additional fixation with K-wires, an external fixator, a dorsal plate, or a combination.

**Closure**

Repair the pronator quadratus to its insertion site with a series of 3-0 absorbable horizontal mattress sutures (TECH FIG 6A). In many cases it is impossible to repair the pronator quadratus because the muscle and fascia are extremely thin or the muscle is damaged. In this situation, the muscle can be debrided or simply left in place.

Before skin closure, obtain final radiographs (TECH FIG 6B, C), and assess stability of the distal radioulnar joint. Place a drain only if excessive bleeding is anticipated. Consider methods to minimize postoperative pain: percutaneous placement of a pain pump catheter, injection of a long-acting local anesthetic, close the subcutaneous tissues with 4-0 absorbable suture and reapproximate the skin with interrupted 4-0 or 5-0 nylon sutures or a running subcuticular stitch. Place two layers of gauze and a nonadherent gauze over the wound, wrap the wrist and forearm with thick Webril (Kendall, Mansfield, MA), and apply a below-elbow splint in a neutral wrist position (TECH FIG 6D). If there is injury to the ulnar wrist (eg, ulna styloid fracture, distal radioulnar joint injury), immobilize the forearm with an above-elbow or Munster splint.

**TECH FIG 6**

A. The pronator quadratus has been repaired. B. AP radiograph demonstrating correction of the articular surface, radial height (lines), and radial inclination (dotted line). C. Lateral radiograph demonstrating correction of the palmar tilt (dotted line). D. A bulky dressing is applied with a volar splint holding the wrist in a neutral position. A pain pump catheter has been inserted for additional pain control.
We do not recommend use of the volar fixed-angle plate as a reduction tool in the acute setting. It is best employed (if at all) for a malunion, or perhaps for a fracture with minimal articular comminution.

This technique is difficult, because it has to account for the longitudinal and translational alignment of the plate before the reduction has been achieved.

Perform the surgical approach previously described.

Address first any distal articular involvement with reduction and K-wire fixation.

Affix the plate to the distal fragment, accounting for where the plate will sit on the radius shaft once the reduction is completed.

Place the screws so that they are parallel to the articular surface on the lateral x-ray view (TECH FIG 7A, B).

On the AP radiograph, align the plate with the perpendicular of the radial inclination of the distal radius (20 degrees; TECH FIG 7C, D).

Once distal fixation is complete, secure the proximal plate to the radius shaft, thereby completing the reduction.

Close and splint as described previously.

**TECH FIG 7** • A. The volar plate is applied with the distal screws placed first (parallel to distal articular surface). B. Reducing the plate to the diaphysis proximally accomplishes the reduction. C. The plate is applied at approximately a 20-degree angle relative to the distal articular surface or to the amount of angulation that is estimated. D. By reducing the plate to the diaphysis, the distal angulation is corrected.

**PEARLS AND PITFALLS**

**Preoperative planning**
- Obtain multiple radiographs in different positions (eg, several oblique views), especially in the setting of comminution or articular involvement.
- Obtain a CT scan if assessing the pattern of fracture when radiographs alone are difficult or uncertain.

**Surgical approach**
- Avoid crossing the distal flexion creases of the wrist.
- Avoid exposure ulnar to the midline of the flexor carpi radialis.
- Use extra care with deep dissection in the presence of hematoma or significant swelling.

**Fracture reduction**
- Employ traction across the wrist with a device or weights.
- Use a lobster-claw clamp on the proximal radius shaft for control of the forearm and as a reference for the lateral margins.
- Use instruments to disimpact and reduce articular fragments through the fracture itself, either volarly, dorsally, or both.
- Employ a temporary K-wire to stabilize the reduction before placement of the plate.

**Plate alignment**
- Confirm appropriate radial-ulnar positioning of the proximal plate using a true AP radiograph (ie, forearm in supination with open view of the distal radioulnar joint).
POSTOPERATIVE CARE

- The wrist is splinted in a neutral position, leaving the digits free.
- If the fracture is particularly tenous or there is injury to the ulnar wrist, a long-arm or Munster splint is applied.
- The patient is instructed to perform active ROM exercises for the digits every hour and to engage in strict elevation for at least 3 days.
  - It is critical to emphasize edema prevention and immediate ROM of the digits.
- At 1 week postoperatively, the splint is removed and the wound is examined.
- If swelling permits, the therapist fabricates a molded Orthoplast splint (Johnson & Johnson Orthopedics, New Brunswick, NJ) to be worn at all times.
- Active ROM exercises of the wrist are implemented 1 week postoperatively.
- At 4 to 6 weeks, putty and grip exercises are added.
- At 6 to 8 weeks, the splint is discontinued, and progressive strengthening exercises are advanced.
- If necessary, progressive passive ROM can begin, including use of dynamic splints.
- At 10 to 12 weeks, the patient usually can be discharged to all activities as tolerated.

OUTCOMES

- Overall good to excellent results can be expected in over 80% of patients with ROM, strength, and outcomes scoring.\textsuperscript{10,11,15,17}
- Studies comparing volar fixation to other forms of fixation (eg, external fixators, pins, and dorsal plating) have revealed similar if not superior results.
  - Results appear to be superior in the early recovery period, with the final outcome yielding equivalent results among all fixation groups.
  - Some studies suggest better maintenance in overall reduction compared to other forms of fixation.

COMPLICATIONS

- Complication rates as high as 27% have been reported.
- Complications can be categorized into those involving hardware, fracture, soft tissues, nerves, and tendons.\textsuperscript{7}
- Failures of hardware, such as plate or screw breakage, can occur but are rare. Usually such failures are an indication of other problems, such as nonunion.
- The hardware becomes unacceptably prominent in a minority of patients.
  - This complication may become evident only after some time has elapsed, as swelling of fibrous tissue subsides and bone remodels.
  - The most common sites include the dorsal wrist, when screws have been inserted, and the radial wrist, when a plate has been used.
  - It can be avoided with careful screw and plate placement and radiographic verification of their position.
  - Nonunion and delayed union are unusual. Consider a diagnosis of osteomyelitis or other risk factors such as smoking.
  - Loss of fracture reduction and fixation can occur, and is most common in patients with osteopenic bone or comminuted and articular fractures.
  - This can be avoided with frequent and early follow-up with repeat radiographs.
  - If instability is suspected, the fracture can be casted.
  - In the operating room, if instability is suspected, additional fixation should be considered (eg, external fixator, pins, bone graft).
  - Soft tissue complications are proportional to the energy of the initial injury.
  - Open wounds usually can be addressed with local measures.
  - Significant swelling must be addressed with early aggressive modalities. Swelling can lead to other complications, such as joint stiffness and tendon adhesions.
  - Nerve injuries can be the result of initial trauma or subsequent surgical trauma.
    - Assess and document neurologic status before surgery.
    - Avoid further injury to nerves with careful placement of retractors.
    - The palmar cutaneous branch of the median nerve can be injured during incision and exposure.
    - Postoperative neuromas can cause pain and sensitivity along scar.
    - Avoid the nerve with a well-placed incision radial to the flexor carpi radialis and careful deep dissection.
    - Postoperative swelling also can lead to median neuropathy. Carpal tunnel release should be performed if there is any suspected compression neuropathy or if this is to be anticipated as a result of postoperative swelling.
    - Tendon complications include adhesions and ruptures.
    - Most tendon adhesions involve the dorsal extensor tendons resulting in extrinsic extensor tightness.
    - Flexor tendon adhesions are uncommon and involve primarily the flexor pollicis longus.
    - Tendon ruptures have been described, especially involving the flexor pollicis longus and the extensor pollicis longus, as a result of plate and screw prominence, respectively.
      - The distal screws must not be left prominent, and caution must be applied when drilling.
      - The sagittal and coronal profiles of the plate being used must be taken into consideration—some plates are very prominent and extend far radially.
REFERENCES

DEFINITION
- High-energy fractures of the distal aspect of the radius with extensive comminution of the articular surface and extension into the diaphysis represent a major treatment challenge. Standard plates and techniques may be inadequate for the management of such fractures.
- Before the introduction of the bridge plating technique, treatment of these injuries was limited to cast immobilization or external fixation with or without Kirschner wire augmentation. Both of these methods are associated with unacceptably high complication rates.

ANATOMY
- The articular surface of the distal radius is tilted 21 degrees in the anteroposterior plane and 5 to 11 degrees in the lateral plane.
- The dorsal cortex surface of the radius thickens to form the tubercle of Lister.
- A central ridge divides the articular surface of the radius into a scaphoid facet and a lunate facet.
- Because of the different areas of bone thickness and density, fractures tend to occur in the relatively weaker metaphyseal bone and propagate intra-articularly between the scaphoid and lunate facets.
- The degree, direction, and magnitude of applied load may cause coronal or sagittal splits within the lunate or scaphoid facets.

PATHOGENESIS
- Two subsets of patients with distal radius fractures continue to represent unique treatment challenges:
  - Patients with high-energy wrist injuries with fracture extension into the radial diaphysis
  - Patients with multiple injuries who require load bearing through the injured wrist to assist with mobilization and nursing care

NATURAL HISTORY
- Lafontaine et al. showed that the end results of comminuted distal radius fractures treated by closed methods resembled the prereduction radiographs more than any other radiographs during treatment, even when the reduction successfully restored wrist anatomy.
- A number of studies clearly show that restoration of normal anatomy after distal radius fracture provides better function.
- Functional outcome scores in patients without anatomic reduction are poor.
- Malunion of the distal radius has been associated with pain, stiffness, weak grip strength, and carpal instability in a substantial percentage of patients. Long-term consequences include degenerative arthritis in up to 50% of patients with even minimal displacement in the young adult population.
- As surgical treatment (plating in particular) ensures more consistent correction of displacement and maintenance of reduction, there has been a trend toward operative treatment in both the elderly and the young population.

PATIENT HISTORY AND PHYSICAL FINDINGS
- In the management of high-energy distal radius fractures, a complete history should include the mechanism of injury. These fractures are commonly the result of axial loading as opposed to the bending forces, which are all low-velocity fractures.
- Examination of the soft tissue envelope of the wrist should be performed to rule out open fractures.
- Because of the high-energy nature of these fractures, patients are at increased risk of neurovascular compromise. Careful examination for signs of impending compartment syndrome as well as median nerve dysfunction from an acute carpal tunnel syndrome should be clearly documented.
- Associated injuries should be ruled out, and appropriate patient clearance according to advanced trauma life support guidelines should be obtained.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Good-quality pre- and post-reduction wrist radiographs should be obtained preoperatively to assess the fracture pattern and rule out associated injuries to the carpus or distal radioulnar joint (DRUJ).
- CT scans may be helpful to assess complex intra-articular distal radius fractures.

NONOPERATIVE MANAGEMENT
- There is no acceptable nonoperative management for high-energy comminuted distal radius fractures.

SURGICAL MANAGEMENT
- The use of internal distraction plating or bridge plating for distal radius fractures was introduced by Burke and Singer. The technique was expanded by Ruch et al., who described the use of a 12- to 16-hole 3.5-mm plate dynamic compression plate (DCP) (Synthes, Paoli, PA) placed in the floor of the fourth dorsal extensor compartment to span from the intact radius diaphysis to the third metacarpal.
- The bridge plating technique provides strong fixation and allows for distraction across impacted articular segments.
- The technique can be combined with a limited articular fixation approach for fracture patterns with intra-articular extension.
Bridge plating of the distal radius was further refined by Hanel et al.9 The authors described a variant of the bridge plating technique using 2.4-mm AO plates passed extra-articularly through the second dorsal compartment and secured onto the dorsal-radial aspect of the radius diaphysis and the second metacarpal (Table 1).

Preoperative Planning

- A 22-hole 2.4-mm titanium mandibular reconstruction plate (Synthes, Paoli, PA) or a 2.4-mm stainless steel plate specifically designed for use as a distal radius bridge plate (DRB plate, Synthes, Paoli, PA) is used for distal radius bridge plating.
- The mandibular reconstruction plate is made of titanium and has square ends and scalloped edges and threaded holes to accept locking screws. The DRB plate that the authors currently use is made of stainless steel and has tapered ends to facilitate sliding the plate within the extensor compartment; it also has locking screws.

### Table 1

<table>
<thead>
<tr>
<th>Indication</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metadiaphyseal comminution of the radius</td>
<td>Extensive comminution in metadiaphyseal region is difficult to treat with standard implants used for distal radius fractures.</td>
</tr>
<tr>
<td>Need for weight bearing through the upper extremity</td>
<td>Patients with associated lower limb injuries may require the need for early weight bearing through the upper extremities.</td>
</tr>
<tr>
<td>Polytrauma</td>
<td>Nursing care of the multiply injured patient may be easier with spanning internal fixation than with external fixation.</td>
</tr>
<tr>
<td>Augmented fixation</td>
<td>In osteoporotic bone, bridge plating can be used to augment tenuous fixation.</td>
</tr>
<tr>
<td>Carpal instability</td>
<td>Carpal instability, particularly radiocarpal, isolated or in combination with a distal radius fracture, may be held in a reduced position with the help of spanning internal fixation.</td>
</tr>
</tbody>
</table>

Positioning

- With the patient anesthetized and supine on the operating table, the involved extremity is draped free and centered on a radiolucent hand table.
- Finger traps are applied to the index and middle fingers and 4.5 kg of longitudinal traction is applied through a rope and pulley system.
- A C-arm comes in from above or below the hand table (FIG 1).

Approach

- Under image intensification, the closed reduction maneuver described by Agee1 is performed.
- Plates are passed extra-articularly through the second dorsal compartment and secured onto the dorsal-radial aspect of the radius diaphysis and the second metacarpal.
- The interval between the extensor carpi radialis longus (ECRL) and brevis (ECRB) is developed and the diaphysis of the radius exposed.
- The DRB plate is introduced beneath the muscle bellies of the outcroppers extraperiosteally and advanced distally between the ECRL and ECRB tendons.

**CLOSED REDUCTION MANEUVER OF AGEE**

- Longitudinal traction is first used to restore length and to assess the benefit of ligamentotaxis for the restoration of articular stepoff (TECH FIG 1A,B).
- Next, the hand is translated palmarly relative to the forearm to restore sagittal tilt and to assess the integrity of the volar lip of the radius (TECH FIG 1C-F).
- Finally, pronation of the hand relative to the forearm is performed to correct the supination deformity.
- Once the initial reduction maneuver is completed, the bridge plate is then applied.

**TECH FIG 1** Radiographs show an AP projection of the wrist injury before (A) and after (B) distraction is applied. (continued)
**APPROACH AND PLATE INSERTION**

- The DRB plate is superimposed on the skin from the radial diaphysis to the distal metadiaphysis of the second metacarpal. The position of the plate is verified with image intensification and markings are placed on the skin at the level of the proximal and distal four screw holes of the plate (TECH FIG 2A–C).
- The subcutaneous tissues are infiltrated with 0.25% bupivacaine with epinephrine to promote hemostasis.
- A 5-cm incision is made at the base of the second metacarpal and continued along the second metacarpal shaft. In the depths of this incision, the insertions of the ECRL and ECRB are identified as they pass beneath the distal edge of the second dorsal wrist compartment to insert on the second and third metacarpal bases respectively.
- A second incision is made just proximal to the outcropper muscle bellies (abductor pollicis longus and extensor pollicis brevis), in line with ECRL and ECRB tendons. The interval between the ECRL and ECRB is developed and the diaphysis of the radius exposed (TECH FIG 2D,E).
- The DRB plate is introduced beneath the muscle bellies of the outcroppers extraperiosteally and advanced distally between the ECRL and ECRB tendons (TECH FIG 2F).
- Some resistance may be encountered as the plate emerges distally but can usually be easily overcome with gentle manipulation of the plate (TECH FIG 2G).
- Occasionally, the plate will not pass through the compartment. In these cases, a guidewire or stout suture...
TECH FIG 2 • (continued) D. The ECRL and extensor carpi radialis brevis (ECRB) tendons just proximal to the abductor pollicis longus in the forearm. E. Development of the interval between the ECRL and ECRB tendons to gain access to the radius shaft. F. The proximal aspect of the plate over the radius and in between the ECRL and ECRB. It is important to ensure that the plate runs within the second compartment and not superficial to the first and third compartment tendons. G. The plate is advanced proximal to distal and emerges distally over the second metacarpal. H. A third incision is marked out just ulnar to the tubercle of Lister. I. The extensor pollicis longus tendon has been released from its compartment, and bone graft is inserted through the dorsal fracture line just ulnar to the bridge plate.

PLATE FIXATION AND ARTICULAR FIXATION

- After the bridge plate is passed, it is then secured to the second metacarpal by placing a nonlocking fully threaded 2.4-mm cortical screw through the most distal plate hole. The proximal end of the plate is then identified in the forearm.
- If the radial length has not been restored, then the plate, secured to the second metacarpal, is pushed distally until the length is reestablished and a fully threaded 2.4-mm nonlocking screw is placed in the most proximal plate hole. By using nonlocking screws the plate is effectively lagged onto the intact bone.
- Plate alignment along the longitudinal axis of the radius is guaranteed by securing the most distal and most proximal screw holes first.
- The remaining holes are secured with fully threaded locking screws inserted with bicortical purchase.
- It has been our experience that as the plate is passed along the radial diaphysis, through the second compartment and along the second metacarpal, extra-articular alignment, radial inclination, volar tilt, and radial length are restored.
- Intra-articular reduction may be further adjusted by using limited periarticular incisions to allow for direct...
Manipulation of articular fragments, placement of subchondral bone grafts, repair of intercarpal ligament injuries, and augmentation of fracture fixation with Kirschner wires and periarticular plates.

- Displaced volar medial fracture fragments that are not reduced with this technique require a separate volar incision and appropriate buttress support.
- The biomechanical stability of spanning plates is strong and predictable. Behrens et al., studying the rigidity of external fixator configurations, demonstrated that rigidity is directly proportional to how close the longitudinal fixator bar is to the bone and the fracture. A bridge plate, resting directly against the radius proximally and metacarpals distally, therefore optimizes the conditions to obtain the strongest possible fixator construct.
- A DRB plate fixed with a minimum of three screws at either end of the plate confers significantly more stability than would an external fixator used to stabilize a comparable fracture (TECH FIG 3).

**DISTAL RADIOULNAR JOINT MANAGEMENT**

- DRUJ stability is assessed after radius reconstruction. If the DRUJ is stable, the limb is immobilized in a long-arm splint with the forearm in supination for the first 10 to 14 days postoperatively.
- If the DRUJ is unstable, and there are no contraindications to prolonging the operation, repair or reconstruction of DRUJ and triangular fibrocartilage complex is undertaken.

**PEARLS AND PITFALLS**

**Hardware removal**
- At the time of hardware extraction, if a mandibular reconstruction plate was used, the screws are removed and the plate is twisted axially 720 degrees to break up the soft tissue adhesions and callus that tend to grow around and onto the scalloped edges of the titanium plate. This maneuver is not usually required when the smooth-edged stainless steel DRB is used.
- A removable short-arm splint is worn for 2 to 3 weeks after plate removal. Hand therapy at this point is directed at regaining motion and strength.

**POSTOPERATIVE CARE**

- Digit range-of-motion exercises start within 24 hours of surgery. Load bearing through the forearm and elbow is allowed immediately, as well as the use of a platform crutch when the patient is physiologically stable. One month postoperatively the platform is removed and weight bearing is allowed through the hand grip of regular crutches. Lifting and carrying are restricted to about 4.5 kg until fracture healing.
- DRUJ stability and forearm motion are assessed 2 weeks after reduction. If the patient can supinate the forearm with lit-
tle effort and the DRUJ is stable, then splinting is discontinued and axial loading through the extremity is allowed at this point.
- If the patient has difficulty maintaining supination, or if the DRUJ was reconstructed acutely, a removable long-arm splint is fabricated.
- If the DRUJ was transfixed with Kirschner wires, then the wires are removed on the third postoperative week and DRUJ stability is reassessed.
- Supplemental Kirschner wires for articular fixation are removed 6 weeks postoperatively.
- The DRB plate and screws are removed usually no earlier than 12 weeks after injury.

OUTCOMES
- The bridge plating technique for distal radius fractures was reviewed in a retrospective study consisting of 62 consecutive patients treated in this fashion.9 The series represents the senior author’s 10-year experience with the technique at a Level 1 trauma center. Patients managed with bridge plating either for distal radius fractures with extensive metadiaphyseal comminution or for distal radius fractures associated with other injuries requiring weight bearing through the affected extremity represented 13% of distal radius fractures treated with operative fixation during this period. Fracture healing occurred in all 62 patients.
- In each case radial length was within 5 mm of neutral ulnar variance, radial inclination was greater than 5 degrees, and palmar tilt was at least neutral.
- There were also no articular gaps or stepoffs greater than 2 mm and the DRUJ was stable in all cases.
- The plates were removed on average 112 days after placement.
- Forty-one of the 62 patients have returned to their previous levels of employment. Of the remaining 21 patients, 8 were unemployed at the time of injury and remain so.
- Thirteen patients sustained multiple injuries requiring considerable changes in occupation and lifestyle. Only 1 of these 13 patients considers the wrist fracture to be the limiting factor in failing to return to work.
- Overall these results compare favorably with the findings of Burke and Singer5 and Ruch et al.17
- Similarly, Ruch et al.17 showed that 64% of patients obtained excellent radiographic and functional results and another 27% of patients obtained good results in their prospective cohort of patients with comparable pathology.
- The authors of each of these studies propose that distraction plating allows fracture reduction and fixation over a broad metadiaphyseal area while effectively diverting compression forces away from the fracture site.
- The use of bridge plating in the treatment of distal radius fractures avoids the complications of external fixation. A bridge plate can remain implanted for extended periods without deleterious effects on functional outcome. All patients in our series went on to heal with acceptable metadiaphyseal and intra-articular alignment. In patients with multiple traumatic injuries, bridge plating allowed earlier postoperative load bearing across the affected wrist. This enabled independent transfers and the use of ambulatory aids. Application of bridge plates is simple and surgical time is comparable with the application of an external fixator.

COMPLICATIONS
- There was one documented hardware failure in the series in a patient who initially refused to have the implant taken out and continued to work in heavy manual labor for 19 months before the bridge plate failed.
- In addition, there were no cases of excessive postoperative finger stiffness or reflex sympathetic dystrophy.
- This reflects the overall infrequent complications reported in the literature for bridge plating of the distal radius. In fact, Burke and Singer5 reported no complications, and Ruch et al.17 reported no hardware failures and only three patients who developed long finger extensor lag of 10 to 15 degrees.

REFERENCES
**DEFINITION**
- The distal ulna is the fixed point around which the radius and the hand function (FIG 1A).
- Fractures of the distal ulna are often inadequately treated in comparison to its larger counterpart, the radius (FIG 1B, C).
- The current literature gives little guidance as to the management of these fractures and associated injuries.

**ANATOMY**
- The ulnar head forms the fixed point on which the hand and radius rest (FIG 2A).
- The radius rotates around the distal ulna through the distal radioulnar joint (DRUJ) during forearm pronation and supination.3,4
- This joint is connected to the carpus by a complicated ligament apparatus, the triangular fibrocartilage complex (TFCC).
- The stability of the DRUJ is achieved through bony congruity between the sigmoid notch of the radius and the ulnar head supported by the ulnoradial ligaments1,4 (FIG 2B).
- The spheres of the two articular surfaces differ (FIG 2C).
- Sixty percent of the joint surfaces are in contact in neutral forearm position.1
- In full pronation and supination there is only 10% bony contact.1
- The ligaments run from the fovea of the ulnar head and the base of the ulnar styloid to the dorsal and palmar edges of the sigmoid notch on the distal radius1,9 (Fig 2B).

**PATHOGENESIS**
- Isolated ulnar fractures most commonly occur when the forearm is struck by an object, explaining the eponym “nightstick fracture.”
- Distal ulnar fractures are most often due to a fall on an outstretched hand.
- It is a common understanding that ulnar-sided injuries are more often caused by falls backward in which the forearm is in supination, loading the ulnar side of the distal forearm and wrist and causing distal ulnar fractures, triquetral chip fractures, TFCC injuries, and so forth.
- In contrast, radial-sided injuries are more often caused by falls forward, loading the radial side of the forearm and wrist and causing scaphoid fractures, distal radius fractures, and so forth.

**NATURAL HISTORY**
- Many distal ulnar fractures leave only marginal long-term problems.
- Some distal ulnar malunions cause DRUJ incongruency with subsequent instability or blocked forearm rotation (FIG 3). This is why management of these deceptive fractures is important.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Posteroanterior, lateral, and oblique radiographs typically reveal the pathology.
FIG 2 • A. The distal ulna is the fixed point around which the radius rotates in pronation and supination. Through the ulnocarpal ligament the distal ulna relates to the hand, allowing daily hand activities. B. The distal radio-ulnar joint is stable because of bony congruity between the ulnar head and the sigmoid notch on the radius. The ulnorialar ligament inserts in the fovea and the base of the ulnar styloid and has a dorsal and palmar ligament attached to the dorsal and palmar part of the sigmoid notch respectively. They act as reins in the pronation and supination motion. C. The spheres of the two articular surfaces differ: the curvature of the ulnar head has a shorter radius, whereas the curvature of the sigmoid notch has a greater radius.

FIG 3 • A,B. Radiographs showing a distal radius fracture together with an ulnar head and styloid fracture. The complexity of the ulnar-sided injury was underappreciated. C. Intraoperative fluoroscopic image after fixation of the distal radius fracture, revealing displaced and unstable ulnar fractures. (continued)
CT is useful in examining articular fractures of the ulnar head.
MRI is sometimes needed to evaluate the integrity of the TFCC.
Arthroscopy should be considered if a radiograph leads the physician to suspect DRUJ dissociation without radiographic explanations, such as a displaced ulnar styloid base fracture.

**SURGICAL MANAGEMENT**

**Findings and Indications**

**DRUJ Dissociation**
- Radiographs occasionally reveal DRUJ dissociation in the absence of an ulnar-sided fracture (FIG 4). This results from detachment of the unioradial ligament (FIG 5A).
- Such unioradial ligament injuries have been found to cause DRUJ laxity and a worse outcome after distal radius fractures in patients without osteoporosis (FIG 5B).
- Arthroscopically assisted repair or open repair and reattachment of the unioradial ligament to the fovea of the ulnar head are required to restore stability in the DRUJ (FIG 5C) (see Chap. HA-49).

**Ulnar Styloid Fractures**
- The importance of ulnar styloid fractures and the need for operative intervention depends on the involvement of the unioradial ligament insertion site around the fovea of the ulnar head at the base of the styloid (FIG 6A).
- Generally, ulnar styloid fractures should be operated on if the fracture is at the base of the ulnar styloid and is displaced more than 2 mm (FIG 6B,C).
- Radial translation of the fractured ulnar styloid is caused by the detachment of the unioradial ligament. This increases the indication (FIG 6D) more than axial, distal fracture displacement (detaching the ulnotriquetral collateral ligament).
- Ulnar styloid fractures at the tip are likely to be stable and do not require fixation, as the unioradial ligament remains attached to the ulnar head at the base of the styloid (FIG 6E,F).
- Ulnar-sided injuries associated with distal radius fractures should be carefully assessed radiographically and clinically after open reduction and internal fixation (ORIF) of the radius fracture.
- Ulnar fracture reduction and DRUJ joint stability are often improved after treatment of the radius fracture.
- Stable DRUJ means that the unioradial ligament is not attached to the fractured ulnar styloid and therefore can be treated nonoperatively.
- Unstable DRUJ indicates that the unioradial ligament is detached with the styloid fracture. The styloid should be reduced and stabilized or the ligament reattached.

**FIG 3 • (continued)**

D,E. The distal radius fracture was stabilized using a volar locking plate. The ulnar head and styloid fractures were partially reduced and fixed with two Kirschner wires. The surgeon adequately secured the ulnar styloid fracture but not the ulnar head fracture and postoperatively did not restrict forearm rotation. F,G. These radiographs reveal the eventual ulnar head malunion that resulted in distal radioulnar joint instability and diminished forearm rotation. The situation was salvaged using an ulnar head replacement prosthesis.

**FIG 4 •**

A. An undisplaced distal radius fracture with no obvious distal ulna pathology. B. The same fracture with a stress test to the distal radioulnar joint (DRUJ), and an obvious DRUJ dissociation is seen as a sign of a complete unioradial ligament detachment in the absence of an ulnar styloid fracture.
A B C

**FIG 6** • A. The ulnar ligament has superficial and deeper components, which insert at the fovea of the ulnar head and partly attach to the base of the ulnar styloid. Consequently, a fracture at the base of the ulnar styloid may or may not detach the main distal radioulnar joint-stabilizing ligament. B,C. Ulnar styloid fractures at the base may detach the ulnar ligament and should be operated on if they are displaced more than 2 mm. D. Radial displacement (detaching the ulnar ligament) increases the indication for surgical treatment. E,F. Ulnar styloid tip fractures represent avulsion fractures from the ulnotriquetral collateral ligament. They demand no further treatment.
Ulnar Styloid Nonunion
- The main physical findings of ulnar styloid nonunion are ulnar-sided wrist pain worse with loading in rotation and tenderness over the ulnar styloid. Symptoms from an ulnar styloid nonunion are related to the following:
  - DRUJ instability from a malfunctioning ulnoradial ligament (peripheral TFCC detachment) (Fig 5B)
  - Impingement of the overlying extensor carpi ulnaris (ECU) tendon
  - Abutment on the carpus (Fig 7A,B)
  - Soft tissue irritation from the loose body (Fig 7C,D)

Ulnar Head Fractures
- Ulnar head fractures are most often associated with distal radius fractures, and the pattern of the distal radius fracture will have a strong influence on the overall functional outcome.
- Ulnar head fractures are seen either alone or with involvement of extra-articular portions of the distal ulna, proximally toward the diaphysis or distally including the styloid (Fig 3A,B).

Distal Ulnar Neck and Shaft Fractures
- A distal ulnar neck or distal shaft fracture is a fracture that occurs within 4 cm of the distal dome of the ulnar head (Fig 8A-D).

FIG 7 • A,B. Abutment of the ulnar styloid into the triquetrum on the ulnar side of the carpus. C,D. An ulnar styloid nonunion causing problems as a loose body.

FIG 8 • A,B. This ulnar shaft fracture is by definition within 4 cm of the distal dome of the ulnar head. C,D. This ulnar shaft fracture is more proximal and should be considered an isolated ulnar fracture. However, there may still be involvement in the distal radioulnar joint (DRUJ), which needs to be taken into account. The DRUJ should be examined for stability after open reduction and internal fixation. (continued)
Some distal ulnar fractures in association with distal radius fractures realign after manipulation and are considered to be stable once the radius is reduced. It is difficult to immobilize unstable fractures with a cast alone. Three-point fixation, even in an above-elbow cast, is not effective (FIG 8E,F).

Comminuted Intra-Articular Distal Ulnar Fractures
- Comminuted distal ulnar fractures that are irreducible and cannot be reconstructed have been mentioned in the literature in only one case report.

It is generally recommended that the initial approach be geared toward restoring the anatomy and maintaining the overall alignment of the ulna and DRUJ.

Approach
- The described approach is used for all distal ulnar fractures, including the ones extending into the neck of the ulna and into the distal shaft.
- This approach can, for instance, access an ulnar styloid fracture or nonunion and at the same time visualize, assess, and allow treatment of any associated TFCC pathology.

INCISION AND EXPOSURE
- Approach the distal ulna through a dorsal zigzag incision centered over the DRUJ (TECH FIG 1AB).
- This approach allows reattachment of all crucial stabilizing structures at the time of wound closure.
- Carefully protect the dorsal sensory branches of the ulnar nerve (TECH FIG 1C).
- Incise the retinaculum overlying the fifth extensor compartment (TECH FIG 1D).
- Elevate the ulnar retinacular flap in the interval between the extensor retinaculum and the separate dorsal sheet for the ECU tendon.
- Preserve the integrity of the separate ECU compartment (TECH FIG 1E).
- Open the dorsal capsule of the DRUJ using an ulnary based flap raised from the 4–5 septum (TECH FIG 1F).
- Identify the 4–5 intercompartmental artery.
Options for fixation of ulnar styloid base fractures include the following:
- Single or double Kirschner wires (TECH FIG 2A,B)
- Tension band wiring (TECH FIG 2C)
- Wire loop or suture
- Screw fixation (TECH FIG 2D)

Begin the capsular incision at the neck of the ulna and extend it to the 4-5 intercompartmental artery, which is diathermied.

The incision continues along this line to the level of the radiocarpal joint, where it then extends distally and ulnarly along the dorsal radiotriquetral ligament to the triquetrum.
- By staying in a flat layer along the dorsal cortex of the radius, the dorsal ulnoradial ligament attachment is not violated.
- The DRUJ and the spanning TFCC are then readily visualized. The ulnocarpal joint is often hidden behind the synovium over the meniscus homolog (TECH FIG 1G).
- If required, remove the synovium dorsal to the ulnoradial ligament to gain access to the ulnar styloid and the ulnocarpal joint.
- In cases of a distal neck fracture without any intra-articular involvement or soft tissue components, the approach stays proximal to the capsular flap. However, the retinacular flap needs to be raised to address the distal metaphyseal fractures.
Chapter 14  ORIF OF ULNAR STYLOID, HEAD, AND METADIAPHYSEAL FRACTURES

**TECH FIG 2** • The ulnar styloid can be fixed in various ways to secure reattachment of the ulnaradial ligament and thereby stabilize the distal radioulnar joint. **A,B.** Single (not rotationally stable) or double Kirschner wires. **C.** Tension band wiring. **D.** Screw fixation (not rotationally stable).

**ULNAR STYLOID NONUNIONS**

- Reattachment of the nonunited fragment to the ulnar head is indicated if the fragment is large.5
- If the fragment is small, it should be excised and the ulnaradial ligament reattached directly to the fovea of the ulnar head.5
- If the fragment is small and located distally and there is no DRUJ instability, the ulnar styloid can be excised without any associated ligament procedure.5

**ULNAR HEAD FRACTURES**

- Ulnar head fractures without a proximal extra-articular component
  - Fractures that are displaced (with an intra-articular stepoff) or unstable are treated with ORIF using buried headless compression screws6 or Kirschner wires.
  - Immobilization after fixation depends on the stability of the fracture and its fixation.
- Ulnar head fractures with a proximal extra-articular component
  - The intra-articular component is reduced and stabilized.
  - If the extra-articular component extends proximally toward the neck of the distal ulna a condylar blade plate is recommended (**TECH FIG 3**), whereas tension band wiring is recommended if the extra-articular component involves the ulnar styloid (Tech Fig 2C).
  - Immobilization after fixation depends on the stability of the fracture and its fixation.

**TECH FIG 3** • Irreducible or unstable distal forearm fractures require open reduction and internal fixation.10 AP and lateral radiographs show a dorsally displaced distal forearm fracture fixed with a blade plate.
DISTAL ULNAR NECK AND SHAFT FRACTURES

- Irreducible or unstable fractures require ORIF.\textsuperscript{10}
- This can be achieved using either a condylar blade plate\textsuperscript{10} (Tech Fig 3) or tension band wiring supplemented by intrafragmentary screws (TECH FIG 4).

![Tech Fig 4](image)

**TECH FIG 4 •** A, B. AP and lateral radiographs show a dorsally displaced distal forearm fracture. Open reduction and internal fixation was performed using both a dorsoradial and a dorsoulnar approach to stabilize the fractures. C. Because of the comminution around the ulnar styloid base, fixation was achieved with a suture loop.

COMMINUTED INTRA-ARTICULAR DISTAL ULNAR FRACTURES

- Three treatment options exist for comminuted intra-articular distal ulnar fractures:
  - Restoration of the anatomy and overall alignment of the ulna and DRUJ as mentioned above
  - This can be accomplished with manipulation and above-elbow cast immobilization alone or alternatively by surgical means with temporary wiring or external fixation.
  - The potential problems with this management technique are wrist stiffness and reduced forearm rotation that may not be corrected with a late salvage procedure.
  - Primary distal ulnar head replacement\textsuperscript{2}
    - Theoretical advantage is reduced stiffness (from having early movement) and less DRUJ pain.
  - Total or partial excision of the ulnar head as well as DRUJ arthrodesis with distal ulnar neck resection (Sauve-Kapandji procedure)

POSTOPERATIVE CARE

- Stable fixation of the distal ulnar complex still requires protection postoperatively with a below-elbow splint.
- Intermediate stable fixation requires 4 weeks of protection using a sugartong-type splint to allow flexion and extension of the elbow but protect against uncontrolled pronation and supination.
- Unstable fixation after internal, external, or nonoperative treatment requires above-elbow protection in neutral forearm rotation to limit movement for the first 6 weeks. There is otherwise a risk that rotational forces will cause a nonunion or malunion.

OUTCOMES

- Outcome is influenced by the fact that most distal ulnar fractures are neglected in comparison to the more common and more extensively treated distal radius fractures.
- The outcome can surely be improved if distal ulnar fractures are treated more directly and aggressively.
- The outcome will also improve if the relationship between the ulnar styloid and the ulnoradial ligament is fully understood and addressed.

COMPLICATIONS

- Stiffness of the DRUJ with limited pronation and supination
- Infection
- Nonunion
- Malunion

REFERENCES


DEFINITION
- Distal radius malunion is best defined as malalignment associated with dysfunction.
  - Malalignment does not always result in dysfunction. In particular, the vast majority of older, low-demand patients function very well with deformity.
  - Dysfunction can include loss of motion, loss of strength, or pain.\textsuperscript{1,2,5}
- Pain can be the most difficult to associate with deformity. Osteotomy for pain—as with any surgery for pain—is relatively unpredictable and should be undertaken with caution. Carpal malalignment, ulnocarpal impaction, and distal radioulnar joint malalignment are all potentially painful and can be variably addressed.
- The relationship between distal radius malunion and carpal tunnel syndrome is disputed. Some surgeons claim a direct causal relationship as well as the ability to improve carpal tunnel syndrome with osteotomy alone.

ANATOMY
- Loss of alignment can be measured on radiographs.
  - Angulation of the articular surface on the lateral view is measured as the angle between a line connecting the dorsal and palmar lips of the distal radius articular surface on the lateral view and a line perpendicular to the radius shaft.
  - Ulnarward inclination (often called radial inclination, a misnomer since the articular surface tilts toward the ulna) is measured as the angle between a line connecting the ulnar limit and the radial limit of the distal radius articular surface on the posteroanterior (PA) view and a line perpendicular to the radial shaft.
  - Ulnar variance is a better measure of shortening of the radius than radial length. It is measured as the distance between two lines drawn perpendicular to the radial shaft on the PA view, one at the level of the most ulnar corner of the lunate facet and the other at the distal limit of the ulnar head.
  - Positive ulnar variance means that the ulna is longer than the radius. Negative means the ulna is shorter.
- Loss of articular surface alignment can be measured on radiographs as gap, step, or subluxation.
  - This is most accurately measured using CT images (FIG 1).
  - Sources of variability in radiographic measurements include variation in the radiographs, imprecision in the measurement techniques, and imprecision in the selection of the points of reference.

PATHOGENESIS
- Fractures of the distal radius heal rapidly. A malaligned healing fracture can be considered a malunion within 4 to 6 weeks of injury.
- Risk factors for fracture instability include age, metaphyseal comminution, dorsal tilt, ulnar variance, and lack of functional independence.
- Manipulation of previously reduced fractures that redisplace in a cast or splint signifies instability and is not worthwhile.
- Limitations of various treatment techniques may contribute to creation of a malunion.
  - Percutaneous pins alone may not be sufficient to maintain alignment when there is substantial metaphyseal comminution.
  - External fixation alone without ancillary percutaneous pin fixation of the fracture
  - Early removal of pins or an external fixator. Settling of the fracture can also be observed after implant removal more than 6 weeks after injury, particularly when there is substantial metaphyseal comminution.
  - Nonlocked plates may loosen in the osteopenic metaphyseal bone.
- Complacency must be avoided. Many older patients desire optimal wrist alignment and function, and treatment decisions should not be made on chronological age alone.

NATURAL HISTORY
- Ulnar-sided wrist pain can improve for a year or more after fracture of the distal radius, so patience is warranted.
- Lack of forearm rotation may be related to capsular contracture or bony malalignment. For slight malunions, patience with exercises and rehabilitation is advisable.

Risk factors for fracture instability include age, metaphyseal comminution, dorsal tilt, ulnar variance, and lack of functional independence.
- Manipulation of previously reduced fractures that redisplace in a cast or splint signifies instability and is not worthwhile.
- Limitations of various treatment techniques may contribute to creation of a malunion.
  - Percutaneous pins alone may not be sufficient to maintain alignment when there is substantial metaphyseal comminution.
  - External fixation alone without ancillary percutaneous pin fixation of the fracture
  - Early removal of pins or an external fixator. Settling of the fracture can also be observed after implant removal more than 6 weeks after injury, particularly when there is substantial metaphyseal comminution.
  - Nonlocked plates may loosen in the osteopenic metaphyseal bone.
- Complacency must be avoided. Many older patients desire optimal wrist alignment and function, and treatment decisions should not be made on chronological age alone.

NATURAL HISTORY
- Ulnar-sided wrist pain can improve for a year or more after fracture of the distal radius, so patience is warranted.
- Lack of forearm rotation may be related to capsular contracture or bony malalignment. For slight malunions, patience with exercises and rehabilitation is advisable.
While it is often stated that an extra-articular distal radius malunion leads to future arthrosis, there are no data to support this contention.

After a recovery period of 1 to 2 years from fracture, the functional deficits seem fairly stable.

Articular incongruity or subluxation in relatively nonarticular areas can be reasonably well tolerated, but in most cases intra-articular incongruity will lead to arthrosis, pain, and dysfunction. There is no clear time frame for these changes—indeed, symptoms do not correlate well with radiographic anatomy and the predictors of arthrosis are not well established.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Pain should be very discrete and specific. It is important that there be a direct correlation of the pain with a clear operative target. Vague, diffuse, or disproportionate pain should not be treated with osteotomy. Pain alone is not a good indication for osteotomy, so the interview should elicit specific aspects of the pain for which there is a good operative target and the risks of surgery are justified.
- Lack of motion should be clearly due to malalignment and not due to pain or squeamishness—likewise for instability of the distal radioulnar joint (DRUJ).
- Range of motion: A goniometer is used to measure wrist flexion, extension, radial and ulnar deviation, supination, and pronation.
- Ulnocarpal compression: The carpus is forcefully ulnarily deviated toward the ulna.
- Consistent reproduction of usual pain with ulnar deviation tasks is consistent with ulnocarpal impaction.
- The examiner can test for DRUJ instability by stabilizing the radius and trying to subluxate the distal ulna dorsal and volar from the sigmoid notch of the radius.
- Substantially less stability than the opposite side may correlate with symptomatic DRUJ instability, but this is a very difficult and subjective test.
- Scaphoid shift test: Instability would indicate a possible scapholunate interosseous ligament tear, indicating a potential dissociative rather than the typical nondissociative carpal malalignment usually associated with distal radius malunion.
- Grip strength is one measure of wrist dysfunction, but it is largely determined by pain and effort—both strongly influenced by psychosocial factors.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Posteroanterior and lateral radiographs of the wrist (FIG 2A–D) can be supplemented by specific radiographs for evaluation of the joint surface, particularly for potential articular malunions.
- Comparison with the opposite, uninjured wrist is useful and serves as a template for surgical correction.
- CT, particularly three-dimensional CT, is useful to precisely evaluate the joint surfaces (FIG 2E).
- Neurophysiologic tests (nerve conduction velocity and electromyography) are ordered to evaluate any symptoms or signs of carpal tunnel syndrome that may need to be addressed.

**DIFFERENTIAL DIAGNOSIS**

- Stiffness: capsular stiffness and tendon adhesions
- Numbness: idiopathic carpal tunnel syndrome
- Pain: another discrete source of pain or even idiopathic pain

**NONOPERATIVE MANAGEMENT**

- Nonoperative management is appropriate for low-demand and infirm individuals. Splints are weaned after 6 weeks of cast immobilization. Patients who struggle to regain motion may benefit from working with an occupational therapist or a certified hand therapist. Normal activities are resumed in 3 or 4 months. The patient may return every 2 or 4 months or so until satisfied with the result.
- Patience is warranted in many situations, particularly for patients with ulnar-sided wrist pain thought due to an extra-articular malunion.
- This discomfort is the last pain to go away after a distal radius fracture and routinely lasts up to a year.

---

**FIG 2 • A,B. AP and lateral radiographs of extra-articular dorsally angulated malunion. C,D. PA and lateral radiographs of an extra-articular dorsally displaced malunion. E. CT shows rotational deformity associated with a volarly displaced extra-articular fracture. (Copyright Diego Fernandez, MD, PhD.)**
Surgical Management

- Surgery is appropriate when a radiographic deformity correlates with a specific anatomically correctable problem and the deformity is associated with a substantial risk of dysfunction and arthrosis.
- The patient must understand the risks and benefits of intervening.
- The surgeon should be wary of pain as the primary complaint, because pain is strongly influenced by psychosocial factors, and pain relief is an achievable goal only when consistent with an objective, correctable anatomic deformity such as discomfort clearly associated with a substantial ulnocarpal impingement.
- When the issue is restriction of motion and there is less than 20 degrees of dorsal tilt or less than 5 mm of ulnar positive variance, a nonoperative approach may be warranted.
- There are no fixed rules or thresholds for acceptable alignment. The correlation with symptoms and dysfunction is more important.
- Intra-articular osteotomies should be considered only when the malalignment is simple and the planned correction is straightforward.
- For instance, malalignment of volar shearing fracture would be considered when the fragment is large, there is little or no articular comminution or impaction, and the dorsal fragments are not healed in a malaligned position.

- Distal radius osteotomy need not be performed urgently. The patient should have demonstrated excellent exercise skills and full finger motion, and there should be no significant nerve or tendon dysfunction or edema.
- In the case of an intra-articular malunion, intervening early (optimally within 6 months, definitely within 1 year of the fracture) when the fracture is not completely healed may take precedence over these concerns.

Preoperative Planning

- The desired angular, rotational, and length corrections are planned based on preoperative radiologic studies, including a radiograph of the opposite wrist if uninjured (FIG 3A,B).
- It can be useful to draw and write out a reconstruction plan, particularly for complex malunions (FIG 3C–E). In that way every contingency is anticipated and the surgery is likely to go more smoothly.

Positioning

- The patient is positioned supine with the arm supported on a hand table.
- A nonsterile pneumatic tourniquet is used and inflated after exsanguination and before the skin incision.

Approach

- The operative approach is either dorsal or volar, depending on the deformity and the chosen surgical technique.

---

**FIG 3 • A,B.** Preoperative plans for dorsal osteotomy in the patient in Techniques Figures 1 to 3: preosteotomy plan (A) and postosteotomy and corticocancellous bone grafting plan (B). **C.** Preoperative plan for an extra-articular osteotomy through a volar approach in the patient in Techniques Figures 4 and 5. (continued)
Exposure

- Make a longitudinal incision centered over the tubercle of Lister, in line with the third metacarpal (TECH FIG 1A).
- Elevate skin flaps, taking care to protect the branches of the superficial radial nerve in the radial skin flap.
- Incise the retinaculum over the third extensor compartment. Remove the tendon of the extensor pollicis longus (EPL) and transpose it radialward (TECH FIG 1B).
- The EPL tendon will be left in the subcutaneous tissues at the completion of the procedure.

Dorsal Extra-Articular Distal Radius Osteotomy: Corticocancellous Graft

- Elevate the fourth dorsal compartment and its tendons subperiosteally.
- Preserve the integrity of this compartment.
- It is usually not possible to elevate the second dorsal compartment subperiosteally, so simply retract the extensor carpi radialis brevis and longus tendons radially after opening the compartment.

Osteotomy and Realignment

- Kirschner wires drilled parallel to the articular surface can facilitate monitoring of realignment (TECH FIG 2A).
- A distractor or small external fixator may facilitate realignment and provisionally stabilize the fracture.
- The proximal threaded pin is drilled into the radial diaphysis perpendicularly in a position that will not interfere with implant application.
- The distal threaded pin is drilled at an angle equal to the desired correction of the lateral tilt of the distal radius articular surface so that distraction of the two pins will bring this pin parallel to the proximal pin (perpendicular to the radius), thereby restoring alignment.
- The pins should be drilled so that they also help restore the appropriate ulnarward inclination of the distal radius articular surface when distracted.
- Planned angular corrections can be monitored with sterile geometric templates.
- The osteotomy is made parallel with the distal Kirschner wire and as close to the original fracture site as possible using an oscillating saw (TECH FIG 2B).
- If the fracture is not yet completely healed (nascent malunion—usually within 4 months of injury), recreate the original fracture line by carefully removing fracture callus at the fracture site.
- This callus can be saved and used as bone graft.
- If the fracture is solidly healed, attempt to identify the prior fracture site. If this is uncertain, choose a site that creates a distal fragment large enough to facilitate manipulation and internal fixation while trying to stay distal enough to take advantage of the healing capacity of metaphyseal bone.
A lamina spreader can be used to help realign the distal fragment as well (TECH FIG 2C,D).
- Care must be taken when operating on osteoporotic bone.
- Additional provisional stability can be provided by placing 1.6-mm smooth Kirschner wires.
- If the ulnar variance can be restored with angular realignment alone, the volar cortex can be cracked and hinged open in an attempt to maintain some stability of the osteotomy. If lengthening of the volar cortex is required to restore ulnar variance, a second distractor in another plane (eg, direct radial) may prove useful for obtaining and maintaining alignment.

Graft Insertion and Fixation
- Once the osteotomy is created and the radius realigned, bone graft is inserted.
- Harvest bone graft (TECH FIG 3A). Either a corticocancellous (structural) bone graft or cancellous bone graft can be used.
  - Potential advantages of a structural graft include immediate structural support (TECH FIG 3B) and the possibility of using a smaller implant and thereby avoiding tendon irritation.
  - A cancellous (nonstructural) bone graft can be harvested using trephines (TECH FIG 3C). This avoids tedious, difficult, and unpredictable harvest and contouring of corticocancellous grafts, as well as the morbidity associated with harvest of a standard iliac crest bone graft.
- Apply a single T- or Pi-shaped plate or two 2.0- or 2.4-mm plates (one applied dorsally, ulnar to the tubercle of Lister, and the other applied radially between the first and second dorsal compartments).
- When a structural, corticocancellous bone graft is used, a single plate or a plate and separate screw may be adequate (TECH FIG 3D–H).
- Plates with angular stable screws or blades in the distal fragment may be more reliable than standard screws, particularly if the bone is of poor quality and if nonstructural graft is chosen.
- Once implants are placed and stability is ensured, remove all provisional fixation devices.
- This entire process is monitored using image intensification to confirm appropriate osteotomy site, correction of alignment, and implant placement.
- Repair the extensor retinaculum with absorbable suture.
- In some cases, a flap of retinaculum is brought deep to the tendons to add a layer of protection between the implants and extensor tendons.
- We usually do not close the retinaculum, and we no longer make retinacular flaps.
- The tourniquet is deflated and hemostasis ensured.
- The skin is closed.
- A bulky dressing incorporating a volar plaster wrist splint is applied.
Exposure

- Use a volar-radial Henry (flexor carpi radialis [FCR]) approach for both dorsally and volarly angulated malunions (see Fig 2C,D).
- Make a 5- to 7-cm longitudinal incision over the FCR tendon ending at the wrist flexion crease.
- If more exposure is required, the incision is angled or zigzagged at least 45 degrees toward the scaphoid distal pole.
- Incise the FCR sheath, retract the tendon ulnarly, and incise the floor.
- Leave the radial artery undissected and protected in the radial soft tissues.

**TECH FIG 3**  
A. Corticocancellous bone graft is harvested from the iliac crest. B. After final sculpting it is applied to the osteotomy site. C. Autogenous cancellous bone graft is harvested from the iliac crest using a trephine. D. A 2.0-mm condylar blade plate can provide fixed-angle internal fixation. E,F. Intraoperative photographs of the fixation. G,H. Final AP and lateral radiographs. (Copyright Diego Fernandez, MD, PhD.)
Sweep the fat overlying the pronator quadratus together with the digital flexors and median nerve ulnarward with a sponge or blunt elevator.

Proximally in the incision, elevate the most distal aspect of the origin of the flexor pollicis longus from the volar distal radius (taking care to cauterize a consistent artery in this region) and retract it ulnarly with a small Hohmann retractor placed around the ulnar border of the radius.

Expose the radial border of the radius using a blunt elevator and Hohmann retractors.

Incise the pronator quadratus over its most radial and distal limits (L-shaped incision) and elevate it subperiosteally.

Leaving the periosteum with the muscle can facilitate later repair.

For dorsally angulated malunions, release of the radial and dorsal soft tissues facilitates realignment.

The brachioradialis is Z-lengthened and the periosteum is elevated from the radius shaft proximally.

After osteotomy in the manner detailed above (for the dorsal approach to malunions), pronate the proximal radius shaft out of the wound, providing access to the dorsal periosteum, which can be isolated and divided.

With the release of the brachioradialis and the dorsal periosteum, realignment of the radius is usually comparable to an acute fracture.

Volarly angulated malunions do not need an extensive soft tissue release in most cases. The plate can facilitate realignment by pushing the distal fragments into position as the proximal screws are tightened.

### Realignment and Provisional Fixation

- The fragments are realigned using the techniques described above (Tech FIG 4).
- The techniques are similar to those for acute fractures once an adequate soft tissue release has been performed.
- Apply a fixed-angle volar implant.
- Insert provisional Kirschner wires either through or adjacent to the plate (see Tech Fig 4).

### Plate Fixation

- Placement of the plate will frequently help reduce the proximal and distal fragments (Tech FIG 5A,B).
- After final plate fixation and removal of provisional fixation, apply cancellous graft to the osteotomy site (Tech FIG 5C–F).
- Excellent access is available radially for placement of the bone graft.
- The tourniquet is deflated and hemostasis ensured.
- Repair the pronator quadratus if possible.
- It can be sutured to the brachioradialis tendon.
- The skin is closed.
- A bulky dressing incorporating a volar plaster wrist splint is applied.
Intra-articular osteotomy should be attempted only when there is a simple fracture line that can be clearly identified by direct visualization as well as under image intensification (TECH FIG 6A–C).

- Incompletely healed fractures (fewer than 3 to 4 months since injury) are ideal.

- Depending on the locations of the malunited articular fragments, perform either a dorsal or a volar exposure in the manner detailed above.

- When a dorsal exposure is used, a transverse capsulotomy allows access to the joint and monitoring of the articular osteotomy and realignment.

- In the case of a volar exposure, the capsule is not incised, but articular exposure may be possible through the osteotomy site.

- The osteotomy should recreate the original fracture line. This is monitored directly and under image intensification.

- Reduction is accomplished by soft tissue release and direct fragment manipulation. For many malunions it is necessary to remove bone or callus from the fracture site to realign the fracture fragment. Callus or bone is removed until the fracture fragment fits properly (TECH FIG 6D).

- Provisional Kirschner wires are used to hold the reduction (TECH FIG 6E,F).

- The implants are then applied.

- Dorsally a single T- or Pi-shaped plate or two 2.0- or 2.4-mm plates (one applied dorsally, ulnar to the tubercle of Lister, and the other applied radially between the first and second dorsal compartments) can be used (TECH FIG 6G,H).

- Volarly, a T-shaped plate is usually used.

- After final plate fixation, provisional fixation is removed.

- This entire process is monitored using image intensification to confirm appropriate osteotomy site, correction of alignment, and implant placement.

- Deflate the tourniquet, close the wound, and apply the splint in the manner detailed above.
Preoperative plan

- A poor or incomplete preoperative plan will increase the amount of uncertainty and hesitation during surgery. This will increase the operative time and the frustration level and will decrease the satisfaction with the surgery.
- Making a detailed preoperative plan will improve the efficiency and efficacy of the procedure.

Extra-articular malunions

- Manipulating the distal fragment can be much more difficult with poor-quality bone.
- The use of a distractor or small external fixator greatly facilitates realignment and provisional stabilization of the fragments.
- Consider using two distractors in perpendicular planes (eg, one dorsal and one direct radial) to help obtain and maintain alignment.
- Restoration of length in addition to that gained with angular realignment (ie, lengthening of both the dorsal and volar cortices) is much more difficult.
- The most difficult part of performing an osteotomy for a dorsal angulated malunion from a volar approach is realignment of the bone.
- An extended FCR exposure allows release of the dorsal periosteum and Z-lengthening of the brachioradialis, both of which facilitate realignment of the radius.

Intra-articular malunions

- Handling small articular fracture fragments can be difficult.
- Each fragment can be realigned using a Kirschner wire as a joystick.
- The articular osteotomy is easiest when the original fracture lines can be identified.
- Try to intervene within 3 months of injury when articular malunion is identified.
POSTOPERATIVE CARE

- Active and active-assisted exercise of the fingers and forearm, finger exercises to reduce swelling, and active functional use of the limb for light tasks are encouraged immediately.
- The initial plaster splint is exchanged for a custom Orthoplast removable splint 2 weeks after the surgery.
- The patient gradually weans out of the splint between 4 and 6 weeks after surgery and initiates active and active-assisted wrist exercises.
- Strengthening and forceful use of the arm are restricted until early radiographic union is apparent.
- Unrestricted use of the limb is allowed when solid union is present clinically and radiographically.

OUTCOMES

- Fernandez’ articles describing dorsal osteotomy with cortico-cancellous bone graft with and without Bower arthroplasty of the DRUJ established the value of the technique for improving function in patients with symptomatic distal radius malunions.
  - He documented good or excellent results in 75% and 80% of patients respectively, noting that satisfactory results depend upon the absence of degenerative changes in the radiocarpal and intercarpal joints, and the presence of adequate preoperative range of motion of the wrist.
- Corrective osteotomy with carefully preoperatively planned structural corticocancellous bone graft does not reliably achieve the planned correction.
- Nonunions, loss of alignment, and major complications were not reported in these series.
- Jupiter and Ring demonstrated that early correction of distal radius deformity shortened the period of disability without increasing complications, and that the combination of cancellous autograft and locking plates was as reliable as corticocancellous bone grafting.
  - Nonunions, loss of alignment, and major complications were not reported in these series.
- Several small articles have established the safety and efficacy of volar osteotomy for a dorsally displaced fracture.
- Shea et al established the safety and efficacy of osteotomy for volar extra-articular malunions in a case series.
- Fernandez et al established the safety and efficacy of osteotomy for a radially deviated extra-articular malunion in a case series.
- Several case series have documented the safety and efficacy of intra-articular osteotomy.

COMPLICATIONS

- Nonunion
- Loss of alignment
- Loss of fixation
- Infection
- Wound problems
- Nerve injury

REFERENCES

Percutaneous Fixation of Acute Scaphoid Fractures

Peter J.L. Jebson, Jane S. Tan, and Andrew Wong

DEFINITION

- Located in the proximal carpal row, the scaphoid serves as an important link between the proximal and distal carpal rows. It is the most commonly fractured carpal bone, accounting for about 1 in every 100,000 emergency room visits.12
- There are about 345,000 scaphoid fractures annually in the United States.
- A scaphoid fracture classically occurs in a young, active adult due to a fall onto an outstretched hand.
- The Herbert classification categorizes scaphoid fractures into acute stable, acute unstable, delayed union, and established nonunion patterns.

ANATOMY

- The scaphoid has a complex three-dimensional geometry that has been described as a "twisted peanut."8 Anatomically the scaphoid is organized into proximal pole, waist, and distal pole regions.
- The scaphoid articulates with the radius, lunate, capitate, trapezium, and trapezoid; thus, its surface is almost completely covered with hyaline cartilage. This feature has several important implications, including articular disruption during wire or screw insertion, paucity of vascular supply, and the absence of periosteum.
- Lacking periosteum, the scaphoid heals almost completely by primary bone healing, resulting in minimal callus and a biomechanically weak early union.17
- Blood supply comes from branches of the radial artery that enter the scaphoid via two main routes7:
  - A dorsal branch, which enters the scaphoid via the dorsal ridge, provides the primary supply and 70% to 80% of the overall vascularity, including the entire proximal pole (via retrograde endosteal branches).
  - A volar branch, which enters through the tubercle, supplies 20% to 30% of the internal vascularity, all in the distal pole.
- The precarious blood supply contributes to the high incidence of nonunion after a fracture at the scaphoid waist or proximal pole. It also places the proximal pole at risk for the development of avascular necrosis.

PATHOGENESIS

- The typical mechanism of injury involves a fall onto the wrist. Studies have demonstrated that wrist extension of more than 95 degrees combined with more than 10 degrees of radial deviation is required for a scaphoid fracture to occur. In this position, the scaphoid abuts the distal radius, resulting in fracture.
- Seventy to 80% of scaphoid fractures occur at the waist region, while 10% to 20% involve the proximal pole and 5% occur at the distal pole and tuberosity.
- In children, the most common location for a scaphoid fracture is the distal pole.2

NATURAL HISTORY

- The true natural history of an untreated scaphoid fracture is unknown due to limitations in the existing literature, particularly with respect to study design.14 However, several retrospective studies have suggested that if a nonunion occurs, a predictable pattern of wrist arthritis develops usually within 10 years of the injury.14,16
- Unrecognized, untreated, or inadequately treated scaphoid fractures have an increased likelihood of nonunion and secondary carpal instability. A fracture through the proximal pole has the highest likelihood of nonunion, followed by a fracture of the scaphoid waist.
- If the scaphoid fracture is unstable, extension forces at the proximal fragment (via the lunate and scapholunate ligament) and flexion forces at the distal fragment result in a flexion (“humpback”) deformity of the scaphoid.
- This loss of scaphoid support results in carpal instability, most frequently a dorsal intercalated segment instability (DISI) pattern, which eventually leads to arthritis as previously described.
- The overall incidence of nonunion after fracture of the scaphoid waist region is about 5% to 10%.13

PATIENT HISTORY AND PHYSICAL FINDINGS

- A patient with an acute or subacute scaphoid fracture presents with radial-sided wrist pain, swelling, and loss of motion, particularly with dorsiflexion.
- Classic physical examination findings include:
  - Edema over the dorsoradial aspect of the wrist
  - Tenderness to palpation volarly over the distal tubercle
  - Pain with axial compression of the wrist (scaphoid compression test)
  - Acutely, swelling and ecchymoses over the volar radial wrist

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Initial imaging studies for a suspected scaphoid fracture should include a posteroanterior (PA) view with the wrist in ulnar deviation, semipronated and semisupinated 45-degree oblique views, and a lateral view.
- The PA ulnar deviation view produces scaphoid extension, permitting visualization of the entire scaphoid.
- The semipronated view permits visualization of the waist and distal-third regions.
- The semisupinated view provides visualization of the dorsal ridge.
- The lateral view can demonstrate a waist fracture, fracture displacement and angulation, and overall carpal alignment.
Displaced and unstable fractures are defined by the following criteria:
- At least 1 mm of displacement
- More than 10 degrees of angular displacement
- Fracture comminution
- Radiolunate angle of more than 15 degrees
- Scapholunate angle of more than 60 degrees
- Intrascaphoid angle of more than 35 degrees
- CT scan is helpful in identifying and characterizing an acute fracture and evaluating for a nonunion. Thin 1-mm cuts are obtained in the sagittal and coronal planes.
- MRI is useful for diagnosing an occult fracture and, when combined with gadolinium administration, can be used to assess the vascularity of the proximal pole and the presence of avascular necrosis.
- Technetium bone scan has been shown to be up to 100% sensitive in identifying occult fractures but lacks specificity. It is optimally used 48 hours after injury.

Differential Diagnosis
- Scapholunate injury
- Wrist sprain
- Wrist contusion
- Fracture of other carpal bones
- Distal radius fracture

Nonoperative Management
- Nonoperative management, specifically cast immobilization, is indicated for a nondisplaced, acute (less than 4 weeks from injury) fracture of the distal pole. For a nondisplaced, acute waist fracture, there is debate regarding the preferred treatment approach—cast immobilization or surgical stabilization.
- With cast immobilization, there is no consensus regarding the preferred position of the wrist, the need to immobilize other joints besides the wrist, and the duration of immobilization.4
  - Clinical studies have demonstrated no benefit with thumb immobilization, nor any influence of wrist position on the rate of union.
  - Studies have also demonstrated no difference in union rates with use of a long-arm versus short-arm cast; however, a small randomized prospective study by Gellman et al5 demonstrated a shorter time to union and fewer nonunions and delayed unions with the initial use of a long-arm cast.

In general, cast immobilization is required for 6 weeks after a distal pole fracture and 10 to 12 weeks following a nondisplaced waist fracture.
- Confirmation of fracture union requires serial plain radiographs demonstrating progressive obliteration of the fracture line and clear trabeculation across the fracture site.6
- If there is any question regarding fracture union, a CT scan should be obtained.

Surgical Management
- Operative treatment is advocated for fractures that are unstable or displaced (see above criteria) and following a significant treatment delay.
- Percutaneous fixation is indicated for:
  - Nondisplaced fractures of the scaphoid waist
  - Displaced fractures of the scaphoid waist
  - Proximal pole fractures
- Percutaneous stabilization of scaphoid fractures may be performed using either the dorsal arthroscopically assisted reduction and fixation (AARF) approach17-19 or the volar approach.3,10
  - Regardless of the technique used, the screw must be inserted in the middle third or central axis of the scaphoid, as this provides the greatest stability and stiffness, improves fracture alignment, and decreases time to union.1,20,21

Preoperative Planning
- All imaging studies should be reviewed to identify the location of the fracture and the size of the scaphoid, both of which influence implant selection.
- Plain radiographs should be templated to determine the approximate screw length.
- Required equipment:
  - Portable mini-fluoroscopy unit
  - Kirschner wires
  - Cannulated headless compression screw system
  - Wrist arthroscopy equipment for AARF

Positioning
- The patient is positioned supine on the operating table, with the shoulder abducted 90 degrees and the arm on a radiolucent hand table.
- A pneumatic tourniquet is applied to the upper arm.
- The portable fluoroscopy unit is positioned at the end of the hand table.

Dorsal Arthroscopy-Assisted Reduction and Fixation

Nondisplaced Fracture of the Scaphoid Waist or Proximal Pole
- Position the wrist to obtain a PA view of the wrist.
- Under fluoroscopic guidance, gently pronate the wrist until the scaphoid appears as an oblong cylinder, indicating that the proximal and distal poles are aligned.
- Flex the wrist about 45 degrees until the cylinder rotates into the plane of imaging, forming a “ring” sign. The center of the ring indicates the central axis of the scaphoid (TECH FIG 1).
- Using a 14-gauge angiocatheter as a guide for wire insertion, place the tip of a 0.045-inch guidewire through the catheter and onto the proximal pole of the scaphoid, at the center of the scaphoid ring. Confirm correct positioning with fluoroscopy.
- Insert the guidewire down the central axis of the scaphoid using a wire-driver. Keep the wrist flexed to avoid bending the wire.
- Insert the guidewire through the trapezium and advance it until the proximal tip of the guidewire clears the radiocarpal joint such that the wrist can be extended for arthroscopic examination.
Confirm correct wire position with fluoroscopy.
- The radial midcarpal portal is used to evaluate the accuracy of fracture reduction.
- The 3-4 and 4-5 portals are used to assess the integrity of the radiocarpal and intercarpal ligaments.
- Suspend the hand vertically in finger traps and apply 10 lb of traction to the upper arm to distract the radiocarpal and midcarpal articulations.
- Create a small longitudinal incision over each portal site, and bluntly dissect down to the capsule with a hemostat.
- Enter the capsule with a blunt trocar.
- Perform a diagnostic arthroscopy to assess for any associated injuries and to evaluate the fracture reduction.
- Remove the hand from traction for screw insertion.
- Position the wrist again to obtain the “ring” sign, and maintain the wrist in flexion.
- Drive the guidewire from dorsal to volar, perpendicular to the fracture line, until the distal tip lies just within the distal pole of the scaphoid (TECH FIG 2A–C).
- Place a second guidewire of equal length against the tip of the proximal pole, parallel and next to the first guidewire. The difference between lengths of the protruding wires represents the length of the scaphoid.
- Subtract at least 4 mm from the length of the scaphoid to obtain the desired screw length.
- Make a small longitudinal incision around the guidewire, and bluntly dissect down to the joint capsule. Carefully retract the extensor pollicis longus and extensor digitorum communis tendons away from the surgical site.
- Use the cannulated reamer to ream to 2 mm short of the distal articular. It is critical not to ream closer than 2 mm, as this may cause loss of fracture compression during screw insertion.
- Insert an Acutrak or mini-Acutrak screw (Acumed, Beaverton, OR) of appropriate length (at least 4 mm shorter than the measured scaphoid length) to within 1 to 2 mm of the distal surface.
- The tip of the screw should not penetrate the distal surface, and the proximal end of the screw should rest 2 mm deep to the proximal articular cartilage (TECH FIG 2D,E).
- Confirm satisfactory screw position and fracture reduction with fluoroscopy. The screw should be inserted down the central axis of the scaphoid. If any doubt exists, use the arthroscopic portals to confirm that the screw is buried in the scaphoid.

Before screw insertion, the position of the Kirschner wire must be changed from its position used for arthroscopy. The Kirschner wire should be driven from volar to dorsal until the distal end lies just beneath the articular surface of the scaphoid. (continued)
The 3-4 portal and the radial midcarpal portals provide the best view to ensure that the fracture is adequately reduced and that there is no violation of the midcarpal joint.

**Displaced Scaphoid Waist Fracture**
- Insert two percutaneous 0.062-inch smooth Kirschner wires dorsally into each fragment perpendicular to the long axis of the scaphoid to be used as joysticks to reduce the fracture (**TECH FIG 3A,B**).
- Position the wrist as previously described.
- The guidewire from the Acurtrak system is inserted from proximal to distal, starting dorsally and aiming for the central axis of the distal fragment.
- The guidewire is driven through the distal fragment and out through the volar skin of the hand. The protruding tip is then pulled volarly until the wire is only in the distal fragment (**TECH FIG 3C**).
- The proximal fragment, which is now freely mobile, is reduced manually using the Kirschner wire joysticks.
- Once the fracture is reduced, the central guidewire is driven from volar to dorsal into the proximal fragment, securing it in place (**TECH FIG 3D**).

**TECH FIG 2** (continued) D,E. Screw fixation of minimally displaced scaphoid fracture via the dorsal percutaneous technique. The screw tip should rest within 1 to 2 mm of the distal cortex. Excellent compression should be obtained with this technique.

**TECH FIG 3** • A. Reduction of a displaced scaphoid waist fracture using Kirschner wire joysticks. B. The Kirschner wire joystick technique for fracture reduction. C. The guidewire is pulled volarly until it remains only in the distal fragment. (continued)
■ The guidewire is further advanced from volar to dorsal until its distal tip is just within the subchondral bone of the distal articular surface. This allows for measurement of the screw length as previously described.
■ An additional 0.045-inch Kirschner wire is inserted parallel to the guidewire to prevent rotation of the scaphoid fragments during reaming and screw implantation.
■ Maintenance of reduction during and after screw insertion is confirmed with fluoroscopy, and all wires are subsequently removed.

Alternatively, the guidewire may be placed directly through the trapezium into the scaphoid distal pole. We do not prefer this approach due to concerns about the development of scaphotrapezial arthritis.

Advance the guidewire to the subchondral bone of the proximal pole.

Place a second guidewire of equal length against the surface of the distal scaphoid, adjacent and parallel to the first guidewire. The difference between the lengths of the wires represents the length of the scaphoid.

Subtract 4 mm from the length of the scaphoid to obtain the desired screw length.

Use the cannulated reamer to ream to within 2 mm of the proximal cortex. It is critical not to ream closer than 2 mm from the proximal cortex, as this may result in a lack of compression during screw insertion.

Insert an Acutrak or mini-Acutrak screw of appropriate length, remove the guidewire, and confirm satisfactory screw position and fracture reduction with fluoroscopy.

VOLAR PERCUTANEOUS APPROACH

■ Position the patient in a supine position with the shoulder abducted and the forearm in supination. The wrist is placed into an extended and ulnarly deviated position over a rolled towel to gain access to the distal pole of the scaphoid.

■ Position the portable fluoroscopy unit such that PA and lateral views of the wrist can be obtained. Image intensification is used to locate the distal scaphoid tuberosity.

■ A small longitudinal stab incision is made at this point, and the soft tissues are bluntly dissected down to the scaphotrapezial articulation.

■ Introduce the guidewire on the distal scaphoid tuberosity. Under image guidance, the wire is advanced toward the center of the proximal pole, aiming for the tubercle of Lister (TECH FIG 4).

■ The volar prominence of the trapezium may be partially excised to facilitate the correct starting point and trajectory for the guidewire.

■ Alternatively, the guidewire may be placed directly through the trapezium into the scaphoid distal pole. We do not prefer this approach due to concerns about the development of scaphotrapezial arthritis.

■ Advance the guidewire to the subchondral bone of the proximal pole.

■ Place a second guidewire of equal length against the surface of the distal scaphoid, adjacent and parallel to the first guidewire. The difference between the lengths of the wires represents the length of the scaphoid.

■ Subtract 4 mm from the length of the scaphoid to obtain the desired screw length.

■ Use the cannulated reamer to ream to within 2 mm of the proximal cortex. It is critical not to ream closer than 2 mm from the proximal cortex, as this may result in a lack of compression during screw insertion.

■ Insert an Acutrak or mini-Acutrak screw of appropriate length, remove the guidewire, and confirm satisfactory screw position and fracture reduction with fluoroscopy.
POSTOPERATIVE CARE
- Dressings are applied and the limb is immobilized in a forearm-based splint, immobilizing only the wrist. The thumb and fingers remain free for range-of-motion exercises.
- The patient is instructed in the importance of limb elevation and finger range-of-motion exercises.
- At 2 weeks postoperatively, the sutures are removed, a removable wrist splint is applied, and a wrist range-of-motion exercise program is initiated.
- If the patient is noncompliant, the fracture is deemed unstable, or the fixation is less than ideal, then a short-arm cast is applied for at least 6 weeks.
- Plain radiographs are obtained at 2, 6, 12, and 24 weeks postoperatively.
- The splint (or cast) is discontinued when union is confirmed on serial plain radiographs. If there is any question regarding fracture union, a CT scan is obtained.
- Unprotected strenuous activity or contact sports are not permitted until 3 months postoperatively.

OUTCOMES
- Results of contemporary techniques of percutaneous fixation are excellent; it has been shown to allow for earlier mobilization and return to activity and high satisfaction rates compared to nonoperative measures. 5,17,22
- Earlier mobilization avoids complications such as muscle atrophy and joint stiffness.
- Percutaneous techniques result in decreased soft tissue damage compared to conventional open techniques. 22
- In a recent series of 27 consecutive patients, the union rate (confirmed by CT) was 100%. The average time to union was 12 weeks, with a prolonged time to union noted in patients with a proximal pole fracture. 18

COMPLICATIONS
- Complications are rare with percutaneous fixation techniques. The risks associated with open reduction and internal fixation, such as damage to the ligamentous support of the carpus and disruption of the dorsal blood supply, are minimized.
- Possible complications include15,19:
  - Nonunion
  - Malunion
  - Injuries to the dorsal sensory branch of the radial nerve
  - Extensor tendon injury
  - Infection
  - Technical problems: screw protrusion, screw malposition, bending or breakage of guidewire
  - Erosion of the trapezium and discomfort from the head of the screw has been reported with the use of a percutaneous cannulated screw inserted via the volar approach. 22

REFERENCES
DEFINITION
- The scaphoid is the most commonly fractured carpal bone, accounting for 1 in every 100,000 emergency department visits.12
- Scaphoid fractures typically result from a fall on an outstretched hand.
- Scaphoid nonunion or proximal pole avascular necrosis (AVN) after a fracture has been associated with considerable morbidity and a predictable pattern of wrist arthritis.15,17,18
- The complex anatomy and tenuous blood supply to the scaphoid make operative management of these fractures technically challenging.18
- The Herbert classification system organizes scaphoid fractures into four groups: acute stable, acute unstable, delayed union, and established nonunion.

ANATOMY
- The scaphoid has a complex three-dimensional geometry that has been likened to a “twisted peanut.” It can be divided into three regions: proximal pole, waist, and distal pole.
- The scaphoid functions as the primary link between the forearm and the distal carpal row and therefore plays a critical role in maintaining normal carpal kinematics.
- Articulating with the scaphoid fossa of the radius, the lunate, capitate, trapezium, and trapezoid, more than 70% of the scaphoid is covered with articular cartilage.
- Gelberman and Menon8 have described the vascular supply of the scaphoid. The main arterial supply is from the radial artery; it enters the scaphoid via two main branches:
  - A dorsal branch, entering through the dorsal ridge, is the primary supply and provides 70% to 80% of the vascularity, including the entire proximal pole via retrograde endosteal branches.
  - A volar branch, entering through the tubercle, supplies the remaining 20% to 30%, predominantly the distal pole and tuberosity.
- The proximal pole is at increased risk for avascular necrosis (AVN) secondary to disruption of its tenuous retrograde blood supply after a fracture of the scaphoid waist or proximal pole.
- Due to its tenuous vascular supply, the scaphoid heals almost entirely by primary bone healing, resulting in minimal callus formation.
- The size and shape of the scaphoid, in combination with its precarious blood supply, demands attention to detail and accurate implantation of fixation devices during fracture fixation.

PATHOGENESIS
- Scaphoid fractures are most commonly seen in young, active males who fall on an outstretched upper extremity.12
- With the wrist dorsiflexed greater than 95 degrees, in combination with 10 degrees or more of radial deviation, the distal radius abuts the scaphoid and precipitates a fracture.12
- Most of these fractures occur at the waist region, although 10% to 20% occur in the proximal pole.
- Proximal pole fractures are associated with an increased risk of nonunion, delayed union, and AVN.
- In children, scaphoid fractures are less common and are most frequently seen in the distal pole.

NATURAL HISTORY
- An untreated or inadequately treated scaphoid fracture has a higher likelihood of nonunion. The overall incidence of nonunion is estimated at 5% to 10%, but the risk is significantly increased with nonoperative treatment of a displaced waist or proximal pole fracture.
- The natural history of scaphoid nonunions is controversial, but they are believed to result in a predictable pattern of progressive radiocarpal and midcarpal arthritis.8,9,14,15,17,18
- In an established scaphoid nonunion, the distal portion of the scaphoid may flex, producing a “humpback” deformity of the scaphoid. The loss of scaphoid integrity can result in carpal instability and abnormal carpal kinematics, most frequently manifesting as a dorsal intercalated segment instability (DISI) pattern.
- The pattern of carpal instability and secondary arthrosis due to an unstable scaphoid nonunion has been termed a SNAC wrist (scaphoid nonunion advanced collapse pattern of wrist arthritis).11,17
- In the SNAC wrist, there is a loss of carpal height with proximal capitate migration, flexion and pronation of the scaphoid, and secondary midcarpal arthritis.17
- Factors associated with the development of a scaphoid fracture nonunion include14:
  - Delayed diagnosis or treatment
  - Inadequate immobilization
  - Proximal fracture
  - Initial and progressive fracture displacement
  - Fracture comminution
  - Presence of associated carpal injuries (ie, perilunate injury)

PATIENT HISTORY AND PHYSICAL FINDINGS
- Scaphoid fractures classically occur in the active, young adult population after a fall onto an outstretched hand. Patients present with radial-sided wrist pain.
- Classic physical examination findings include:
  - Swelling over the dorsoradial aspect of the wrist
  - Erythema over the volar radial aspect of the wrist
  - Tenderness to palpation in the “anatomic snuffbox”
  - Tenderness with palpation volarly over the distal tubercle
  - Pain with axial compression of the wrist (scaphoid compression test)
- Scaphoid fractures can be part of a greater arc injury.
- The physician should examine the entire wrist carefully for areas of tenderness and swelling.
Plain radiographs are scrutinized for an associated ligamentous injury or disruption of the midcarpal joint as seen in the transscaphoid perilunate fracture-dislocation.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- The following plain radiographs should routinely be ordered in the patient with a suspected scaphoid fracture: posteroanterior (PA), oblique, lateral, and dedicated scaphoid views.
  - The PA view allows visualization of the proximal pole of the scaphoid.
  - The semipronated oblique view provides the best visualization of the waist and distal pole regions.
  - The semisupinated oblique view provides the best visualization of the dorsal ridge.
  - The lateral view permits an assessment of fracture angulation, carpal alignment, and carpal instability.
  - The dedicated scaphoid view is a PA view with the wrist in ulnar deviation. This results in scaphoid extension, allowing visualization of the scaphoid in profile (FIG 1A).
- The following criteria define a displaced or unstable fracture as noted on plain radiographs²,⁶,⁰¹⁴:
  - At least 1 mm of displacement
  - More than 10 degrees of angular displacement
  - Fracture comminution
  - Radiolunate angle of more than 15 degrees
  - Scapholunate angle of more than 60 degrees
  - Intrascaphoid angle of more than 35 degrees
  - CT with reconstruction images in multiple planes is used to identify an acute fracture not detected on plain radiographs (FIG 1B,C).
  - CT is most useful in evaluating an established scaphoid nonunion or malunion.⁶
- Since plain radiographs are often unreliable, CT is preferred for confirming union after a scaphoid fracture.
- MRI may be indicated in the evaluation of a suspected scaphoid fracture not detected on plain radiographs (FIG 1D,E). MRI is highly sensitive, with a specificity approaching 100% when performed within 48 hours of injury.¹³
  - MRI with gadolinium contrast is helpful in assessing the vascularity of the proximal pole, particularly in the patient with an established nonunion.
  - A technetium bone scan has been shown to be up to 100% sensitive in identifying an occult fracture.²⁰ Unfortunately, it is also associated with a low specificity and often will not be positive immediately after the fracture.

DIFFERENTIAL DIAGNOSIS
- Scapholunate injury
- Wrist sprain
- Wrist contusion
- Fracture of other carpal bone
- Greater arc injury
- Distal radius fracture

NONOPERATIVE MANAGEMENT
- Nonoperative management is indicated for a nondisplaced, stable scaphoid waist or distal pole fracture. Unstable fractures and nondisplaced fractures of the proximal pole are indications for internal fixation based on studies that have demonstrated a poor outcome with nonoperative treatment.²,⁴,¹⁴
- The appropriate type and duration of cast immobilization remain controversial. We recommend a long-arm thumb spica cast for the first 6 weeks, followed by a short-arm thumb spica cast.
cast until the clinical examination and radiologic studies (usually a CT scan) confirm fracture union.
- Clinical studies have failed to demonstrate any benefit from including the thumb or fingers in the cast.\(^2,4\)
- Similarly, wrist position has not been proven to improve scaphoid fracture healing.
- Numerous studies have revealed no difference in union rates for a long-arm versus short-arm cast; however, a randomized prospective study by Gellman et al.\(^10\) documented a shorter time to union and fewer nonunions and delayed unions with initial use of a long-arm cast.
- The morbidity of a nonoperative approach, specifically cast immobilization, has become of increasing concern. A prolonged duration of immobilization is often required for waist fractures, and this can be accompanied by muscle atrophy, stiffness, reduced grip strength, and residual pain. In addition, cast immobilization can cause significant inconvenience for the patient and interfere with activities of daily living. The prolonged duration of immobilization is of particular concern in the young laborer, athlete, or military personnel, who typically desire expedient functional recovery.\(^5,16,21\)
- If the clinical history and physical examination are suggestive of a scaphoid fracture but initial radiographs are negative, the wrist should be immobilized for 2 weeks. Repeat radiographs are then obtained. If a fracture is present, resorption of the fracture may be noted. If wrist pain and “snuffbox” tenderness persist but radiographs are negative, a bone scan may be obtained. A negative scan excludes the presence of a scaphoid fracture. A positive scan may indicate an occult fracture or ligamentous injury. CT or MRI is usually indicated for further evaluation.\(^13,20\)
- If it is determined that a scaphoid fracture is present, ORIF of the scaphoid fracture is recommended. Clinical studies have revealed no difference in union rates for a long-arm versus short-arm cast; however, a randomized prospective study by Gellman et al.\(^10\) documented a shorter time to union and fewer nonunions and delayed unions with initial use of a long-arm cast.

**SURGICAL MANAGEMENT**

- Indications for open reduction and internal fixation (ORIF) of scaphoid fractures include\(^2,14\):
  - Any proximal pole fracture
  - A displaced, unstable fracture of the scaphoid waist
  - Associated carpal instability or perilunar instability

- Associated distal radius fracture
- Delayed presentation (more than 3 to 4 weeks) with no prior treatment
- A nondisplaced, stable scaphoid waist fracture (Herbert A2 type) in a patient who wishes to avoid the morbidity of cast immobilization. In this clinical scenario, operative treatment should occur only after an explanation of the rationale for, and the risks and benefits of, operative treatment versus cast immobilization.

**Preoperative Planning**

- All imaging studies should be reviewed to accurately define the fracture pattern.
- Required equipment:
  - Portable mini-fluoroscopy unit
  - Kirschner wires
  - Cannulated headless compression screw system. We prefer to use the Accutrak or mini-Acutrak screw system (Accumed, Beaverton, OR), but any cannulated screw system that permits screw insertion beneath the articular surface may be used.

**Positioning**

- General or regional anesthesia may be used.
- The patient is positioned supine on the operating table with a radiolucent hand table at the shoulder level.
- The fluoroscopy unit is draped and positioned at the end of the hand table.
- A pneumatic tourniquet is carefully applied to the proximal arm.
- An intravenous antibiotic is provided before inflation of the tourniquet as prophylaxis for infection.
- The limb is prepared and draped, followed by exsanguination of the limb with an Esmarch bandage and tourniquet inflation, usually to a pressure of 250 mm Hg.

**Approach**

- ORIF of scaphoid fractures can be performed through either a dorsal or volar approach.
- The specific approaches that will be described include:
  - Open dorsal approach\(^16\)
  - Open volar approach

**TECHNIQUES**

**OPEN DORSAL APPROACH (AUTHORS’ PREFERRED APPROACH)**

**Exposure**

- If the fragments are displaced, requiring reduction, pronate the forearm and make a longitudinal skin incision, about 3 to 4 cm long, beginning at the proximal aspect of the tubercle of Lister and extending distally along the axis of the third metacarpal (TECH FIG 1A).
  - If the fracture is nondisplaced, a smaller skin incision and capsulotomy may be used.
  - Raise skin flaps at the level of the extensor retinaculum.
  - Incise the extensor retinaculum overlying the third compartment immediately distal to the tubercle of Lister and carefully release the fascia overlying the extensor pollicis longus (EPL) tendon, permitting gentle retraction of the EPL radially. Similarly incise the dorsal hand fascia longitudinally.
  - Gently retract the extensor digitorum communis (EDC) tendons ulnarly while retracting the extensor carpi radialis brevis (ECRB) and longus (ECRL) tendons radially with the EPL, thus exposing the underlying radiocarpal joint capsule (TECH FIG 1B).
  - Make a limited inverted T-shaped capsulotomy with the transverse limb placed just distal to the dorsal rim of the radius and the longitudinal limb directly over the scapholunate articulation (TECH FIG 1C).
  - The tubercle of Lister is helpful in locating the articulation.
Carefully elevate the capsular flaps from the dorsal lunate, the dorsal component of the scapholunate ligament, and the proximal pole of the scaphoid.
- Evacuate fracture hematoma.
- It is often helpful to extend the longitudinal limb of the capsulotomy to expose the scaphocapitate articulation and the radial aspect of the midcarpal joint.
- Especially when elevating the radial flap, take care to avoid stripping the dorsal ridge vessels entering at the scaphoid waist region.

Fracture Reduction and Provisional Fixation
- Distract the carpus manually via longitudinal traction on the index and long fingers.
- If the fracture is displaced, insert 0.045-inch Kirschner wire joysticks perpendicularly into the proximal and distal scaphoid fragments to assist in the reduction (TECH FIG 2A).
- The accuracy of the reduction can be determined by assessing congruency of the radioscaphoid and scaphocapitate articulations.
- When a satisfactory reduction has been achieved, obtain provisional fixation with derotational 0.045-inch Kirschner wires.
  - The first wire is inserted dorsal and ulnar to the central axis of the scaphoid, into the trapezium for enhanced stability.
  - The second derotational wire may be inserted volar and radial to the anticipated central axis insertion site if more fixation is needed.
  - The derotational wires must be placed such that they will not interfere with central axis guidewire placement, reaming, and screw insertion (TECH FIG 2B).

Guidewire Placement
- The starting position for guidewire is at the membranous portion of the scapholunate ligament origin (TECH FIG 3A,B).
- In very proximal fractures, the starting point for the guidewire is as far proximally in the scaphoid as possible, at the mid-aspect of the membranous portion of the scapholunate ligament complex. This point is critical to avoid propagation of the fracture into the proximal scaphoid during insertion of the screw.
With the wrist flexed over a bolster, insert the guidewire down the central axis of the scaphoid in line with the thumb metacarpal.

- Be very patient with this important step; proceed with reaming and screw insertion only after central placement has been confirmed on the PA, lateral, and 30-degree pronated lateral views (TECH FIG 3C).
- It is critical to insert the wire in the optimal position in all three views to avoid violating the midcarpal joint or the volar surface of the scaphoid.
- Take care to avoid bending the guidewire.
- Advance the wire up to but not into the scaphotrapezial joint.

**Screw Insertion**

- Determine screw length by measuring the guidewire (TECH FIG 4A).
- In the case of minimal fragment separation, subtract 4 mm from the measured length of the wire to allow recession of the proximal screw beneath the articular surface.
- If fragments are more displaced, consider compression and choose an even shorter screw.
- Advance the wire into the trapezium to avoid loss of position during drilling.
Use the cannulated drill (TECH FIG 4B), tap the bone if necessary, and manually insert the screw (TECH FIG 4C,D).

We use the larger Acutrak screw when feasible, but the mini-Acutrak system may be necessary in patients with a small scaphoid or if the fracture is located proximally such that insertion of an Acutrak screw may result in inadvertent propagation of the fracture to the insertion site with fragmentation of the proximal scaphoid.

Remove the guidewire and assess screw position via fluoroscopy using the same views.

**OPEN VOLAR APPROACH**

**Exposure**

- Radially deviate the wrist and palpate the scaphoid tubercle.
- Make a 3- to 4-cm incision centered over the scaphoid tubercle, directed distally toward the base of the thumb and proximally over the flexor carpi radialis (FCR) tendon sheath. If the superficial volar branch of the radial artery is encountered, cauterize it at the level of the wrist flexion crease.
- Open the FCR sheath and retract the tendon ulnarily. Open the floor of the sheath distally to expose the underlying volar wrist capsule.
- Distally, develop the interval by splitting the origin of the thenar muscles in line with their fibers over the distal scaphoid and trapezium.
- Incise the capsule longitudinally, taking care to avoid damage to the underlying articular cartilage.
- Proximally, divide the thickened radiolunate and radioscpahocapitate ligaments to allow exposure of the proximal scaphoid pole.
- Identify the scaphotrapezial joint with a Freer elevator and bluntly expose it.
- Dissection over the radial aspect of the scaphoid is limited to avoid injury to the dorsal ridge vessel.
- Define and clear the fracture site by irrigation, sharp excision of periosteal flaps, and curetting of debris and hematoma.
- Assess the instability of the fracture by wrist manipulation.
- It is critical to identify any bone loss, as compression during screw placement can result in an iatrogenic malunion.

**Fracture Reduction and Fixation**

- Obtain correct fracture alignment through longitudinal traction followed by wrist manipulation.
- An anatomic reduction may also be achieved by direct manipulation of the fragments with a dental pick, pointed reduction forceps, or joystick Kirschner wires.
- Place a provisional 0.045-inch Kirschner wire to secure the reduction. Insert the wire in a retrograde manner from volar distal to dorsal proximal, gaining fixation in the proximal pole.
- It is critical to place this wire such that it does not interfere with central axis screw placement.
- The central axis guidewire is placed, taking into consideration all the factors detailed above.
- To gain the needed dorsal starting position in the distal scaphoid pole, displace the trapezium dorsally with an elevator or resect a small portion of the proximal volar trapezium with a rongeur (TECH FIG 5).

The cannulated compression screw may be inserted using a freehand technique or a commercial device, which may facilitate simultaneous fracture reduction and guidewire positioning.

- Fluoroscopy is invaluable during wire and screw insertion and to confirm accurate placement and fracture reduction as described above.
- Precisely repair the volar wrist capsule and radiolunate and radioscpahocapitate ligaments with permanent suture.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Injury to the scaphoid blood supply</th>
<th>Meticulous limited dissection of the capsule. Avoid any dissection on the dorsal ridge of the scaphoid.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malpositioning of guidewire</td>
<td>Pronate and flex wrist during the dorsal approach to allow appropriate trajectory. Confirm position on multiple views to ensure insertion in the central axis of the scaphoid.</td>
</tr>
<tr>
<td>Screw position</td>
<td>Select a screw that is 4 mm shorter than measured length unless fracture fragments are separated; in that case choose a shorter screw. Drill 2 mm short of the distal pole.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- The patient is immobilized in a below-elbow volar thumb spica splint and discharged to home with instructions on strict limb elevation and frequent digital range-of-motion exercises.
- At 2 weeks, the patient returns for suture removal. Range-of-motion exercises are begun and a removable forearm-based thumb spica splint is worn. The splint is discontinued at 4 to 6 weeks postoperatively.
- If the fracture involves the proximal pole or if significant comminution was noted at surgery and there is concern regarding stability of the fixation, immobilization in a short-arm cast for 6 to 10 weeks is indicated. Typically, such fractures take longer to achieve union.
- After cast removal, a formal supervised therapy program is initiated to achieve satisfactory range of motion, strength, and function.
- Fracture healing is assessed at 2, 6, and 12 weeks postoperatively with plain radiography. Fracture union is defined as progressive obliteration of the fracture and clear trabeculation across the fracture site. (FIG 2).
- If there is any question regarding fracture union, a CT scan is obtained at 3 months postoperatively or before the patient is allowed to return to unrestricted sporting activities.

OUTCOMES

- Surgical fixation of unstable, displaced scaphoid fractures has been increasingly advocated, given the unsatisfactory outcomes that have been reported with nonoperative management.²,⁴,¹⁴
- Rigid internal fixation allows for early physiotherapy throughout the healing phase, a more rapid time to union, improved range of motion, and rapid functional recovery.⁵,¹⁰,¹⁶,²¹ Several studies have reported a high rate of union and excellent clinical outcome with minimal morbidity using both limited open and percutaneous techniques.¹,³,⁵,¹⁰,¹⁹,¹⁹,²¹
- Clinical and biomechanical studies have also recently documented the importance of screw position after fixation of scaphoid fractures.⁷,¹⁸ Central placement of the screw is biomechanically advantageous, with greater stiffness and load to failure. Trumble et al¹⁸ demonstrated more rapid progression to union with central screw position in cases of scaphoid nonunion.
- A volar approach has traditionally been used for screw insertion. However, recent studies have raised potential concerns regarding eccentric screw placement and damage to the scaphotrapezial articulation with this approach.²¹
- Our preferred technique for fixation of a scaphoid proximal pole or waist region fracture involves a limited dorsal approach with compression screw fixation.¹⁶ The technique is simple and permits visualization of a reliable starting point for screw placement within the central axis of the scaphoid, offering a significant potential advantage over the volar approach. We recently reported our clinical experience in a consecutive series of nondisplaced scaphoid waist fractures.³

COMPLICATIONS

- Postoperative wound infections are rare and can be prevented with routine preoperative antibiotic prophylaxis, thorough wound irrigation, and appropriate soft tissue management.
- Intraoperative technical problems
  - Inadvertent bending or breakage of the guidewire can occur if the wrist is dorsiflexed with the wire in position or during drilling before screw insertion.
  - Care should be taken to confirm that the screw is fully seated beneath the articular cartilage to avoid prominence and erosion of the distal radius articular surface. Similarly, failure to carefully judge accurate screw length intraoperatively can result in prominence and erosion of the scaphotrapezial articulation.
  - Nonunion with or without AVN can occur despite compression screw fixation, particularly with a proximal pole or displaced waist fracture. Stripping of the dorsal ridge vasculature should be avoided. Supplemental cancellous bone graft from the distal radius may be used at the time of fixation if desired.
- Other potential but rare complications
  - Hypertrophic scar
  - Injury to the dorsal branches of the superficial radial nerve
  - Damage to the scaphotrapezial articulation
  - Proximal pole fragment comminution

FIG 2 • A healed scaphoid waist fracture after ORIF via the dorsal approach. Although the screw may appear slightly long, both the proximal scaphoid and distal scaphoid are covered with hyaline cartilage not detected on diagnostic imaging. (Property of Peter J.L. Jebson, MD.)
REFERENCES

DEFINITION
- Scaphoid nonunion describes a wide spectrum of conditions.
- The classification system shown in Table 1 describes them in the context of treatment options.

ANATOMY
- The scaphoid is almost entirely covered with cartilage and provides the mechanical link between proximal and distal carpal rows.
- Blood supply is from volar and dorsal, entering distally. The volar artery supplies only the distal tubercle region. The proximal pole is primarily dependent on intraosseous blood supply, similar to the head of the proximal femur.

PATHOGENESIS
- Mechanical instability and decreased perfusion are the most common causes of scaphoid nonunion.
- These factors work to exacerbate each other. Micromotion disrupts vascular perforators (often the only blood supply), leading to bone resorption and further decrease in mechanical stability.
- Proximal pole fractures are particularly at risk for nonunion for both mechanical (long distal lever arm and a small proximal contact area) and vascular reasons.
- Infection is rarely a cause of scaphoid nonunion but should not be forgotten in the workup and treatment.

NATURAL HISTORY
- Although progression is variable, patients often develop a dorsal intercalated segment instability (DISI) deformity (as described for scapholunate ligament injuries) and advance through stages of degeneration (scaphoid nonunion advanced collapse [SNAC] wrist arthritis) over decades.
- SNAC wrist stage I: affects only radial styloid; stage II: arthritis at radioscapoid joint; stage III: involvement of the scaphocapitate and capitolunate joints; stage IV: pancarpal arthritis with preservation of the radiolunate joint

PATIENT HISTORY AND PHYSICAL FINDINGS
- In established nonunions, patients present with wrist pain and in many cases are unaware of their original injury many years before.
- Findings on examination typically include radial-sided wrist tenderness on palpation and decreased range of motion, particularly extension (secondary to the DISI deformity of the carpus).
- Other than information regarding previous operative and nonoperative treatments, the additional information for evaluation and treatment decisions comes more from imaging.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- CT scan with 1-mm slices in the plane of the scaphoid can help delineate bony anatomy in established nonunions and can determine if there is any evidence of healing in early nonunions.
- MR with intravenous contrast will help determine proximal pole vascularity.
- The time and equipment required for vascularized bone grafting are more substantial than those needed for simple open reduction and internal fixation (ORIF) of the scaphoid with nonvascularized bone graft.

DIFFERENTIAL DIAGNOSIS
- Bone cyst
- Infection
- Acute fracture
- Pressier disease (scaphoid avascular necrosis [AVN])

NONOPERATIVE MANAGEMENT
- If a nonunion has not previously been given a trial of conservative care and if there is no significant resorption, casting and a bone stimulator could be attempted prior to surgical fixation.

SURGICAL MANAGEMENT
- Surgical treatment must solve three obstacles:
  - Re-establishment of local perfusion
  - Replacement of necrotic tissue with an osteoconductive and osteoinductive matrix
  - Stable fixation
- Not all proximal pole nonunions with AVN require a vascularized graft.
- If the distal scaphoid is well perfused and good fixation can be achieved, healing can proceed via creeping substitution.
- Guidewire placement and reaming for screw fixation helps re-establish vascular channels.
- Palmar flexion of the distal fragment and DISI position of the carpus must be corrected at the time of surgery.
- The surgical technique described in this chapter is appropriate to repair grade I to III scaphoid nonunions.
- If a grade IV nonunion lacks significant flexion deformity and has an intact fibrous shell to contain bone graft, one may consider treatment of these fractures using the minimally invasive method reviewed in this chapter.
- Grade V and VI nonunions are characterized by substantial bone loss, synovial nonunion, and significant flexion deformity. They are therefore not suitable for percutaneous treatment.

Preoperative Planning
- Advanced degenerative changes secondary to scaphoid nonunion are a relative contraindication to repair of a nonunion.
### Table 1: Classification of Scaphoid Nonunion

<table>
<thead>
<tr>
<th>Classification Grade</th>
<th>Illustration</th>
<th>Category</th>
<th>Characteristics</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td></td>
<td>Delayed presentation</td>
<td>Fractures presenting 4–12 weeks after injury</td>
<td>Screw fixation alone usually sufficient</td>
</tr>
<tr>
<td>II</td>
<td></td>
<td>Fibrous</td>
<td>Intact cartilaginous envelope and no sclerosis or resorption</td>
<td>Percutaneous débridement, bone sclerosis or resorption graft, and fixation</td>
</tr>
<tr>
<td>III</td>
<td></td>
<td>Minimal sclerosis</td>
<td>Resorption &lt;1 mm with minimal sclerosis</td>
<td>Percutaneous débridement, bone graft, and fixation</td>
</tr>
<tr>
<td>IV</td>
<td></td>
<td>Moderate resorption and sclerosis</td>
<td>Resorption &lt;5 mm, maintained alignment</td>
<td>Either percutaneous or open depending on intact envelope around fracture site</td>
</tr>
<tr>
<td>V</td>
<td></td>
<td>Extensive resorption and sclerosis</td>
<td>Resorption 5–10 mm but maintained alignment</td>
<td>Typically requires open bone grafting and fixation</td>
</tr>
<tr>
<td>VI</td>
<td></td>
<td>Pseudarthrosis</td>
<td>Profound resorption, deformity, independent fragment motion</td>
<td>Open fixation and strut grafting</td>
</tr>
</tbody>
</table>

**Subtype**

- **a** Proximal pole | Greater risk of nonunion and AVN | Dorsal approach, may require supplemental fixation to decrease micromotion

- **b** AVN | Confirmed on gadolinium-enhanced MR or lack of punctate bleeding. Decreased mechanical strength and difficulty healing. | Early AVN may be suitable to rigid fixation and grafting; more advanced AVN may require vascularized graft or salvage operation
### Table 1 (continued)

<table>
<thead>
<tr>
<th>Classification Grade</th>
<th>Illustration</th>
<th>Category</th>
<th>Characteristics</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td></td>
<td>Ligamentous injury</td>
<td>Suggested by static and dynamic imaging or direct arthroscopic observation</td>
<td>Débridement, pinning, or direct repair depending on grade</td>
</tr>
<tr>
<td>d</td>
<td></td>
<td>Deformity</td>
<td>Humpback flexion deformity must be corrected.</td>
<td>This typically requires cortical strut graft and rigid fixation.</td>
</tr>
</tbody>
</table>

- Advanced imaging, as discussed earlier, is crucial for appropriate preoperative planning.

**Positioning**
- The patient is placed supine.
- Traction for arthroscopy can be performed with either a traction tower or a simple horizontal pulley traction system.

**Approach**
- A dorsal approach is used for proximal pole fractures to provide the most secure fixation (as a basic principle, think of securing the island to the mainland).
- Waist fractures can be treated either dorsally or volarly.
  - The dorsal approach is preferred.
- Nonunion of a distal pole scaphoid fracture, although rare, is best approached volarly.

### PLACEMENT OF THE TARGETING GUIDEWIRES

- A fluoroscopic survey is undertaken to evaluate the fracture, scaphoid alignment, and fragment mobility.
  - Other occult carpal fractures are sought.
  - The wrist is ulnarly deviated to extend the distal fragment.
  - A smooth 0.062-inch dorsal-to-volar targeting Kirschner wire is placed in the distal fragment in the center position.
  - A smooth 0.062-inch lateral targeting wire is placed in the center of the distal fragment from radial to ulnar.
  - These Kirschner wires form a “crosshair” target to guide placement of the central axis guidewire (TECH FIG 1).

**PLACEMENT OF THE DISTAL CENTRAL AXIS DEROTATION WIRE**

- Placement of the first central axis wire in the distal fragment is undertaken.
  - Place a 19-gauge needle into the fracture site and confirm position fluoroscopically.
  - Use the position of the needle to introduce a double-cut 0.045-inch Kirschner wire into the fracture site and down the medullary canal of the distal fragment, using the distal crossed targeting Kirschner wires as guides.
  - Exit at the base of the thumb in an area devoid of neurovascular structures and withdraw it until the proximal tip is at the fracture site.
  - This first Kirschner wire will be used only to maintain a reduction and serve as a derotation wire, so perfect central axis placement is not necessary.
FRACTURE REDUCTION

- From dorsal to volar drive a 0.062-inch Kirschner wire into the proximal fragment to serve as the proximal joystick.
- Flex the distal dorsal-to-volar targeting Kirschner wire toward the proximal fragment joystick wire to correct the flexion deformity of the distal fragment (TECH FIG 2A,B).
- Sometimes a percutaneous snap may need to be introduced for additional leverage or to correct translational deformities.
- Confirm fragment position fluoroscopically while holding the reduction.
- Drive the distal fragment wire that is at the base of the thumb retrograde into the proximal fragment to secure the reduction (TECH FIG 2C).
- Again, perfect placement in the proximal pole is not necessary, as this wire is used only temporarily.

PLACEMENT OF THE PROXIMAL CENTRAL AXIS GUIDEWIRE

- With the wrist partially flexed and under fluoroscopy, impale a 19-gauge needle into the proximal ulnar corner of the proximal pole (TECH FIG 3A,B).
- Drive a 0.045-inch Kirschner wire toward the thumb base, correcting its direction based on the external crossed-wire targeting guide.
- A successfully placed central axis scaphoid wire will hit the crossing wires in the distal scaphoid.
- The guidewire is driven volarly past this intersection, through the trapezium, and exits at the thumb base in a zone devoid of neurovascular structures.
The guidewire is withdrawn until the trailing edge crosses the radiocarpal joint and the wrist can be safely extended without bending the wire. There are now two intramedullary Kirschner wires down the length of the scaphoid, one used to capture the initial reduction and the other placed down the long axis to be used as a guide for eventual screw insertion (TECH FIG 3C). The use of two Kirschner wires limits bending forces and acts as an antirotation construct during scaphoid reaming and screw placement.

**ARTHROSCOPIC EVALUATION AND REAMING**

- The arm is exsanguinated and the extremity is placed in a traction tower with 12 pounds distributed between four finger traps.
- Fluoroscopy can be used with 19-gauge needles to identify the radiocarpal and midcarpal portals. This maneuver limits iatrogenic injury to the joint, which can result from multiple attempts to introduce a blunt trocar blindly.
- A small hemostat is used to separate the soft tissue and enter the wrist joint. A blunt trocar is placed at the radial midcarpal portal and a small joint angled arthroscope is introduced.
- Additional 19-gauge needles are inserted to establish outflow.
- A probe is introduced at the ulnar midcarpal portal, and the competency of the carpal ligaments is evaluated by directly stressing their attachments to detect partial and complete tears.
- Any scapholunate interosseous ligament (SLIL) injury detected is graded using the Geissler grading system. Grade I and II ligament injuries are treated with débridement and shrinkage alone. Grade III injuries are treated with débridement and, after fracture repair, carpal pinning for 6 weeks. Grade IV instability requires open repair of the dorsal SLIL ligament with or without capsulodesis.
- Tears of the triangular fibrocartilage complex are classified using the Palmer classification and are treated based on established guidelines.
- Fracture reduction is thoroughly evaluated arthroscopically.
- It is important to determine the presence of a fibrous capsule around the nonunion site. If there is no fibrous capsule, percutaneous bone graft is contraindicated as it will dissipate into the surrounding synovial fluid.
- If vascularity of the proximal fragment is in question, flex the wrist in the traction tower.
- Drive the central axis guidewire retrograde through the proximal fragment, ream over the wire to the level of the nonunion site.
- Withdraw the central axis wire to the fracture site (while keeping the derotation Kirschner wire in place to maintain reduction) and introduce the scope into the proximal fragment through the previously reamed tract.
- Stop the inflow and let down the tourniquet. Inspect the cancellous bone of the proximal pole with the scope for the appearance of punctate bleeding (TECH FIG 4).
- Keep the wrist in a flexed position and retrograde the central axis wire so it is equally exposed dorsally and volarly.
- Hand ream, under fluoroscopy, to within 2 mm of the distal cortex. Then withdraw the central axis wire volarly back to the level of the fracture site.

**TECH FIG 4** - Inspect the cancellous bone of the proximal pole with the scope for the appearance of punctate bleeding. A. Devascularized proximal pole with no punctate bleeding. B. Vascularized proximal pole.

**DÉBRIDEMENT OF THE NONUNION SITE AND BONE GRAFTING**

- A grade I scaphoid nonunion (delayed presentation) typically does not require débridement or bone grafting.
- For grade II or III nonunions, insert a small curved curette through the path that was just reamed and débride the nonunion site (TECH FIG 5A).
- Avoid disrupting the peripheral fibrous shell so there is a contained cavity within which to pack bone graft.
- Using an 8-gauge bone biopsy needle, harvest cores of cancellous bone from either the distal radius or iliac crest. Introduce the bone biopsy cannula into the reamed proximal pole tract.
- Pack plugs of bone graft through the cannula into the nonunion site until the radiolucent image of the nonunion site becomes radiopaque (TECH FIG 5B).
The wrist is flexed and the central axis scaphoid guidewire at the base of the thumb is driven dorsally.

- The wire is adjusted until the trailing end is in the subchondral bone of the distal scaphoid pole.

- A second wire of equal length is placed percutaneously against the proximal scaphoid pole, next to and parallel with the guidewire.

- The difference in length between the trailing end of each wire represents the scaphoid length. The screw length selected should be 4 mm less than the scaphoid length.

- This permits 2 mm of clearance of the screw at each end of the scaphoid, thus ensuring complete implantation without screw prominence.

- The most common reported complication of percutaneous screw stabilization for scaphoid fractures is implantation of a screw that is too long.1

- Advance the central axis wire so it is exposed equally volar and dorsal.

- Re-ream the entire path of the screw to within 2 mm of the opposite cortex. This creates a path through the bone graft for the screw and prevents exploding the graft through the cortical shell with a blunt screw.

- The scaphoid should never be reamed to the opposite bone cortex (overdrilling). This reduces fracture compression and increases the risk of motion at the fracture site.

- Place the headless cannulated screw. If the screw is advanced to the distal cortex, attempts to advance the screw further will force the fracture fragments to gap and separate.

- A standard-size Acutrak screw will best resist flexion moments.4

- In unstable nonunions, as the screw is advanced it is advisable to use the joysticks to maintain a counterforce compression at the fracture site.

- If screw fixation provides only modest stability, additional fixation is advantageous.

- In proximal pole nonunions the bending forces of the long lever arm of the distal scaphoid can be neutralized with a Kirschner wire or screw from the distal scaphoid into the capitate (TECH FIG 6A).

- Micromotion can be decreased with a Kirschner wire down the second or third web space locking the capitolunate articulation.

- With the wrist partially flexed the radiolunate joint can be secured with a Kirschner wire, preventing the tendency of DISI position (TECH FIG 6B).
**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Central wire placement</th>
<th>Use the crossed Kirschner wire targeting guide in the distal fragment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achieving and maintaining reduction</td>
<td>Ignore the proximal fragment first and place a wire down the distal fragment. Use joysticks and percutaneous hemostats for the reduction, then drive the wire retrograde to capture the reduced proximal fragment. A DISI deformity can be corrected and a deforming force minimized on the nonunion by flexing the wrist, thereby reducing the lunate and then capturing it by a Kirschner wire from the radius into the lunate.</td>
</tr>
<tr>
<td>Avoid over-reaming</td>
<td>This reduces compression at the fracture site. Ream under fluoroscopy and stay 2 mm short of the opposite cortex.</td>
</tr>
<tr>
<td>Place the correct screw length</td>
<td>A screw needs to be long enough to maximize mechanical fixation while being short enough to avoid pushing against the opposite cortex and distracting the fracture, and to avoid intra-articular prominenence. Measure 4 mm less than the scaphoid along the central axis guidewire.</td>
</tr>
<tr>
<td>Decrease “windshield wipering”</td>
<td>Use a headless screw with a large shank diameter (eg, regular Acutrak).</td>
</tr>
<tr>
<td>Decrease micromotion</td>
<td>Add supplemental fixation as needed between the scaphocapitate, capitolunate, or radiolunate articulations.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- A short-arm volar splint and bulky dressing are applied in the operating room and the patient returns in 1 week for suture removal.
- If fixation is secure (as in a waist nonunion), then additional immobilization is not necessary.
- Proximal pole nonunions, especially those with AVN, or other unstable patterns are protected with a short-arm cast until bridging bone is visible on CT scan.
- Early finger motion and gentle hand strengthening are encouraged to reduce swelling and promote axial loading, encouraging fracture healing.
- Serial CT scans can be performed every 6 weeks to assess healing.
- Plain radiographs are not reliable for assessing healing.
- Clinical symptoms are also not a reliable indicator of healing. Rigid fixation alone may provide a painless wrist after surgery before actual bridging bone has occurred.
- Contact sports and heavy labor are restricted until healing is confirmed on CT.

**OUTCOMES**

- Many grade I to IV nonunions have been successfully treated with this technique (data not yet published).
- As more case series are reported, we will be better able to define the functional outcomes, indications, contraindications, and rate of union of percutaneous treatment of these injuries.

**COMPLICATIONS**

- Complications are often related to screw placement.
- Screws placed outside the central axis have less stable fixation and therefore an increased risk of nonunion.
- A screw that is too long risks wear of the radioscaphoid joint.
- Infection and scar tenderness are reported complications but are uncommon.

**REFERENCES**

DEFINITION

- The scaphoid is the most commonly fractured carpal bone in the wrist. Scaphoid fractures that fail to heal after 6 months of treatment are categorized as nonunions and represent about 5% to 10% of all scaphoid fractures.
- Untreated nonunions have been reported to lead to progressive arthrosis and wrist pain.6
- Volar wedge bone grafting is an effective surgical technique in the treatment of certain scaphoid nonunions based on:
  - Location of the fracture
  - Degree of the deformity
  - Vascularity of the scaphoid
- This general technique can also be adapted to increase its versatility.

ANATOMY

- Nearly 80% of the scaphoid’s surface is covered by articular cartilage.6
- Through ligamentous connections, the scaphoid serves as the bridge or link between the proximal and distal rows. Due to these strong tethers proximally and distally, it is highly susceptible to an acute fracture after a fall on an outstretched hand (FIG 1).18
- Other key factors that influence scaphoid fracture healing are its tenuous vascular supply and its unique bony architecture.
  - The vulnerable vascularity of the scaphoid, especially the proximal pole, is well described in the literature.8,14,15,16,20
  - This is due to the fact that the scaphoid has a retrograde blood supply, with 70% of the vascular supply through the dorsal ridge vessel and 30% provided through branches to the scaphoid tubercle (at the level of the radiocarpal joint via superficial palmar branch perforators off the radial artery).
  - The complex geometry of the bone makes it difficult to anatomically reduce the bone fragments.

PATHOGENESIS

- Although there may be a variety of reasons for the development of a scaphoid nonunion, a fractured scaphoid usually fails to heal for three primary reasons:
  - The fracture is either undetected or untreated within the first 4 weeks after the injury.
  - The location of the fracture is proximal, resulting in poor vascularity of the most proximal fragment.
  - The fracture is displaced more than 1 mm.

NATURAL HISTORY

- Scaphoid nonunion advanced collapse (SNAC), described in the literature, is a predictable sequence of changes that occurs as a result of scaphoid nonunion leading to wrist arthrosis, often associated with pain and limitation of motion.1,5
- In studying patients with painful wrists over a 15-year period to determine who will develop symptoms, it is evident that the incidence of symptomatic wrist pathology requiring reconstruction is significantly higher for scaphoid nonunions that have gone untreated.1
- Techniques used to detect an acute scaphoid fracture and its susceptibility to nonunion, wrist pain, and corresponding arthrosis have been discussed in great detail in the literature.14,15,20

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient who presents with a scaphoid nonunion is usually a man between the ages of 18 and 25.
- Unrecognized injuries in adolescence may present with pain related to early SNAC wrist arthrosis in the middle-aged adult.
- Patients generally complain of wrist pain that limits range of motion or hinders activities such as pushups, weightlifting, and opening a door. Moderate to heavy pinch and grip pain have also been described.
- A specific event resulting in the original scaphoid fracture years before is rarely cited by the patient on presentation.
- Consistent physical examination findings include subtle tenderness in the region of the scaphoid tubercle or the anatomic snuffbox, limited wrist extension compared to the contralateral side, and localized pain on the radial side along the radiolunate or scaphoid with loaded wrist extension.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Standard radiographs include posteroanterior (PA), lateral, and scaphoid oblique 45- and 60-degree pronated views (FIG 2). Such views:
  - Confirm the diagnosis
  - Provide information regarding displacement, angulation, shortening, and the presence of a “humpback deformity”
Nonoperative management may be appropriate for minimally symptomatic scaphoid nonunions. All factors should be taken into consideration when determining the most appropriate treatment: scaphoid nonunion alone is not an absolute reason for surgery.12

**SURGICAL MANAGEMENT**

Volar wedge bone grafting is the preferred surgical technique for treatment of a scaphoid nonunion without osteonecrosis but with shortening, an increased intrascaphoid angle causing a “humpback deformity,” and concomitant carpal collapse. Although many scaphoid nonunions without deformity can be effectively treated with the described procedure, other approaches and grafting techniques that are less invasive may be an option, especially for proximal pole nonunions.2

Determining which bone graft is necessary depends on how much shortening is anticipated.3

- The benefits of distal radius bone grafting include its location within the same surgical site and the fact that it is not limited in size and can be harvested as a vascularized or nonvascularized graft. One important disadvantage is the creation of a relatively large defect and stress riser within the distal radius. Also, the surgical incision is more extensile and it is not possible to get a bicortical or tricortical piece of bone for a more structural bone graft.

- Iliac crest bone graft may be harvested in large quantities and as a bicortical or tricortical piece of bone. It is relatively simple to procure and has a long history of success in such cases, a standard by which all others are currently measured. The disadvantages of this type of bone graft include a separate incision with associated morbidity, as well as a reported risk of cutaneous nerve injuries. Also, it cannot be converted to a vascularized pedicle bone graft.

- When an MRI reveals the presence of osteonecrosis, a vascularized procedure should be considered (see Chap. HA-20).14,15,20

**Preoperative Planning**

After assessing all diagnostic studies, including plain films, MRI and CT scans, the type of bone graft is determined.

- Two types of fixation screws can be used.
  - One type of screw has a smooth shank and two threaded heads. This screw is strong and creates high compression but may not be appropriate for all nonunions. The scaphoid nonunion fragments must be large enough to ensure that no threads of the screw cross into the bone graft site.
  - The other type of compression screw uses a deferential pitch between the proximal and distal portion of the screw. This screw may be more versatile, although it lacks compression strength compared to the above-mentioned screw.

- If compression screws are not deemed appropriate for the type of nonunion that exists, multiple Kirschner wires can be used.

- A regional anesthetic block is used for most patients and is helpful for alleviating postoperative pain. When iliac crest grafting is chosen, additional general anesthesia is needed.

- All radiographic studies are reviewed and brought to the operating room for re-evaluation during the case.

**DIFFERENTIAL DIAGNOSIS**

- De Quervain’s tendinitis
- Scaphotrapeziotrapezoidal arthritis
- Scaphoid lunate instability, static and dynamic
- Radial styloid fracture
- Trapezial ridge fracture

**NONOPERATIVE MANAGEMENT**

Surgery is generally indicated for established scaphoid nonunions that are displaced and symptomatic because of the strong likelihood that radiocarpal arthrosis may develop with this type of persistent nonunion.18,20

- Nonoperative management may be appropriate for minimally symptomatic scaphoid nonunions. All factors should be taken into consideration when determining the most appropriate treatment: scaphoid nonunion alone is not an absolute reason for surgery.12

**SURGICAL MANAGEMENT**

Volar wedge bone grafting is the preferred surgical technique for treatment of a scaphoid nonunion without osteonecrosis but with shortening, an increased intrascaphoid angle causing a “humpback deformity,” and concomitant carpal collapse. Although many scaphoid nonunions without deformity can be effectively treated with the described procedure, other approaches and grafting techniques that are less invasive may be an option, especially for proximal pole nonunions.2

Determining which bone graft is necessary depends on how much shortening is anticipated.3

- The benefits of distal radius bone grafting include its location within the same surgical site and the fact that it is not limited in size and can be harvested as a vascularized or nonvascularized graft. One important disadvantage is the creation of a relatively large defect and stress riser within the distal radius. Also, the surgical incision is more extensile and it is not possible to get a bicortical or tricortical piece of bone for a more structural bone graft.

- Iliac crest bone graft may be harvested in large quantities and as a bicortical or tricortical piece of bone. It is relatively simple to procure and has a long history of success in such cases, a standard by which all others are currently measured. The disadvantages of this type of bone graft include a separate incision with associated morbidity, as well as a reported risk of cutaneous nerve injuries. Also, it cannot be converted to a vascularized pedicle bone graft.

- When an MRI reveals the presence of osteonecrosis, a vascularized procedure should be considered (see Chap. HA-20).14,15,20

**Preoperative Planning**

After assessing all diagnostic studies, including plain films, MRI and CT scans, the type of bone graft is determined.

- Two types of fixation screws can be used.
  - One type of screw has a smooth shank and two threaded heads. This screw is strong and creates high compression but may not be appropriate for all nonunions. The scaphoid nonunion fragments must be large enough to ensure that no threads of the screw cross into the bone graft site.
  - The other type of compression screw uses a deferential pitch between the proximal and distal portion of the screw. This screw may be more versatile, although it lacks compression strength compared to the above-mentioned screw.

- If compression screws are not deemed appropriate for the type of nonunion that exists, multiple Kirschner wires can be used.

- A regional anesthetic block is used for most patients and is helpful for alleviating postoperative pain. When iliac crest grafting is chosen, additional general anesthesia is needed.

- All radiographic studies are reviewed and brought to the operating room for re-evaluation during the case.
Positioning
- The patient is placed in the supine position with the upper extremity positioned on a hand table.
- If an ipsilateral iliac crest bone graft is used, the hip on the same side as the affected hand is prepared and draped. A small bump is placed under the hip for patients with significant adipose tissue.
- A tourniquet is applied to the proximal arm.

Approach
- The location of the scaphoid nonunion helps determine the surgical approach. Wedge bone grafting of a waist nonunion is performed using a standard volar approach.
- For proximal pole fractures with evidence of osteonecrosis, a dorsal approach with possibly a vascularized bone graft would be a more amenable surgical approach.13,19

VOLAR WEDGE BONE GRAFTING USING DISTAL RADIUS BONE GRAFT AND INTRAOSSEOUS COMPRESSION SCREW FIXATION

Incision and Initial Dissection
- An incision is drawn over the flexor carpi radialis (FCR) tendon and extended distally between the glabrous skin of the thenar eminence, angled across the wrist flexion crease (TECH FIG 1A).
- After exsanguination the skin is incised and the FCR tendon is identified. Distally in the wound a volar branch of the radial artery is often sacrificed to gain exposure (TECH FIG 1B).
- The floor of the FCR tendon is sharply incised over the entire course of the incision and the digital flexors and median nerve are swept ulnarly. They are carefully protected throughout the case. A blunt Wheatlander is used to maintain visualization of this interval between the radial artery and the FCR tendon.
- The volar extrinsic ligaments, the radioscaphocapitate (RSC) and long radiolunate (LRL), are identified and precisely incised. Much of the LRL and a portion of the RSC are left intact, helping to stabilize the proximal pole (TECH FIG 1C).
- This stability facilitates the reduction of the distal fragment to the proximal fragment.
- Preserving this ligamentous support also helps maintain fracture reduction during the placement of an intraosseous compression screw by counteracting the torque created during screw insertion.
- Deep dissection proceeds to the scaphotrapezial joint. This interval is exposed using a transverse capsular incision for later insertion of the intraosseous screw.
- The articulation between the scaphoid and capitate is carefully exposed. This visualization will be important during reduction of the scaphoid fragments.
- During exposure it is critical to avoid dissection over the distal dorsoradial scaphoid to avoid interrupting the contribution by the dorsal ridge vessel.

Nonunion Exposure and Preparation
- A no. 64 Beaver blade and Freer elevator are used to define the location of the nonunion and the borders of the scaphoid itself. Time spent here makes reduction and bone graft placement simpler later (TECH FIG 2A,B).
- Two joystick K-wires are placed, one angled proximally in the proximal fragment and one angled distally in the distal fragment (TECH FIG 2C).
Chapter 19  
VOLAR WEDGE BONE GRAFTING AND INTERNAL FIXATION OF SCAPHOID NONUNIONS  

**TECHNIQUES**

**K-wire joysticks**

Fractured scaphoid

**TECH FIG 2** • A, B. A Freer elevator identifies the nonunion site. C. K-wires are used as joysticks to control the scaphoid proximal and distal fragments. D. Manipulation of the K-wires allows for access to the nonunion site for débridement and then graft placement.

- These K-wires facilitate manipulation of the fragments and therefore access to the nonunion site for débridement (TECH FIG 2D).
- The proximal and distal poles are examined carefully for osteolysis and sclerosis. A small curette or rongeur is used for débridement and removal of intervening fibrous tissue. Débridement is complete once good punctate bleeding is noted. In some situations deflating the tourniquet temporarily can be of value in assessing viability of the fragments.

**Fracture Reduction and Preliminary Stabilization**

- A retrograde K-wire may be inserted along the longitudinal axis of the scaphoid to temporarily hold the reduction.
- If placed in an appropriately eccentric position this K-wire may serve effectively as the derotation K-wire (used later to avoid fragment rotation during screw insertion) and yet remain out of the path of the screw.
- Restoration of scaphoid length and anatomic reduction of the fragments are best assessed by direct visualization and fluoroscopy.
- Lateral images will reveal correction of the DISI deformity.
- PA images document proper length of the scaphoid and determine if the Gilula lines are re-established.9
- The size of the volar wedge graft needed to maintain the reduction is now determined based on the volar defect noted after the reduction is accomplished.

By bringing the joystick/crossed K-wires into a more parallel position (relative to one another) and rotating the distal K-wire into slight supination, initial fracture reduction is often accomplished by removing the humpback (TECH FIG 3).
TECH FIG 3 • The scaphoid joysticks are used to reduce the fracture, and the length is estimated to determine the size of the volar wedge graft.

Distal Radius Graft Harvest
- A two-fingerbreadths incision is made more proximally than initially described. This provides the necessary access to the distal radius.
- The pronator quadratus is elevated using cautery, and the distal radius is perforated using K-wires to outline the size of the graft needed to fill the volar defect.
  - Great care is taken to avoid destabilizing the radial cortex of the radius.
- A curved osteotome introduced on three sides allows harvest of the corticocancellous wedge.
- A curette is then used to harvest as much cancellous bone as necessary.

Graft Contouring and Insertion
- The volar cortical defect in the reduced scaphoid is "regularized" using a small water-cooled sagittal saw or a fine rongeur.
  - Very little bone is removed from the fracture fragments to create a standard-shaped trough.
  - Creating such a "regular" defect makes insertion of the wedge graft easier and more secure.
- The same saw or rongeur is used to shape the corticocancellous graft to match the "regularized" defect.
- The prepared proximal and distal fragments are packed with cancellous bone and the corticocancellous graft is tapped into place (TECH FIG 4A).
- Before graft insertion, the longitudinal K-wire, whether it is the K-wire placed to maintain reduction or the K-wire over which the cannulated compression screw is to be placed, is withdrawn into the distal pole and then reinserted after placement of the graft into the trough.

Cannulated Intraosseous Compression Screw Fixation
- At the level of the scaphotrapezial joint a small rongeur is used to remove a portion of the trapezial lip. This facilitates the placement of the K-wire and screw down the longitudinal access of the scaphoid, helping secure center placement of the screw within the bone. A center screw position has been demonstrated to lead to increased healing rates.
- A K-wire from the compression screw system is then inserted in a retrograde direction (distal to proximal) into the center of the scaphoid, perpendicular to the fracture line.
  - If the K-wire is not perpendicular to the fracture, compression generated from the screw may malreduce the fragments.
- Once the K-wire is in perfect position, as judged fluoroscopically, and is fixed in the far (proximal) cortex of the scaphoid, the length is measured.
  - Factors such as cartilage thickness and distance between the fracture fragments is taken into account. It is critical that the screw not be too long and enter the radiocarpal joint.
- While some surgeons advocate advancing the K-wire into the distal radius after the measurement is taken so that the wire remains in position during drilling, that practice is dangerous. It is preferable to leave the K-wire in the scaphoid.
  - Advancing the K-wire can result in cutting the guidewire during drilling or screw placement (particularly with a second-generation compression screw that has cutting flutes at the distal end).
  - If not already present, an eccentric K-wire is placed to maintain the reduction during screw insertion.
  - Under fluoroscopic guidance, a cannulated drill is used followed, in some cases, by a cannulated bone tap. The screw is then placed over the K-wire and the guidewire is removed.
  - Especially during drilling, the surgeon must be careful to remain parallel with the wire.
  - The corticocancellous bone graft must be visualized at all times during these procedures to make certain position is maintained. Maintaining finger pressure over the graft during screw insertion is helpful.
- Imaging confirms proper screw location, fracture reduction, and construct stability. The K-wire is removed from the cannulated screw and the eccentric K-wire is removed (TECH FIG 4B,C).
- The wound is then irrigated and the volar extrinsic ligaments are repaired precisely with permanent suture. The remainder of the joint capsule may be closed with an absorbable suture.
  - Bone filler, preferably cadaver dried cancellous bone chips, can be inserted into the distal radius harvest site with a small tamp to compress and fill the defect. This potentially decreases the risk of hematoma formation. The periosteal sleeve is then closed over the distal radius with absorbable suture.
  - Skin is closed using nylon suture, and the tourniquet is then deflated after placement of a thumb spica splint.
If compression screw fixation is not feasible, then retrograde, nonthreaded K-wires are recommended and placed in the same manner as described above for the bone screw.
- The wires should be left under the skin and removed once the bone has healed.
- K-wires provide adequate stability and may be a better fixation choice with large bone grafts.

**Iliac Crest Graft Harvest**

- Rather than obtaining bone graft from the distal radius, a standard technique of harvesting bone from the iliac crest may be used.16,20
- A 2- to 3-cm incision is made just inferior to the superior border of the iliac crest just posterior to the anterior superior iliac spine (ASIS).
- The incision is kept below the belt line to minimize postoperative incisional tenderness.
- The incision is posterior to the ASIS to avoid iatrogenic nerve injury and subsequent numbness and pain over the proximal lateral thigh.
- Dissection is accomplished using cautery through the deep fascia down to the crest. The superior crest is exposed and muscles are released from a portion of the outer table using cautery and an elevator.
- A water-cooled sagittal saw and a curved osteotome are used to harvest a bicortical segment of corticocancellous graft.
- The graft is slightly larger than the measured defect in the scaphoid.
- The inner table is left intact.
- The harvested outer table will be volar when the graft is placed in the scaphoid and the superior crest will be radial.
- A curette is used to harvest cancellous bone graft.
- The wound is copiously irrigated and temporarily packed with thrombin-soaked Gelfoam while attention is redirected to the scaphoid.
- After the scaphoid is reconstructed, the Gelfoam is removed and the wound again irrigated.
- If indicated, a small suction drain is placed below the fascia.
- The wound is closed in layers with a running locking stitch used for the fascia.
- A local anesthetic with epinephrine may be injected before harvest of the graft or after closure.

**K-WIRE FIXATION**

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>When MRI reveals osteonecrosis in a scaphoid nonunion</th>
<th>Volar wedge bone grafting and internal fixation is the treatment option that is most effective when applied to scaphoid waist fractures, distal-third fractures of the scaphoid without osteonecrosis, or scaphoid waist fractures with concomitant carpal collapse and a nondissociated DISI pattern. When osteonecrosis is present, a vascularized procedure is preferable.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgeon prefers an adaptable graft should physical findings during the procedure reveal osteonecrosis not revealed on MRI</td>
<td>The advantage of harvesting from the distal radius rather than the iliac crest exists when the MRI is inconsistent with physical examination findings during the procedure. Harvesting from the distal radius allows the surgeon to use a modified pedicle technique using the pronator quadratus and the periosteum of the distal radius and place it into the volar defect as a vascularized bone graft if necessary.20</td>
</tr>
<tr>
<td>Fixation for greatest chance of bone healing</td>
<td>While either compression bone screws or K-wires can be used as effective fixation in this procedure, compression screws are believed to improve chances of overall bone healing.7,11,18</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE
- When a screw is placed for internal fixation, a thumb spica splint is applied after the procedure.
- The patient returns for a follow-up visit 10 days after surgery. During this visit, the hand is examined for swelling and sutures may be removed.
- A thumb spica, short-arm cast is applied, leaving the interphalangeal joint free. The patient is followed radiographically at intervals of 3 to 4 weeks.
- CT scans are the most predictable way to determine if the scaphoid has healed. This evaluation is recommended before allowing the patient to resume vigorous activities.

OUTCOMES
- Symptomatic scaphoid nonunions with shortening respond well to volar wedge bone grafting with internal fixation, particularly when scaphoid length is restored and when any bony union is achieved.
- A higher rate of bone healing is achieved when a compression bone screw is used as the internal fixation. Reported results show that internal fixation leads to better functional results than standard techniques of bone grafting.7,11,16–18
- Bones failing to heal after the procedure have been shown to respond well to vascularized grafts. Other options for failure to heal include partial scaphoid excision, complete scaphoid excision with four-corner fusion, proximal row carpectomy, radial styloidectomy, and complete wrist fusion.

COMPLICATIONS
- Radiographic findings may not match the findings at surgery. This affects the outcome to varying degrees, depending on the type of graft harvested.
- Persistent nonunion and osteonecrosis resulting in wrist arthritis
- Scarring associated with repair of the capsule, causing some postoperative stiffness

REFERENCES
DEFINITION
- Scaphoid fractures account for 60% of carpal bone fractures.
- Nonunions occur in up to 15% of scaphoid fractures and often result from delayed treatment, inadequate immobilization, displacement of the fracture, or proximal pole involvement or in the setting of avascular necrosis (AVN).

ANATOMY
- The blood supply to the scaphoid travels in a distal to proximal direction and emanates from the radial artery. Intraosseous vessels traverse the scaphoid to supply the proximal pole.
  - In about 30% of scaphoids, there is either a single or no vascular channel found reaching the proximal pole.
  - Studies of vascularity of the distal radius have identified several sources of vascularized bone graft available for nonunion treatment.
  - Animal studies of vascularized bone grafts have documented a significant increase in blood flow present when compared to nonvascularized grafts.

PATHOGENESIS
- Without adequate blood flow, the normal bone healing response cannot be completed. The scaphoid fracture site fills with fibrous connective tissue and motion persists at the site of the fracture.
  - In some cases, the bone undergoes changes of AVN with cellular death, edema, and the eventual loss of trabecular architecture.
  - Studies have shown that in cases in which the trabecular bone pattern has been lost, union may be difficult if not impossible to achieve.

NATURAL HISTORY
- Nonunion of the scaphoid severely alters the normal carpal biomechanics and subjects the cartilage to shear forces detrimental to its survival.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Often patients recall injuring their wrists several years before developing pain severe enough to seek medical attention.
- Patients usually complain of limited range of wrist motion and pain, often with grip or weight bearing. The patients have often significantly reduced their activity level due to persistent pain.
- In most cases the patient will experience tenderness to palpation at the anatomic snuffbox (FIG 1A), the radial styloid–scaphoid joint (FIG 1B), or the distal pole of the scaphoid (FIG 1C), which is palpable on the palmar side of the wrist.
- Wrists with established scaphoid nonunions have an arc of motion that is significantly reduced from the uninvolved side, primarily in extension.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standard radiographic studies include posteroanterior (PA), lateral, and scaphoid (ulnar deviation) views (FIG 2).
  - Classic radiographic findings begin at the radial styloid-distal pole of scaphoid interface and proceed to involve the entire scaphoid fossa, the midcarpal joint, and eventually the entire radiocarpal articulation.
  - CT is essential for determining union as well as for identifying patients in whom the normal trabecular bone pattern has been lost.
  - MRI is useful in evaluating the scaphoid for vascularity, although definitive determination of avascularity may be difficult.

FIG 1 • A. Tenderness at the anatomic snuffbox is a classic finding of scaphoid nonunion. B. The radial styloid–scaphoid interface is the earliest site of degenerative change in scaphoid nonunions, and patients will often display tenderness at that location. C. The distal pole of the scaphoid is palpable at the base of the thumb on the palmar aspect of the wrist. Tenderness at this region is usually found in cases of scaphoid nonunion.
Conflicting reports regarding the usefulness of gadolinium enhancement have been published over the past several years.

**DIFFERENTIAL DIAGNOSIS**
- Ligamentous injury to the wrist
- Wrist synovitis
- Intraosseous ganglia
- Primary AVN of the scaphoid

**NONOPERATIVE MANAGEMENT**
- Nonoperative treatment is limited for established non-unions.
- Investigators have attempted the use of bone stimulators, which use either electrical stimulation or ultrasound.
  - There is little evidence in the literature supporting the use of these units for treatment of established scaphoid nonunions.

**SURGICAL MANAGEMENT**
- A vascularized distal radial bone graft is indicated for scaphoid nonunions with and without evidence of avascularity.
- Correction of a “humpback deformity” requires extensive mobilization of the pedicle when attempting the use of a dorsally sourced graft, and a palmar vascularized graft may be more appropriate.
- For significant collapse, a nonvascular iliac crest graft may be required to create a compression-resistant construct.
- When early degenerative changes are present, a radial styloidectomy should accompany the use of a vascularized distal radial graft.
- The presence of more advanced degenerative joint disease or carpal malalignment is a contraindication to performing surgery to obtain bony union.

**Preoperative Planning**
- Radiographs must be evaluated to rule out degenerative joint changes or carpal instability patterns, which are often found in established nonunions.

**Positioning**
- The patient is placed supine on the operating table with the arm placed on an armboard.
- Surgery is performed under tourniquet control.

**Approach**
- Vascularized grafting is carried out through a dorsal approach. Anatomic studies have shown that the dorsal irrigating vessels are of greater diameter and are further from the articular surface than irrigating vessels on the palmar surface of the radius.

**TECHNIQUES**

**VASCULARIZED DISTAL RADIUS BONE GRAFTING USING THE 1,2-INTERCOMPARTMENTAL SUPRARETINACULAR ARTERY**

**Exposure**
- A curvilinear incision is made over the dorsoradial aspect of the wrist, centered between the first and second extensor compartments (TECH FIG 1A).
- The 1,2-intercompartmental supraretinacular artery (1,2 IC SRA) lies on the surface of the retinaculum between the first and second compartments (TECH FIG 1B).
  - The irrigating branch enters the distal radius and supplies bone distal and dorsal to the brachioradialis insertion.
  - Avoidance of exsanguination before tourniquet inflation facilitates its identification.
- The first and second compartments are unroofed on their radial and ulnar aspects, respectively, to avoid damage to this irrigating vessel.

**Graft Harvest**
- The periosteum is scored with a scalpel to outline the graft shape, which measures 1.5 cm in the longitudinal dimension and 0.5 to 0.75 cm in the transverse dimensions (TECH FIG 2A). The distal graft margin extends to a point 0.5 to 1 cm from the articular surface.
- Osteotomes are used to elevate the cortical cancellous graft.
The soft tissue envelope containing the vessel is elevated from the radial periosteum distal to the site of graft harvest (TECH FIG 2B). This can usually be accomplished with a scalpel or Freer elevator.

- The 1,2 IC SRA is not dissected free; rather, it is left as part of the retinacular septum.
- The tourniquet is deflated and perfusion of the vascularized bone graft is ensured (TECH FIG 2C).

**Graft Placement**

- The joint capsule is incised in the distal portion of the incision and the scaphoid nonunion is identified.
- A radial styloidectomy greatly increases the exposure of the scaphoid and eliminates the possibility of bone graft impingement.
- Intervening fibrous tissue and sclerotic bone are removed from the nonunion site using rongeurs and curettes to prepare the scaphoid for graft placement.
- Cancellous bone graft from the distal radius is packed proximally and distally to fill voids created by débriding sclerotic bone.
- The carefully contoured vascularized graft is then rotated into the nonunion site and pressfit into position, taking care to avoid torsion of the vascular pedicle (TECH FIG 3A).
- Kirschner wires are advanced from the distal pole of the scaphoid to the proximal pole to secure the graft in place (TECH FIG 3B).
- The radial capsule is closed loosely with absorbable suture and the skin is closed in a routine fashion.
- The pedicle must not be compressed.
- The patient is placed in a short-arm thumb spica splint.
**POSTOPERATIVE CARE**
- Kirschner wires are removed when healing is observed, usually 4 to 6 weeks after surgery.
- CT scanning may be required to document complete healing before the patient resumes risky activities.
- MRI may be useful in evaluating the scaphoid for vascularity and may be done after Kirschner wire removal.

**OUTCOMES**
- A recent meta-analysis\(^2\) found a scaphoid union rate of 88% with the use of a vascularized bone graft. Individual series report union rates ranging from 60% to 100%.
- Previous reports have shown that patients with MRI evidence of AVN or loss of trabecular bone pattern noted on CT have a decreased level of success with reconstructive surgery. Treatment is rarely successful when both findings are present.
- A recent study\(^1\) has identified risk fractures for failure: proximal pole AVN, radiographic degenerative changes, loss of carpal alignment, inadequate fracture fixation, tobacco use, advanced age, and female gender.

**COMPLICATIONS**
- Failure to gain union
- Progressive degenerative changes
- Impingement of bone on radial styloid
- Infection

**REFERENCES**
DEFINITION
- The scaphoid is the most frequently fractured bone in the carpus. In acute fractures, appropriate treatment yields union rates greater than 90%.1 However, without proper diagnosis and treatment scaphoid fractures frequently result in nonunion. Initial treatment for a scaphoid nonunion is typically open reduction and internal fixation (ORIF) with bone graft, vascularized or unvascularized. Despite appropriate internal fixation and bone grafting, failure rates of 15% have been documented.4 If internal fixation and bone grafting fails, the surgeon is then left with difficult choices:
  - Revision ORIF with bone grafting (failure rate of 50%)2
  - A salvage procedure with lower morbidity and a higher rate of satisfactory results
  - Currently, there are no acceptable prostheses available to replace the scaphoid.
  - When the index treatment or procedure has failed and the patient has persistent pain caused by a chronic scaphoid nonunion (FIG 1) with posttraumatic arthritis limited to the distal pole of the scaphoid and radius, partial scaphoid excision (distal fragment) provides a reasonable, low-morbidity alternative treatment option.3–5

ANATOMY
- The carpus is divided into proximal (scaphoid, lunate, triquetrum, pisiform) and distal (trapezium, trapezoid, capitate, hamate) rows.
- The scaphoid bone represents the bridge between these two rows. Largely covered by articular cartilage, it has important intrinsic and extrinsic ligamentous attachments (radioscaphocapitate, long radiolunate, scapholunate, and scaphotrapezial-trapezoid). In its precarious position as an intercalated rod between the proximal and distal carpal row, the scaphoid is at mechanical risk for fracture when an abnormal stress is applied (eg, forced dorsiflexion).
- After a fracture of the scaphoid, the vascular anatomy specific to this bone contributes to problems in bone healing.7 Taleisnik and Kelly describe three groups of vessels responsible for scaphoid blood supply: laterovolar, dorsal, and distal vessels (FIG 2). The laterovolar vessels are the main contributors to the intraosseous blood supply.

![FIG 1](image1.png) Failed open reduction and internal fixation of a scaphoid nonunion (PA and lateral views).

![FIG 2](image2.png) A. Volar intraosseous blood supply to the scaphoid with laterovolar and distal vessels visualized. B. Dorsal intraosseous blood supply to the scaphoid.
Variations exist in the exact number and locations of the volar vessels entering the scaphoid, but in all studies the most significant vessels enter the scaphoid distal to its waist.

The proximal pole is at risk secondary to its tenuous blood supply.\(^7\)

**PATHOGENESIS**

- Based on its retrograde pattern of blood supply, a more proximal fracture of the scaphoid will have an increased potential to form a nonunion.
- Patients with scaphoid fractures who present with delays in both diagnosis and treatment can develop a nonunion. In addition, patients with comminution, displacement, or improper immobilization of the scaphoid fracture can develop nonunions.

**NATURAL HISTORY**

- A scaphoid nonunion leads to the development of posttraumatic arthritis in the region of the radioscaphoid joint. How quickly this arthritis develops and progresses varies, but most patients will show radiographic evidence of degenerative changes within 5 to 10 years of their nonunion.
- Arthritis first develops between the distal pole of the scaphoid and the radial styloid (scaphoid nonunion advanced collapse [SNAC] wrist stage I; **FIG 3A**).
- The degenerative changes occur at this location due to the abnormal motion between the ununited distal scaphoid fragment and the radial styloid.
- Left untreated, stage I SNAC will progress to involve the entire radioscaphoid articulation (SNAC stage II) and eventually diffuse arthritis of the wrist (SNAC stages III and IV) (**FIG 3B–D**).

**FIG 3** • **A.** Arthritis observed between the distal pole of the scaphoid and the radial styloid (scaphoid nonunion advanced collapse [SNAC] grade I).

**B–D.** Stage I SNAC can progress to involve the entire radioscaphoid articulation (SNAC grade II) with eventual diffuse arthritis of the wrist (SNAC grade III and IV).
Patients sometimes do not seek medical care until pain and decreased range of motion in the wrist become increasingly severe. In these cases, initial radiographic studies reveal a scaphoid nonunion and associated arthritis.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Most patients are young to middle-aged men who sustained a dorsiflexion injury to their involved wrist. Some patients will present with no previous treatment and a chronic nonunion (FIG 4), and some will have failed to respond to either operative or nonoperative therapy.
- Pain aggravated by motion and use, loss of motion, and loss of grip strength, all slowly worsening over the preceding years, are consistent presenting complaints.

- It is critical to know the patient’s smoking history, occupation, and previous operations, as these will dictate future interventions.
- The examiner should palpate the anatomic snuffbox, which lies on the dorsum of the wrist between the extensor pollicis longus and extensor pollicis brevis tendons. Pain in this region is indicative of a fracture.
- Measurements of grip strength and range of motion (ROM) need to be ascertained.
  - Strength is often decreased by as much as 30% to 40% if the patient is experiencing pain.
  - There will often be a decrease in extension and radial deviation of the wrist relative to the contralateral unaffected side.
  - Limited active ROM of the wrist can indicate carpal pathology.
  - Decreased grip strength in association with physical findings can indicate carpal pathology.
- During palmar flexion the examiner may notice both a fullness and a hard bone excrescence on the dorsal radial aspect of the wrist. This fullness is secondary to synovitis and the hard excrescence is the result of the hypertrophic distal pole of the scaphoid.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- We routinely order true posteroanterior (PA), lateral, and ulnar and radial deviation views of the wrist. These views assist in determining whether a partial scaphoid excision is indicated.
  - The lateral plain radiograph allows one to determine the degree of dorsal intercalated segment instability (DISI) (FIG 5A).
  - If the radiographs reveal intercarpal arthritis (FIG 5B) or a small avascular proximal pole, partial scaphoid excision may be contraindicated.
  - If no radioscaphoid arthritis is observed, another procedure (eg, vascularized bone graft) to salvage the scaphoid might be considered.
- MRI is helpful in evaluating the joint surfaces and the blood supply of the proximal scaphoid fragment.
• However, MRIs rarely change the decision to perform a distal pole excision, as plain radiographs most often give adequate and accurate information.
• From a radiographic perspective, the ideal candidate for distal pole excision of the scaphoid has a nonunion of the scaphoid fracture in the midwaist or distal pole with concomitant degenerative joint disease between the distal radius and distal pole only.

**DIFFERENTIAL DIAGNOSIS**

• Scaphoid fracture
• Scaphoid nonunion
• Radioscaphoid arthritis
• Midcarpal arthritis
• Carpometacarpal arthritis

**NONOPERATIVE MANAGEMENT**

• Nonoperative management of chronic wrist pain should be considered before any surgical intervention. Chronic wrist pain is never an emergency and simple noninvasive techniques can be used to control pain.
• The treatment of any painful joint begins with intermittent immobilization (wrist splinting), activity modification, and nonsteroidal anti-inflammatory medications (NSAIDs).
• If immobilization and NSAIDs are ineffective, temporary pain relief can almost always be gained with a steroid injection. These temporizing treatments also put the pain in perspective for the patient. The patient may conclude that medication and splinting is all that is necessary.
• During the nonoperative management period, the surgeon gains a perspective on the degree of patient discomfort and simultaneously gauges the patient’s expectations.
• The operation will work better and the patient will be more satisfied if the patient’s expectations and surgeon’s expectations are similar.

**SURGICAL MANAGEMENT**

• Surgical options to treat persistent pain resulting in compromised function in a patient with a scaphoid nonunion and arthritis limited to the area between the distal fragment of the scaphoid and the radial styloid (stage I SNAC wrist arthritis) include:
  • Open reduction and internal fixation (ORIF) combined with radial styloidectomy
  • Resection of the distal scaphoid fragment
  • A patient with an untreated scaphoid nonunion and no arthritis most often has ORIF of the scaphoid with bone grafting as the initial procedure. In a patient with SNAC wrist grade II, it is too late for distal pole excision; this patient may require a proximal row carpectomy or scaphoid excision with intercarpal fusion.
  • Most patients requiring excision of the distal pole have undergone prior treatment that has failed and both the surgeon and the patient are searching for a reliable procedure with low morbidity to help alleviate the patient’s pain and augment function.
  • Distal scaphoid excision requires that the robust and taut radioscapoid and long radiolunate ligaments exist to support the remaining proximal carpus and prevent collapse (dorsal intercalated segment instability [DISI] of the wrist).
• Contraindications to distal pole excision include:
  • Pre-existing significant DISI deformity. The DISI deformity may indeed get worse with distal pole excision in an individual with poor ligamentous support.
  • Proximal pole that is less than half the entire size of the scaphoid. If the distal fragment is greater than 50% of the size of the scaphoid, resultant collapse of the carpus may occur with severe morbidity.

**Preoperative Planning**

• Before deciding if distal pole excision of the scaphoid is a reasonable choice, radiographs or other images (eg, CT or MRI) must be carefully reviewed.
• If the distal pole is to be excised, there must be enough proximal pole left to support the capitate and the remainder of the carpus. At least one third of the scaphoid must remain. If only a very small (and possibly an avascular) proximal pole remains, the carpus is likely to collapse, resulting in failure of the procedure.

**Positioning**

• The patient is placed in the supine position with application of a pneumatic tourniquet.

**Approach**

• The distal pole of the scaphoid can be excised through either a dorsal or palmar approach. The approach may be dictated by existing scars.
• The palmar approach is the preferred method due to the relatively accessible palmar position of the distal fragment.
• An advantage of the dorsal approach is the ease of excision of the posterior interosseous nerve for wrist denervation.
• A radial styloidectomy can be performed through either approach.

**VOLAR APPROACH TO DISTAL POLE OF SCAPHOID EXCISION**

**Incision and Scaphoid Excision**

• An incision is made directly over the flexor carpi radialis (FCR) tendon, incorporating any previous incisions (TECH FIG 1A,B).
• The tendon is retracted ulnarly and the subsheath of the tendon incised longitudinally (TECH FIG 1C).
• The radiocarpal joint capsule is opened longitudinally and the distal pole of the scaphoid is excised with osteotomies and rongeurs (TECH FIG 1D–G).

**Radial Styloidectomy**

• If indicated, a radial styloidectomy can be performed at this point using an osteotome.

• In this situation, the distal pole may be too large to excise and a radial styloidectomy can accomplish the same purpose.
• The styloidectomy should be large enough so that the arthritic distal pole no longer touches the radius in radial deviation.

**Wound Closure**

• The capsule and volar extrinsic ligaments are closed with interrupted absorbable 4-0 sutures.
• The skin is closed with interrupted nonabsorbable 4-0 sutures.
TECH FIG 1 • A. Chronic scaphoid non-union with scaphoid nonunion advanced collapse (SNAC). The patient had no previous treatment. B. An incision is made directly over the flexor carpi radialis (FCR) tendon. C. The tendon is retracted and its subsheath opened longitudinally. D. The radiocarpal joint is opened longitudinally and the scaphoid is visualized. E,F. The distal pole of the scaphoid is excised with osteotomies and rongeurs. If indicated, a radial styloidectomy can be performed at this point. G. Excised distal pole of the scaphoid.

DORSAL APPROACH TO DISTAL POLE OF SCAPHOID EXCISION

- An incision is made over the radial aspect of the carpus, incorporating any old incisions (TECH FIG 2).
- The radial sensory nerve is identified and retracted.
- The interval between the extensor pollicis longus and the radial wrist extensors is entered.
- The radial artery and its branches are retracted and protected, and then the joint capsule is incised.
- The distal scaphoid fragment will be deep and is best removed using rongeurs after defining its borders with a No. 15 blade.
- A radial styloidectomy can be performed if necessary as mentioned above.
- The capsule is closed with absorbable 4-0 suture.
- The skin is closed with interrupted nonabsorbable 4-0 sutures.
- The patient is placed in a well-padded forearm-based splint, leaving the finger metacarpophalangeal joints and thumb interphalangeal joint free. This volar splint is placed after either the volar or dorsal approach.

TECH FIG 2 • An incision over the dorsoradial aspect of the wrist may be used when prior surgery has been performed.
POSTOPERATIVE CARE

- Patients are immobilized for 2 weeks in a well-padded volar splint.
- The splint and sutures are removed 2 weeks after the procedure.
- A removable orthosis is applied and the patient is instructed on active and passive ROM exercises.
- Once active and passive ROM has been achieved, strength exercises are started (usually at 4 weeks postoperatively).
- Regaining full ROM and strength typically takes about 3 months.
- Pain relief is noticeable within 2 to 4 weeks of surgery.

OUTCOMES

- Review of outcomes in the literature suggest that both ROM and grip strength improve postoperatively.
- Pain relief can be expected if the proper indications for surgery are followed.
- All patients have some degree of DISI preoperatively, and this pattern of deformity may worsen after excision of the distal pole of the scaphoid. DISI deformities that are severe can result in both loss of motion and pain. This problem is not well documented in the literature but certainly exists.
- In the patient undergoing multiple procedures, outcomes of distal pole excision are better than attempting another bone graft and internal fixation, where the failure rate can approach 50%.

COMPLICATIONS

- The presence of midcarpal arthritis undiagnosed before distal pole excision can lead to persistent pain.
- Resection of too large a distal pole (more than two thirds) can result in collapse of the scaphoid.
- If the procedure is performed in a very loose-jointed individual, the DISI pattern may significantly worsen, leading to persistent pain.

REFERENCES


DEFINITION
- These injuries include fractures of the lunate, triquetrum, pisiform, hamate body or hook, capitate, trapezoid, and trapezial body or ridge.
- Any fracture involving the carpal bones should raise suspicion of associated carpal instability.

ANATOMY
- Certain anatomic features of the carpal bones make them more susceptible to injury. These include the unique osteologic regions of some of the carpal bones, such as the hook of the hamate, the ridge or tubercle of the trapezium, and the neck of the capitate.
- The slender shape and projection of the hamate hook make it an obvious injury target for direct trauma to the palmar-ulnar surface of the wrist (Fig 1A). The hook can be identified before incision by placing the interphalangeal joint of the surgeon’s thumb on the pisiform and flexing the thumb toward the first web space. The surgeon’s thumb tip will land directly on top of the hook.
- The trapezial ridge may be considered a radial-sided analogue to the hamate hook in that it is a relatively prominent volar projection, further accentuated by the deep groove for the flexor carpi radialis tendon that runs along its ulnar side (Fig 1B).
- The strong, inelastic transverse carpal ligament attaches to the hamate hook ulnarily and the trapezial tubercle radially.
- These facts make the ridge of the trapezium more susceptible to fracture after direct trauma to the thenar region of the hand.
- The constricted neck portion of the capitate lies between the dense head proximally and the body distally. The body, which accounts for the distal half of the capitate, is rigidly constrained by its associations with the index, middle, and ring finger metacarpal bases, the trapezoid, and the hamate. As a result the capitate neck is a biomechanically vulnerable area.
- Transverse plane fractures through the capitate neck are reported as being the most common.
- Fractures across the neck place the head at risk for avascular necrosis because the blood supply to the capitate flows retrograde toward the head proximally.

PATHOGENESIS
- Traumatic fractures of the carpal bones may occur via direct or indirect mechanisms.
- Direct mechanisms include crush injuries, which should alert the physician to the possible development of compartment syndrome of the hand. Compressive trauma to the hand in the anteroposterior plane will flatten the palmarly directed concave longitudinal and horizontal arches of the carpus and should raise suspicion for potential carpal body fractures and axial disruptions.
- The presence of a seemingly unusual carpal bone fracture may be a herald of a globally destructive injury to the hand and other associated injuries, such as carpometacarpal (CMC) fracture-dislocations, longitudinal fractures of the metacarpals, severe thumb damage, and significant soft tissue injuries. This constellation of pathologies has been referred to as the “exploded hand” (Fig 2).
- More focused direct trauma to individual carpal bones may also cause a fracture. Examples of this include direct blows to the dorsum of the hand, causing capitate fractures, or direct injury from a racquet or club, causing a hamate hook fracture.

![Fig 1A](image1A.png) ![Fig 1B](image1B.png)

**FIG 1** • A. CT scan showing hamate hook. B. CT scan showing trapezial ridge.

![Fig 2](image2.png)

**FIG 2** • “Exploded hand” is a constellation of injuries that can include carpometacarpal fracture-dislocations, longitudinal fractures of the metacarpals, severe thumb damage, and significant soft tissue damage. (Reprinted from Graham TJ. The exploded hand syndrome: logical evaluation and comprehensive treatment of the severely crushed hand. J Hand Surg Am 2006;31A: 1012–1023; copyright 2006, with permission from Elsevier.)
Indirect trauma includes the progressive perilunate instability patterns that are well described and may lead to fractures of the lunate, capitate, triquetrum, or other carpal bones.

Scaphocapitate syndrome involves a dorsiflexion and radial deviation mechanism by which the scaphoid bone fractures and is followed by a fracture of the capitate through the neck in the coronal plane. The capitate head may rotate up to 180 degrees from its anatomic position.

A progressive perilunate instability pattern can produce a similar coronal fracture through the capitate neck but normally without such a severe degree of capitate head rotation.

More minor indirect trauma mechanisms can cause isolated carpal bone fractures.

The commonly seen avulsion fractures from the dorsum of the triquetrum may occur when a fall onto the palmar-flexed wrist causes the dorsal radiotriquetral (also known as dorsal radiocarpal) ligament to avulse a portion of the dorsal cortex.

An impaction type of fracture of the triquetrum may be seen more often in patients with an elongated ulnar styloid.

**NATURAL HISTORY**

The natural history of carpal bone fractures depends both on the specific bone in question as well as associated impairment of other structures.

All of the carpal bones have at least three articular surfaces, except the pisiform, which articulates only with the triquetrum. Anatomic reduction of articular facets is a primary surgical goal in an effort to decrease the incidence and severity of post-traumatic arthritis.

Avascular necrosis can have a profoundly negative impact on final outcome after carpal bone fracture.

Concerns of vascular disruption arise when lunate and capitate fractures occur, although generally fractures of the lunate are not associated with avascularity.

The potential for nonunion is most often seen with hamate hook fractures, capitate neck fractures, and trapezial ridge fractures, especially Palmer type II fractures that involve the tip and not the base of the ridge.

Barring nonunion, the related instabilities and involvement of other hand components are the most troublesome and will most significantly affect patient outcome.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

Ascertaining the mechanism of injury is the most important component of the patient history.

Neurovascular symptoms should be explored, especially when a severe crush or high-energy mechanism is involved, or in cases of hamate hook or pisiform fractures, with special attention to the ulnar neurovascular structures within the canal of Guyon.

A complete evaluation of the median, radial, ulnar, and digital nerves is warranted. Assessment of capillary refill, color, temperature, and Doppler signal determines the vascular status.

The examiner should observe the patient’s hand and wrist for swelling, deformity, and skin and soft tissue injuries, including possible open fractures or fracture-dislocations.

Swelling and soft tissue damage give an indication as to the severity of the injury. The presence of deformity alerts the examiner to possible carpal dislocations that require emergent reduction. Open fractures and fracture-dislocations will guide surgical management.

The examiner should ask the patient where the pain is most significant. The examination should start away from and progress toward this point. The hand, forearm, and elbow should also be palpated to assess for possible associated injuries.

The most obvious area of pain and tenderness is usually the most structurally significant. However, it may mask other more subtle injuries that should be detected by a more thorough global examination.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Routine AP, lateral, and oblique views of the wrist and hand are obtained (FIG 3A).
- Radiographs of the elbow and forearm are ordered if indicated.
- Fluoroscopic images, including dynamic stress and distraction views, help to rule out carpal instability.
- Special views, often best performed with fluoroscopy, help to profile difficult-to-see structures.
- The hook of the hamate is evaluated with the carpal tunnel view and supinated and oblique lateral view with the wrist in radial deviation and the thumb abducted, as if the patient was holding a cup (referred to as the papillon view) (FIG 3B).
- The trapezial ridge is visualized on the carpal tunnel view (FIG 3C).
- The pisotriquetral joint is best seen on a 45-degree supinated lateral view of the wrist.
- CT scans effectively assess osseous detail and will often detect more subtle associated carpal fractures that may be missed on routine radiographs.
- CT is considered the imaging modality of choice for confirming a hamate hook fracture if plain films are nondiagnostic.

**NONOPERATIVE MANAGEMENT**

Isolated carpal bone fractures without associated carpal instability, significant displacement, or intra-articular stepoff may be managed nonoperatively.

- This usually includes use of a cast or brace for several weeks (usually 4 to 6 weeks) until symptoms have improved, tenderness is resolving, and radiographs are stable.
- Short-arm thumb spica casts or splints have been recommended for isolated trapezium and capitate fractures. The digits should be left free.
- A specific fracture of note is the hamate hook.

- These fractures can be treated with cast immobilization if nondisplaced and acute (less than 1 month).
- There is a relatively high rate of symptomatic nonunion, and surgical intervention may eventually be necessary.
- Similar to the treatment of the hamate hook, trapezial ridge fractures may be initially immobilized and later excised if symptomatic nonunion develops.

**SURGICAL MANAGEMENT Indications**

- Indications for surgical management of these fractures include those that significantly involve an articular surface or are structurally destabilizing to the remainder of the carpus, such as a displaced or unstable capitate body fracture.
- Other operative indications include those that are true for most fractures, such as open injuries and those requiring nerve, vessel, tendon, ligament, or soft tissue repair.
If stable and near-anatomic reduction of carpal fractures is not possible, primary limited arthrodesis or carpectomy may be indicated.

Because of the unique nature of each carpal bone, more specific indications will be considered for each fracture.

Late reconstructive options include partial or total wrist arthrodesis or proximal row carpectomy for symptomatic arthritic changes.

Trapezial excision with thumb metacarpal suspension-plasty may be used for posttraumatic arthritis after trapezial body fractures.

Total or hemi-wrist arthroplasty for select cases may become a more popular option as techniques improve.

**Lunate Fractures**

In general, fractures that are of sufficient size and displacement should be reduced and internally fixed.

Fractures that involve the palmar surface of the lunate where stout volar extrinsic wrist ligaments (long and short radiolunate) and vascular conduits (radioscapholunate ligament of Testut) attach should be stabilized.

If the capitate is subluxated volarly relative to the lunate and radius, such as when there is a lunate palmar lip fracture, this must be corrected with reduction and fixation of the lunate palmar fragment.

These fractures are routinely approached palmarly as described in Techniques.

Alternatively, a standard 3–4 interval dorsal exposure (described under capitate fractures) can be used if the fracture pattern dictates a dorsal approach and fixation.

**Triquetral Fractures**

In general, displaced fractures of the triquetral body that are of sufficient size are best treated by open reduction and internal fixation (ORIF).

This can be accomplished through use of pins or screws into the triquetrum alone or in combination with pinning to the lunate or to the hamate as dictated by the fracture.

The triquetrum may be removed in its entirety if it is not amenable to repair.

An apparently isolated fracture of the triquetrum may in fact be part of a reverse perilunate instability pattern (in which the portal of energy entry is at the ulnar wrist) and may be associated with other fractures and ligament disruptions.

**Pisiform Fractures**

The pisiform, similar to another sesamoid bone, the patella, most often fractures in a transverse pattern via an indirect avulsion mechanism through the flexor carpi ulnaris (FCU) or in a pattern of comminution from a direct blow.

Virtually all pisiform fractures are treated nonoperatively initially and then excised late if immobilization of the fracture fails to relieve symptoms after 2 or 3 months.

Fractures that are of sufficient size and displacement can be reduced and internally fixed, although this is rarely indicated.

The approach described in Techniques can be used for fixation or excision of the pisiform.

The pisiform is the last carpal bone to ossify, usually by age 12, and may have a nonpathologic fragmented appearance before complete ossification.

**Hook of Hamate Fractures**

Like pisiform fractures, most acute hamate fractures are treated nonoperatively initially. If the fracture remains persistently symptomatic or nonunited, excision is indicated, even for base fractures (FIG 4A).

ORIF is associated with relatively high complication rates and provides little or no advantage over simple fragment excision.

If ORIF is desired, the hamulus is exposed as described in Techniques and standard internal screw fixation principles are used.

**Hamate Body Fractures**

Fractures of the hamate body are often associated with fourth or fifth CMC dislocations (FIG 4B,C). ORIF is recommended to reduce the articular surfaces and stabilize the CMC joints.

These injuries most often result from a dorsal shear mechanism with fracture of the hamate body in the frontal plane. The metacarpals displace dorsally and proximally with the dorsal hamate fracture fragment.
Capitate Fractures
- Capitate fractures are by and large associated with significant trauma to the wrist.
  - In addition to fractures associated with progressive perilunate instability patterns and the scaphocapitate syndrome, capitate fractures may also occur due to axial loading along the middle finger ray or via direct trauma.
  - If caused by axially directed forces, the fracture line is often in the frontal plane, similar to the hamate dorsal shear fractures described earlier. The capitate may be essentially divided in half in this frontal plane.
  - In these cases, ORIF is performed through a dorsal approach.
  - Truly isolated capitate fractures with minimal displacement heal by immobilization, but this often takes time.

Trapezoid Fractures
- The trapezoid is believed to be the least frequently fractured carpal bone.
  - As with the other bones of the distal carpal row, assessment of the associated index CMC joint is necessary to rule out a fracture-dislocation.
  - Frontal plane dorsal shear fractures of the trapezoid can destabilize the index CMC.
  - These fractures and fracture-dislocations can often be treated by closed reduction and pinning.
  - If an open approach is required to reduce the articular surface and CMC joint, a standard 3–4 dorsal approach may be used. Fixation can be accomplished with pins or screws.
  - A limited exposure (as described below) is an alternative.

Trapezium Fractures
- Fractures of the body of the trapezium nearly always involve one of its four articular facets and frequently lead to subluxation of the thumb CMC joint (FIG 5).
  - If internal fixation is not possible, trapezial excision and palmar oblique ligament reconstruction, or an alternative procedure used for routine thumb CMC osteoarthritis, is performed.

Preoperative Planning
- Examination under anesthesia, possibly with concomitant fluoroscopic imaging, helps confirm whether carpal instability coexists.
  - The surgeon should ensure that all needed fixation implants and systems are available before bringing the patient to the operating room.
  - A hand table, a well-padded upper arm tourniquet, and a mobile mini-fluoroscopy unit are used.
  - Anesthesia and analgesia may be obtained through regional or general methods.

Approach
- Carpal fractures may be approached dorsally, palmarly, radially, or ulnarily depending on the reduction needs, implants used, and fracture location and characteristics.
  - Some surgeons use wrist or small joint arthroscopy as an aid to fracture reduction and management.
ORIF OF LUNATE FRACTURES

Incision and Dissection
- An extended carpal tunnel approach is used for palmar exposure.
- The incision begins in the palm, just ulnar to the thenar crease and in line with the radial border of the ring finger. If the surgeon is comfortable with the deep anatomy, especially the possible anatomic variations involving the thenar motor branch, the incision in the palm may also be along the thenar crease itself.
- It is extended proximally until the distal volar wrist crease is reached.
- A curved or zigzag continuation of the incision is made at the crease so as to avoid crossing perpendicular to the wrist crease, which might cause excessive scarring and a flexion contracture.
- The incision may be continued into the distal forearm, staying ulnar to the palmaris longus so as to avoid damage to the palmar cutaneous branch of the median nerve (TECH FIG 1A).
- It is deepened distally until the palmar fascia is encountered (TECH FIG 1B). This fascia is incised in line with the skin incision.

Reduction and Fixation
- The palmar lip fracture of the lunate is identified, cleaned, and anatomically reduced.
- The fracture may be fixed with small interfragment screws or buried Kirschner wires (TECH FIG 2).
- Screws are favored if at all possible to minimize chances of hardware migration into the carpal tunnel.

**TECH FIG 1** • Fixation of lunate palmar lip fractures. 
A. Carpal tunnel approach. The incision can be continued into the distal forearm, staying ulnar to the palmaris longus to avoid damage to the palmar cutaneous branch of the median nerve. 
B. Palmar fascia and antebrachial fascia exposed. 
C. Transverse carpal ligament released from hamate hook. 
D. Volar wrist capsule exposed.
Chapter 22  SURGICAL TREATMENT OF CARPAL BONE FRACTURES, EXCLUDING THE SCAPHOID 2289

Techniques

Fluoroscopic images are necessary to confirm that the volar carpal subluxation has been corrected with fixation of the lunate fracture.

The volar wrist capsule is repaired with permanent suture and the median nerve and digital flexors are allowed to return to their normal resting position.

The transverse carpal ligament may be repaired in a lengthened fashion or left divided (our preference).

Subcutaneous tissue and skin closure is performed according to the surgeon’s routine.

Access to the triquetrum is usually achieved through the standard dorsal approach to the wrist that is described for capitate fractures.

If there is truly isolated triquetral pathology, a more limited dorsal approach between the fifth and sixth extensor compartments is used.

This incision is centered distal to that which would be used for distal radioulnar joint (DRUJ) exposure.

The fifth compartment (extensor digiti minimi [EDM]) is retracted radially while the sixth compartment (extensor carpi ulnaris [ECU]) is retracted ulnarly.

The carpal capsule is incised longitudinally or obliquely depending on the fracture and the integrity of the dorsal radiotriquetral ligament.

The triquetral fracture may now be cleaned, reduced, and fixed with mini-screws or Kirschner wires as the fracture pattern prescribes.

Supplemental pinning to the lunate or hamate is performed as needed.

The capsule is closed with nonabsorbable suture, followed by routine subcutaneous tissue and skin closure.

ORIF OF TRIQUETRAL FRACTURES

The risk for hardware migration, penetration into the pisotriquetral joint, and other complications in the region of the ulnar neurovascular bundle must be weighed against the good results expected with simple excision.

The split FCU is closed with a nonabsorbable suture and the subcutaneous tissue and skin are sutured in routine fashion.

Hook of hamate excision

Once the level of the hook is reached distally, the ulnar neurovascular bundle is gently retracted ulnarly.

Soft tissue attachments to the tip of the hook are incised longitudinally, including the transverse carpal ligament radially and the pisohamate ligament ulnarly and proximally.

The deep motor branch of the ulnar nerve should be identified as it passes distally around the base of the hamate hook in an ulnar-to-radial direction and must be protected during excision (TECH FIG 3E).

At this point the pisiform can be excised or internally fixed with mini-fragment screws or Kirschner wires.

The risk for hardware migration, penetration into the pisotriquetral joint, and other complications in the region of the ulnar neurovascular bundle must be weighed against the good results expected with simple excision.

The split FCU is closed with a nonabsorbable suture and the subcutaneous tissue and skin are sutured in routine fashion.

Hook of hamate excision

The hook can be identified before incision by placing the interphalangeal joint of the surgeon’s thumb on the pisiform and flexing the thumb toward the first web space. The surgeon’s thumb tip will land directly on top of the hook.

The hamate hook can be approached through a volar incision (preferred) or directly ulnar, proceeding palmar to the small finger metacarpal and dorsal to the abductor digiti minimi.

A longitudinal or curvilinear skin incision is made, centered over the hook (TECH FIG 3A).

The ulnar nerve and artery are identified proximally first and then traced distally, ulnar and superficial to the hamate hook (TECH FIG 3B–D).

A curvilinear incision is made with special care not to cross the distal volar wrist crease perpendicularly. The incision is made centered on or just radial to the pisiform.

The ulnar neurovascular bundle is identified proximally and traced distally just past the pisiform body.

The pisohamate ligament is divided.

The flexor carpi ulnaris (FCU) tendon insertion, if intact, is divided longitudinally and subperiosteally elevated from the radial and ulnar margins of the pisiform.

At this point the pisiform can be excised or internally fixed with mini-fragment screws or Kirschner wires.

The risk for hardware migration, penetration into the pisotriquetral joint, and other complications in the region of the ulnar neurovascular bundle must be weighed against the good results expected with simple excision.

The split FCU is closed with a nonabsorbable suture and the subcutaneous tissue and skin are sutured in routine fashion.

Hook of hamate excision

Once the level of the hook is reached distally, the ulnar neurovascular bundle is gently retracted ulnarly.

Soft tissue attachments to the tip of the hook are incised longitudinally, including the transverse carpal ligament radially and the pisohamate ligament ulnarly and proximally.

The deep motor branch of the ulnar nerve should be identified as it passes distally around the base of the hamate hook in an ulnar-to-radial direction and must be protected during excision (TECH FIG 3E).

The digital flexors within the carpal canal are identified. The ring and small finger flexors, especially the profundus tendons, are inspected to ensure integrity and should be débrided or repaired as needed (TECH FIG 3F).

The tendons are then gently retracted radially.
TECH FIG 3 • Excision of hamate hook fractures. A. The cardinal line of Kaplan, drawn from the apex of the first web space to the ulnar border of the hand, intersects a second line drawn along the ulnar margin of the ring digit at the hamate hook (circle). A 3-cm incision is centered over the hamate hook, gently curving with the radial border of the hypothenar eminence. B. The ulnar nerve and artery can be found proximally first and then traced distally, ulnar and superficial to the hamate hook. C. The ulnar artery is encountered first, volar and radial to the ulnar nerve. D. With the artery retracted ulnarly, the common digital nerve to the fourth web space and the small digit ulnar sensory nerve are visualized. The deep motor branch and the hypothenar motor branch have already been given off. E. The hamate hook is subperiosteally exposed and its margins are palpated with an elevator. The deep motor branch curves radially, closely associated with the distal surface of the hook. F. Care is also taken to protect the flexor tendons during exposure and resection, seen here on the radial margin of the hook.
The hook is cleared of all soft tissue attachments down to the level of the fracture site.
- A no. 69 Beaver blade helps make this exposure precise.
- Using a rongeur or similar tool, the fractured hook is removed piecemeal, again with care to protect the deep ulnar motor branch and other structures.
- Once the fragment is removed, the remaining base is inspected and smoothed with a rongeur, curette, or similar tool until there are no sharp bony prominences.
- The surrounding periosteum is closed if possible.
- Subcutaneous tissue and skin closure is performed in a routine manner.

**HAMATE BODY FRACTURES**

- A dorsal longitudinal or curvilinear incision is made centered over the ring or small finger CMC joints (TECH FIG 4A).
- The ring and small finger extensor tendons are retracted radially or ulnarily together or individually as needed.
  - There can be significant variation in the anatomic appearance and interconnections of the extensor digitorum communis tendons to the ring and small fingers as well as the EDM (TECH FIG 4B). These variations usually dictate which direction to retract the tendons and whether to retract them together or individually to give the best access to the CMC joints.
- The CMC joint capsule and dorsal CMC ligaments are incised longitudinally. The CMC joint is cleared of any hematoma and bone fragments (TECH FIG 4C).
- The fracture site is cleared of hematoma and reduced while directly visualizing the distal articular surface.
  - A dental pick is useful to reduce small fragments.
  - The fracture is temporarily stabilized with Kirschner wires and fluoroscopic images are taken to confirm reduction (TECH FIG 4D,E).
- If there is a large dorsal fragment, two or more dorsal-to-volar lag screws (usually 2.0-mm screws or smaller) are placed perpendicular to the fracture line into the hamate body (TECH FIG 4F,G).
- If there are several small fragments, individual screws may be used for each piece, or a dorsal plate may be more effective (TECH FIG 4H).
  - Fluoroscopic images are necessary to confirm that the screws do not protrude outside of the hamate hook, potentially damaging ulnar neurovascular structures or flexor tendons.
  - The dorsal capsuloligamentous sleeve is closed if possible, thus providing a smooth gliding surface between the extensor tendons and the CMC joint and hardware.
  - The CMC joints may be pinned temporarily if still unstable.
  - In the acute setting, if the dorsal hamate fracture is of sufficient size and securely stabilized and the joint capsule is closed, this is usually not necessary.
  - Soft tissues and skin are closed in a routine manner.

**CAPITATE FRACTURES**

- Often a standard approach to the dorsal carpus is required and is carried out through the routine 3-4 extensor compartment interval.
- A dorsal midline longitudinal or curvilinear skin incision is made, in line with the middle finger ray and centered on the capitate.
- Full-thickness skin flaps are elevated radially and ulnarily.
- The extensor pollicis longus (EPL) is identified, released from its third extensor compartment, and transposed radially.
- The plane between the extensor tendons and the wrist capsule is developed by elevating the second and fourth compartments radially and ulnarily, respectively.
- The joint capsule and dorsal intercarpal ligament are usually divided longitudinally for access to the capitate body.
  - Alternatively, the capsule can be opened longitudinally distal to the dorsal intercarpal ligament (TECH FIG 5).
  - The capsule can be incised transversely distal to the ligament and in line with its fibers, provided that exposure of the capitate is adequate for reduction and fixation of the fracture.
- The fracture site is explored, cleaned as necessary, and stabilized with mini-screws, plates, or pins as indicated.
- The EPL tendon is left transposed, superficial to the extensor retinaculum.
- The retinaculum is closed over the second and fourth compartments, followed by routine closure of subcutaneous tissue and skin.

**TECH FIG 4 • (continued)** E. Temporary Kirschner wire. F,G. Screw fixation. H. Plate fixation.

**TECH FIG 5 • Dorsal intercarpal ligament anatomy.**
TRAPEZIOD FRACTURES

- The trapezoid is approached through a limited dorsal longitudinal or curvilinear incision centered over the index CMC.
- Care must be exercised to identify and protect dorsal radial sensory nerve branches.
- The EPL tendon is identified, released, and transposed radially if needed.
- In the case of limited exposure of the trapezoid, simple retraction of the EPL distal to the extensor retinaculum is effective.

A longitudinal interval is developed between the extensor carpi radialis longus (ECRL) and brevis (ECRB) tendons with radial and ulnar retraction, respectively.
- It is important to stay ulnar to the ECRL to avoid inadvertent damage to the dorsal branch of the radial artery.
- The capsule is divided longitudinally, exposing the trapezoid and the index CMC joint.
- Fracture fixation is carried out with mini-screws or pins, the capsule is closed, and routine subcutaneous tissue and skin closure is performed.

TRAPEZIUM FRACTURES

- Fractures of sufficient size and significant displacement are internally fixed (TECH FIG 6).
- Excision rather than internal fixation may be warranted based on preoperative and intraoperative considerations.
- Unless the fracture planes dictate a specific approach for fixation, the surgeon has the option of using whichever approach he or she is most comfortable with for routine surgical treatment of thumb CMC arthritis (see Chap. HA-102).
- The Wagner approach (described below) is one such approach frequently used for surgical reconstruction of thumb CMC arthritis and is an effective exposure for internal fixation of body fractures.
- Isolated trapezial ridge fractures and nonunions are best approached using the flexor carpi radialis (FCR) approach centered on the scaphotrapezial joint, with retraction of the FCR ulnarly or radially out of its trapezial groove to gain access to the ridge. The Wagner approach is also effective.
- For the Wagner approach, an incision is made along the radial border of the thumb metacarpal at the glabrous skin border.
- At the distal volar wrist crease, the incision is continued ulnarily to the level of the FCR tendon.
- Superficial radial sensory nerve and lateral antebrachial cutaneous nerve branches may be encountered and should be carefully preserved.
- The thenar musculature is elevated in a radial-to-ulnar direction off the thumb metacarpal base.
- Once the FCR tendon sheath is reached, it is incised longitudinally and the tendon is retracted ulnarily if necessary.
- The capsule overlying the trapeziometacarpal and scaphotrapezial joints is opened and the joints are visualized.
- The entire length of the trapezium may be exposed if needed, but it is critical to avoid subperiosteal dissection where not necessary for accurate fracture reduction.
- Extensive exposure may result in delayed union or nonunion.
- At this point, internal fixation is performed if technically feasible, usually using lag screw fixation.
- The capsule is carefully reapproximated and the subcutaneous tissues and skin are closed.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Carpal instability</th>
<th>Be aware of the carpal instability patterns that can accompany these fractures and treat accordingly.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Failure to recognize an associated carpal instability pattern can lead to progressive carpal collapse and degeneration.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fracture identification</th>
<th>Preoperative imaging is critical so that all fractures that require stabilization are identified; consider CT scanning if plain radiographs are insufficient.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Failing to identify all unstable fractures before or during surgery can necessitate a return to the operating room.</td>
</tr>
</tbody>
</table>
We recommend hamate hook excision as opposed to fixation due to the minimal, if any, added benefit with fixation and the concern for significant nerve and tendon injuries with internal fixation.

<table>
<thead>
<tr>
<th>Screw size</th>
<th>Use small interfragmentary screws or even small plates for fracture fixation whenever possible to decrease chances for hardware migration and to increase stability and possibly allow earlier range of motion.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excision versus fixation</td>
<td>We recommend hamate hook excision as opposed to fixation due to the minimal, if any, added benefit with fixation and the concern for significant nerve and tendon injuries with internal fixation.</td>
</tr>
<tr>
<td>Future surgery</td>
<td>Be sure the patient is aware of the possible need for further surgery in the future, such as for hamate hook excision, addressing capitate avascular necrosis, excisional arthroplasty or arthrodesis for post-traumatic articular degeneration of any joints involved with the initial trauma, and so forth.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- Patients are placed in a well-padded volar plaster wrist splint postoperatively.
  - The digits, including the metacarpophalangeal (MCP) joints, are left free unless there is some contraindication, like a dorsal hamate fracture with CMC dislocation, which may require inclusion of MCP joints.
  - This allows early digital range of motion and elevation.
  - Following ORIF of a trapezial fracture, a short-arm thumb spica splint is applied.
  - Two weeks postoperatively the patient is placed in a custom fabricated splint (assuming there is no associated carpal instability).
  - If pins were used and are left outside of the skin, pin care is initiated at this time. Pins are usually removed 4 to 8 weeks postoperatively.
  - In the case of a CMC joint fracture in which relatively large fracture fragments are anatomically stabilized with rigid internal fixation, near-immediate postoperative range of motion is initiated.
  - For most other fractures, a total of about 6 weeks of wrist immobilization is followed by progressive range of motion.

**OUTCOMES**

- Most isolated carpal bone body fractures unite, and it is generally thought that these patients do quite well with regard to symptomatic and functional recovery.
  - The potentially symptomatic exceptions involving the hamate hook and trapezial ridge are easily treated by excision. Posttraumatic symptoms from other fractures, such as of the pisiform, trapezium, or triquetrum, may usually be addressed with isolated carpal bone excision with or without reconstruction, depending on the bone in question and other soft tissue and ligamentous considerations. For those carpal bones that cannot typically be simply excised, such as the hamate body and capitate, symptomatic posttraumatic changes may require partial or total wrist arthrodesis or other reconstructive options.
  - Associated injuries are often the most problematic, and patients must understand the guarded prognosis for severe destabilizing carpal injuries.

**COMPLICATIONS**

- Those complications common to all surgical procedures may occur, including but not limited to bleeding, infection, damage to structures, failure of surgery, potential need for more surgery, and untoward effects of anesthesia.
  - Patients must also understand the relative severity of their injuries and risk for pain, stiffness, and loss of function.
  - Capitate neck fractures are sometimes associated with nonunion or delayed union (up to 50% or more of isolated fractures) and may be analogous to scaphoid proximal pole fractures.
  - Treatment of such nonunions is similar for both entities.
  - Although rare, avascular necrosis of the capitate head may follow a capitate neck fracture that disrupts the vascular supply.
  - The capitate head may be excised with or without interpositional arthroplasty if attaining union is not likely because of avascularity or other issues.
  - Intra-articular fractures of the carpal bones are often complicated by posttraumatic arthritis. When symptomatic, treatment with traditional arthritis remedies, such as activity modification, anti-inflammatory medications, immobilization, or steroid injection, can be tried. If these fail to relieve the patient’s symptoms to his or her satisfaction, the patient may elect to proceed with partial or total wrist arthrodesis, partial carpectomy, whether of the proximal row or otherwise, or selective arthroplasties as indicated.

**REFERENCES**

DEFINITION
- Kienböck disease is a disorder of undetermined etiology that results in avascular necrosis (AVN) of the lunate.\(^5\)

ANATOMY
Lunate Vascularity
- The extraosseous blood supply of the lunate is extensive: branches of the radial and anterior interosseous arteries form a dorsal lunate plexus and branches of the radial, ulnar, and anterior interosseous arteries as well as the recurrent deep palmar arch form a volar plexus.
- The intraosseous blood supply is variable. Because the lunate is covered by cartilage proximally and distally, vessels can enter the bone only at its dorsal and volar poles.\(^1,13\)
- Three studies have identified “lunates at risk” from a vascular standpoint. The vulnerable lunate is one that has large areas of bone dependent on a single intraosseous vessel, which occurs in 7% to 20%. In addition, 31% of lunates have no internal arterial branching.\(^6,7,16\) These internal vascular arrangements may render the lunate more vulnerable to AVN, as injury to the single vessel could not be compensated for by collateral flow.

Ulnar Variance
- The standard posteroanterior (PA) wrist radiograph is taken with the shoulder and elbow at 90 degrees and the forearm in neutral rotation.
- In this view, the length of the distal ulna with respect to the distal radius is called ulnar variance (FIG 1).
- When the ulna is the same length as the radius, it is said to have neutral ulnar variance. When the ulna is shorter than the radius, it is referred to as negative ulnar variance, and when the ulna is longer than the radius it is referred to as positive ulnar variance.
- Theoretically, a negative ulna variance increases shear forces on the lunate.
  - The triangular fibrocartilage complex (TFCC) is thicker in these patients and the difference in compliance between it and the ulnar edge of the radius is accentuated, leading to greater shear force.
  - In addition, loads across the radiocarpal joint are borne disproportionately by the radius.\(^5\)
  - In the North American population, Kienböck disease is associated with an ulnar negative variance.
  - This relationship does not hold true in the Japanese literature.\(^1\)
  - Other authors have noted a tendency toward smaller lunates in patients with Kienböck disease.\(^3\)

PATHOGENESIS
- The cause of Kienböck disease is incompletely understood. Current thinking is that acute or repetitive trauma causes excessive shear forces on a lunate at risk, interrupting its intraosseous vascularity and leading to AVN.\(^1,2\)
- While a history of injury is elicited in over 50% of cases, the absence of a single traumatic event is still very common.
- Fracture of the lunate has been reported in up to 82% of lunates with Kienböck disease.\(^3\) However, it remains unclear whether these fractures are the cause or the result of AVN.
- Kienböck disease is not seen after lunate or perilunate dislocations.\(^5,13\)
- Although transient ischemia may be seen after carpal fracture-dislocations, this spontaneously resolves after 5 to 32 months and should be treated expectantly.\(^1,2\)
- The key feature of transient ischemia is that no progressive radiographic collapse occurs, as opposed to Kienböck disease, where radiographic changes and collapse are predictable.
- It has been suggested that Kienböck disease may be due to venous outflow obstruction with intraosseous vascular congestion, rather than arterial insufficiency. Increased intraosseous pressure has been shown in lunates with Kienböck disease, as well as in femoral heads with AVN.
The most common complaints are dorsal central wrist pain, rarely bilateral.3,21

The male–female ratio is approximately 3:1 to 7:1. It is patients between 20 to 40 years of age.

Most patients with Kienböck disease are young, active patients between 20 to 40 years of age.

This has led to significant concerns about the long-term effects of this disorder.

The male–female ratio is approximately 3:1 to 7:1. It is rarely bilateral.3,21

Regardless of gender, more than 95% of patients are engaged in heavy manual labor.21

The most common complaints are dorsal central wrist pain, stiffness, and significant weakness of grip, which is often reduced to 50% of the opposite hand.1,5,13

There may be a long history of symptoms before presentation.

The pain may vary in intensity from mild discomfort to constant, debilitating pain. It is often activity-related and improves with rest and immobilization.

A history of trauma is variable.1,5

The wrist is typically mildly swollen dorsally, consistent with synovitis, and is tender over the lunate.

Flexion and extension are predictably diminished.

Wrist flexion is more likely to be limited than extension because the volar pole of the lunate often extrudes so that it impinges against the volar rim of the distal radius.

Forearm rotation is not affected.13

While Kienböck disease has been reported in association with steroid use, septic emboli, sickle cell disease, gout, carpal coalition, and cerebral palsy, there is no well-defined correlation with any systemic or neuromuscular process that warrants screening when considering the diagnosis.3

IMAGING AND OTHER DIAGNOSTIC STUDIES

Radiographic Classification

Kienböck disease is diagnosed radiographically,12 and staging is based on plain radiographs.

In 1977, Lichtman and Degnan12 modified Stahle’s original radiographic classification in an attempt to help guide treatment decisions (FIG 2).

Stage I

Radiographs are normal, although a linear fracture without sclerosis or lunate collapse is occasionally present.

MRI shows the characteristic changes of AVN (FIG 3A).5,21

Stage II

The lunate becomes sclerotic and radiodense, similar to the radiologic appearance of other bones with AVN (FIG 3B). A coronal fracture splitting the lunate into dorsal and volar fragments may be noted.

Late in stage II, some loss of lunate height on the radial side may be evident.

The lunate retains its overall shape, and its anatomic relationship to the other carpal bones is not significantly altered.12,21

Stage III

The lunate collapses in the coronal plane and elongates in the sagittal plane. The carpal architecture is altered and the capitate begins to migrate proximally.

Stage IIIA

Lunate collapse has occurred, but carpal height is relatively unchanged and carpal collapse has not yet led to proximal migration of the capitate or scaphoid flexion. Therefore, the carpal kinematics have not yet been significantly altered.12,21

Stage IIIB

The carpal collapse with proximal capitate migration has led to fixed scaphoid flexion, which may be noted on the AP radiograph as the “cortical ring sign.”3,12,21

Stage IV

Arthritis of the radiocarpal or midcarpal joint has resulted from the collapse, fractures, and altered carpal kinematics, leading to joint space narrowing, osteophyte formation, subchondral sclerosis, and degenerative cysts.3,21

MRI and CT

MRI is extremely sensitive in detecting changes in marrow fat that are consistent with, but not diagnostic of, AVN.

Decreased signal on T1 sequences represents replacement of the normal fatty marrow by dead bone or fibrous tissue.21
Because MRI detects only the loss of marrow fat and not AVN specifically, to consider an MRI diagnostic for Kienböck disease over 50% of the lunate should be hypointense on T1 because the changes of Kienböck disease are diffuse, as opposed to other conditions such as ulnocarpal impaction, fractures, and intraosseous tumors, which cause more focal MRI changes.\(^4,20,22\)

- It is possible that a large enchondroma, interosseous ganglion, or other marrow-replacing lesion could lead to MRI changes in over 50% of the lunate. Thus, there is currently no truly pathognomonic imaging sign for Kienböck disease.\(^4\)

- T2 images typically show low signal intensity, which represents replacement of the normal fatty marrow by fibrosis.\(^21\)
- An increased T2 signal may occur if intramedullary edema is present or if revascularization is occurring.\(^3,4,20\)

Thus, when the T2 images show normal or increased signal intensity, an earlier stage of disease with a better prognosis can be inferred.\(^20,21\)

- Although it cannot diagnose AVN directly, MRI is still the optimal imaging modality and gold standard for diagnosing Kienböck disease, especially before trabecular bone has been destroyed.
- Gadolinium-enhanced MRI may provide a more sensitive means of evaluating lunate vascularity.
- CT may upstage the disease compared with radiographs in 89% of those originally considered to have stage I, 71% with apparent stage II, and 9% with apparent stage III disease on radiographs.\(^3\)
- Once lunate collapse has occurred, CT best reveals the extent of necrosis and trabecular destruction.\(^3\)
Differential Diagnosis

- Unnocarpal impaction
- Rheumatoid arthritis
- Radial-sided triangular fibrocartilage tears
- Posttraumatic arthritis
- Acute fracture
- Carpal instability
- Lunate fracture
- Enchondroma
- Osteoid osteoma
- Bone island
- Occult or intraosseous ganglion
- Intraosseous cyst
- Transient ischemia
- “Bone bruise”
- Paget disease
- Gaucher disease

Nonoperative Management

- A trial of 2 weeks to 3 months of immobilization may be attempted for patients with stage I Kienböck disease, especially young patients with hyperintense lunates on T2 MR images.
- The theory behind the use of immobilization is that by decreasing the forces across the carpus, the lunate may be able to revascularize.12
- Most series report poor results with immobilization, and progressive collapse is common.
- There is no study of immobilization consisting of patients with only stage I Kienböck disease. Consequently, the efficacy of immobilization in patients with stage I disease is anecdotal.
- Immobilization does not decrease compressive forces across the lunate, which are imparted by the capitae. The capitae may still force any fracture fragments apart, leading to collapse and displacement.
- Immobilization leads to stiffness.
- The earlier the lunate is unloaded, the less collapse is anticipated. For this reason, early surgical decompression may be considered rather than immobilization, and many clinicians treat stage I disease surgically.13
- In Trumble and Irving’s series of 22 patients with various stages of Kienböck disease treated with immobilization, 17 showed disease progression with continued collapse of the lunate and 5 showed no improvement.22
- In Lichtman et al’s series, 19 of 22 had unsatisfactory results.2,3
- When immobilization fails to reverse the avascular changes, the process will almost always advance to stage II, where surgical management is strongly recommended.2,3
- In a series of patients with stage II or more advanced disease treated with immobilization, 76% (19/25) had either undergone total wrist arthrodesis or experienced daily problems with their wrists at mean 8 (1–11) year follow-up.15
- A study of 18 patients with stage II or III disease treated nonoperatively were compared with those treated by radius shortening.
- Patients treated surgically had less pain and better grip strength.
- In some patients with stage III disease treated nonoperatively there was rapid deterioration to carpal collapse.
- Although radius shortening did not reverse or prevent carpal collapse, it slowed the process.18

Surgical Management

- There is no agreement on the optimal way to treat Kienböck disease.5 Multiple options for surgical management exist and the results do not vary significantly between the different procedures.
- The mainstays of treatment are radius-shortening osteotomy and proximal row carpectomy.5
- Two major radiographic features influence treatment choice: the stage of the disease and ulnar variance.12
- Radius-shortening osteotomy is currently the benchmark against which other treatments are judged.13
- For stages I to IIIB, radius-shortening osteotomy is a very popular option in patients who are ulnar negative. While the use of radius shortening in stage IIB is controversial, because lunate height and normal carpal kinematics will not be re-established, potentially leading to progressive degenerative changes, very good results have been demonstrated in these patients with this procedure.2,24,25 Radius shortening is contraindicated for stage IV disease unless symptoms are severe and salvage procedures are not desired.24
- Radius shortening decreases joint compression forces at the radiolunate joint by redistributing them to the radiocapitate and ulnolunate joints. In addition, it relatively lengthens the tendons crossing the wrist, diminishing overall joint compressive forces.17
- As opposed to ulnar lengthening, no intercalary bone graft is required and only one interface needs to heal, instead of two.
- In addition, radial shortening leads to a relative lengthening of the musculotenonidus units crossing the wrist, resulting in less force transmission across the carpus. Ulnar lengthening does not provide this particular advantage.24
- After radial shortening, the ulnar head and TFCC support more of the wrist’s compressive load through the triquetrum and the ulnar aspect of the lunate. The TFCC is thicker in patients with ulna-minus variance, which provides a compliant pad to support the ulnar carpus.
- Because radial-shortening osteotomy is an extra-articular procedure, it does not alter normal carpal joints or interfere with intracarpal relationships. It “burns no bridges,” and intracarpal procedures can always be undertaken at a later date if the radial shortening is ineffective and disease progression occurs.24
- In patients who are ulnar-neutral or ulnar-positive, a radial closing wedge osteotomy (FIG 4) or capitae shortening with or without capitohamate fusion can be performed.
- While radius shortening in patients with neutral or positive ulnar variance is not advised, good results have been reported even in these patients.1,24
- For stages I to IIIA, revascularization using a vascularized pedicle or bone graft may be performed and may be combined with radius shortening or another unloading procedure (see Chap. HA-24).
- In patients with stage IIIB disease, proximal row carpectomy, scaphotrapeziotrapezoid fusion, or scaphocapitate fusion may be performed with or without lunate excision and soft tissue interposition.
- For stage IV disease, proximal row carpectomy or total wrist fusion may be indicated. A study of arthroscopic débridement for stage III or IV disease showed some pain relief at 19 months of follow-up.14
Based on the hypothesis that Kienböck disease is due to venous obstruction, “metaphyseal core decompression” of the distal radius has also been reported with good results.8

- Wrist denervation may also be considered and can be used as an adjunct at any stage.3

- Lateral closing wedge osteotomies increase lunate coverage (joint contact area) in proportion to the decrease in radial inclination.
  - This transfers the compressive forces of the capitate from the lunate to the scaphoid, decreasing pressure at the radiolunate joint.17,23
  - To keep the wrist straight in relation to the forearm, the patient is forced to ulnarily deviate the wrist, extending the scaphoid, which may further transfer forces from the capitate to the scaphoid and decrease forces on the lunate.19

Preoperative Planning

- Good-quality, standard preoperative PA radiographs should be taken with the shoulder and elbow flexed 90 degrees and the forearm in neutral rotation.
- While many authors have recommended removing sufficient bone during radial shortening to result in an ulnar-neutral to 1-mm-positive variance,3 90% of the strain reduction occurs within the first 2 mm of shortening.1,5

Positioning

- The patient is positioned supine with the arm on a radiolucent armboard.

Approach

- A volar approach to the radius is performed.

**VOLAR APPROACH**

- A longitudinal incision is made over the flexor carpi radialis (FCR) tendon, ending distally at the distal volar wrist crease (TECH FIG 1A).
- The approach is continued through the FCR sheath (TECH FIG 1B), with the FCR tendon retracted ulnarly to protect the palmar cutaneous branch of the median nerve (TECH FIG 1C).
- The plane between the FCR and deep muscles of the radius (pronator quadratus and FCR) is bluntly dissected (TECH FIG 1D).
- The distal border of the pronator quadratus and the radial insertions of the pronator quadratus and flexor pollicis longus muscles are incised with Bovie electrocautery, with care taken to retract and protect the radial artery, which does not need to be formally identified.
- The volar surface of the radius is then subperiosteally exposed in a radial to ulnar direction (TECH FIG 1E).
- Circumferential subperiosteal dissection should be avoided to preserve maximal blood supply to the osteotomy.
Part 6  HAND, WRIST, AND FOREARM  •  Section III  CARPAL FRACTURES AND AVASCULAR NECROSIS

**RADIUS-SHORTENING OSTEOTOMY**

**Initial Plate Application**
- Traditionally, a seven-hole 3.5-mm dynamic compression plate is placed as far distally as possible without riding up the volar lip of the distal radius.\(^2\)
- However, the newer fixed-angle volar plates used for fixation of distal radius fractures work very well and allow the osteotomy to be placed in metaphyseal bone.
- To decrease the risk of nonunion, the osteotomy should be performed as distal as possible to be through metaphyseal cancellous bone, staying proximal to the DRUJ.
- The plate is placed over the distal radius so that its distal fixation will be within 2 to 3 mm of the subchondral bone, without intra-articular penetration. The plate is provisionally fixed with Kirschner wires (TECH FIG 2).
- Following fluoroscopic confirmation of appropriate placement, four fixed-angle screws are placed distally.

**Radius Osteotomy**
- The osteotomy is marked proximal to the distal fixation and proximal to the DRUJ (TECH FIG 3A).
- The plate is removed and the osteotomy is made at a 45-degree angle, from distal volar to proximal dorsal (TECH FIG 3B).
- An oblique osteotomy has less potential for nonunion than a transverse osteotomy\(^1\) and allows placement of an interfragmentary compression screw for additional fixation.

---

**TECH FIG 1** • A. Incision. B. Dissection proceeds through the flexor carpi radialis (FCR) sheath. C. The FCR is retracted ulnarly to protect the palmar cutaneous branch of the median nerve. D. The pronator quadratus is exposed. E. The volar distal radius is subperiosteally exposed.

**TECH FIG 2** • A, B. The volar locking plate is placed so that its distal fixation (represented radiographically by a Kirschner wire) travels just proximal to the subchondral surface. Distal locking screw fixation is placed but not fully tightened.
The 2 to 3 mm to be taken is measured out and marked and the full amount of bone to be taken is removed from volar to dorsal so that the dorsal cortex remains intact to stabilize the bone during bone removal (TECH FIG 3C).

The dorsal cortex is then removed last (TECH FIG 3D).

During the osteotomy, constant cool irrigant is used to avoid thermal osteonecrosis.

While a slight (1 mm) concave bend in the plate over the osteotomy site may occasionally be needed to achieve compression of the dorsal osteotomy surface, this is not usually necessary.

A longitudinal line may be marked across the osteotomy site to allow rotational assessment. However, the flat surface of the volar cortex allows for easy assessment of rotation.

An elevator can be placed on the dorsal surface of the osteotomy to protect the extensor tendons from the saw.

Two to 3 mm of shortening may be appropriate regardless of the amount of negative ulnar variance present.

For the reasons noted above, I prefer to shorten the radius by only 2 to 3 mm.

Excellent results have been reported with osteotomies that do not fully correct the radius length to neutral variance.²⁴,²⁵

The 2 to 3 mm to be taken is measured out and marked and the full amount of bone to be taken is removed from volar to dorsal so that the dorsal cortex remains intact to stabilize the bone during bone removal (TECH FIG 3C).

The dorsal cortex is then removed last (TECH FIG 3D).

Final Plate Application and Osteotomy Fixation

The plate and its distal fixation are then replaced.

Approximation of the two bone ends may also be facilitated by radial deviation of the wrist²⁴ and use of a Verbrugge clamp.

A bicortical screw is placed 1 cm proximal to (not through) the plate (TECH FIG 4A).
The hooked end of the Verbrugge is placed in the plate’s most proximal screw hole and the bifid end is placed around the screw proximal to the plate (TECH FIG 4B).

The Verbrugge clamp is closed manually, imparting tremendous mechanical advantage to compress the osteotomy.

The first screw is placed in a compression mode eccentrically in the plate hole just proximal to the osteotomy (TECH FIG 4C).

Reduction of the osteotomy and fixation are evaluated fluoroscopically.

Adjustments are made as necessary and the remaining screws are placed (TECH FIG 4D).

A lag screw is placed obliquely across the osteotomy through the most distal of the proximal plate holes for additional fixation (TECH FIG 4E–H).

After irrigation, osteoperiosteal shingling may be performed with allograft or bone substitute placed over the shingled cortex to facilitate healing (TECH FIG 4I).
Forearm rotation should be checked to ensure that it is full.
- If forearm rotation is limited after osteotomy, the radius should be translated radially or a lateral closing wedge component added.\textsuperscript{17}
- Radiographs often show some mild residual gap at the osteotomy site even with full compression under direct vision.\textsuperscript{24}

Intraoperative radiographs may not demonstrate the eventual ulnar variance (amount of radial shortening) because of soft tissue restraints at the DRUJ. In these cases, postoperative radiographs will demonstrate the anticipated correction.\textsuperscript{17}

**RADIUS CLOSING WEDGE OSTEOTOMY**

A 15-degree radial closing wedge osteotomy is performed 4 to 5 cm proximal to the tip of the radial styloid and proximal to the DRUJ.\textsuperscript{23}

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Radial shortening</th>
<th>Two to 3 mm of shortening is all that is needed in the vast majority of cases. Shortening the radius by only 2 to 3 mm makes compression of the osteotomy easier.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In cases of significant DRUJ obliquity, shortening the radius greater than 2 mm may lead to DRUJ problems.</td>
</tr>
<tr>
<td>Fragment handling</td>
<td>If rotation is not full or the DRUJ is compromised after osteotomy, radial translation of the distal fragment should be considered.</td>
</tr>
<tr>
<td>Verbrugge clamp</td>
<td>Use of a Verbrugge clamp compressing against a screw proximal to the plate gives the surgeon a tremendous mechanical advantage in shortening the osteotomy.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- The extra-articular nature of this procedure combined with stable internal fixation allows for quick postoperative rehabilitation.
- The wrist is splinted for 2 weeks, after which a removable splint may be used and gentle motion started.
- The osteotomy usually heals in 2 to 3 months, although 4 or 5 months is occasionally required.

**OUTCOMES**

A review of the reported series by Weiss\textsuperscript{24} in 1993 included 121 patients treated with radius shortening, with about 85% good or excellent results at just over 4 years of follow-up.

- One study reviewed 30 wrists after radial shortening osteotomy for stages I to IIIB Kienböck disease at mean 3.8 years of follow-up.\textsuperscript{25}
  - Pain decreased in 87% and grip strength improved in 49%. However, the radiographic appearance of the lunate changed little if at all.
  - The authors noted that good results could be obtained by shortening less than that required to attain neutral ulnar variance.
  - The exact amount of radius shortening may not be as important as the relative unloading of the lunate resulting from the shortening of the radius. The amount of shortening needed to be effective may be only about 2 mm. Radial shortening may therefore be used in ulnar-neutral wrists.
  - In addition, excellent results were realized in patients with stage IIIA and IIIB disease. There was one nonunion. Only 10 of 30 wrists had evidence of possible lunate revascularization, as indicated by decreased sclerosis and a more normal trabecular pattern.
- Clinical improvement after radius shortening or radial wedge osteotomy does not necessarily correlate with the radiographic results.\textsuperscript{1,5,19} It appears that the lunate “stands still in time” after radius shortening, with no significant further deterioration or improvement in the lunate architecture or height.\textsuperscript{24}
- Another study reviewed 68 radius-shortening osteotomies at a mean of 52 months of follow-up.\textsuperscript{17}
  - Pain was diminished in 93%, grip strength was improved in 74%, and motion was improved in 52% and worsened in 19%.
  - Twenty-five patients had undergone one or more additional procedures concurrently, which did not lead to a significant difference in clinical outcomes.
  - Complications were uncommon; there were no nonunions, but ulnocarpal impaction developed in two patients.
  - Lunate density was improved in 40%, unchanged in 46%, and increased (worsened) in 14%.
  - Fifty-five percent of wrists that underwent concurrent vascularized bone grafting of the lunate had an improved radiographic appearance, compared to only 20% that underwent isolated radius shortening.
- It has been suggested that prognosis is improved in younger patients due to increased remodeling potential.\textsuperscript{12}
  - Teenage patients (aged 11 to 19 years) were treated by radius shortening or lateral closing wedge osteotomy.\textsuperscript{9} Two had neutral or positive ulnar variance. At a mean 30 months of follow-up, 10 of 11 were pain-free. Five of six with stage IIIB disease had excellent outcomes.
The other patient had moderate wrist pain during strenuous activity, leading to only a fair result after lateral closing wedge osteotomy for stage IIIB disease.

Radiographic improvement, indicating possible lunate revascularization, was seen in 8 of 11 patients.

There were no complications of radial overgrowth or growth abnormalities in these patients.

Twenty-five patients were followed for a minimum of 10 years (mean 14.5 years) after radial osteotomy. 23

Nonunion has been reported in up to 6% of cases. 5

COMPLICATIONS

Nonunion has been reported in up to 6% of cases. 5

If the fixation remains stable, treatment should consist of autogenous cancellous bone grafting if healing has not occurred by 5 or 6 months.

A second operation may occasionally be necessary for plate removal, but this is uncommon.

Care must be taken not to overshorten the radius, or DRUJ incongruity or ulnocarpal impaction may occur. 24

REFERENCES


DEFINITION
- Lunate revascularization for Kienböck disease involves transfer of either a vessel or a pedicled bone graft to the lunate in an attempt to reverse avascular necrosis.
- Vascularized bone grafts from the pisiform, volar and dorsal radius metaphysis, second metacarpal head, and iliac crest (via free microvascular graft) have all been reported.
- Unloading procedures, like a capitate shortening osteotomy, are often combined with a revascularization procedure to protect the graft and to alter forces through the lunate.

ANATOMY
Vascular Anatomy of the Dorsal Distal Radius
- The dorsal distal radius is primarily supplied by the branches of the radial artery and the posterior division of the anterior interosseous artery (pAIA) (Fig 1).
- The 2, 3 intercompartmental, supraretinacular artery (2, 3 ICSRA) is superficial to the extensor retinaculum and passes between the second and third extensor compartments (Fig 1).
- The fourth extensor compartment artery (ECA) is located deep to the extensor retinaculum in the fourth extensor compartment (Fig 1).
  - It lies directly adjacent to the posterior interosseous nerve on the radial floor of that compartment.
  - It originates from the pAIA or the fifth ECA.
  - It anastomoses with the dorsal intercarpal arch and the dorsal radiocarpal arch.
  - The fourth ECA is a source of numerous small nutrient arteries to the dorsal radius at the level of the fourth extensor compartment that penetrate deeply into cancellous bone.
  - The fifth ECA is located deep to the extensor retinaculum in the fifth extensor compartment or within the septum between the fourth and fifth extensor compartments (Fig 1).
  - It is the largest of the four dorsal vessels.
  - It originates from the pAIA and anastomoses distally with the fourth ECA, the dorsal intercarpal arch, the radiocarpal arch, the 2, 3 ICSRA, and/or the oblique dorsal artery of the distal ulna.
  - The fourth and fifth ECA pedicle is ideal for use in grafting the lunate because of the large diameter of the fifth ECA, the length of combined pedicle, the ulnar location of the fifth ECA (away from necessary incisions), and the multiple anastomoses, which provide retrograde flow.
  - The fifth ECA by itself seldom provides direct nutrient branches to the radius.
  - A 2, 3 ICSRA graft based on antegrade flow through the fifth ECA can be used if the fourth ECA is damaged or not present.

Vascular Anatomy of the Dorsal Hand
- The blood supply to the hand consists of a series of anastomotic arches over the carpus that form the dorsal carpal arch, usually with contributions from both the radial and ulnar arteries (Fig 1).3,8
- The dorsal carpal arch lies distal and deep to the extensor retinaculum.
- The dorsal metacarpal arteries lie just deep to the fascia overlying the interossei muscles.
- The second, third, and fourth dorsal metacarpal arteries arise from the dorsal carpal arch. They terminate by dividing into digital arteries.
The digital arteries are also supplied by perforating branches from the deep palmar arch.
- The first and fifth dorsal metacarpal arteries are direct branches from the radial and ulnar arteries respectively.
- The second dorsal metacarpal artery is the preferred vascular source for vessel implantation due to its size and predictable presence.
  - If this vessel is damaged or cannot be found, the third dorsal metacarpal artery may be used.

SURGICAL MANAGEMENT
- Treatment of Kienböck disease is based on the following factors:
  - Lichtman stage
  - Ulna variance
  - Presence of arthritic changes
  - Integrity of the lunate’s cartilaginous shell (FIG 2)
  - Patient symptoms and other patient-specific factors
- Nonsmokers with Stage I to IIIA Kienböck disease, an intact lunate cartilaginous shell (as determined using sagittal images and at surgery), and limited arthritic changes are suitable candidates for treatment using a vascularized grafting procedure (FIG 3).
- Relative contraindications to vascularized grafting include:
  - Previous surgery with exposure of the dorsal aspect of the hand and wrist
  - Age more than 60 years
  - History of peripheral vascular diseases or poorly controlled diabetes
  - Vascular grafting is accompanied by a lunate unloading procedure.
  - Unloading has been shown to improve symptoms related to Kienböck disease (see Chap. HA-23).
  - Altering force distribution through the lunate serves to protect the vascular grafts and to encourage revascularization.

FIG 2 • A. At the time of surgery the articular surfaces are carefully evaluated. B. T2-weighted MRI sagittal image of the lunate revealing a coronal plane fracture line, separation of volar and dorsal fragments, and interruption in the cartilaginous envelope. (Copyright Thomas R. Hunt, III, MD.)

FIG 3 • A, B. AP and lateral radiographs showing stage II–III Kienböck disease with sclerosis and subtle, early collapse. There is no evidence of a coronal plane fracture line. C. T1-weighted MRI coronal image showing loss of marrow signal of the lunate. (Copyright Thomas R. Hunt, III, MD.)
Unloading procedures commonly used in conjunction with a vascular procedure include:

- Capitate shortening osteotomy is our preferred choice in patients with positive or neutral ulna variance. This procedure is completed before inserting the vascular graft or vessel.
- Scaphocapitate pinning or external fixation (4 to 6 weeks) is used when ulna variance is positive and a contraindication to capitate shortening osteotomy exists.
- Radius shortening and angular osteotomy is used when ulna variance is negative (see Chap. HA-23).
- Intercarpal arthrodesis (see Chap. HA-88).

Preoperative Planning

- The surgeon should review all imaging studies to determine the stage of the disease, ulna variance, and the status of the lunate’s articular shell.

Positioning

- The patient is positioned supine with the arm on a radiolucent armboard.
- A proximal arm tourniquet is applied. Gravity exsanguination of the limb before tourniquet inflation allows visualization of the vessels.

Approach

- The surgeon should consider arthroscopic assessment before the open approach if the status of the lunate articular shell is in question.
- The 4-5 portal and ulnar midcarpal portal should be avoided as they may damage 4+5 ECA.
- Dorsal approaches to the hand and the wrist are used.
- Specific incision placement varies based on the graft choice and associated lunate unloading procedure.

**VASCULARIZED BONE GRAFTING**

Exposure and Identification of the Fourth and Fifth Extensor Compartment Arteries

- Make a 5- to 6-cm longitudinal skin incision between fourth and fifth extensor compartments, ending distally between the third and fourth metacarpal bases.
- Incise the fifth extensor compartment.
- Identify the fifth ECA and its venae comitantes on the radial aspect of the compartment lying adjacent to or partially within the septum and separating the fourth and fifth extensor compartments (TECH FIG 1).
- Trace the fifth ECA proximally to its origin from the posterior division of the anterior interosseous artery as it emerges from the interosseous membrane.
- Identify the fourth ECA arising from the same feeding vessel.
- Trace the fourth ECA distally and identify the area of greatest vascular penetration into bone, typically 1 cm proximal to the radiocarpal joint.

Lunate Preparation

- Elevate the extensor retinaculum as a radial-based flap from the fifth through the second extensor compartments to allow joint capsulotomy.
- Carefully protect the dorsal carpal arch.

**TECH FIG 1** • A. The fifth extensor compartment artery is identified and carefully traced proximally to its origin from the posterior division of the anterior interosseous artery. B. Matching clinical photograph showing fourth and fifth extensor compartment arteries. (B: Copyright Thomas R. Hunt, III, MD.)
Perform a ligament-splitting capsulotomy and protect the scapholunate and lunotriquetral ligaments.

Inspect the lunate, its cartilage shell, and surrounding articular surfaces.

Consider vascularized bone grafting only if the shell is not compromised, the bone is not fragmented, and the joint is not arthritic.

Enter the noncartilaginous portion of the dorsal lunate cortex using a small curette or a 2- to 3-mm round burr.

Through this dorsal cortical window and under direct visualization and fluoroscopic guidance, carefully remove necrotic bone from the lunate by hand with curved and straight curettes.

Leave a shell of intact subchondral bone.

If the lunate is collapsed, expand it gently using a small blunt-ended lamina spreader.

The amount of expansion obtained is highly variable.

Use of a lamina spreader in this manner is not suggested in cases with bone fragmentation.

Determine the graft size required by measuring the dorsal excavated area of the lunate.

**Elevation of the Vascularized Bone Graft**

Using a smooth 0.045-inch Kirschner wire, outline the area of the distal radius most infiltrated by nutrient vessels from the fourth ECA.

The size of the graft is influenced by the nutrient vessels and the earlier measurement.

Ligate the posterior division of the anterior interosseous artery proximal to the fourth and fifth ECA branches (TECH FIG 2).

Sharply elevate the vascular pedicle from the bone while protecting the nutrient vessels at the graft site.

Complete elevation of the corticocancellous graft using sharp osteotomes, with judicious handling of the vascularized pedicle (Tech Fig 2).

Deflate the tourniquet to verify blood flow to the graft.

Protect the pedicle graft in a moist sponge.

**Placement of the Vascularized Bone Graft into the Lunate**

Obtain cancellous bone graft from the donor site in the distal radius and pack this graft into the lunate cavity using fluoroscopic images for guidance.

Using small, precise rongeurs, contour the corticocancellous pedicle graft to the size needed.

Insert the vascularized bone graft with the cortical surface arranged in a proximal–distal orientation and without tension on the vascular leash (TECH FIG 3).

This allows the graft to serve as a strut to help maintain lunate height during revascularization.

No internal fixation is necessary to secure the graft in the lunate.

**Closure**

Repair the capsule using absorbable suture, taking great care to avoid pressure on the vascular pedicle.

Close the extensor retinaculum with absorbable suture and the skin with Prolene.

Apply a nonocclusive dressing and a volar, below-elbow splint.
Incision and Approach

- Make an extensive dorsoradial incision extending from the second metacarpophalangeal joint to a point about 4 cm proximal to the wrist, which gently slopes ulnarly around the tubercle of Lister.
  - Visualize and protect the dorsal sensory branch of the radial nerve.
- Incise the extensor retinaculum over the third compartment and transpose the extensor pollicis longus into a subcutaneous position.
- Retract the contents of the fourth extensor compartment ulnarly and the second extensor compartment radially.
- Use fluoroscopy to confirm the lunate's location.
- Perform a standard ligament-splitting capsulotomy.
  - Take care to avoid injury to the transverse basal dorsosal metacarpal arch from which the vascular pedicle arises.
- Inspect the lunate and surrounding joints. Perform a synovectomy as required.

Elevation of the Second Dorsal Metacarpal Vascular Pedicle

- In the interval between the second and third metacarpals, incise the interosseous muscle fascia from proximal to distal.
  - The vessels lie underneath the aponeurosis that covers the interosseous muscles.
- Elevate the artery and venae comitantes along with a thin layer of surrounding perivascular areolar tissue from the second dorsal web space to the dorsal carpal arch (TECH FIG 4A).
  - Identify and coagulate all branches off this main metacarpal artery.
  - Ligate the vessel at its most distal location.
  - This should provide a 5- to 6-cm vessel of adequate length to reach the dorsal lunate.

Lunate Preparation and Implantation of the Vascular Bundle

- Curette and expand the lunate as discussed earlier.
- Pack autogenous cancellous bone graft into the lunate.
- Use a 2.7-mm bit and drill from dorsal to volar through the body of the lunate.
- Sew a 5-0 monofilament suture to the end of the mobilized vessel, then place the suture ends through the eye of a straight needle.
- Feed the vessel into the avascular portion of the lunate by passing the needle from dorsal to volar through the previously drilled hole, exiting the palmar skin just ulnar to the flexor carpi radialis tendon (TECH FIG 4B).
  - Make a small skin incision over the needle and tie the suture over the palmar antebrachial fascia.
  - Release the tourniquet to assess vessel patency.
  - Achieve hemostasis and close the capsule, retinaculum, and skin in the manner described earlier.
  - Apply a nonocclusive dressing and a volar, below-elbow splint.
If this trial reduction reveals that the proximal hamate is prominent in the midcarpal joint or the hamate–lunate articulation is incongruous, perform a hamate osteotomy in the same manner and at the same level as the capitate osteotomy.

**Capitate Osteotomy**

- After the capsular-sparing incision is performed for the vascular procedure but before the graft or vessel is inset into the lunate, identify the waist of the capitate and confirm the osteotomy site with fluoroscopic imaging.
  - The osteotomy should correspond to the level of the scaphotrapeziotrapezoidal joints (TECH FIG 5A).
- Use a sharp osteotome, a fine water-cooled saw, or both to resect a 2.0-mm wafer bone from the capitate (TECH FIG 5B).
- Complete the proximal cut before the distal cut.
- Perform a trial reduction using a Freer elevator in the midcarpal joint to control and compress the proximal capitate fragment.

**Osteotomy Fixation**

- Compress the two cut surfaces of the capitate manually as discussed earlier in preparation for placement of a cannulated, headless compression screw.
- Place the guidewire across the osteotomy site of the capitate from proximal to distal.
- Wrist flexion helps present the capitate head into the field. Be careful to avoid distraction of the osteotomy with this maneuver.
Confirm the placement of the guidewire with fluoroscopy.

- Insert the headless compression screw over the guidewire and achieve compression across the osteotomy site (TECH FIG 6A).

- Complete the vascular procedure as indicated and close the wrist capsule, the extensor retinaculum, and the skin (TECH FIG 6B).

- Apply a bulky hand dressing with a volar splint.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Tourniquet</th>
<th>Gravity exsanguination allows visualization of the vessels, simplifying exposure and harvest.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lunate preparation</td>
<td>Examine the cartilage shell of the lunate before harvesting the vascularized graft. Separation of dorsal and volar fragments can take place during débridement and bone expansion if performed in patients with a fracture line noted on the sagittal MRI views.</td>
</tr>
<tr>
<td>Elevation of vascularized bone graft</td>
<td>Elevate the vascular pedicle with its perivascular tissue sufficiently to allow tension-free placement of the graft.</td>
</tr>
<tr>
<td>Capitate osteotomy</td>
<td>Evaluate the prominence of the hamate at the midcarpal joint. If present, consider performing a hamate shortening osteotomy as well.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- Remove the dressing 10 to 14 days postoperatively and apply a below-elbow cast for 3 weeks.

- Remove the cast 4 to 5 weeks after surgery and initiate supervised therapy emphasizing active wrist motion. Over the next 4 weeks the patient can progress to active assisted and then passive range-of-motion exercises.

- A removable splint is used for 3 to 4 weeks.

- Evaluate the progress of healing using serial radiographs.

- Strengthening is initiated at 3 months after surgery and slowly progressed.

- Patients undergoing revascularization of the lunate are followed for 1 to 3 years.

**OUTCOMES**

- Lunate revascularization techniques have demonstrated promising clinical results for Kienböck disease.1,7

- Mazur et al4 described the results of nine reverse-flow pedicle grafts obtained from the radius metaphysis in patients with stage IIIA Kienböck disease.

- Grip strength was improved by 25%, ultimately measuring 60% to 100% of the opposite side.

- Range of motion of the wrist joint was not significantly different from the preoperative status.

- Radiographic measurements demonstrated no change in the modified carpal height ratio, lunate index, or scapholunate angle.

- MRI data demonstrated progressive signs of revascularization over time. Normalization of T2 values was seen initially by 18 months, followed by normalization of T1 values by 36 months.

- Moran et al5 retrospectively reviewed the results of 24 patients treated with vascularized bone graft using 4+5 extensor compartment artery (4+5 ECA).

- Grip strength improved from 50% to 89% of the unaffected side.

- Ninety-two percent of the patients had significant improvement in their pain.

- Seventy-seven percent of patients showed no further collapse on postsurgical radiographs.
Seventy-one percent of the patients showed evidence of revascularization with improvement in the T2 signal, T1 signal, or both.

Waitayawinyu et al9 described the results of 14 patients who had capitate shortening osteotomy with vascularized bone grafting for Kienböck disease; all had positive ulna variance.

Grip strength was improved from 58% to 78% of the normal side.

Average time to osteotomy healing was 48 days.

COMPLICATIONS

Failure of revascularization of the lunate or progression of disease may necessitate a second procedure such as intercarpal arthrodesis, proximal row carpectomy, total wrist arthrodesis, or wrist denervation.

Continued inflammation or disease progression may cause persistent pain, which may require brief periods of splinting during symptomatic flares.

REFERENCES


DEFINITION
- Thumb carpometacarpal (CMC) joint instability can occur as a result of ligament laxity or trauma.
- Regardless of the cause, injury to the stabilizing ligaments surrounding the CMC joint leads to instability and dorsoradial subluxation or dislocation of the thumb metacarpal.

ANATOMY
- The thumb CMC joint is a biconcave-convex joint similar to a horseback rider’s saddle.4
- The base of the thumb metacarpal has a prominent volar styloid process (beak) that articulates with a recess in the volar trapezium when in flexion.
- There are 16 ligaments that provide stability to the thumb CMC joint.1 Of these ligaments, the two that provide the most restraint against dorsoradial subluxation of the thumb metacarpal are the dorsoradial and volar beak ligaments (FIG 1).1,4,12,15
- The volar beak ligament (deep anterior oblique ligament, palmar ligament, ulnar ligament) originates from the volar central apex of the trapezium and inserts onto the volar beak of the thumb metacarpal.1 It lies immediately under a more widely based superficial anterior oblique ligament, which is located immediately deep to the thenar musculature and has a broad insertion across the base of the thumb metacarpal.
- The dorsoradial ligament originates from the dorsoradial tubercle of the trapezium and inserts onto the dorsal base of the thumb metacarpal. It is the thickest, widest, shortest, and strongest of the CMC ligaments.4

PATHOGENESIS
- The biconcave-convex nature of the thumb CMC joint allows for a wide range of thumb motion but is inherently unstable.7 Laxity or incompetence of the supporting ligaments, especially the volar beak or dorsoradial ligaments, will cause instability of the thumb CMC joint.10,12 Especially in middle-aged women, the cause of the laxity is often idiopathic.
- In addition, there is a population of patients who have inherent ligament laxity, such as those with collagen disorders like Ehlers-Danlos syndrome.
- In the setting of trauma, acute thumb CMC joint dislocation occurs with axial loading and flexion of the thumb metacarpal. In all reported cases, the dislocation occurs in a dorsoradial direction.11,12

NATURAL HISTORY
- Ligamentous laxity at the thumb CMC joint may cause degenerative changes to the joint cartilage and lead to arthritis, corresponding to higher stages in the Eaton–Littler staging system.2
- If the ligamentous laxity is symptomatic and causing pain, ligament reconstruction can be successful in reducing pain in over 90% of patients. Ligament reconstruction has also been shown to potentially halt the progression of arthritis.5

FIG 1 • The stabilizing ligaments of the thumb carpometacarpal joint. Of these, the dorsoradial and volar beak ligaments are the most important in preventing dorsoradial subluxation of the thumb metacarpal.
For traumatic dislocations, a stable reduction is important for thumb function. If the thumb CMC joint remains unstable, functions such as key pinch and grasp may be compromised.

Open ligament reconstruction of these unstable thumb CMC joint dislocations may decrease the incidence of recurrent instability and joint degeneration compared to closed reduction and pinning.\textsuperscript{11}

**PATIENT HISTORY AND PHYSICAL FINDINGS**

**Nontraumatic Ligamentous Laxity**

- The history should include questions about ligament laxity involving other joints. Metabolic diseases such as Ehlers-Danlos syndrome are notable.
- Radiographic findings often do not correlate with symptomatology. Therefore, it is important to elicit from the patient the exact symptoms and their severity.
- Any history of previous nonoperative treatments should be noted. If splinting and steroid injections have not been attempted, it may be beneficial to attempt these treatment modalities before discussing surgery.
- The physical examination should determine the degree of subluxation and reducibility of the thumb CMC joint.
- The thumb metacarpophalangeal (MCP) joint should also be examined for possible hyperextension laxity.
- Pinch strength and opposition should be tested and compared to the contralateral side.
- The hand should also be evaluated for concomitant carpal tunnel syndrome, flexor carpi radialis tunnel syndrome, and De Quervain tenosynovitis, as these may also need to be addressed.

**Traumatic Injuries**

- In addition to the evaluation cited for nontraumatic laxity, the history and physical examination should include the following:
  - Time and nature of the injury
  - Status of the thumb before injury
  - Stability of joint reduction: This is of major concern in the physical examination because assessment of stability will determine the treatment path.
  - Associated MCP joint collateral ligament injury and stability
  - Other associated hand injuries are important to note as well.
  - Tests to perform include the ballottement test and the grind test.
  - Tenderness associated with dorsal pressure indicates symptomatic subluxation.
  - Crepitance and pain are positive indicators of CMC pathology.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- A true lateral film of the thumb is one in which the sesamoids volar to the thumb MCP joint overlap each other.
- A 30-degree oblique stress view of the thumb CMC joint is performed by pressing the radial side of the thumb tips together. This maneuver will subluxate the thumb metacarpal base radially, thereby demonstrating the degree of laxity in the radial direction.\textsuperscript{14}

**DIFFERENTIAL DIAGNOSIS**

- De Quervain tenosynovitis
- Flexor carpi radialis tunnel syndrome
- C6 radiculopathy
- Trigger thumb

**NONOPERATIVE MANAGEMENT**

- For symptomatic ligament laxity and stage I or II basal joint disease, conservative management should first be attempted. This includes thumb spica splint immobilization and anti-inflammatory medications.\textsuperscript{6,13}
- If the symptoms do not improve, a steroid injection into the CMC joint can be attempted. The number of injections should be limited to a maximum of three; theoretically more than three injections increases joint morbidity.
- In the scenario of acute trauma, reduction of the CMC joint should be performed by applying axial traction and palmar-directed pressure to the base of the thumb metacarpal, along with pronation of the thumb metacarpal. After reduction, if the joint remains reduced, the injury can be treated with cast immobilization.
- If the joint is unstable at all after an attempt at closed reduction, surgical management is indicated.\textsuperscript{11}

**SURGICAL MANAGEMENT**

- Freedman et al\textsuperscript{5} have demonstrated that ligament reconstruction for symptomatic thumb CMC joint laxity can halt or slow the progression to degenerative arthritis. By providing joint stability, shear forces on the CMC joint and translation of the metacarpal on the trapezium can be minimized.
- In the presence of articular pathology, arthroplasty may be the treatment of choice, depending on the degree of chondromalacia.
- If greater than 20 degrees of MCP hyperextension is present with lateral pinch, MCP capsulodesis or arthrodesis may also need to be considered.\textsuperscript{14}
- If carpal tunnel syndrome or De Quervain tenosynovitis is present, carpal tunnel release or first dorsal compartment release may be needed at the time of surgery.
- For traumatic thumb CMC joint dislocations, Simonian and Trumble have shown that ligament reconstruction was superior to percutaneous pinning of unstable joints.\textsuperscript{11}
- When the injury pattern results in fracture-dislocations such as unstable Bennett and Rolando fractures, percutaneous pinning or open reduction and internal fixation may be the treatment of choice.

**Preoperative Planning**

- Plain films should be reviewed.
- In the case of acute trauma, associated fractures and hand injuries should be addressed.
A preoperative Allen test should be performed since all procedures involving the thumb CMC joint are in close vicinity to the radial artery, and iatrogenic injury may occur.

**Positioning**
- The procedure is performed with the patient supine and the arm on a standard hand table.
- The operating table should be turned away from the anesthesia machines to allow the surgeon and assistant to sit across from each other at the hand table.

**Approach**
- A number of techniques have been described for ligament reconstruction of the thumb CMC joint using a variety of different tendons, including the flexor carpi radialis, palmaris longus, extensor carpi radialis longus, extensor pollicis brevis, and abductor pollicis longus (APL).
- The technique presented here is the classic volar ligament reconstruction described by Eaton and Littler. This method effectively reconstructs both the volar and dorsal ligaments using the flexor carpi radialis.

**MODIFIED WAGNER APPROACH TO THE THUMB CMC JOINT**
- The incision is started longitudinally along the radial side of the thenar mass, at the junction between the glabrous and nonglabrous skin. The distal extent of the incision is near the midpoint of the thumb metacarpal (TECH FIG 1A).
- Proximally at the wrist crease, the incision is brought transversely across the wrist to the ulnar side of the flexor carpi radialis tendon.
- Once through the skin, care should be taken to avoid transection of superficial radial sensory nerve branches that may be crossing the operative field.
- The soft tissue is bluntly dissected until the thenar musculature is identified (TECH FIG 1B). The radial border of the thenar muscle mass is incised and the muscles are elevated extraperiosteally to expose the CMC joint capsule. The capsule is incised and the thumb metacarpal base, the CMC joint, and the trapezium exposed (TECH FIG 1C).
- Blunt dissection is continued dorsally toward the extensor pollicis longus and brevis tendons. The dorsal metacarpal cortex is exposed between these tendons.

**FLEXOR CARPI RADIALIS GRAFT HARVEST**
- The flexor carpi radialis tendon is identified just radial to the palmaris longus tendon at the wrist crease. The tendon sheath is then opened.
- A transverse incision is made proximally in the forearm overlying the flexor carpi radialis musculotendinous junction, about 8 to 10 cm proximal to the wrist crease (TECH FIG 2A,B).
- The soft tissue is bluntly dissected until the tendon sheath is identified and opened. The flexor carpi radialis tendon is then exposed.
- A longitudinal split is made in the midline of the tendon just proximal to its insertion onto the trapezium. A 0 Prolene suture is then passed through the longitudinal split (TECH FIG 2C).
A pediatric feeding tube is now passed from the proximal wound into the distal wound, just under the flexor carpi radialis tendon sheath but superficial to the flexor carpi radialis tendon fibers. The tip of the feeding tube is cut off, and the two ends of the Prolene suture are passed through the end of the feeding tube from distal to proximal. Once the suture is seen in the proximal wound, the feeding tube can be removed, leaving the ends of the Prolene suture in the proximal wound site (TECH FIG 2D–F).

TECH FIG 2 • A. Flexor carpi radialis harvest incision is made 8 to 10 cm proximal to the wrist crease. B. Flexor carpi radialis musculotendinous junction. C. A longitudinal split is made through the flexor carpi radialis distally and a 0 Prolene suture is passed through it. D. A pediatric feeding tube is passed from the proximal to the distal wound. E. The Prolene suture is then passed through the feeding tube from distal to proximal. F. The feeding tube is removed, leaving the Prolene suture ends in the proximal wound. G. The two suture ends are pulled, thereby dividing the flexor carpi radialis tendon in half until the proximal wound is reached. The flexor carpi radialis tendon spirals, so the distal radial half corresponds to the proximal ulnar half of the tendon. H. The split flexor carpi radialis tendon is delivered into the distal wound.
The two suture ends in the proximal wound are now pulled so that the rest of the suture is delivered from the distal to the proximal wound. In so doing, the suture will divide the flexor carpi radialis tendon in half along its course into the proximal wound (TECH FIG 2G).

At this time, the ulnar half of the tendon is transected proximally just after the musculotendinous junction. The fibers of the flexor carpi radialis tendon spiral, so the ulnar half of the tendon will continue to become the radial half of the tendon distally at the wrist. Before transection, traction should be applied to the proximal ulnar half of the tendon to ensure that it corresponds to the distal radial half of the tendon.

The split flexor carpi radialis tendon is finally delivered into the distal wound (TECH FIG 2H).

**METACARPAL TUNNEL PLACEMENT AND FLEXOR CARPI RADIALIS GRAFT PASSAGE AND FIXATION**

- A tunnel is made from dorsal to volar in the thumb metacarpal, 1 cm distal to the articular base. The tunnel should start dorsal to the APL insertion and then course parallel to the articular surface, exiting volarly just distal to the insertion of the volar beak ligament onto the metacarpal base.
  - The tunnel is started by first drilling a 0.045 Kirschner wire from dorsal to volar in the manner described.
  - The tunnel is enlarged by drilling a 0.062 Kirschner wire, followed by a 3.5-mm drill (TECH FIG 3A,B).
  - Once completed, a nylon whipstitch is placed in the end of the flexor carpi radialis graft. The ends of the stitch are passed through the metacarpal tunnel from a volar to dorsal direction. The stitch is pulled dorsally, delivering the flexor carpi radialis graft through the metacarpal tunnel to the dorsum (TECH FIG 3C).
  - As the graft exits the dorsal hole in the metacarpal, the thumb is extended and abducted. The graft is pulled tightly and then allowed to relax 2 to 3 mm to set the appropriate tension.
  - Once the graft tension is set, the graft is sutured to the metacarpal periosteum where it exits the dorsal hole using nonabsorbable 3-0 suture material.
  - The flexor carpi radialis graft is then passed under the APL tendon radially toward the volar side of the wrist. The graft is sutured to the APL with similar nonabsorbable 3-0 suture material as it is passed underneath it.
  - The graft is then passed underneath and around the ulnar portion of the flexor carpi radialis tendon that has remained intact. The graft is also sutured to the flexor carpi radialis tendon as it is looped around it.
  - If there is additional length to the graft, it is brought back dorsally and again passed underneath and sutured to the APL (TECH FIG 3D).
  - A 0.045-inch Kirschner wire is drilled from the radial thumb metacarpal base into the trapezium to immobilize the CMC joint. The wire is removed after 5 weeks once adequate soft tissue healing has occurred (TECH FIG 3E).
TECH FIG 3 • (continued)  D. The flexor carpi radialis graft is passed underneath and sutured to the abductor pollicis longus, the remaining flexor carpi radialis, and back dorsally to the abductor pollicis longus if the graft length permits.  E. A 0.045 Kirschner wire is drilled from the thumb metacarpal into the trapezium to protect the ligament repair.

WOUND CLOSURE

- The thenar muscle mass is reapproximated and sutured using synthetic absorbable 3-0 suture material.
- The proximal and distal skin incisions are closed with 5-0 nylon sutures (TECH FIG 4).
- The hand is then placed in a short-arm thumb spica splint.

TECH FIG 4 • Final wound closure with nylon sutures.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>In the setting of stage I or II basal joint disease and ligament laxity, the status of the articular cartilage must be carefully assessed intraoperatively. If significant cartilage damage is present, arthroplasty may be preferred.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach</td>
<td>Care must be taken to identify and preserve the superficial radial sensory nerve and lateral antebrachial cutaneous nerve branches to prevent neuroma formation.</td>
</tr>
</tbody>
</table>
| Flexor carpi radialis graft harvest | The entire insertion of the flexor carpi radialis onto the second metacarpal base must be left intact.  
Transect the proximal portion of the graft near the musculotendinous junction to ensure that adequate graft length will be obtained.  
Once the graft harvest is completed, the graft should occasionally be moistened through the remainder of the procedure to prevent desiccation and tenocyte injury. |
| Metacarpal tunnel placement | Start with a small-diameter tunnel. Gradually increase the diameter of the tunnel until the graft fits snugly through it.  
When creating the tunnel, be careful not to injure the insertion of the APL onto the radial base of the thumb metacarpal. |
| Flexor carpi radialis graft passage and fixation | It is important to set the appropriate graft tension. After placing a few periosteal sutures to hold the graft, make sure that the thumb can still be brought back into a neutral position.  
Before weaving the graft under the APL and around the intact flexor carpi radialis tendons, check an image to ensure that the CMC is adequately reduced.  
Braided synthetic suture such as Ethibond is soft and may be less palpable than stiffer suture such as Prolene. |
POSTOPERATIVE CARE
- AP, lateral, and oblique films or fluoroscopic mini C-arm views are obtained intraoperatively to evaluate CMC joint congruency and Kirschner wire placement.
- The thumb spica splint is left in place for 2 weeks. At 2 weeks of follow-up, the dressings are taken down, sutures are removed, and a new thumb spica splint is applied.
- At 5 weeks of follow-up, the Kirschner wire is removed and a removable thumb splint is used for protection. The splint can be removed for therapy, which can be started at this time.
- Therapy should start with active range-of-motion exercises of the wrist, thumb CMC, MCP, and interphalangeal joints. Thumb abduction, flexion, and opposition are emphasized.
- Strengthening exercises can be started at 2 months after surgery, and full activity without restrictions can begin at 3 months.

OUTCOMES
- When performed for stage I basal joint disease, ligament reconstruction has been shown to improve pain and establish joint stability.
  - In a number of long-term follow-up studies of over 5 years, 87% to 100% of patients demonstrated joint stability against stress testing, 29% to 67% of patients reported no pain, and 83% to 100% reported marked improvement in pain. Interestingly, only 0% to 37% of patients progressed to a higher stage of arthritis.\(^5,8\)
  - Freedman et al\(^5\) reviewed their long-term results of 24 thumbs that underwent ligament reconstruction for stage I or II disease. After a minimum of 10 years of follow-up, 29% of patients reported no pain, 54% reported pain with strenuous activity only, and 17% of patients had pain during activities of daily living. When tested against stress, 87% demonstrated joint stability.
  - Simonian and Trumble\(^11\) found that 89% of patients who underwent ligament reconstruction after traumatic thumb CMC dislocation had no pain with work at 2 years of follow-up. Also, none of the patients in this treatment group had any evidence of joint instability, and no revision procedures were required. This is in contrast to 50% of patients who had residual joint instability and pain after closed reduction and percutaneous pinning. Of this treatment group, 38% required revision surgery and underwent ligament reconstruction. 12% of these patients required CMC arthrodesis.

COMPLICATIONS
- Residual joint instability
- Residual pain, likely due to untreated arthritis involving surrounding joint articulations, such as the scaphotrapezial joint
- Radial artery injury
- Superficial radial nerve or lateral antebrachial cutaneous nerve injury
- Pin tract infection

REFERENCES
DEFINITION
- The first carpometacarpal (CMC) joint comprises the thumb metacarpal base and the trapezium.
- The thumb CMC joint is vital to the function of the hand, and injuries can result in pain, weakness, and loss of grip or pinch strength.
- Two fracture-dislocation patterns commonly result from trauma to the thumb CMC joint: Bennett and Rolando fractures.
  - Bennett fractures are intra-articular fractures in which the metacarpal shaft is radially displaced by the pull of the abductor pollicis longus tendon, leaving an intact ulnar fragment at the base of the thumb metacarpal that is held reduced by the strong volar beak ligament (**FIG 1A**).
  - Rolando fractures are complex intra-articular fractures involving the base of the thumb metacarpal that often have a T- or Y-type pattern. These fractures are classically described as being three-part; however, the name also applies to more comminuted fracture variants (**FIG 1B**).

ANATOMY
- Understanding the deforming forces in these fracture-dislocations is important when deciding on treatment options and determining prognosis.
- The thumb metacarpal serves as the site of attachment for several tendons, including the abductor pollicis longus (APL) at the proximal base, the adductor pollicis (AP) distally, and the thenar muscles volarly.
- The articular surfaces of the thumb metacarpal base and trapezium resemble reciprocally interlocking saddles and allow motion in many planes.
- Joint stability is maintained by five primary ligaments: the anterior-volar (beak), the posterior oblique, the dorsal radial, and the anterior and posterior intermetacarpal ligaments (**FIG 2**).

**FIG 1 • A.** A typical Bennett fracture is a unicodial fracture of the base of the first metacarpal with the fracture fragment consisting of the volar-ulnar corner of the proximal metacarpal.  
**B.** A Rolando fracture is multifragmentary, with the entire articular base of the metacarpal being involved. By definition, no portion of the metacarpal shaft is in continuity with the carpometacarpal joint.

**FIG 2 • A,B.** Anterior and posterior views of the thumb basal joint stabilizing ligamentous structures. The crucial anterior, volar-oblique (beak) ligament is often attached to the displaced Bennett fragment.
Buchler et al\(^2\) described three zones at the base of the thumb metacarpal (FIG 3):
- Zone 2 represents the central portion of the joint that is normally loaded.
- Zone 1 includes the volar aspect of the joint.
- Zone 3 involves the dorsal aspect of the joint.
- The trapezium has several important adjacent articulations. These include the first metacarpal base, the radial aspect of the second metacarpal base, the scaphoid, and the trapezoid (along with the trapezium, these last two make up the STT joint).

PATHOGENESIS
- Bennett fractures occur when the partially flexed thumb metacarpal is axially loaded, resulting in a Bennett articular fragment (the volar-ulnar portion of the metacarpal base) and the remainder of the metacarpal that displaces dorsally, proximally, and radially.
- Rolando fractures result from a similar injury mechanism and may have a variable degree of comminution at the base of the thumb metacarpal.
- In Bennett-type fractures, the thumb metacarpal shaft is displaced dorsally and proximally by the pull of the APL at the metacarpal base, and angulated ulnarly by the AP and the extensor pollicis longus (EPL) tendons, which insert more distally on the digit.\(^{15}\)
- Rolando-type fractures are subject to the same deforming forces, except that the APL can sometimes displace both the shaft and the dorsal-radial basilar articular fragment.
- Due to the deforming forces that act on the fracture fragments, both injury patterns are usually unstable and difficult to reduce and stabilize by closed means.

NATURAL HISTORY
- Injuries to the thumb CMC joint are the most common of all thumb fractures.\(^4,8\)
- Nonoperative treatment is generally reserved for nondisplaced fractures. There is a low likelihood of maintaining reduction using closed means in displaced fractures.
- Residual subluxation of the metacarpal shaft leads to basal joint incongruity and the potential for developing posttraumatic arthrosis.\(^5\) In addition, residual intra-articular step-off greater than 1 mm may predispose to the development of arthrosis, although this has not been found to be true in all studies.\(^5,6,19\)

PATIENT HISTORY AND PHYSICAL FINDINGS
- Most of these fractures occur with direct trauma to the thumb tip, often from a fall or sports-related injury.
- The injury is most common in young males, and two thirds occur in the dominant hand.\(^8,15\)
- The history should reveal whether the patient had pre-existing basal joint arthritis, which is common and will affect treatment options and expected results.
- Common physical examination findings include tenderness and ecchymosis surrounding the thumb CMC joint, crepitus with attempted motion, instability, and a "shelf" deformity resulting from displacement of the metacarpal shaft dorsally (FIG 4).\(^{16}\)
- Metacarpal subluxation or dislocation represents an unstable fracture.
- Range of motion is decreased and may be associated with crepitus. Adjacent joints may also have arthrosis and decreased range of motion.
- It is important to perform a complete neurovascular examination and to search for associated pathology such as wrist ligamentous injuries.
- Neurovascular injuries are uncommon but compartment syndrome should be suspected in higher-energy injuries.
- Tendon function should be examined, specifically the EPL, flexor pollicis longus (FPL), and extensor pollicis brevis (EPB).
IMAGING AND OTHER DIAGNOSTIC STUDIES
- AP, lateral, and oblique images of the hand should be obtained, although the oblique plane of the thumb in relation to the hand may make these images difficult to interpret.
- A true AP view of the thumb CMC joint can be obtained with the forearm maximally pronated with the dorsum of the thumb placed on the cassette (FIG 5A).17
- A true lateral view, advocated by Billing and Gedda,1 is obtained with the hand pronated 20 degrees and the thumb positioned flat on the cassette. The x-ray beam is tilted 10 degrees from vertical in a distal-to-proximal direction (FIG 5B).
- Radiographs of the contralateral, uninjured basal joint are helpful in certain cases as a template for reconstruction.
- Computed tomography may be indicated if a significant amount of articular comminution is present or when plain films inadequately demonstrate the pathology.
- A traction view may be helpful in Rolando-type fractures in which nonoperative treatment is being considered and tomography is not available (FIG 5C).
- Fluoroscopy alone should be used with caution in ensuring anatomic reduction as this has recently been shown to be less accurate than plain x-rays or direct visualization.3

DIFFERENTIAL DIAGNOSIS
- Bennett-type fracture
- Rolando-type fracture
- Basal joint degenerative joint disease
- STT joint arthrosis
- Thumb CMC joint ligamentous injury
- Trapezial body fracture
- De Quervain tenosynovitis

NONOPERATIVE MANAGEMENT
- Nondisplaced, minimally comminuted fractures may be treated with closed reduction and thumb spica casting, but precise molding of the cast and close observation for fracture displacement are necessary.
- In a Bennett fracture, closed treatment may be indicated if there is minimal displacement between the volar ulnar fragment and the metacarpal shaft. Most importantly, a concentric reduction of the metacarpal base in Bennett fractures must be maintained.6
- Several factors make closed treatment of these intra-articular fractures problematic and worsen results:
  - Difficulty in providing accurate three-point molding of the thumb metacarpal
  - Treatment of patients 4 or more days after the initial injury
  - Difficulty assessing the adequacy of reduction with radiographs taken through the cast4,9
- Some studies looking at closed treatment have demonstrated decreased motion, grip strength, and radiographic evidence of degenerative joint disease at long-term follow-up.14
- Development of degenerative changes may occur if there is any residual subluxation of the thumb metacarpal shaft.5,8

SURGICAL MANAGEMENT
- The majority of displaced Bennett fractures and almost all Rolando fractures require percutaneous Kirschner wire fixation or open reduction and internal fixation.
- The goals of surgery are to restore the articular congruity of the thumb CMC joint and to align the first metacarpal base articular surface with the trapezium.
- In thumb CMC joint fractures associated with trapezial body fractures, the trapezial articular surface should first be reduced anatomically before proceeding to the thumb metacarpal fracture.16

**Bennett Fractures**
- Closed reduction and percutaneous pinning is the preferred treatment for most Bennett fractures with displaced fracture fragments representing less than 25% to 30% of the articular surface.16,18

**FIG 5** A. An ideal AP view of the thumb and carpometacarpal joint is taken with the forearm hyperpronated and the dorsum of the thumb on the cassette. B. A true lateral view of the carpometacarpal joint is obtained with the radial aspect of the thumb on the cassette and the other fingers clear of the x-ray beam. C. A fluoroscopic view of a Rolando fracture with traction applied. Distraction at the carpometacarpal joint helps to delineate the fragments at the base of the metacarpal. (Copyright John Capo, MD.)
The metacarpal base often needs to be pinned to the unfractured second metacarpal, trapezoid, or trapezium to lessen the deforming forces on the fracture.

Residual displacement of the joint surface greater than 2 mm after attempted closed reduction and percutaneous pinning or impaction in the force-bearing aspect of the joint surface (Buchler zone 2) necessitates open reduction.15

Rolando Fractures

Closed reduction with longitudinal traction and percutaneous pinning is indicated if successful reduction can be achieved under fluoroscopic guidance; however, this is usually successful only when large T- or Y-type fragments are present.

If the joint cannot be reduced by closed methods, open reduction and internal fixation with a combination of smooth wires, screws, and 1.5- to 2.7-mm L, T, or blade plates is indicated.

Significant comminution may require either external fixation or a combination of external fixation, limited internal fixation with Kirschner wires and small (1.3 or 1.5 mm) screws, and cancellous bone grafting as advocated by Buchler et al.2

An additional option is tension-band wiring with or without external fixation, as described by Howard.11 The external fixator maintains length and alignment, while the tension-band construct provides stability to the fracture fragments.

Preoperative Planning

A thorough history and physical examination are mandatory to choose the appropriate treatment and rule out associated injuries.

True AP, lateral, and oblique radiographs of the thumb should be obtained in all cases. Traction radiographs help assess the effects of ligamentotaxis on fracture reduction.

Surgery may be performed acutely, but if significant soft tissue swelling is present, elevation in a well-padded thumb spica splint for 2 to 5 days may be necessary before undergoing operative fixation.16

Positioning

The patient is placed supine on the operating room table.

A radiolucent hand table is used to allow for intraoperative fluoroscopy.

The patient is moved toward the operative side to center the hand on the table.

A non-sterile tourniquet is placed on the upper arm.

General, regional (axillary or infraclavicular), or local (wrist block with local infiltration) anesthesia can be used, although muscle relaxation is often necessary to obtain proper reduction.16,18

Approach

The Wagner approach can be used for both Bennett and Rolando fractures in which open reduction is necessary.

**CLOSED REDUCTION AND PERCUTANEOUS PINNING OF BENNETT AND ROLANDO FRACTURES**

- Longitudinal traction, abduction, and pronation of the thumb is performed while applying direct manual pressure over the metacarpal base.16

- Traction is maintained and the reduction is held while fluoroscopy is used to verify acceptable fracture reduction and alignment of the articular surface (**TECH FIG 1A,B**).

**TECH FIG 1 • A,B.** Lateral and PA views of a Bennett fracture with intraarticular displacement. C. The metacarpal base is first reduced to the trapezium and then a pin (0.045) is placed across the carpometacarpal joint. Two additional pins are provisionally placed and readied to stabilize the Bennett fracture fragment. D. The two smaller pins (0.035) are then advanced across into the Bennett fragment. (Copyright John Capo, MD.)
Incision and Dissection

- A Wagner approach is used for open reduction of a Bennett fracture (TECH FIG 2A).
- An incision is made on the dorsal-radial aspect of the thumb CMC joint, at the junction of the glabrous and nonglabrous skin, and curved in a volar direction toward the distal wrist crease to the flexor carpi radialis (FCR) tendon sheath (TECH FIG 2B).
- The palmar cutaneous branch of the median nerve, the superficial radial nerve, and distal branches of the lateral antebrachial cutaneous nerve are at risk in this approach and should be carefully protected (TECH FIG 2C).
- The thenar muscles are elevated extraperiosteally from the CMC joint and a longitudinal capsulotomy is made to expose the joint and the fracture fragments.
- An effort should be made to preserve all soft tissue attachments to the fracture fragments.
- The fracture line is exposed and cleaned of all hematoma and early callus.
- Large fragments may be manipulated percutaneously with Kirschner wire "joysticks" and then stabilized.
- The wires are bent and cut outside of the skin, followed by application of a well-padded thumb spica splint with the thumb in abduction and wrist in extension.
- If less than 2 mm of step-off cannot be obtained by closed reduction, the surgeon should consider abandoning this technique for an open reduction and internal fixation.¹⁶,¹⁸
- In rare instances, a similar technique can be used for Rolando fractures, with large T- or Y-type fracture patterns with minimal comminution.

OPEN REDUCTION AND INTERNAL FIXATION OF BENNETT FRACTURES

TECH FIG 2 * A. A preoperative radiograph demonstrating a large (~40%) Bennett fracture with intra-articular displacement. B. The typical incision for open reduction and internal fixation of a Bennett or Rolando fracture. The proximal aspect starts at the flexor carpi radialis tendon sheath. In the case of a Rolando fracture, especially one treated by plate fixation, the distal portion of the incision should extend along the thumb metacarpal. C. Distal nerve branches are seen during the exposure of these fractures. The nerves can usually be retracted dorsally to allow exposure of the carpometacarpal joint. D. The thenar muscles are reflected volarly and the carpometacarpal joint is entered. The volar, oblique fracture is now clearly visualized. Care is taken to maintain soft tissue attachments. (Copyright John Capo, MD.)
Reduction and Fixation

- The displaced thumb metacarpal shaft should be reduced to the volar-ulnar fragment under direct visualization and secured with fine reduction clamps or Kirschner wires (TECH FIG 3A).
- One or two 0.045-inch smooth Kirschner wires are used to provisionally hold the reduction, or in certain fracture patterns they can serve as the definitive means of fixation.
- Alternatively, 1.3- to 2.0-mm screws can be placed in an interfragmentary compression fashion for added stability (TECH FIG 3B).7
- One Kirschner wire is removed at a time and replaced with a screw.
- Generally, the path of the removed Kirschner wire effectively guides the drill in the appropriate direction. Use of a mini-fluoroscopy unit is helpful.

- Care should be exercised to avoid overcompression, which may cause an alteration in the arc of curvature of the articular surface.
- If fixation is tenuous, the metacarpal base can be pinned to the second metacarpal or to the carpus for added stability.
- Anatomic reduction of the articular surface is verified under direct visualization.
- The wound is closed in layers with absorbable suture in the capsule, followed by nylon sutures in the skin. A thumb spica splint is applied.
- The screws should be precisely evaluated fluoroscopically to be certain they are not in the CMC joint or adjacent second metacarpal base (TECH FIG 3C,D).

TECH FIG 3 • A. The fracture is cleared of hematoma and then reduced with a pointed reduction forceps. A provisional Kirschner wire is placed percutaneously from the dorsal metacarpal shaft into the fragment. B. Two screws of 1.3 mm diameter are placed in a lag fashion from the metacarpal shaft into the fracture fragment. C,D. Lateral and AP postoperative views showing reduction of the fracture and articular surface with two screws inserted in different planes. (Copyright John Capo, MD.)
OPEN REDUCTION AND INTERNAL FIXATION OF ROLANDO FRACTURES

Incision and Dissection
- The previously described Wagner approach is used to expose the thumb CMC joint (TECH FIG 4A,B).
- The radial portion of the incision is extended distally to expose the diaphysis of the thumb metacarpal. Branches of the radial sensory nerve must be protected at this stage (TECH FIG 4C).

Reduction and Fixation
- The basilar-articular fragments are then reduced under direct visualization and provisional fixation is performed with Kirschner wires or bone reduction clamps (TECH FIG 5A).
- A lag screw can be placed in a transverse direction by overdrilling the proximal cortex to compress the basilar fragments together, followed by application of a minifragment neutralization plate or by additional Kirschner wires to stabilize the shaft (TECH FIG 5B,C).6,16
- If greater fracture stability is desired, a small (1.5 to 2.7 mm) T, L, or blade plate can be used alone.
  - The palmar radial incision is extended further distally to expose the thumb metacarpal shaft to accommodate the plate.
  - Reduction is obtained using the above techniques, with axial traction to maintain appropriate length and bone reduction forceps or smooth Kirschner wires to provisionally hold the articular reduction.
- Once the fracture fragments are aligned, the plate is secured to the thumb metacarpal, with the transverse portion of the plate placed over the basilar fracture fragments.16
- The most palmar and dorsal proximal holes of the T portion of the plate can be drilled eccentrically to allow for compression at the fracture site between the basilar fragments,7,13 followed by fixation of the plate to the metacarpal shaft with cortical screws (TECH FIG 5D,E).
- Additionally, a lag screw can be placed between the shaft and the basilar fragment either within or outside of the plate. An appropriate bit is used for overdrilling of the shaft fragment, followed by core drilling of the distal basilar fragment. This interfragmentary screw increases the stability of the construct and may allow for earlier functional range of motion (TECH FIG 5F–I).
- The joint surface reduction is visualized directly with distal traction of the thumb and ensured to be anatomic.
- The wound is then irrigated and closed in layers, followed by immobilization in a well-padded thumb spica splint.

TECH FIG 4 • A,B. Preoperative radiographs of a Rolando fracture demonstrating severe intra-articular comminution. C. The thumb thenar muscles have been elevated from the carpometacarpal joint and a capsulotomy has been performed. The fracture fragments are identified and cleared of hematoma. (Copyright John Capo, MD.)
TECH FIG 5 • A. The articular surface is first reduced and provisionally stabilized with multiple small Kirschner wires. B, C. Intraoperative fluoroscopic lateral and AP views demonstrate excellent restoration of the joint surface. Kirschner wires have been placed from the thumb metacarpal into the trapezium and second metacarpal to stabilize the construct. D. The two proximal holes of the T plate are drilled offset for articular fragment reduction. E. The two proximal screws are tightened to compress the proximal fragments. F, G. AP and lateral views of a comminuted, displaced Rolando fracture. (continued)
APPLICATION OF AN EXTERNAL FIXATOR FOR COMMINUTED ROLANDO FRACTURES

- Before this procedure, a radiograph of the contralateral thumb CMC joint is advised for templating and to judge postreduction length.
- A mini-external fixator (2.0- to 2.5-mm pins) is applied to the thumb and index metacarpals using standard technique with a quadrilateral frame configuration.²,¹²
- Exposure and open reduction are then performed as discussed previously.
- Distraction is maintained using the external fixator, and the depressed joint fragments are elevated and aligned using the preoperative radiograph of the opposite side as a guide.
- A sharp dental pick is an excellent tool to manipulate small fragments.
- 0.045-inch smooth Kirschner wires or interfragmentary screws can then be used to secure the fracture fragments.
- The external fixator is loosened to decrease the flexion deformity of the thumb metacarpal shaft, and to ensure the base of the thumb is maintained in the proper position. It should be co-linear with the base of the second metacarpal base.
- At the end of the procedure the thumb should be in 45 degrees of palmar and radial abduction and about 120 degrees of pronation in relation to the plane of the hand (TECH FIG 6).
- The incision is irrigated and closed in layers.
Chapter 26  OPERATIVE TREATMENT OF THUMB CARPOMETACARPAL JOINT FRACTURES

TECHNIQUES

POSTOPERATIVE CARE

Bennett Fractures

- A thumb spica splint is applied in the operating room. Pin sites are inspected at 1 week and a thumb spica cast is applied for 4 to 6 weeks, until fracture union.
- Hand therapy is begun early for thumb IP and MP joint motion and index through small finger range of motion.
- Pins are removed at 4 to 6 weeks and therapy is advanced to the CMC joint along with intermittent immobilization using a removable thumb spica splint.16
- In patients treated with interfragmentary compression screws and therefore more stable fixation, active range-of-motion exercises can be started at 1 to 2 weeks postoperatively with a removable splint for protection.

Rolando Fractures

- Patients treated with closed reduction and percutaneous pinning are placed in a thumb spica splint, which is removed at 1 week for pin inspection. A thumb spica cast is applied for an additional 4 to 5 weeks.
- The pins are removed in the outpatient office at 6 weeks after surgery. A removable splint may be continued for 2 to 4 additional weeks while active range-of-motion exercises are advanced.16
- In patients treated with stable plate fixation, active range-of-motion exercises may be instituted at 1 to 2 weeks after surgery. Patients typically wear a removable splint for 2 to 4 weeks.
- If a severe injury dictated the use of external fixation, the pins and frame should remain in place for about 6 weeks, or until fracture stability is adequate based on interval radiographs. A removable thumb spica splint can then be worn for an additional 4 to 6 weeks.

OUTCOMES

- The majority of patients can expect a successful recovery after operative treatment of Bennett or Rolando fractures (FIG 6).
Superior results are seen in operatively treated fractures in which there is no residual subluxation of the thumb metacarpal shaft and less than 2 mm of intra-articular displacement.\textsuperscript{5,15}

It is generally agreed that if pain and articular incongruity persist after 6 months of observation after closed or open treatment, arthrodesis of the thumb metacarpal to the trapezium or basal joint arthroplasty may be indicated.

- CMC joint fusion is durable, but patients have difficulty with placing their hand on a flat surface and getting the hand into a pants pocket.
- Basal joint arthroplasty for acute fractures should be reserved for older, lower-demand patients.

**COMPLICATIONS**

- Malunion and subsequent arthrosis resulting from inadequate articular reduction
- Pin tract infection
- Injury to the superficial cutaneous nerves during open dissection and percutaneous fixation
- Contracture of the first web space from immobilization or pinning of the thumb in an adducted position

**REFERENCES**

DEFINITION
- Disruption of the restraining structures on the volar surface of the joint between the metacarpal and proximal phalanx of the thumb may result in excessive joint motion and abnormal hyperextension.
- Often painful, this instability frequently causes significant functional deficits because so much of what humans do with their hands depends on having a stable, pain-free thumb to oppose the other digits.
- Acute injuries, including joint dislocations, must be treated correctly and promptly to afford the best chance for successful outcomes.
- Chronic volar instability is seen less often than is collateral ligament incompetence, but it should not be overlooked. It can be treated effectively with a variety of techniques, which will be discussed in this chapter.

ANATOMY
- The thumb metacarpophalangeal (MP) joint has features of both a ginglymus (hinge) joint and a condyloid joint. The joint moves mostly in a flexion–extension mode (ginglymus-style), but there are also elements of rotation and abduction—adduction in the normal joint (condyloid).
- Thumb MP joint motion varies widely from individual to individual because of the spectrum of metacarpal head geometry seen in “normal” hands.
- Some metacarpal heads are more rounded and allow greater flexion, extension, and rotation, while others are flatter and allow relatively less range of motion (ROM).
- The joint derives its stability mostly from soft tissue constraints, not bony architecture (FIG 1).
- The proper collateral ligaments originate from the region of the lateral condyles of the MC and pass palmarly and obliquely to insert on the palmar portion of the proximal phalanx.
- The accessory collateral ligaments originate from the same region but slightly more proximal and traverse distally and palmarly in an oblique fashion to insert on the volar plate and sesamoids.
- The volar plate serves as the floor of the MP joint. The adductor pollicis inserting into the ulnar styloid sesamoid at the distal edge of the volar plate and the insertions of the flexor pollicis brevis and abductor pollicis brevis into the radial sesamoid at the radial-distal edge of the volar plate provide additional volar support.
- Those muscles also contribute fibers to the extensor mechanism by way of the adductor and abductor aponeuroses and thus provide a modicum of lateral joint stability.
Dorsally, the extensor pollicis brevis inserts onto the base of the thumb proximal phalanx and the extensor pollicis longus inserts at the base of the thumb distal phalanx; both traverse the MP joint and add to the stabilizing forces surrounding the joint.
- The MP joint capsule itself surrounds the joint and contributes slightly to stability.

**PATHOGENESIS**
- Dorsal dislocations of the thumb MP joint are much more common than are volar dislocations.4,5
- The typical mechanism is a hyperextension force strong enough to rupture the volar plate and joint capsule.
  - For example, when a ball strikes a player’s thumb or when there is a direct blow or fall that drives the phalanx into sudden hyperextension
- Occasionally the radial or ulnar collateral ligaments (or both) of the MP joint are ruptured along with the volar plate. Their treatment is addressed in other chapters.
- Sometimes the instability occurs in the setting of a patient with generalized ligamentous laxity such as Ehlers-Danlos syndrome (or other collagen disorders), but in those situations symptoms are less common and patients typically learn to compensate for the joint laxity.

**NATURAL HISTORY**
- Posttraumatic instability left untreated may result in weakness of pinch and grip and progress to painful arthrosis due to the abnormal biomechanics of the damaged joint.

**HISTORY AND PHYSICAL EXAMINATION**
- In traumatic cases it is important to inquire about the mechanism of injury.

If patients recall which way the thumb was “pointing” at the time of injury, it helps the examiner determine which structures were likely injured.
- Was the joint dislocated and did it reduce spontaneously or with assistance from a coach, trainer, or the patient?
- How difficult was the reduction?
- Physical examination should include an assessment of ROM and grip and pinch strength, particularly in comparison with the contralateral thumb. Focal areas of tenderness should be ascertained. Residual tenderness along the volar plate may persist long after the injury.
- The examiner should observe the resting joint posture; dislocated joints exhibit obvious deformity.
- The examiner should check for open wounds and assess vascular status. Open wounds or vascular compromise mandate emergent treatment.
- Limited or absent interphalangeal joint ROM suggests flexor pollicis longus tendon entrapment.
- Dislocated or painful MP joints will have limited ROM.
- Volar plate stability is assessed, since instability must be recognized and treated appropriately to maximize outcomes.
- Severe collateral ligament injury is uncommon in conjunction with volar plate instability but must be recognized and treated where indicated.
- An acute dislocation is rarely subtle, but when patients present with chronic instability symptoms, there may be guarding against full joint extension and soft tissue thickening in areas of chronic pathology.

**IMAGING AND DIAGNOSTIC STUDIES**
- Plain radiographs of the thumb in three views (AP, lateral, and oblique) are requisite.
- Injury films will reveal the direction of joint dislocation and any associated fractures (FIG 2A–C).

![FIG 2](A) AP and (B) lateral injury films. (continued)
In the chronic setting, films may show evidence of prior fractures or bony injuries as well as the positions of the sesamoid bones relative to the joint space. In cases of chronic volar plate instability, the proximal phalanx may show subtle dorsal subluxation on the metacarpal head (that is more commonly noted when there has been injury to the dorsal capsule in association with collateral ligament damage).

- Arthritic changes at the MP joint seen on the plain films will alter the treatment options. If the chronically unstable joint is already arthritic at the time of presentation, then an arthrodesis will be a better option than a soft tissue reconstruction.
- Fluoroscopic real-time imaging and stress testing may confirm the suspected joint instability (FIG 2D).
- A digital block may be placed to facilitate an adequate examination.
- Ultrasound, MR imaging, and arthrography are advocated by some, but these studies are rarely of additional value in the assessment of thumb MP joint stability.

FIG 2 • (continued) C. Oblique injury film of the thumb (vs. hand) show a dorsal metacarpophalangeal joint dislocation (arrows). D. Fluoroscopic imaging shows joint instability.

DIFFERENTIAL DIAGNOSIS

- Fracture
- Collateral ligament injury
- Ligament laxity, generalized (eg, Ehlers-Danlos syndrome)
- Arthritis
- Locked trigger thumb (stenosing tenosynovitis)

NONOPERATIVE MANAGEMENT

- Most acute thumb MP dislocations can be reduced closed.
- The reduction maneuver for a dorsal dislocation involves very slight hyperextension of the MP joint followed by direct volarly directed pressure on the base of the proximal phalanx to gently slide the phalanx over the metacarpal head and back into proper alignment.
- Subtle, slight rotation (pronation and supination) at the same time may help ease any interposed soft tissue out of the way as the phalanx reduces.
- Longitudinal traction and excessive hyperextension should be avoided because the soft tissue tension generated may cause one or more structures surrounding the joint to slip between the metacarpal head and the proximal phalanx, blocking reduction.
- The volar plate, the flexor pollicis longus, and one or both sesamoid bones have all been described as culprits that have become incarcerated in the joint space, preventing reduction.2,3,5,9
- Once the joint is reduced, the patient should be able to flex and extend the thumb joints and the radiographs should show concentrically reduced and congruent joint surfaces (FIG 3).
- If either of those conditions is not met, it suggests there may be residual soft tissue interposed in the joint, an indication for open reduction.
- After successful closed reduction, the thumb should be splinted in flexion to relax the injured volar structures.
- After a few days, when the acute swelling has dissipated, the splint may be changed to a thumb spica cast, again with the MP joint flexed, for an additional 2 to 3 weeks. Rehabilitation can commence thereafter, emphasizing ROM exercises within a safe zone of motion from full flexion to just short of neutral extension and then increasing gradually to unrestricted ROM and hand use by 6 weeks after injury.
- For patients engaged in activities that risk forced hyperextension of the thumb, taping or splinting may be required during these endeavors for an additional period.
- Failure to recognize or treat the acute instability or overly aggressive progression to full, unlimited hand use may result in chronic volar instability.
Nonoperative management then is limited to providing the patient with a custom-molded splint to prevent hyperextension of the MP joint. A properly trained hand therapist is invaluable in assisting patients who prefer to manage the problem nonoperatively and use a protective splint rather than proceeding with surgical treatment for their chronic instability. Volar dislocation is very rare. There are only a few cases reported in the literature, and all required open reduction. 

Surgical Management

Open reduction is required when attempts at closed manipulation and reduction of acute dislocations fail. Failure is typically the result of soft tissue interposition in the joint that blocks reduction. Tissue interposition may have happened at the time of the original injury or as a result of a well-meaning coach, friend, or medical colleague trying to reduce the dislocation by applying vigorous traction, which can cause the soft tissues to become incarcerated. Chronic instability, which is persistently symptomatic despite nonoperative treatment, is best treated with a soft tissue stabilization technique unless moderate to severe arthrosis is present or the instability is global and exceedingly severe. In those cases, arthrodesis is the treatment of choice.

Preoperative Planning

The physician should review all imaging studies. In most cases, those will be limited to plain radiographs and perhaps spot films from fluoroscopic evaluations. Films should be reviewed for any bony abnormalities, especially nondisplaced fractures. One should avoid fracture displacement during intraoperative manipulation of the thumb. In fracture-dislocations of the MP joint, larger fragments are stabilized using Kirschner wires or screws and smaller avulsion-type fragments are excised and the ligament is secured to the bone. For chronic cases, it is important to review the films and rule out osteoarthrosis, which would warrant different treatment strategies. Examination under anesthesia with the assistance of fluoroscopy can be useful to confirm the degree and direction of joint instability. Spot films obtained before and after surgical stabilization can be helpful visual aids for use in postoperative discussions with the patient and his or her family to explain again the nature of the problem and how it was treated.

Positioning

The patient should be supine on the operating table with a standard hand table attached and projecting out from the operating table to support the operative hand. A tourniquet should be placed on the operative arm and checked for proper function and pressure before initiation of the surgery (typically 250 mm Hg or 100 mm Hg greater than systolic blood pressure).

Approach

Acute, irreducible MP joint dislocations are best approached from the volar side of the joint so that any soft tissues that may be trapped in the joint can be identified and carefully protected, before they are injured by approaching them “blindly” from the dorsal side! That assumes there are no open wounds, which then would alter one’s approach accordingly by incorporating the traumatic wound into the surgical incision.
A lateral approach is also possible, but less often used.

Chronic MP joint volar instability that is amenable to soft tissue stabilization should also be approached from the volar aspect of the joint so the pathology can be visualized and addressed directly.

If chronic MP joint instability has resulted in arthritis, arthrodesis is a better solution. This may be accomplished in a variety of ways using a variety of hardware options, including screws, plates, and wires. All are best placed through a dorsal approach.

**OPEN REDUCTION OF ACUTE MP JOINT DISLOCATIONS**

- Make a zigzag (Bruner-type) incision, centered at the level of the MP joint.
- Gently elevate the skin flaps to expose the underlying soft tissues, which will by definition be displaced from their usual locations (*TECH FIG 1*).
- Identify the neurovascular bundles and mobilize them enough to ensure their protection.
- Small rubber loops can be placed around them if desired both for protection and for easy identification.

Retract the soft tissues enough to identify whatever structure is interposed into the MP joint and reflect it out of the joint.

Most often that is the flexor pollicis longus tendon or the volar plate. The volar plate may have the sesamoids still attached to its distal edge if it has failed proximally.

Reduce the joint and check for smooth, congruent joint motion.

Check the stability of the collateral ligaments. Providing the joint does not gap open more than 25 degrees due to

---

*TECH FIG 1* • Open reduction of dorsal thumb metacarpophalangeal joint dislocation. A. Make a volar surgical approach and carefully identify the neurovascular bundles; tag and protect them with soft rubber loops (*). B. The flexor pollicis longus (*solid arrow*) is interposed and trapped behind the metacarpal head (*open arrow*). C. Umbilical tape (*arrow*) passed around the flexor pollicis longus delivers the tendon safely out of harm’s way, allowing the joint to be reduced. D. Intraoperative fluoroscopy is helpful for verifying anatomic reduction (*arrow*) with congruent joint surfaces and smooth gliding through a safe range of motion.
collateral ligament damage (rare), no further treatment for that component of the joint injury is needed.

- In some cases it may be possible to place sutures through the volar plate at its torn proximal or distal edge and tack that back to its normal insertion point. Otherwise, simply replacing the plate in normal alignment will be adequate when combined with proper rehabilitation (discussed later in the chapter).
- Replace the neurovascular bundles and flexor pollicis longus into their proper locations and close the wound in routine fashion.

### TECHNIQUES

**In some cases it may be possible to place sutures through the volar plate at its torn proximal or distal edge and tack that back to its normal insertion point. Otherwise, simply replacing the plate in normal alignment will be adequate when combined with proper rehabilitation.**

**Replace the neurovascular bundles and flexor pollicis longus into their proper locations and close the wound in routine fashion.**

### CHRONIC VOLAR INSTABILITY

**Volar Plate Advancement and Sesamoid Arthrodesis**

- The Tonkin procedure\(^{11}\) was originally described to treat MP instability resulting secondarily from osteoarthrosis of the thumb carpometacarpal joint or in patients with cerebral palsy, but it is now considered a valuable technique for treating posttraumatic instability of the MP joint.
- Approach the MP joint through a volar or volar-radial incision (TECH FIG 2A).
- Divide the accessory radial collateral ligament at its insertion into the volar plate and mobilize the plate to advance it proximally (TECH FIG 2B).
- Denude the articular surface of the sesamoid bones. A Beaver blade works well.

- Decorticate a trough along the retrocondylar fossa of the metacarpal neck to accept the sesamoids.
- Drill Keith needles through that area of the retrocondylar fossa using a wire driver. The needles should exit the metacarpal dorsally (TECH FIG 2C).
- Advance the sesamoids and volar plate into the prepared trough and secure the sutures dorsally (TECH FIG 2D).
- **Variations:**
  - Schuurman and Bos\(^{10}\): Place sutures through the proximal edge of the volar plate and pass them through the metacarpal via the Keith needles. Reinforce the construct with nonabsorbable sutures to local tissue where possible.

**TECH FIG 2** • Sesamoid arthrodesis in the manner of Tonkin. A,B. Through a volar or radial lateral approach, create a cortical defect in the metacarpal retrocondylar fossa (solid arrow), which will accept the denuded sesamoids while preserving the articular surface of the metacarpal head (dashed arrow). C. Advance and secure the volar construct including the sesamoids into the prepared trough (arrow), using sutures in the volar plate that are brought through the metacarpal neck via Keith needles drilled through the bone. D. The sutures are tensioned and tied over the dorsal metacarpal (*). (continued)
**TECH FIG 2 • (continued) E.** A Kirschner wire is drilled across the metacarpophalangeal joint to keep it flexed 30 degrees, protecting the repaired volar structures during initial healing.

- Eaton and Floyd: Place sutures in the proximal corner of the volar plate and pass them subperiosteally from volar to dorsal around the metacarpal and secure them to advance the volar plate snugly into the prepared retrocondylar fossa.

- Pin the MP joint in about 30 degrees of flexion using a Kirschner wire (TECH FIG 2E).
- Close the wound in routine fashion and apply dressings and a thumb spica splint.
- Remove the sutures at 10 to 14 days as usual and apply a thumb spica cast.
- Remove the Kirschner wire and cast at 4 to 6 weeks and begin active flexion exercises.

**Tendon Graft Tenodesis**

- A procedure used by Littler and cited by Glickel et al has been described whereby a free tendon graft (usually the palmaris longus) is woven through drill holes in the proximal phalanx and metacarpal and secured in place to provide a passive restraint against MP joint hyperextension.
- However, the bulk of soft tissue that results from this procedure and the amount of dissection needed to perform it have caused this operation to fall out of favor.
- Local tissue mobilization in conjunction with suture anchors provides a better solution.

**ARTHRODESIS**

**Cannulated Headless Compression Screw Fixation**

- Make a dorsal longitudinal approach (TECH FIG 3A–D).
- Split the interval between extensor pollicis longus and brevis.
- Split the joint capsule longitudinally.

- Mobilize the joint adequately. That requires releasing the remaining collateral ligaments and recessing the volar plate enough to deliver the metacarpal head fully into view.
- Use a water-cooled oscillating saw to remove the metacarpal head. Angle the cut from dorsal-distal to
TECH FIG 3 • (continued) D. Through a dorsal approach, the interval between the extensor pollicis brevis and longus (arrow) is developed and the joint is entered. E. Remove the metacarpal head with an oscillating saw. F. Prepare the base of the proximal phalanx with a burr. G. The opposing bone surfaces should be flush-cut and angled slightly so the final arthrodesis position is 15 to 20 degrees of flexion. H. The guidewire for the chosen cannulated screw is drilled across from metacarpal into the medullary canal of the proximal phalanx. I. Its position is checked with fluoroscopy. J. After the proper implant length is measured and the leading cortex overdrilled, the screw is inserted over the guidewire. K. Confirm correct final positioning with fluoroscopy. L. The joint capsule is closed and the extensor mechanism reaproximated.
palmar-proximal so that the final positioning will leave the MP joint surface flexed about 15 degrees (TECH FIG 3E).
- All the flexion for the arthrodesis will be accomplished by this cut. Preparation of the proximal phalanx base will be perpendicular to the longitudinal axis of that bone and will not add flexion.
- Use a burr to prepare the base of the proximal phalanx, removing any remaining articular cartilage and eburnated subchondral bone (TECH FIG 3F). Osteophytes and ridges should be trimmed away also to make a flush surface that will oppose the MC surface (TECH FIG 3G).
- Alternatively, carefully protect the underlying flexor pollicis longus and use a water-cooled oscillating saw to remove the needed bone.
- Avoid excessive bone resection that will shorten the thumb. Cup and cone reamers are an alternative to straight bone cuts and may minimize shortening and maximize flexibility in positioning the arthrodesis.
- Reduce the fusion surfaces and drive a guidewire for the selected cannulated screw set from the metacarpal into the medullary cavity of the proximal phalanx (TECH FIG 3H).
- Be certain that the starting point for the guidewire is sufficiently proximal on the dorsal surface of the metacarpal that the screw does not fracture the cortical bridge when inserted.
- Alternatively, the guidewire may be drilled in a retrograde fashion starting at the cut end of the metacarpal head. The fusion surfaces are then reduced and the guidewire is advanced into the phalanx in an antegrade manner.
- Consider placing a second temporary Kirschner wire to increase stability and minimize rotation during screw insertion.
- Confirm that the overall alignment is satisfactory radiographically and clinically (TECH FIG 3I).
- The metacarpal and phalanx should be co-linear in the AP plane and flexed about 15 to 20 degrees in the lateral plane. Rotation should be neutral or slight pronation for pinch.
- Intraoperative fluoroscopy is helpful to confirm correct alignment.
- Adjust the position of the guidewire for the cannulated screw such that its distal tip is just past the narrowest portion of the proximal phalanx. A screw ending at this level will experience excellent purchase and gain maximum stability. Measure the Kirschner wire length, choose the screw (keeping in mind the likelihood of compression at the arthrodesis site), and then advance the guidewire distally into the cortex.
- Drill, tap, and place the selected screw, avoiding any prominence over the dorsal metacarpal. Tighten securely while the reduction is compressed manually (TECH FIG 3J).
- Reconfirm correct alignment in all planes, paying particular attention to rotation. Confirm satisfactory hardware positioning (TECH FIG 3K).
- Morselized bone graft can be harvested from the resected metacarpal head and packed in and around the arthrodesis site if needed.
- Close the joint capsule with absorbable suture to minimize extensor tendon adhesions.
- Approximate the extensor tendon interval with interrupted, inverted permanent suture and close the wound in a routine fashion (TECH FIG 3L).
- Place a forearm-based thumb spica splint.

**Plate and Screw Fixation**

- It may be desirable to use plate and screw fixation rather than cannulated screws in such cases as nonunion after attempted arthrodesis, failure of implant arthroplasty, and traumatic injuries with severe deformity, bone loss, or segmental defects (TECH FIG 4).
- The advantage of plates and screws is that more rigid, secure fixation can be achieved immediately, avoiding the concern for rotation or loosening around a single cannulated screw.
- The disadvantage of that technique is that hardware prominence and tendon irritation and adhesions are more often a subsequent source of trouble.
- If plate and screw fixation is chosen as the desired technique, then the overall approach and bone preparation are similar to that described for the cannulated screw technique.
- With the arthrodesis site reduced and temporarily stabilized with a Kirschner wire, a 2.0-mm, five-hole compression plate is contoured to the dorsal surface of the bones.
- The plate is first secured distally and then applied proximally using compression technique principles.
- It is critical to avoid long screws and irritation of the flexor pollicis longus.
- Closure and postoperative care are similar to that described earlier.

**TECH FIG 4** - Arthrodesis with plate and screw fixation.
**PEARLS AND PITFALLS**

| Initial treatment | - Acute MP joint dislocations should be reduced promptly, but straight traction should be avoided because it can result in soft tissue entrapment and turn a simple dislocation into a complex, irreducible injury requiring open reduction.  
- The joint should be immobilized and protected long enough and rehabilitated carefully enough to avoid chronic volar instability. |
| Treatment indications | - Chronic volar instability without arthritic change can be treated with a variety of capsulodesis procedures.  
- When arthritic changes have developed as a result of chronic instability, MP joint arthrodesis should be done. |
| Hardware problems | - Cannulated screws work well for MP arthrodesis and leave the hardware buried.  
- Plates and screws, Kirschner wire fixation, and transosseous wiring techniques can be effective ways of achieving arthrodesis but are more likely to cause hardware problems requiring subsequent treatment. |

**POSTOPERATIVE CARE**

**Acute Dislocation**
- The MP joint is generally stable once a dislocation is reduced acutely, whether by closed or open methods.  
- The MP joint should be held in about 30 degrees of flexion in a short-arm thumb spica splint or cast for 2 weeks.  
- ROM exercises can begin thereafter, using a removable thumb spica splint for an additional 4 weeks, gradually weaning out of the splint and advancing activities as symptoms allow.  
- Supervised hand therapy is often helpful for patients to guide their recovery of motion and strength and optimize their outcomes.

**Chronic Instability**
- Volar plate advancement procedures and the Tonkin sesamoid arthrodesis procedure should be protected with the thumb MP joint flexed in a cast for 4 to 6 weeks, depending on the surgeon’s assessment of tissue quality and patient compliance. Then supervised ROM can begin, but MP joint hyperextension forces should be avoided for 8 to 12 weeks.  
- MP joint arthrodesis procedures require longer protection so that the fusion site is not stressed or disrupted before final bony union.  
- Generally it is best to use a thumb spica splint (plaster) for the first 10 to 14 days after surgery until the swelling decreases and the sutures are removed.  
- Then a thumb spica cast can be used for an additional 3.5 to 4 weeks, at which time a custom-molded, removable splint can be used to protect the arthrodesis site but allow ROM of the uninvolved adjacent joints of the hand to prevent undue stiffness.  
- By 12 weeks most arthrodeses are healed solidly enough to allow unrestricted hand use.

**OUTCOMES**
- Acute volar instability and dorsal dislocations of the MP joint that are treated appropriately can be expected to have a good prognosis.\(^2\),\(^3\),\(^9\) Whether the dislocation is reduced closed or open reduction is required, once the joint is reduced it is usually stable.  
- Following rehabilitation as outlined above, there well may be some residual joint stiffness. While that may continue to improve for up to 1 year after injury, the lost range of motion is rarely a functional problem.  
- Tonkin et al.\(^11\) reported successful outcomes in 38 of 42 cases (90%) of sesamoid arthrodeses for chronic MP joint volar instability. Those results compare favorably with outcomes following other capsulodesis and volar plate reinforcing procedures. The advantage of all such procedures is that hyperextension is blocked, restoring stability to the joint, while still allowing the MP joint to flex. Mean loss of flexion compared with the preoperative condition was 8 degrees in the series reported by Tonkin et al.\(^11\)  
- Outcomes after arthrodesis for chronic volar instability must be viewed with the proper surgical goal in mind. The goal is to relieve pain (from instability and arthritic change) and provide stability to the thumb ray. Success rates are high, barring any unfortunate complications as discussed next.

**COMPICATIONS**
- Complications following MP joint dislocations are uncommon and mostly limited to the sequelae of concomitant soft tissue injuries.  
- Damage to the adjacent neurovascular structures can result from the initial traumatic injury or careless surgical technique at the time of open reduction.  
- Damage to the flexor pollicis longus tendon may occur when it gets trapped in the joint or again when it is manipulated surgically during an open reduction.  
- A complication encountered more often is persistent, chronic instability of the MP joint that results from failure to recognize the nature of the original injury or rehabilitate it properly.  
- Complications after treatment for chronic MP joint volar instability are likewise uncommon and generally related to failure of the chosen procedure.  
- Volar plate advancement can fail due to stretching out over time or a second trauma that causes acute rupture of the repair or sutures.  
- Nonunion of attempted arthrodesis is always a risk, but fortunately in the small joints of the hand, including thumb MP joints, it is uncommon. Nonunion rates range from 0% to 12% in several reported series.\(^12\)  
- Hardware causing soft tissue irritation is a potential complication. That can be from superficial pin tract infections in cases where Kirschner wires are used to maintain joint reduc-
tion to extensor tendon irritation when fusions are done using plates and screws.

REFERENCES


DEFINITION
- Ulnar collateral ligament (UCL) and radial collateral ligament (RCL) tears of the thumb metacarpophalangeal joint (MCP) are common injuries resulting from disruption of the continuity of these ligaments.
- These disruptions are frequently the result of an athletic injury, a fall, or a motor vehicle accident.

ANATOMY
- The MCP joint of the thumb is transitional between a condyloid and ginglymus joint. The articulating surface of the base of the proximal phalanx is a shallow concavity that provides relatively little intrinsic stability. Hence, most of the joint’s stability is afforded by its ligament and capsular supports.
- The RCL and UCL are both structurally similar, composed of both proper and accessory components, and are the main stabilizers of the thumb MCP joint.
- The proper collateral ligaments, which originate from a fossa in the metacarpal neck dorsal to the axis of rotation, are the primary ligamentous supports. They fan out from their proximal origins to distal insertions on the lateral and volar aspect of the base of proximal phalanx.
- The accessory collateral ligaments act as supplementary supports originating from the palmar aspect of the metacarpal neck fossa and inserting into the volar plate and the sesamoid on respective sides of the joint.
- The collateral ligaments provide not only medial and lateral stability but also stability in the dorsovolar plane by virtue of their dorsal origin and their volar insertion.
- The volar plate is a central fibrocartilaginous structure extending from the neck of the metacarpal proximally to the base of the proximal phalanx distally.
- One difference between the ulnar and radial sides of the MCP joint is related to the aponeurosis. The broad abductor aponeurosis covers the entire radial side of the MCP joint, whereas the much narrower adductor aponeurotic sheath spans the ulnar side of the joint.

PATHOGENESIS
- Acute injury of the UCL usually results from sudden forceful abduction and extension at the thumb MCP joint. This can take place during a fall on an outstretched hand with the thumb abducted, as seen in skiers, or in baseball players when the glove strikes the ground while fielding.
- The extent of the injury and the grade of the injury depend on the loading force at the time of impact. The most common injury of the thumb MCP joint is a partial disruption or sprain of the UCL.
- Tears of the UCL can occur anywhere within the ligament’s substance, although most take place at or near the site of insertion into the proximal phalanx, sometimes with an avulsion fracture (FIG 1A).
- The narrower adductor sheath on the ulnar aspect of the joint allows superficial displacement and entrapment of the torn proximal end of UCL, termed a Stener lesion (FIG 1B). Because of the broader abductor aponeurosis, however, such a lesion is not seen on the radial side.
- RCL injuries are generally caused by sudden abduction and extension of the MCP joint, commonly occurring during athletic injuries. They can also occur by direct blunt impact to the lateral side of the thumb.
- The RCL is more often injured close to its origin on the dorsal radial metacarpal head. It may also be disrupted in its midsubstance.

NATURAL HISTORY
- Untreated UCL injuries are relatively common. Patients are often sent away being told they simply have a “sprain.” If instability is present and not corrected, the patient may experience pinch weakness and eventually chronic pain.
- Untreated RCL tears are even more common and often result in late degenerative arthritis, commonly requiring MCP arthrodesis.
- Less severe avulsions may lead to prominent osteophytes on the dorso radial aspect of the metacarpal neck, suggesting the prior injury.
- Mondry first described the unstable thumb MCP joint in 1940, while Watson-Jones mentioned the importance of the UCL in relation to stability of the MCP joint of the thumb.
- Campbell described gamekeeper’s thumb as a chronic instability of the UCL in Scottish gamekeepers.
- Gerber et al. popularized the term skier’s thumb to refer to acute UCL injuries.
- Stener outlined the ligamentous anatomy of the thumb MCP joint and subsequent pathoanatomy of the lesion now termed the Stener lesion. Stener also described avulsion of the UCL leading to articular fracture of the proximal phalanx, now popularly referred to as a “bony gamekeeper’s thumb.”
- Moberg and Stener reported that UCL disruption is 10 times more common than RCL disruption. This frequency has been widely confirmed.
Frank and Dobyns reported that RCL injuries are somewhat more common than initially thought, with incidences ranging from 23% to 35% of collateral ligament injuries. This has echoed our experiences with the more subtle RCL injuries often being neglected, causing late morbidity.

### PATIENT HISTORY AND PHYSICAL FINDINGS

#### UCL Tears
- Patients with UCL tears present with pain, stiffness, tenderness, and swelling of the MCP joint. The defining symptom, however, may be marked pinch weakness.

- On examination there is discrete tenderness over the ulnar joint line, at the ulnar side of the metacarpal neck, and most classically at the volar ulnar base of the proximal phalanx.
- Physical examination is critical in establishing the need for surgical treatment by distinguishing between a partial and a complete ligament tear.
- A valgus stress examination comparing the stability of the injured versus the uninjured UCL is the best method to detect a complete tear.
- The stress test may be aided by live fluoroscopy and the use of a local anesthetic block.
- The presence of an associated fracture should not deter the examiner from performing a stress test. Nondisplaced avulsion fractures at the insertion site of the proper collateral ligament may coexist with a complete ligament tear.
- The results of the stress test are based on angular instability of the joint and the quality of the “end point.”
- Laxity of more than 30 degrees in extension and 15 degrees in flexion as compared to the contralateral side should be highly suggestive of a complete tear of the UCL.
- The presence of fullness or a palpable mass on the ulnar aspect of the metacarpal head and neck, representing a Stener lesion, is strongly suggestive of a completely disrupted and retracted UCL.
- Volar subluxation of the MCP joint signifies loss of the dorsal volar stabilizing effect of the collateral ligament and is also consistent with a complete tear.

#### RCL Tears
- RCL tears present as localized tenderness over the radial base of the proximal phalanx but more commonly over the metacarpal head.
- The dorsoradial aspect of the metacarpal head may be prominent due to soft tissue swelling.
- Acute RCL injuries are assessed in the same manner as discussed for UCL injuries.
- For the stress test of the RCL in extension and 30 degrees of flexion, laxity of the joint greater than 30 degrees as compared to the uninjured side suggests a complete tear of the RCL.
- The emphasis on distinguishing partial tears from complete tears does not directly affect treatment and therefore is less important than for UCL injuries. Even complete RCL tears are not capable of retracting behind the aponeurosis and therefore may be treated nonoperatively.
- RCL injuries are more common than often thought. Significant radial-sided pain with laxity or subtle radiographic signs of dorsal capsule avulsion necessitate treatment.

#### IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographs include posteroanterior, lateral, and oblique views of the thumb. Images of the contralateral thumb are used for comparison and may reveal subtle joint subluxation.
- Stress radiographs of the MCP joint in full extension and in 30 degrees of flexion are rarely required though occasionally
can help distinguish between a partial and complete ligament injury.4,12

- MCP joint arthrography, MRI, and ultrasound have all been used to determine the degree of ligament injury and displacement but are almost never required.
- On MRI, a Stener lesion is characterized by a “yo-yo on a string” sign.

**DIFFERENTIAL DIAGNOSIS**

- Diffuse capsular injury without discrete ligament tear
- Fracture or articular cartilage injury
  - The articular surface is best assessed via arthroscopy or perhaps MRI.
- Arthritis
  - Diffuse soft tissue injury involving a previously asymptomatic but arthritic joint can result in persistent pain.

**NONOPERATIVE MANAGEMENT**

- Treatment depends on the severity of injury, the type of tear,7,14,16,17,20,22 and the presence of an avulsion fracture involving a significant portion of the articular surface or an open physis.
- Partial UCL and partial and complete RCL tears without volar subluxation of the proximal phalanx can be effectively managed by immobilization, then protected mobilization using a removable splint for a total of 4 to 6 weeks.
  - Initial immobilization is traditionally accomplished using a thumb spica cast. Such a cast allowing wrist motion is preferable.
  - Alternatively, a customized thermoplastic splint that immobilizes only the thumb MCP joint and leaves the wrist and interphalangeal joint free can be used for reliable patients with less severe injuries.

**SURGICAL MANAGEMENT**

- Complete UCL disruption, especially if denoted by a Stener lesion or joint subluxation, should be treated surgically. Additionally, a displaced avulsion fracture involving a significant portion of the articular surface should be reduced and stabilized operatively.
- An avulsion fracture of the proximal phalanx can be effectively managed by arthroscopic techniques.3,23,24 Occasionally, it is necessary for an arthroscopic procedure to be converted to an open procedure if reduction of a large or comminuted fracture fragment in the proximal phalanx is not feasible (FIG 3).
- Injuries associated with a Stener lesion warrant open repair.
- Partial tears of RCL are best managed by cast immobilization, whereas complete tears associated with palmer subluxation require open surgical repair of the ligament and dorsal capsule.10
- Arthroscopy can also be a useful adjunct to open procedures as it allows a more thorough débridement and evaluation of concomitant pathology.
- A regional anesthetic combined with light intravenous sedation is generally adequate for the procedures detailed below.
ACUTE UCL DISRUPTIONS

Arthroscopic Treatment of UCL Avulsion Fractures

- Traction is applied using a finger trap placed on the thumb with 5 pounds of counterforce.
  - A traction tower is not used in order to facilitate fluoroscopy.
- Palpate the joint and then inject 1 to 2 mL of lidocaine using an 18-gauge needle.
  - Take care to avoid injuring the articular cartilage.
- Insert a 1.9-mm 30-degree arthroscope via a longitudinal portal stab wound on the radial side of the extensor pollicis longus tendon.
  - This allows the best visualization of the ulnar-sided pathology.
- Insert a 2-mm full-radius shaver in the ulnar portal and evacuate the hematoma and any minute bone fragments that may prevent visualization.
- Perform a synovectomy, with emphasis on the ulnar side. This allows clear delineation of the avulsed fracture fragment (TECH FIG 1A).
- Insert a small probe through the ulnar portal and hook the fragment on its radial side, within the fracture site. Gentle proximal and radial traction on the ulnar fragment typically accomplishes the reduction.
- Preoperative radiographs help to plan the specific maneuver necessary for fracture reduction, but the arthroscopic picture will ultimately determine the direction of fragment derotation required to achieve anatomic reduction of the joint.
  - Reintroduce the shaver as needed for débridement and to assist fracture reduction.
  - Insert a 0.035-inch Kirschner wire percutaneously into the joint just proximal and ulnar to the reduced bony fragment (TECH FIG 1B).
- Arthroscopic visualization aids in placement and orientation of the transfixing Kirschner wire using the wire driver (TECH FIG 1C).
  - Using the wire driver, engage the radial cortex to stabilize the fracture fragment.
  - Use both fluoroscopy and arthroscopy to determine the adequacy of fragment reduction as well as to confirm proper wire placement and fracture stability (TECH FIG 1D,E).
  - Cut the wire just underneath the skin (TECH FIG 1F).
  - Close the skin and apply a bulky thumb spica plaster splint while the thumb is still suspended.
  - Final fluoroscopic pictures are taken and the tourniquet is released.

Open Repair of Complete UCL Disruptions

- Make a curvilinear or a longitudinal lazy-Z incision with the superior or dorsal portion proximal.
- The UCL origin is more dorsal and fans out in volar fashion.

TECH FIG 1 • A. With the arthroscope in the dorsoradial portal and the shaver in the dorsoulnar portal, arthroscopic débridement is performed before reduction of the fragment. B. The fragment is reduced arthroscopically and stabilized with a Kirschner wire. C. Arthroscopic view showing the Kirschner wire and the fracture fragment before reduction. D. This displaced and rotated bony avulsion fracture at the attachment of the UCL is reduced arthroscopically and stabilized. E. Radiograph showing anatomic arthroscopic reduction and pinning. F. The Kirschner wire, fixing the avulsed fragment, is cut beneath the skin.
Dissect the subcutaneous tissues with small tenotomy scissors, taking care to maintain hemostasis using a bipolar cautery.

Identify the dorsal radial sensory nerve branches and gently retract them dorsally.

Take note of the oblique transverse fibers of the adductor aponeurosis. In more severe injuries the aponeurosis my be torn, revealing the underlying UCL.

Divide the adductor aponeurosis longitudinally, allowing the muscular origin of the adductor pollicis to pull back the fascia and facilitate posterior retraction of the aponeurosis.

The torn UCL is seen directly under the incised adductor aponeurosis (TECH FIG 2A).

In the case of a Stener lesion, the retracted and displaced stump of the UCL is visualized just superficial to the proximal edge of the adductor aponeurosis before incision.

Determine the direction of the UCL fibers and incise the joint capsule on the ligament’s dorsal margin.

Inspect the joint, and perform a limited débridement and synovectomy as indicated.

Precisely determine the location and degree of UCL injury.

Less common intrasubstance tears are repaired primarily with 3-0 or 4-0 permanent suture in a mattress or figure of 8 configuration.

Avulsion of the ligament attachment from the base of the proximal phalanx is most frequently encountered and is treated by reattaching the ligament's insertion.

Isolate the anatomic insertion site for the proper collateral ligament on the volar ulnar base of the proximal phalanx and prepare the site for ligament attachment by débriding the remaining soft tissue down to bleeding bone.

Creating a small bony trough at the insertion site helps stimulate bleeding and ligament attachment (TECH FIG 2B).

Prepare the UCL stump by mobilizing it on its margins and freshening the distal end with a no. 15 blade.

Insert a 2-mm or smaller suture anchor into the prepared bony site and verify its position with fluoroscopy.

While the thumb is deviated in an ulnar direction, reattach the ligament stump to the proximal phalanx by placing a horizontal mattress stitch using the suture from the anchor.

Repair the accessory portion of the UCL by placing 3-0 or 4-0 permanent suture from the ligament into the ulnar margin of the volar plate.

Additional permanent sutures may be placed to secure the repaired UCL to surrounding soft tissues.

Close the capsule to the dorsal margin of the ligament using 4-0 absorbable suture.

Precisely reconstruct the adductor aponeurosis with 4-0 inverted interrupted permanent suture and close the skin.

Ensure restoration of stability and maintenance of full MCP joint flexion.

Place a forearm-based thumb spica splint.

Very severe injuries with extensive disruption of soft tissue stabilizers may rarely require augmentation with a temporary Kirschner wire.

ACUTE RCL DISRUPTIONS

Make a dorsoradial curvilinear or a longitudinal lazy-Z incision similar to that used for the repair of UCL disruptions, and dissect the soft tissues as detailed earlier.

Incise the adductor aponeurosis in line with the RCL.

Radial-sided lesions are often coupled with concomitant avulsions of the dorsal capsule. If the capsule is intact, incise it along the dorsal margin of the RCL to inspect the joint.

Isolate the ligament and its point of disruption, and then mobilize the structure to allow for anatomic repair.

Typically, disruptions take place at the proximal origin (TECH FIG 3A).

Débride the bone and ligament stump in the manner detailed for open repair of UCL avulsions.

Remove reactive bone and early osteophytes at the site of ligament or capsule avulsion with a rongeur.

Place a 2.0-mm or smaller suture anchor in the collateral recess, the dorsoradial distal metacarpal.

Ensure proper placement radiographically.

Reattach the ligament to its anatomic point of origin using the suture from the anchor (TECH FIG 3B).

Repair the capsule and further secure the RCL to surrounding soft tissue with 3-0 or 4-0 permanent suture (TECH FIG 3C).
PEARLS AND PITFALLS

- MCP ligamentous lesions require a high index of suspicion.
- The obvious lesions with instability will likely get appropriate repairs with subsequent rehabilitation programs.
- Missing a significant ligament tear may cause few physical problems short term but may become a chronic painful lesion long term.
- This is where arthroscopy may also play a good role. The chronically painful lesions may not demonstrate laxity or even a gross physical problem. Nevertheless, the pain is present and repeat corticosteroid injections are certainly not a solution. Arthroscopic synovectomy or capsular or ligamentous débridement will alter the articular milieu enough to allow for resolution of chronic pain and swelling. All this is coupled with rapid resolution of symptoms and recovery of range of motion.

POSTOPERATIVE MANAGEMENT

- Bony gamekeeper’s thumb
  - A fiberglass thumb spica cast is applied at 1 week postoperatively and the pin is removed under local anesthesia at about 5 weeks postoperatively.
  - A brief course of physical therapy is initiated. The patient is given a hand-based thumb–carpometacarpal type of removable splint to be used during strenuous activities.
  - Therapy is usually short term owing to less swelling and stiffness as compared with open approaches.
  - All unrestricted activities are permitted at 8 weeks.
- UCL and RCL injuries: True ligament-to-bone healing is necessary, so 6 weeks of postoperative thumb spica immobilization is critical to success.

OUTCOMES

- Many contralateral thumbs display a flexion arc of less than 20%; therefore, the normal restoration of full motion is not the goal. Good stability without pain should be the aim.
- RCL injuries of the thumb tend to have a higher tendency to develop posttraumatic arthritis.
- Our long-term experience has shown the need for late arthrodesis on only two occasions. These are cases in which significant volar subluxation is present, and the articular wear at time of surgery was likely predictive of this long-term outcome.
- A chronically painful thumb, with any degenerative changes on radiographs, coupled with volar posturing of the phalanx, should likely be considered straightaway for fusion.
- Thorough counseling of the patient indicating the minimal deficit produced by arthrodesis is helpful.

COMPLICATIONS

- Careful surgical dissection should avoid the most common complication, which would be iatrogenic trauma to the dorsal sensory nerve. Once done, there are minimal complications associated with this area of hand surgery.
- Other complications can include stiffness, as previously discussed, infection, persistent instability, or chronic pain syndromes.
- Recalcitrant pain or instability can simply be managed by arthrodesis, still portending a good functional outcome.
REFERENCES

Reconstruction of Chronic Radial and Ulnar Instability of the Thumb Metacarpophalangeal Joint

Steven Z. Glickel and Louis W. Catalano III

DEFINITION
- Chronic instability of the ulnar collateral ligament (UCL) and the radial collateral ligament (RCL) of the metacarpophalangeal (MCP) joint of the thumb usually results from unrecognized or untreated acute tears of the ligament.
- Persistent laxity may cause pain and weakness and, eventually, osteoarthritis resulting from asymmetrical wear of the articular cartilage.

ANATOMY
- The MCP joint of the thumb has characteristics of both a condyloid and a ginglymus joint. The radial condyle is taller in the dorsovolar dimension than the ulnar condyle.
- The dorsoulnar and dorsoradial digital nerves are terminal branches of the superficial sensory branch of the radial nerve and invariably cross the operative field in the plane immediately superficial to the adductor and abductor aponeuroses, respectively.
- They are at risk during reconstruction of the collateral ligaments. During the exposure of the joint, the nerve should be mobilized and gently retracted.
- The adductor aponeurosis is an extension of the tendon of the adductor pollicis muscle, which contributes obliquely oriented fibers to the extensor mechanism distal to the vertical fibers.
- The abductor aponeurosis is wider than the adductor aponeurosis. Hence, a ruptured ligament is separated from its deep insertion by the aponeurosis, preventing ligament healing.
- The abductor aponeurosis is wider than the adductor aponeurosis. When the RCL tears, the ends of the torn ligament remain deep to the abductor aponeurosis. Hence, a Stener type of lesion rarely occurs on the radial side.

PATHOGENESIS
- The UCL of the MCP joint of the thumb is usually torn by forceful abduction and extension of the thumb, as in a fall on the outstretched hand with the thumb abducted. The proximal phalanx deviates radially and, if there is sufficient force, the proximal phalanx avulses from its insertion on the base of the proximal phalanx. As the proximal phalanx deviates radially, the ruptured UCL stump retracts proximal and superficial to the adductor aponeurosis. Hence, the avulsed ligament is separated from its deep insertion by the aponeurosis, preventing ligament healing.
- The abductor aponeurosis is wider than the adductor aponeurosis. When the RCL tears, the ends of the torn ligament remain deep to the abductor aponeurosis. Hence, a Stener type of lesion rarely occurs on the radial side.

NATURAL HISTORY
- Over time, chronic tears of the collateral ligaments of the thumb MCP joints cause weakness of pinch and grip due to lack of stability and pain.
- Incompetence of the UCL diminishes the thumb’s ability to act as a stable post against which to pinch with the index finger. Patients often have difficulty holding large objects that require counterpressure by a stable thumb. Patients with chronic RCL instability often have pain with torsional motions like unscrewing jar tops.

In summary, chronic instability of the thumb MCP joint can cause pain, weakness, and instability. Reconstruction procedures may be necessary to restore function and prevent further injury.

- The proper ulnar and radial collateral ligaments originate from fossae of the condyle of the metacarpal head on the radial and ulnar sides and pass obliquely from dorsal proximal to volar distal to insert on the volar third of the base of the proximal phalanx. The ligament widens as it goes from its metacarpal origin to its proximal phalangeal insertion.
- The proper collateral ligaments are tight in MCP joint flexion and lax in extension.
- The accessory collateral ligaments originate on the metacarpal head contiguous with but just volar to the proper collateral ligament and extend obliquely across the MCP joint, inserting on the sesamoid and volar plate.
- The accessory collateral ligaments are tight in extension and lax in flexion.
- By definition, to have a complete ligament rupture, both the proper and the accessory collateral ligaments must be torn.
- The Stener lesion is a palpable soft tissue mass on the ulnar aspect of the MCP joint. It results from a tear of the UCL caused by forceful radial deviation of the proximal phalanx, angulating the MCP joint 70 degrees or more. The ligament tears distally at or near its insertion on the volar ulnar base of the proximal phalanx. As the proximal phalanx deviates radially, the ruptured UCL stump retracts proximal and superficial to the adductor aponeurosis. Hence, the avulsed ligament is separated from its deep insertion by the aponeurosis, preventing ligament healing.
- Two primary causes of chronic instability of the UCL exist.
  - Inadequate treatment of an acute, complete UCL disruption, with or without an associated Stener lesion
  - Progressive attenuation of the ligament due to repetitive trauma
- Tears of the RCL typically result from forceful ulnar deviation and extension of the MCP joint.
  - Proximal and distal avulsions of the ligament occur with roughly equal frequency.
  - Intrasubstance tears occur infrequently.
- Chronic instability of the radial RCL has three primary causes.
  - Most commonly, chronic laxity is due to lack of recognition of the pathology and therefore inadequate or late treatment.
  - Even when recognized, conservative management may fail.
  - Chronic attenuation due to repetitive trauma is less common.
• Chronic laxity may cause incongruity and asymmetrical wear of the MCP joint, which may progress to posttraumatic osteoarthritis of the joint.
• Arthritis of the joint causes pain, stiffness, and progressive weakness.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

• Obtaining a relevant history from patients with chronic instability of the thumb MCP joint includes eliciting a history of trauma to the thumb in the recent or distant past.
• Patients are questioned about pain in the thumb, particularly if it is exacerbated by forceful pinch and grasp and torsional activities like turning keys in locks, turning doorknobs, or unscrewing jar tops.
• The examine should establish the chronicity of the symptoms and whether they are increasing in severity.
• Assessment of instability of the thumb MCP collateral ligaments is primarily clinical.
• Clinical examination begins with observation.
• The resting posture of the thumb at the MP joint is occasionally indicative of pathology. The joint may be angulated or rotated in its resting posture if the collateral ligament is grossly incompetent and the instability is chronic.
• In thumbs with chronic RCL instability, there is often a dorsal prominence on the radial aspect of the metacarpal head. Such a prominence is generally not present in cases of chronic UCL instability.
• The involved side of the joint is usually tender to palpation.
• Palpation of a fullness or soft tissue mass on the ulnar side of the metacarpal head is strongly suggestive of a Stener lesion.
• Stability of the collateral ligament is tested in extension and 30 degrees of MCP joint flexion (under local anesthesia if needed). There is no consensus in the literature concerning the degree of instability that is diagnostic of a complete tear.
• Valgus stress of the MCP joint in flexion is used to assess the stability of the proper UCL, whereas stress with the joint in extension is used to assess the accessory UCL as well.
• The criteria for diagnosis of a complete ligament disruption that are most accurate were described by Heyman et al and include 30 to 35 degrees of laxity of the ulnar side of the MCP joint when stressed in extension and 15 degrees more laxity than the contralateral thumb when stressed in 30 degrees of flexion.
• Laxity in extension suggests that the accessory and proper collateral ligaments are both torn.
• A more subtle, but often more helpful, finding is the presence or absence of a discrete endpoint to joint opening when stressed. Absence of a solid endpoint is strongly suggestive of a complete ligament tear.
• To test for joint degeneration, the MP joint is passively moved in extension and flexion combined with radial and ulnar deviation. The joint is axially loaded as it is deviated. Crepitus and pain strongly suggest the presence of osteoarthritis, a contraindication to reconstruction of an unstable MCP joint.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

• Radiographic evaluation includes PA, lateral, and oblique radiographs of both thumbs.
• Fractures should be ruled out.
• The lateral view may show volar subluxation of the MCP joint, which is fairly common and may be the result of extension of the collateral ligament tear to involve the dorsal capsule. This may occur with UCL or RCL tears. An isolated tear of the dorsal joint capsule very rarely causes volar subluxation without an associated collateral ligament injury.
• A comparison lateral radiograph of the contralateral thumb is extremely helpful if volar subluxation is suspected.
• Stress views of the MP joint have been recommended to radiographically demonstrate instability.
• Most experienced clinicians rely almost exclusively on physical examination and static plain radiographs to make the diagnosis.
• MRI, ultrasound, and arthrography are rarely indicated to assess completeness of the UCL tear, particularly in the setting of a chronic injury.
• The use of arthroscopy as a diagnostic and treatment modality in the setting of chronic UCL instability remains investigational.

**DIFFERENTIAL DIAGNOSIS**

• Fracture of the metacarpal head or base of the proximal phalanx
• Synovitis of the MCP joint
• Chronic partial tear of the UCL or RCL
• MCP joint arthrosis

**NONOPERATIVE MANAGEMENT**

• Customized hand-based thermoplastic splints, nonsteroidal anti-inflammatory medication, and corticosteroid injections may improve the synovitis and pain resulting from chronic instability and early degenerative arthritis.

**SURGICAL MANAGEMENT**

• The indication for reconstruction of chronic UCL or RCL disruption is failure of conservative treatment, with persistent pain and instability of the MCP joint.
• Instability alone is a soft indication for surgery.
• Theoretically, the asymmetric wear of the articular cartilage resulting from chronic laxity causes degeneration of the articular cartilage. This can be used as an argument for prophylactic reconstruction.
• Most patients without pain are hesitant to consider surgery and the prolonged rehabilitation required after surgery.
• Contraindications to reconstruction of UCL or RCL tears include osteoarthritis, “multidirectional” instability, and fixed subluxation of the joint.
• Mild chondromalacia is a relative contraindication to reconstruction and may be better treated by MCP arthrodesis.
• If an arthritic joint is stabilized, pain is likely to persist and increase over time, necessitating conversion to an arthrodesis.
• Fixed instability of the MCP joint is an uncommon contraindication to ligament reconstruction.
• Reconstruction of the incompetent ligament in this scenario requires an extensive joint release, creating “multidirectional” instability.
• Failure to release the joint adequately results in rapid recurrence of the preoperative deformity and instability.
Reconstruction of chronic instability may involve mobilization of the disrupted ligament, mobilization of local tissues, or ligament replacement using a tendon graft.

- The decision is made at the time of surgery.
- The more chronic the injury and the more dramatic the laxity and deformity, the more likely the need for replacement of the ligament with a graft.

**Preoperative Planning**

- The patient is asked to actively bring all five digits together and simultaneously flex the wrist against resistance. The volar wrist is inspected for the presence of a palmaris longus tendon.
- Examination under anesthesia may show even greater joint laxity than expected.

**Positioning**

- The patient is supine on the operating room table with the arm on a hand table at an angle slightly less than perpendicular to the torso.

**Approach**

- Lazy-S incision centered over the MCP joint
- Midaxial incision
- Chevron-shaped incision centered over the midaxial point of the MCP joint

**RECONSTRUCTION OF CHRONIC UCL DISRUPTIONS USING TENDON GRAFT**

**Exposure**

- Incise the skin over the ulnar joint line (TECH FIG 1A,B).
- Elevate skin flaps and retract them with 4-0 silk sutures.
- Identify and protect the branch of the dorsoulnar digital nerve that invariably crosses the wound (TECH FIG 1C).
- Identify the frequently fibrotic adductor aponeurosis.
  - The proximal stump of the torn UCL may be visualized at the proximal margin of the adductor aponeurosis if a Stener lesion is present.
- Incise the adductor aponeurosis longitudinally, exposing the underlying torn UCL (TECH FIG 1D).
- If the ligament cannot be defined and mobilized sufficiently for direct repair or reinsertion the remnant of the ligament is excised, exposing the ulnar side of the distal metacarpal head, the base of the proximal phalanx, and the MCP joint (TECH FIG 1E).
- The MCP joint is “booked open” to visualize the articular cartilage.
- Significant degenerative disease is a contraindication to reconstruction (TECH FIG 1F).

**TECHNIQUES**

- Incise the skin over the ulnar joint line (TECH FIG 1A,B).
- Elevate skin flaps and retract them with 4-0 silk sutures.
- Identify and protect the branch of the dorsoulnar digital nerve that invariably crosses the wound (TECH FIG 1C).
- Identify the frequently fibrotic adductor aponeurosis.
  - The proximal stump of the torn UCL may be visualized at the proximal margin of the adductor aponeurosis if a Stener lesion is present.
- Incise the adductor aponeurosis longitudinally, exposing the underlying torn UCL (TECH FIG 1D).

**TECH FIG 1**

- **A.** The lazy-S incision used for ulnar collateral ligament reconstruction. The proximal incision is dorsal and the distal incision is midaxial. **B.** A chevron-shaped incision is made centered over the ulnar side of the metacarpophalangeal joint. **C.** A dorsal ulnar sensory nerve branch is identified and protected throughout the surgery. **D.** The adductor aponeurosis is incised longitudinally about 2 mm from the extensor expansion, providing a cuff of tissue dorsally to facilitate an adequate repair at the end of the procedure. (continued)
Bone Preparation

- Make two holes in the ulnar base of the proximal phalanx using hand-held gouges of increasing diameter (TECH FIG 2A).
  - The diameter of the hole required depends on the size of the tendon graft to be used for reconstruction.
  - The preferred donor is the palmaris longus, which is usually fairly thin and can fit in a relatively small hole.
  - The gouge holes must be made far enough apart to preserve a substantial bony bridge between the holes.
  - A bridge that is too narrow can fracture during passage of the tendon graft.
- Place the holes at the 7 and 11 o’clock positions in the base of the proximal phalanx if looking at the right thumb end on. Make the holes at an angle of about 45 degrees to the bone surface and direct them toward each other in order to converge within the medullary canal and create a bone tunnel.
- Prebend a 28-gauge stainless steel wire into the approximate arc of curvature of the bone tunnel to facilitate its passage.
- Pass the wire through the bone tunnel and secure the ends with a hemostat.
- Create a second bone tunnel in the metacarpal neck. Use the gouges beginning at the fossa from which the UCL normally originates and extending slightly obliquely, from distal to proximal, across the metacarpal, exiting radially (TECH FIG 2B,C).
  - Most often the small, medium, and large gouges are used to create one large hole since both ends of the tendon graft are passed through this hole.

TECH FIG 2 • A. The proximal phalangeal holes are made at the 7 and 11 o’clock position; the surgeon must be careful to make a wide bone bridge to avoid fracture. A 28-gauge wire is placed into the bone tunnel to assist with passage of the tendon graft. B. A large gouge is used to create a single hole in the metacarpal head. An incision is made radially over the end of the gouge to allow for fixation of the graft. C. The adductor aponeurosis has been divided and the collateral ligament remnants have been excised. Gouge holes have been made in the base of the proximal metacarpal head.
A second 28-gauge stainless steel wire is placed through this bone tunnel and the ends are secured with another hemostat.

Preset a 0.045-inch Kirschner wire (sharp at both ends) in the metacarpal head for later advancement across the MCP joint.

Radially deviate the proximal phalanx to expose the metacarpal head.

Starting in the center of the metacarpal head and aiming at an angle of about 45 degrees, advance the wire retrograde through the radial cortex of the metacarpal shaft until it is just below the articular surface of the metacarpal head.

**Tendon Graft Harvest and Passage**

Harvest the palmaris longus (PL) for use as a graft.

If the palmaris is absent, use half of the flexor carpi radialis (FCR) tendon or the plantaris tendon.

The obvious advantage of the FCR is its availability without requiring a second surgical site.

Make a short transverse incision over the PL tendon at the distal wrist flexion crease (TECH FIG 3A) and mobilize the tendon distally.

Make a second, proximal incision over the PL musculotendinous junction and mobilize the tendon at this level and under the skin bridge.

Use of a tendon stripper is an alternative method of harvest.

After incising the PL as distal as possible, apply firm traction and withdraw the tendon through the proximal incision, and then divide the tendon at the musculotendinous junction.

Secure the tendon graft to the limb of the stainless steel wire emerging from the more volar of the two proximal phalangeal gouge holes by tying a knot around one end of the tendon graft (TECH FIG 3B) or by using a grasping suture placed through the graft.

Moisten the tendon graft with saline.

Pull the wire to draw the tendon into and through the bone tunnel, emerging from the dorsal hole (TECH FIG 3C).

The tendon is pulled using moderately firm traction and a circular motion of the wire.

Avoid fracturing the bony bridge between the gouge holes by pulling too firmly on the wire with a vector of pull away from the bone.

The wire is removed from the end of the tendon.

Remove this wire and tie the ulnar end of the wire previously placed in the metacarpal bone tunnel around both ends of the tendon graft.

Using the same technique combining lubrication, traction, and rotation of the wire, bring the two ends of the graft together and through the metacarpal gouge hole, exiting radially (TECH FIG 3D,E).

Set the tension of the reconstruction by pulling on both limbs of the graft simultaneously and stressing the joint with radially directed force on the proximal phalanx.

Flexion and extension should not be limited and the joint should open minimally with stress.

When the desired tension is achieved, tie the ends of the graft in a knot (TECH FIG 3F).

Suture the knot to the adjacent periosteum with two mattress sutures stitches of 3-0 braided synthetic suture.

Alternatively, place a bone anchor adjacent to the metacarpal tunnel on the radial side and use the loaded sutures to secure the knot.

Transfix the MCP joint by driving the previously placed Kirschner wire antegrade, across the joint into the proximal phalanx (TECH FIG 3G,H).

Bend and cut the proximal end of the Kirschner wire superficial to the skin.

Suture the tendon graft to the native collateral ligament remnants using 3-0 braided synthetic suture (TECH FIG 3I).

Repair the adductor aponeurosis with 5-0 absorbable PDS suture (TECH FIG 3J).

Reapproximate the skin with either subcuticular 4-0 Prolene or interrupted, absorbable 5-0 suture.

A forearm-based thumb spica splint is applied, leaving the thumb interphalangeal joint free.
**Hand Fractures and Dislocations**

**Reconstruction of Chronic RCL Disruptions Using Tendon Graft**

- The steps used to stabilize the radial MCP joint using a tendon graft are much the same as those detailed for reconstruction of chronic UCL disruptions.

**Exposure**

- Center the skin incision over the radial MCP joint line (**TECH FIG 4A**).

- Identify and protect the branch of the dorsoradial digital nerve (**TECH FIG 4B**).

- Incise the adductor aponeurosis longitudinally, exposing the underlying torn RCL.

- In thumbs with chronic instability the RCL may be densely fibrotic and adherent to the underlying ligament.

**TECH FIG 3** *(continued)*

- E. The graft has been passed through the gouge holes and is secured on the radial side of the thumb metacarpophalangeal joint by tying the ends into a knot; it is further secured with sutures to local tissue. **F.** The graft ends are tied into a knot and secured to the local periosteum with 3-0 nonabsorbable suture. **G,H.** AP and lateral radiographs verify concentric joint reduction and proper placement of the transfixing 0.045-inch Kirschner wire. The Kirschner wire is left in place for 6 weeks. **I.** The tendon graft is sutured to the dorsal and volar remnants of the native collateral ligament for additional fixation. **J.** The adductor aponeurosis is repaired with 5-0 absorbable suture. This layer must be repaired separately from the collateral ligament as differential gliding between the two layers occurs with thumb motion.

**TECH FIG 4**

- A lazy-S incision is used for radial collateral ligament reconstruction. **B.** A dorsal radial sensory nerve branch is identified and protected.
TECH FIG 5 • A. Two holes are made in the base of the proximal phalanx using a small, then a medium gouge. A 28-gauge wire is placed through the bone tunnel to be used later for passage of the graft. B. An axial view of the proximal phalanx of a right thumb demonstrating the 1 and 5 o’clock positions of the gouge holes when viewed from the side. C. A single large hole is made in the metacarpal neck and another 28-gauge wire is placed through this hole, exiting ulnarly.

- Excise the remnant of the RCL, exposing the radial side of the metacarpal head, base of the proximal phalanx, and MCP joint.
- Deviate the MCP joint to visualize the articular cartilage and ensure the absence of significant arthrosis.

**Bone Preparation**
- Using hand-held gouges of increasing diameter in the manner previously detailed, make two holes in the radial base of the proximal phalanx.
  - The holes are made at the 1 and 5 o’clock positions in the base of the proximal phalanx if looking at the right thumb end on (TECH FIG 5A,B).
  - The holes are made at an angle of about 45 degrees directed toward each other to create a continuous bone tunnel within the medullary canal.
  - The holes must be spaced far enough apart to maintain a substantial bony bridge.
  - A 28-gauge stainless steel wire is passed from one hole to the other through the medullary canal to be used for later passage of the tendon graft in the manner described above for UCL reconstruction.
- Create a bone tunnel in the metacarpal neck beginning at the fossa from which the RCL normally originates on the radial side of the metacarpal head and extending slightly obliquely, from distal to proximal, across the metacarpal, exiting ulnarly (TECH FIG 5C).
- A second 28-gauge stainless steel wire is placed through this hole and the ends are secured with a second hemostat.
- Preset a 0.045-inch Kirschner wire in the metacarpal head to be used later for transfixing the MCP joint.

**Tendon Graft Passage**
- Introduce the tendon graft into the prepared bone tunnels using the techniques described for UCL reconstruction (TECH FIG 6A,B).
- The tension of the reconstruction is set and the graft secured in the manner reviewed.
- The MCP joint is transfixied and the wound closed (TECH FIG 6C).
- A forearm-based thumb spica splint is applied, leaving the thumb interphalangeal joint free.

TECH FIG 6 • A. Both tendon ends are pulled together through the metacarpal head, exiting ulnarly. B. Converging gouge holes are made at the base of the proximal phalanx and an oblique hole is made in the metacarpal head. Subsequently, the graft is passed through these holes. (continued)
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traction on the dorsoulnar digital nerve</td>
<td>Excessive traction on the dorsoulnar digital nerve may cause numbness, paresthesia, and dysesthesia on the dorsoulnar aspect of the thumb distal to the incision.</td>
</tr>
<tr>
<td>Tools</td>
<td>Using hand-held gouges gives the operator good control of the direction and progressive enlargement of the holes in the proximal phalanx and metacarpal. If power tools are used to make the holes, soft tissue adjacent to the holes can be inadvertently wrapped up in the spinning instrument. The heat generated by a burr may also burn the bone.</td>
</tr>
<tr>
<td>Making holes in the proximal phalanx</td>
<td>The most important aspect of making the holes in the base of the proximal phalanx is to make them wide enough apart to maintain a substantial bone bridge. The greatest risk is making the holes too close together. The consequence is that the bridge fractures when the tendon graft is pulled through the holes.</td>
</tr>
<tr>
<td>Tying the wire</td>
<td>The wire used for passage of the tendon graft should be tied with hemostats, not manually; it can cut the skin of the surgeon’s fingers if done manually.</td>
</tr>
<tr>
<td>Graft tension</td>
<td>The graft can be made too tight, limiting motion of the MP joint and possibly causing pain postoperatively. The knot in the graft should be sutured after the tension has been set and felt to be appropriate. Less likely is the possibility that the graft is too loose, allowing persistent laxity of the joint. After the tension is set, the joint should be flexed and extended to ascertain that the reconstruction is not too tight to allow motion or too loose to adequately correct the instability.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- The thumb is immobilized in a thumb spica cast for 6 weeks postoperatively.
- At 6 weeks after surgery, the cast and pin are removed.
  - The thumb is immobilized after cast removal in a customized, thermoplastic short opponens splint fashioned by the hand therapist.
  - The splint is worn most of the time except when the patient is exercising the thumb or is sedentary.
  - Therapeutic exercise is done with the therapist and at home and includes active and active assisted range of motion in flexion and extension, avoiding force on the proximal phalanx, which would stress the reconstruction.
  - Patients are instructed to do 12 repetitions four or more times per day.
  - After 2 weeks, the thermoplastic splint is eliminated except for strenuous activity.
  - Patients continue range-of-motion exercises and begin strengthening with soft putty and light gripping.
  - At 12 weeks after surgery, pinch and grip strengthening and light free weights are initiated.
  - Full, unrestricted activity is allowed 16 weeks postoperatively.
- Patients are expected to regain about 80% of the range of motion of the contralateral thumb MP joint and nearly full range of motion of the interphalangeal joint.
  - Key pinch strength should be more than 90% of the contralateral, uninjured thumb at final follow-up.

OUTCOMES

- Reconstruction of the UCL using the technique described in this chapter produces results only slightly less favorable than UCL repair.
- Range of motion of the MCP joint averaged 80% of the uninjured side. Motion of the interphalangeal joint is often limited initially after reconstruction but at final follow-up was 94% of the unoperated thumb. Key pinch strength averaged 95% and grip strength averaged 103% of the unoperated thumb not corrected for handedness.
- Sixty-nine percent of patients had no pain postoperatively and the remainder had mild or intermittent pain. Eighty-eight percent of patients had no functional limitations, 8% had minimal limitations, and 2% had moderate functional limitation.
None of the reconstructions that had normal or minimally degenerated cartilage required revision due to development or progression of degenerative disease.\(^\text{11}\)

Results of RCL reconstruction in the hands of the same authors were similar to those of UCL reconstruction.\(^\text{6}\)

Range of motion of the MCP joint on the operated side was 59% of the unoperated side and interphalangeal range of motion was 94% of the unoperated thumb.\(^\text{6}\)

Both grip and key pinch strength were equal in the operated and unoperated thumbs.\(^\text{6}\)

The MCP joints were equally stable to stress in operated and unoperated thumbs.\(^\text{6}\)

Patients had minimal pain and no significant functional limitations. All returned to their preoperative occupations.\(^\text{6}\)

COMPLICATIONS

Some patients develop transient hypesthesia on the dorsal aspect of the thumb distal to the incision due to intraoperative traction on a branch of the radial sensory nerve.

This generally resolves over several weeks.

Occasionally, patients develop stiffness of the MP joint that is persistent. This may be the result of the reconstruction being too tight.

The MCP joint occasionally develops some laxity postoperatively, which may be a consequence of the reconstruction being too loose or the patient being too aggressive during rehabilitation.

The bony bridge between the proximal phalangeal gouge holes can theoretically crack intraoperatively, but this has not happened to the authors or their colleagues.

If it did occur, an alternative form of fixation of the graft to the proximal phalanx would have to be used, like suturing the graft to the adjacent periosteum, pulling it out through a gouge hole on the opposite side of the phalanx, or employing a suture anchor.

REFERENCES

DEFINITION
- Fractures and dislocations of the carpometacarpal (CMC) joints of the index through small fingers involve intra-articular fractures at the base of the metacarpals or pure dislocations between the metacarpals and carpus. The fracture can involve the base of the metacarpal or the trapezoid, capitate, or hamate articular surface.
- These fractures and dislocations can result in instability and articular incongruity (FIG 1).

ANATOMY
- The CMC joints connect the metacarpals and the distal carpal row.
- The shape and degree of constraint present in the joints differ from finger to finger.
  - The index and middle fingers have highly constrained articulations due to the shape of the index CMC articulation and supporting soft tissues. These include the flexor carpi radialis tendon, extensor carpi radialis longus and brevis tendons, and very strong capsular insertions. This provides for a strong radial column for the hand, and efficient force transfer to the radius (FIG 2A).
  - The ring and small fingers have a gliding articulation on the hamate, which allows for the closure of the hand around objects and is very important in power grip. This mobility makes them more susceptible to injury. The extensor carpi ulnaris tendon attaches to the base of the small finger metacarpal.4
  - The deep motor branch of the ulnar nerve crosses around the base of the hamate hook and runs along the volar surface of the CMC joints (FIG 2B). It is vulnerable at the time of injury or during fixation.

PATHOGENESIS
- Injuries of the CMC joints may be divided into two broad categories.
  - The first, involving a load applied to a flexed metacarpal, is by far the most common mechanism. This injury usually involves the ring and small fingers displacing dorsally as a unit relative to the hamate. This may occur as a dislocation only or include a marginal fracture of the hamate.8
  - The second mechanism involves an axially directed force that creates a comminuted fracture of the articular surface (FIG 3A). Severe crushing injuries can cause multiple dislocations and fractures diffusely throughout the CMC region1,7 (FIG 3B, C).

NATURAL HISTORY
- The natural result of an untreated fixation dislocation is progressive arthritis of the involved joints.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The patient’s history is important to assess the mechanism of injury, which provides further clues regarding concomitant injuries in the extremity.
Examine the hand for tenderness and local swelling.
Assess neurovascular integrity, especially function of the deep branch of the ulnar nerve (first dorsal interosseous contraction).
Examine the limb for other injuries.
Associated injuries should be detected by examination and verified by radiographs.
Preoperative notation of nerve function is important when comparing function following reduction and fixation.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
Radiographs of the CMC joints require careful positioning to assess each joint.

The transverse metacarpal arch causes the CMC joints of the index and middle fingers to appear in an oblique projection when a standard PA radiograph is obtained of the ring and small finger CMC joints, and vice versa (**FIG 4A**).
A true frontal radiograph is most easily obtained by positioning the hand in an AP projection with the dorsum of the hand placed flat on the cassette (or image intensifier, if using fluoroscopy). The base of the affected metacarpal should lie on the cassette (**FIG 4B**). This will result in a far more accurate portrayal of the joint, essential for assessing the fracture as well as checking hardware position after fixation.
Visualization of the joint surfaces at the base of the ring and small fingers differs in a typical PA projection (**FIG 4C**) and a properly positioned film of the same patient (**FIG 4D**).
The same principle holds for obtaining lateral radiographs. A semisupinated lateral view will best visualize the base of the index and middle CMC joints, and a semipronated lateral view will best show the bases of the ring and small finger CMC joints. A CT scan should be obtained in most cases to assess for articular injury. CT also is especially helpful for visualizing impacted articular surface fragments. The best visualization and determination of fracture patterns will be possible if the scan is obtained after preliminary reduction of any displaced fractures or dislocations associated with a fracture (FIG 4E).

DIFFERENTIAL DIAGNOSIS
- Metacarpal fracture
- Carpal bone fracture
- Carpometacarpal fracture/dislocation
- Fracture associated with neurovascular injury

NONOPERATIVE MANAGEMENT
- Nondisplaced fractures can be treated in a below-elbow cast that incorporates the affected digit or digits and one adjacent digit. Special attention should be paid to positioning the hand in an intrinsic-plus position. Capsular contractures of the metacarpophalangeal (MCP) joints can develop relatively rapidly in hands with the MCP joints immobilized in extension.
- Radiographs following cast immobilization should be checked carefully to ensure that no dorsal subluxation is present and should be repeated at weekly intervals for the first 2 weeks to prevent healing in a displaced position.
- These injuries, especially those involving a dislocation, have a known propensity for recurrent dorsal subluxation following reduction. Most will require operative fixation. Some authors believe nonoperative management does have a role despite intra-articular displacement and shortening.

SURGICAL MANAGEMENT
Preoperative Planning
- Careful review of all imaging studies will facilitate planning of fracture fragment exposure and identify sites for internal fixation.

Positioning
- The patient is positioned supine on the operating table with a standard arm table.
- The surgeon often is more comfortable seated on the head side of the arm table. This avoids the neck strain that may
result from looking “over the top” that happens when the arm externally rotates and the surgeon is seated on the axilla side of the table (FIG 5A).

Approach

- A dorsal extensile approach provides satisfactory exposure of any of the CMC joints.
- Incisions placed between metacarpals allow access to two adjacent joints.
- Cross the wrist with oblique extensions if necessary.
- Marking out the anticipated locations of nearby nerve branches can be helpful (FIG 5B).

DORSAL EXPOSURE

- Following incision of the skin, careful spreading dissection should be used to locate and protect the dorsal cutaneous nerve branches in the operative field.
- Ulnar sensory nerves are most commonly encountered during exposure of the CMC joints of the ring and small fingers (TECH FIG 1), and radial sensory nerves during exposure of the index and middle finger CMC joints.
- Extensor tendons are mobilized and retracted.

FRACTURE EXPOSURE

- Careful mobilization of the fracture fragments with minimal soft tissue stripping is important.
- The rongeur is useful because it is helpful to débride fracture callus and hematoma.
- Incisions placed between metacarpals allow access to two adjacent joints.
- Cross the wrist with oblique extensions if necessary.
- Marking out the anticipated locations of nearby nerve branches can be helpful (FIG 5B).

FRACTURE REDUCTION

- The fracture is then reduced and held provisionally using fine K-wires (TECH FIG 2A). The surgeon must be aware of the planned location for definitive hardware placement, given the limited room available.
- Pins temporarily driven across the base of an articular fragment into the corresponding carpal bone can be helpful in stabilizing any mobile pieces of bone (TECH FIG 2B).
- The conventional technique of first reconstructing the articular surface, followed by securing the shaft to the reassembled joint surface, is useful.
Confirmation of the provisional reduction should be obtained with fluoroscopy before any definitive screw placement (TECH FIG 2C). The corresponding articular surface on the uninjured bone is used as a mold for the fragments, serving as a guide to reassembly of the injured bone.

This technique works regardless of whether the injury is in the metacarpal base, as pictured in these figures, or in a distal articular injury of one of the carpal bones (TECH FIG 2D).

**DEFINITIVE FIXATION**

- Wires can be replaced by screws if fragment size permits (TECH FIG 3A).
- Placing the fragments under compression manually and inserting screws sometimes is preferable to using the lag screw technique, which requires overdrilling the near side and may risk iatrogenic comminution.
- Simple K-wire fixation is satisfactory for isolated dislocations with fracture (TECH FIG 3B).
- The insertion point for a percutaneous wire often is quite distant from the dislocation site in crushed and severely swollen hands.

**TECH FIG 2**
A. Provisional fracture reduction using the hamate surface as a mold for articular reduction of the metacarpal base. B. Initial reduction of the shaft and stabilization of the articular surface. C. Fluoroscopic view of articular reduction. D. Dorsal hamate lip fixation with three screws.

**TECH FIG 3**
The construct can be protected by placing the affected metacarpal under slight distraction and pinning it to the adjacent metacarpal.

Alternatively, the proximally directed deforming force of the extensor carpi ulnaris can be reduced by detaching it from the base of the small finger metacarpal at the beginning of the procedure, and securing it to the hamate at the close, thereby avoiding proximal pull on the base of the small finger metacarpal.

I have never found it necessary to use this alternative approach, but it may be helpful in a delayed presentation, where myostatic contractures due to shortening are present.

Aftercare following operative fixation falls into three general phases: acute swelling control and wound healing (10–14 days), fracture consolidation and maintenance of digit range of motion (4–6 weeks), and restoration of global hand function and strength (2–6 months).

Immediate measures following surgery include strict elevation and range-of-motion exercises through a full arc of motion. This limits swelling, reduces pain, and prevents accumulation of protein-rich edema fluid that will slow rehabilitation.

The relative speed at which the hand can be mobilized during the weeks after surgery depends on a number of factors, including the magnitude of the original injury, stability of fixation, reliability of the patient, and specific occupational or athletic needs.

The radiograph in Tech Fig 2D shows the hand of a physician with stable fixation of a dorsal hamate injury who was mobilized and given a 1-pound lifting restriction shortly after surgery to allow continuation of his residency training.

In contrast, unreliable patients require immobilization for 6 weeks in a cast (see Tech Fig 3B).

Patients should be warned that full grip strength is the last thing that will recover and may take months. It is not uncommon for patients to report pain with a handshake for an extended period of time.

Opinions on outcomes vary with regard to overall success. A dichotomy exists between recommendation for operative and nonsurgical treatment. Kjaer-Petersen and colleagues found that, regardless of treatment, long-term symptoms were present in 38% of patients at 4.3 years of follow-up.

Petrie and Lamb, who used immediate, unrestricted motion, reported on results at 4.5 years. Even with metacarpal shortening and irregularities in the articular surface, only one patient had work limitations.

Another study found that pain was related to the degree of posttraumatic arthritis secondary to articular incongruity and advocated anatomic reductor and internal fixation.

Multiple CMC dislocations were reviewed by Lawliss and Gunther, and poor results were noted in dislocations of the second and third CMC joints (which require higher energy for dislocation) and in those patients with an ulnar nerve injury.

Complications include those common to any periarticular surgery:

- Failure of wound healing
- Hematoma formation
- Neurovascular injury
■ Neuroma formation
■ Tendon adhesions
■ Posttraumatic arthritis
■ Nonunion or malunion
■ Joint stiffness
■ Weakness

Occasionally small fragments may resorb, leading to collapse and articular incongruity (FIG 6).

Long-term arthritis can be treated with fusion of the affected joint.4

Alternatively, an interposition “anchovy” using the palmaris longus as a biologic spacer can be inserted after resection of the arthritic joint surfaces, analogous to that performed for thumb basal joint arthritis.3

REFERENCES

DEFINITION

- Metacarpal fractures are most significant when they disrupt function of the associated digit.
- The treatment of metacarpal fractures affects finger function and must be weighed against the sequelae of the fracture itself.
- Intra-articular fractures may involve the carpometacarpal (CMC) joint or metacarpophalangeal (MCP) joint.
  - CMC joint injuries are discussed in other chapters.
- Intra-articular MCP joint fractures have an increased risk of stiffness and posttraumatic arthritis.

ANATOMY

- The metacarpals are long tubular bones with relatively flat surfaces dorsally. The medial and lateral cortices converge volarly, making the cross-section triangular. The bone may be quite narrow in the mid-diaphyseal region, with the fourth metacarpal being particularly gracile.
- Dorsal and volar interossei muscles envelop the medial and lateral surfaces. When undisturbed, the muscles provide abundant blood supply to the underlying bone (FIG 1A). When severely disrupted, the muscles have the potential for disabling scarring and “intrinsic contracture.”
- Deep transverse intermetacarpal ligaments lie at the level of the metacarpal head and may contribute to posttraumatic MCP joint contracture (see Chapter HA-108). The adjacent lateral furrow or so-called collateral recess allows passage of the interosseous tendon and may serve as a portal of entry for Kirschner wire fixation into the intramedullary canal.

PATHOGENESIS

- Metacarpal fractures typically result from one of two mechanisms of injury:
  - Most commonly, an axial load is transmitted from the MCP joint down the shaft of the metacarpal. Such injuries include the spectrum of fractures from a low-energy fifth metacarpal neck “boxer’s fracture” to a high-energy comminuted shaft fracture caused by a blow from the steering wheel in a motor vehicle collision.
  - The metacarpal less commonly is injured by a crush-type injury that flattens the metacarpal arch bridging the carpus to the phalanges. Crush injuries typically involve multiple metacarpals and are often associated with other fractures and significant soft tissue trauma.
  - Extra-articular fracture orientation may be characterized as transverse, oblique, or spiral, and with or without comminution. As with other long tubular bones, the exact pattern depends on the degree of shear and torsion associated with the applied load. The fracture typically has apex-dorsal malalignment secondary to the flexion force applied by the lumbrical and interossei muscles.

NATURAL HISTORY

- Most metacarpal fractures heal uneventfully without surgery.
- Low-energy transverse or oblique fractures of a single metacarpal usually maintain acceptable alignment and heal without any measurable functional deficit.
- Spiral fractures, comminuted fractures, and fractures of multiple metacarpals are more likely to shorten and rotate, resulting in tendon imbalance and overlapping of the fingers.
- Fractures of the metacarpal neck (usually the fourth or fifth) may have varying degrees of apex-dorsal malalignment.
  - Flexion of the fourth or fifth metacarpal heads beyond 30 and 45 degrees, respectively, results in a visible pseudoextensor lag and sometimes pain in the palm during grasping.
  - Less angulation is tolerated in the index and middle metacarpals as there is less compensatory motion available at the radial-sided CMC joints.
- Cadaveric studies of fifth metacarpal neck “boxer’s fractures” have demonstrated that every 2 mm of shortening causes an average of 7 degrees of extensor lag and 30 degrees of angulation results in 22% loss of finger range of motion.
- Nevertheless, there is no well-defined relationship between angular fracture malalignment and symptoms. However,
rotational malalignment is poorly tolerated as it results in digital scissoring and difficulty with grasp.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Physical examination methods include:
  - Inspection. The examiner should visualize the fingers as the patient carries them through an arc of motion. All nail beds should point toward the scaphoid tubercle with finger flexion.
  - Extensor lag. The examiner should assess the resting posture of the MCP joint and active MCP extension. Apex-dorsal malalignment results in some loss of active MCP joint extension.
  - Palpation. The examiner should determine the degree of dorsal fracture eminence or palmar metacarpal head prominence. Dorsal callus is usually only a cosmetic concern. The palmar head prominence may be painful with grasp.

The examination is not complete without carefully assessing for associated injuries:

- Open wound: The most common (and often missed) open wound results from a tooth puncture into the MCP, the so-called fight bite. These injuries should be treated urgently with surgical débridement before infection develops.
  
- CMC dislocation: Metacarpal base fractures are often associated with CMC joint subluxation or dislocation. These injuries may go unrecognized until a true lateral radiograph of the hand is inspected.
  
- CMC fracture-dislocation
  
- MCP dislocation
  
- Fight bite
  
- Pathologic fracture (eg, enchondroma)

**DIFFERENTIAL DIAGNOSIS**

- CMC fracture-dislocation
- MCP dislocation
- Fight bite
- Pathologic fracture (eg, enchondroma)

**NONOPERATIVE MANAGEMENT**

- Nondisplaced and minimally displaced metacarpal fractures should be protected in a thermoplast splint or cast for 3 to 4 weeks, followed by gradual mobilization. The MCP joints should be immobilized in flexion to (1) relax the intrinsic muscles and prevent further deformity at the fracture site and (2) place the MCP collateral ligaments on stretch.

- Apex-dorsal malalignment of the border metacarpals may be partially corrected with reduction and splinting.

- Rotational malalignment cannot be reliably corrected with nonoperative means.

**Jahss Maneuver**

- Reduction is accomplished under a hematoma block with this maneuver (FIG 2).

- The metacarpal shaft is stabilized and the MCP joint flexed 90 degrees.

- While distracting at the fracture site, upward force is applied to the proximal phalanx and metacarpal head to realign the neck and shaft.

- A splint with three-point molding is applied with dorsal compression at the fracture site and volar support for the metacarpal head and base.

- A cast is applied 10 to 14 days later.

- Joint mobilization begins at 4 weeks.

**SURGICAL MANAGEMENT**

- Surgical reduction and stabilization is indicated for malrotated fractures, open fractures, unstable fractures (especially involving the border metacarpals), or fractures associated with joint disruption, tendon injury, or neurovascular injury.

- Relative indications for surgery include fractures associated with significant extensor lag, palmar metacarpal head

---

**FIG 2** Jahss maneuver: correction of apex dorsal malalignment as shown by Jahss in 1938.
prominence, more than 5 mm of shortening, and the presence of multiple displaced metacarpal fractures.

- Percutaneous surgical techniques are often adequate for low-energy metacarpal shaft fractures and for most metacarpal neck fractures.
- Open reduction and internal fixation should be considered for open fractures, shaft fractures with significant comminution, and fractures associated with joint disruption, tendon injury, or neurovascular injury.
- Dorsal plating is the most biomechanically stable fixation, although it is potentially more disruptive to the soft tissues than other methods, such as crossed Kirschner wires or interosseous wires.
- Crush-type injuries flatten the bony arch of the hand, often resulting in open metacarpal neck fractures with varying degrees of soft tissue injury. Carpal and CMC joint injuries also occur and are discussed in other chapters.

- Crush fractures associated with mild to moderate soft tissue injury with or without disruption of the extensor mechanism may be stabilized by conventional pinning techniques or by a T-type plate applied distally up to the proximal margin of the joint capsule (FIG 3A,B).
- Occasionally, crush injuries result in long oblique neck fractures, which may be stabilized with lag screws alone (FIG 3C).
- More stable internal fixation is recommended over percutaneous pins when early motion is necessary (eg, associated extensor laceration).
- Crush fractures associated with severe soft tissue injury or internal degloving are best pinned percutaneously (FIG 3D–F).
- The dorsal soft tissues are often tenuous and surgical incisions can result in necrosis and the need for otherwise unnecessary soft tissue coverage procedures.
- Metacarpal fractures resulting from projectiles are graded as either low or high energy.

**FIG 3** • A. Oblique view of the hand demonstrates fourth and fifth metacarpal shaft fractures. B. Repair may be achieved with conventional plates using a T-shape to gain additional fixation in the metaphyseal bone near the metacarpal head or base. C. Long oblique fractures of the fourth and fifth metacarpal heads have been stabilized with multiple lag screws. An adjacent transverse fracture of the ring finger proximal phalanx has been repaired with a plate. D. Clinical photograph of a crushed hand reveals global swelling and splitting of the skin indicative of severe internal degloving. E. Radiograph confirms fracture of all five metacarpals and the carpus. F. Fractures are stabilized with percutaneous pins to avoid additional trauma from surgical dissection.
- Simple comminuted fractures caused by low-energy projectiles with small entry or exit wounds are best treated with limited exposure and débridement, and fracture pinning (FIG 4A). Callus usually forms because the fracture fragments, although comminuted, remain vascularized.
- If there is a large area of bone loss, more rigid plate and screw fixation supplemented with bone graft may be safely performed.\(^3\)
- Complex, comminuted fractures resulting from high-energy projectiles and associated with large open wounds and metal debris should be carefully cleansed, taking measures to minimize devascularization of the fracture fragments.
- Tendons, nerves, and vessels may need to be repaired.
- Provisional fixation with Kirschner wires may be considered if serial débridements are anticipated.
- If and when soft tissues allow, consideration should be given to rigid stabilization of the fractures with a bridge plate technique to facilitate mobilization (FIG 4B).
- Bone grafting may be necessary but can be delayed until there is minimal risk of wound infection (FIG 4C).
- Simple thumb metacarpal shaft fractures usually heal in acceptable alignment with nonoperative management. The massively comminuted thumb metacarpal may be difficult to control in a splint or cast alone. Spanning external fixators are effective for these injuries in order to maintain the first web space while fracture consolidation occurs (FIG 4D,E).

**Preoperative Planning**
- A surgical technique is selected based on the clinical examination, radiographs, and the surgeon’s preference.
- The “best” technique is usually the method that is least disruptive to the soft tissues while allowing early digital mobilization.
- The “best” technique depends on patient factors. For example, a grossly contaminated and devitalized open metacarpal fracture may be treated with percutaneous Kirschner wires to minimize further soft tissue stripping. In contrast, a simple closed transverse metacarpal fracture in a dentist would be considered for dorsal plating to facilitate a prompt return to work.
- The “best” technique also depends on surgeon factors. A surgeon facile with the technique of collateral recess pinning may quickly stabilize multiple metacarpal fractures. A surgeon inexperienced in this technique may spend considerable time and frustration trying to pass wires. Poorly placed percutaneous wires in any technique may cause more soft tissue problems (eg, infection) than open reduction and fixation.

![FIG 4 • A. A radiograph of the hand shows percutaneous fixation of displaced metacarpal fractures from a gunshot wound. B. Higher-energy projectiles may cause considerable displacement and comminution, as shown in this radiograph. Bridge plating is performed to improve alignment while minimizing soft tissue dissection. C. This index metacarpal developed a nonunion and segmental defect after nonoperative treatment of a gunshot-related fracture. A locking plate applied with cancellous bone graft to fill the void resulted in solid healing. D. Fractures of the first ray, as shown in this radiograph, often result in contraction of the thumb–index web space. E. A clinical photograph shows application of an external fixator to allow fracture consolidation in a functional position.](image-url)
In the operating room, the contralateral hand is examined, note is made of the patient’s native digital rotation, and contralateral radiographs are reviewed to assess appropriate metacarpal length.

Positioning
- The patient is positioned supine with the affected extremity placed on a hand table. A brachial tourniquet is applied.
- Surgery may be performed under regional or general anesthesia.

Approach
- Percutaneous landmarks are described in the Techniques section.
- A single extra-articular metacarpal fracture is approached with a dorsal longitudinal incision.
- Crossing dorsal sensory nerves are sought and avoided, particularly as they pass over the bases of the border metacarpals.
- The extensor mechanism is retracted to one side and the underlying metacarpal exposed in an extraperiosteal fashion.
- At closure, hardware may often be covered by the fascia of the interosseous muscles.
- Multiple metacarpal fractures are exposed by way of separate dorsal longitudinal incisions placed between affected metacarpals. If necessary, each incision may be extended as a Y distally to facilitate exposure of each metacarpal head and neck. Alternatively, the incision may be designed as a lazy S to facilitate exposure of both metacarpals (FIG 5A,B).
- Intra-articular fractures are approached by longitudinally splitting the extensor tendon over the MCP (FIG 5C).

![A longitudinal incision may have legs distally (or proximally) to facilitate exposure of multiple metacarpal heads (bases). B. A curvilinear or S-shaped incision allows the skin to be sewn back for ease of operating without an assistant. C. The index metacarpophalangeal joint capsule is seen after dividing the interval between the extensor indicis proprius and the extensor digitorum communis.](image)

Closed Reduction and Pinning of Metacarpal Fractures

A multitude of methods for pinning metacarpal fractures have been described.
- We have found collateral recess pinning to be an expedient and elegant technique for managing the wide spectrum of closed and open, simple and comminuted, single and multiple metacarpal shaft fractures.
- In contrast, a technique called bouquet pinning is uniquely suited for neck fractures of the border metacarpals.
- These two techniques are illustrated in view of the technical challenge associated with these procedures.

Collateral Recess Pinning of Metacarpal Shaft or Neck Fractures

- Obtain gross alignment in a closed fashion (TECH FIG 1A).
- Flex the MCP joint to facilitate control of the distal fragment and subsequent pin placement (TECH FIG 1B).
- Place a 0.045-inch smooth Kirschner wire by hand onto the radial (or ulnar) collateral recess and confirm appropriate placement at the deepest concavity of the collateral recess (TECH FIG 1C).
- An oblique or near true lateral view confirms placement in the sagittal plane.
Advance the wire with power into the shoulder of the metacarpal and down the intramedullary canal to the fracture site (TECH FIG 1D).

Reduce the fracture and advance the wire, keeping it intramedullary and seating it in the bone of the metacarpal base (TECH FIG 1E).

Consider advancing the wire using a mallet rather than power in order to “bounce” off the far cortex and remain intramedullary.

Pass a second wire, completing fracture stabilization (TECH FIG 1F,G).

Reduction and fixation is optimized when the wires cross the fracture site.

**Bouquet Pinning of Metacarpal Neck Fracture**

Make a longitudinal 2-cm incision over the radial aspect of the second metacarpal base and CMC joint (TECH FIG 2A,B) for the index or on the corresponding ulnar side of the small metacarpal base.

The wrist extensor is elevated partially but not completely detached.

Prepare a 0.045-inch smooth Kirschner wire by cutting off the sharp tip, gently bending the pin along its length, and...
creating a deflection of the pin in the plane of the original bend about 3 mm from its leading end (TECH FIG 2C).

- Locate an entry site into the medullary canal at the proximal aspect of the metaphysis using fluoroscopy.
- Enter the canal with a 2-mm drill and enlarge the introitus to about 5 mm.
- Introduce the precontoured 0.045-inch Kirschner wire and direct it distally, at the most acute angle possible (TECH FIG 2D).
- Advance and direct the wire down the canal and across the reduced fracture site using two large needle holders (TECH FIG 2E).
- Insert several additional 0.045- or 0.035-inch Kirschner wires to complete the bouquet and maintain the reduction.

- The goal is to tension the wires off the intact proximal cortex and enter the distal fragment in varied locations, creating a “bouquet” effect.
- Cut the pins flush with the canal and “nudge” them inside with a bone tamp (TECH FIG 2F).
- A lateral radiograph confirms correction of the preoperative apex-dorsal angulation (TECH FIG 2G).

**Alternative Methods**

- The combination of a longitudinal “collateral recess” pin and a transverse pin is a technically simple method of fixation for certain border metacarpal neck and base fractures (TECH FIG 3).

**OPEN REDUCTION AND INTERNAL FIXATION OF METACARPAL FRACTURES**

- Traditional AO techniques may be used to stabilize metacarpal fractures: long oblique or spiral fractures are secured with multiple screws, while short oblique and transverse fracture patterns require plate fixation.

**Dynamic Compression Plating for Transverse Fractures**

- Dynamic compression plating is performed using a dorsal longitudinal approach.
■ Incorporate open wounds or previous incisions as needed (TECH FIG 4A).
■ Identify and protect dorsal sensory nerve branches (TECH FIG 4B).
■ Expose the fracture in an extraperiosteal fashion.
■ In addition to the dorsum, visualize both the radial and ulnar margins to help guide reduction.
■ Apply the appropriately sized dynamic compression plate to the dorsum of the distal fracture fragment and clamp it proximally to obtain provisional fracture reduction (TECH FIG 4C).
■ Plate size and length depend on the patient and the fracture. The most commonly used are 2.0 to 2.5 mm.
■ Add a subtle concave bend to the plate before application to the bone to help compress the volar cortices.
■ Assess sagittal and coronal plane alignment by direct inspection of the fracture site; assess rotation clinically with the aid of tenodesis (TECH FIG 4D).
■ Fill screw holes in compression mode, achieving at least four cortices of fixation in both the proximal and distal fragments (TECH FIG 4E).
■ Fluoroscopy confirms anatomic fracture reduction and appropriate hardware placement (TECH FIG 4F,G).
■ Close the periosteum and interosseous muscle fascia over the plate to provide a smooth gliding surface for the extensor mechanism (TECH FIG 4H).

**TECH FIG 4** • A. A malrotated open index metacarpal fracture from an industrial machine accident. B. A branch of the radial sensory nerve crosses the metacarpal. C. A 2.4-mm dynamic compression plate is secured distally with a screw and proximally with a clamp to obtain provisional reduction. D. Digital rotation is inspected. E. In the absence of comminution, the plate may be applied in compression mode. F,G. AP and lateral views demonstrate anatomic reduction and appropriate screw lengths. H. The plate is covered by fascia to minimize extensor tendon irritation.
Neutralization Plating with Lag Screw Fixation for Short Oblique Fractures

- A short oblique fracture can be compressed with a lag screw and protected with a neutralization plate. In this case of pathologic fracture, a lag screw crosses an enchondroma cavity filled with bone graft. A T-type plate has been selected to optimize distal fixation without disrupting the MCP joint capsule (TECH FIG 5A).

- The exposure of short oblique metacarpal fractures is similar to transverse fractures. Adequate bone must be exposed proximal and distal to the fracture site to allow at least four cortices of screw fixation (TECH FIG 5B,C).

- Provisional fracture reduction can usually be achieved with a fracture reduction clamp. If fracture geometry allows, a plate (2.0 to 2.5 mm) can be contoured and held in place without disturbing the reduction (TECH FIG 5D).

- A lag screw may be placed alone or through the plate. Lag screw placement through the plate reduces soft tissue dissection and improves stability (TECH FIG 5E,F).

- Screw holes are filled in the remainder of the plate to protect the fracture site (TECH FIG 5G,H). Standard cortical screws may be used, although many modern plate systems also have the option for locking screws to improve fixation in metaphyseal bone.

**TECH FIG 5** - A. Short oblique fractures can be lagged together before placement of a dorsal plate. B. This cadaver specimen demonstrates a short oblique fracture at the proximal metadiaphyseal junction of the index metacarpal. C. Fluoroscopy reveals the proximity of the fracture to the carpometacarpal joint. D. The unstable distal fragment is controlled by a small pointed clamp to facilitate reduction. The reduction is maintained by a second clamp, which may also be used to hold a plate. E. A screw is inserted across the fracture site with lag technique to achieve optimal compression. F. Fluoroscopy confirms the reduction. G. Additional screws are placed, neutralizing forces at the fracture site. H. Final radiograph.
Lag Screw Fixation for Long Oblique and Spiral Fractures

- Lag screws obviate the need for excessively long plates (TECH FIG 6A). Ideally, one screw is placed perpendicular to the fracture to maximize compression and another screw is placed perpendicular to the intramedullary axis of the metacarpal to resist axial loads.
- A long oblique ring metacarpal fracture is exposed enough to see the length of the fracture line; however, further proximal and distal dissection is unnecessary as a plate will not be used (TECH FIG 6B). The distal extent of the volar fracture fragment approaches the metacarpal head as clarified by careful fluoroscopic imaging (TECH FIG 6C).

- Long spiral and oblique fractures typically key into position easily with the aid of a pointed clamp (TECH FIG 6D). Fluoroscopy may be used to confirm reduction as the entire fracture length may be difficult to visualize (TECH FIG 6E). Rotational alignment should also be assessed clinically as described above.
- Lag screws are placed in different planes to achieve fracture compression and resist loads applied to the metacarpal (TECH FIG 6F).
- A final lag screw is placed proximally with strict adherence to good technique in order to avoid splintering of the metacarpal (TECH FIG 6G–I).
- Live fluoroscopy is best to confirm reduction and screw lengths when there are multiple screws in different planes (TECH FIG 6J).

TECH FIG 6 • A. Longer oblique and spiral fractures are more securely fixed with screws alone. Plate constructs must be excessively long to provide four cortices of fixation proximal and distal to the fracture site. B. A long oblique ring finger metacarpal fracture extends to the metacarpal head, but dissection distally can be kept to a minimum by using lag screws as the sole means of fixation. C. Fluoroscopy helps define the fracture anatomy, especially at the apex of the volar fragment—an area that will be hidden from direct inspection once the fracture is reduced. D. The pointed clamp secures the reduction while lag screws are placed. E. Fluoroscopy is used to confirm reduction because volar fracture lines may not be easily visible. Long oblique and spiral fractures may look well reduced dorsally while remaining displaced or malrotated. F. Ink marks the proximal extent of the fracture after two lag screws have been placed. G. Careful AO technique is followed to place a third 2.0-mm screw in the small remaining area. A 2.0-mm drill makes a glide hole through the dorsal cortex. (continued)
Metacarpal head fractures often occur in the coronal plane (TECH FIG 7A) and may be associated with fractures of the neck or shaft.

Make a longitudinal or curvilinear incision over the metacarpal head (TECH FIG 7B).

Split the extensor mechanism and incise the capsule longitudinally (TECH FIG 7C).

Flex the MCP joint to facilitate exposure of the fracture (TECH FIG 7D).

Reduce the fracture with a dental pick or small pointed reduction forceps.

Insert guidewires from a cannulated headless screw set to maintain the reduction (TECH FIG 7E).

Insert headless screws over the guidewires (TECH FIG 7F).

Close the extensor mechanism with 4-0 nonabsorbable suture (TECH FIG 7G).

Confirm appropriate screw placement and fracture reduction radiographically (TECH FIG 7H,I).
TECH FIG 7 • (continued) E. The fracture has been reduced with the proximal phalangeal base to restore metacarpal head congruity. Provisional fixation is achieved with two guidewires. F. Definitive fixation with cannulated headless screws facilitates early rehabilitation. G. The repaired extensor incision will tolerate active and active assisted motion immediately. H, I. AP and lateral views reveal a smooth articulation.

PEARLS AND PITFALLS

Indications
- Most metacarpal fractures have good functional results with nonoperative treatment.
- Surgery always causes some disturbance in the extensor mechanism, MCP joint capsule, or intrinsic muscles.

History
- Antecedent pain or minimal precipitating trauma should raise the possibility of a pathologic fracture.
- A fight-related injury may have an associated open wound. Some of these patients will have prior fracture deformities, which may be confused with an acute injury.

Examination
- Rotational malalignment is poorly tolerated and must not be overlooked.
- Crush injuries of the metacarpals may be associated with:
  - Fractures and dislocations of the carpus and CMC area
  - Compartment syndrome and carpal tunnel syndrome

Exposure
- Metacarpals heal quickly when exposure is limited and the bone remains within the well-vascularized bed of intrinsic musculature.
- Massive crush and high-energy projectile injuries cause the MOST internal tissue disruption and are often best treated with the LEAST surgical tissue dissection.
POSTOPERATIVE CARE

- Protective splints or casts are typically worn for 4 to 6 weeks after surgery depending on the stability of fixation, the soft tissue envelope, and treatment of associated injuries.
- The interphalangeal joints should undergo immediate active and active assisted motion to promote tendon gliding and prevent capsular contracture.
- It is also important to mobilize the MCP joint as this allows the greatest extensor excursion over the fracture site. If necessary due to swelling, comminution of the metacarpal neck, or troubles with soft tissue healing, the MCP joint may be immobilized in the safe position (flexed 70 degrees) for about 3 weeks.
- Kirschner wires are removed about 4 weeks after surgery. When callus is slow to form on radiographs and the fracture site remains tender, wires may be left in place for several more weeks if the pin sites remain free of infection.
- Bone grafting should be considered if union is not achieved by 8 to 12 weeks.
- Plates may be removed 4 to 6 months after surgery if they are causing pain or extensor tendon irritation.

OUTCOMES

- The literature provides no conclusive evidence that either of the methods of fixation of metacarpal fractures is superior.
- Surgical stabilization of a single closed extra-articual metacarpal fracture generally results in a good functional outcome. Nonoperative management of these injuries will also result in a good functional outcome, behooving the surgeon to identify an appropriate surgical indication—most commonly malrotation.
- Outcome after surgical management of multiple or open metacarpal fractures is less predictable and mostly depends on the patient’s long-term digital motion. Peritendinous adhesions and capsular contracture can be minimized by even small amounts of motion during the early postoperative period.
- Nonunion is rare and usually is associated with infection, segmental bone loss, or a compromised soft tissue envelope. Occasionally, an innocuous-appearing transverse fracture may be slow to heal due to the combination of soft tissue stripping for plate fixation and the small surface area of the fracture.

COMPLICATIONS

- Malunion (flexion or rotational deformity)
- Delayed union or nonunion (more common with surgery)
- Pin site or surgical wound infection
- Extensor tendon adhesions or rupture
- MCP or interphalangeal capsular contractures

REFERENCES

DEFINITION

- Extra-articular fractures of the phalanges include metaphyseal and diaphyseal fractures of the proximal, middle, and distal phalanges.
- Extra-articular fractures of the phalanx can range from an isolated injury, which is relatively simple to treat, to a complex trauma involving multiple structures; these latter injuries are often profoundly difficult to reconstruct and can severely affect the function of the hand.

ANATOMY

- The phalanges are the long, tubular bones of the hand that enable a functional arc of motion.
- While each phalanx of each ray is similar, there are anatomic differences that account for the normal cascade and curvature of the digits, allowing for flexion and extension.
- The extensor mechanism of the finger glides directly on top of the phalanges, with only a thin layer of periosteum and peritenon between bone and tendon (FIG 1).
- Fractures of the phalanges and the resultant bleeding, swelling, and scarring can greatly inhibit extensor function.
- Early motion of the extensor mechanism can help minimize adhesions between bone and tendon. This is an essential principle that must be kept in mind when treating these injuries.
- Hardware, particularly a plate, placed dorsally beneath the tendon may interfere with extensor tendon function and risk its integrity. This has led many to recommend alternate fixation methods as well as plate placement on the lateral aspect of the bone.

- A dorsal implant may abrade the tendon, especially if the end of the plate is at the level of the proximal interphalangeal joint.
- Even a low-profile dorsal plate can lead to extensor imbalance. A plate on the proximal phalanx effectively shortens and tightens the central slip tendon, leading to limited proximal interphalangeal flexion.
- There is even less room to place a dorsal plate under the triangular ligament and terminal tendon over the middle phalanx (FIG 2).

PATHOGENESIS

- Because the fingers project from the hand, they are subject to bending and twisting forces in a wide variety of situations.
- The fracture pattern depends on the position of the digit at the time of injury and the direction and degree of force applied.
- As a rule, long spiral fractures tend to result from torsional forces and transverse fractures tend to occur after angular and three-point bending forces.
- Fingers are also subject to direct trauma, such as a blow from a hammer, crush injury from a window or door, or even a gunshot.
- These injuries are often associated with skin, tendon, nerve, and artery injuries, all of which worsen the prognosis for recovery of function.
- Most distal phalangeal fractures are comminuted in nature and result from a crush mechanism. Significant displacement of the fragments is associated with a nail bed disruption.

**FIG 1** • A. Anatomic dissection of a digit showing the relationship and position of the lateral bands and extensor digitorum communis (EDC). B. Anatomic dissection showing the EDC with the important insertion of the central slip, which should not be detached if possible during the surgical approach.
Fractures of the proximal phalanx will generally assume a position of apex volar angulation.

The intrinsic muscle tendons, inserting on the proximal phalanx base, pull the proximal fragment into flexion and the central slip pulls the distal fragment into extension (FIG 3). Fractures of the middle phalanx deform less predictably but often assume an apex volar angulation due to the pull of the flexor digitorum sublimis tendon on the volar base of the middle phalanx proximal fragment and the force exerted by the terminal extensor tendon on the distal fragment.

Both the extensor and flexor tendons insert on the distal phalanx at the base only. The flexor tendon insertion is more distal than the extensor tendon insertion. It is possible to have an extra-articular fracture between the two insertion sites, a so-called Seymour fracture, which angulates in a dorsal apex direction.

NATURAL HISTORY

Extra-articular fractures of the phalanges usually heal without treatment, but often with deformity.

It has been shown that there is a linear relationship between the degree of proximal phalanx angulation and the extensor lag.\(^{13}\)

The correction of such deformity must be balanced with the potential for stiffness after surgical intervention as well as other potential surgical complications.

PATIENT HISTORY AND PHYSICAL FINDINGS:

Knowledge of the mechanism of injury, time from injury to treatment, previous treatments rendered, and the injury’s impact on the patient’s career and hobby skill set is critical. It must be determined whether the patient has previously injured the digit and what, if any, preinjury functional limitations existed.

The clinician should evaluate the cascade of the digits, looking for subtle changes in the attitude and position of the fingers. This may help to localize areas of injury. Pain with palpation helps localize the area of injury if there is no clear deformity of the digit and assesses fracture healing. Phalangeal fractures can be displaced in an AP or lateral plane, rotated, or shortened or can exhibit a combination of these deformities.

Resultant hand function will depend on the specific deformity and its location along the skeleton. The more proximal the fracture, the greater the potential deformity at the fingertip. Rotational deformity affects ultimate function the greatest, especially if it causes the fingers to scissor (FIG 4A).

Rotation can be evaluated by asking the patient to flex and extend the digits as a unit. The clinician should compare the relative position of the injured digit to adjacent digits on the injured and uninjured hand.

A digital anesthetic block can facilitate the examination. The digits should generally point toward the distal pole of the scaphoid during flexion.
It is often difficult for the patient to make a fist at the initial assessment due to pain and swelling. In these cases, comparing the plane of the nail bed of the injured finger to the adjacent nail beds and comparing with the other hand can provide a valuable clue to the presence of a rotational deformity (FIG 4B).

- Neurocirculatory status
  - Altered skin color and diminished turgor and capillary refill of the digit are clear indicators of vascular compromise.
  - Two-point discrimination can be used to assess innervation density and is an excellent method for evaluating the integrity of digital nerves.
- Condition of the soft tissue envelope
  - The skin may be visibly damaged with lacerations, degloving, or burns. Its condition will influence treatment.
  - A subungual hematoma is common with a distal phalanx fracture.
- Unstable fracture patterns must be recognized (Table 1).

**IMAGING AND OTHER DIAGNOSTIC STUDIES:**

- AP, oblique, and lateral radiographs will provide sufficient imaging for the majority of extra-articular phalangeal fractures.
  - Critical evaluation may show subtle rotational malalignment if a true lateral view of either the base or the condyles of a phalanx does not match up across its corresponding joint.
  - Slightly oblique lateral views are useful for imaging fractures at the base of the proximal phalanx, where the overlap on a true lateral view makes evaluation difficult.
- A mobile, small fluoroscopy unit allows magnification to help characterize subtle injuries and dynamic evaluation to gauge fragment stability.
- More sophisticated imaging (MRI, CT, ultrasound) is rarely needed to make the diagnosis of a phalangeal fracture or to guide treatment.

**DIFFERENTIAL DIAGNOSIS**

- While there are other causes of hand pain and deformity (e.g., osteoarthritis, congenital deformity, tumor, infection), the patient history and plain radiographs should leave little doubt that the patient has a phalangeal fracture.
- If a fracture is not evident, all the following diagnoses should be considered:
  - Acute sprains
  - Metacarpophalangeal (MP) and interphalangeal dislocations
  - Mallet finger
  - Phalangeal contusions
  - Benign and malignant lesions of the digits
  - Soft tissue injuries
  - Collateral ligament injury
  - Boutonnière or swan-neck injuries
  - Sagittal band ruptures
  - Tendon ruptures
  - Pulley ruptures
  - Stenosing tenosynovitis or trigger finger
  - Acute infection

**NONOPERATIVE MANAGEMENT**

- Many phalangeal fractures are stable and can be treated effectively by closed means. Each fracture must be addressed individually, taking into account the condition of the soft tissue envelope, the fracture characteristics, and the functional needs of the patient.
- Mild (nonrotational) deformities do well with immobilization and protection while the fractures heal, but unstable or malrotated fractures benefit from surgical intervention.
- Distal phalanx fractures are most commonly amenable to nonoperative treatment.

| Table 1 Unstable Extra-articular Fracture Patterns of the Phalanx |
|-----------------|-----------------|-----------------|
| Fracture Pattern | Cause (Forces) | Technique       |
| Spiral oblique fractures | Inherently unstable | Long oblique – Lag screws |
| P1 short transverse fractures | Intrinsic interossei tend to pull the proximal fragment into flexion. The distal segment is pulled into extension by the action of the central slip insertion into the base of the middle phalanx. | - Intrafocal pinning—intramedullary pinning across the metacarpophalangeal joint in flexion - Eaton-Belsky pinning |
| P2 short transverse fractures | Fractures proximal to the flexor digitorum superficialis (FDS) insertion cause extension of the proximal fragment and flexion of the distal fragment. Fractures distal to the FDS insertion become flexed due to the strong pull of the FDS. | - Oblique/crossed Kirschner wires |
| P3 transverse fractures proximal to the tuft | Instability possible with loss of support to the nail bed Action of the flexor digitorum profundus to the proximal fragment with a floating distal fragment | - Retrograde intramedullary pinning across the distal interphalangeal joint |
| Comminuted fractures | | - Oblique/crossed Kirschner wires |

- Long oblique – Lag screws
- Short oblique – Lag screws
- Kirschner wires
- Plate and screws
- Intrafocal pinning—intramedullary pinning across the metacarpophalangeal joint in flexion
- Eaton-Belsky pinning
- Oblique/crossed Kirschner wires
- Plate and screws
- Tension banding
- Retrograde intramedullary pinning across the distal interphalangeal joint
- Bladed plate and screws
- Blade plate and screws
- External fixator
Results are good or excellent in more than 70% of extra-articular phalangeal fractures treated nonoperatively.1,5,7,10

Early motion is always desirable, but it is somewhat less important with closed treatment.

Immobilization beyond 3 weeks has been shown to increase stiffness12 and lead to worse outcomes.

Closed treatment
- Less scarring to the extensor mechanism
- Less ability to move early, unless the fracture is very stable
- Minimal ability to hold a corrected deformity

Internal fixation
- Greater scarring of the extensors, especially with a dorsal approach and a dorsal implant
- Early motion essential
- Greatest ability to hold the fracture in a stable, corrected position

If a fracture is incomplete, complete but nondisplaced, or impacted (such as the metaphysis at the base of the proximal phalanx), a short period (1 to 2 weeks) of splinting followed by buddy taping to the adjacent digit is appropriate (FIG 5).

A fracture that can be adequately reduced but is relatively unstable can occasionally be held reduced with a splint.
- This has the advantage of avoiding a trip to the operating room and the possible complications of surgical fixation but requires close follow-up and serial radiographs to ensure that reduction is maintained (FIG 6).

**SURGICAL MANAGEMENT**

- When considering any surgery, it is necessary to balance the potential benefits of surgery with the risks of the procedure.
- The goal of surgery is to restore alignment and to stabilize the fracture to a degree sufficient to begin early motion.
Any phalangeal fracture with a significant injury to the soft tissue envelope has a worse prognosis.

Stable fixation (to the degree that it does not further compromise the soft tissues) and early motion assume a greater importance in phalangeal fractures with associated soft tissue injuries.

Patients with open fractures are treated with the appropriate intravenous antibiotic therapy. Once the decision is made to surgically intervene, the surgeon must decide which mode of fixation will best suit the fracture pattern (Table 1).

This decision is often made intraoperatively and is frequently based on the ability of the fracture to be adequately reduced closed.

Fractures that are reduced closed are stabilized externally with a cast or fixator or are held with Kirschner wires placed percutaneously.

Kirschner wiring and external fixation are techniques that, when appropriately applied, will result in acceptable outcomes without potential soft tissue surgical interruption and scarring.

Open reduction and internal fixation with plates and screws will potentially provide stable fixation but without early mobilization could result in decreased range of motion.

Overly aggressive soft tissue stripping will cause extensor tendon adhesions, and bulky implants will affect extensor tendon balance and function.

An algorithm can be used to aid in the decision-making process (FIG 7).

Methods

Percutaneous Wire Fixation

Closed reduction with percutaneous fixation can be used to treat the majority of unstable spiral fractures of the phalanges.

The technique is also suitable for transverse metaphyseal fractures, but it may be less suited for transverse diaphyseal fractures.

When the wires are inserted radial and ulnar to the extensor mechanism, percutaneous wire fixation offers the advantage of minimal disruption of the soft tissues in general, and the extensor mechanism in particular.

This technique is best suited for fractures less than 10 days old. After that time, early healing makes accurate closed reduction more difficult.

Kirschner wires provide less stable fixation than plates and screws and may restrict soft tissue gliding due to their prominence. This restriction of early motion may lead to increased stiffness.

Interosseous Wire Fixation

Interosseous wire fixation is more rigid than Kirschner wire fixation but requires open reduction and additional dissection to expose the bone surfaces.

This method of fixation is less bulky than a plate and, as such, is particularly well suited for fractures of the middle phalanx when percutaneous pinning is not possible.

Interosseous wiring works best with a transverse fracture. The wires provide compression to stabilize the fracture. Interosseous wiring will not work if the fracture is comminuted. Interosseous wiring is made more stable when it is combined with pin fixation and placed in a 90-degree configuration.

Lag Screw Fixation

Lag screw fixation is best suited for oblique and simple spiral fractures.

- Lag screws can be used alone if the length of the fracture is greater than twice the diameter of the bone at the level of the fracture.
- If the obliquity is less, a neutralization plate should be added.
- Comminuted and transverse fractures are not amenable to lag screw fixation.

Contemporary lag screws are extremely low profile, making them an excellent fixation option in the phalanx, especially the middle phalanx.

- Lag screw fixation is more rigid than Kirschner wire fixation, and unlike wires, the screws do not need to be removed.
- Lag screws can be inserted percutaneously, but the procedure can be technically challenging.

- Usually, an oblique fracture will be visualized best in the AP plane and the screws inserted from the lateral aspects.
- Spiral fractures frequently require the screws to be placed in two planes.
- Multiplanar screw fixation greatly increases the biomechanical stability (FIG 8).

Plate Fixation

Plate fixation is best suited for transverse fractures, short oblique fractures, periarticular metaphyseal fractures, and comminuted fractures, in which the plate serves as a bridge to maintain phalangeal length.

- Midshaft, transverse fractures are fixed with a straight plate. At least two screws should be placed in either side of the fracture site with fixation of four cortices (FIG 9).
- If close to the metaphysis, a T plate, a Y plate, or a condylar blade plate will allow improved fixation compared with a straight plate.

Displaced Phalanx Fracture

Reducible (Stable) Reducible (Unstable) Irreducible

Nonsurgical treatment
- Buddy taping
- Casting/splinting

Percutaneous treatment
- Kirschner wiring
- External fixation

Open surgical treatment
- Lag screw fixation
- Plate and screws
- Blade plating
- Tension band wiring

FIG 7 • Decision algorithm for the progression to open surgical treatment for phalangeal fractures and the subsequent treatment options for fixation.
Adding a lag screw across an oblique fracture, either through the plate or as an adjunct to plate fixation, will add to the rigidity of the construct.

Compression, obtained by eccentrically drilling one or more of the screws in the plate, will increase fracture stability.

Plate fixation requires more extensive soft tissue dissection and increases the risk of postoperative extensor scarring.

Immediate motion of the digits is essential to minimize the scarring.

Plates are more bulky and may lead to extensor mechanism imbalance, especially near the central slip insertion and on the middle phalanx.

Preoperative Planning

Preoperative posteroanterior, lateral, and oblique radiographs are essential.

Evaluation of these studies helps determine the plane of the fracture and the size of the fracture fragments, allowing the surgeon to choose the best surgical approach and the ideal fixation technique.

The surgeon must be certain that all potential implants are available. Surgical error can frequently be traced to implant availability problems.

Many sets include only one or two plates of a given size and shape. In the case of multiple digit involvement, extra plates and screws are helpful.

Intraoperative imaging using a mini fluoroscopy unit is essential, and its availability should be ensured.

The surgeon should plan for alternative approaches and means of fixation should comminution or soft tissue problems preclude the original plan.

Positioning

The patient is placed supine on the operating table with a radiolucent hand table attached.

A padded arm or forearm tourniquet is used for all cases.

Approach

The phalanx is most commonly approached laterally or dorsally. The exact approach used for open reduction is often based on the location of the fracture as it relates to the extensor mechanism (FIG 10).

The sagittal bands at the MP joint, the central slip insertion, and the triangular ligament should be preserved whenever possible (FIG 11).

Motion is necessarily delayed after surgery if these structures are incised and subsequently repaired.

A portion of the lateral band may be excised rather than repaired as part of the midaxial approach (FIG 12).

Longitudinal incisions in the midportion of the extensor tendon and especially in the midaxial interval between the extensor and the lateral band allow early motion.

At the middle phalanx level, a midaxial approach on the edge of the terminal tendon is preferred so that the tendon can be pulled to the side, exposing the bone (FIG 13).

The midaxial approach is also useful when using lag screw fixation, as the screws are usually inserted on the lateral aspect of the bone.
Fracture Reduction

- Before performing any reduction maneuver, obtain posterior-anterior and lateral C-arm images for reference.
- If the fracture is very close to the MP joint, a slightly oblique lateral view will show the fracture better by avoiding some of the overlap of the other MP joints.
- Unstable spiral fractures of the phalanges are usually shortened, rotated, and angulated (TECH FIG 1A).
- Begin the reduction by applying longitudinal traction.

- This can be accomplished with direct traction on the digit. Use a moist gauze, fingertraps, or a pointed towel clip applied distal to the fracture.
- While traction is applied, correct the rotational deformity (TECH FIG 1B). Any angular deformity is then corrected before placing a reduction clamp across the fracture.
- Flexing the MP joint stabilizes the proximal P-1 fragment by tightening the collateral ligaments.
- Apply a reduction clamp (a towel clip-like device with sharp points) across the fracture percutaneously to hold the reduction.

PERCUTANEOUS KIRSCHNER WIRE FIXATION
When considering the cross-sectional anatomy of the finger, remember that the bone lies in the dorsal two thirds, not in the midline (TECH FIG 1C). Thus, the clamp tips should enter the skin dorsal to the midlateral line.

- Placing the clamp at a slight angle so that it is more perpendicular to the fracture will aid stability of the reduction through fracture compression.
- Reduction can further be fine-tuned by twisting the clamp slightly when tightening.

**Fracture Stabilization**

- After checking the reduction with the fluoroscope, drill the Kirschner wires across the fracture site until they gain purchase in the far cortex (TECH FIG 1D).

- Usually 0.045-inch Kirschner wires are used in the proximal phalanx, although fixation in the small finger and in the more distal phalanges may require the smaller 0.035-inch Kirschner wire size (TECH FIG 2).
- Diamond-tipped smooth Kirschner wires are preferred.
- Crossed wires can be used to secure transverse fractures.
- This method is useful for metaphyseal fractures (TECH FIG 3) and to stabilize middle phalanx fractures to avoid the need for plate fixation (TECH FIG 4).
- Avoid distraction at the fracture site when using crossed wires.
Part 6 HAND, WRIST, AND FOREARM • Section IV HAND FRACTURES AND DISLOCATIONS

TECHNIQUES

INTEROSSEOUS WIRE FIXATION

Exposure
- Open reduction and fairly extensive fracture exposure is required for placement of the intraosseous wires, especially when using a dorsovolar wire.
- Expose the fracture using either a dorsal or midaxial approach.
- Place the bone in the “shotgun” position (apex dorsal) and gently elevate the soft tissues from the proximal and distal fragments 3 to 5 mm at the fracture site.
- Drill transverse and anteroposterior holes 2 to 5 mm away from the fracture site using a 0.045 smooth Kirschner wire.

Fracture Reduction and Stabilization
- Reduce the fracture and verify reduction through direct observation and with a mini C-arm.
- Pass a 24-gauge steel wire through the transverse hole and a second wire through the anteroposterior holes.
- Tighten the wire loops sequentially by pulling the wire away from the fracture and twisting slowly to stabilize and compress the fracture (TECH FIG 5).
- Do not fully tighten the first wire until the second wire has been at least partially tightened.
- Plan placement of the wire loops so as to lay them flat against bone and minimize soft tissue irritation.
- If greater stability is required, drill a 0.035 to 0.045 smooth Kirschner wire obliquely across the fracture.

TECH FIG 4 • A. AP and lateral radiographs showing a displaced fracture of the middle phalanx of the middle finger and minimally displaced middle phalanx fracture of the ring finger. Note the importance of the lateral radiograph to assess the displacement of the middle finger fracture. B. The middle finger fracture was stabilized with crossed pins. The ring finger was fixed with a single pin to avoid displacement after early motion was started. C. The healed fractures after pin removal.

TECH FIG 5 • AP radiograph of a middle phalanx infected nonunion treated by débridement, squaring of the fracture ends, and 90-90 interosseous wiring.
LAG SCREW FIXATION

- Lag screws can be inserted percutaneously, but the procedure is technically challenging. Precise reduction of the fracture is the first priority and should not be sacrificed in an attempt to limit incision length.
- Most often, the midaxial approach will provide the best exposure with the least amount of soft tissue stripping.
- Screw size and number are determined based on fracture location, fracture characteristics, and the size of the bone fragments (TECH FIG 6).
  - When considering the use of multiple screws and screw location within the fragment, screws should be placed at least two diameters from the tip of the fracture and centered within the fragment.
  - The distance between screws should be at least two screw diameters.
  - The screws’ orientation should be between perpendicular to the fracture line and perpendicular to the bone itself.
    - Screws placed perpendicular to the fracture provide maximal compression.
    - Screws placed more perpendicular to the bone provide axial stability.
    - Screws should always be drilled along a diameter (ie, crossing though the middle of the bone).
  - Reduce and hold the fracture with a clamp while the drill is advanced across the fracture site into the opposite cortex (TECH FIG 7A).
  - To gain a lag effect, create a gliding hole in the near cortex using a drill bit that is the same size as the screw’s outer diameter (TECH FIG 7B).

TECH FIG 6 • Screw size is determined by the bone size. Usually 1.5-mm or 2.0-mm screws are used in the proximal phalanx and 1.3-mm or 1.5-mm screws in the middle phalanx.

A. First drill
B. Overdrill

TECH FIG 7 • A. The tap drill for the chosen screw size is drilled from the near cortex, across the fracture and into the far cortex. The hole should be oriented so the drill crosses through the center of the bone and is centered in the far fragment as well. B. To gain a lag effect, the near cortex is opened to the outer diameter of the screw (overdrilled) so the screw threads will engage only in the far cortex, compressing the fractures as the screw is tightened.
Plates can be placed either dorsally or laterally on the bone. Lateral placement via the midaxial approach has the advantage of less extensor disruption and potentially fewer adhesions. Lateral plate placement effectively resists compressive forces. If the plate is applied to the dorsal surface, avoid overdrilling and placement of a long screw that may damage the flexor tendons. Once exposed, clear the fracture site of soft tissue and reduce the fracture.

Fixation of Metaphyseal Fractures: T-Plate Technique

- Provisionally place the plate on the bone using a pointed reduction clamp, a specialized plate-holding clamp, or a screw at one end of the plate.
- Insert the screw in the middle of the T plate first, but before screw tightening align the plate perpendicular to the adjacent joint (TECH FIG 9A).
- Perform the final fracture reduction and insert a screw on the other side of the fracture (TECH FIG 9B).
- Assess the length, angulation, and most importantly the rotation clinically and radiographically.

During final tightening, exert steady forward pressure and turn the screw slowly to avoid stripping the far cortex. Repeat the procedure for additional screws (TECH FIG 8). Alternatively, reduce the fracture with a clamp, then stabilize it with a Kirschner wire smaller than the core diameter of the screw. Place the first lag screw as described, then remove the Kirschner wire and insert the second screw through the predrilled Kirschner wire hole.

PLATE FIXATION

- Plates can be placed either dorsally or laterally on the bone.
- Lateral placement via the midaxial approach has the advantage of less extensor disruption and potentially fewer adhesions. Lateral plate placement effectively resists compressive forces.
- If the plate is applied to the dorsal surface, avoid overdrilling and placement of a long screw that may damage the flexor tendons.
- Once exposed, clear the fracture site of soft tissue and reduce the fracture.

Fixation of Metaphyseal Fractures: T-Plate Technique

- Provisionally place the plate on the bone using a pointed reduction clamp, a specialized plate-holding clamp, or a screw at one end of the plate.
- Insert the screw in the middle of the T plate first, but before screw tightening align the plate perpendicular to the adjacent joint (TECH FIG 9A).
- Perform the final fracture reduction and insert a screw on the other side of the fracture (TECH FIG 9B).
- Assess the length, angulation, and most importantly the rotation clinically and radiographically.

- Insert the remaining screws (TECH FIG 9C).
- In the case of comminution, the plate is used to bridge the fracture fragments (TECH FIG 10).
Chapter 32  OPERATIVE TREATMENT OF EXTRA-ARTICULAR PHALANGEAL FRACTURES 2389

TECH FIG 10 • A. Preoperative posteroanterior and lateral radiographs showing a comminuted index finger proximal phalanx fracture with significant shortening, angulation, and rotation, and a middle finger proximal phalanx fracture with reasonable alignment. The middle finger had a significant crush injury and a large volar wound. B. The index finger proximal phalanx fracture is fixed with a T plate, which is used to restore alignment, length, and rotation while bridging the fracture. Rather than risking additional vascular compromise to the middle finger with pins or open reduction, the relatively stable fracture of the middle proximal phalanx was treated by closed means. Active motion of both fingers was started 1 week after open reduction and internal fixation.

TECH FIG 11 • A. Intramedullary Kirschner wires can be stacked in the canal to provide intramedullary support to a phalangeal fracture. Wires are inserted from the sides to minimize extensor tendon damage. B. In the case of soft tissue damage with bone loss, a square U-shaped bend in a Kirschner wire can be used to temporarily maintain length while the soft tissue heals.

OTHER METHODS

- Some authors have described using Kirschner wires as stacked intramedullary nails to secure phalangeal fractures. Intrafocal pinning is an excellent way to stabilize juxta-articular fractures of the proximal phalanx.2
  - By placing several wires along the canal, the fracture can be stabilized sufficiently to allow early motion.
  - Inserting the wires along the sides minimizes extensor tendon injury (TECH FIG 12A).
- Other methods of fixation not commonly used for extra-articular phalangeal fractures include external fixation and bridging Kirschner wire fixation (TECH FIG 12B).
  - These rarely used methods are most useful for temporary fixation while allowing the soft tissue injuries to heal.
  - External fixation is more advantageous for border digits. For treatment of extra-articular phalangeal fractures, these fixators should not be placed across a joint if at all possible.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Thorough history and physical must be obtained.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recognizing malalignment and especially rotation is crucial.</td>
</tr>
<tr>
<td>Choice of technique</td>
<td>Preoperative planning is critical.</td>
</tr>
<tr>
<td></td>
<td>Choose the least invasive method that will align and stabilize the fracture.</td>
</tr>
<tr>
<td></td>
<td>If open reduction is planned, and especially if plate fixation is chosen, stable fixation must be obtained to allow early motion.</td>
</tr>
</tbody>
</table>
Kirschner wiring
- Avoid placing crossed pins with their intersection at the level of the fracture, as this may cause rigid distraction.
- Smooth pin wiring is not without complications.  

Plate fixation
- Placing the plate laterally or dorsolaterally may minimize the negative effects on the extensor mechanism.
- Do not detach the insertion of the central slip at the dorsal base of the middle phalanx.
- Augmenting fixation with a lag screw either through or adjacent to the plate markedly increases fracture stability.
- If plating dorsally, avoid placing overly long screws, which may damage flexor tendons.
- Always check plate placement and length fluoroscopically.
- Thoughtful placement of temporary Kirschner wires will avoid frustration with simultaneous fracture reduction and plate placement.
- Temporary Kirschner wire placement can maintain fracture reduction as well as take the place of predrilling for screws; replace the Kirschner wire with an appropriately sized screw.
- After a midaxial approach and placement of a plate on the proximal phalanx, excise rather than repair the lateral band to minimize scarring and maximize motion.

External fixation
- Useful in markedly comminuted fractures with bone loss
- Avoid spanning joints if possible.
- Most applicable for border digits

Distal phalanx fractures
- Nonunions can be painful.
- Support of the nail bed can help prevent later nail deformities.
- Temporary pinning through the distal interphalangeal joint can provide stability and is an easier technique than cross-pinning in the distal phalanx.

Problems
- Recognize and correct malalignment in the operating room. Clinical and radiographic assessment is required throughout the process of fracture reduction and stabilization. Always compare with the contralateral hand.
- With postoperative swelling, it is our practice to always include more than one digit in the postoperative dressing to avoid potential vascular complications.

Postoperative care
- Early evaluation and treatment by an experienced hand therapist will improve outcome.
- Diligent pin care in Kirschner wire and external fixator constructs is necessary to avoid infection.

POSTOPERATIVE CARE
- Postoperative care depends on the location of the injury and the bony fixation.
- The best outcomes are achieved with restoration of anatomic alignment, respect for the soft tissue envelope, and early range of motion.
- Treatment by an experienced hand therapist is a key component.
  - In the early phases, therapy consists of edema control and mobilization of adjacent digits and joints.
  - If adequate fracture stabilization is obtained, then mobilization of the involved digit is started almost immediately.
  - If fracture fixation is not ideal, active motion of the involved segment should be started no later than 3 to 4 weeks after surgery regardless of the radiographic appearance.
  - Protected mobilization should include removable splints that allow motion of adjacent digits and joints. As healing progresses, these splints are eliminated and buddy taping is employed.
- Return to full activity is usually possible by 8 weeks.

OUTCOMES
- Virtually all phalangeal fractures will heal in 4 to 6 weeks. Malalignment, especially rotation, and stiffness will diminish the outcome.
- Most simple fractures treated with splinting, percutaneous pinning, or open reduction and internal fixation will regain near-full motion in 2 to 6 months, if the principles are followed and the proper intraoperative and postoperative techniques are employed.
- In complex injuries where early motion is delayed because of concomitant soft tissue injury or prolonged splinting, the final outcome will be worse.
- Sometimes hardware removal, tenolysis, and joint release are needed to improve motion.
  - Such procedures should be attempted only after tissue equilibrium has been reached (usually at least 4 months after the initial injury or surgery).

COMPLICATIONS
- Loss of motion
  - Surgical: careful soft tissue handling with avoidance of prominent hardware
  - Postoperative: Elevation, ice, early motion of all non-injured joints, and controlled mobilization of injured segments as soon as possible are the best preventive measures.
- If the problem persists and despite good therapy passive motion greatly exceeds active motion, tenolysis is a reliable method of treatment.
- Malunion
  - Malreduction is common and, once secured with a plate and screws, difficult to correct. It is important to assess rotation on all phalangeal fractures before final fixation.
- Accurate assessment is often difficult because the patient cannot make a full fist. Therefore, a reduction that was
thought to be adequate in the face of restricted motion may prove inadequate once full motion is regained.
- If significant enough, osteotomy should be considered.
- Neurovascular injury while pinning a fracture
- By observing the cross-sectional anatomy of the digit, damage to the neurovascular bundle can usually be avoided when inserting the wires.
- Care must be taken when the wire passes through the second cortex, as it will usually be heading directly toward the neurovascular bundle.
- Inserting the wires initially by hand until bone contact is made and using small open incisions may decrease the chance of injury when inserting the wire close to the neurovascular bundle.
- Complex regional pain syndrome
- Early recognition and treatment are essential.
- A high index of suspicion is needed to identify key symptoms:
  - Swelling despite elevation and other edema-control efforts
  - Stiffness, especially in adjacent digits, despite efforts toward early mobilization
  - Color changes in the hand
  - Mottling or shiny appearance of the skin
  - Abnormal hair growth
  - Burning pain in the hand
- Tendon rupture
- Nonunion
- Infection
- Pin loosening and migration
- Implant failure
- Pain and symptoms from retained hardware

REFERENCES
3. Crofoot CD, Saing M, Raphael J. Intrafocal pinning for juxtaarticu-
4. Eaton RG, Hastings HH. Point/counterpoint: closed reduction and internal fixation versus open reduction and internal fixation for displaced oblique proximal phalangeal fractures. Orthopedics 1989;12:
911–916.
39–50.
DEFINITION
- Phalangeal condylar fractures include unicondylar and bi-condylar intra-articular fracture of the distal ends of the proximal and middle phalanx. Proximal phalangeal condylar fractures are more common.
- Table 1 demonstrates the variety of condylar fracture patterns typically observed.

ANATOMY
- Collateral ligaments, finger position, and direction of force play a role in both fracture pattern and the direction of displacement (FIG 1).
- Blood is supplied to the condyles by a branch of the digital artery and vein that travels with the collateral ligaments. Care must be taken not to disrupt this blood supply or to strip small fragments of their soft tissue attachments.

PATHOGENESIS
- These fractures often are sports-related injuries.
- The mechanism is hypothesized to be tension or rotation force through the collateral ligaments for an oblique fracture and compression and subluxation in the case of a coronal fracture.1,5
- Fractures often are unstable because there is a minimal periosteal sleeve, and forces seen at the joint are substantial.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Condylar Fracture Patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture Configuration</td>
<td>Illustration</td>
</tr>
<tr>
<td>Type I: unicondylar short oblique</td>
<td><img src="image" alt="Type I: unicondylar short oblique illustration" /></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Type II: unicondylar long oblique</td>
<td><img src="image" alt="Type II: unicondylar long oblique illustration" /></td>
</tr>
</tbody>
</table>

(continued)
### Table 1: Condylar Fracture Patterns (continued)

<table>
<thead>
<tr>
<th>Fracture Configuration</th>
<th>Illustration</th>
<th>Characteristics</th>
<th>Fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type III: dorsal coronal</td>
<td><img src="image1" alt="Illustration" /></td>
<td>Often stable</td>
<td>Nondisplaced Fracture: &lt;25% and stable joint: consider nonoperative treatment or excision. &gt;25% and nondisplaced: could consider nonoperative treatment, but must follow closely. Otherwise, two percutaneous K-wires. Displaced Fracture: &gt;25% and displaced or &lt;25% with subluxed joint: joystick closed reduction and K-wires, or open reduction and K-wires (rarely screws).</td>
</tr>
<tr>
<td>Type III: dorsal coronal</td>
<td><img src="image2" alt="Illustration" /></td>
<td>Unstable</td>
<td>Nondisplaced Fracture: &lt;25% and stable joint: consider nonoperative treatment or excision. &gt;25% and nondisplaced: could consider nonoperative treatment, but must follow closely. Otherwise, two percutaneous K-wires. Displaced Fracture: &gt;25% and displaced or &lt;25% with subluxed joint: joystick closed reduction and K-wires, or open reduction and K-wires (rarely screws).</td>
</tr>
<tr>
<td>Type V: bicondylar</td>
<td><img src="image3" alt="Illustration" /></td>
<td>Unstable</td>
<td>A nondisplaced fracture: could consider K-wires. Usually requires open reduction and screws, plates, or K-wires</td>
</tr>
<tr>
<td>Type IV: triplane-type bicondylar</td>
<td><img src="image4" alt="Illustration" /></td>
<td>Unstable</td>
<td>Percutaneous K-wires Usually requires open reduction with dorsal-to-volar screws</td>
</tr>
</tbody>
</table>
Most commonly, the condyle toward the midline of the hand (ie, the middle finger axis) is fractured: the ulnar condyle in the index finger and thumb and the radial condyle in the ring and small fingers.

**NATURAL HISTORY**

- In developed countries, these fractures rarely go untreated, but they often are undertreated given that their presentation may be interpreted as a “minimally displaced finger fracture.”
- Similar to any proximal interphalangeal (PIP) joint injury, lack of immobilization in full extension or prolonged immobilization will likely lead to a stiff finger.
- If treated conservatively, displacement of the fracture, a common occurrence, will lead either to early painful arthritic changes, or rotational malalignment on full flexion, or both.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- A typical patient is a 24-year-old male baseball player who has sustained an angular impact to the finger from the ball.
- A high index of suspicion is required when evaluating these patients. The patient often is still able to bend the finger, and the fracture line can be subtle, but even nondisplaced fractures are prone to subsequent displacement.
- Joint subluxation is an absolute indication for surgery and must be assessed carefully both radiographically and clinically.
- With any fracture displacement, a rotational deformity of the finger usually occurs, best assessed either looking end on at the digit or evaluating position with PIP flexion (FIG 2A).
- Subtle joint depression may lead to angular deformity; this is best assessed by examining fingers in full extension (FIG 2B).

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- The fracture pattern dictates the type of fixation or treatment.
- Multiple views should be obtained as needed to understand the geometry. Fluoroscopy often is helpful in obtaining precise views.
- Osteochondral fragments often are larger than they appear, because the cartilage is radiolucent.
- Hidden fracture lines are common and often are not visualized until surgery.
- CT occasionally is helpful.
DIFFERENTIAL DIAGNOSIS
- Collateral ligament or volar plate avulsion
- PIP dislocation
- Distal shaft fracture

NONOPERATIVE MANAGEMENT
- Reports regarding the results of nonoperative treatment present conflicting results.
- Weiss et al found five of seven nondisplaced fractures treated conservatively went on to displace and required surgery.
- In an 11-year follow-up study, using a functional outcome score, O’Rourke et al. demonstrated several interesting points:
  - 27% of patients experienced joint aching in cold weather.
  - Four patients at 1 year follow-up had moderate pain and considered arthrodesis. However, by the time they got off the waiting list their symptoms had subsided to the point that they declined surgery.
  - No patient had less movement in the joint at year 11 than at year 1.
  - 25% of patients had continued improvement in range of motion after 12 months follow-up.
  - Three patients with displaced bicondylar fractures treated conservatively had outcomes of good, fair, and poor, respectively.
  - Three patients with displaced unicondylar fractures treated conservatively had a good outcome; however, in O’Rourke et al’s discussion, they conclude that these fractures should be treated with reduction and fixation.
- Operating on nondisplaced or minimally displaced fractures can be viewed in two ways:
  - On the other hand, there is minimal morbidity in percutaneous pinning, and that would minimize the likelihood of displacement in a fracture that often is unstable.
  - Given the propensity for displacement and the potential functional difficulties with malunion, we recommend, at a minimum, percutaneous stabilization of most condylar fractures.
  - Several review texts suggest that coronal fractures of less than 25% of the joint surface with a stable congruent joint can be treated nonoperatively or with fragment excision. Although this may be true, there are few biomechanical or clinical outcomes data to support the statement.

SURGICAL MANAGEMENT
Preoperative Planning
- Preoperative planning should be mindful of the goals of treatment of any articular fracture established by the AO:
  - Anatomic reduction of the articular surface
  - Restoration of stability
  - Minimizing soft tissue injury
  - Early mobilization
  - Access to a mini C-arm is highly advantageous.
  - Fluoroscopic examination under anesthesia provides a good sense of joint stability and fracture fragment orientation.
  - Fracture reduction, implant placement, and fracture stability are effectively evaluated fluoroscopically.

Positioning
- The patient is positioned supine with a hand table.
- If an assistant is unavailable, finger-trap traction also may be helpful.

Approach
- A unicondylar fracture typically is approached either between the central slip and lateral band (FIG 3) or via a mid-axial approach.
The lateral (mid-axial) approach is suggested as a means to minimize extensor mechanism scarring, but only if significant joint incongruity or comminution is absent.
- If more extensive joint visualization is needed, the extensor mechanism can be incised and repaired later (FIG 4).
- A bicondylar or triplane fracture requires a more global joint and fragment exposure.
- A dorsal, slightly curvilinear incision is made.
- The extensor tendon may be split longitudinally, but preferably incisions are made on its borders, allowing mobilization and excellent joint exposure.
- A palmar approach is rarely used except for volar coronal shear fractures.

### SHORT AND LONG OBLIQUE FRACTURE WITH PERCUTANEOUS REDUCTION, K-WIRES, MINIFRAGMENT SCREWS, OR CANNULATED HEADLESS COMPRESSION SCREWS

#### Tips for Achieving Fixation
- Visualize the fracture well using live fluoroscopy.
  - Fracture displacement typically is in an oblique plane, sometimes not well appreciated on the straight anteroposterior or lateral views.
  - Use of the view on live fluoroscopy that best shows the displacement will make it possible to determine when reduction has truly been achieved.
- Apply traction and rotation to the distal aspect of the finger to assist reduction through ligamentotaxis (TECH FIG 1A).
- If necessary, make a Brunner-style volar incision, and retract the flexor tendons to expose the volar plate.
- If possible, reflect the volar plate on one side and a little up the lateral edge for exposure via a triangle-shaped flap.
- If more complete exposure is needed, make a transverse incision along the proximal edge of the volar plate, leaving enough proximal cuff to reattach the volar plate.
- Elevate the volar plate on a distal hinge, repair the fracture, and then reattach the volar plate.
- The PIP joint is prone to stiffness from injury, so every effort should be made to minimize surgical injury to the soft tissues.
- Avoid at all costs stripping soft tissue attachments from small fracture fragments.

### TECHNIQUES

**SHORT AND LONG OBLIQUE FRACTURE WITH PERCUTANEOUS REDUCTION, K-WIRES, MINIFRAGMENT SCREWS, OR CANNULATED HEADLESS COMPRESSION SCREWS**

**Tips for Achieving Fixation**
- Visualize the fracture well using live fluoroscopy.
  - Fracture displacement typically is in an oblique plane, sometimes not well appreciated on the straight anteroposterior or lateral views.
  - Use of the view on live fluoroscopy that best shows the displacement will make it possible to determine when reduction has truly been achieved.
- Apply traction and rotation to the distal aspect of the finger to assist reduction through ligamentotaxis (TECH FIG 1A).
  - Try percutaneous manipulation of the fragment with a dental pick.
  - If reduction is achieved, place either a pointed reduction clamp or the first K-wire to hold it.
  - If the dental pick does not work, place one prong of a pointed reduction clamp through the skin into the stable condyle, then place the other prong into the fragment and try to reduce the fragment with a slight rotation of the clamp (TECH FIG 1B).
  - Resist the urge to use clamp compression to force a reduction, because the small fragments shatter easily.
Chapter 33  ORIF OF PHALANGEAL CONDYLAR FRACTURES

**TECHNIQUES**

- Hold the PIP joint in extension while driving wires.
  - This position keeps the lateral bands dorsal, and the entry of the K-wire can be just volar to the lateral bands.
  - The condyle, as viewed on a lateral image, is the area with the least excursion of the collateral ligaments; therefore, K-wires in the volar position cause the least restriction of motion.
- The use of 0.028-inch K-wires avoids further fragmentation of fragments and usually provides sufficient fixation.

**Fixation Choices**

- In our practice, if we can achieve a percutaneous reduction, we prefer the use of multiple 0.028-inch K-wires.
- If we have to open to achieve the reduction, we prefer the stability of screw fixation.
  - Occasionally, fragments are too small or comminuted for screw fixation, necessitating the use of K-wires.

**K-Wire Fixation**

- A single K-wire is not sufficient fixation.
- Drive two K-wires from the fragment into the shaft either transversely or obliquely depending on the fracture orientation (TECH FIG 2).
  - The first wire should be placed perpendicular to the fracture line to maximize fixation and minimize displacement while capturing the reduction.
  - Additional wires should be placed slightly oblique to the first wire so that the fracture fragment cannot displace along the axis of two parallel wires.
  - The best bone quality is found distal and volar; therefore, to avoid injury, insert wires from contralateral

**Screw Fixation**

- Screw fixation should avoid the collateral ligaments by one of four methods (TECH FIG 3):
  - Flexing the joint and passing the screw distal and dorsal to the collateral ligaments
  - Keeping the joint in extension, with subperiosteal stripping of a limited portion of the collateral ligament origin from proximal to distal
  - Excising a small window in the collateral ligament for the screw head, which is gently countersunk
  - Placing the screw proximal to the collateral ligament if the fracture extends far enough proximally
- Screw fixation must not impinge on the collateral ligaments through any of the four methods listed, or the screw will cause permanent difficulties with joint motion.
- Screw fixation should be with 1.0- or 1.3-mm screws placed in lag fashion (TECH FIG 4A–E).
- For longer oblique fractures, make a stab incision, spread with a snap, and place three screws or three or more wires spaced along the fracture (TECH FIG 4F).
TECH FIG 3 • The four methods for screw placement to minimize impingement on collaterals. Methods A and C require seating the screw head almost flush with the bone. A. Creation of a small window in the collateral for screw placement. B. Reflection of the proximal part of the collateral ligament for screw placement. C. Flexion to allow exposure of the condyle for screw placement. D. In a longer fracture, placement of the screw proximal to collateral insertion.

TECH FIG 4 • Placement of a lag screw. A. 0.076-inch drilling is done through both cortices. B. The joint is flexed to permit placement of the screw out of the way of the collateral ligaments. C. Overdrilling only the proximal cortex with a 1.0-mm drill. D. Compression of fragments by a reduction clamp while placing the lag screw. E. Position of the screw head after extension of the joint. F. Long oblique fracture maintained with three 0.028-inch K-wires.
The first screw should be placed in lag mode, perpendicular to the fracture line, to prevent displacement of the fracture during compression.

If there is good compression, the second and third screws can be in neutralization mode.

If compression from the first screw was poor, additional screws can be placed in the lag mode.

Consider placing one screw more perpendicular to the long axis of the phalanx to resist axial forces.

While screws are being placed, the reduction can be held either by a reduction clamp or with a temporary K-wire. The hole made by the temporary K-wire, after removal, can be used for the last screw.

**DORSAL AND VOLAR CORONAL SHEAR FRACTURE WITH SCREWS OR K-WIRES**

- A dorsal approach typically is used for dorsal fractures and a volar approach for volar fractures.
- Dental picks are used for all fragment manipulation and reduction.
- Traction generally does not help reduction.
- Because fragments usually are very small, fixation with 0.028-inch K-wires may involve crossing the joint surface.
- Typically, a trade-off must be made in terms of implant position.
- For example, in a dorsal shear fragment, it may be necessary for a K-wire to pass through the dorsal articular surface of the fragment into the condyle below. Try to stay as dorsal as possible to minimize impingement in extension, while still securing the fragment adequately. It is possible to bury a screw beneath the articular surface, but if it is possible to use K-wires, they are preferred for their small and temporary footprint. A dorsal shear fracture with a nonarticular component would be a better choice for screw fixation than an all-articular fragment.
- We do not have experience with absorbable implants, but would be concerned about their use due to the small size of the fragments and resorption products.

**BICONDYLAR FRACTURE WITH OPEN REDUCTION AND INTERNAL FIXATION**

- Use a dental pick to align the condylar fragments and secure with a K-wire or screw.
- Similar to previous discussion, if reduction is achieved percutaneously, one or two K-wires may be used to secure the condyles to each other.
- Typically, open reduction is required, in which case screws are preferred whenever possible.
- Occasionally, if it is difficult to secure the two condylar fragments to each other, try reducing the largest condylar piece to the shaft and hold it with a K-wire. Then reduce the smaller condylar piece or pieces to the main construct. Once the entire reduction is achieved and held with clamps or K-wires, a screw can be placed transversely across the condyles.
- If minimal metaphyseal comminution is present, the condylar fragments are secured to the shaft using K-wires (TECH FIG 5).
**Condylar Plate**
- If metaphyseal comminution is present, consider a condylar plate (TECH FIG 6).
- The reduction starts with the condylar fragments, ignoring any proximal comminution.
- These fragments are held temporarily while the condylar plate is drilled and placed into just the distal fragment.
- Care must be taken to align the plate on the condyles so that the plate aligns with the shaft, once the condylar/plate construct is reduced to the shaft, bypassing the comminution.

**TECH FIG 6 • A,B.** Radiographs of a bicondylar fracture. **C,D.** Postoperative radiographs after reduction and application of a condylar plate fixation. (Courtesy of Alan Freeland, MD.)

**TRIPLANE FRACTURE WITH OPEN REDUCTION AND FIXATION USING LAG SCREWS AND K-WIRES**
- An extensile dorsal approach is used.
- TECH FIG 7 shows a triplane fracture in a 42-year-old carpenter with a table saw injury, who was treated as follows:
  - The collateral ligaments were attached to the two volar condylar pieces.
  - Lag screws were placed into each condyle from dorsal to volar.
  - A K-wire was used to secure the condyles to the shaft and keep the joint reduced.
  - Metaphyseal comminution has been treated with bone grafting and, in some cases, distraction external fixation for 3 weeks, after which motion is commenced.¹

**TECH FIG 7 •** Triplane fracture in a 42-year-old carpenter with a table saw injury. **A.** Lateral radiograph shows the injury. **B.** Clinical photograph of the injury with the collateral ligaments attached to the two volar condylar pieces. **C,D.** Postreduction photograph and radiograph demonstrating lag screws placed into each condyle from dorsal to volar. A K-wire was used to secure the condyles to the shaft and keep the joint reduced. **E,F.** AP and lateral radiographs 1 year postoperatively. (Courtesy of Jesse Jupiter, MD)
PEARLS AND PITFALLS

| Difficulties with closed reduction and pinning | • Try using traction with rotation, a dental pick, pointed reduction clamp, or a K-wire as a joystick into the displaced fragment. |
| Preventing fracture of a small fragment | • Make sure the screw diameter is no more than one third the size of the fragment and is placed one screw diameter from the edge of the fragment. |
| Maintaining reduction and pinning small fragments | • Use a cannulated reduction forceps. |
| Obtaining maximum mechanical stability | • Place the screw from the fragment into the phalanx, “from the island to the mainland.” |
| Maximizing reduction with small intra-articular fragments | • Reduce the large fragments first. Often the smaller pieces then fall into place with soft tissue tensioning or can be excised: “Rule of Vassals, or Majority Rule.” |
| Minimizing postoperative adhesions | • Avoid plating the phalanges whenever possible. Meticulous handling of soft tissue, and sharp dissection where possible rather than blunt spreading minimizes tissue trauma and permits early active range of motion (AROM). |

POSTOPERATIVE CARE

• Fracture stability dictates the protocol, but most patients should be started on AROM within 1 week, with extension splinting of the PIP joint while at rest.
  • It is important for the surgeon and therapist to communicate regarding the extent of injuries, type of fracture fixation used, and co-existing conditions, because these variables will affect the rate of healing and progression of therapy.
  • Exercises should be performed at least six times per day.
  • When immobilization is involved, it is extremely important for the patient to perform AROM to all noninvolved joints to prevent secondary weakness and stiff joints in the involved extremity, as well as to aid edema control.
• 1–7 days after surgery
  • Control edema with Coban wraps (3M, St. Paul, MN), compressive digit sleeves, elevation and AROM, and contrast baths (if no pin or sutures are present).
  • A hand-based safe-position splint including the involved digit and an adjacent digit is worn between exercises and at night. Use a forearm-based splint including all digits if multiple digits are involved.
  • AROM exercises are used based on the stability of fracture:
    • Composite flexion and extension of the digits
    • Blocking of the PIP and DIP joints to provide differential gliding of the flexor digitorum superficialis and profundus tendons (especially important following a volar exposure)
    • Reverse blocking (metaphalangeal [MP] joints passively flexed with active interphalangeal [IP] joint extension), flexor and extensor tendon glides
  • 7–14 days post-surgery
    • Gentle assisted AROM and passive ROM may begin as tolerated, again based on fracture stability. Passive ROM should not begin with K-wires in place.
    • Avoid painful ROM and monitor splints closely for excessive forces on the PIP joint. This can result in a counterproductive inflammatory and fibroblastic response.
    • Early scar management (approximately 10–14 days)
      • When the incision or pin site has healed, begin scar massage with lotion.
      • Superficial heat application applied before scar massage helps increase scar pliability.
  • If scar sensitivity develops, introduce scar desensitization, to include stimulation of the sensitive scar with graded textures and tactile pressure and tapping of scar, progressing as the patient develops increased tolerance to each stimulus.
  • If scar adherence persists, use iontophoresis with Iodex (Baar Products, Inc., Downingtown, PA) to soften the scar.
  • For a raised scar, encourage scar remodeling by use of a nocturnal scar pad, such as elastomere or Otoform K (AliMed, Deham, MA).
  • After initial fracture healing (about 4–6 weeks)
    • Assisted and passive ROM should be started if they have not been initiated earlier.
    • Continue the “safe position” splint between exercises and at night.
    • As the patient’s pain level decreases and functional use of the involved digit increases, reduce the splint to a gutter splint worn at night to prevent PIP flexion contracture.
  • If a flexion contracture develops at the PIP joint, consider serial extension casting of the involved digit. The contracture should be no more than 45 degrees, because the patient will have difficulty donning the serial cast with any greater degree of joint contracture. Dynamic splinting or static progressive splinting by day may be used as needed.
    • Progressively wean splints as passive ROM improves, and encourage active ROM.
    • Strengthening (about 8 weeks)
      • Progressive strengthening can be initiated with light putty and further progressed with activities appropriate for the patient’s occupation.
    • About 10 weeks
      • Discharge all splinting.
      • Encourage unrestricted use of the involved digit and hand.
    • In closed fractures, with a good soft tissue envelope and blood supply, K-wires should be removed at about 3 weeks to facilitate rehabilitation.

Overcoming Issues Related to Rehabilitation

Decreased PIP Joint Flexion

• The reason for decreased flexion at the PIP joint must be determined. If the joint has full PIP joint flexion on passive ROM and decreased PIP joint flexion on active ROM, the problem most likely is caused by adhesions.
Treatment should attempt to regain ROM through active exercise:
- Before treatments, application of heat is useful to increase tissue extensibility for increased ROM gains and assist the patient with increased tolerance to exercise.
- Superficial modalities such as moist hot pack, paraffin, and fluidotherapy may be used. Benefits of fluidotherapy include the ability to actively stretch with application of heat.
- Ultrasound may be used to heat deeper tissues.

Exercises
- Tendon glides
- Isolated blocking of the flexor digitorum superficialis and profundus tendons to maximize differential tendon gliding
- Active flexion of the digit against resistance, such as hook fist exercises performed with therapeutic putty, or raking the digits through putty
- Blocking splint for exercise: the MP joints are blocked in extension by a splint with the PIP joints free. The patient performs active PIP flexion and extension to increase differential glide of the tendons (FIG 5A).
- Neuromuscular electrostimulation of the flexor digitorum superficialis and profundus may be used to assist active ROM and tendon glide.
- If the fracture is healed and passive ROM of the joint is limited in flexion, passive ROM exercises and splinting alternatives will assist to progressively stretch a tight joint capsule and elongate shortened ligaments. Splinting options include:
  - Static progressive splinting
  - Use of a dynamic flexion splint (FIG 5B)

Passive ROM and joint mobilizations are appropriate if the fracture is healed.
- Use of heat (as discussed earlier) to increase tissue extensibility will make the patient more comfortable and help increase ROM. To assist stretch into flexion with heat, try wrapping the digit(s) in flexion with Coban and dipping them in paraffin.

**Decreased PIP Joint Extension**
- The appropriate treatment approach depends on the structures involved. If the PIP joint can be passively placed into full extension but is unable to actively extend, the extensor apparatus may be scarred down.
- The following treatments are beneficial to increase active extension of the PIP joint.
  - Before beginning the exercises, use of superficial heat modalities and ultrasound will assist to increase tissue extensibility, ROM gains, and the patient’s tolerance to exercises.
  - Active exercises include:
    - Active reverse blocking (passively flex the MP joints while actively extending the IP joints to transmit the extension force to the IP joints).
    - A reverse blocking splint is helpful to assist the patient with reverse blocking (FIG 5C).
  - Block the MP joint in flexion while actively extending the PIP joint into extension with simultaneous neuromuscular electrostimulation of the extensor digitorum communis muscle and the intrinsic muscles.
  - Active extension against resistance, such as theraputty
If the fracture is healed and passive ROM of the PIP is limited with extension, exercises and splinting can assist with improving passive ROM.
- Serial casting PIP into extension
- Finger-based dynamic PIP extension splint (FIG 5D)
- Dynamic extension splint with MP block in flexion
- Passive ROM and joint mobilizations with heat applied before these manual activities are appropriate if the fracture is healed.

**Scar Adhesions Limiting Tendon Glide**
- Active ROM, including extensor/flexor tendon glides, and scar massage and reverse scar massage (opposite the direction of the adhesion with active ROM) are key to decreasing adhesions of the tendon.
- These modalities work well in conjunction and may be used individually or in combination based on the patient’s individual needs.
  - Superficial heat (eg, fluidotherapy, moist heat, paraffin)
  - Ultrasound
  - Scar pad (eg, elastomere, Otoform K)
  - Iontophoresis with Iodex to soften scar

**OUTCOMES**
- In one series of 36 patients, the arc of motion of the PIP joint averaged 72 degrees with a 13-degree extensor lag. Patients with volar coronal fractures fared worse, with an average arc of 57 degrees.5
- In the McCue series of 32 patients treated with open reduction and two K-wires, flexion averaged greater than 93 degrees and extensor lag averaged less than 5 degrees.3

**COMPLICATIONS**
- Loss of PIP joint motion is the most common complication.
  - Fixation must be secure enough to allow early motion.
  - Delay of motion of the hand by more than a few weeks significantly decreases final outcome. Ideally, motion should be initiated in the immediate postoperative period.
  - Increases in motion may be obtained up to 1 year after the injury, although opportunity does decrease with time.2
  - Dorsal capsulotomies and extensor tenolysis are options for patients lacking flexion.
  - Loss of reduction is common if fractures are not stabilized or are stabilized with only one point of fixation.5

**REFERENCES**
DEFINITION

- The laymen’s term “jammed finger” often is used to indicate an injury sustained to the proximal interphalangeal (PIP) joint. If the force behind this injury is sufficient, the joint may suffer a fracture-dislocation, an injury that may be difficult to treat.

- PIP fracture-dislocations in the dorsal direction are caused by disruption of the volar fibrocartilaginous plate, fragmentation of the middle phalanx where it attaches to this plate, and damage to the collateral ligaments on each side of the joint. Instability with dorsal displacement of the middle phalanx may result, accentuated by the unbalanced pull of the central slip.

- Stiffness, pain, persistent subluxation, osteoarthritis, and permanent dysfunction are common sequelae, even with dedicated treatment in the best of circumstances.

- Dynamic external skeletal traction, extension block pinning or pinning, transarticular pinning, open reduction with internal fixation (ORIF), and volar plate arthroplasty are the techniques most often used to address this problem.

- None of these techniques have proven to be satisfactory for all patients in all instances.

- Extension block pinning has been used with reasonable success to reduce and stabilize unstable PIP fracture-dislocations.

  - A K-wire is placed into the head of the proximal phalanx, mechanically blocking full extension and thereby preventing dorsal subluxation of the middle phalanx.

  - The advantages of this technique include its simplicity and the early mobility it affords an injured joint. It can be used alone or in combination with volar plate arthroplasty or ORIF.

ANATOMY

- The PIP joint acts mostly as a hinge joint in the sagittal plane, although it does possess a few additional degrees of motion in the coronal and axial planes. It has an average range of flexion–extension of 105 degrees.

- The joint has a great deal of stability throughout its range of motion.

- When healthy, the joint is most stable in full extension.

  - A tongue-and-groove structure, formed by the bicondylar head of the proximal phalanx and the reciprocal concave surfaces of the middle phalanx, contours closely in this position.

  - As the joint flexes, the ligamentous elements take up responsibility for maintaining stability.

  - The volar plate, a structure that is ligamentous at its origin on the proximal phalanx and cartilaginous at its insertion on the middle phalanx, and the two collateral ligaments, one on the radial and one on the ulnar side of the joint, are the most important (FIG 1).

  - Two out of three of these structures must be impaired for displacement of the middle phalanx to occur.

PATHOGENESIS

- Although the PIP joint may become dislocated in any direction, displacement of the middle phalanx dorsally is the most common.

- Simultaneous hyperextension and compression forces—such as those seen when a ball strikes the tip of the finger—stress the volar plate and the collateral ligaments.

  - Type I injury

    - If the force of injury is mild, partial disruption of the collateral ligaments and the volar plate at its distal insertion on the middle phalanx are the only consequences.

    - The articular surfaces remain intact and the joint is stable.

    - If appropriate treatment is initiated promptly, an excellent long-term result is anticipated.

  - Type II injury

    - If the force of injury is more substantial, bilateral longitudinal splitting of the collateral ligaments may occur in addition to rupture of the volar plate. Complete dorsal displacement of the middle phalanx is then possible due to unopposed pull of the central slip.

    - The joint can be readily reduced and usually is stable following the reduction.

  - Type III injury—stable

    - If an avulsion fracture of the middle phalanx occurs at the attachment of the volar plate, the joint may still remain stable. When less than 30% to 40% of the joint surface is involved, the joint is stable following reduction because collateral ligament integrity is maintained.

  - Type III injury—unstable

    - If the fracture at the base of the middle phalanx involves more than 40% to 50% of the articular surface, collateral ligament support is lost. The joint exhibits persistent dorsal subluxation of the middle phalanx due to unopposed pull of the extensor tendon and lack of volar restraints.
■ Closed reduction may not be possible, and treatment is more difficult, often leading to unsatisfactory overall results.20

**NATURAL HISTORY**

■ The outcome following even a minor injury is often less satisfactory than the patient anticipates. Although it is possible for a PIP joint that has suffered a fracture-dislocation to regain fully normal function, this often is not the case. Persistence of a stiff joint with a cosmetically thickened outline is common.
  ■ Delay in treatment or lack of vigilant care negatively affects outcome.10
  ■ Prolonged immobilization of the joint following reduction leads to stiffness. Early mobilization can avoid stiffness and promote nutrition of the damaged articular cartilage.19
  ■ Patients should be reassured, however, that carefully planned treatment and compliance with the postoperative therapy regimen leads to long-term satisfactory results in most cases.10

**PATIENT HISTORY AND PHYSICAL FINDINGS**

■ The history should elicit the manner in which the digit was injured, the nature of any medical treatment or manipulation of the digit before the current visit, and how much time has elapsed since the injury.
  ■ The likelihood of a favorable result diminishes with increased time from injury, particularly beyond 6 weeks.9
  ■ The digit will look surprisingly normal at presentation in many cases, particularly if it was previously reduced.
  ■ A transverse skin injury on the volar side of the PIP joint may indicate that the volar plate has been disrupted.25
  ■ The integrity of the neurovascular status should be documented on examination before digital anesthetic block and reduction.18
  ■ With the forearm supinated and the hand relaxed, observe the position of the patient’s fingers. Note the axial and rotational alignment of the digit.
  ■ The uninjured, quiescent hand has increasing flexion tone in the digits from the radial side to the ulnar side,2 a phenomenon known as the flexion or resting cascade (FIG 2A).
  ■ Observe the patient’s fingers directly and fluoroscopically as he or she attempts to move them through a normal range of motion. Dorsal subluxation often can be detected visually and through palpation.
  ■ Digital or wrist block anesthesia can be used to relieve discomfort associated with motion (FIG 2B).
  ■ If the joint can be moved through a full arc of motion without subluxation, adequate joint stability remains, and only brief immobilization will be required.
  ■ If redisplacement occurs, significant instability results. The position of redisplacement is a clue both to the specific site of ligament injury and the optimal position for joint immobilization.8 Loss of active extension implies central slip injury.
  ■ For grossly stable digits, manipulate the joint passively through the normal range of motion. Gentle lateral and dorsovolar shearing stresses are applied at full extension and at 30 degrees of flexion. The findings are compared to those of the contralateral uninjured digit (FIG 2C).
  ■ The position of the PIP joint at the point of instability suggests which of the soft tissue supports has been injured. Instability at more than 70 degrees of flexion indicates damage to the collateral ligaments. Instability in extension indicates disruption of both the collateral ligaments and the volar plate. The degree of joint laxity suggests the extent of injury to the ligaments, from microscopic tearing to complete rupture.
  ■ Palpate the PIP joint from all sides to determine point tenderness. Point tenderness often is valuable in localizing the injured structure.
  ■ Absence of point tenderness on the condyles may rule out significant injury to these structures. If the volar lip of the middle phalanx has been fractured, minor tenderness over the dorsum of the middle phalanx and greater tenderness volarly and laterally will be present.3

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

■ Obtain anteroposterior, lateral, and oblique radiographs of the injured digit. Assess the digit for joint dislocation, subluxation, and fracture.18
  ■ Evaluate the radiographs before performing the physical examination to detect potentially unstable fractures or dislocations before they are manipulated.18
  ■ Radiographs of the hand as a whole (eg, the “fanned four-finger lateral” view) are not adequate. Subtle fracture-dislocations may be missed due to poor depiction of the areas of suspected pathology.23
  ■ Fluoroscopy is extremely valuable in defining the pathoanatomy and determining stability.
CT scanning occasionally is indicated, particularly to assess suspected articular depression.  

**DIFFERENTIAL DIAGNOSIS**
- Fracture
- Fracture-dislocation
- PIP dislocation
- Collateral ligament and PIP joint sprain
- PIP volar plate injury
- PIP joint infection
- Localized soft tissue infection
- Flexor digitorum profundus tendon rupture
- Extensor tendon central slip injury
- Closed pulley rupture (flexor sheath)
- Swan neck/boutonniere deformity

**NONOPERATIVE MANAGEMENT**
- Most type I, type II, and type III stable injuries (and some type III unstable injuries) are amenable to nonoperative treatment.
- The joint can be immobilized for a short time to afford the patient comfort and to allow soft tissue recovery.
- A dorsal splint is applied to the digit at 20 to 30 degrees of flexion, avoiding immobilization beyond 30 degrees to lessen the risk of flexion contracture.
- The duration of immobilization reflects the minimum amount of time needed to effect healing and obtain joint stability. Type I injuries are immobilized for several days; type III injuries may be immobilized for up to 3 weeks.
- Avoidance of prolonged immobilization and patient education are the most important aspects of this treatment, because stiffness and contracture are very common.
- Extension block splinting allows early motion of a joint while preventing extension past an angle where instability is possible.
- First, the position in which the joint re-displaces is determined.
- A length of aluminum splint is then bent to an angle 10 or 15 degrees greater than this point of redisplacement and secured to the dorsum of the hand with adhesive tape or as part of a short-arm cast. The hand is positioned with 25 degrees of extension at the wrist and 45 to 60 degrees of flexion at the metacarpophalangeal joint (FIG 3A,B).
- If the angle of the splint is greater than 60 degrees, the arc of motion may be insufficient for the patient to achieve adequate flexibility, and it may be necessary to consider another treatment regimen.
- An extension block splint made from two pieces of AlumaFoam (Hartmann International, Rock Hill, SC) and spanning only the finger itself is another option (FIG 3C,D).
- The two Alumafoam pieces are held to each side of the PIP joint with adhesive tape and are bent such that they
come into contact with each other at a particular degree of extension, thus preventing motion beyond that point.21
- In general, extension block splinting is recommended for fractures involving less than 40% of the articular surface. Successful results have been noted, however, with fractures involving up to 75% of the joint.12
- Following application of the splint, radiographs are taken to confirm satisfactory reduction, and the patient is encouraged to flex the finger as much as the swelling allows.
- As the fracture-dislocation heals, the extension block splint is progressively adjusted toward full extension, usually during a period of 3 to 8 weeks.7 Weekly radiographs and splint adjustments are required.
- In certain instances, the digit may be too short, stocky, or swollen for such treatment, or patient compliance and sophistication for such a regimen may be in question. In such a case, extension block pinning may be the better option.
- Because of the possibility of recurrent subluxation, the use of conservative treatment must be matched with frequent and careful assessment of the joint. Serial radiographs should be obtained weekly to document continued reduction of the joint and progressive healing of any fractures.7

SURGICAL MANAGEMENT
- Operative treatment is indicated for those unstable fracture-dislocations in which closed treatment does not provide a congruent reduction of the joint. This includes most type III unstable injuries with fractures that involve more than 40% to 50% of the volar articular surface.
- As noted earlier, many surgical options are available. The choice of procedure is based on the exact nature of the injury and the surgeon’s comfort with each option.
- Dynamic skeletal traction methods, which use the principle of ligamentotaxis to maintain concentric joint reduction, are especially useful when the fracture is significantly comminuted.1
  - These methods allow early active range of motion.
  - Drawbacks include the following:
    - Significant prowess on the part of the surgeon is required, as are close postoperative supervision and adjustment.
    - The external device may be cumbersome for the patient.
  - ORIF is especially useful when the avulsed volar fragment is large and minimally comminuted.11 If the joint is stabilized with transarticular pinning as part of the ORIF procedure, however, stiffness usually results.
  - Volar plate arthroplasty, or the use of the distal aspect of the fibrocartilaginous volar plate to resurface the comminuted volar articular surface of the middle phalanx, is another option that can be employed when comminution of the volar fragment makes other techniques infeasible.7 Most authors have reported reasonably favorable results, but residual stiffness and contracture have been reported as well.9
  - Simple reduction with transarticular pinning (with no attempt at articular reconstruction) may be useful in injuries with less than 40% articular involvement. Extension block splinting may be just as effective in these milder instances, however, and it enjoys a lower risk of joint contracture.10
  - Extension block pinning is a viable alternative for mild to moderately unstable fracture-dislocations under the following circumstances:
    - The fracture-dislocation cannot be reduced and stabilized effectively with an extension block splint.14,22,24
    - Patient compliance is uncertain.
    - The finger is too short or swollen to fit appropriately into an extension block splint.
    - It may be used alone or in combination with an ORIF or a volar plate arthroplasty procedure.3

Preoperative Planning
- Before the operation, the patient should be provided realistic expectations regarding outcome.
  - He or she should be aware of the possibility that immobilization, splinting, and long-term rehabilitation may be necessary.
  - The patient should be instructed to keep the injured hand clean before the procedure and to avoid additional skin injury to minimize the potential for infection. Fingernails should be trimmed and cleaned and the hands thoroughly scrubbed with antiseptic soap before the operation.
  - Intraoperative decision-making often is necessary. The surgeon should be comfortable in the performance of a number of alternative procedures and should have the necessary equipment available should findings require an alteration in the original surgical plan.

Positioning
- The method of preparing, draping, and positioning the upper extremity is the same as for most hand surgeries.
  - A well-padded, proximal upper extremity tourniquet is applied.

Approach
- Because extension block pinning is a percutaneous technique, no approach is required.

EXTENSION BLOCK PINNING14,22,24
- The PIP joint is reduced by flexing the joint to 90 degrees and applying axial traction.
  - Concentric reduction of the joint is confirmed with fluoroscopy (TECH FIG 1A).
  - If an open wound is present or the joint cannot be manipulated into an acceptable reduction, such as may occur with soft tissue entrapment, open reduction becomes necessary.
  - Following reduction through either open or closed methods, and with the joint flexed 90 degrees or more, a smooth 0.035- to 0.045-inch K-wire is placed percutaneously into the distal, dorsal aspect of the proximal phalanx across the dorsal lip of the base of the middle phalanx (TECH FIG 1B).
  - The wire is inserted in a retrograde direction, approximately 30 degrees off the long axis of the proximal phalanx.
  - When placing the K-wire centrally, hyperflexing the PIP joint prevents tethering of the extensor mechanism to the proximal phalanx, which would limit joint flexion. Alternatively, the K-wire can be placed to one side of the central tendon to avoid tethering the extensor mechanism.
The wire is guided with fluoroscopy through the shaft of the proximal phalanx and is left protruding from the head of the bone. Fluoroscopy is used to confirm a congruous joint reduction following the procedure.

The joint is then passively extended to the limit of the K-wire, and the reduction of the joint is again critically evaluated fluoroscopically (TECH FIG 1C).

If the joint continues to subluxate dorsally at extension, a V-shaped gap between the articular surfaces of the head of the proximal phalanx and the dorsal lip of the middle phalanx will be seen on radiograph. With the pin in this position (TECH FIG 1D), the patient will be able to move the finger actively but will not be able to extend the digit beyond the point where subluxation is possible due to mechanical blockage by the pin (TECH FIG 1E,F).

An arc of more than 60 degrees is ideal.

**TECH FIG 1** • Dorsal block pinning. A. Fluoroscopic view confirms adequate joint reduction. Note that fracture reduction is not anatomic but is considered acceptable in this clinical scenario. B. Insertion of the retrograde K-wire with the joint hyperflexed to avoid tethering the extensor mechanism. C. Passive intraoperative extension of the joint to the level of the K-wire. The dorsal joint remains concentrically reduced. D. The K-wire is left protruding through the bone, and its placement is confirmed by fluoroscopy. E,F. The patient should be able to move the finger through an arc of about 60 degrees.

**PEARLS AND PITFALLS**

- The patient’s ability to comply with fairly complex and intensive hand therapy should be confirmed before surgery.
- The insertion point for the K-wire can be located by a freehand technique and then confirmed with fluoroscopy.
- Easy passive flexion of the joint through an arc of 60 degrees or greater should be confirmed following pin insertion.
- The surgeon should remain hypervigilant for the presence of a V sign in full passive extension.
- The surgeon should ensure that the skin is not tented by the Kirschner wire.
**POSTOPERATIVE CARE**

- The patient should have a thermoplastic splint fabricated for protection and should begin a supervised program with a hand therapist 3 to 5 days after surgery.
- Gentle active range-of-motion exercises are allowed immediately and should be encouraged in most cases.
- If the injury is especially serious—eg, injuries that required volar plate arthroplasty or that contained significant comminution—immobilization for up to 2 weeks may be indicated.
- Pin care must be explained carefully and performed regularly.
- The pin is removed 3 weeks after surgery, and vigorous active flexion and extension are encouraged. Reverse blocking is initiated.
- Full extension should be limited for 1 additional week.
- Active and passive joint exercises, including dynamic extension splinting, is initiated after 6 to 8 weeks of therapy, until full motion is achieved.
- Buddy taping or wrapping can be used, if added, longer-term protection is needed.

**OUTCOMES**

- The outcome for intervention into PIP fracture-dislocations depends mostly on the severity of the initial injury.
- Because few cases of extension block pinning used as the sole intervention are available in the literature, it is difficult to assess the long-term outcome of the procedure.
- Inoue and Tamara reported the use of extension block pinning in 14 cases of fracture-dislocation of the PIP joint with an average fracture fragment size of 38% of the articular surface (range 25% to 60%). Ten patients regained full range of motion, and four patients regained a more limited range (89, 65, 64, and 40 degrees, respectively). The average ROM for all patients was 94.4 degrees.
- The authors attributed the four cases with less satisfactory results to the use of a 60-degree extension block splint post-operatively in one patient and significant comminution in the other three patients.
- Viegas reported the use of this technique in three cases of fracture-dislocation of the PIP joint. One case involved a 45% single fragment fracture seen 1 day postinjury and another a 35% comminuted fracture seen 17 days post-injury. Following pin removal and 1 month of passive and active exercises, both patients regained full range of motion. A third case involved a 75% comminuted fracture seen 2 days post-injury. The patient’s ROM after pin removal was 30 to 65 degrees. Because the patient did not return for further care, no final outcome was available.
- Twyman and David reported the use of this technique in two cases of fracture-dislocation of the PIP joint. The extent of injury in each patient was not specified, but quick recovery to satisfactory ROM in both patients was reported (20 to 100 degrees and 15 to 110 degrees, respectively).

**COMPLICATIONS**

- Persistent pain and swelling
- Stiffness
- Flexion contracture and extensor lag
- Redisplacement of the joint and persistent subluxation
- Angulation and rotation of the middle phalanx
- Weakness
- Boutonniere deformity
- Post-traumatic arthritis (not necessarily symptomatic)

**REFERENCES**

DEFINITION

- Proximal interphalangeal (PIP) joint bone injuries may affect the convex side of the joint (end of the proximal phalanx) or the concave side of the joint (base of the middle phalanx).
- Convex-side injuries are typically simple (two-fragment) injuries best treated with open reduction and internal fixation if surgery is required.
- Concave-side injuries tend to be comminuted (multifragmented), presenting either as fracture-subluxations or dislocations or a pilon fracture.
- Fracture subluxations-dislocations typically involve dorsal displacement of the main (dorsal) fragment of the middle phalanx (FIG 1A), although volar and lateral subluxations and dislocations are less common (FIG 1B,C).
- Dorsal fracture-dislocations typically occur after a hyperextension injury of the PIP joint.
- Pilon fractures are compression fractures of the base of the middle phalanx (rarely the distal phalanx) and are characterized by depression of the central articular component and splaying of the articular margins.
  - This may be associated with longitudinal fracture extension that may reach most of the length of the middle phalanx.
  - There is typically marked comminution of the base of the middle phalanx (FIG 1D,E).
  - The fracture typically occurs due to a longitudinal (end-on) force, crushing the base of the middle phalanx (rarely the distal phalanx or thumb proximal phalanx). This may occur due to a fall or miscatching a ball (eg, at cricket or baseball).

ANATOMY

- The distal end of the proximal phalanx is a convex surface made up of two condyles. The proximal end of the middle phalanx is a concave surface (FIG 2A).
The two bones are linked and stabilized by ligaments (FIG 2B).
These structures resist dorsal subluxation of the PIP joint when loaded:
- Volar plate
- Collateral ligaments (radial and ulnar)

PATHOGENESIS
- The tendon attachments are dorsal proximal and weak through the central slip and volar distal and strong through the flexor digitorum superficialis tendon slips. Thus, the flexor forces dominate the extensor forces.
- The shape of the joint and the soft tissue restraints allow a powerful lever arm to work for flexion. If, however, the volar restraint fails (particularly in a dorsal fracture-dislocation), the resultant forces lead to dorsal subluxation and proximal migration of the main dorsal fracture fragment of the middle phalanx (FIG 3A).
- Research work and clinical experience have shown that the joint will be stable if up to 42% of the volar half of the middle phalanx articular surface is damaged as measured on a lateral radiograph (FIG 3B).
- In practice, subluxation can occur with as little as 10% to 15% of joint surface loss, but that is uncommon.
- For pilon fractures, the condyles of the proximal phalanx are driven up into the base of the middle phalanx, displacing the central part of the articular surface distally and splaying the dorsal-volar and lateral margins of the middle phalanx joint surface. This injury is longitudinally unstable and results in proximal migration and diminution or obliteration of the joint space, usually with significant articular incongruity.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Most patients present within a few days, although later presenters (up to 2 to 3 weeks) are common and some very late presenters (after 6 weeks) are also seen.
  - The delays are usually due to underestimation of the severity of the injury either by the patient (who thinks he or she has a sprain and it will resolve) or medical/paramedical staff (who fail to perform or interpret properly an adequate radiograph).
  - The finger will be swollen and tender, centered around the PIP joint.
  - An angular deformity may be evident.
  - Subluxation of the joint may be clinically evident, visually or by palpation.
  - There will be reduced range of movement throughout the finger and particularly in the PIP joint.

Fracture-Dislocation Involving the Proximal Interphalangeal Joint
- Most are mild injuries with limited volar plate avulsion that reduce either spontaneously or with assistance, usually under local anesthesia (FIG 4A–D). Radiographs may reveal a small volar bone avulsion from the base of the middle phalanx. These injuries are longitudinally stable.
  - The examiner must test for stability through a full arc of motion.
  - If there is a tendency for subluxation, the position of the joint that allows this instability is recorded.
  - More severe injuries (ie, involving a greater part of the volar lip) may be longitudinally unstable, resulting in persistent subluxation of the PIP joint with attendant clinical findings as described above.
Subluxation and dislocation are best visualized on the lateral radiograph and may be quite subtle, appearing as joint incongruity at the dorsum of the joint (the triangle sign, due to dorsal overhang of the base of the middle phalanx) (FIG 4E).

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- The key investigation is plain radiology.
- Often only radiographs of the hand are taken in the emergency department. These are not adequate. Posteroanterior and lateral radiographs need to be taken, centered on the PIP joint of the injured finger (FIG 5).
- The key information obtained from the radiographs (supplemented by physical examination) can be used to differentiate stable from unstable injuries, either of fracture-subluxations or dislocations or pilon fractures.
- Fluoroscopy can be of great value in assessing the injury and joint stability.

**DIFFERENTIAL DIAGNOSIS**
- Soft tissue
  - Volar plate injury
  - Collateral ligament injury
  - Central slip injury
- Bone
  - Proximal phalanx condylar injury
  - Proximal phalanx distal diaphyseal injury
  - Middle phalanx proximal diaphyseal injury

**NONOPERATIVE MANAGEMENT**
- If the injury is stable, early protected mobilization can start within 1 week of injury.

**Fracture-Dislocation**
- A stable injury (the majority of cases) can be treated with early mobilization concentrating on regaining extension, which is commonly lost.
  - Only if there is significant pre-existing volar plate laxity (often occurs in young women) is there a need for an extension block splint for up to 6 weeks.
  - Most patients regain full or nearly full movement but may be left with minor swelling and stiffness and mild cold discomfort.
  - Heavy activity may cause discomfort.
  - In approximately 5% of patients the joint remains significantly swollen and uncomfortable beyond 6 weeks. This is probably due to persistent joint synovitis, which usually resolves with a steroid injection.
  - If the joint is unstable but there is limited volar joint damage (less than about 30 degrees), it may reduce when held in flexion with a dorsal block splint.
Joint reduction and congruity must be documented radiologically and should not require more than about 50 degrees of joint flexion, or unacceptable PIP joint stiffness may result.

Patients should be encouraged to flex and extend to the splint. They should be seen weekly for 4 weeks. Flexion of the splint is reduced by about 10 degrees each week. At each increase in extension, the reduction needs to be precisely checked radiologically.

A reasonable range of movement with only a mild flexion contracture and loss of flexion is anticipated.

Pilon Fractures

The minority of pilon fractures have minimal displacement (less than 1 mm) and a reasonable joint space (FIG 6). These are usually stable injuries but must be carefully assessed clinically.

Most of these patients can achieve a range of movement from 10 to 20 degrees short of full extension to 70 to 80 degrees of flexion with only mild discomfort.

Patients can start early gentle mobilization with part-time protection in a splint at night and outdoors for 4 weeks.

Patients treated with early, protected mobilization need clinical and radiologic review weekly for at least 2 to 3 weeks.

Most patients will achieve a nearly full range of motion with minimal pain, stiffness, or swelling.

If there is greater displacement, then surgery is almost always needed to achieve longitudinal stability and early movement.

**Surgical Management**

Preoperative Planning

The proximal wire is always placed at or near the center of rotation of the injured joint.

Distal wire placement needs to be planned.

For fractures localized to the base of the middle phalanx, the distal wire can be anywhere from the midpart of the middle phalanx or more distal. In fact, the middle phalanx is narrowest at this point, so the wire is more easily placed distally.

**FIG 5** • Hand radiographs are interpretable only with a true lateral radiograph of the proximal interphalangeal joint.

**FIG 6** • Pilon fracture that was sufficiently congruent and comfortable to respond to early mobilization with a good long-term result. This could not have been predicted radiologically, and all cases require clinical assessment.
If the fracture extends distally, as can easily occur with pilon fractures, the distal wire should be distal to that extension to ensure adequate fixation and stability. The distal wire can be placed as far distal as the head of the middle phalanx.

I have never had a fracture so distal that the distal wire could not gain adequate fixation.

The procedure is best performed under local anesthesia. This allows the patient to participate during the operation. The patients also understand what has happened and is often clearer about the postoperative regimen.

At least 10 mL of plain 0.5% bupivacaine is injected at the midmetacarpal level. Bupivacaine works more slowly than lidocaine, but if given before skin preparation, it usually works completely by the time surgery starts. It then provides prolonged anesthesia for 12 to 36 hours. This helps reduce postoperative pain.

**Positioning**

Informed consent is needed, with a discussion of the risks and benefits of the various conservative (nonoperative) and surgical options.

**Approach**

The operation is performed closed with insertion of percutaneous wires.

---

**INSERTING THE WIRES**

- I use 1.1-mm K-wires: 0.9-mm wires are too flexible and 1.6-mm wires are too rigid. I know that 1.2-mm wires have been used successfully. I suspect that wires from 1.0 to 1.3 mm are fine, but I recommend 1.1-mm wires.
- Identify the level of the center of rotation of the PIP joint with the image intensifier and mark this level on the skin (**TECH FIG 1A,B**).

---

Risks include infection, nerve injury, stiffness, scar tenderness, nonunion, malunion, the need for revision procedures, and the risk associated with any operation (ie, making the patient worse).

The digit needs to be marked very clearly, especially if the patient is receiving general anesthesia (the minority of patients).

Typically 1.5 g of cefuroxime is administered preoperatively. There is no need for postoperative antibiotics.

The patient lies supine with the affected hand out on an armboard at 90 degrees to the table (ie, standard position for hand surgery).

A proximal arm tourniquet is applied as a backup to the digital tourniquet.

The skin is prepared with chlorhexidine in an alcohol solution with a pink dye to ensure that all the fingers have been fully painted. If the finger has had adhesive dressings on it or has not been well cleaned, the anesthetized finger is scrubbed before skin preparation.

The operated arm is draped steriley.

---

**TECH FIG 1 • A, B**. Checking the position for the first wire at the level of the center of rotation of the proximal interphalangeal joint with the image intensifier and marking it on the skin. **C**. Wire inserted across the head of the proximal phalanx and confirmed on the image intensifier before advancing further. **(continued)**
TECH FIG 1 • (continued) D,E.
Finding and marking the position of the distal wire as for the proximal wire. This placement is more distal in the head of the middle phalanx than average because the distal interphalangeal joint was also injured. F,G. Inserting the distal wire and confirming its position on the image intensifier.

- Placing this wire too far proximal of the construct will restrict full joint movement. This is the most important step in the whole procedure.
- Identify an appropriate level in the distal half to two thirds of the middle phalanx, distal to any fracture extension in the shaft of the middle phalanx, with the image intensifier.
- Mark this level on the skin.
- This wire may be inserted near the center of rotation of the distal interphalangeal (DIP) joint, in the distal middle phalanx. This is acceptable because the bone is wider and provides more margin for error (TECH FIG 1D,E).

- Insert the wire partially through the middle phalanx and check carefully (posteroanterior and lateral) on the image intensifier (TECH FIG 1F,G).
- Aim to be perpendicular to the long axis of the finger and parallel to both the plane of rotation and the first wire (which should also be in the plane of rotation).
- Insert the wire so equal lengths are present on either side of the finger (by doing this for the proximal wire, where it is less important, you will have a guide for the distal wire). This helps in the wire bending. If one end is too short it can become difficult to bend, especially in patients with long fingers.

BENDING THE WIRE

- Wire bending is the more technically demanding part of the procedure. It is important to understand and follow the steps carefully.
- One may create the construct in reverse of that described below, but this results in motion on the proximal wire rather than the distal wire, which in theory increases the risk of pin track and PIP joint sepsis.
- To ensure enough but not too much clearance from the finger, the wire is held with a medium needle holder against the skin, then manually bent past a right angle (because there is spring in the wire).
- Bend the opposite half of the wire to the same degree and in the same direction.
- Bend the distal wire on each side through 90 degrees (TECH FIG 2A,B).
- Bend each half of the distal wires to make the linkage between the wires (TECH FIG 2C,D).
- It is critical that this bend is sufficiently distal in the wire (proximal relative to the finger) to ensure that the construct is long enough and provides adequate joint distraction.
- If the bend is not distal enough, it is difficult to salvage, and you will probably need to remove the distal wire and insert a new wire.
- Grip the distal wires with the medium needle holder just after the second bend and bend the distal end back up about 135 degrees, creating a Z shape (TECH FIG 2E).
- The proximal wire will sit in the distal narrow angle of the Z.
- It important to put the Zs at the same level, although the construct can tolerate some mismatch.
- If the Zs are at different levels, careful unbending or further bending of the wires should help.
- The proximal wire is flicked into place in the distal angle of the Z (TECH FIG 2F).
- It should bow, showing that tension has been applied across the construct and thus traction across the joint.
- Improved fracture and joint alignment can be visualized on the image intensifier.
TECH FIG 2 • A,B. Grasping the distal wire with the needle holder and making the first bend. C,D. Start and completion of the second wire bend. E. Third wire bend shown on a freestanding wire. F. The properly bent distal wire is placed around the proximal wire distracting the joint.

TIDYING UP AND ENSURING THE CONSTRUCT DOES NOT DISENGAGE

Proximal Wire
- Bend the proximal wire down. Place the medium needle holder on the wire, pushing the Z construct of the distal wire against the skin (TECH FIG 3A,B).
- This ensures that the construct is neither too bulky nor too close to the finger, allowing for some swelling.
- A distance of about 3 to 4 mm is effective.
- Bend the proximal wire down about 135 degrees (TECH FIG 3C).
- Cut the proximal wire with wire cutters about 3 mm after the bend and crimp the cut ends (TECH FIG 3D,E).
- If too short, it cannot be bent; if too long, it will abut the finger.

TECH FIG 3 • A,B. Grasping the proximal wire and making the first bend on the proximal wire shown on a patient. C. Bend the wire approximately 135 degrees. D. Cut the proximal wire 3 mm after the bend. E. Crimping cut ends of proximal wires.
**Chapter 35  DYNAMIC EXTERNAL FIXATION OF PROXIMAL INTERPHALANGEAL JOINT FRACTURE-DISLOCATIONS 2417**

**TECHNIQUES**

**TECH FIG 5 •** Drawing of a Suzuki frame showing a third (middle) wire in position, where it can act as a force couple.

**Distal Wire**
- Crimp the distal point of the wire and the part of the proximal wire just outside the skin down together with the medium needle holders (TECH FIG 4A).
- Do not crimp too far or the middle phalanx wire will be gripped and not allow full rotation.
- The wire has to be bent enough to ensure that the construct cannot disengage.
- Bend the distal tail of each Z over to ensure that the proximal wire cannot disengage (TECH FIG 4B).
- This process leaves slightly irregular cut wire ends. These need to be kept close to the construct and typically do not cause problems, but if they do they can be covered postoperatively.
- Check the final fracture position on the image intensifier (TECH FIG 4C,D).

**Force Couple**
- Some surgeons advocate a force couple—that is, a third wire in the proximal end of the middle phalanx that hooks under the bent distal middle phalanx wire to force the middle phalanx volar and improve dorsal joint subluxation (TECH FIG 5).
- We have not needed a force couple, nor is there any evidence as yet to support its use.

**TECH FIG 4 •** A,B. Distal wire bends completed. The fourth bend is just to prevent disengagement of the construct. C,D. The position of the final construct on a patient on whom, for the only time in my practice, I used a double fixator on one finger. The proximal interphalangeal joint had a pilon fracture, which is well but not perfectly reduced. The distal interphalangeal joint had a fracture-dislocation that is also well but not perfectly reduced.

**At the end of the operation, if the patient is under local anesthesia, ask him or her to watch the injured digit while extending the PIP joint to neutral and flexing to at least 90 degrees.**
- This method of educating the patient is painless and gives him or her greater confidence in the postoperative period.
PEARLS AND PITFALLS

- External fixation is typically very reliable and flexible in the treatment of PIP fractures and dislocations. The indications for open reduction and internal fixation are extremely limited due to the degree of fracture comminution and the morbidity associated with even limited open methods of treatment.
- At operation the key is to place the proximal wire at or just proximal to the center of rotation of the PIP joint in the head of the proximal phalanx.
- Bending of the wires requires practice but with experience becomes easy. It is important to avoid putting twist into the wires to optimize motion in the construct.
- Sufficient tension in the construct and across the joint is critical.
- If inadequate, the wire bends may be adjusted, but probably the distal wire will need to be replaced.

POSTOPERATIVE CARE

- The construct should not disimpact if made properly. If it does, it can usually be adjusted in clinic with further wire bending. Local anesthesia may be needed.
- The hand is elevated maximally for 3 to 5 days and movement is started once the patient is comfortable.
- The use of a long-acting local anesthetic means the patient can go home and start taking simple oral analgesics (eg, ibuprofen and diclofenac, paracetamol and codeine, or both).
- Opiate analgesics are rarely required, and almost no patient complains of significant pain.
- The analgesics should continue for at least 24 hours but not longer than 1 week.
- Long slow stretches both into extension and into flexion are emphasized. They should be performed hourly.
- The stretches should be held for 5 minutes at a time. They should not be painful, although they need to be at least on the edge of discomfort or in the mildly uncomfortable range. Painful stretches will lead to more swelling, increase the risk of complex regional pain syndrome type I, and discourage the patient from performing exercises.
- Formal therapy visits begin the second postoperative week. In addition to PIP motion, DIP motion is emphasized. The therapist works with these patients at least weekly.
- The patient is checked after 5 to 7 days.
- The dressing is removed and radiographs are performed to ensure that the reduction has been maintained.
- The dressings are left off and the patient is instructed in pin track care (see below), care of the sharp wire points (ie, covering them with tape if necessary), and stretching exercises, supported by a hand therapist.
- The pins are cleaned and dried as one would for their hand day to day.
- Assuming the pin tracks stay dry, nothing more needs to be done.
- If the pin tracks start oozing, clean with preboiled water four times a day.
- If the pin sites do not improve within 24 hours, I advise the patient to seek medical help for antibiotics.
- The redness and oozing should resolve within 2 to 3 days. If not, the patient may require intravenous antibiotics and early pin removal, but this is extremely rare.
- The patient is checked again about 2 weeks postoperatively.
- At this stage the finger will still be mildly swollen.
- There should be minimal or no pain except with stretches.
- The pin tracks should be clean and dry.
- The range of movement should be in the PIP joint a fixed flexion deformity of no more than 10 degrees and flexion to at least 50 degrees, and in the DIP joint full extension and flexion to at least 50 degrees.
- If this has been achieved, the patient returns to the office 4 to 5 weeks postoperatively for wire removal. There appears no good reason to leave the wires in longer, and the incidence of pin track sepsis increases after 4 weeks.
- Final review takes place 10 to 12 weeks after surgery.

OUTCOMES

- The finger will still be mildly swollen; this will never resolve fully.
- The final range of movement will have been achieved; it should be about 10 to 90 degrees in the PIP joint and full (0 to 70 degrees) in the DIP joint. There should be no rest pain but there will probably be some aches with heavy use. The pin tracks should have healed with minimal if any tenderness or cosmetic abnormality.
- Pilon fractures typically reduce only in part, with at least one impacted fragment remaining impacted in the middle phalanx.
- Because the concave side of the joint seems to tolerate some incongruency well, this fragment is not routinely disimpacted.
- Fracture-dislocations also tend to reduce incompletely, with some mild residual dorsal subluxation of the joint surface (ie, widening of the joint on the lateral view). If mild, this too is well tolerated.
- Traction devices generally give reliable results, with range of motion of about 89 degrees and only 2% poor results; open reduction and internal fixation gives range of motion of 79 degrees and 10% to 12% poor results.

COMPLICATIONS

- Complications are uncommon but recovery is never full, as indicated above.
- Pin track infection is the most common risk, but if the wires are removed between 4 and 5 weeks it is uncommon (less than 10% of cases). It typically resolves with cleaning, elevation, and 2 to 3 days of oral antibiotics (typically flucloxacillin 500 mg four times a day and amoxicillin 500 mg three times a day).
- Mild malunition is accepted and well tolerated.
- Nonunion has not occurred as a functional problem, although radiographs may show odd ununited peripheral fragments of bone.
- Nerve injury may occur.
- Significant poor results and persistent rest pain occur in only about 3% to 5% of patients.
REFERENCES

DEFINITION
- Proximal interphalangeal (PIP) joint fracture-dislocations are intra-articular injuries that include a concomitant soft tissue injury to the surrounding capsular and ligamentous structures.
- The injury can result from axial, bending, and torsional loads, or combinations thereof.
- These injuries of the finger are relatively common and potentially disabling, and may result in:
  - Joint stiffness
  - Persistent subluxation
  - Posttraumatic arthritis
  - Chronic pain
- Stability and alignment are more important goals than articular congruency in determining a successful outcome.\(^{18}\)
- Evaluation and treatment may be delayed, with the injury dismissed as a “jammed finger.”

ANATOMY
- The PIP joint is a hinge joint, consisting of radial and ulnar condyles on the proximal phalanx, with matching concavities on the middle phalangeal base. This construction allows for a wide range of motion (ROM) in flexion and extension, but relative rigidity in abduction and adduction.
- The PIP joint has an arc of motion of 120 degrees and accounts for 85% of the motion required to grasp an object.\(^2\)
- The joint derives its stability from its bony articular congruence and its soft tissue restraints (FIG 1).
- The volar plate resists dorsal stress, is taut in extension, and often fails distally from bone.
- Checkrein ligaments are slender proximal extensions of the volar plate under which branches of the digital arteries pass, supplying the joint and vincula and nourishing the flexor tendons.
- Collateral ligaments, the primary soft tissue restraints, have two components:
  - The proper collateral ligaments (radial and ulnar), which insert on the middle phalanx, provide the principal resistance to abduction/adduction stress. These ligaments are commonly injured in dorsal dislocations. Injury to the radial collateral ligament is more common than injury to the ulnar collateral ligament by nearly six-fold.
  - The accessory collateral ligaments arise from a conjoined origin just volar to the proper collateral ligament and insert on the volar plate.
  - The extensor complex limits volarly directed stress.
  - The central slip attaches to the dorsal tubercle on the base of the middle phalanx.
  - The conjoint lateral bands run obliquely on each side of the joint.
  - The transverse retinacular ligament connects the central slip and the conjoint lateral bands and extends laterally.
- For a dislocation to occur, at least one, often two, and sometimes all three of these structures must be significantly disrupted.

PATHOGENESIS AND CLASSIFICATION
- The PIP joint is uniquely susceptible to injury.
- The pattern of joint injury depends on the direction, degree, and rate of force application.
- The three main groups of PIP fracture dislocations are defined by the mechanism of injury force and the direction of deformity (FIG 2).
- Dorsal subluxation, or dislocation of the middle, the most common type, is caused by hyperextension and axial loading of the middle phalanx against the head of the proximal phalanx. The result is a fracture involving the base of the middle phalanx and dorsal positioning of the middle phalanx.
- This injury can be subclassified into three types based on the amount of volar middle phalanx articular surface involved, as determined on a lateral radiograph.\(^{13}\) The degree of instability is directly proportional to volar lip fragment size due to the loss of collateral ligament support, and the articular buttress (see Fig 3B in Chap. HA-35).
- Stable: less than 30% of the articular surface, reduced in extension
Chapter 36  ORIF OF PROXIMAL INTERPHALANGEAL JOINT FRACTURE-DISLOCATIONS

Tenuous: 30% to 50% of the articular surface, reduction maintained with less than 30 degrees of flexion

Unstable: either more than 50% of the articular surface or 30% to 50% of the articular surface, but requiring more than 30 degrees of flexion to maintain reduction

Volar subluxation, or dislocation of the middle phalanx, is less common and is thought to be caused by forced flexion of an extended joint.

Stable: joint reduction in extension

Unstable: palmar subluxation of middle phalanx with the joint extended

Pilon injuries are not associated with significant subluxation or dislocation. They are caused by an axial force on a partially flexed PIP joint, resulting in comminution of the articular surface of the middle phalanx (most commonly, volar and dorsal articular fragments surrounding a central depressed fragment)

Unicondylar fractures of the head of the proximal phalanx, another variant of this injury type, are included in a classification system proposed by Weiss and Hastings21 (see Chap. HA-33).

These injuries also can be accompanied by dislocation of the PIP joint and nearly always are unstable and require operative fixation. They often are amenable to the same approaches and fixation methods presented here.

NATURAL HISTORY

Following injury, the PIP joint quickly stiffens. Pain and instability limit motion initially; then the joint capsule and ligaments become fibrotic.

Over time the unreduced PIP joint will become arthritic and painful.

HISTORY AND PHYSICAL FINDINGS

Patients present following a traumatic event to the digit, frequently one that occurred some time ago.

In the acute setting, the primary complaints are pain and swelling of the joint and digit.

Patients with subacute and chronic injuries are focused primarily on stiffness, loss of function, and persistent swelling, and secondarily on pain.

The history must include a detailed description of the mechanism of injury and any previous treatment.

- Inspection
  - Evaluate the skin and soft tissues for swelling and for any open or healed wounds that could indicate an open fracture-dislocation.
  - Deformity in extension or flexion indicates whether the dislocation is volar or dorsal, respectively.
  - Axial or rotational malalignment may result from articular depression of a condyle. This can be recognized clinically as subtle angulation when full digital extension is attempted.

- Tenderness
  - The acute location of greatest tenderness on palpation may indicate which soft tissue structures are injured.

- ROM
  - Adequate evaluation may be difficult in the acute setting due to pain. After neurologic examination, a digital block may be necessary.

- Elson test (FIG 3)
  - From a 90-degree flexed position over the edge of a table, ask the patient to actively extend the PIP joint of the involved finger against resistance. If the central slip is intact, the examiner will feel an extension force from the middle phalanx. In addition, the distal interphalangeal (DIP)
Part 6  HAND, WRIST, AND FOREARM  •  Section IV  HAND FRACTURES AND DISLOCATIONS

joint remains flail during this effort, because the competent central slip prevents the lateral bands from acting distally.

- An absence of extension force at the PIP joint and fixed extension at the DIP joint (due to the extensor action of the lateral bands alone) is diagnostic of a complete rupture of the central slip. In the acute setting, the patient may be reluctant to perform this test due to pain, but this can be relieved by proximal infiltration with local anesthetic around the dorsal sensory nerves of the digit.7

- Note the range of motion through which the joint remains reduced. In the case of a dorsal dislocation, the degree of extension that results in instability or redislocation determines the angle for the extension block splint.

- An irreducible joint is consistent with entrapment of a soft tissue structure (eg, volar plate, collateral ligament, flexor or extensor tendon) in the joint, which usually necessitates urgent surgery.

- The neurovascular examination usually is normal.

- Subjective complaints of paresthesias and objective measure of capillary refill should be noted, both pre- and post-reduction.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Posteroanterior (PA), lateral, and partially supinated and pronated oblique radiographs of the involved digit(s) are required.

- Oblique views help to identify fracture planes and determine the extent of comminution, valuable for surgical planning.

- It is critical to determine amount of articular involvement on a true lateral film in full PIP joint extension to evaluate stability of the joint.

- Radiographs can be misleading, suggesting that a very simple fracture involving only a small fragment of the bone has occurred. This fragment is potentially the major attachment of a collateral ligament, the volar plate, or a tendon. The resultant incompetence of these structures can render the joint grossly or potentially unstable (FIG 4A).

- V sign13 (FIG 4B)

- On a postreduction true lateral radiograph of the digit, divergence of the dorsal articular surfaces from the central portion of the joint creates a V-shaped gap between the articular surfaces of the head of the proximal phalanx and the undamaged portion of the middle phalanx base.

- The presence of this sign indicates an incompletely reduced joint.

- Dynamic fluoroscopy is extremely valuable in evaluating the reduction and its stability.

- Hinged flexion is a variant of the V sign in which congruent rotation of the joint is replaced by abnormal translation as the joint is actively flexed and extended across the flattened fracture segments.

- The joint position that results in instability or redislocation is best determined fluoroscopically.

**DIFFERENTIAL DIAGNOSIS**

- Pure dislocation (simple or complex)

- Extra-articular fractures

- “Jammed finger”—collateral sprain9,14,23

- Volar plate injury

- Central slip injury

**NONOPERATIVE MANAGEMENT**

- Prompt recognition of the complexity of injury and an understanding of the appropriate treatment options are essential for optimal management of these fractures.

- Although fractures and dislocations of the PIP joint have the potential to be disabling, most can be treated with closed reduction, splinting, early motion, and close follow-up.

- Closed reduction is almost always successful for acute dorsal PIP dislocations. Volar dislocations are more problematic, especially if the deformity has a rotary component.

- Reductions performed immediately after the injury often can be accomplished without anesthesia. If reduction is delayed, a digital block with 1% lidocaine (without epinephrine) is helpful.

- Always make sure to complete a careful neurologic examination of the digit before performing an anesthetic block. Confirm adequate anesthesia before manipulation.

- Be gentle, and limit the number of attempts. Irreducible dislocations usually are caused by soft tissue interposition.

- Dorsal dislocations can be reduced with gentle traction on the finger with the wrist in the neutral position, followed by pressing the base of the middle phalanx in a volar direction while holding the proximal phalanx steady.
Advantages and Disadvantages of Techniques for Repair of PIP Joint Fracture-Dislocations

Table 1

<table>
<thead>
<tr>
<th>Technique</th>
<th>Indications</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Pearls</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORIF</td>
<td>Minimal comminution</td>
<td>Anatomic reduction</td>
<td>Technically difficult if multiple fragments</td>
<td>Consider other options in older patients (&gt;60 yo), eg, dorsal block pinning.</td>
</tr>
<tr>
<td>Volar plate arthroplasty</td>
<td>&lt;50% articular surface involved</td>
<td>Can use bone graft</td>
<td>Increased risk of infection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Comminution base of P-2</td>
<td>Early ROM</td>
<td>Redislocation (especially if &gt;50% P-2 base fractured</td>
<td></td>
</tr>
<tr>
<td>Osteochondral autograft</td>
<td>Highly unstable dislocations:</td>
<td>Restores volar buttress</td>
<td>Stiffness</td>
<td></td>
</tr>
<tr>
<td>(ie, hemihamate, radial</td>
<td>- &gt;60% of articular surface involvement</td>
<td>Biologic replacement of articular surface</td>
<td>Arthritis</td>
<td></td>
</tr>
<tr>
<td>styloid, toes)</td>
<td>- Acute or chronic dislocation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ORIF, open reduction with internal fixation; P-2, middle phalanx; ROM, range of motion.

Volar dislocations without a rotatory component usually are reducible with gentle traction.
- Place the wrist in the neutral position and apply a dorsally directed force to the middle phalanx and a volarly directed force on the proximal phalanx.
- These dislocations, which usually can be treated with closed reduction, commonly involve an avulsion of the central slip.
- Volar dislocations with a rotatory component often are difficult to reduce by closed means. The head of the proximal phalanx becomes trapped between the central slip and one of the lateral bands of the extensor mechanism.
- These injuries occasionally can be reduced closed by placing the metacarpophalangeal (MCP) and PIP joints in 90 degrees of flexion with the wrist extended, applying light traction, and rotating the middle phalanx in the direction opposite to the deformity.

Surgical Management

Surgical management is difficult for two reasons:
- The fracture fragments can be small and comminuted, making anatomic reduction and stabilization with implants difficult.
- The need for early mobilization of the joint to prevent stiffness requires rigid fixation of these fragments.
- These fractures have a high risk of redisplacement, and patients must be warned of the possibility that repeat surgical treatment of the fracture may be necessary.
- The specific injury and fracture pattern often dictate the most appropriate method of treatment. Some methods can be used in combination.
- For stable, reducible fractures, typically involving less than 30% of the articular surface, treatment includes:
  - Extension block splinting and pinning
  - Traction, dynamic or static (see Chap. HA-35).
- Unstable, irreducible fractures, typically involving more than 30% to 50% of the joint, require:
  - External fixation
  - Percutaneous fixation
  - Open reduction with internal fixation using K-wires, screws, cerclage wires
- When dorsal fracture-dislocations are associated with bone loss or fracture comminution to such a degree that a stable reduction is unobtainable using the methods listed earlier, two salvage procedures are commonly employed.

- **Volar plate arthroplasty.** The volar plate is advanced into the middle phalangeal defect, simultaneously restoring stability and resurfacing the damaged articular surface (see Chap. HA-37).
- **Hemi-hamate autograft reconstruction.** The fractured middle phalangeal base is débrided, and the defect is replaced using a size-matched portion of the dorsal/distal hamate osteoarticular surface and secured with mini-fragment screws (see Chap. HA-38).

Table 1 illustrates some of the indications, advantages, and disadvantages of open reduction and internal fixation and some of the salvage options discussed in this chapter.

**Indications**
- Unstable and tenuous fractures requiring more than 30 degrees of flexion to maintain reduction
- Closed management of these fractures requires extreme flexion to prevent redislocation is likely to result in a flexion contracture.
- Fractures with fragments that are irreducible by closed methods and amenable to internal fixation with available hardware
- Significant articular depression, displacement, or incongruity

**Goals**
- Stable, anatomic fixation of the fracture resulting in a concentric reduction of the PIP joint
- Early range of motion designed to enhance cartilage and soft tissue healing, enhance joint remodeling, and minimize adhesions and contractures
- Anatomic restoration of the congruous joint surface is a desirable but less important treatment goal and does not supersede a concentric PIP reduction and early motion.

**Preoperative Planning**
- Radiographic evaluation, as discussed earlier
- The surgeon must be adept at using the various techniques, and the patient should be counseled that intraoperative observations will dictate the definitive method of fixation.

**Positioning**
- The patient is placed supine with a radiolucent hand table.
- A brachial tourniquet is placed on the upper arm before draping and is inflated to 250 mm Hg just before the incision is made.
Surgery can be performed under a wrist or digital block, but an axillary block is preferred to obtain adequate sensory anesthesia and motor relaxation of the flexors and extensors.

The operative hand is supinated, and a “lead hand” can be used to hold it in place.

Operative Equipment
- A mini C-arm fluoroscopy unit is necessary to confirm fracture reduction, joint reduction, and correct placement of implants.
- Mini-fragment plate and screw set
- 24-gauge wire
- K-wires

Approach
- The volar (Bruner) approach, the dorsal (Chamay) approach, and the mid-axial approach are all useful.
- The approach is chosen based on the fracture pattern and the direction of instability.
- When most of the fracture comminution is dorsal, a Chamay or mid-axial approach is selected.
- When most of the comminution is volar, as is more common with dorsal fracture-dislocations, a volar Bruner incision is employed.

EXPOSURE

Volar Approach (Bruner)\textsuperscript{3,10}
- A palmar zigzag skin incision is made from the MCP joint crease across the PIP joint to the DIP flexion crease. In a larger or longer digit, two limbs of a Bruner incision may be necessary between the flexion creases (TECH FIG 1A,B).
- An ulnarily based, thick subcutaneous flap is mobilized at the level of the flexor sheath.
- The digital neurovascular structures are mobilized from the flexor sheath apparatus.
  - These procedures are necessary to avoid traction on the associated structures if the joint is dorsally displaced during exposure and fixation.
- The flexor sheath over the PIP joint (including the A3 pulley) is incised on three sides, creating a rectangular flap between the A2 and A4 pulleys (TECH FIG 1C).
  - Alternatively, the flexor sheath may be split longitudinally to expose the underlying flexor tendons.
- The flexor digitorum profundus and flexor digitorum superficialis tendons are retracted to the side to expose the volar plate (TECH FIG 1D).
  - A Penrose drain placed around the tendons permits atraumatic retraction.
- The PIP joint and bare surface of the volar fragment are exposed by dividing the volar plate in the transverse plane just proximal to its distal insertion.
  - Make sure to leave a small amount of the distal portion attached to the bony fragment of the middle phalanx for later repair.
  - Retract the main portion of the volar plate proximally, creating a proximally based flap. The volar plate is not excised.
- Sharp recession of the collateral ligaments at their proximal or distal volar attachments may be required to access fragments that are more dorsal than the volar third of the middle phalangeal base or to reduce chronic subluxations.
  - Most often, the collateral ligaments are elevated only from their middle phalangeal insertion.

TECH FIG 1 • A. The Bruner approach uses a palmar zigzag skin incision from the metacarpophalangeal (MCP) flexion crease across the PIP joint level to the DIP flexion crease. B. In larger digits, two limbs may be necessary between flexion creases. C. Once the flexor sheath is exposed, it can be incised on three sides between the A2 and A4 pulleys and the flap retracted laterally. Alternatively, the sheath can be split down its center longitudinally to expose the flexor tendons. The pathways of the incisions are demonstrated by the dotted line. D. After retraction of the incised flexor sheath, the flexor digitorum and profundus tendons (FDP, FDS) are exposed. Gently retract them to one side with a blunt retractor to expose the volar plate and the base of the middle phalanx. Not uncommonly, the volar plate is still attached to the volar lip of the middle phalangeal fracture fragment. E,F. Shotgun exposure of the PIP joint. E. The PIP joint is distracted while the flexor tendons are retracted laterally. F. The joint is then gently hyperextended until it maintains this shotgun alignment of its own accord (~130 degrees), exposing the articular surfaces (arrow, fractured volar middle phalanx base). (D-F: hand is to the left and the finger is to the right).
Chapter 36  ORIF OF PROXIMAL INTERPHALANGEAL JOINT FRACTURE-DISLOCATIONS

TECHNIQUES

If comprehensive exposure of the PIP joint is required, the collateral ligaments are released from their site of insertion, and the PIP joint is distracted and then gently hyperextended until it maintains this alignment of its own accord (about 130 degrees). This has been referred to as “shotgun” exposure of the joint6 (TECH FIG 1E,F).

Watch the neurovascular bundles closely during this hyperextension maneuver to ensure they can easily subluxate dorsally.

Dorsal Approach (Chamay)4

A longitudinal skin incision is made over the dorsal aspect of the proximal phalanx proximally and then is curved laterally and distally around the dorsal aspect of the PIP joint. After superficial dissection is carried down to expose the extensor mechanism, a distally based, V-shaped flap of central slip is created, with the apex of the flap extending to the proximal third of the proximal phalanx. This pedicle flap of central slip is then pulled distally with a hooked retractor to expose the PIP joint.

The first structure encountered in the subcutaneous fat is Cleland’s ligament, which contains fibers that run volar to dorsal and consist of thin fascial layers surrounding the digital nerve and artery with skin. It can be isolated from adjacent fat at the level of the PIP joint.

Once Cleland’s ligament is divided, carry the dissection slightly volarward, deep to the neurovascular bundle, and expose the lateral aspect of the middle phalanx and lateral margin of the flexor sheath.

The neurovascular bundle remains in the volar flap.

Enter the joint between the volar plate and the accessory collateral ligament and inspect the joint.

Additional exposure is gained by elevating the collateral ligament at the origin or the insertion.

Mid-Axial Approach

Identify the midaxial line by marking the axes of the IP joints and drawing a line through these points proximally and distally (TECH FIG 3A).

If comprehensive exposure of the PIP joint is required, the collateral ligaments are released from their site of insertion, and the PIP joint is distracted and then gently hyperextended until it maintains this alignment of its own accord (about 130 degrees). This has been referred to as “shotgun” exposure of the joint6 (TECH FIG 1E,F).

The repair is strong and will allow early active motion within the first 48 hours.

Midlateral Midaxial

A. Diagrams demonstrating the midaxial (blue line) and midlateral (red line) approaches. The midlateral approach is shown for reference, but the midaxial approach is the one most often used clinically. Midaxial approach (blue): flex the finger and mark the motion axes of the IP joints by marking the points at the IP joints where the flexion creases end dorsally. Draw a line through these points proximally and distally (blue line). B. In a cross-section diagram of these approaches, the midaxial dissection will be dorsal to the neurovascular bundle and the midlateral dissection will be at the level of the neurovascular bundle.

FRACTURE AND JOINT REDUCTION

The joint and fractures are exposed, cleansed of hematoma, and fully evaluated.

If soft tissues are interposed, a fine curved hemostat or dental pick may be introduced to clear the fracture site.

Make the skin incision on this midaxial line. The digital nerve and artery lie about 2 mm volar to the margin of the incision (TECH FIG 3B).

Avoid a radial-sided incision on the index finger and an ulnar-sided incision on the small finger. These surfaces are important for contact and should be protected from potential scar sensitivity.

The first structure encountered in the subcutaneous fat is Cleland’s ligament, which contains fibers that run volar to dorsal and consist of thin fascial layers surrounding the digital nerve and artery with skin. It can be isolated from adjacent fat at the level of the PIP joint.

Once Cleland’s ligament is divided, carry the dissection slightly volarward, deep to the neurovascular bundle, and expose the lateral aspect of the middle phalanx and lateral margin of the flexor sheath.

The neurovascular bundle remains in the volar flap.

Enter the joint between the volar plate and the accessory collateral ligament and inspect the joint.

Additional exposure is gained by elevating the collateral ligament at the origin or the insertion.

A dental pick or Freer elevator may be used to carefully manipulate and elevate depressed articular fragments, restoring articular congruity.

Maintain cancellous and subchondral bone on the articular cartilage-bearing fragments.
- Cancellous bone grafting may be required to prevent articular surface collapse in highly comminuted fractures.
- Allo- or autograft (often harvested from the dorsal distal radius) can be used. The graft material is packed into the metaphysis through either direct application or a cortical window.
- Small 0.045- or 0.030-inch K-wires may be used to provisionally stabilize the reduction.
- Preliminary joint reduction, fracture reduction, and articular restoration are confirmed under direct vision and with fluoroscopy.
- Fracture fixation may proceed through various methods, depending on fracture pattern and surgeon-preference.

**MINI-FRAGMENT FIXATION**

- Screw fixation, if attainable, provides excellent stability and may allow earlier ROM and improved functional restoration. This form of stabilization is indicated for larger and fewer fragments (TECH FIG 4A–D).
  - Be aware that these fragments are often more comminuted than believed, and screws may further comminute the bone, making ultimate fixation difficult.
  - After anatomic reduction of the fragments is achieved by careful manipulation and the fragments are stabilized with clamps or K-wires (as needed), appropriately sized screws, typically in the 1.0- to 1.7-mm range, are chosen.
  - The screw hole is drilled as perpendicular to the fracture plane as possible.
  - The depth is measured.
- If possible, an interfragmentary lag technique is preferred. This is done by overdrilling the near fragment cortex with a drill equal to the screw’s outer diameter.
  - A self-tapping, minifragment cortical screw is placed.
  - Countersinking of screws or use of headless screws may be helpful to avoid soft tissue tethering and tendon irritation (TECH FIG 4E).
- If the fragment is large enough, two screws, or a screw and a supplementary threaded K-wire (0.028 inch), can be used to prevent rotation of the fragment (TECH FIG 4F,G).
- After the procedure, PIP joint ROM usually is compromised, with a residual flexion contracture occurring in more than 80% of cases of volar fracture and dorsal instability.

**TECH FIG 4 • A–C.** Preoperative AP, lateral, and oblique radiographs demonstrating a displaced small finger PIP intra-articular fracture with a large dorsal/ulnar fragment. **D,E.** Intraoperative photos show the dorsal approach to the PIP joint. **D.** The fragment was large enough to be amenable to microscrew fixation. **E.** Using standard AO technique, a 1.7-mm screw was placed to achieve stable fixation of the fragment. The head of the screw has been countersunk. (continued)
CERCLAGE WIRE TECHNIQUE

- The cerclage wire technique allows reduction of multiple small articular fragments and provides adequate fixation to allow early ROM exercises (TECH FIG 5A).
  - A thorough joint release is required, which carries the risk of increased fibrosis and stiffness postoperatively.
  - A volar incision with a “shotgun” exposure of the PIP joint is used (TECH FIG 5B).
  - Judicious elevation of the central slip is performed.

- A thin ring of periosteum around the bony fragments of the middle phalanx is cleared by sharp dissection.
- This allows the wire loop to seat directly against bone, providing firm fixation of the fracture fragments.
- The normal shape of the base of the middle phalanx (reverse funnel contour) also aids in fixation of the wire and prevents postoperative slippage, even with early ROM.
- 24-gauge steel wire is formed into a loop and twisted on itself until the loop is partially closed, just larger than the base of the middle phalanx.
- After fracture reduction, the loop of wire is seated and gently tightened, allowing circumferential compression of the fracture fragments (TECH FIG 5C).
- Final confirmation of articular reduction is made, with careful attention to the correction of central depression and joint subluxation (TECH FIG 5D).
- The twisted portion of the loop is placed on the volar or volar lateral surface or the middle phalanx base, flush to the cortex, at the edge of the volar plate.
- The wire is covered by the repaired volar plate to prevent mechanical irritation of the flexor tendons.

**Supplementary K-Wire Addition**

- A supplementary K-wire may be necessary, depending on fracture configuration (TECH FIG 6A,B).
- The cerclage wire is loosely twisted around the base of the middle phalanx, maintaining the position of the articular fragments prior to the replacement of the central and volar depressed fragment (TECH FIG 6C).
- After replacement of the central fragment and further fixation with a K-wire, the cerclage wire is tightened (TECH FIG 6D,E) and the tail cut.
CLOSURE AND SPLINTING

- The volar plate and central slip flaps are closed with a 4-0 nonabsorbable suture.
- The flexor tendon sheath is closed using either absorbable or nonabsorbable 5-0 or 6-0 suture.
- The tourniquet is deflated, and hemostasis is achieved with bipolar cautery.
- The skin is closed with 5-0 nylon suture.
- The patient is placed into an intrinsic-plus volar splint.

The skin is closed with 5-0 nylon suture. Usually, the MP joints are flexed 70 to 90 degrees and the IP joints are extended based on the stability of fixation and joint reduction.

PEARLS AND PITFALLS

- PIP fracture-dislocations often are missed by athletic trainers and patients, dismissed as a “jammed finger.”
- Avoid forceful passive testing for stability, which can convert a partial tear to a complete one. Instability of any of these structures to passive stress is unlikely to change the management of an injury that is stable with active range of motion. The one potential exception to this is complete rupture of the radial collateral ligament of the index finger PIP joint in a young active patient. This injury may be surgically repaired primarily because stability at this joint (required for a normal pinch grip) may be more important than full ROM.
- Make sure to preserve the A2 and A4 pulleys. Failure to do so will result in bowstringing of the flexor tendons and a failed outcome.
- Screw fixation should not be attempted for fracture fragments that are too small or too comminuted (eg, more than three fragments).
- To avoid recurrent dislocation, any bony defect remaining behind the repaired volar plate complex should be filled with bone graft.

POSTOPERATIVE CARE

- Progressive active and active assisted range of motion does not begin until postoperative day 2 to 5, depending on initial patient comfort.
- A thermoplastic splint provides protected mobilization.
- Relatively more aggressive flexion than extension (less than 30 degrees) is pursued with the therapist.
- Close weekly follow-up for the first 3 weeks is necessary to monitor for any loss of reduction.
- All restrictions on motion are removed at 5 to 6 weeks, and radiographic signs of healing are followed.
- Therapy is continued for 1 to 2 months after removal of the splint, to recover motion and strengthen the hand.

OUTCOMES

- Green and Akelman reported on two patients with dorsal fracture-dislocations who underwent ORIF and reported an average active range of motion of 95 degrees at 1-year follow-up, with neither patient demonstrating any evidence of subluxation.
- Hastings and Carroll reported on 15 patients treated with ORIF using various combinations of K-wire fixation, tension band wire fixation, and screw fixation. Eventual average postoperative ROM was 17 to 90 degrees.
- Dietch et al reported on 24 patients with unstable dorsal fracture dislocations of the PIP joint treated with two methods, volar plate arthroplasty and ORIF. At an average follow-up of 46 months, results indicated that if reduction of the joint is maintained, patients could expect few functional deficits despite radiographic degenerative changes and loss of mobility.
- Weiss reported on 12 patients with dorsal fracture-dislocations treated with cerclage wire fixation and reported an average ROM of 89 degrees at 2 years follow-up, with no complications and only one patient with evidence of radiographic degenerative changes.
- Stern et al reported on 20 patients with pilon fracture-dislocations of the PIP joint. They used three treatment methods: splinting, skeletal traction, and open reduction with K-wire fixation. After a clinical and radiographic follow-up of 25 months, skeletal traction led to fewer complications and clinically comparable outcomes to open reduction (achieving an average ROM of 80 degrees vs. 70 degrees, respectively).
- While clinical experience supports anatomic reduction of intra-articular fractures in weight-bearing joints such as the hip or knee, most laboratory and clinical reports support the theory that anatomic surface restoration is unnecessary if subluxation is corrected and motion is instituted shortly after injury.

COMPLICATIONS

- Degenerative arthritis
- Loss of PIP joint motion, stiffness, flexion contracture, and extensor lag
- Loss of fixation or redisplacement
- Persistent subluxation or dislocation
- Infection
- Malunion
- Boutonnière deformity
- Pain
REFERENCES

DEFINITION
- Volar plate arthroplasty (VPA) provides a volar restraint to dorsal subluxation and dislocation of either the middle or distal phalanx base to maintain reduction of the proximal interphalangeal (PIP) or distal interphalangeal (DIP) joint. It resurfaces the volar portion of the injured joint using local tissue (volar plate).
- VPA is used much more commonly for PIP joint stability than DIP joint stability.

ANATOMY
- The volar plate, which is the primary restraint against hyperextension instability, lies palmar to both the PIP and DIP joints, separating the joint from the flexor tendon(s).
  - At its origin, the volar plate is “swallowtail” shaped and connected only by proximal checkrein ligaments to the phalanx and fibrosseous tendon sheath (FIG 1A).
  - Distally, the VP is primarily cartilaginous. It inserts centrally via the periosteme and laterally with a conjoined insertion through the collateral ligaments (FIG 1B).
  - The volar plate glides proximally and distally with joint motion.
- The collateral ligaments originate on the dorsal radial and dorsal ulnar surfaces proximal to the joint. The proper collateral ligaments insert on the volar radial and volar ulnar surface distal to the joint, and the accessory collateral ligaments insert into the lateral margin of the volar plate, creating a box-type configuration (see Fig 1B).
  - In subacute or chronic cases of dorsal joint subluxation or dislocation, these ligaments contract, thereby accentuating the deformity by virtue of their oblique orientation.
  - The flexor digitorum superficialis (FDS) inserts just distal to the volar plate on the middle phalanx.
  - Due to the direction of pull, forces exerted by the FDS may accentuate dorsal subluxation of the middle phalanx base when the volar restraints are lost.

PATHOGENESIS
- Injuries to the PIP and DIP are caused by longitudinal compression or hyperextension forces (common in sports injuries) and typically occur in young, active individuals.
- Dorsal fracture dislocations of the PIP occur with damage to the volar articular surface of the middle phalanx when a force drives it dorsally against the condyles of the proximal phalanx.
- Chronic subluxation or dislocation (more than 6 weeks) often occurs, especially with the PIP joint when the injury is perceived as minor and is considered a “sprain.”

NATURAL HISTORY
- Chronic subluxation of the PIP joint leads to poor function and degenerative arthritis.
  - Flexion of the joint is limited and painful.
- Despite optimal surgical treatment, PIP joint fracture-dislocations often result in some loss of PIP or DIP joint motion.
- PIP joint injuries, even those that do not require surgical treatment, commonly result in a protracted period of symptoms (eg, swelling, stiffness, pain) beyond what patients expect from a “minor” injury.

PATIENT HISTORY AND PHYSICAL FINDINGS
- When taking the patient’s history, ask about the mechanism of injury, time since injury, any prior injuries, and the direction of deformity. Time since injury and mechanism of injury help determine the most appropriate treatment for any particular PIP joint injury.
Inspect the finger for any swelling or deformity. Clinical deformity may be subtle, even with significant subluxation.

Examine range of motion, noting degrees of PIP motion. With joint subluxation, patients will have painful and limited flexion.

Examine joint stability; joints that are dislocatable will need intervention for stability (eg, extension block splinting, VPA).

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Every patient with a PIP injury must have anteroposterior, lateral, and oblique radiographs to evaluate for a PIP joint fracture or subluxation (FIG 2A).
  - The severity of the fracture and degree of involvement of the middle phalanx often are much greater than they appear on these radiographs.
  - In evaluating for a subluxation by radiographs, a true lateral view of the PIP joint is mandatory. A dorsal V sign at the joint indicates that the articular surfaces are neither congruent nor parallel (FIG 2B).
  - Fluoroscopy allows dynamic evaluation of the joint and its stability and often is also the best way to obtain magnified images and a perfect lateral view.
  - CT scans rarely are needed but can effectively evaluate the articular surfaces and define the bone loss.

**DIFFERENTIAL DIAGNOSIS**

- Acute central slip injury (ie, boutonniere deformity)
- PIP joint fracture
- PIP dislocation
- Volar plate or collateral ligament sprain without instability

**NONOPERATIVE MANAGEMENT**

- Closed reduction and extension block splinting are appropriate for PIP fracture subluxations when a stable concentric joint reduction is obtained and maintained in an acceptable position.
  - If more than 65 degrees of flexion is required to maintain reduction, surgical reconstruction should be strongly considered.
  - Articular defects will often dramatically remodel in a concentrically reduced, mobilized joint.

**SURGICAL MANAGEMENT**

- For simplicity, the techniques here describe VPA for the PIP joint, but the same principles may apply to the DIP joint. The primary difference is that the FDP insertion on the volar base of the distal phalanx makes exposure of the volar plate more complicated.
- **Indications**
  - Acute fracture-dislocations that are unstable after closed reduction of the PIP joint in cases in which the volar base of the middle phalanx is not reconstructable, or if surgical reconstruction is less likely to achieve a functional result
  - Chronic subluxations or dislocations up to 2 years following trauma
  - A normal articular contour of the proximal phalanx is a prerequisite.
  - An intact dorsal cortex and dorsal articular surface are required.
  - Some authors (eg, Burton4) use VPA for chronic osteoarthritis in select situations.

**Preoperative Planning**

- Fractures typically involve over 30% of the surface of the middle phalanx base, and the joint is subluxated or dislocated. If the fracture involves under 30% of the joint surface, it typically can be managed either in a closed manner or with less invasive techniques for the acute scenario.
- The literature is unclear whether a specific degree of involvement of the articular surface precludes VPA (ie, is too large), but involvement of the dorsal cortex is a contraindication.
  - VPA is a less successful treatment for injuries involving over 50% to 60% of the middle phalanx articular surface. In these cases, recurrent subluxation is common.
  - In chronic dislocations, soft tissue contracture and heterotopic bone may make dissection and relocation more complex.

**Positioning**

- The patient is positioned supine on the operating table with the affected arm on a hand table.
- Intraoperative fluoroscopy is critical to this procedure, and it is important to position the hand relative to the fluoroscopy unit so that a true lateral view of the injured PIP joint may easily be obtained.
- The surgery is performed under tourniquet control.
PRIMARY INCISIONS AND EXCISIONS ON THE VOLAR SIDE

- The joint is exposed using two limbs of a Bruner incision centered at the PIP flexion crease, elevating a radially based flap (TECH FIG 1A).
- The radial and ulnar neurovascular bundles are identified and mobilized throughout the field to prevent a traction injury when the PIP joint is hyperextended to achieve optimal visualization (TECH FIG 1B).
- The flexor sheath is incised as a rectangular flap between the A2 and A4 pulleys and protected for later repair.
- The flexor tendons are atraumatically retracted radially or ulnarily, as needed to visualize the volar plate (TECH FIG 1C,D).

DETACHMENT OF THE VOLAR PLATE

- The volar plate is detached from the middle phalanx or fracture fragments, including as much tissue as possible.
- The volar plate is incised from the proper and accessory collateral ligaments through an incision along its radial-and ulnar-most margins (Tech Fig 1D).
- The volar plate flap must be as long and broad as possible to maintain adequate stability of the arthroplasty. It should be symmetrical radially and ulnarily to avoid angular deformities.
- The collateral ligaments are excised.
- The joint is then hyperextended approximately 180 degrees (“shotgunning”) to achieve maximum visualization of the base of the middle phalanx (TECH FIG 2).
- Small fragments of depressed articular cartilage or subchondral bone are débrided and saved for possible later use.
- Care is taken to avoid over-resection and loss of the dorsal articular support.

TECH FIG 1 • A. The Bruner incision is centered over the PIP flexion crease, with the vertex on the ulnar side. B. To prevent traction injuries, mobilization of the neurovascular bundles is necessary. C. Illustration of retraction of the flexor tendons and neurovascular bundles relative to the volar plate. D. The flexor tendons must be retracted radially and ulnarily to access the volar plate. The proposed incision to detach and mobilize the volar plate is outlined in pen.

TECH FIG 2 • Shotgunning. Hyperextending the joint allows clear visualization of the volar plate to the left, the avulsed bone, and the articular surface of each phalanx. The trough is fashioned symmetrically in the coronal plane, at the dorsal-most aspect of the articular defect to the right.
SHAPING THE ARTICULAR SURFACE OF THE MIDDLE PHALANX

- A transverse trough is fashioned with an osteotome or a rongeur across the middle phalanx and finished with a small curette, at the juncture between the intact articular surface and the fracture defect (Tech Fig 2).
- This trough must be symmetric in the coronal plane to avoid angular deformity. The depth of the trough at its dorsal side should be the thickness of the volar plate, thereby allowing a smooth transition from articular cartilage to transposed volar plate.

TRANSPOSING THE VOLAR PLATE

- A 3-0 nonabsorbable grasping suture (eg, Bunnell fashion) is placed in both the ulnar- and radial-most margins of the volar plate flap (TECH FIG 3A).
- Two straight Keith needles are passed through each side of the base of the middle phalanx using a wire driver. They are placed as far radially, ulnarly, and distally in the bone defect as possible, and directed centrally to penetrate the cortex distal to the central slip insertion (TECH FIG 3B).
- The sutures are tensioned as the middle phalanx is flexed, bringing the volar plate into the defect at a level that produces a smooth transition from the intact dorsal base of the middle phalanx to the volar plate.
- The joint should remain flexed about 20 to 25 degrees so the volar plate can advance both distally and dorsally.
- Examine the reduction with a true lateral fluoroscopic view on a mini C-arm (TECH FIG 3C).
- The base of the middle phalanx should glide over the head of the proximal phalanx and should not hinge open dorsally.
- The fingertip should be able to touch the distal palmar crease (110 degrees of flexion).
- If the PIP joint lacks substantial extension or has inadequate flexion, it may be necessary to advance the volar plate distally by teasing the checkrein ligaments from their origin or by fractional lengthening through step-cutting (Tech Fig 3A).

**TECH FIG 3**

- **A.** Sutting the volar plate. Sutures are passed through the margins of the volar plate and through the base of the middle phalanx using straight Keith needles. The volar plate is advanced into the trough, resurfacing the PIP joint. It may be necessary to advance the volar plate by step-cut lengthening of the checkrein ligaments. **B.** Bone resection. This diagram shows the needle holes in relation to the resected bone, the collateral ligament stubs, and the extensor mechanism central tendon. The holes in the middle phalanx should be as far dorsal and lateral as possible for maximum stability. **C.** The PIP joint has now been reduced and stabilized as shown.
**SECURING THE VOLAR PLATE**

- The sutures may be tied over a button dorsally.
- Alternatively, the sutures may be tied directly onto periosteum via a small incision distal to the central slip insertion. Care must be taken to ensure the sutures do not entrap the lateral bands or injure the central slip.

- In the acute setting, fractured bone fragments collected during the volar plate detachment may be placed in the defect of the middle phalanx, distal to the advanced volar plate. This provides support to the base of the phalanx.
- A K-wire is used with the joint in slight flexion to maintain reduction for 3 weeks (TECH FIG 4).
- Alternatively, the joint reduction can be maintained with an articulated external fixator to allow for early motion.

**TECH FIG 4** Lateral diagram of VPA. The overall diagram of this procedure illustrates the joint with a double-ended K-wire for stability and the volar plate secured by sutures.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Angular deformity</th>
<th>The trough must be transverse, and tension of the volar plate flap must be symmetric on the two sides.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recurrent subluxation</td>
<td>Fixation with a K-wire or articulated fixator for 2 to 3 weeks is recommended.</td>
</tr>
<tr>
<td>Loss of flexion</td>
<td>Aggressive range of motion to restore flexion at both the PIP and DIP joints is essential and safe, because these injuries typically are more stable in flexion.</td>
</tr>
<tr>
<td>Neurologic injury</td>
<td>Meticulous dissection of both neurovascular bundles is required before “shotgunning” the joint open.</td>
</tr>
<tr>
<td>Loss of extension</td>
<td>Some loss of extension is expected. Failure to lengthen the checkrein ligaments may lead to an unacceptable contracture.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- The K-wire PIP joint fixation is removed at 2 to 3 weeks, when active flexion and extension are begun.
- An extension block splint is used during weeks 3 to 6 after the operation.
- Motion of the DIP is encouraged before K-wire removal, because deficits in DIP motion have been reported after VPA.
- After 6 weeks, the pullout suture, if one was used, is removed.
- A dynamic extension splint may be used at 6 weeks if the achieved extension is not as expected based on intraoperative range of motion.

**OUTCOMES**

- More normal PIP motion is restored in acute injuries than in chronic injuries: 85 degrees of active PIP motion versus 60 degrees.
- Patients can expect to see continued improvement in range of motion up to 1 year after VPA.
- Mild contractures of the DIP joint (10 to 20 degrees) are common. Patients are encouraged in DIP motion during rehabilitation.

**COMPLICATIONS**

- Angular deformities
- Pin and wire track infections
- Pain
- Stiffness
- Degenerative arthrosis

**REFERENCES**

DEFINITION
- Proximal interphalangeal (PIP) joint fracture-dislocations occur with the following fracture patterns:
  - Palmar lip fracture-dislocations: Fracture of the middle phalanx palmar lip with dorsal subluxation of the middle phalanx on the head of the proximal phalanx
  - Dorsal lip fracture-dislocations: Fracture of the dorsal lip of the middle phalanx with palmar subluxation of the middle phalanx
  - Pilon fractures: Pilon fractures include a loss of continuity of both the dorsal and palmar cortical margins of the middle phalangeal articular surface. The base of the middle phalanx usually is highly comminuted, and the articular fragments may be significantly impacted.
- PIP fractures are further classified as “stable” or “unstable.”
  - Stable fractures maintain concentric joint reduction throughout the range of motion (ROM).
  - Unstable fractures sublux or dislocate during parts of the motion arc.
- Dorsal lip fracture treatment is complicated by the need to re-establish continuity of the extensor tendon insertion onto the middle phalanx.
- Pilon fractures are best treated with some form of traction and early motion.
- Unstable palmar lip fractures are amenable to treatment with hemi-hamate autograft and are the focus of this chapter.

ANATOMY
- The PIP joint is a complex hinge articulation that provides more than 95 degrees of flexion while maintaining stable, concentric reduction of the joint surfaces.
- Several forces encourage dorsal migration of the middle phalanx: the extensor tendon lifts the middle phalanx and the mid-middle phalanx superficialis insertion levered in a hook, preventing dorsal translation.
- The only restraints on middle phalangeal dorsal translation are the palmar plate and the cup-shaped geometry of the middle phalanx articular surface. The middle phalangeal palmar lip wraps around the proximal phalanx head and acts as a hook, preventing dorsal translation.
- Palmar lip fractures disrupt both of the restraints to dorsal subluxation. The palmar plate is no longer attached, and the middle phalangeal palmar lip is disrupted. The slope of the remaining middle phalangeal articular surface encourages the middle phalanx to travel up and over the proximal phalangeal head.
- A direct relation exists between the amount of palmar articular surface disrupted and stability (FIG 1B).
  - Hastings has shown that when 42% of the palmar articular surface is damaged, the joint always exhibits dorsal instability.
- In the clinical setting, fractures with as little as 30% articular surface involvement can be unstable.

FIG 1 - A. Unstable PIP fracture-dislocation. The upward pull of the central tendon insertion and the distal superficialis insertion pull and push the middle phalanx up and over the proximal phalangeal head. The only forces preventing dorsal subluxation are the middle phalanx palmar lip and the palmar plate, both of which are lost in an unstable PIP palmar lip fracture. B. PIP instability after a fracture. A direct relation exists between the amount of middle phalanx palmar lip destroyed by the fracture and the resultant PIP joint stability. Articular damage in excess of 50% of the joint surface always renders the joint unstable, whereas fractures involving less than 30% usually are stable. Tenuous fractures (ie, those with articular damage of 30% to 50% of the joint surface), must be assessed with lateral radiographs. If the joint will not stay reduced with less than 30 degrees of flexion, it must be classified as “unstable.”
Hemi-hamate arthroplasty restores stability by rebuilding the cup-shaped geometry of the middle phalangeal base and restoring the palmar plate attachment.

**PATHOGENESIS**

- The middle phalangeal palmar lip fracture that is associated with unstable dorsal PIP fracture-dislocations is created by either avulsion of the fracture fragment or an impaction shear mechanism.
- Avulsion fractures result from PIP joint hyperextension and traction through the palmar plate attachment (FIG 2A).
  - The fracture fragment is not comminuted and represents less than 30% of the articular surface.
  - These injuries usually are stable and rarely require surgical intervention. If the joint is unstable, osteosynthesis with lag screws often is possible because of the lack of comminution and the substantial size of the fragment.
- Impaction shear PIP fracture-dislocations result from a longitudinally applied load to the tip of the finger with the PIP joint slightly flexed, such as in a mishandled ball catch. The force drives the middle phalanx into and over the proximal phalangeal head, resulting in a middle phalangeal palmar lip fracture that is highly comminuted (FIG 2B).
  - Up to 80% of the joint surface can be involved, and the articular fragments are often deeply impacted into the soft metaphyseal bone.
- Disruption of the terminal extensor tendon (mallet finger) often occurs in association with unstable dorsal PIP fracture-dislocations.

**NATURAL HISTORY**

- The long-term prognosis for PIP fracture-dislocations is theoretically affected by the quality of the joint surface restoration and the maintenance of concentric reduction of the middle phalanx on the proximal phalangeal head.
- The PIP joint seems to tolerate less than perfect restoration of a smooth joint surface. As long as motion is initiated quickly, small gaps and step-offs seem to be tolerated. Long-term, some remodeling occurs, and most patients do not need to be treated for symptomatic posttraumatic degenerative arthritis.
- Joint reduction that is less than perfect is not well tolerated. When the middle phalanx rides dorsally on the proximal phalangeal head, PIP flexion occurs by “hinging” at the fracture margin. The joint pivots on the palmar edge of the fracture, and the proximal phalanx falls into the fracture defect at the palmar base of the middle phalanx. The proximal phalangeal articular cartilage suffers accelerated wear, while the remaining undamaged middle phalangeal articular surface remains unused throughout the motion arc (FIG 3).
- Treatment of unstable PIP palmar lip fractures is directed toward re-establishing joint stability so that flexion occurs by “gliding” of the remaining middle phalangeal articular cartilage on the head of the proximal phalanx.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Assess alignment in the coronal plane. Lateral deviation suggests asymmetric compression of articular fragments.

**FIG 2 • Fracture types.**

A. Avulsion fracture. Avulsion fractures usually are caused by a forced PIP joint hyperextension. The fragment is not comminuted and involves less than 30% of the joint surface. The PIP joint is most often stable.

B. Impaction shear fracture. This type of PIP fracture-dislocation is caused by a longitudinal load to the joint. The fracture fragments are comminuted and impacted into the middle phalanx. The joint reduction often is unstable.

**FIG 3 • Gliding or hinging.**

A. Normal PIP flexion occurs as the middle phalanx glides around the proximal phalanx head.

B. When the middle phalanx palmar lip is lost, PIP flexion can occur by hinging at the fracture margin. Treatment of unstable PIP fracture-dislocations must rebuild the cup-shaped middle phalangeal base and restore a normal gliding motion.
- Assess alignment in the sagittal plane. Lack of colinearity of the middle and proximal phalanges suggests persistent joint subluxation or dislocation.
- Associated mallet injuries must be treated concurrently with a DIP extension splint.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Plain radiographs in the posteroanterior (PA) and lateral planes provide the mainstay of radiographic evaluation of PIP fracture-dislocations.
- Inspect the lateral radiograph to determine the percentage of joint surface fractured and the quality of the reduction.
- If the joint is not concentrically reduced with less than 30 degrees of flexion, the joint is classified as unstable and must be treated appropriately (see Fig 1B).
- On every lateral radiograph taken throughout the treatment course, carefully scrutinize the quality of the reduction. The remaining articular cartilage on the middle phalanx base must be in full contact with the proximal phalanx head. Any dorsal gap between the two surfaces—a “V” sign—indicates persistent instability and must be corrected (FIG 4).
- The percentage of the middle phalanx articular surface consumed by the fracture can be used to predict joint reduction stability.5,6,9 (see Fig 1B):
  - Less than 30%: The reduction usually is stable. The middle phalanx almost always remains concentrically reduced on the head of the proximal phalanx throughout a full ROM.
  - 30% to 50%: The reduction is tenuous. The middle phalanx may or may not subluxate dorsally when the PIP joint is extended. If any subluxation is noted on the lateral radiograph with the PIP joint fully extended, flex the joint to 30 degrees and repeat the lateral radiograph.
  - If concentric reduction is achieved and the palmar fragments are sitting where they will reconstitute a palmar lip, some form of extension block treatment may be employed.
  - If the joint will not stay reduced with less than 30 degrees of flexion, the joint is unstable and must be treated accordingly.
  - Over 50%: The PIP joint is unstable, and surgical intervention usually is required to rebuild the cup-shaped geometry of the middle phalanx base and to reattach the palmar plate.
- Inspect the PA view to determine asymmetric compression of middle phalanx articular fragments leading to varus or valgus angulation.
- CT or MRI evaluation rarely is necessary.

**DIFFERENTIAL DIAGNOSIS**
- In patients with a history of recent trauma and radiographic confirmation of a large PIP palmar lip fracture associated with dorsal subluxation, the diagnosis of an unstable PIP dorsal fracture-dislocation is obvious.
- Dorsal dislocation and disruption of the middle phalanx palmar lip also may be seen in chronic PIP fracture-dislocations and occasionally in association with various forms of arthritis.

**NONOPERATIVE MANAGEMENT**
- Unstable PIP fracture-dislocations rarely can be managed nonoperatively. When over 50% of the middle phalanx articular surface is consumed by fracture, all restraints to dorsal subluxation are lost. The cup-shaped geometry of the middle phalanx base must be restored and the palmar plate reattached. Both goals can be accomplished with ostesynthesis of a single large fragment,2,3,8 palmar plate arthroplasty,1 or a hemi-hamate osteochondral autograft.5,15,16
- Stable PIP fracture-dislocations are treated nonoperatively. If the joint does not hyperextend and the lateral radiograph in full extension confirms concentric reduction, buddy tape the fingers and allow early ROM. If the joint hyperextends, some flexion must be maintained for 3 weeks while the fracture fragments consolidate enough to restore functional palmar plate continuity. Apply a dorsal blocking splint that prevents PIP hyperextension but allows full active flexion.
- Nonoperative treatment of tenuous PIP fracture-dislocations requires careful thought, patient cooperation, and meticulous follow-up.
  - The primary treatment goal is to maintain joint reduction while the middle phalanx palmar fragments consolidate and restore the cup-shaped geometry of the middle phalanx base. Joint reduction must be achievable with less than 30 degrees of flexion, and the palmar fragments must fall into a position that will restore the middle phalanx palmar lip.
  - A secondary goal is to provide immediate active ROM. Any treatment method that prevents extension past 30 degrees and allows full flexion can be employed. Options range from simple extension block splints11 or pins14 to external traction12,13 or complex frame constructions.7,10

**SURGICAL MANAGEMENT**
- Hemi-hamate osteochondral autograft is indicated for the treatment of unstable PIP fracture-dislocations. The middle phalanx dorsal cortex must be intact.
- Hemi-hamate arthroplasty is a valuable salvage procedure for treatment that has failed with traction, external fixation devices, extension block splinting, or palmar plate arthroplasty.
- Chronic PIP dorsal dislocations also are amenable to treatment with hemi-hamate autograft if enough intact cartilage remains on both sides of the joint. Undamaged cartilage must be present on the palmar 50% of the proximal phalanx head and on at least a small rim of the middle phalanx dorsal articular surface.

**FIG 4 • Unstable PIP palmar lip fracture-dislocation. Extensive damage has occurred to the palmar lip of the middle phalanx, but the dorsal cortical margin and a small amount of dorsal articular cartilage remain intact. Even slight dorsal subluxation can be detected by looking for a V-shaped gap between the middle and proximal phalanges.**
Preoperative Planning

- Review the radiographs to determine the extent of articular surface damaged by the fracture, joint stability, and the quality of the remaining articular surface.
- Patients with extensive pre-existing degenerative arthritis may be better served with a PIP arthrodensis or total joint arthroplasty than with hemi-hamate arthroplasty.
- Assess the finger for radial or ulnar deviation. If coronal plane angulation is observed, it will be necessary to level the middle phalangeal joint surface during fracture site preparation and graft placement.
- Examine the patient for a mallet finger. If the terminal extensor tendon has been damaged, plan to include a mallet splint in the postoperative regimen.

Positioning

- Position the patient supine with the arm extended onto a radiolucent hand table.
- A mini C-arm is required for the procedure.
- Either regional or general anesthesia may be used, depending on the patient’s or surgeon’s preference.
- Perioperative antibiotics are provided.
- An upper arm tourniquet is applied. This is preferred over a forearm tourniquet, which puts pressure on the flexor muscles and causes excessive finger flexion.
- If necessary, the dorsum of the hand is shaved at the fourth and fifth carpometacarpal (CMC) joints to facilitate harvesting of the graft.

Approach

- We recommend performing the PIP portion of the procedure through a Brunner incision, because this incision provides excellent visualization of the fracture, the pulley system, and the neurovascular bundles.
- The hamate graft is harvested through a transverse incision at the level of the fourth and fifth CMC joints.

FRACTURE SITE PREPARATION

- Use a lead hand to position the hand palm up with the fingers extended. It will be necessary to remove the lead hand intermittently to facilitate use of fluoroscopy.
- Make a Brunner incision from the base of the finger to the DIP flexor crease (TECH FIG 1A).
- Coagulate intervening vessels with bipolar cautery as the full-thickness flaps are elevated.
- Identify the neurovascular bundles proximally and mobilize them away from the flexor sheath throughout the length of the dissection.
- Divide Cleland’s ligaments dorsal to the neurovascular bundles. This allows full visualization of the collateral ligaments and facilitates retraction of the neurovascular bundles without excessive traction.
- Retract skin flaps with 5-0 nylon suture.
- Open the flexor tendon sheath from the distal end of the A2 pulley to the proximal edge of the A4 pulley. Start the dissection with a longitudinal incision along the edge of the flexor tendon sheath that is closest to the surgeon.
- Create a flexor tendon sheath flap by making transverse incisions at the proximal end of A4 and the distal margin of A2. Elevate the flexor tendon sheath flap away from the surgeon (TECH FIG 1B).
- Take care to prevent superficial damage to the flexor tendons while incising the flexor sheath.
- With the flexor tendons retracted away from the midline, make longitudinal incisions down the lateral margins of the palmar plate to separate the palmar plate from the accessory collateral ligaments. The distal attachment of the palmar plate will already be detached (ie, avulsed) as a result of the injury, but it still may need to be gently mobilized. Leave any remaining bone fragments attached to the distal edge of the palmar plate.
- If the fragments are large enough to accept interfragmentary screws, consider open reduction and internal fixation instead of proceeding with the hemi-hamate autograft.
- Release the collateral ligaments distally. Leave a small stump on the middle phalanx to facilitate repair at the end of the procedure.
- “Shotgun” the joint open (TECH FIG 1C).
- Retract the flexor tendons away from the midline.
- Hyperextend the PIP joint to expose the base of the middle phalanx and the head of the proximal phalanx.
- If necessary, use a Freer elevator to prevent impingement of the intact dorsal base of the middle phalanx against the head of the proximal phalanx.
- Caution: forceful hyperextension may lead to fracture of the dorsal articular fragment.
- Only if absolutely necessary, release 1 to 2 mm of the A4 pulley to facilitate adequate mobilization of the flexor tendons. The A4 pulley is essential for finger function and must not be released completely.
- Assess the damage to the articular surfaces of the middle phalanx and the head of the proximal phalanx.
- Prepare the middle phalanx to receive the autograft (see Tech Fig 1C).
- Elevate and excise impacted fragments of articular cartilage.
- Use an oscillating saw to level the surface of the bony defect and to remove sufficient bone to allow graft placement. Make the cuts parallel to the dorsal margin of the articular surface and the long axis of the phalangeal shaft. Make the height of the intact articular surfaces equal at both the radial and ulnar margins. Limit thermal osteonecrosis with liberal use of irrigation.
- The proximal to distal length of the cut usually is only about 5 to 7 mm. Take care to avoid notching the dorsal or distal portion of the cut, because this may weaken the shaft.
- Carefully measure the defect in the middle phalanx base to determine the appropriate graft size. Make notes of
A Brunner incision, as depicted in this cadaver dissection, provides excellent visualization of the neurovascular structures, the flexor tendons, and the fracture site. Creating a flexor tendon sheath flap. Elevate a flap of the flexor tendon sheath from the distal end of the A2 pulley to the proximal edge of the A4 pulley. Preserve the flap so that it may be used to cover the palmar plate and the graft during closure. “Shotgun” the joint and prepare the fracture site. The PIP joint has been hyperextended 180 degrees to expose the fracture site. Note the palmar plate (A), the collateral ligaments (B) and the fracture defect (C). The fracture defect must be prepared so that it is of equal height and thickness on the radial and ulnar sides of the middle phalanx. Measuring graft dimensions. Measure the fracture defect to determine the medial-to-lateral width (A), proximal-to-distal depth (B), and anterior-to-posterior height (C) of the needed graft. Transfer these measurements to the dorsal surface of the hamate.

- **A**: Width of the fracture defect. Measure the distance from the radial margin to the ulnar margin of the fracture defect. The graft must be centered on the central ridge of the proximal phalanx. Prepare the fracture site so that radial and ulnar extent of the fracture defect are equal.
- **B**: The proximal-to-distal size of the defect. To avoid creating an uneven joint surface that causes angulation in the coronal plane, the proximal-to-distal defect size should be equal on the radial and ulnar margins or the middle phalanx.
- **C**: Height of articular surface at the central ridge. Measure the distance from the dorsal aspect of the fracture defect to what would be the most palmar extent of the middle phalanx palm. It will be necessary to estimate this based on a lateral view of the proximal phalanx and from the preoperative radiographs (percentage of joint involvement).

Return the joint to neutral and place a moist sponge on the finger incision while the graft is harvested.

**HARVESTING THE HAMATE GRAFT**

- Identify the distal articular margin of the hamate with fluoroscopy and mark the skin with a transverse line.
- Make a transverse 2-cm incision just proximal to the articular line.
- Bluntly dissect to mobilize the subcutaneous nerves, vessels, and extensor tendons.
- Longitudinally incise the hamate-CMC joint capsule, and then subperiosteally elevate the flaps to provide adequate visualization of the articular surfaces and the dorsum of the hamate (**TECH FIG 2A**).
- The apex of the distal articular surface between the fourth and fifth metacarpal articular surfaces will become the
new central ridge of the middle phalangeal base once the
graft is transferred.

- A 12-mm segment is trimmed from the flexible plastic
  ruler that accompanies the marking pen. A fine-tipped
  marker is preferred, because it will not bleed as much on
  the bone. Less soft tissue on the dorsum of the hamate
  also helps prevent the ink from bleeding.

- Using a fine-tip marker and ruler, mark the dimensions
  of the graft on the hamate. To ensure stability of the
  CMC joints, leave at least 2 mm of the radial edge of the
  fourth metacarpal–hamate articulation and 2 mm of the
  ulnar edge of the fifth metacarpal–hamate surface.

- Harvest a graft that is of adequate height to fill the mid-
  dle phalanx defect, but do not fracture the dorsal cortex
  of the hamate.

- Use an oscillating saw to make the cuts in the hamate
  very carefully. Alternatively, define the graft dimensions
  with a series of holes made with a K-wire, and then make
  the cuts with an osteotome (TECH FIG 2B).

  - To ensure that the graft is not too small, make the os-
    teotomies on the outside of the measured lines.

  - Protect the articular surfaces at the base of the fourth
    and fifth metacarpals with a Freer elevator.

- Estimate the depth of the cuts by marking the saw
  blade or osteotome and measuring how deeply it
  penetrates the hamate.

- Create a notch in the hamate cortex proximal to the
  most proximal cut using a rongeur or by making an an-
  gled cut from proximal to distal with the saw. The notch
  is necessary to allow the final coronal cut to be made
  with a curved osteotome (TECH FIG 2C).

- Using extreme care, make the final cut in the hamate
  and complete the graft harvest.

- Gently advance an angled osteotome from proximal
  to distal, aiming to complete the cut through the
  distal hamate articular surface at the predetermined
  depth.

- Protect the metacarpal articular surfaces with an
  elevator.

- Take slightly more bone than needed. It is easier to
  trim excess than to deal with a graft that is too small.

- Keep the graft protected in a moist saline sponge during
  wound closure.

- After the wound is irrigated, securely close the capsule
  over the fourth and fifth CMC joints with a 4-0 braided,
  nonabsorbable suture. Close the skin in layers.

**TECH FIG 2** • A. Exposure of the fourth and fifth metacarpal–hamate joints. Through a transverse skin incision and
longitudinal capsular incision, as demonstrated in this cadaver dissection, expose the distal hamate articular surface
and mark the graft dimensions. B. Use an oscillating saw or, as depicted in this cadaver dissection, K-wire holes and
an osteotome, to make the cortical cuts in the dorsal surface of the hamate. C. Making the final hamate cut. A
curved osteotome is used to make the final coronal cut that separates the graft from the hamate. It is necessary to
make a back cut in the proximal hamate cortex to allow the osteotome to approach the cut at the proper angle.
(A–C: wrist is to the left and fingers are to the right.)

**GRAFT FIXATION**

- “Shotgun” the PIP joint open to expose the fracture site.

- Carefully trim the graft with a rongeur or oscillating saw
  so that it fits precisely into the prepared defect at the
  middle phalanx base.

- It is very important to tailor the graft so that it restores
  the cup-shaped contour of the middle phalanx base.
  Joint stability will be restored only by restoring a concave
  middle phalanx articular surface that includes a stout
  palmar lip (TECH FIG 3A–C).

- A common error is to set the graft at an angle that cre-
  ates a dorsal–proximal to palmar–distal slope. This car-
  pentry error fails to restore joint stability and encourages
  the dorsal migration of the middle phalanx on the prox-
  imal phalangeal head (TECH FIG 3D,E).

- Temporarily fix the graft with a centrally placed 0.028-
  inch K-wire.

- Lag 1.0- or 1.3-mm screws on either side of the provi-
  sional K-wire.

- If the graft is large enough, augment the fixation with a
  third screw placed into the hole that remains once the K-
  wire is removed (TECH FIG 3F).

- Relocate the middle phalanx on the proximal phalanx,
  and assess the joint for stability and alignment.

- The joint should remain in position throughout a full
  ROM. Dorsal subluxation suggests that the graft has
  been set too flat, failing to restore a concave articular
  surface.
- The joint should exhibit neutral alignment. Varus or valgus angulation suggests that the graft has not been set perpendicular to the long axis of the middle phalanx.
- Assess screw length and graft placement with fluoroscopy. The hamate articular cartilage is thicker than the middle phalanx cartilage. This discrepancy creates the illusion that the hamate has not been set flush with the middle phalanx, but a lack of step-off already has been confirmed by direct inspection of the joint surface (TECH FIG 3G).
- Often, the distal edge of the graft protrudes beyond the volar cortex of the middle phalanx fracture defect. Shave the graft edge to smooth the transition from graft to middle phalanx.

**TECH FIG 3**  
**A.** This lateral preoperative radiograph demonstrates a chronic, unstable PIP fracture-dislocation in a 19-year-old woman. Joint flexion occurs as the middle phalanx hinges at the palmar fracture margin and the proximal phalanx falls into the fracture defect.  
**B.** The graft has been inset to recreate a middle phalanx articular surface that is concave and matches the curvature of the proximal phalanx head.  
**C.** The graft must be contoured and set into the middle phalanx in a manner that restores the cup-shaped geometry of the middle phalanx base. Failure to restore a concave joint surface creates a flat surface (D) that encourages dorsal subluxation of the middle phalanx (E).  
**F.** Relocation of the joint. The joint has been relocated and stability confirmed by taking the joint through a full range of motion and ensuring that subluxation does not occur. Note how nicely the hamate graft recreates the palmar lip of the middle phalanx.  
**G.** Lateral radiograph of the graft. The lateral radiograph gives the false appearance that a step-off exists between the graft and the remaining middle phalangeal articular cartilage.

**CLOSURE**
- Repair the palmar plate and palmar margin of the middle phalanx. It may be necessary to secure the sutures through small drill holes.
- Repair the collateral ligaments to the stumps that were left on the middle phalanx during the approach.
- Interpose the flexor tendon sheath flap under the flexor tendons and over the PIP joint.
- Obtain hemostasis after the tourniquet is deflated.
- Close the skin.
- Apply a bulky dressing and splint holding the PIP joint in slight flexion.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Recurrent dorsal subluxation</th>
<th>This is most commonly caused by failure to inset the graft in a position that restores the cup-shaped middle phalanx base.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angulation in the coronal plane</td>
<td>The graft must be positioned perpendicular to the long axis of the middle phalanx. After provisional graft fixation, clinically assess the finger for varus or valgus angulation and adjust the graft to achieve neutral alignment.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- The goal of hemi-hamate arthroplasty is to operatively restore osseous PIP stability. Assuming that this goal has been attained and confirmed with lateral radiographs in extension that demonstrate concentric reduction, ROM is begun within the first week.
- Apply a postoperative dressing that controls edema and supports the PIP joint in a slightly flexed posture.
- Within the first week, begin active PIP flexion within an extension block splint that prevents extension past 20 degrees. The therapists may choose to fabricate a hand-based dorsal extension block splint if swelling is excessive, but a figure-eight splint is preferable.
- Encourage full active and passive motion at the MP and DIP. If a concomitant mallet injury is being treated, splint the DIP joint in full extension, but do not inhibit motion at the other joints.
- If the radiographs at 3 weeks show concentric joint reduction and solid graft fixation, begin gentle active assisted ROM.
- At 6 weeks postoperatively, again confirm solid graft fixation and concentric joint reduction radiographically, discontinue figure-eight splinting, and then begin passive ROM into flexion and correction of an excessive PIP flexion contracture with dynamic extension splinting.

OUTCOMES

- We have previously reported the outcome of 13 patients with unstable PIP dorsal fracture-dislocations treated with hemi-hamate autograft. The original results were extremely encouraging, and our long-term results have not dampened our enthusiasm for the procedure.
- Eleven of the 13 patients returned for examination and final radiographs, one patient’s results were assessed by chart review, and one patient was lost to follow-up.
- Pain
  - Pain in the injured digit was minimal, and was rated at an average of 1.3. Two patients had regular pain, and six noted occasional aching discomfort.
  - Graft donor site aching discomfort was noted only rarely in three patients. The remaining patients were asymptomatic.
- Motion
  - ROM in the PIP averaged 85 degrees (range 65 degrees to 100 degrees).
  - Most patients had a slight PIP flexion contracture that averaged 9 degrees (range 0 degrees to 25 degrees).
  - The ROM of the MP joint averaged 90 degrees (range 75 degrees to 100 degrees), and the motion at the DIP joint averaged 60 degrees (range 35 degrees to 80 degrees).
- Stability
  - Two of 12 patients demonstrated slight dorsal subluxation on the lateral radiograph, but neither patient had symptoms or functional problems.
  - One of the two patients with dorsal subluxation also demonstrated 20 degrees of ulnar instability, but she was not symptomatic from this abnormality.
- Radiographs
  - An apparent articular surface step-off between the graft and native middle phalanx cartilage commonly is observed. This phenomenon is caused by the greater thickness of the cartilage on the graft compared to the middle phalanx cartilage.
  - All grafts united, as demonstrated by bridging trabeculae.
  - None of the grafts demonstrated sclerosis that suggested osteonecrosis.
  - Graft reabsorption was not observed.
- Long-term outcome
  - Our experience with PIP hemi-hamate arthroplasty is too short to definitively determine the ultimate fate of the transferred articular cartilage.
  - Early results do not suggest that autograft will lead to excessive rates of cartilage degeneration causing symptomatic posttraumatic changes.

COMPLICATIONS

- The complication rate in our original patient cohort was low. No patients developed infection, and no patients required subsequent surgery.
- Dorsal subluxation was noted in 2 of 12 patients. One was believed to have been caused by an incompetent palmar plate. The other case of dorsal subluxation was attributed to a graft that was not appropriately contoured to restore the cup-shaped geometry of the middle phalanx base.
- Donor site morbidity has not occurred. To date, no patient has had instability or significant pain at the fourth or fifth CMC joints.
- We have maintained an acceptably low complication rate in our subsequent experience.

REFERENCES


DEFINITION
- Injuries about the distal interphalangeal joint (DIP) consist of avulsion injuries of the terminal extensor tendon or the flexor digitorum profundus (FDP) tendon, or isolated dislocations of the DIP joint.
- Isolated dislocations of the DIP joint are rare injuries in which the distal phalanx is dislocated either dorsal or volar relative to the middle phalanx.
- A “bony” mallet finger (ie, mallet fracture) is an intra-articular bony avulsion at the insertion site of the terminal extensor tendon on the dorsal base of the distal phalanx that results in inability to actively extend the DIP joint.
- A “non-bony” mallet finger is an injury to the extensor mechanism at or near the insertion onto the distal phalanx that typically results in inability to actively extend the DIP joint.
- “Jersey finger” is an avulsion of the FDP tendon, with or without its bony attachment, from the volar base of the distal phalanx. It typically results in inability to actively flex the DIP joint.

ANATOMY
- The DIP joint is stabilized by the radial and ulnar collateral ligaments, the volar plate, and the firm insertions of the FDP and terminal tendons of the extensor mechanism.
- The extensor mechanism terminates with the confluence of the lateral bands into a single terminal tendon, which inserts on the dorsal base of the distal phalanx. The terminal tendon is a strong, flat, thin segment that averages 10.1 mm in length and 5.6 mm in width.
- The terminal tendon insertion, on average, is 1.4 mm proximal to the germinal matrix of the fingernail.
- The volar surface of the terminal tendon usually is adherent to the dorsal capsule of the DIP joint.
- The FDP tendon inserts on the volar surface of the base of the distal phalanx. It is surrounded by the flexor tendon sheath. The A4, A5, and C3 pulleys secure the FDP tendon around the level of the DIP joint.
- The vinculum longus profundus and vinculum brevis profundus are thin mesenteries providing vascular supply to the distal portion of the FDP tendon. They also provide a weak attachment of the FDP tendon to the flexor tendon sheath.

PATHOGENESIS
- Mallet finger injuries are the result of a disruption to the extensor mechanism at or near the insertion to the base of the distal phalanx. Such disruptions can occur as a result of a laceration or a sudden flexion force to an extended DIP joint. The disruption of the extensor mechanism leaves the pull of the FDP unopposed, leaving the DIP joint in a flexed posture.
- Dislocations of the DIP joint are rare due to the inherent stability provided by the collateral ligaments, the volar plate, and the flexor and extensor tendon insertions. However, when a dislocation does occur, the distal end of the middle phalanx usually “buttonholes” through these structures, making reduction more difficult.
- “Jersey finger” injuries occur as a result of disruption to the FDP, from either a laceration or a sudden extension force applied to a flexed DIP joint, causing an eccentric contraction. The disruption of the FDP tendon leaves the pull of the extensor mechanism unopposed, resulting in an extended posture of the DIP joint.

NATURAL HISTORY
- Mallet finger injuries can occur in any finger, but most commonly are seen in the three most ulnar digits.
- Left untreated, a mallet finger injury can progress to a secondary “swan neck” deformity.
- With the disruption of the extensor mechanism at the DIP joint, the pull of the lateral bands adds to the extension force of the central slip at the PIP joint, thereby creating an imbalance in forces at the PIP joint and a hyperextension deformity at that joint.
- Despite treatment, residual deformity, usually in the form of a dorsal prominence, can be seen in up to 80% of cases.
- About 75% of cases of FDP avulsions involve the ring finger. Although some researchers hypothesize that this happens because the ring finger protrudes the farthest when the hand is held in a flexed position, this theory has never been proven.
- Leddy and Packard proposed the classification system that is still widely used today for FDP avulsion injuries, based on the level of retraction of the tendon. Other authors since have made modifications, including the addition of a fourth type of injury.
- Type I FDP avulsions retract into the palm, thereby disrupting the vincular system and leading to poor blood supply. Surgery should be performed within 7 to 10 days.
- Type II injuries retract to the level of the PIP joint or distal A2 pulley. An associated small bony fleck often is seen on the lateral radiograph. Because the proximal blood supply is preserved through the long vincula, these injuries can be successfully treated as late as 6 weeks from the time of injury.
- Type III injuries usually are associated with a bony avulsion, and as a result, do not retract proximal to the A4 pulley. These injuries are treated as bony injuries with open reduction and internal fixation and can be treated late if required.
- Type IV injuries are bony avulsion injuries in which the tendon also has separated from the avulsed bony fragment. Time to treatment depends on the level of tendon retraction.
PATIENT HISTORY AND PHYSICAL FINDINGS
- As with all hand injuries, patients should be questioned about their hand dominance and occupational requirements so the surgeon can better understand individual needs and goals.
- The following examinations should be performed to determine possible injuries:
  - FDP function
    - Inability to flex at the DIP joint implies disruption of the FDP tendon.
    - Limited, weak, or painful flexion may indicate a partial injury or a complete disruption with intact vinculae or pseudotendon.
  - DIP joint extensor mechanism function
    - Inability to extend at the DIP joint implies disruption of the terminal extensor tendon. Weak extension implies a partial or less severe injury. Loss of passive extension indicates a possible fracture or dislocation.
  - Axial injuries to an extended DIP joint often are the culprit in mallet finger injuries.
    - The history often reveals an axial blow to the fingertip, such as when catching a ball.
    - The patient will be unable to actively extend at the DIP joint.
  - “Jersey finger” injuries often are the result of a sudden extension force on a flexed DIP joint, such as when grabbing for another player’s shirt while playing football.
    - These patients will be unable to actively flex through the DIP joint.
    - Active PIP flexion will be present but may be moderately diminished due to pain or stiffness.
  - Most dislocations of the DIP joint are the result of sporting injuries.7,8

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs of the affected hand (PA, lateral, and oblique) and dedicated views of the affected finger (PA, lateral, and oblique) should be obtained, and usually are sufficient for making the diagnosis in association with a thorough clinical examination.
  - Mallet finger injuries can be associated with a bony avulsion. Any joint subluxation should be noted, and the size of the avulsed fragment should be estimated (FIG 1).
  - In FDP avulsion injuries, the location of the retracted flexor tendon often can be appreciated by finding a bony fragment on the lateral radiograph of the affected digit (FIG 2A).

FIG 1 • Lateral radiographs usually are the most helpful in identifying a mallet fracture. Note that in this image, the avulsed fragment includes more than 50% of the articular surface. There is no significant volar subluxation in this case.

FIG 2 • A. Flexor digitorum profundus (FDP) avulsion in which a bony fragment has been caught up at the A4 pulley. B. Lateral radiograph of a finger demonstrates chronic dorsal dislocation of the DIP joint, with associated arthrosis. C. Axial cut MRI at the level of the proximal phalanx shows both FDP and flexor digitorum superficialis (FDS) tendons are present. D. At the level of the middle phalanx, only the FDS tendon can be seen. (B–D: Copyright Thomas R. Hunt III, MD.)
Ultrasound sometimes can be helpful in determining continuity of the flexor tendon or identifying the location of the retracted proximal flexor tendon stump.

MRI also is valuable in determining flexor tendon continuity and level of tendon retraction (FIG 2C,D).

**DIFFERENTIAL DIAGNOSIS**

- Osteoarthritis
- Inflammatory arthropathy
- FDP rupture
- FDP laceration
- Terminal extensor tendon rupture (mallet finger)
- Mallet fracture

**NONOPERATIVE MANAGEMENT**

- For tendinous mallet fingers and mallet fractures involving less than one third of the articular surface and without joint subluxation, a variety of splints are available.
- We prefer immobilizing the DIP joint with a prefabricated polyethylene extension splint.
- Casting of the DIP joint also has been described.
- Full-time splinting in extension is recommended for 6 weeks, followed by 6 weeks of part-time splinting. During this second 6 weeks, we advise our patients to wear the splint for any heavy activity and at night, and we emphasize the inclusion of gentle DIP joint flexion, not exceeding 20 degrees in the first 2 weeks, and then gradually increasing to full flexion over the course of 6 weeks. If any loss of extension is experienced during this time, we advise the patient to return immediately to full-time splinting and to follow up in our clinic.
- Nonoperative treatment of acute FDP lacerations or ruptures at the DIP joint is not recommended unless the patient is unwilling to comply with postoperative splinting or rehabilitation.
- In subacute and chronic FDP lacerations or avulsions, the functional necessity of DIP joint motion should be carefully considered, and nonoperative treatment should be considered.
- Literature directing treatment in cases of delayed diagnosis is scarce.
- If the patient does not have any functional limitations as a result of the injury, we prefer to defer surgical management.
- If the patient is troubled by a tender mass in the palm but the hand is functional, we recommend excision of the tendon alone.
- Instability and weakness of pinch can become problematic. In such cases, we recommend tenodesis or arthrodesis.
- Only if the function of the DIP is crucial to the performance of daily activities do we recommend a staged reconstruction of the flexor tendon.

Closed reduction of isolated DIP joint dislocations can be attempted under a digital block.

- For dorsal dislocations, the FDP tendon or the volar plate can be interposed, blocking the reduction as the head of the middle phalanx buttonholes through the interval between the FDP tendon and the collateral ligament.8
- For dorsal dislocations, gentle traction and extension through the DIP joint can assist in reducing the interposed volar plate.
- In volar dislocations, the head of the middle phalanx can buttonhole through the interval between the terminal extensor tendon and the collateral ligament.7
- For volar dislocations, gentle traction can be used while guiding the condyle of the middle phalanx back through the interval between the terminal extensor tendon and the collateral ligament.
- In either case, a gentle reduction maneuver should be attempted, keeping in mind the structures that are likely to be interposed in the joint. Care should be taken to avoid excessive traction, which may tighten the tendon and ligament, preventing reduction.

**SURGICAL MANAGEMENT**

- Surgical treatment of mallet fractures is reserved for those fractures associated with joint subluxation.
- Operative treatment is recommended for all acute flexor tendon avulsions at the DIP joint and selected subacute or chronic cases.
- The level of retraction of the tendon on the flexor side determines the urgency with which the injury needs to be addressed (see Table 1). Although Type I and II injuries can be treated up to 6 weeks with good results, we recommend treating these injuries sooner when possible to optimize recovery and function.
- For isolated dislocations of the DIP joint, surgical management is indicated in those cases where closed reduction is unsuccessful. Generally, no surgical stabilization is required.

**Preoperative Planning**

- All images should be reviewed.
- For isolated dislocations, a review of the relevant anatomy, including the volar plate, flexor and extensor tendons, and collateral ligaments, is essential to understand which structures might be interposed in the DIP joint.

**Positioning**

- The patient is placed supine on the operating room table with the affected arm outstretched on an arm board. When

---

**Table 1**

<table>
<thead>
<tr>
<th>Type</th>
<th>Level of Tendon Retraction</th>
<th>Vascularity</th>
<th>Approximate Time to Surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Palm</td>
<td>Vincucae are disrupted, leading to dysvascularity of tendon</td>
<td>7–10 days</td>
</tr>
<tr>
<td>II</td>
<td>Distal A-2 pulley or PIP joint</td>
<td>Vincucae remain intact, providing vascularity and preventing further retraction</td>
<td>Up to 6 weeks</td>
</tr>
<tr>
<td>III</td>
<td>A-4 pulley</td>
<td>Bony attachment prevents retraction beyond the A-4 pulley</td>
<td>6 weeks +</td>
</tr>
<tr>
<td>IV</td>
<td>The tendon is avulsed from a bony avulsion fracture, and can retract to any level</td>
<td>Determined by the level of tendon retraction</td>
<td>Determined by the level of tendon retraction</td>
</tr>
</tbody>
</table>
treated a flexor tendon injury, a flexible aluminum hand-holder can be useful for positioning the hand during the exploration.

- A well-padded tourniquet is placed high on the arm.

**Approach**

- **Mallet fingers**
  - We prefer to treat mallet fingers with percutaneous techniques.
  - Percutaneous treatment is more likely to succeed if the injury is treated within the first 3 to 5 days after the injury, although we have successfully treated cases as late as 6 weeks.
  - If open treatment is to be attempted, a variety of incisions can be used, including straight longitudinal, lazy-S type, H-type, and Bruner incisions. Meticulous soft tissue handling is vital to minimize trauma to the skin. Great care must be taken to avoid injury to the germinal matrix proximal to the nail fold.
  - “Jersey fingers”
  - A volar Bruner incision is used and is extended proximal enough to identify or retrieve the proximal tendon stump.
  - In type I injuries, one oblique limb of the Bruner incision over the A1 pulley region often is used to retrieve the retracted tendon.
  - Care is taken to preserve the A2 and A4 pulleys.
  - For open reduction of isolated DIP dislocations, the approach is dictated by the direction of the dislocation.
  - Dorsal dislocations are approached volarly, and volar dislocations are approached dorsally.

**TREATMENT OF MALLET FINGERS**

**Extension-Block Pinning of Mallet Fractures**

- The DIP joint is flexed initially, pulling the avulsed fragment volarly.
- A dorsal block pin is inserted obliquely from distal to proximal under fluoroscopy. A 0.045-inch K-wire usually is ideal, although 0.035-inch K-wires are sometimes preferred if the finger is small.
- The pin should enter at the dorsal edge of the articular surface of the middle phalanx, and bicortical purchase should be obtained (TECH FIG 1A,B). The dorsal blocking pin should not actually engage the fracture fragment, because this may result in comminution of the bone.
- Anteroposterior and lateral views on fluoroscopy should be obtained to ensure appropriate positioning (TECH FIG 1C).
- The distal phalanx is then extended, reducing and compressing the fracture.
- A second K-wire is inserted in a retrograde manner from the distal tip of the distal phalanx to the level of the DIP joint (TECH FIG 1D).
- While holding the digit extended with the fracture and DIP joint reduced, the second smooth K-wire is advanced retrograde across the DIP joint into the middle phalanx (TECH FIG 1E,F).
- The K-wires are cut, and protective plastic caps are placed over the exposed ends.
- The finger is then placed in a protective dressing.

**TECH FIG 1**

**A** With the DIP joint flexed, a K-wire is inserted at the dorsal edge of the articular surface of the middle phalanx. **B.** Bicortical purchase is obtained. **C.** PA fluoroscopic image confirms good bony purchase in both the dorsal and volar phalanx. **D.** With the DIP joint extended, a retrograde K-wire is introduced through the tip of the distal phalanx. **E.** Once reduction is confirmed, this retrograde pin is advanced into the middle phalanx. **F.** A final PA image confirms good placement of pins.
Pinning of Non-Bony Mallet Fingers
- For patients whose compliance is in doubt, or to assist with occupational requirements, a single 0.045- or 0.062-inch K-wire can be inserted in a retrograde manner through an extended DIP joint.
- The pin can be left either protruding through the skin and covered with a pin cap, or under the skin.

Pull-Through Button Technique for Flexor Digitorum Profundus Avulsions
- The fingers are held in an extended position using an aluminum hand.
- The volar surface of the injured finger is exposed through a Bruner incision, and the edges of the avulsed tendon are identified (TECH FIG 2A).
- The proximal segment of the tendon is retrieved, pulled out to length, and secured using a small-gauge needle directed transversely across the tendon (TECH FIG 2B).
- Using a 2-0 monofilament nonabsorbable suture (or other permanent suture appropriate for tendon repair), the proximal segment of the avulsed tendon is captured using a Krakow or Bunnell suture technique (TECH FIG 2C).
- The proximal segment of tendon is then threaded through the flexor pulley system.
- The volar base of the distal phalanx is prepared with a rongeur to expose bleeding bone.
- Two straight Keith needles are introduced into the volar wound and, using a wire driver, driven from the volar base of the distal phalanx, through the nailbed, and exiting through the center of the fingernail on the dorsal side (TECH FIG 2D,E).
- A small square of sterile felt and a plastic sterile button are placed over the exposed tips of the Keith needles (TECH FIG 2F).
- The two free ends of suture are threaded through the eyelets of the Keith needles, and the needles are advanced through the nailbed, felt, and button.
- The distal end of the avulsed tendon is pulled into its prepared footprint at the volar base of the distal phalanx, and the suture is then carefully tied over the button (TECH FIG 2G,H).
- Additional fixation is obtained by securing the tendon to tendon remnants at the insertion site.
- As an alternative to tying over the nail and a button, the Keith needles may be advanced through the proximal portion of the distal phalanx, avoiding the germinal matrix. A 3-mm transverse incision is then made over the exiting Keith needles, and the suture is tied down on bone.
- The wound is closed in standard fashion, and the hand is secured in a dorsal extension blocking splint (TECH FIG 2I).

Suture Anchor Technique for Flexor Digitorum Profundus Avulsions
- The approach, identification, and suture of the avulsed profundus tendon are the same as in the pull-through button technique.
- Two small suture anchors are introduced into the volar base of the distal phalanx in a trajectory from proximal-volar to distal-dorsal, or, as recently described by McAllister et al., may be placed in a distal-volar to proximal-dorsal trajectory.

TECH FIG 2 • A. A volar Bruner incision is planned. B. The avulsed tendon is identified and held in the wound with a small-gauge needle. C. The avulsed tendon is captured with a Krakow technique. D. Keith needles are advanced through the volar wound to exit in the center of the fingernail. (continued)
direction, taking special care not to violate the dorsal cortex. This placement ensures maximum bony purchase in the thickest portion of the distal phalanx and ensures maximum pullout strength.

- Fluoroscopic imaging can be used to ensure proper anchor placement and document that the suture anchors have not violated the dorsal cortex or the joint.
- A modified Kessler pattern of suturing can then be used to secure the FDP tendon in place at the base of the distal phalanx.
- The wound is closed and the splint applied in the manner described.

**Treatment Technique for Flexor Digitorum Profundus Disruption With Bony Avulsion**

- If the avulsed fragment is large enough, some authors recommend open reduction and internal fixation using small screws or wires.
- It is recommended that the fragment have a diameter at least 2½ times the diameter of the screw to avoid comminution of the bony fragment.\(^5\)
- Intraoperative radiographs are imperative to confirm reduction.

**TECH FIG 2 • (continued)**

**E.** A side view shows the Keith needles exiting through the fingernail. **F.** Sterile felt and a plastic button are threaded over the needles. **G.** The finger is flexed down, and the sutures are pulled through. **H.** The suture is securely tied over the button. **I.** The patient is immobilized initially in an extension block splint.
PEAKS AND PITFALLS

| Prevent proximal pin migration in nonbony mallet fingers | For cases in which we bury the pin, we prefer to make a small 90-degree bend in the distal end of the wire to prevent proximal migration of the pin into the phalanges. |
| Tendon retrieval in FDP avulsions | It is helpful to use a "milking" technique from proximal to distal in the forearm and palm, with the wrist in a flexed position, to deliver the proximal end of the tendon. Doing so can often decrease the length of the incision that is required for the repair. |
| Skin irritation with use of button | It is recommended to place a small piece of felt between the patient’s nail and the button to decrease irritation (see Tech Fig 2F,G). |
| PIP flexion contracture | Delayed treatment of a type I FDP avulsion can result in a PIP flexion contracture. If nearly full passive joint extension is not obtainable following tendon reinsertion, the repair should be abandoned. |
| Extension block pinning | Full DIP extension is not required to achieve reduction of the fracture. Avoid multiple attempts at K-wire placement. Avoid forced extension of the DIP joint, which may result in fracture at the entrance site of the dorsal block K-wire. Early treatment is easier and more effective. |

POSTOPERATIVE CARE

- Mallet fractures
  - The patient is allowed nearly full activity immediately postoperatively, including PIP joint and MCP joint motion.
  - An antibiotic ointment may be applied to the pin sites twice daily.
  - The patient should be counseled thoroughly on keeping pin sites clean.
  - The patient is seen for follow-up around postoperative day 10, and as needed for 4 weeks.
  - Pins are removed in the office setting when there is no tenderness to palpation at the fracture site and there is evidence of bridging trapezialis at the fracture site (usually about 4 to 5 weeks).

- FDP avulsions/lacerations
  - The patient is evaluated 3 to 5 days postoperatively, and if a strong repair has been accomplished and the patient is deemed compliant, a forearm-based dorsal extension block splint is fitted and the patient is enrolled into a directed hand therapy rehabilitation protocol with immediate edema control.
  - In the compliant patient, place-and-hold exercises, initially in the splint and then with the wrist in slight extension, are started between postoperative days 5 and 7.
  - Further progression is based on the protocol described by Cannon and Strickland, and typically includes tendon glides and wrist tenodesis activities at 5 weeks, and progressive strengthening at 7 to 8 weeks.

OUTCOMES

- For extension block pinning of mallet fractures, one study by the primary author reported average time to bony union of 35 days.
  - An average follow-up time of 74 weeks, range of motion averaged 4 to 78 degrees. For isolated dislocations of the DIP joint, case studies suggest that active range of motion at the DIP joint from 0 to 65 degrees is regained by 4 to 12 months postreduction. Most patients with FDP avulsions treated acutely are able to work between 8 and 18 weeks after the surgery, with some studies suggesting that an earlier return to work is seen with a suture anchor repair.
  - An 8- to 10-degree flexion contracture and a similar lack of terminal flexion at the DIP joint often are encountered.

COMPLICATIONS

- Pin tract infection
- Migration of pins
- Loss of reduction
- Nail deformity
- Dorsal skin necrosis from splinting
- Joint stiffness
- Loss of grip strength
- Tendon adherence
- Tendon rupture

REFERENCES

DEFINITION
- **Malunion** results when a fracture fragment heals in incorrect anatomic alignment.

ANATOMY
- Metacarpals and phalanges are tubular structures with a smooth dorsal surface covered by the extensor tendon and its expansions.
- Metacarpals are triangular in cross section. The medial and lateral surfaces meet at the volar ridge, providing attachment to the intermetacarpal ligaments proximally and distally help splint fractured bones, making functionally significant malunions of the ring and small metacarpals less common.
- Phalanges are bean-shaped in cross section. The volar aspects of the proximal and middle phalanges are in intimate relation to the flexor digitorum profundus (FDP) and superficialis (FDS) tendons, particularly in the region of the annular pulleys (FIG 1).
  - As a result, the tendons are vulnerable to damage from drills and screws used in a dorsovolar direction. This problem is especially significant in the region of the annular pulleys, where the tendons are strapped against the volar cortex, rendering them vulnerable to damage.

PATHOGENESIS
- Malunions most often occur secondary to lack of treatment or inadequate nonoperative care.
  - Malunion following internal fixation is uncommon, but when present usually results from inadequate stability or poor patient compliance.
  - Extra-articular malunions (EAM) often are multiplanar, but usually there is one major component to the deformity that causes the functional deficit.
  - The more proximal the malunion, the greater the deformity.
  - Just 1 degree of rotation at the fracture site may translate to 5 degrees at the finger tip.
  - 5 degrees of fracture malrotation can cause 1.5 cm of digital overlap when the fingers are flexed.
  - Soft tissue pathology such as neurovascular deficits, trophic changes, joint contractures, and tendon adhesions can coexist.
  - Results of corrective osteotomy are significantly poorer in the presence of such complicating factors.

NATURAL HISTORY
- Significant EAM can cause crossing or scissoring of fingers, pain due to distortion of joints, disturbance of muscle/tendon balance, and reduction of grip strength.
- EAMs associated with shortening can lead to an extension lag proportional to the degree of shortening. The effect is more pronounced in proximal phalanges compared to metacarpals.
- Intra-articular malunion (IAM) with a significant step (0.5 mm) or gap (1 mm) may cause joint surface incongruity, synovitis, capsular loosening or stiffness, and, ultimately, painful posttraumatic arthrosis.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The value of a good history and physical examination cannot be overemphasized. The decision as to whether surgical treatment is to be offered depends almost entirely on a history suggestive of a significant functional impairment or pain.
  - Injury specifics
    - The original injury and method(s) of treatment
    - Location
      - Phalanx versus metacarpal
      - Extra-articular versus intra-articular versus combined deformities
    - History of complicating factors, eg, infection and chronic mediated pain syndrome
    - Duration of malunion, particularly relevant in deciding surgical strategy (reducing the fracture vs osteotomy)
    - Associated injuries such as soft tissue defects and neurovascular injuries
  - Specific patient characteristics
    - Skeletal maturity
    - Hand dominance
    - Degree of deformity, swelling, stiffness, weakness of grip, and pain
    - Occupation and avocational pursuits as well as patient expectations and goals
    - Ability to cooperate with postoperative therapy regimen

FIG 1 Structures on the volar aspect of the metacarpals and phalanges. The flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) tendons are intimately associated with the volar aspect of the phalanges and, to a lesser extent, the metacarpals. This dissected specimen also depicts the vinculae (V) and the A-1 and A-2 annular pulleys. (From http://www.turntillburn.ch.)
IMAGING AND OTHER DIAGNOSTIC STUDIES

- Good-quality radiographs taken in three precise planes (anteroposterior, lateral, and oblique) are sufficient for simple EAMs.
- Radiographs of the opposite hand are helpful in preoperative planning for complex EAMs.
- IAMs and combined malunions may require CT scans with three-dimensional reconstruction.

DIFFERENTIAL DIAGNOSIS

- Fibrous nonunion
- Nonunion with soft tissue contracture
- Sequelae of epiphyseal injury or growth arrest
- Erosive arthritis

NONOPERATIVE MANAGEMENT

- Hand therapy is directed toward maximizing the range of motion (ROM) of the digits, promoting optimal tendon excursion, and improving the grip strength.
- In less dramatic deformities, physical therapy is the first line treatment. Many patients will gain enough functional improvement that they decide to “live with” the deformity.
- Initiation of therapy allows the opportunity to assess the patient’s personality with respect to compliance and realistic expectations.

SURGICAL MANAGEMENT

Timing of Correction

- Treatment of nascent malunions results in improved outcomes.
- IAMs must be corrected as soon as possible if there is a significant articular step and no overwhelming technical difficulties are anticipated.1
- In the case of an EAM, after 6 to 8 weeks from the injury, a “wait and watch” policy before osteotomy is advisable to see whether the malunion causes significant functional or cosmetic problems.

Location of Correction

- At or near the apex of the deformity for angular and complex EAMs
- In the proximal metaphysis of the malunited bone for rotational EAMs. With improved osteotomy techniques and fixation implants, a proximal metacarpal osteotomy is no longer recommended for treatment of a P-1 rotational malunion.5

Type of Osteotomy

- For angular EAMs, a closing wedge osteotomy is preferable, especially in the setting of intrinsic tightness. This approach is most commonly used for dorsal apex metacarpal malunions. An opening wedge osteotomy is best in the setting of an extension lag and pseudoclaw deformity, which are more commonly seen in apex volar phalangeal malunions. An incomplete osteotomy may be used for either of these cases.
- For rotational and combined rotational/angular EAM correction, a complete osteotomy is required.4 Metacarpal neck EAM from a previous Boxer’s fracture without significant shortening may be corrected with a pivot osteotomy.5
- Condylar advancement osteotomy4 is suitable for IAM correction in many cases.

Severity of Deformity

- Malunion does not always mandate a corrective osteotomy. Patients possess a significant capacity to adapt to minor deformities. For instance, slight overlap of adjacent digits due to rotational malunion may be unsettling and unsightly, but it is consistent with good hand function.3 Similarly, a proximal diaphyseal malunion of the small-finger metacarpal can contribute to tendon imbalance and flexion contracture of the proximal interphalangeal joint, but the hand may function effectively.7
- Multifragment IAMs and those with established posttraumatic arthritis are best treated by arthrodesis or arthroplasty rather than repositioning osteotomy.

Preoperative Planning

- In addition to precise evaluation of the bony deformity, careful assessment of the soft tissue envelope, gliding capacity of the flexor and extensor tendons, joint mobility, and neurovascular status is critical.
- Plan for adjunct procedures (eg, tenolysis, capsulotomy) that may be required.
- Determine the optimal location for placement of internal fixation.
- Decide on opening or closing wedge osteotomy. In the presence of an extension lag, an opening wedge is preferred, whereas, in the presence of intrinsic tightness, a closing wedge is preferred.
- Provide for soft tissue coverage as needed.
- Preoperative templates are created for bony correction.
- The proximal and distal fragments are each outlined then superimposed over an outline of the contralateral uninjured bone.
- The type and location of the osteotomy, the size of the bone graft needed (in the case of an opening wedge osteotomy), as well as the method of fixation are determined.
- In the rare cases requiring large corticocancellous interposition grafts, iliac crest bone graft harvest is planned.

Positioning

- The patient is positioned supine with the shoulder abducted to 90 degrees, elbow extended, and the extremity on an arm table.
- Place a proximal arm, non-sterile tourniquet.
- If required, prep for ipsilateral iliac crest graft harvest.
- Perform an examination under anesthesia to determine joint ROM and stability.

Approach

- A dorsal approach through a dorsal skin incision in the intermetacarpal space is used for the second through fourth metacarpals (FIG 2A).
- A midaxial approach through a midaxial skin incision at the junction of the wrinkled dorsal and smooth volar skin is used for the fifth metacarpal and the proximal and middle phalanges (FIG 2B).
- Coronal plane correction is best accomplished with a lateral buttress plate placed over the bone graft (FIG 2C,D).
- Dorsal plates should be avoided in the phalanges due to extensor tendon adhesions and resulting loss of motion.
**INCOMPLETE OSTEOTOMY FOR ANGULAR CORRECTION**

**Metacarpal Closing Wedge Osteotomy**

- Make a dorsal incision in the interval between either the index–long or ring–small metacarpals, depending on the bone to be treated (see Fig 2A).
  - An incision at the junction of the glabrous skin often is appropriate for small metacarpal malunion correction (see Fig 2B).
- Retract the extensor tendon to expose the metacarpal (TECH FIG 1A).
- Make a dorsolateral incision through the metacarpal's periosteum, and carefully free this layer from the dorsum of the metacarpal with a no. 15 blade (TECH FIG 1B).
  - At completion of the operation, this periosteal and muscle layer will be closed, serving to protect the extensor tendons from the underlying internal fixation.
- Subperiosteally expose the circumference of the bone at the planned osteotomy site.
- Pass two small Hohmann retractors, one radially and one ulnarily, to protect the tendons and neurovascular structures.
  - Take care not to put undue tension on these structures.
- Precisely identify the apex of the deformity by determining the intersection between the true anatomic axis of both the proximal and distal fragments.
  - Place a 0.35-mm K-wire parallel to the proximal fragment and under radiographic guidance mark the anatomic axis using diathermy or a marking pen.
  - Mark the distal fragment in a similar manner.
- Design the osteotomy around the intersection of these two marks (TECH FIG 1C).
  - Plan the cuts perpendicular to the long axis of each fragment.
  - The size of the bone wedge to be removed is determined based on preoperative templates and intraoperative measurements.
  - Center and apply a six- or seven-hole 2.0- to 2.7-mm compression plate to the dorsum of one fragment using two screws.
  - Moderately tighten the screws.
  - Plan for six cortices of fixation proximal and distal to the osteotomy if possible.
  - Juxta-articular osteotomies are best stabilized using condylar plates, T-plates, or Y-plates. Locking plates also may be of value in these cases.
  - Remove one screw and rotate the plate away from the osteotomy site.
  - Create an incomplete osteotomy, starting on the dorsal convex surface and using a water-cooled sagittal saw or sharp osteotome.
    - Complete the distal bone cut before making the proximal bone cut.
    - An elastic pillar of bone is left intact volarly on the concave side to act as a hinge.
    - In some cases, complete correction and osteotomy reduction can be obtained only if the volar cortex is cut and only the volar periosteum is left intact as the hinge.
    - Correction is adequate when the true anatomic axes of the proximal and distal fragments are parallel (TECH FIG 1D).
  - The dorsal plate often will serve as a guide to reduction when it sits flat on the dorsum of both fragments.
Chapter 40  CORRECTIVE OSTEOTOMY FOR METACARPAL AND PHALANGEAL MALUNION

**TECHNIQUES**

**TECH FIG 1 • A.** Extensor tendons have been retracted to expose the dorsal surface of the metacarpal sagittal plane malunion. **B.** The deep subtendinous layer of the metacarpal is demonstrated. Note that the periosteum is still intact. This layer is repaired covering the implant to prevent tendon adhesions. **C,D.** Method of using K-wires to determine the apex of the deformity. After removing a wedge, the size of which is determined by preoperative templating (**C**), deformity correction is confirmed when the K-wire markings are observed to be parallel (**D**). **E.** Dorsally applied T-plate with three screws distal and three screws proximal to the osteotomy.

- Re-apply the plate, tightening the two screws. Reduce the osteotomy, and secure the other fragment by applying the other side of the plate in compression (**TECH FIG 1E**).
- Insert the remaining screws and assess reduction clinically and radiographically.
- Close the periosteal and muscle layer between the plate and the extensor tendons with absorbable suture, and close the skin in the usual manner.
- Place a forearm-based splint with the wrist mildly extended and the metacarpophalangeal (MP) joints immobilized in 60 to 70 degrees of flexion. The proximal interphalangeal (PIP) joints are left free.

**Phalangeal Opening Wedge Osteotomy**

- Make a mid-axial skin incision (**TECH FIG 2A**).
- Protect against injury to the dorsal sensory nerve branch (**TECH FIG 2B**).
- Incise the lateral band as required (**TECH FIG 2C**), and expose the circumference of the bone subperiosteally at the site of the planned osteotomy.
- Use a “no touch” technique with the extensors and insert small Hohmann retractors to visualize the bone and the deformity.
- Apply K-wires to precisely locate the site of the deformity and serve as a guide for correction in the manner detailed earlier (**TECH FIG 2D,E**).
- Make an incomplete osteotomy on the concave side at the apex of the deformity perpendicular to the distal fragment.
- Contouring of the bone graft is simplified if the osteotomy is made perpendicular to the distal fragment. This leaves only the proximal portion of the graft irregular.
- Provisionally stabilize the fragments with a longitudinal K-wire and assess clinically and radiographically.

**TECH FIG 2 • A.** Lateral incision for proximal phalangeal osteotomy. **B.** Dorsal cutaneous nerve. **C.** Lateral approach to the proximal phalanx. The sagittal band has been cut and elevated to expose the proximal phalanx. (continued)
Hand Fractures and Dislocations

TECHNIQUES

Harvest either a corticocancellous wedge of bone or cancellous bone from the dorsal distal radius just proximal and ulnar to Lister’s tubercle.
- The size of the graft is determined by preoperative templating and intraoperative measurement.
- Contour the graft using a water-cooled sagittal saw.
- Insert the graft to correct the deformity and apply a lateral six-or seven-hole 1.5- to 2.0-mm compression plate (TECH FIG 2F).
- Plan for six cortices of fixation proximal and distal to the osteotomy, if possible.

Juxta-articular osteotomies are best stabilized using condylar plates, T-plates, or Y-plates. Locking plates also may be of value.
- If possible, close the thin periosteal layer between the plate and the extensor tendons with absorbable suture, and close the skin in the usual manner.
- Do not repair the lateral band. Check the correction clinically and compare with the preoperative pictures.
- Place a forearm-based splint with the wrist mildly extended and the MP joints immobilized in 60 to 70 degrees of flexion. The IP joints are immobilized in full extension.

COMPLETE OSTEOTOMY FOR ROTATIONAL AND COMBINED ROTATIONAL/ANGULAR MALUNIONS

- Perform a dorsal approach for malunions of the second through fourth metacarpals and a lateral approach for the fifth metacarpal and phalangeal malunions, as detailed earlier.
- Identify and mark the true anatomic axis of the proximal and distal fragments using 0.35-mm K-wires under radiographic guidance in the manner already reviewed. Define the apex of the angular deformity (see Tech Figs 1C and 2D,E).
- Insert one K-wire proximal and one distal to the malunion, perpendicular to the long axis and in a true dorsal-volar direction. This defines the rotational deformity.
- In the manner detailed previously, perform the osteotomy (opening vs closing) needed to correct the angular portion of the malunion using a water-cooled sagittal saw or a sharp osteotome.
- Insert a longitudinal K-wire to temporarily stabilize the fragments.
- Early correction of the angular malunion aids in plate contouring and placement.

Select a suitable plate (1.5 to 2 mm for P-1 and 2.0 to 2.7 mm for metacarpals), contour it to the lateral bony surface of the proximal fragment, align it to the anatomic axis, and insert screws through the plate fixing it to that fragment.
- Harvest, contour, and insert bone graft if required.
- Remove the longitudinal K-wire and correct the rotational portion of the malunion by bringing the dorsal-volar K-wires into a parallel position while still maintaining angular correction (TECH FIG 3A).
- Secure the distal fragment to the plate in a compression mode.
- Fine-tune the rotational alignment while maintaining the angular correction by using a gliding hole rotation plate (TECH FIG 3B,C).
- Check the correction and range of motion clinically (TECH FIG 3D).
- Close the wound and splint as previously discussed.
TECH FIG 3 • A. K-wires previously were inserted in the dorsovolar plane, perpendicular to the dorsal surface of the proximal and distal fragments. The position of these K-wires defines the degree of rotational malunion. After correction of the sagittal plane deformity, the K-wires are manipulated into a parallel position to achieve rotational correction. B, C. Use of the rotation plates (in this case, VariAx Hand Locking Plate Module [Stryker]). The screw in the perpendicular gliding hole is positioned (but not tightened) ulnar or radial, depending on the direction of the rotational correction desired. The osteotomy is compressed, and the screws in the parallel oblong holes are tightened first. The rotational correction is then obtained, and the gliding hole screw is tightened to obtain controlled correction. D. View after correction of a combined rotational and angular malunion of the fifth metacarpal. (B, C: Courtesy of Stryker Osteosynthesis.)

CONDYLAR ADVANCEMENT OSTEOTOMY

- Condylar advancement osteotomy avoids the problem of handling a small condylar malunion (TECH FIG 4A), which is difficult to fix securely and is susceptible to osteonecrosis.9
- Make a sweeping dorsal, curved skin incision over the involved MP or PIP joint.
  - MP: Incise the sagittal band and then the capsule.
  - PIP: Enter the interval between the lateral band and the central slip and incise the capsule.
  - Protect the origin of the collateral ligament and its accompanying vascularity.
- Carefully dissect the extensor tendon gently off the bone over the region of the proposed osteotomy.
- Evaluate the condition of the joint. If significant arthrosis is present, consider a salvage procedure rather than a repositioning osteotomy.
- Resect a wedge of bone between the condyles with a water-cooled sagittal saw (TECH FIG 4B).
- Make a counter-cut in the diaphysis and advance the mal-united condyle distally to restore articular congruity (TECH FIG 4C).
- Stabilize the mobilized fragment using interfragmentary screws (TECH FIG 4D).
  - Insert the first screw parallel with the joint to ensure precise joint reduction.

TECH FIG 4 • Condylar advancement osteotomy for unicondylar malunion.
PELALS AND PITFALLS

Indications
- Define the goals of treatment with the patient, and ensure that they are realistic.
- In the case of an intra-articular malunion, consider a salvage procedure rather than a repositioning osteotomy in the face of arthrosis.

Preoperative assessment
- Understand the “personality” of the malunion as well as the patient. Bony as well as soft tissue aspects of the deformity must be understood.

Operative planning
- The plane of the deformity and the different components of the deformity, as well as the true extent of the deformity, must be factored in planning the location, orientation, and extent of the osteotomy.

Operative technique
- Atraumatic bone and soft tissue handling is critical, especially in regard to the extensor mechanism overlying P-1. An oscillating power saw with a thin blade and a field of excursion similar to the diameter of the bone is needed. Copious saline irrigation is used to prevent thermal necrosis.
- Accurate plate and screw placement is essential. A screw offset of 1 mm can cause as much as 10 degrees of rotation.

Implants
- Stable fixation is needed to allow early range of motion.
- Consider using implants a size larger than used for acute fractures, particularly if extensive soft tissue release has been performed.
- Newer-generation locking plates and screws are valuable when fixation in the metaphysis is required.

Postoperative
- Institute early postoperative therapy.

POSTOPERATIVE CARE
- If adequate stability is obtained at the time of surgery, remove the postoperative splint 3 to 5 days after surgery and initiate protected motion.
  - Initiate an early active and active assisted ROM program.
  - When not performing ROM exercises, rest the hand in a volar splint in a functional position (MP joints flexed to 60–70 degrees and IP joints fully extended), apply a compression bandage, and elevate.
  - Progress to passive ROM exercises, and use reverse blocking exercises to strengthen and rebalance the extensors.
  - If needed, and if healing is progressing appropriately, use static or dynamic splints to address pending joint contractures.
  - Encourage functional use of the hand long before the radiographs show complete bony consolidation.

OUTCOMES
- Encouraging results have been reported. In the largest reported series of 59 osteotomies Buchler et al reported the following:
  - A 100% union rate
  - Satisfactory correction of the deformity in 76% of cases
  - A net gain in active ROM in 89% of the patients
  - Excellent and good functional results in 96% of patients requiring bony corrections only and 64% for those requiring bony and soft tissue correction

COMPLICATIONS
- Incomplete or inadequate correction (up to 24% of patients)
- Iatrogenic damage to soft tissues (up to 4% of patients)
- Residual stiffness

REFERENCES
DEFINITION
- Scapholunate and lunotriquetral interosseous ligament tears are common wrist injuries occurring in isolation or as part of the perilunate injury pattern.
- Interosseous ligament injuries are being diagnosed with an increased frequency as a result of recent advances in imaging and arthroscopy.
- Management of these injuries has proven to be a difficult clinical problem. Surgical management has been more reliable in pain relief than in altering the natural history.

ANATOMY
- The scapholunate complex is subject to significant loads, since the scaphoid is the only carpal bone to span from the proximal to the distal carpal row.
- The proximal carpal row flexes with radial deviation and extends with ulnar deviation.
  - The scaphoid “wants” to flex and the triquetrum “wants” to extend.
  - The lunate (the intercalated segment) is tethered between the scaphoid and triquetrum. A large amount of potential energy exists in the proximal carpal row.
- Stability is provided to the scapholunate complex by the intrinsic scapholunate interosseous ligament (SLIL) as well as extrinsic capsular ligaments, especially the dorsal radiocarpal (DRC), dorsal intercarpal (DIC) ligament, and volar radioscaphocapitate (RSC) and scaphotrapezial-trapezoid (STT) ligaments.
- The SLIL is a C-shaped structure consisting of a stronger dorsal ligamentous portion (2 to 3 mm thick), a volar ligamentous portion (1 mm thick), and a proximal fibrocartilaginous (membranous) portion.2
- Isolated injuries to the SLIL appear to be associated with dynamic instability, whereas static instability usually indicates additional injury to the secondary ligamentous stabilizers, including the DIC ligament.16
- The lunotriquetral complex is also stabilized by an intrinsic lunotriquetral ligament (LTIL) and extrinsic (volar and dorsal) capsular ligaments.
- The LTIL is C-shaped, analogous to the SLIL, consisting of dorsal and volar ligamentous portions and a membranous proximal portion. In contrast to the SLIL, the volar ligamentous portion of the LTIL is stronger and more significant functionally.12
- As with the scapholunate complex, isolated injuries to the LTIL are usually insufficient for the development of static instability. Presence of a static deformity indicates additional injury to extrinsic ligamentous structures (volar lunotriquetral, ulnolunate, and ulnocapitate ligaments or the dorsal radio-carpal and intercarpal ligaments).7,20

PATHOGENESIS
- Mayfield et al7 postulated that scapholunate disruption is the initial component of the lesser arc perilunate injury pattern, which occurs when force is applied to the thenar area with the wrist in extension, supination, and ulnar deviation.
  - Depending on the amount of kinetic energy involved, the injury may or may not extend to the ulnar side of the wrist.
- SLIL injuries can be sprains, partial tears, or complete tears (with or without injury to the extrinsic ligament stabilizers).
  - With complete SLIL tears the scaphoid flexes and the lunate is pulled by the triquetrum into extension (dorsal intercalated segment instability [DISI] pattern).
  - With complete SLIL tears the ligament usually fails at the bone-ligament interface off the scaphoid.
- Arthroscopic evaluation has revealed associated SLIL injuries in up to 30% of intra-articular distal radius fractures.3
- LTIL disruption may be traumatic or atraumatic in origin.
  - Traumatic LTIL rupture may occur as the final component of a greater or lesser arc perilunate injury pattern.9
  - Isolated LTIL tears may result from a fall on an outstretched hand in extension, pronation, and radial deviation (reverse perilunate injury)11 or from a dorsally applied force on a flexed wrist.25
  - Atraumatic ruptures of the LTIL may occur secondary to inflammatory arthritis or ulnar impaction syndrome.18

NATURAL HISTORY
- Tears of the SLIL or LTIL, with or without extrinsic ligamentous injury, may lead to various degrees of carpal instability (predynamic, dynamic, or static), alteration of normal carpal mechanics and kinematics, and early degenerative changes in the radiocarpal and midcarpal joints.
- A complete SLIL tear is associated with the development of a DISI deformity, which may be dynamic or static (indicates additional injury to the extrinsic ligaments).
  - As a DISI deformity forms, abnormal radiocarpal contact loading occurs as the proximal carpal bones shift in position and lose congruency.
  - Abnormal flexion and hypermobility of the scaphoid over time leads to degenerative changes of the radioscaphoid and capitulunate joints and ultimately collapse, termed scapholunate advanced collapse (SLAC) wrist degeneration.22,23
- These degenerative changes have been documented to begin as early as 3 months after injury.
A complete LTIL tear is associated with the development of a volar intercalated segment instability (VISI) deformity. The natural history of partial tears of the SLIL or LTIL is at present poorly defined. Partial scapholunate and LT injuries may cause chronic, activity-related wrist pain in the absence of radiologic findings.23 Predynamic or dynamic instability may cause attenuation of extrinsic ligaments with progressive development of further instability and static changes.29,30 There is evidence that this process typically requires many years.10

**PATIENT HISTORY AND PHYSICAL FINDINGS**

Dorsoradial or ulnar-sided wrist pain with a history of a fall, sudden loading, or twisting of the wrist should raise suspicion for a SLIL or LTIL tear, respectively. However, it is not uncommon for the patient to deny any significant injury. Patients frequently complain of weakness, swelling, and loss of range of motion of the wrist. A sensation of instability or “giving way” is often reported, occasionally associated with a painful clunk. A detailed physical examination of the wrist may provide significant information for the diagnosis of ligamentous injuries and help to rule out other wrist pathology. Examination of the wrist begins with evaluation for any deformity or swelling and determination of wrist range of motion. Key tests and maneuvers specifically evaluating the scapholunate and lunotriquetral ligaments are as follows:

- **Grip strength and pain:** Diminished grip strength correlates with wrist pathology.
- **The presence of pain at the central aspect of the wrist with attempted grip has also been associated with scapholunate ligament pathology.**
- **Deep palpation of scapholunate interval:** Point tenderness indicates SLIL injury, scaphoid injury, or ganglion cyst.
- **Watson’s scaphoid shift test:** Pain with or without a clunk or catch sensation is highly suggestive of scapholunate instability.
- **Scaphoid ballottement test:** Pain and increased anteroposterior laxity are highly suggestive of scapholunate instability.
- **Deep palpation of lunotriquetral interval:** Point tenderness indicates LTIL injury or triangular fibrocartilage complex (TFCC) pathology.
- **Ulnar wrist loading:** A painful snap indicates lunotriquetral instability, midcarpal instability, or TFCC complex pathology. This maneuver will also be painful if ulnar impaction is present.
- **Triquetrum ballottement test:** Pain and increased anteroposterior laxity are highly suggestive of lunotriquetral instability.
- “**Ulnar sniffbox**” tenderness: Pain with or without crepitus indicates lunotriquetral instability, TFCC complex pathology, or triquetrohamate pathology.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

Initial imaging of the wrist should always include AP and lateral radiographs, combined with special views depending on the suspected pathology. If scapholunate pathology is suspected, a bilateral pronated grip anteroposterior (Mayo Clinic) view should be obtained for comparison to the contralateral side. Abnormal findings in static scapholunate instability include:

- **AP view:** increased scapholunate interval (3 mm or more; comparison to contralateral wrist), scaphoid cortical “ring sign,” and triangular appearance of lunate.
- **Lateral view:** flexion of scaphoid and dorsiflexion of lunate, as determined by increased scapholunate angle (more than 60 degrees) and increased lunocapitate angle (over 10 degrees) with dorsal translation of capitate.
- **Radiographic findings in patients with lunotriquetral tears are often normal. Abnormal findings in static lunotriquetral instability include:**
  - **AP view:** proximal translation of triquetrum or lunotriquetral overlap without gapping, and interruption of Gilula’s arc.
  - **Lateral view:** flexion of scaphoid and lunate, as determined by normal or decreased scapholunate angle (less than 45 degrees), increased lunocapitate angle (more than 10 degrees) with volar translation of capitate, and a negative lunotriquetral angle.
  - **Provocative views (radial-ulnar deviation, flexion-extension views) or videofluoroscopy may demonstrate asynchronous scapholunate motion (dynamic scapholunate instability) in cases with suspected SLIL injury and normal standard views. Increased, synchronous mobility of the scapholunate complex with diminished motion of the triquetrum indicate an LTIL injury.**
  - **Wrist arthrography has a sensitivity of only 60% compared to arthroscopy and cannot determine the extent of any tear present.**26
  - **MRI (with or without arthrography) has limited value in evaluating interosseous ligament injuries. Reported sensitivity rates for SLIL injuries range from 40% to 65% compared to arthroscopy.17 MRI is even less reliable in diagnosing LTIL injuries.**
  - **Arthroscopy (radiocarpal, midcarpal with probing) remains the gold standard in evaluation of SLIL and LTIL injuries.**

**DIFFERENTIAL DIAGNOSIS**

- **Differential diagnosis of scapholunate injuries and radial-sided wrist pain**21
  - Scaphoid fracture or nonunion
  - Scaphotrapezial arthritis
  - Radiocarpal arthritis
  - De Quervain’s tenosynovitis
  - Dorsal ganglion cyst
  - Dorsal wrist impaction syndrome
  - Perilunate instability
  - Isolated DRC ligament tear
- **Differential diagnosis of lunotriquetral injuries and ulnar-sided wrist pain**18
  - TFCC injury
  - Distal radioulnar joint (DRUJ) instability or arthritis
  - Ulnar impaction syndrome or chondromalacia
  - Ulnar styloid impingement syndrome
  - Extensor carpi ulnaris (ECU) tendon subluxation
  - Psotriquetral arthritis
  - Triquetrohamate instability
NONOPERATIVE MANAGEMENT

- SLIL and lunotriquetral injuries associated with dynamic instability may respond to initial nonoperative treatment for 6 to 12 weeks.
- Conservative management typically includes a combination of the following:
  - Splinting
  - Nonsteroidal anti-inflammatories
  - Intra-articular (radiocarpal) corticosteroid injections
  - Occupational therapy and work restrictions
  - Re-education of wrist proprioception with flexor carpi radialis strengthening

SURGICAL MANAGEMENT

- The selection of surgical treatment for SLIL and LTIL injuries is based on the severity of symptoms, the degree of instability (dynamic or static), chronicity (acute, subacute, or chronic), arthroscopic findings (Geissler grade; see TECH FIG 1), and reparability of the ligament.
- Dynamic instability (based on positive physical findings with provocative maneuvers, abnormal stress radiographs, arthroscopic findings) that has failed to respond to nonoperative treatment may be treated arthroscopically.
  - Arthroscopic options include simple débridement, débridement with thermal shrinkage, and débridement (with or without shrinkage) with percutaneous pinning.
  - Static instability and severe dynamic instability are indications for open surgery.
  - Surgical options include open repair or augmentation (especially of acute or subacute injuries), capsulodesis, and tenodesis.
- Patients developing carpal collapse with arthritic changes require salvage procedures such as radial styloidectomy, proximal row carpectomy, and limited wrist fusions (eg, STT, scaphocapitate, scaphoidectomy plus four-corner fusion, reduction-association scapholunate [RASL] procedure, lunotriquetral fusion).
- The focus of this chapter is on arthroscopic procedures described for management of dynamic scapholunate or lunotriquetral instability. Newer arthroscopic alternatives advocated for management of more advanced pathology are also described.

Arthroscopic Procedures

- Arthroscopic débridement of SLIL and LTIL injuries
  - Indications: Predynamic or dynamic instability; arthroscopic findings of a partial ligament tear with an unstable tissue flap (Geissler grade II); with or without synovitis
  - The ideal patient for this technique is one with mechanical symptoms (pain with crepitation or clicking) attributable to impingement of unstable tissue flaps and resulting synovitis.
- Arthroscopic débridement and thermal shrinkage of SLIL and LTIL disruptions
  - Indications: Predynamic or dynamic instability; arthroscopic finding of a partial ligament tear (Geissler grade I or II). The dorsal segment of the SLIL should be intact for this procedure.
  - This technique provides an option for the management of lax, redundant ligaments with no frank tear (Geissler grade I) where simple débridement is not an option.
  - Thermal shrinkage is performed in an attempt to increase stability and improve long-term outcome compared to simple débridement.
  - Radiofrequency probes use a high-frequency alternating current to generate heat. This leads to denaturation (uncoiling) of the collagen triple helix with reduction in overall ligament length.
  - Use of this device is contraindicated in patients with pacemakers or other implantable electronic devices.
- Arthroscopic débridement and percutaneous pinning of SLIL and LTIL disruptions
  - Indications: Acute or subacute dynamic instability (Geissler grades II and III)
  - This technique aims to induce the formation of fibrous union between the two involved carpal bones.
- Arthroscopic radial styloidectomy
  - Indications: Early (stage I) scapholunate advanced collapse (SLAC) wrist (ie, radial styloid–scaphoid impingement or arthritis) with focal and reproducible clinical findings of radial styloid pain exacerbated by wrist flexion and radial deviation
  - This procedure may provide significant pain relief until a salvage procedure (proximal row carpectomy, scaphoid excision, four-corner fusion) becomes necessary.
- Arthroscopic RASL procedure (see Chap. HA-46) and lunotriquetral fusion
  - Indications: Static instability (Geissler grade IV); lunotriquetral arthritis
  - Early (stage I) SLAC wrist is not a contraindication.
  - The RASL procedure aims to achieve fibrous union while maintaining mild rotation at the scapholunate joint, thus approximating normal wrist kinematics. On the other hand, bony fusion is the goal in the lunotriquetral joint.

Preoperative Planning

- A careful review of the patient’s history, physical findings, as well as static and stress radiographs may provide the surgeon with a reasonable impression of what will be required.
- In most cases, however, a decision on the type of procedure to be performed is made intraoperatively based on the arthroscopic findings and associated pathology.
- Consideration must therefore be given to have the following available: radiofrequency probes, mini C-arm, drills, Kirschner wires of various widths, and headless compression screws.

Positioning

- The patient is placed in the supine position with the extremity on a hand table.
- Any possible donor site for ligament reconstruction or augmentation should also be prepared and draped in a sterile fashion.
- The extremity is placed in a tower distraction device with 10 to 12 lb (5 to 6 kg) of distraction and 12 to 15 degrees of wrist flexion (FIG 1).
- The arthroscope monitor is placed on the opposite side of the hand table from the surgeon.
If percutaneous pinning or use of other implants is anticipated, a small fluoroscopy unit is placed adjacent to the head of the operating table.

**Approach**

- Arthroscopic evaluation and management of scapholunate and lunotriquetral injuries can typically be performed through standard dorsal wrist portals (3–4, 4–5, 6R, midcarpal).
- The additional use of a radial volar portal through the flexor carpi radialis (FCR) sheath has been advocated for better visualization of the volar portions of the SLIL and LTIL, as well as the DRC and DIC ligaments.\(^1\,\!^{19}\)

**Fig 1** A. Positioning for arthroscopy of the wrist. B. The monitor should be visible to the surgeon. If use of fluoroscopy is anticipated, the C-arm is placed adjacent to the head of the operating table.

**Arthroscopic Evaluation**

- An 18-gauge needle is used to distend the radiocarpal joint with 7 to 10 mL of normal saline.
- A 2.7-mm, 30-degree arthroscope is preferred for wrist arthroscopy.
- Typical working portals include the 3–4, 4–5, 6R, and midcarpal portals. Outflow is established through the 6U or 6R portal.
- The entire radiocarpal joint is evaluated in a systematic manner, usually from radial to ulnar.
- The SLIL is best visualized through the 3–4 portal with probe insertion through the 4–5 or 6R portal. The 4–5 portal is used for instrumentation.
- Occasionally the avulsed portion of the SLIL may make visualization through the 3–4 portal difficult. In this situation, the arthroscope is transferred to the 6R portal and directed radially.
- The proximal portion of the SLIL is easily visualized by following the radiocapitate ligament (ligament of...
Testut) to its insertion. The volar radioscapholunate and long radiolunate ligaments (wider) are visualized radially, and the short radiolunate is located ulnar to the ligament of Testut.

- The LTIL is best visualized through the 4–5 or 6R portal, with use of the 3–4 and 6R for instrumentation.
- Both ligaments should be evaluated in their entirety (dorsal, proximal, and volar portions).
  - If visualization of the volar portions of the SLIL and LTIL is inadequate, an additional volar portal through the FCR sheath may be used, but this has rarely been necessary in our experience.
- In patients with gross scapholunate instability, the arthroscope is finally turned toward the dorsum of the scaphoid and lunate to identify possible avulsion of the DIC or DRC ligament.

ARTHROSCOPIC DÉBRIDEMENT

- A thorough diagnostic arthroscopy (radiocarpal plus midcarpal) is performed to verify the diagnosis and rule out instability or other associated pathology.
- The inflamed synovium is excised with a 2.5- or 2.7-mm full-radius resector.
- Any unstable tissue flaps are resected with a suction punch or synovial resector.
- Redundant tissue is then resected to a stable rim with the synovial resector or bipolar radiofrequency probe.

ARTHROSCOPIC DÉBRIDEMENT AND THERMAL SHRINKAGE

- Diagnostic arthroscopy is performed as previously described.
- Geissler grade II tears are débrided with a synovial resector to a stable rim (TECH FIG 2A). Thermal shrinkage of the intact portion of the ligament is then performed with a 2.3-mm bipolar radiofrequency probe.
- Attenuated ligaments (Geissler grade I) are treated with thermal shrinkage alone.
- Thermal shrinkage is performed by applying the radiofrequency probe in a paintbrush fashion (2.3-mm radiofrequency probe [Mitek VAPR®, Westwood, MA]) (TECH FIG 2B). The goal is to evenly distribute the thermal energy throughout the ligament.

Techniques

- A probe is then inserted through the 4–5 or 6R portal to reassess stability from both the radiocarpal and midcarpal joint.
- Débride-ment should generally be limited to the proximal membranous portion of the SLIL or LTIL.
- Unwarranted débride-ment of the dorsal (SLIL) or volar (LTIL) portions of the ligamentous complex may lead to further instability.
- Carpal stability should be assessed both before and after débride-ment.
ARThROSCOPIC DÉBRIDEMENT AND PERCUTANEOUS PINNING

- Diagnostic arthroscopy is performed as previously described.
- All residual tissue of the torn ligament (SLIL or LTIL) is débrided with a 2.5- or 2.7-mm full-radius resector.
- The cartilage of the apposing surfaces of the involved carpal bones is then débrided to bleeding bone with a 2.5- or 2.7-mm aggressive full-radius resector and a 2.9-mm barrel abrader (TECH FIG 3A).
- The extremity is then removed from the distraction tower.
- If necessary, congruity of the joint is improved by external (pressure on the distal pole of scaphoid) or internal maneuvers (percutaneous Kirschner wires used as joysticks).

- The joint is stabilized by percutaneously inserting three or four 0.045-inch (1.1-mm) Kirschner wires under fluoroscopic control.
- The scapholunate joint is typically stabilized with two Kirschner wires across the scapholunate joint (radial to ulnar) followed by one or two Kirschner wires across the scaphocapitate joint (TECH FIG 3B).
- The lunotriquetral joint is similarly stabilized with two Kirschner wires across the lunotriquetral joint (ulnar to radial) followed by one or two Kirschner wires across the lunocapitate joint.
- The pins are then cut subcutaneously or bent outside the skin per surgeon preference.

ARThROSCOPIC RADIAL STYLOIDECTOMY

- Diagnostic arthroscopy is initially performed to delineate the chondral lesions and accurately stage the SLAC wrist.
- The arthroscope is placed in the 3–4 or 4–5 portal.
- Excision of the radial styloid is performed through the 1–2 (or 3–4) portal with a side-cutting 3.5-mm sheathed burr.
- Arthroscopic evaluation of articular cartilage and intra-operative radiographs should be used to determine the extent of resection.
- The origin of the radioscapophocapitate ligament is visualized and preserved during bone resection.
- Although the tendency is to overestimate the amount of bone resected, excision of more than 4 mm may jeopardize the ligament and result in ulnar carpal dislocation.

ARThROSCOPIC RASL PROCEDURE AND LUNOTRIQUETRAL FUSION

- Diagnostic arthroscopy with evaluation of chondral lesions is performed as described previously.
- The apposing surfaces of the joint to be fused are débrided to bleeding bone with a 2.5- or 2.7-mm aggressive full-radius resector and a 2.9-mm barrel abrader.
- Complete decortication is verified from both the radiocarpal and midcarpal joints.
- In the case of the RASL procedure, a side-cutting 3.5-mm sheathed burr is then used to perform an arthroscopic radial styloidectomy through the 1–2 (or 3–4) portal as described previously.
- Kirschner wires (0.062 inch or 1.6 mm) are then inserted percutaneously from the dorsum into the involved carpal bones (distal scaphoid-lunate or lunate-triquetrum). Positioning of the wires should be slightly eccentric to allow for subsequent placement of the screw centrally. The Kirschner wires are used as joysticks to reduce the joint under fluoroscopic (with or without arthroscopic) control.
- It is essential to verify adequate reduction of the capitotrapezial joint on the lateral view.
- A Köcher clamp may be placed across the Kirschner wires to maintain reduction.
■ An additional 0.045-inch (1.1-mm) Kirschner wire may be inserted through the dorsal rim of the distal radius into the lunate for provisional stabilization of the lunate.

■ A 0.035-inch (0.9-mm) guidewire is then placed across the joint (scapholunate or lunotriquetral) under fluoroscopic control.

■ In the case of the RASL procedure, the guidewire should be placed through the 1–2 portal, across the scaphoid waist toward the proximal-ulnar corner of the lunate, thus approximating the normal axis of rotation of the scapholunate joint (TECH FIG 4).

■ A cannulated headless compression screw is then placed across the joint. Length measurement should be reduced by about 4 mm to accommodate for joint compression and to ensure that the screw is completely countersunk into bone.

■ After satisfactory reduction and fixation are verified, the wrist capsule incision is repaired.

■ In patients with lunotriquetral instability as a result of ulnar impaction syndrome, fusion of the lunotriquetral joint must be combined with an arthroscopic wafer procedure or an open lunotriquetral arthrodesis.

---

**PEARLS AND PITFALLS**

| Diagnosis | ■ Meticulous examination and arthroscopy of the entire wrist are necessary to ensure diagnosis and treatment of concomitant pathology.

| Indications | ■ Arthroscopic débridement with or without thermal shrinkage is not adequate management for static scapholunate or lunotriquetral instability.

| Contraindications | ■ Use of radiofrequency probes for débridement or thermal shrinkage is contraindicated in patients with pacemakers or implantable electronic devices.

| Surgical technique | ■ Wrist arthroscopy for evaluation of SLIL or LTIL tears must include arthroscopy of the midcarpal joint.

■ Carpal stability should be assessed both before and after any débridement of the SLIL or LTIL.

■ Débridement of functionally significant portions of the SLIL (dorsal) or LTIL (volar) should be kept to a minimum to prevent further destabilization.

■ Thermal shrinkage should be performed with specially designed radiofrequency probes. Otherwise, the probe should be applied in a paintbrush fashion for only a few seconds at a time with adequate outflow to avoid reaching ablation temperatures.

| Rehabilitation | ■ If thermal shrinkage is performed, the wrist should be immobilized for at least 2 weeks postoperatively and protected for an additional 4 weeks to allow healing of treated tissue.

---

**POSTOPERATIVE CARE**

■ Patients treated with arthroscopic débridement alone are placed in a cock-up wrist splint postoperatively and instructed to initiate range-of-motion exercises at 48 hours.

■ Patients treated with arthroscopic débridement and thermal shrinkage are placed in a full-time short-arm splint postoperatively. Range-of-motion exercises are initiated at 2 to 4 weeks, with use of a removable cock-up splint between sessions. Strengthening exercises are initiated at 4 to 6 weeks.

■ Patients treated with arthroscopic débridement and percutaneous pinning are placed in a short-arm splint, changed to a short-arm cast after suture removal. The cast is maintained until pin removal, which is performed at 8 to 10 weeks for the scapholunate and at 4 to 6 weeks for the lunotriquetral joint. Range-of-motion exercises are then initiated, with progression to strengthening as tolerated.

■ Patients treated with an arthroscopic RASL procedure are placed in a short-arm splint for only 2 or 3 weeks. Range-of-motion exercises are then initiated, with progression to strengthening as tolerated. Conversely, patients treated with arthroscopic fusion of the lunotriquetral joint are immobilized until radiographic fusion is obtained.

**OUTCOMES**

■ Ruch and Poehling15 reported excellent results with arthroscopic débridement alone in 14 patients with partial SLIL or lunotriquetral tears, or both, and predominantly mechanical symptoms. At a minimum follow-up of 2 years, all patients reported complete relief of their mechanical symptoms, while pain was significantly reduced and grip strength was restored.

■ Weiss et al27 have treated both partial and complete SLIL and lunotriquetral tears with arthroscopic débridement alone
in an attempt to elicit scar formation with some degree of stabili-zation. Excellent pain relief and increased strength were achieved in 17 of 19 patients with partial tears, but only in 17 of 24 patients with complete tears. No radiologic progression was noted at 27 months follow-up.

Darlis et al\(^6\) reported substantial pain relief in 14 of 16 pa-tients with Geissler grade I or II SLIL tears treated with arthro-scopic débridement and thermal shrinkage. Wrist motion was main-tained and there was no radiologic evidence of instability at 19 months of follow-up.

Hirsh et al\(^6\) reported excellent results in 9 of 10 patients with Geissler grade II SLIL tears treated with arthroscopic débridement and thermal shrinkage at 28 months of follow-up.

Whipple\(^28\) reported his results with percutaneous pinning in patients with scapholunate instability. Symptom duration of more than 3 months and a side-to-side gap difference of more than 3 mm were associated with poor outcomes. Pain relief was satisfactory in only 53% of patients with both of these factors.

Darlis et al\(^3\) reported management of chronic (longer than 3 months) dynamic scapholunate instability (Geissler grades III, IV) with arthroscopic débridement and percutaneous pinning in patients who did not wish to undergo open surgery. Results were suboptimal, with significant pain relief and improved grip strength in 6 of 11 patients. At 33 months of follow-up there was no radiologic evidence of progression to static instability, but three patients required additional surgery to address persistent pain.

Clinical experience with the arthroscopic RASL procedure and lunotriquetral fusion is limited. Rosenwasser et al\(^14\) reported excellent results using the open RASL technique in 20 patients with static instability. At 54 months of follow-up, patients had achieved 91% of their normal wrist motion and 87% of contralateral grip strength. The authors noted that the procedure may be performed arthroscopically, but thought that experience with the open technique should first be obtained.

COMPLICATIONS

- Injury to branches of superficial radial sensory nerve (espe-cially with use of 1–2 portal) or dorsal branch of ulnar nerve (6R, 6U portals)
- Injury to radial artery (radial volar portal). This portal should be established through the floor of the FCR sheath.
- Persistent pain or instability
- Need for additional surgery (ligament reconstruction, capsulodesis, tenodesis, proximal row carpectomy, partial or complete wrist fusion)

REFERENCES

DEFINITION

- Scapholunate instability is the most common form of carpal instability.
- Scapholunate interosseous ligament (SLIL) injury can result in a predictable pattern of arthritis over time: scapholunate advanced collapse (SLAC).12
- Acute tears (<6 weeks from injury) versus chronic tears (>6 weeks from injury)
  - Acute tears tend to be amenable to primary ligament repair.
  - Chronic tears tend to require ligament reconstruction procedures.
- Static or dynamic instability
  - Static instability: any or all of the five characteristic changes on standard plain radiographs (see below)
  - Dynamic instability: normal plain radiographs; however, with loaded (grip view) plain radiographs, any or all of the five characteristic changes may become present.10
- Fixed versus reducible deformity
  - Fixed deformity: the static radiographic changes are not passively correctible
  - Reducible deformity: the static radiographic changes are passively correctible
  - This distinction can be determined preoperatively by noting improvement in the static changes on plain radiographs of the wrist in radial deviation compared with AP views of the wrist.

ANATOMY, PATHOGENESIS, AND NATURAL HISTORY

- See Chapter HA-41.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Typical presentation follows a fall on an outstretched hand with acute onset of wrist pain and mild dorsal wrist swelling.
- Key physical examination findings are reviewed in Chapter HA-41.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs may reveal five characteristic findings suggestive of SLIL pathology (FIG 1).
  - Terry Thomas sign: gap between the scaphoid and lunate of more than 3 mm on posteroanterior (PA) radiograph
  - Cortical ring sign: Cortical hyperdensity is seen on PA radiograph as the scaphoid moves into increasing flexion.1
  - Angular changes in the carpal rows
    - Scapholunate angle: Normal is 30 to 60 degrees (mean 46 degrees); with SLIL injury, more than 60 degrees6
    - Capitolumate angle: Normal is −15 to 15 degrees (mean 0 degrees); with SLIL injury, more than 15 degrees
  - Radiolunate angle: Normal is −10 to 10 degrees (mean 0 degrees); with SLIL injury, more than 10 degrees
  - Quadrangular lunate: As the lunate moves into extension it assumes a rectangular appearance on PA radiograph.
  - Disruption of Gilula’s lines: Gentle concentric arcs follow the proximal and midcarpal rows. These lines are disrupted with SLIL tears as the relationship of the proximal row is lost.
- Arthrography: sensitivity 56%, specificity 83%, accuracy 60%13
  - False-positive results have been documented with communication of contrast shown in asymptomatic patients.1
- CT arthrography: sensitivity 86% to 100% (100% sensitive in the detection of dorsal ligament tears), specificity 50% to 79% (79% specific in the detection of dorsal ligament tears), accuracy 78% to 83%7
- MRI: sensitivity 25% to 60%, specificity 77% to 100%, accuracy 64% to 78%8
  - Specifically, palmar tears of the SLIL were identified with a sensitivity of 60% and specificity of 77% in a cadaveric study. However, the more important stabilizing dorsal portion tears were seen in 0 of 9 specimens.7
  - Ultrasound: sensitivity 46%, specificity 100%, accuracy 89%2
- A negative result with various imaging studies does not prove an absence of ligamentous injury. Arthroscopy has become the gold standard for the diagnosis of SLIL tears.

DIFFERENTIAL DIAGNOSIS

- Dynamic SLIL instability or partial SLIL tear
- Radiocarpal arthritis
- Scaphoid fracture
- Keinböck or Preiser disease

FIG 1 • AP and lateral plain radiographs of a patient with scapholunate ligament tear.
NONOPERATIVE MANAGEMENT
- Nonoperative methods are unsuccessful in treating dynamic or static acute scapholunate ligament injuries.
  - 0 of 19 patients with dynamic instability treated with immobilization, nonsteroidal anti-inflammatories, and activity modification had substantial reduction in symptoms even up to 12 weeks into treatment.*

SURGICAL MANAGEMENT
- Indications
  - Wrist pain with an acute tear (<6 weeks)
    - These patients may or may not have static radiographic changes.
  - Should static radiographic changes be present, plain radiographs in radial deviation can show if the radiographic changes are fixed (and therefore are not amenable to soft tissue repairs) or correct in radial deviation (and therefore are amenable to soft tissue repairs).
  - Wrist pain with dynamic instability
  - We advocate diagnostic arthroscopy before open treatment.

Preoperative Planning
- General or regional anesthesia
- Equipment
  - Mini suture anchors (1.8 mm)
  - Kirschner wire driver and smooth wires (0.045 and 0.062 inch)
  - Arthroscopic equipment (see Chap. HA-41)
  - Mini C-arm

Positioning
- The patient is positioned supine with a hand table.
- The bed is turned such that the hand table faces the corner opposite anesthesia.
- Fluoroscopy can then move in and out from the opposite corner perpendicular to the patient.
- An upper arm nonsterile tourniquet should be placed.
- The operative arm is prepared and draped. Slack is left in the armboard portion of the drape to allow the sterile wrist traction tower to slide under the arm above the elbow.
- The operative wrist is suspended in a wrist traction tower.

Approach
- A preoperative examination of both wrists is performed and documented, noting passive range of motion, swelling, and the Watson scaphoid shift test.
- Arthroscopy is recommended before open reconstruction because of the lack of diagnostic accuracy of available imaging modalities.
- Wrist arthroscopy is considered the gold standard for diagnosis of SLIL pathology and can confirm the diagnosis and degree of instability before making a larger skin incision.
- Geissler staging of SLIL tears is covered in Chapter HA-41.

DIRECT SLIL REPAIR
- Specific indications for direct SLIL repair with or without dorsal capsulodesis
  - Geissler III or IV complete SLIL tear
  - Injury less than 6 weeks old
    - It is rare that a repairable ligament is available more than 3 months after injury.
  - Minimal degenerative changes in the radiocarpal and midcarpal joints
  - Static radiographic changes that are not fixed
  - Adequate SLIL tissue
- Make a standard longitudinal dorsal incision just ulnar to the tubercle of Lister and dissect to the extensor retinaculum.
- Raise flaps at the level of the extensor retinaculum, exposing the retinacular edges proximally and distally.
  - Superficial radial and ulnar dorsal cutaneous nerve branches will be within these flaps.
- Incise the extensor retinaculum over the third extensor compartment and transpose the extensor pollicis longus (EPL) tendon into the radial subcutaneous space.
- Arthroscopic equipment (see Chap. HA-41)
- Mini C-arm

Expose the dorsal capsule and dorsal extrinsic radiocarpal ligaments (dorsal radiocarpal [DRC] and dorsal intercarpal [DIC] ligaments).
- Incise the dorsal capsule, leaving a 1- to 1.5-cm ulnar-based flap (TECH FIG 1A).
  - Leaving the capsule attached ulnarily provides a capsular flap available for capsulodesis or augmentation of a repair if desired.
- This flap of tissue will parallel the DIC and include the capsule and portions of the DIC and DRC.
- With the scaphoid, SLIL, and lunate exposed, note any arthritic changes, the location of the SLIL disruption (typically it avulses off the scaphoid) (TECH FIG 1B,C), and any injury to the DIC ligament.
- In cases of high energy the DIC may avulse off its scaphoid and lunate attachment.
- Place joystick Kirschner wires (0.062 inch) into the scaphoid and the lunate.
- The SLIL is probed in the radiocarpal and midcarpal joints.
  - A 1-mm arthroscopic probe passable in the scapholunate interval and rotated 360 degrees is indicative of a grade III Geissler lesion.
  - A “drive-through” sign with a 2.7-mm arthroscope is indicative of a grade IV Geissler lesion.
- Midcarpal arthroscopy most effectively reveals the degree of instability.

TECHNIQUES

DIAGNOSTIC WRIST ARTHROSCOPY
- See Chapter HA-41.
- The 3-4 portal is used for viewing.
- The 6U portal is used for outflow (typically an 18-gauge needle with sterile IV tubing).
- The 4-5 is used for placement of instruments.

DIRECT SLIL REPAIR
- Specific indications for direct SLIL repair with or without dorsal capsulodesis
  - Geissler III or IV complete SLIL tear
  - Injury less than 6 weeks old
    - It is rare that a repairable ligament is available more than 3 months after injury.
  - Minimal degenerative changes in the radiocarpal and midcarpal joints
  - Static radiographic changes that are not fixed
  - Adequate SLIL tissue
- Make a standard longitudinal dorsal incision just ulnar to the tubercle of Lister and dissect to the extensor retinaculum.
- Raise flaps at the level of the extensor retinaculum, exposing the retinacular edges proximally and distally.
  - Superficial radial and ulnar dorsal cutaneous nerve branches will be within these flaps.
- Incise the extensor retinaculum over the third extensor compartment and transpose the extensor pollicis longus (EPL) tendon into the radial subcutaneous space.
- Arthroscopic equipment (see Chap. HA-41)
- Mini C-arm

Expose the dorsal capsule and dorsal extrinsic radiocarpal ligaments (dorsal radiocarpal [DRC] and dorsal intercarpal [DIC] ligaments).
- Incise the dorsal capsule, leaving a 1- to 1.5-cm ulnar-based flap (TECH FIG 1A).
  - Leaving the capsule attached ulnarily provides a capsular flap available for capsulodesis or augmentation of a repair if desired.
- This flap of tissue will parallel the DIC and include the capsule and portions of the DIC and DRC.
- With the scaphoid, SLIL, and lunate exposed, note any arthritic changes, the location of the SLIL disruption (typically it avulses off the scaphoid) (TECH FIG 1B,C), and any injury to the DIC ligament.
- In cases of high energy the DIC may avulse off its scaphoid and lunate attachment.
- Place joystick Kirschner wires (0.062 inch) into the scaphoid and the lunate.
TECH FIG 1 • A. Intraoperative photo demonstrating the exposure and location of the dorsal capsular ulnar-based flap. The DIC parallels the more distal transverse limb of the flap. S, scaphoid; L, lunate; T, triquetrum. B. Intraoperative photo demonstrating the flexed scaphoid (S), the capitate (C), and the extended lunate (L). A complete disruption of the scapholunate interosseous ligament (SLIL) is noted. The arrow points at the ulnar-based capsular flap. C. Intraoperative photo showing the scaphoid on the left and the SLIL still attached to the lunate on the right (held by forceps). The capitate head is seen distal to the lunate at the top of the photo. D. Intraoperative photo after suture anchor placement into the scaphoid at the dorsal SLIL footprint on the left, then passed through the SLIL shown on the right. The joystick Kirschner wires are placed into the scaphoid and the lunate in such a manner that when they are brought together, the dorsal intercalated segment instability (DISI) deformity will be corrected and the joint reduced. E. Intraoperative photo after reduction of the joint and DISI deformity using the joystick Kirschner wires and suture repair of the avulsed SLIL. The Kirschner wires in the scaphoid and in the lunate have been brought together from their divergent positions and are now in the same plane, correcting the DISI deformity. The two Kirschner wires have been placed from radial to ulnar (seen on the left of the image), passing through the scapholunate interval and scaphocapitate interval. F,G. AP and lateral intraoperative fluoroscopic images demonstrating Kirschner wire placement across the scaphocapitate joint and the reduced scapholunate joint. Suture anchors can be seen in the scaphoid at the dorsal SLIL footprint. This example shows a third, more distal suture anchor at the scaphoid that was used for dorsal capsule augmentation.
TECHNIQUES

■ Place these wires parallel to the scapholunate joint about 5 mm from the articular surface.
■ The scaphoid joystick should angle proximally and the lunate joystick should angle distally (TECH FIG 1D).
■ The Kirschner wire joysticks are brought together, taking the scaphoid out of flexion and the lunate out of extension to correct any dorsal intercalated segmental instability deformity and reduce the joint.
■ Preliminarily reduce the scapholunate joint and identify the anatomic insertion site for the SLIL.
■ Roughen the SLIL footprint to bleeding bone on the dorsal ulnar portion of the scaphoid and insert one or more mini suture anchors (2.0 or 2.5 mm).
■ Pass the sutures from the suture anchor through the SLIL stump but do not tie them (TECH FIG 1D).
■ With the joint reduced via the joysticks, drive two 0.045-inch smooth Kirschner wires from the scaphoid into the lunate across the reduced scapholunate joint and drive one or two 0.045-inch Kirschner wires through the waist of the scaphoid into the capitate (TECH FIG 1E–G).
■ Secure the SLIL to the prepared site by tying the suture anchor sutures.
■ Remove the joystick Kirschner wires and cut the remainder of the Kirschner wires below the skin.
■ Suture anchors are placed at the DIC footprint on the dorsal more distal scaphoid should it be avulsed and need repair or should capsular flap augmentation be desired (see Direct SLIL Repair with Dorsal Capsulodesis).
■ Close the capsule with 3–0 absorbable suture.
■ Transpose the EPL tendon subcutaneously and repair the extensor retinaculum with 3–0 absorbable suture.

DIRECT SLIL REPAIR WITH DORSAL CAPSULODESIS

■ Indications
  ■ Tenuous SLIL repair
  ■ Chronic scapholunate dissociation (>6 weeks) without arthritis
    ▪ The deformity must be reducible and not fixed.
  ■ Should capsulodesis be required for augmentation, perform the SLIL repair as described above, making the same ulnar-based dorsal capsular incision.
  ■ After the SLIL is repaired, swing the ulnarly based capsular flap over the scapholunate interval and plan the location for its attachment to the scaphoid waist.
  ■ Plan to secure the flap under tension to further stabilize the scapholunate joint.
  ■ Place one or two mini suture anchors (1.8 or 2.0 mm) into the scaphoid at the determined location and another mini suture anchor dorsal-central into the lunate.
  ■ With the capsular flap pulled taut, pass the scaphoid suture anchor sutures through the flap. Then pass the lunate sutures through the central aspect of the flap, estimating suture location to maximize stabilization of the scapholunate joint.
  ■ Once all sutures from the scaphoid and the lunate are placed through the capsular flap, tie them down (TECH FIG 2).

PEARLS AND PITFALLS

| Fluoroscopy | By moving the fluoroscopy unit perpendicular to the patient with the C-arm parallel to the floor and locking all the joints but the most distal fulcrum, the amount of “fighting” with the fluoroscopy unit is minimized. |
| Buried Kirschner wires | Buried Kirschner wires require removal in the operating room but minimize the risk of pin tract infection. |
| Posterior interosseous nerve neurectomy | Consider performing a posterior interosseous nerve neurectomy during the procedure. Identify the nerve on the floor of the fourth extensor compartment, cauterize it and its accompanying vessel, then resect a segment. |
| Joystick placement during reduction of the scapholunate joint | Place the scaphoid Kirschner wire distal in the scaphoid, angling proximally. Remember the scaphoid is flexed and most of the cartilage you will see initially is the radiocarpal articular portion of the scaphoid. Similarly, place the lunate Kirschner wire proximally, angling in a distal direction to correct its extended position. |
POSTOPERATIVE CARE
- The wrist is immobilized in a short-arm thumb spica splint immediately after surgery.
- Sutures are removed at 2 weeks and the wrist is placed into a short-arm thumb spica cast for 8 weeks.
- Radiographs are obtained at 2 and 4 weeks to evaluate reduction and any pin migration.
- Pins are removed at 8 weeks and the wrist is placed back into a short-arm thumb spica splint.
- Gentle active range-of-motion exercises are allowed at 8 weeks, out of the splint for exercises only.
- Immobilization is discontinued at 12 weeks.
- Full activities are allowed at 4 to 6 months.
- Forced hyperextension (push-ups) and axial loading are especially restricted during the 4- to 6-month postoperative period.

OUTCOMES
- Results following direct SLIL repair with capsulodesis are highly variable.
- By not crossing the radiocarpal joint with the capsulodesis, theoretically wrist motion will be maximized.
- Szabo et al. showed mean loss of wrist flexion of 10 degrees, extension of 15 degrees, radial deviation of 20 degrees, and ulnar deviation of 11 degrees at 2 years of follow-up for chronic (>6 weeks) SLIL tears treated with DIC capsulodesis.
- Grip strength was unchanged from the preoperative assessment (mean 41).
- Results of the procedure typically do not hold over time radiographically.
- Minimum 5-year follow-up for chronic SLIL tears treated with DIC capsulodesis showed:
  - Immediate postoperative scapholunate angle of 56 degrees at 5 years increased to 62 degrees
  - Immediate postoperative scapholunate gap of 2.6 mm at 5 years increased to 3.5 mm
  - Also, 50% of wrists show arthritic changes at 5 years.
- Radiographic changes have not correlated with clinical results over time.
- Wrist flexion decreased 19 degrees at 5-year follow-up compared with preoperative values.
- Extension and radial and ulnar deviation remained unchanged at 5 years from the immediate postoperative values shown above.
- Grip strength remained unchanged at 5 years (mean 43).
- Outcome instrument scores at 5 years (Mayo Wrist Score):
  - 38% excellent, 19% good, 31% fair, 12% poor outcomes
- No correlation between subjective pain scores and radiographic changes has been shown at 5 years.

COMPlications
- Pin tract infections (this risk is minimized with buried pins)
- Superficial radial nerve injury
- The surgeon should keep skin flaps thick when dissecting on top of the extensor retinaculum (this keeps the superficial radial nerve branches within the flaps).
- The surgeon should make a small stab incision to bluntly dissect down to bone to minimize risk of nerve injury during pin placement.
- Loss of scapholunate reduction
- Arthritic changes in the radiocarpal and midcarpal joints

REFERENCES
DEFINITION
- Scapholunate dissociation (SLD) is the rupture of the anatomic linkage between the scaphoid and lunate and its subsequent progressive dysfunction, with or without carpal malalignment.
- Classical radiographic signs occur only when there is permanent carpal malalignment. This is preceded by complete scapholunate disruption together with failure of the secondary scaphoid stabilizers, namely the scaphotrapezial-trapezoid ligament (STT), the scaphocapitate (SC) ligament, and the radioscapohamate (RSH) ligament.
- However, in many cases, only partial tears or ligament sprains occur and do not produce positive radiologic signs. These injuries are often seen only arthroscopically.
- Dorsal capsulodesis of the radioscapohamate joint was first described by Blatt.2 Now it is one of the most commonly used techniques in the treatment of carpal instability. This procedure involves the creation of a dorsal capsular flap.

ANATOMY
- Scapholunate ligaments are divided into three fibrous structures:
  - Dorsal ligament
  - Volar ligament
  - Thin proximal membrane
- Anatomically, the dorsal scapholunate ligament is the thickest and shortest of the fibrous structures, measuring 2 to 3 mm thick and 2 to 5 mm long. Biomechanically, it is the strongest and most resistant to failure under load (FIG 1A).1 The radioscapohamate (Testut) ligament is only a path for vascularization and innervation of the scaphoid and lunate.
- Scaphoid position and relationship with lunate and distal carpal row is maintained by the scapholunate ligaments and by the secondary stabilizers (STT, SC, and RSH ligaments), which prevent excessive scaphoid flexion. These are called secondary stabilizers (FIG 1B).
- The flexor carpi radialis tendon is closely related to the scapholunate joint and acts as a crucial dynamic stabilizer of the scaphoid, preventing it from going into excessive flexion and pronation during a firm grip of an object (FIG 1C).

PATHOGENESIS
- Injury to the scapholunate ligaments occurs when the wrist is hyperextended, ulnarly deviated, and supinated during a fall on an outstretched hand. Because of the osseous configuration and disposition of the bones of the proximal carpal row, when the hand hits the floor, the tubercle of the scaphoid is pushed dorsally and extended. The lunate is held in position by the volar radiolunate (RL) ligaments and resists the tendency to extension transmitted by the scaphoid. The impact of the hand on the floor also pushes the pisiform against the triquetrum and because of the configuration of the joint between the triquetrum and the hamate, the former turns into flexion. If forces exceed the ligaments’ resistance, they will rupture.
- The sequence of failure of the ligaments is from palmar to dorsal. The first to tear is the volar scapholunate ligament, the weaker of the two scapholunate ligaments, followed by the dorsal scapholunate ligament.3
- The participation of the dorsal intercarpal ligament (DICL) in scapholunate instability has been recently supported by the studies of Mitsuyasu et al.8

NATURAL HISTORY
- Most SLDs present as the initial stage of a progressive carpal destabilization. The mechanism of injury produces a spectrum of injuries, ranging from mild scapholunate sprains to complete perilunar dislocations, all being different stages of the same progressive perilunar destabilization process as described by Mayfield et al.9
- If only the palmar scapholunate ligament and the proximal membrane are disrupted, minor kinematic alterations result in predynamic instability. There is no gross carpal malalignment but because there is an increased motion between the scaphoid and lunate causing shear stress, these injuries may be sufficient to promote painful synovial inflammation.
- Complete disruption of the scapholunate ligament complex leads to substantial alteration in kinematic and force transmission parameters (demonstrated in cadaver specimens), but not necessarily static carpal malalignment.8,13 This results in a dynamic instability. The scaphoid is unconstrained at the proximal end, resulting in increased radiolunate motion and correspondingly decreased radioscapoid motion. This is accentuated in a loaded wrist.
- When the secondary stabilizers start to attenuate after repeated use of the wrist, carpal malalignment develops, eventually resulting in static instability. Initially the scaphoid is still reducible, but over time it becomes permanently flexed and pronated (see “Imaging and Other Diagnostic Studies”).
- If the alteration in the motion of the scaphoid persists, the cartilage degenerates and arthrosis develops. This pattern of degeneration is known as scapholunate advanced collapse (SLAC).
- Once arthrosis is present, surgical techniques directed at replacing or reconstructing the injured ligaments are no longer options.
- SLD is a progressive entity. Therefore, reconstruction is advocated as soon as it is diagnosed.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Almost always, patients present after a fall on their outstretched hand. The patient complains of dorsal hand and wrist pain when loading the affected wrist, such as when standing up from a chair.
Predynamic and dynamic stages of SLD are often missed or overlooked. The injury usually is the result of isolated trauma, which the patient does not clearly remember, or is masked by other more severe or obvious injuries (eg, fractured scaphoid and distal radius). A high index of suspicion is required.

- Weakness of grip strength, occasional swelling over the dorsoradial wrist, point tenderness over the scapholunate interval (more pronounced with gripping), and radial-sided wrist pain after excessive or heavy use are common but subtle physical examination findings.
  - The examiner should palpate the scapholunate interval dorsally (1 cm distal to the tubercle of Lister) with the wrist in 30 to 50 degrees of flexion.
  - On palpation of the anatomic snuffbox and palmar scaphoid tubercle, tenderness may also be present, suggesting ligament involvement, synovitis, or an occult ganglion.
  - Provocative tests such as the Watson scaphoid shift test and resisted finger extension test reinforce the possibility of the diagnosis.
  - Watson scaphoid shift test: The scaphoid flexes as the wrist goes from ulnar to radial deviation. The examiner’s thumb prevents the scaphoid from flexing and if the scapholunate ligament is torn or incompetent, the proximal pole subluxates dorsally out of the scaphoid fossa, causing pain. When the thumb pressure is released, there may be a snap, signifying spontaneous reduction of the scaphoid back into the scaphoid fossa. This test is not highly specific and may signify synovitis, an occult ganglia, or radioscaphoid impingement.
  - Sharp pain on the resisted finger extension test has low specificity but high sensitivity.

### IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiographs
  - Posteroanterior (PA) view
    - Elbow flexed at 90 degrees, neutral prono-supination, and the middle finger aligned with the forearm axis. The palm of the hand is in full contact on the film case.
    - Scapholunate gap greater than 3 mm or wider than the contralateral normal side and a cortical “ring” sign suggest static scapholunate dissociation.
    - Decreased space between the radius and the scaphoid signifies cartilage loss and arthrosis.
  - Anteroposterior (AP) view
    - Forearm is in maximal supination.
    - This projection puts the scapholunate interval aligned with the beam of the ray.
  - Lateral view
    - Elbow at 90 degrees of flexion, middle finger aligned with the forearm, and wrist at 0 degrees of extension or flexion
    - This projection allows measurement of the scapholunate angle. An angle greater than 60 degrees indicates disruption of the scapholunate ligaments and often corresponds with widening on the PA and AP views.
    - Clenched-fist AP view demonstrates a widened scapholunate gap compared to the normal side (FIG 2A).
    - Cineradiography reveals abnormal movements between the scaphoid and lunate and an increase in the scapholunate gap as the wrist moves from radial to ulnar deviation.

---

**FIG 1**

- **A.** The elements that maintain the scaphoid in its normal position.
- **B.** Volar view of secondary stabilizers.
- **C.** The dynamic stabilizer of the scaphoid.
**DIFFERENTIAL DIAGNOSIS**
- Occult ganglia
- Synovitis
- Scaphoid fracture, nonunion, and avascular necrosis
- Radiocarpal arthrosis
- Radioscaphoid impingement

**NONOPERATIVE MANAGEMENT**
- Initial conservative management aims at resting the injured limb and decreasing edema. Adequate immobilization with casting or splinting is advocated.
  - This immobilization is frequently therapeutic for patients with predynamic SLD.
  - Elevation of the limb and active finger motion minimize edema.
  - Anti-inflammatory medications can be given for pain relief.
- Physiotherapy may have a role if a Geissler grade 1 is diagnosed by arthroscopy. As the ligaments have not lost their integrity, a period of short immobilization (2 weeks), followed by proprioception re-education of the flexor carpi radialis (FCR), as dynamic stabilizer of the scaphoid, is suggested.
- Nonoperative treatment is seldom indicated when a significant disruption is diagnosed.

**SURGICAL MANAGEMENT**
- Capsulodesis is part of the surgical armamentarium for the treatment of SLD. It is indicated for predynamic SLD, resulting from an isolated partial tear of the scapholunate ligament, and for dynamic SLD when the following criteria are fulfilled:
  - Complete disruption of all scapholunate components (palmar and dorsal)
  - Technically repairable dorsal ligament that has good healing potential
  - Intact secondary stabilizers
  - No cartilage degeneration
- Capsulodesis is not indicated when static SLD is present.

**Arthrologic (Geissler) Grading of Interosseous Ligament Tears**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Attenuation or hemorrhage of interosseous ligament as seen from the radiocarpal joint. No incongruency of carpal alignment in midcarpal space.</td>
</tr>
<tr>
<td>2</td>
<td>Attenuation or hemorrhage of interosseous ligament as seen from the radiocarpal joint. Incongruency or stepoff as seen from midcarpal space. Slight gap (less than width of 1-mm probe) between the carpal bones.</td>
</tr>
<tr>
<td>3</td>
<td>Incongruency or stepoff as seen from both radiocarpal and midcarpal spaces. The 1-mm probe is able to pass through the gap between the carpal bones.</td>
</tr>
<tr>
<td>4</td>
<td>Incongruency or stepoff as seen from both radiocarpal and midcarpal spaces. Gross instability with manipulation noted. A 2.7-mm probe is able to pass through the gap between the carpal bones.</td>
</tr>
</tbody>
</table>

See also Chap. HA-41.
Capsulodesis is used either as an isolated procedure together with Kirschner wire stabilization of the scapholunate joint in predynamic cases, or in combination to augment a direct repair of the dorsal scapholunate ligament in dynamic cases. Due to its structure and position within the wrist, the scaphoid has an inherent tendency to flex and pronate, especially when the wrist is in flexion and radial deviation. The capsular flap created during dorsal capsulodesis acts as a checkrein to tether the scaphoid, preventing it from going into excessive flexion and pronation.

Preoperative Planning
- All preoperative radiographs and diagnostic studies, especially arthroscopic findings, are reviewed.

Positioning
- The patient is under anesthesia and in the supine position with hips and knees flexed at 30 degrees for low back comfort. The arm is exsanguinated and the tourniquet inflated at 250 mm Hg.
- The arm is on the hand table in pronation, presenting the dorsal aspect of the wrist.

BLATT CAPSULODESIS

Exposure
- The tubercle of Lister and the radial styloid are identified by palpation.
- An oblique skin incision is made following a line from a point 1 cm distal and ulnar with respect to the tubercle of Lister, to a point 1 cm distal to the radial styloid (TECH FIG 1).
- Veins are coagulated or ligated.
- Care is taken to identify the branches of the superficial radial nerve and mobilize and retract them with the subcutaneous tissue. This is accomplished taking all the fat with the skin as a flap.
- Communicating vessels from the superficial layers to the deep arches are divided and coagulated.
- The extensor retinaculum overlying the fourth dorsal extensor compartment is incised. The extensor retinaculum is then raised as two flaps, radially and ulnarly based, to free the extensor tendons from the second to fourth compartments.
- A neurectomy of the posterior interosseous nerve can be performed at this point.
- The extensor digitorum communis (EDC) is retracted ulnarily and the extensor pollicis longus (EPL) and extensor carpi radialis brevis (ECRB) radially to expose the dorsal capsule.

Creation of the Capsular Flap
- A rectangular capsular flap, 25 mm long and 10 mm wide, is created by making a transverse capsular incision just proximal to the vascular dorsal carpal arch and elevating the tissue in a distal to proximal direction, leaving the proximal end still attached to the dorsal rim of the distal radius (TECH FIG 2A).
- As the flap is elevated, the scaphoid is exposed (TECH FIG 2B).
- At the dorsum of the scaphoid, a trough is created at a point distal to the axis of rotation of the scaphoid (scaphoid neck) (TECH FIG 2C).

Reducing the Instability
- If the instability is acute, a primary repair of the scapholunate ligament is performed.
- The space between scaphoid and lunate is reduced, using a 1.1-mm Kirschner wire inserted in the scaphoid as a joystick, and then another Kirschner wire is placed in the scaphoid and fixed to the lunate.
- This step should be performed under radiologic guidance. The scapholunate angle in which these bones are fixed should be 45 ± 5 degrees.
- When fixing the scaphoid to the lunate, ensure that the lunate is in a neutral position.
If the capsulodesis is being performed for predynamic instability, the scaphoid is fixed to the lunate in its normal alignment. This is also accomplished by means of a Kirschner wire as described earlier.

Another Kirschner wire is passed from the scaphoid into the capitate to avoid flexion and pronation (TECH FIG 3).

### Securing the Capsular Flap and Wound Closure

- The flap is tightly inserted into the notch created on the dorsum of the scaphoid.
- There are two ways of securing the proximally based capsular flap to the scaphoid:
  - The flap is secured through holes created in the notch and transosseous sutures that are tied on the volar surface of the scaphoid tubercle.
  - The flap is secured to the sutures of a bone anchor (authors’ preferred method) (TECH FIG 4).
- The dorsal capsule is left in situ. The extensor retinaculum is closed with resorbable sutures.
- Layered closure of the wound and skin is performed.

---

**TECH FIG 2 • (continued)**

B. Capsular flap is elevated, allowing visualization of the scaphoid, lunate, and head of the capitate. C. Intraoperative photo showing the scaphoid (S), the capitate (C), and the dorsal scapholunate ligament (SL). A bone trough has been created in the distal scaphoid for insertion of the capsular flap. KW, Kirschner wire in the lunate. (C: Courtesy of A. Lluch, Institut Kaplan.)

---

**TECH FIG 3 • Orientation of the Kirschner wires recommended to stabilize the joints and protect the capsulodesis.**

---

**TECH FIG 4 • A. Placement of two bone anchors in the distal dorsal scaphoid. B. The proximally based capsular flap is prepared for insertion. (continued)**
This method is very similar to Blatt’s technique, the difference being that the capsular flap is distally based. There is no clear advantage to this technique over that described by Blatt.

The same approach is used and the same capsular flap created except that the tissue is left attached to the distal third of the scaphoid. The flap is incised at the radiocarpal joint, tensioned proximally, and anchored to the dorsal radius using a suture anchor. This force extends the distal pole of the scaphoid, reducing the scapholunate joint (TECH FIG 5).

The same approach is used and the same capsular flap created except that the tissue is left attached to the distal third of the scaphoid.

This elevated flap includes the proximal half of the DICL. Separate this portion of the DICL from the capsular tissue in an ulnar to radial direction, maintaining the radial insertion of the ligament.

Transfer this strip of ligament to the dorsum of the lunate into a prepared cancellous trough (TECH FIG 6). This will create a link between scaphoid and lunate, preventing scaphoid flexion and pronation.

The ligament is secured by tying to the suture anchor(s) in the lunate.

This technique represents a variation of a previous version described by Taleisnik and Linscheid\(^{15,17}\) in which the flap was attached to the dorsum of the distal radius.

**HERBERT TECHNIQUE**

- This method is very similar to Blatt’s technique, the difference being that the capsular flap is distally based.
- There is no clear advantage to this technique over that described by Blatt.

**BERGER CAPSULODESIS**

- Use the same approach and exposure as described for the Blatt capsulodesis.
- Raise a rectangular, radially based, capsular flap to allow exposure of the carpus. Its ulnar margin is the radiotriquetral ligament, its proximal margin is the radius, and its distal margin is the midsurface of the DICL.
- This elevated flap includes the proximal half of the DICL. Separate this portion of the DICL from the capsular tissue in an ulnar to radial direction, maintaining the radial insertion of the ligament.
- Transfer this strip of ligament to the dorsum of the lunate into a prepared cancellous trough (TECH FIG 6).
- This will create a link between scaphoid and lunate, preventing scaphoid flexion and pronation.
- The ligament is secured by tying to the suture anchor(s) in the lunate.
- This technique represents a variation of a previous version described by Taleisnik and Linscheid\(^{15,17}\) in which the flap was attached to the dorsum of the distal radius.
**POSTOPERATIVE CARE**

- Blatt recommended wearing a thumb spica cast for 2 months, after which active range-of-motion exercises were begun. The Kirschner wires were left in place for another month before removal, allowing intercarpal motion at 3 months postoperatively. Forceful stress was discouraged for up to 6 months postoperatively.

- We prefer 6 weeks of immobilization in a rigid splint, avoiding extreme motions for one additional month. Kirschner wires can be removed at 8 weeks from the time of surgery.

**OUTCOMES**

- A number of clinical series have reported good results with these procedures.\(^2\)\(^{-}\)\(^4\)\(^,\)\(^6\)\(^,\)\(^7\)\(^,\)\(^10\)\(^-\)\(^12\)\(^,\)\(^14\)\(^,\)\(^16\)\(^,\)\(^18\)\(^,\)\(^19\) The agreement of these series is that tensioning or augmenting the dorsal radioscaphoid capsule offers less surgical morbidity than other alternatives.

- Forceful stress was discouraged for up to 6 months postoperatively.

- The Kirschner wires were left in place for another month before removal, allowing intercarpal motion at 3 months postoperatively.

**OUTCOMES**

- A number of clinical series have reported good results with these procedures.\(^2\)\(^^{-}\)\(^4\)\(^,\)\(^6\)\(^,\)\(^7\)\(^,\)\(^10\)\(^-\)\(^12\)\(^,\)\(^14\)\(^,\)\(^16\)\(^,\)\(^18\)\(^,\)\(^19\) The agreement of these series is that tensioning or augmenting the dorsal radioscaphoid capsule offers less surgical morbidity than other alternatives.

- The radial insertion is incised at the level of the trapezium, trapezoid, and distal third of the scaphoid and then transferred to the scaphoid at the level of the scapholunate ligament insertion.

- The transferred ligament may also be integrated into the scapholunate ligament repair more proximally.

- The transferred ligament is secured using suture anchor(s) into a cancellous trough in the scaphoid.

- Like the Berger capsulodesis, this technique does not specifically limit wrist flexion as it does not cross the radiocarpal joint.\(^14\)

---

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Indication</th>
<th>This procedure should be used only in cases of predynamic and dynamic instability; it is not recommended for static instability.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach</td>
<td>Dorsal and oblique from proximal to distal and ulnar to radial</td>
</tr>
<tr>
<td>Preparation of the flap</td>
<td>Less than 10 mm wide is not adequate.</td>
</tr>
<tr>
<td>Preparation of the scaphoid</td>
<td>Roughen the dorsal aspect of the distal third of the scaphoid. Use bone anchors; it is the simplest and fastest. If making holes for attaching the capsule, direct them distally, to the tubercle. Then tie the sutures directly on the bone and leave the stitch under the skin.</td>
</tr>
<tr>
<td>Reducing instability</td>
<td>If the lunate is not reduced, flexion of the wrist may be limited postoperatively. When securing the scaphoid to the lunate, be sure not to place the scaphoid in more than 70 degrees of extension. This will also limit flexion postoperatively.</td>
</tr>
<tr>
<td>Fixing the flap</td>
<td>Tension is adjusted with the wrist in a neutral position.</td>
</tr>
</tbody>
</table>

---

**TZABO TECHNIQUE**

- The DICL is used to stabilize the scapholunate interval as above except the ligamentous tissue is ulnarily based and is inserted into the scaphoid rather than the lunate (TECH FIG 7).

- Typically a longitudinal capsular incision is used to expose the carpus.

- Care is taken to avoid incising the DICL.

- The DICL is defined and its proximal half separated.

- The radial insertion is incised at the level of the trapezium, trapezoid, and distal third of the scaphoid and then transferred to the scaphoid at the level of the scapholunate ligament insertion.

- The transferred ligament may also be integrated into the scapholunate ligament repair more proximally.

- The transferred ligament is secured using suture anchor(s) into a cancellous trough in the scaphoid.

- Like the Berger capsulodesis, this technique does not specifically limit wrist flexion as it does not cross the radiocarpal joint.\(^14\)

---

**TECH FIG 7** • Szabo’s technique involves transfer of the distal half of the dorsal intercarpal ligament from its attachment to the trapezium and trapezoid (x) to the distal third of the dorsum of the scaphoid (y).
COMPLICATIONS

- Reduction of wrist flexion (FIG 3)
- Failure
- Progression of SLD

REFERENCES

DEFINITION

- Scapholunate dissociation (SLD) is a symptomatic wrist dysfunction that results from partial or total rupture of the scapholunate ligamentous complex, with or without carpal malalignment.
- It may appear either as an isolated injury, or associated with distal radius fractures or displaced scaphoid fractures. Usually the result of trauma (hyperextension and ulnar deviation injury to the wrist), SLD may also result from a chronic inflammatory arthropathy (rheumatoid arthritis, chondrocalcinosis).

ANATOMY

- Under load the scaphoid is inherently unstable owing to its oblique alignment relative to the direction of axial forces being transmitted across the wrist. The amount of instability depends on the following factors:
  - The geometry of the radioscapoid joint (the deeper the scaphoid fossa, the less unstable)
  - The stabilizing efficacy of the periscaphoid ligaments (proximal scapholunate intersosseous ligament complex, dorsal scaphotriquetral [STq], palmar scaphocapitate [SC] and lateral scapho-trapezial-trapezoidal [STT] ligaments)
  - The indirect action of the flexor carpi radialis (FCR) muscle
  - The scapholunate interosseous ligament complex consists of three structures: the two scapholunate ligaments (palmar and dorsal) and the proximal fibrocartilaginous membrane.
  - The proximal membrane connects the two adjacent convex borders of the two bones from dorsal to palmar, separating the radiocarpal and midcarpal joint spaces (FIG 1).
  - The dorsal scapholunate ligament is formed by dense, slightly oblique connective fibers that link the dorsal aspects of the scaphoid and lunate bones.
  - The palmar scapholunate ligament has longer, more obliquely oriented fibers, allowing substantial rotation of the scaphoid relative to the lunate.
  - The dorsal scapholunate ligament has the greatest yield strength (260 Newtons [N] on average), followed by the palmar scapholunate ligament (118 N) and the proximal membrane (63 N).2
  - The proximal portion of the membrane often appears perforated in middle-aged and older individuals, which does not cause instability.

PATHOGENESIS

- When axially loaded, the three proximal bones do not react equally in terms of direction of rotation. The scaphoid tends to rotate into flexion and pronation while the triquetrum is pulled into extension by the dorsally subluxing hamate bone (FIG 2A).
  - If both the palmar and dorsal scapholunate and lunotriquetral (LTq) ligaments are intact, such differences in reactive motion generate increasing torques at both scapholunate and LTq levels, resulting in an increasing coaptation of these joints. Such an increased coaptation further contributes to the proximal carpal row stability (FIG 2B).
  - If the scapholunate ligaments are completely torn, the scaphoid no longer appears constrained by the rest of the proximal row, and tends to collapse into an abnormally flexed and pronated posture (“rotatory subluxation of the scaphoid”).
  - By contrast, the lunate and triquetrum translate ulnarly while rotating abnormally into extension, a pattern of carpal malalignment known as a dorsal intercalated segment instability (DISI) (FIG 2C).

NATURAL HISTORY

- Partial scapholunate ligament injury may not be radiologically demonstrable and may not produce symptoms unless the wrist is overloaded (predynamic instability).
  - If left untreated, a partial scapholunate tear may progress toward a more complete disruption of all three elements of the scapholunate joint, in which case a symptomatic dysfunction usually appears.
  - Radiographically, a gap between the scaphoid and lunate may be seen. This, however, is visible only under certain loading conditions (dynamic instability).
With time, the secondary stabilizers (STT and SC ligaments) may stretch out and become inefficient. In such circumstances, the wrist may progress toward permanent malalignment (static instability) (FIG 3A, B).

- The wrist moves abnormally, with the lunate decreasing its range while progressively adopting an extended position (DISI).
- Conversely, the scaphoid adopts a flexed collapsed position, with its proximal pole subluxing dorsoradially over the edge of the radioscapoid fossa (FIG 3C).

- The abnormal joint contact between radius and scaphoid may cause cartilage deterioration of the proximal pole of the scaphoid and the reactive formation of an osteophyte at the tip of the radial styloid. This condition is known as scapholunate advanced collapse (SLAC), stage 1.
- If untreated, SLAC stage 1 may progress toward a more extended cartilage loss involving the entire scaphoid fossa (SLAC stage 2).
- As the lunate becomes fixed in DISI, the dorsally subluxing capitate may present with cartilage deterioration progressing...
from radial to ulnar until it involves the entire capitoluminate joint (SLAC stage 3).

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Two clinical situations lead to a diagnosis of SLD. One is the patient who presents following violent trauma, such as a fall from a height or a motorcycle accident, who is likely to have a major carpal derangement. Another is the patient who may not recall specific trauma and yet presents with symptoms.
- In the first case, the diagnosis of a major SLD may be obvious.
- In the second case, identification of the true nature of dysfunction may require a high index of suspicion, careful examination, and appropriate diagnostic tools.
- Not uncommonly, arthroscopy is the only way to fully assess the extent of ligament derangement (see Chap. HA-41).
- In both dynamic and static SLD, swelling may be moderate. In acute cases, range of motion may be limited by pain, whereas it may be normal in chronic cases.
- Scapholunate point tenderness: If sharp pain is elicited by pressing this area, the probability of localized synovitis is high. Not all synovitis represents an injury to the scapholunate joint. Occult ganglia may present with a similar type of pain on palpation.
- The resisted finger extension test\(^9\) has low specificity but excellent sensitivity. In the presence of scapholunate injury, sharp pain is elicited at the scapholunate area, representing dorsal subluxation of the scaphoid.
- Scaphoid shift test\(^8\): If the scapholunate ligaments are completely torn, the proximal pole may sublux dorsally out of the radius, inducing pain on the dorsoradial aspect of the wrist. This test has low specificity: occult ganglia, hyperlaxity, or radioscaphoid degenerative arthritis may produce similar symptoms.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Posteroanterior radiographic view of the neutral positioned wrist
  - Increased scapholunate joint space compared with the contralateral side (Terry Thomas sign) suggests static SLD.
  - A foreshortened appearance of the scaphoid with the scaphoid tuberosity projected in the form of a ring over the distal two thirds of the scaphoid (ring sign) indicates rotatory subluxation of the scaphoid. The ring sign is not specific for SLD; it may also be present in static LTq dissociations.
- Lateral radiographic view
  - Increased scapholunate angle compared with the contralateral side. For this to be significant, the wrist needs to be in strict neutral alignment and neutral pronosupination.
  - Arthroscopy is the gold standard technique in the diagnosis of SLD. It is also useful in describing the degree of injury to the interosseous ligaments.\(^4\)
- Magnetic resonance imaging may provide useful information regarding ligament integrity, bone vascularity, presence of local synovitis, and other soft tissue status.

**STAGING**

- **SLD stage 1**: Partial scapholunate ligament injury. Normal wrist alignment. Usually diagnosed by arthroscopy. No abnormal scapholunate gap (Table 1).\(^4,5\)

### Table 1: Staging of Scapholunate Dissociation

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
<th>Stage 5</th>
<th>Stage 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial rupture with normal dorsal scapholunate ligament</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>If ruptured, dorsal scapholunate ligament is repairable</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Scaphoid normally aligned (ie, 45 degrees or less)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Carpal malalignment easily reducible</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Normal cartilage at both RC and MC joints</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>


- **SLD stage 2**: Complete scapholunate ligament injury, reparable. Complete disruption of scapholunate ligaments, the dorsal one being still repairable, with good healing potential. Normal wrist alignment.
- **SLD stage 3**: Complete scapholunate ligament injury, non-reparable, normally aligned scaphoid. Dorsal scapholunate ligament with poor healing capability. Normal carpal alignment.
- **SLD stage 4**: Complete scapholunate ligament injury, non-reparable, reducible rotary subluxation of the scaphoid. Complete SLD plus detachment of the dorsal LTq ligament off the distal margin of the lunate, plus insufficiency of the distal scaphoid stabilizers (STT and SC ligaments). Rotary subluxation of the scaphoid. Radioscaphoid angle greater than 45 degrees. The lunate may appear abnormally ulnarly translated and in DSI.
- **SLD stage 5**: Complete scapholunate ligament injury with irreducible malalignment, but normal cartilage. Fixed, irreducible long-lasting malalignment, without cartilage degeneration.
- **SLD stage 6**: Complete scapholunate ligament injury with irreducible malalignment and cartilage degeneration. Chronic dysfunctional wrists with cartilage degeneration (SLAC).

**NONOPERATIVE MANAGEMENT**

- Acute, minimally dysfunctional SLD, stage 1, may respond well to a period of 3 to 5 weeks of wrist immobilization, anti-inflammatory medication, and subsequent physical rehabilitation.
- Re-education of the dynamic scaphoid stabilizing capability of the FCR muscle may be helpful in minimal scapholunate dysfunctions. The FCR uses the scaphoid tuberosity as a hinge toward its distal insertion into the second metacarpal base. Its contraction generates a dorsally directed vector to the unstable scaphoid that prevents its collapse into flexion. Optimization of the time response of the FCR muscle to wrist loading may prevent progression of scapholunate ligament disruption (FIG 4).\(^4\)

**SURGICAL MANAGEMENT**

- Partial ligament injuries may create discomfort from joint irritation by the ligament remnants. Arthroscopic débridement of these fragments may solve this problem.
- Electrothermal shrinkage of stretched scapholunate ligaments has been shown to be beneficial in selected cases of dynamic
instability. Careful control of intra-articular fluid temperature is mandatory. Burns are not rare if lasers are carelessly applied.4

- Tendon reconstruction of the scapholunate linkage is recommended only in SLD stages 3 or 4—that is, when there is a nonreparable complete scapholunate ligament injury causing carpal malalignment. For this to be successful, however, it is very important that:
  - The malalignment is easily reducible, and
  - The periscaphoid cartilages are completely normal
  - No soft tissue reconstruction can achieve effective carpal stability if the malalignment cannot be reduced with minimal force.
  - Intra-articular fibrosis is the most common cause of irreducibility.
  - Heavy manual workers are not good candidates for this treatment modality; they may require a more solid form of stabilization, such as a partial fusion.
  - Tendon reconstruction cannot solve the loss of protective capsular proprioception, and therefore tenodeses are likely to deteriorate with time if chronically overstressed.

**Preoperative Planning**
- A complete set of plain radiographic views and stress views are mandatory.
- Arthroscans (tomograms taken after three-compartment injection of dye) are very useful to assess cartilage status.
- Best-quality magnetic resonance imaging may provide useful accessory information regarding bone vascularity, synovitis effects, and soft tissue status.
- Arthroscopy is by far the best tool for preoperative planning.

**Positioning**
- An axillary block is used. The patient is in the supine position. The arm is exsanguinated.

**Approach**
- An 8-cm dorsal zigzag, lazy S, or longitudinal incision of the skin and subcutaneous tissue is centered on the tubercle of Lister.
- The dorsal sensory branches of the radial and ulnar nerves are identified and protected.
- The extensor retinaculum is divided along the third compart- ment and the extensor pollicis longus tendon is retracted radially.
- The retinacular septa between compartments II and V are sectioned and the two retinacular flaps so created are retracted. Most septa contain intraseptal vertical vessels that need to be carefully coagulated (FIG 5).

**TECHNIQUES DORSAL LIGAMENT-SPLITTING CAPSULOTOMY (BERGER ET AL1)**

- The first incision is made along the dorsal rim of the radius to the center of the lunate fossa.
- The second incision is made from the end of the first incision following the fibers of the dorsal radiotriquetral ligament to its distal insertion onto the dorsal ridge of the triquetrum (TECH FIG 1A).
- The third incision is made from the STT joint progressing medially along the dorsal intercarpal ligament to its insertion onto the dorsum of the triquetrum.
- By connecting the last two incisions, a radially based capsular flap is created. This flap is carefully elevated by sectioning its connections to the dorsal edge of the three bones of the proximal row (TECH FIG 1B).
- It is important to leave enough dorsal RTq ligament attached to the triquetrum in order to facilitate later ten- sioning of the tendon reconstruction.

**FIG 4** The flexor carpi radialis (FCR) tendon is in close relationship to the scaphoid tuberosity. Based on this, the scaphoid flexion tendency that appears when the bone is unstable can be effectively compensated by the dynamic action of the FCR muscle. Indeed, proprioception re-education of this muscle may be useful in stage 1 scapholunate dissociation.

**FIG 5** Dorsal approach to the wrist through a longitudinal incision. The extensor retinaculum has been divided along the third compartment and retracted in the form of two flaps, radial and ulnar. Extensor tendons are uncovered.
TECH FIG 1 • A. A radially based capsular flap is created by incising the dorsal capsule along the fibers of both the dorsal radiotriquetral ligament and the dorsal intercarpal ligament. B. Once the capsular flap is retracted radially, the scapholunate injury can be inspected (arrow) and a final therapeutic decision can be made.

PALMAR SCAPHOTRAPEZOID PLUS DORSAL RADIOSCAPHOID TENODESIS (BRUNELLI AND BRUNELLI)\(^3\)

- Beginning at the level of the distal pole of the scaphoid, using small transverse palmar incisions along the course of the FCR, a strip of the FCR tendon is obtained.
- The strip is incised at the musculotendinous junction and left attached distally.
- The size of graft harvested depends on the size of the scaphoid and bone tunnel created.
- A 2.7- to 3.2-mm drill hole is started volarly at the distal pole of the scaphoid, entering at the front of the scaphoid tuberosity to emerge dorsally at the level of the scaphoid neck.
- Using a tendon passer or a wire loop, the tendon strip is passed through the bone tunnel.
- While maintaining the proximal pole of the scaphoid reduced on its fossa, two Kirschner wires are passed across the scaphocapitate joint.
- Fluoroscopic assessment of reduction is important. Slight overreduction (radioscaphoid angle of about 60 degrees) is recommended.
- Later stretch of the tenodesis is likely, in which case the scaphoid will recover its ideal alignment of 45 degrees.
- While the wrist is maintained in neutral position, the tendon is tightly anchored to the area of the tubercle of Lister using transosseous nonabsorbable sutures or metal suture anchors (TECH FIG 2).
- The extensor retinaculum is repaired, leaving subretinacular drains. The extensor pollicis longus is usually left superficial to the extensor retinaculum.
- The capsular flap is passed underneath the tenodesis and reattached to its origins by absorbable sutures.

THREE-LIGAMENT TENODESIS (MODIFIED BRUNELLI’S TENODESIS\(^5,8\))

- The transscaphoid tunnel is not transverse across the distal scaphoid (as detailed above), but oblique along the longitudinal axis of bone, from dorsal to palmar, entering at the level of the original insertion site of the dorsal scapholunate ligament, aiming at the palmar tuberosity (TECH FIG 3A).
- So as not to damage the medial or lateral articular surfaces of the scaphoid, we recommend using a 2.7- to 3.2-mm cannulated drill over a Kirschner wire preset under fluoroscopy control.
- The FCR tendon strip is passed through the oblique scaphoid tunnel using a wire loop or a tendon passer (TECH FIG 3B).
- A transverse trough or channel is then made over the dorsum of the lunate with a rongeur. This trough needs to uncover cancellous bone, the only tissue able to generate proper healing of the tendon into bone (TECH FIG 3C).
- To obtain intimate contact between the tendon strip and the lunate cancellous bone, a small anchor suture is placed into the floor of the trough.
The distal end of the dorsal radiotriquetral ligament is then localized. By its insertion on the bone, a slit is created through which the tendon strip is passed volar to dorsal (TECH FIG 3D).

- The dorsal radiotriquetral ligament is used as a pulley to tension the ligament strip.

- The scaphoid, lunate, and capitate are reduced and stabilized with two 1.5-mm Kirschner wires prior to tensioning the tendon graft. One wire is placed across the scapholunate joint and one across the SC joint.

- It is critical to ensure reduction of the scaphoid and the lunate, elimination of any DISI deformity, and proper placement of the wires using fluoroscopy.

- Radially directed tension is applied to the tendon graft already placed around and through the dorsal radiotriquetral ligament (TECH FIG 3E).

- The tendon graft is secured tightly into the cancellous bone channel created in the lunate using the suture anchor (TECH FIG 3F).

- The end of the tendon strip is sutured onto itself with nonabsorbable 3-0 sutures (TECH FIG 3G,H).

- The capsular flap is brought back, over the tendon reconstruction, to its original position by suturing side-by-side the split fibers of the two ligaments involved in the capsulotomy. Some sutures are also placed connecting the capsule and the tendon loop to re-establish the normal capsular attachment to the dorsum of the scapholunate joint.

- The extensor retinaculum is finally reconstructed, drains are placed, and the skin is closed.

TECH FIG 3 • A. A 2.7-mm drill is used to create an oblique tunnel that enters the scaphoid beginning at the site where the dorsal scapholunate ligament originally inserted. The drill exits the scaphoid at the palmar scaphoid tubercle. B. With a tendon passer or a wire loop, the strip of FCR tendon is brought through the bone tunnel exiting dorsally. C. The strip of FCR tendon has been passed through the scaphoid tunnel. A trough has been carved onto the dorsal cortex of the lunate and a suture anchor inserted at that location. A slit has been developed along the fibers of the dorsal radiotriquetral ligament. D. The strip of FCR tendon has been passed through the ligament rent created along the fibers of the dorsal radiotriquetral ligament. E. The strip of FCR tendon is tensioned in a radial direction using the dorsal radiotriquetral ligament as a pulley. (continued)
PEARLS AND PITFALLS

**Indications**
- Never perform a tenodesis if the malalignment is not easily reducible, or if there is cartilage wear at the periscaphoid joints.

**Scaphoid tunnel placement**
- Drill a Kirschner wire from dorsal to palmar and from proximal to distal, aiming at the tuberosity. After fluoroscopy control, use a cannulated 2.7- or 3.2-mm drill depending on the size of the tendon strip obtained. It is best to have a tighter fit rather than a looser fit in the tunnel so that there is less "slop" in the system and potentially less likelihood of loss of reduction. The bone tunnel size, therefore, depends on the tendon graft thickness and also on the size of the scaphoid.

**Pin stabilization**
- One 1.5-mm Kirschner wire enters from the dorsoradial corner of the scaphoid across the scaphoid, aiming at the hook of the hamate.
- A second Kirschner wire enters from the palmar-radial corner of the scaphoid tuberosity, aiming at the lunate.
- Avoid Kirschner wires across the anatomic snuffbox (radial artery at risk).

**Fixation of the split tendon to the lunate**
- The anchor suture in the lunate is not to be used as anchor point for tendon tensioning, but only as a means to maintain the split tendon in full contact to cancellous bone. Tension of the tenodesis relies on the dorsal radiotriquetral ligament.

**Tensioning of the tenodesis**
- Avoid excessive reduction of the DISI by applying too much tension to the graft. A "volar intercalated segment instability" may be created, aside from affecting motion, or may even lead to necrosis.

POSTOPERATIVE CARE
- The wrist is immobilized in a well-padded splint including the metacarpophalangeal joint of the thumb for 10 days.
- After stitch removal, the wrist is maintained in a short-arm thumb spica cast for 5 more weeks.
- A protective removable splint is then fabricated. This will allow resting the joint between sessions of supervised physiotherapy. The splint is used for an additional 4 weeks.
- Before wire removal, at 8 weeks, therapy consists of only gentle radiocarpal mobilization. After pin removal, global active mobilization is emphasized. Aggressive passive mobilization is never recommended.
- Muscle strengthening exercises are not initiated until 10 weeks after surgery.
- Contact sports are to be avoided for 6 months after surgery.

OUTCOMES
- A recently published review of 38 patients with a symptomatic SLD who had a three-ligament tenodesis procedure, with a mean follow-up of 46 months, showed an average range of motion of about 75% of the contralateral side. Average grip strength was 65%. Pain relief at rest was obtained in 28 patients, with 8 complaining of mild discomfort during strenuous activity, and 2 having pain in most activities.
of daily life. Twenty-nine resumed their normal occupational-vocational activities. There were no signs of scaphoid necrosis. Recurrence of carpal collapse occurred in only two wrists. Nine patients showed mild signs of degenerative osteoarthritis at the tip of the radial styloid, but none had substantial symptoms.

COMPLICATIONS

- Recurrence of the malalignment and subsequent development of degenerative arthritis is common when the technique is used inappropriately, in cases with a poorly reducible SLD (stage 5), or when cartilage deterioration is already present (SLAC).
- When reducibility is in doubt, a more aggressive treatment (partial fusion or proximal row carpectomy) is recommended.

REFERENCES

DEFINITION

- Scapholunate ligament tears are the most common form of carpal instability.
- If left untreated, this injury will cause degenerative changes in the wrist.\(^3,6,8,13\)
- Complete tears of the scapholunate ligament exist, yet partial tears, or dynamic instability, occur as well. This diagnosis requires a high index of suspicion and specific imaging. Dynamic instability is defined as a wrist that maintains normal alignment at rest but will collapse with applied load. Consequently, stress radiographs or diagnostic arthroscopy is needed to make the diagnosis.\(^3,13\)
- Treatments of scapholunate ligament tears include primary repair, dorsal capsulodesis, tendon grafting, ligament reconstruction, proximal row carpectomy (PRC), and limited carpal arthrodesis.
  - Primary repair may not be possible if the remnant ligament is not amenable to repair.
  - Tendon weaves are technically challenging and do not recreate the unique motion between the scaphoid and lunate and thus may yield new problems. A PRC alters kinematics and may decrease grip strength.
  - Limited arthrodesis for the chronic scapholunate ligament tear with coincident radiocarpal arthrosis relieves pain but creates a decrease in range of motion and alters the mechanics of the wrist joint, potentially leading to degenerative changes in adjacent joints.\(^3,6,13\)

ANATOMY

- The scapholunate ligament is one of the many intrinsic ligaments of the wrist. It is intra-articular and is composed of collagen fascicles. It consists of three main parts: dorsal, membranous (or proximal), and volar (Fig 1).\(^1,11\)
- The dorsal portion is the strongest of the three. It is 2 to 3 mm thick and 3 to 5 mm long. Its collagen bundles are oriented transversely. It is most important in limiting dorsal–palmar translation. The most dorsal area always merges with the wrist articular capsule. More than 300 Newtons (N) of tensile stress is required for failure.
- The proximal or membranous portion is weak and thin. It is composed of mostly fibrocartilage and there are no neurovascular bundles within it (avascular). Only 25 N of stress will cause this portion of the scapholunate ligament to fail.
- The volar portion of the scapholunate ligament is only 1 mm thick and 4 to 5 mm long. Its collagen bundles are oriented obliquely. The volar and proximal portions are most important in limiting dorsal–palmar rotation. The volar and membranous portions of the scapholunate ligament are intersected by the loose radioscapholunate ligament (ligament of Testut). The amount of stress to failure here is 150 N.
- The scaphocapitate, scaphotrapezium–trapezoid (intrinsic), radioscaphocapitate, long and short radiolunate (volar extrinsic), dorsal radiocarpal, and dorsal intercarpal (dorsal extrinsic) ligaments also provide support and stability in this area.

PATHOGENESIS

- The mechanism of injury is often a fall on an outstretched hand. Mayfield et al\(^9\) described this injury occurring with an axial load in excessive dorsiflexion, ulnar deviation, and midcarpal supination. This position causes the capitate to separate the scaphoid (radial and dorsal) and lunate (ulnar and palmar).
- An ipsilateral distal radius fracture or scaphoid fracture can occur up to 30% of the time.\(^3,4\)
- The lunate will naturally flex with the scaphoid and extend with the triquetrum. In a patient with a scapholunate ligament injury, the connection to the scaphoid is lacking, the scaphoid will flex and rotate away from the lunate because of its other attachments, and the lunate will fall into a dorsal intercalated segment instability (DISI) pattern. For this rotational instability to occur, the dorsal capsular ligaments must be injured as well.
- An acute scapholunate injury may or may not coincide with an injury to the surrounding ligaments (ie, dorsal extrinsics). If it does, a DISI pattern may be noted soon after injury. If there is no injury to the surrounding structures, attenuation of these structures over time may occur and then subsequently cause a DISI pattern. When DISI does occur, this pattern of carpal instability must be corrected for any treatment of this injury to be successful.

NATURAL HISTORY

- The natural history of the wrist with a scapholunate ligament injury has been described by several authors. Pain and instability can result from a static injury. A DISI pattern deformity as described earlier will develop, and a very specific sequential pattern of wrist arthrosis will progress (scapholunate advanced collapse [SLAC]):
  - Stage IA: radial styloid with or without scaphoid arthrosis
  - Stage IB: radioscaphoid arthrosis
“complete” series to include a clenched-fist PA, a radial deviation PA, and flexion and extension lateral radiographs. It is helpful to compare the radiographs with the contralateral extremity.3,13

■ A static scapholunate ligament injury will reveal an increased space between the scaphoid and lunate on a PA radiograph. The normal scapholunate distance is less than 3 mm. If this interval is greater than 3 mm, the patient has what is known as the Terry Thomas sign. Additionally, as mentioned earlier, the scaphoid will collapse into flexion and the tuberosity will project in the coronal plane, revealing a scaphoid ring sign. The astute observer may also note the volar lip of the extended lunate overlapping with the capitate (FIG 2A–C).

■ The lateral radiograph may reveal an increased scapholunate angle. This angle is found by drawing lines through the longitudinal axes of the scaphoid and lunate and measuring the angle. Normally, it falls between 30 and 60 degrees. A radiolunate angle greater than 15 degrees indicates a DISI deformity (FIG 2D).

■ Flexion and extension lateral radiographs will show motion occurring at the lunocapitate joint and an uncoupling of the normally synchronous scapholunate motion.

■ Radial and ulnar deviation radiographs and a clenched-fist radiograph may portray a dynamic instability picture in that a static radiograph reveals no deformity (ie, normal scapholunate gap), but one of these views will reveal an abnormal scapholunate diastasis.

■ The chronic scapholunate injury may have evidence of arthritis on any of these views and the physician must recognize these findings, which indicate an old injury (FIG 2E,F).

■ Magnetic resonance imaging has become valuable in assessing acute or chronic scapholunate ligament tears (FIG 2G).

■ Arthroscopy is the imaging method of choice. It allows the experienced surgeon to diagnose most wrist pathology as well as affording the ability to possibly treat it (FIG 2H).

Geissler et al4 published four stages of scapholunate ligament tears based on arthroscopic examination (see Chap. HA-41).

DIFFERENTIAL DIAGNOSIS

■ Distal radius fracture
■ Scaphoid fracture
■ Radioscaphoid arthritis
■ Scaphotrapezial arthritis

DIFFERENTIAL DIAGNOSIS

Stage II: capitulonate arthrosis
Stage III: pan-arthritis
The radiolunate joint is typically spared.14,15

PATIENT HISTORY AND PHYSICAL FINDINGS

■ Commonly, the patient will describe radial-sided wrist pain, pain with loading activities, and weakness.
■ Physical examination methods include the following:
  ■ Observation and palpation of gross edema
  ■ Wrist range of motion in extension, flexion, ulnar, and radial directions. Decreased range of motion or pain with extremes of motion will be evident.
  ■ Palpation just distal to the tubercle of Lister to assess for scapholunate interval tenderness
  ■ Ballottement test: Pain or instability here is concerning for a scapholunate ligament tear
  ■ Watson test: Pressure on the scaphoid tuberosity during ulnar-to-radial deviation of the wrist prevents the scaphoid from normally flexing. In a wrist with a scapholunate ligament tear, the proximal pole of the scaphoid will dorsally subluxate out of the scaphoid fossa with this maneuver, causing a clunk. A palpable clunk is indicative of instability.
  ■ Grip strength weakness is sensitive but not specific for scapholunate ligament disruption.

■ A complete examination of the wrist should also include evaluation of associated injuries and ruling out differential diagnoses. This includes but is not limited to the following:
  ■ Lunatotriquetral tears: pain with “shuck” of the lunate and triquetrum
  ■ Masses: examine carefully for any cysts or masses that may be causing pain
  ■ Distal radius or scaphoid fracture: tenderness at the distal end of the radius or the snuffbox as well as a fracture noted on radiographs
  ■ Triangular fibrocartilage complex (TFCC) tears: pain with a TFCC stress test, which is an axially applied load via ulnar deviation while moving the wrist through a flexion–extension arc

IMAGING AND OTHER DIAGNOSTIC STUDIES

■ Plain radiographs include posteroanterior (PA), lateral, and scaphoid views, although some authors will advocate the
Part 6  HAND, WRIST, AND FOREARM  •  Section V  WRIST INSTABILITIES

**NONOPERATIVE MANAGEMENT**

- deQuervain tenosynovitis
- Dorsal wrist impaction syndrome
- Dorsal ganglion cyst
- Lunatotriquetral instability
- Midcarpal instability

**SURGICAL MANAGEMENT**

- Less invasive surgical procedures are used for partial scapholunate ligament tears and the wrist with dynamic instability. This can consist of thermal shrinkage through the arthroscope, arthroscopic débridement, and percutaneous pinning of the scaphoid and lunate in a reduced position. A capsulodesis may be considered.
- The surgical treatment of complete scapholunate ligament tears depends on the chronicity of the injury and the presence of joint arthrosis. Ligament injuries older than 3 weeks have a lower rate of healing because of the ligament’s lack of vascularity. In these more subacute or chronic injuries, it may be difficult to obtain a good outcome when performing a primary direct repair of the ligament.\(^5\)
- In addition, repair or reconstruction of the scapholunate ligament is a futile exercise in those joints with SLAC arthrosis, demonstrated by imaging studies preoperatively or arthroscopic findings intraoperatively. These procedures will not address arthritic pain.
- Our algorithm is given in Table 1.
- The purpose of this chapter is to review the techniques for bone-ligament-bone reconstruction of the scapholunate ligament.
- The advantages of this technique compared to other techniques are a more anatomic reconstruction, better approximating carpal kinematics; bone-to-bone healing as opposed to tendon-to-bone healing; and local availability.

### Table 1  Algorithm for Treatment of Scapholunate Ligament Injuries

<table>
<thead>
<tr>
<th>Injury Type</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute (&lt;3–4 wk)</td>
<td>Immobilization vs. arthroscopic shrinkage +/- percutaneous pinning +/- capsulodesis</td>
</tr>
<tr>
<td>Dynamic</td>
<td>Open repair of scapholunate interosseous ligament (treatment of choice) if possible vs. bone-ligament-bone reconstruction vs. tendon weave +/- capsulodesis</td>
</tr>
<tr>
<td>Static</td>
<td>Reconstruction vs. tendon weave +/- capsulodesis (open repair can be done if enough remnant ligament is available)</td>
</tr>
<tr>
<td>Subacute (4–24 wk)</td>
<td>Reconstruction vs. tendon weave +/- capsulodesis</td>
</tr>
<tr>
<td>No arthrosis</td>
<td>Reconstruction vs. tendon weave +/- capsulodesis</td>
</tr>
<tr>
<td>Chronic (&gt;24 wk)</td>
<td>Salvage (ie, scapholunate advanced collapse procedure, proximal row carpometacarpal arthrodesis*)</td>
</tr>
<tr>
<td>With arthrosis</td>
<td>Strong arthrodesis examples include scapho–trapezium–trapezoid, scaphocapitate, scapholunate, and scapholunate–capitate.</td>
</tr>
</tbody>
</table>

---

\(^5\) Intercarpal arthrodesis examples include scapho–trapezium–trapezoid, scaphocapitate, scapholunate, and scapholunate–capitate.
Preoperative Planning

- The surgeon should review radiographs for any evidence of arthrosis. MRI is reviewed for pathology.
- Associated fractures or other soft tissue pathology should be addressed.
- Any evidence of joint arthrosis should indicate to the surgeon that a salvage procedure should be performed rather than a ligament reconstruction.
- A Watson shift test is performed while the patient is under anesthesia. The examiner may better appreciate a clunk while the patient is under anesthesia in contrast to the awake patient where pain may be present, making it difficult for the examiner to perform this maneuver well.

Positioning

- Often, a diagnostic wrist arthroscopy is performed initially.
- The patient is positioned supine. A hand table is appropriately positioned. A nonsterile tourniquet (set to 250 mm Hg) is placed on the upper arm.
- After preparation and draping, the wrist is placed in the arthroscopic tower. About 10 to 15 pounds of traction is used to distract the joint for the arthroscopy.
- Arthroscopy aids in evaluating the extent of the injury to the scapholunate ligament, assessing the quality of tissue remaining, and diagnosing concomitant injuries (FIG 3).

Once the diagnostic arthroscopy is completed and the decision to perform a reconstruction is made, the wrist is taken out of the tower and placed pronated on the hand table.

Approach

- There are several dorsal approaches to the wrist. Some prefer a trans-fourth compartment approach. We prefer an approach between the second and fourth compartments while transposing the extensor pollicis longus.
- Another decision to be made is where to obtain the bone–ligament–bone graft. We prefer local tissue, such as the capitohamate ligament, while some would advocate autograft from the foot. Autograft from the foot creates two operative sites and thus a second potential site of morbidity. In addition, there have been no clinical studies at this point verifying its merit; however, biomechanical studies are encouraging.\(^2,12\)

**FIG 3** • Arthroscopic setup. The arthroscopic tower uses plastic hook-and-eye straps and finger traps. About 10 to 15 lb of traction is used to distract the joint for the diagnostic arthroscopy.

**APPROACH TO THE DORSAL WRIST**

- An incision of about 6 to 8 cm is made just ulnar to the tubercle of Lister, extending distally to include the third metacarpal (TECH FIG 1A).
- The extensor pollicis longus sheath is incised and the tendon is transposed in a radial direction (TECH FIG 1B).
- The interval continues between the second and fourth compartment.
- The posterior interosseous nerve is excised to decrease residual pain.
- A ligament-splitting dorsal wrist capsulotomy described is made through the dorsal intercarpal and dorsal radiocarpal ligaments (TECH FIG 1C).\(^1,3,13\)
- Direct visual inspection and probing allows the surgeon to further assess the scapholunate ligament for direct primary repair versus reconstruction.

**TECH FIG 1** • Approach. A. A 6- to 8-cm incision is made ulnar to the tubercle of Lister, extending distally. B. The third extensor compartment is incised and the tendon is radialized. C. A ligament-splitting incision is made in the capsule.
GRAFT HARVESTING

- Fluoroscopy and an 18-gauge needle can help identify the capitohamate ligament.
- Using a quarter-inch osteotome, a portion of the ligament with bone blocks (10 x 5 x 5 mm) is taken. This concept is quite similar to a bone–patellar tendon–bone autograft for anterior cruciate ligament reconstructions (TECH FIG 2A,B).
- Other ligaments from the upper extremity that can be used include the third metacarpal–capitate ligament, the capito–trapezoid ligament, the second metacarpal–trapezoid ligament, and the dorsal extensor retinaculum bone block. This last choice was the weakest of all in a biomechanical study.

The dorsal tarsometatarsal ligaments between the lateral cuneiform and the third metatarsal or the ligament between the navicular and the first cuneiform of the foot have also been shown to be both geometrically and biomechanically similar to the scapholunate ligament, and they remain an option for grafting.

- If the surgeon prefers this dorsal foot graft, a longitudinal incision is made over the base of the third metatarsal. Sharp dissection is used for exposure to the joint. An osteotome is used to harvest the ligament with large bone blocks as close to the size of the scapholunate recipient site as possible—typically no greater than a 5- to 8-mm-wide section. The remainder of the dorsal ligament as well as the plantar ligament remains in place, ensuring maintained stability for the foot (TECH FIG 2C).

- Fluoroscopy and an 18-gauge needle can help identify the capitohamate ligament.
- Using a quarter-inch osteotome, a portion of the ligament with bone blocks (10 x 5 x 5 mm) is taken. This concept is quite similar to a bone–patellar tendon–bone autograft for anterior cruciate ligament reconstructions (TECH FIG 2A,B).
- Other ligaments from the upper extremity that can be used include the third metacarpal–capitate ligament, the capito–trapezoid ligament, the second metacarpal–trapezoid ligament, and the dorsal extensor retinaculum bone block. This last choice was the weakest of all in a biomechanical study.

The dorsal tarsometatarsal ligaments between the lateral cuneiform and the third metatarsal or the ligament between the navicular and the first cuneiform of the foot have also been shown to be both geometrically and biomechanically similar to the scapholunate ligament, and they remain an option for grafting.

- If the surgeon prefers this dorsal foot graft, a longitudinal incision is made over the base of the third metatarsal. Sharp dissection is used for exposure to the joint. An osteotome is used to harvest the ligament with large bone blocks as close to the size of the scapholunate recipient site as possible—typically no greater than a 5- to 8-mm-wide section. The remainder of the dorsal ligament as well as the plantar ligament remains in place, ensuring maintained stability for the foot (TECH FIG 2C).

PREPARATION OF THE RECIPIENT SITE AND FIXATION

- Using fluoroscopic guidance, 0.062 Kirschner wires are used to reduce the DISI (ie, joystick) and hold the scaphoid and lunate in position (TECH FIG 3A).
- Two Kirschner wires from scaphoid to lunate and, if required, one from scaphoid to capitate to stabilize the reduced scapholunate interval (TECH FIG 3B). More recently, we have been using a cannulated scapholunate screw for fixation.
- A trough is cut in the dorsal aspect of the scaphoid and lunate using an osteotome (TECH FIG 3C). The trough must be large enough to accept the bone blocks of the bone–ligament–bone autograft. We aim to make the trough as equal to the bone blocks as possible.

- The bone blocks are placed into the trough with digital pressure and they are held with a 1.5-mm screw in each bone. It is important to ensure that full flexion and extension of the wrist is still possible after fixation (TECH FIG 3D–F).
- Another option would be to acquire a “press fit” with the bone blocks, thereby bypassing the need for screws. This will decrease the possibility of fragmenting the bone block with the screws. However, we prefer obtaining a larger bone block autograft and using screws for added stability.
- A dorsal capsulodesis (see Chap. HA-43) can be performed for added stability. We prefer using a portion of the dorsal intercarpal ligament. This technique is described elsewhere in this part.
We prefer to deflate the tourniquet and obtain hemostasis before closure. Once hemostasis is achieved, the capsule and extensor retinaculum are closed.

The extensor pollicis longus tendon is left out of its sheath so swelling will not cause any attenuation and possible attritional rupture in its watershed area.

The skin is closed. Kirschner wires are cut under the skin to prevent pin tract infection.

Final radiographs should demonstrate screws to be adequately placed and the scaphoid and lunate to be in good position by noting a decreased scapholunate interval, a reduced scapholunate angle, and no evidence of DISI. The wrist is splinted in neutral or 30 degrees of extension; theoretically, the dorsal rim of the radius buttresses the graft for additional support in this slightly extended position.

PEARLS AND PITFALLS

**Indications**
- Carefully review the history for assessment of chronicity of the injury to determine whether a repair versus a reconstruction is needed.
- Carefully review all imaging studies preoperatively to assess for any arthritic changes that may preclude bone–ligament–bone reconstruction.

**Approach**
- It is helpful to transpose the extensor pollicis longus.

**Donor graft**
- The bone blocks should be large enough to accommodate a 1.5-mm screw without the risk of fragment fracture.

**Recipient site**
- The trough should be large enough to accept the bone blocks without being so large that the scaphoid or lunate would lose their dimensions.
- The scaphoid and lunate must be reduced and pinned before stabilization of the graft; otherwise the graft will be tensioned incorrectly.

**Postoperative care**
- A good outcome will be predicated on supervised postoperative therapy after healing.
POSTOPERATIVE CARE

- The wrist is strictly immobilized for 8 weeks. Finger and elbow range of motion is encouraged.
- Pins are removed at 8 weeks and gentle active range-of-motion exercises are started. A removable splint is still worn when not exercising for an additional 4 weeks.
- Passive range of motion begins at 12 weeks, followed by strengthening.

OUTCOMES

- Patients with a partial tear or dynamic component and patients with a shorter time from injury to treatment have a better outcome.
- Weiss\textsuperscript{16} reported excellent results at a minimum of 2 years of follow-up in 13 of 14 patients with scapholunate gaps of less than 8 mm using a bone–retinaculum–bone autograft, even though it has been shown to be biomechanically weaker than the native scapholunate ligament. This may be due to graft remodeling or hypertrophy in vivo.
- Lutz\textsuperscript{18} used a periosteal flap of iliac crest as the autograft. With an average follow-up of 29 months, they reported 6 of 11 patients to be clinically excellent or good and 5 as fair. Average radiographic parameters improved.
- Hanel\textsuperscript{5} reported that all 39 of his patients treated with the bone-ligament-bone reconstruction outlined in this chapter returned to work, but some had difficulty with return to some sports. All patients would have the surgery again as it had helped their day-to-day activities.
- Although there are no long-term clinical outcome studies in the literature on bone-ligament–bone reconstruction, short-term results are promising. A larger number of patients with a longer follow-up is required to fully recommend this technique for most scapholunate injuries.

COMPLICATIONS

- Fragmentation of the bone block intraoperatively or postoperatively
- Failure of graft to incorporate if the trough made in the scaphoid or lunate is not deep enough to cause punctate bleeding for the incorporation of the graft
- Pin tract infections (which are treated with oral antibiotics)
- Failure to achieve normal carpal alignment

REFERENCES

DEFINITION
- Scapholunate instability occurs as a result of injury to the scapholunate interosseous ligament (SLIL).
- Instability can be categorized based on physical and radiographic findings.
  - Static instability: abnormal alignment of the scaphoid and lunate evident on routine radiographs
  - Dynamic instability: abnormal alignment of the scaphoid and lunate present only on stress radiographs
  - Predynamic instability: no radiographic abnormalities present, but history and physical findings consistent with a SLIL injury
- Reduction and association of the scaphoid and the lunate (the RASL procedure) is used to correct scapholunate instability.

ANATOMY
- The SLIL can be divided into three components: dorsal, palmar, and proximal. Of these, the dorsal component is the thickest and contributes the most to scapholunate stability.¹
- Normally, the interval between the scaphoid and the lunate measures less than 3 mm, but this can vary between patients. The interval should be compared to the contralateral wrist (FIG 1A).

The normal angle between the scaphoid and the lunate measures 46 degrees with the wrist in neutral position (FIG 1B).⁵
- With wrist flexion and extension, there is 25 degrees of obligatory rotation motion between the scaphoid and the lunate. With radial and ulnar deviation, there is 10 degrees of normal motion.⁷

PATHOGENESIS
- SLIL injury typically occurs after a fall onto an extended wrist. The combination of axial load, wrist extension, intercarpal supination, and ulnar deviation leads to supraphysiologic loads across the SLIL.
- Injury can also occur in association with other injuries, such as the constellation seen in perilunate dislocations and distal radius fractures.

NATURAL HISTORY
- The motion of the scaphoid and that of the lunate are linked, such that both bones flex with wrist flexion and radial deviation and extend with wrist extension and ulnar deviation.² After SLIL injury, the synchronous movement between the scaphoid and lunate is lost and the scaphoid flexes while the lunate extends.
- Increased scaphoid flexion leads to point stress at the radiostylo-scaphoid juncture. This is the path to scapholunate advanced collapse and osteoarthritis.
- Dorsal intercalated segment instability (DISI) occurs because of unlinked lunate extension, which creates a scapholunate diastasis and allows for descent and altered kinematics (FIG 2). This results in pain, weakness, and progressive osteoarthritis.
- Over time, a progressive pattern of degenerative arthritis termed scapholunate advanced collapse (SLAC) occurs.¹⁰
  - Arthritic changes first arise between the radial styloid and the scaphoid (stage 1), followed by progression of arthritis into the proximal scaphoid fossa (stage 2). Next, the midcarpal joint becomes involved (stage 3), in particular the capitolunate joint, and eventually pancarpal arthritis is the final result (stage 4).
PATIENT HISTORY AND PHYSICAL FINDINGS

- History should include details of prior wrist trauma, especially in regard to mechanism and timing.
- Acute injuries are those that have occurred within 3 weeks, subacute between 3 weeks and 3 months, and chronic greater than 3 months before presentation. Dates are unreliable, but radiographic changes suggest many are acute-on-chronic injuries.
- After acute trauma, there is usually a repairable scapholunate ligament, whereas in the setting of subacute or chronic injury, the ligament is resorbed or mechanically unsound. The presence of adequate ligament tissue for repair outweighs the reported time since injury.
- Instability may be the result of cumulative trauma, and the patient may present with a history of multiple wrist sprains that ultimately produce chronic wrist pain.
- Physical examination includes the following:
  - Direct palpation of the wrist: Tenderness in this region corresponds to scapholunate ligament injury. May also see fullness or thickness, corresponding to dorsal capsule synovitis.
  - Range of motion: Pain with range of motion may indicate instability, synovitis, and chondral wear.
  - Watson scaphoid shift test: Pain over the scaphoid tubercle with radial deviation indicates SLIL injury.
  - Assessment of both normal and aberrant motion
  - Provocative maneuvers
- Examination of the contralateral uninjured wrist is essential to assess radiographic findings of minimal diastasis or DISI, which may be part of a hyperlaxity syndrome.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs and stress views are critical in diagnosis and consist of:
  - Neutral posteroanterior (PA), lateral, and oblique views
  - PA views in ulnar and radial deviation
  - Clenched-fist PA view in pronation
  - Contralateral wrist films should always be taken for comparison.
- Radiographic evidence of SLIL injury includes:
  - Scapholunate diastasis greater than 3 mm. Comparison should be made with the contralateral side, as ligamentous laxity can produce a normal scapholunate interval of greater than 3 mm (FIG 3A). Scaphoid cortical ring sign, which occurs when the scaphoid is in a flexed posture and the distal tubercle aligns with the proximal scaphoid (FIG 3A).
  - Scapholunate angle greater than 60 degrees (FIG 3B). DISI deformity pattern with capitate dorsal translation and decreased carpal height measurements
- The accuracy of MRI is affected by the strength of the magnet and the use of dedicated wrist coils.
  - Sensitivity ranges from 63% to 92%.
  - Specificity ranges from 86% to 100%, depending on the degree of injury and the type of MRI used.

DIFFERENTIAL DIAGNOSIS

- Scaphoid fracture
- Capitulonate arthritis
- Scaphotrapeziotrapezoidal (STT) arthritis

FIG 3 • A. A widened scapholunate interval (>3 mm) and a scaphoid cortical ring sign are seen on an AP view of the wrist. B. An obtuse scapholunate angle (>60 degrees) is appreciated on a lateral view of the wrist.

NONOPERATIVE MANAGEMENT

- Normal clinical alignment with persistent wrist pain with or without a Watson sign is managed with resting splints until symptoms resolve.
- Occasionally intra-articular steroid injections are performed.

SURGICAL MANAGEMENT

Contraindications to RASL

- A repairable SLIL
- A primary ligament repair is preferable if a ligament of adequate tissue quality is present.
- This is most likely seen in acute injuries (less than 3 weeks) but may be possible in chronic injuries. For this reason, arthroscopy is recommended before performing a RASL procedure to evaluate the quality of the SLIL.
- Presence of significant capitulonate or pancarpal arthritis
- If significant midcarpal, radiolunate, or radioscapoid arthritis is present, a salvage procedure, such as a proximal row carpectomy or a limited wrist fusion, may be a better treatment option.
Focal arthritis between the scaphoid and radial styloid is not a contraindication since a radial styloidectomy is routinely performed during the RASL procedure.

**Positioning**
- The procedure is performed with the patient supine and the arm on a standard hand table.
- The operating table should be rotated 90 degrees to facilitate the use of the image intensifier during the procedure.

**Approach**
- The RASL procedure can be performed either arthroscopically or via an open dorsal approach.
- The arthroscopic RASL should be attempted only after obtaining experience with the open technique, or if already a master arthroscopist.
- The open technique is performed using a dorsal intercarpal ligament-sparing approach.

**DORSAL LIGAMENT–SPARING CAPSULOTOMY**

- Make a longitudinal incision on the dorsal wrist, staying just ulnar to the tubercle of Lister (TECH FIG 1A).
- Bluntly dissect the soft tissue down to the level of the extensor retinaculum, taking care to preserve any dorsal veins and cutaneous nerve branches wherever possible.
- Incise obliquely the extensor retinaculum parallel to the course of the extensor pollicis longus (EPL) tendon (TECH FIG 1B).
- This will open the third and fourth extensor compartments.
- The EPL is retracted radially and the fourth compartment tendons are retracted ulnarly.
- Make an oblique incision through the dorsal wrist capsule parallel and proximal to the dorsal intercarpal ligament (DIC) (TECH FIG 1C).
- The dorsal radiocarpal ligament (DRC) should also be identified and preserved.

**TECH FIG 1 • A.** A dorsal midline incision is made just ulnar to the tubercle of Lister. **B.** An oblique incision is made through the extensor retinaculum parallel to the extensor pollicis longus (EPL) tendon. The EPL is retracted radially and the fourth compartment tendons are retracted ulnarly. **C.** An oblique incision is made through the dorsal wrist capsule parallel and proximal to the dorsal intercarpal ligament. The dorsal radiocarpal ligament should also be identified and preserved.

**STYLOIDECTOMY**

- Once the capsulotomy is performed, identify the scapholunate interval and the SLIL and inspect the radiocarpal and intercarpal joints.
  - If significant arthritis is present in areas other than the radiostyloscapophoid articulation, a salvage procedure is indicated.
- Perform a second incision in the midaxial line over the first dorsal compartment (TECH FIG 2A).
  - The major branch of the superficial radial nerve should be seen and isolated with a vessel loupe.
- Release the first compartment retinaculum and retract the tendons dorsally.
- Incise the capsule longitudinally through the wrist capsule, thereby exposing the radial styloid (TECH FIG 2B).
- Elevate the periosteum overlying the radial styloid and use an osteotome to perform a radial styloidectomy.
  - Remove enough of the radial styloid that radial deviation of the wrist does not cause impingement of the scaphoid and radius.
  - Too aggressive of a radial styloidectomy will compromise the volar radioscaphocapitate ligament, which originates from the base of the radial styloid.
**PREPARATION AND REDUCTION OF THE SCAPHOLUNATE JOINT**

- Place a 0.062-inch Kirschner wire in the lunate and another in the scaphoid to serve as joysticks (TECH FIG 3A).
- To bring the lunate out of extension, place the Kirschner wire in the most proximal portion of the exposed dorsal surface, angled from proximal to distal.
- Similarly, to bring the scaphoid out of flexion, place the Kirschner wire in the most distal portion of the exposed dorsal surface, angled from distal to proximal.
- Keep in mind the eventual path of the Herbert screw when placing the Kirschner wires and try to avoid this area in both bones.

- Remove the articular cartilage of the scapholunate joint using a side-cutting burr (TECH FIG 3B).
- The joysticks can be used to separate the two bones to better visualize the articular surfaces.
- Remove the cartilage until cancellous bone and punctate bleeding are visualized.
- Reduce the scaphoid and lunate by flexing the lunate and extending the scaphoid (TECH FIG 3C).
- A Köcher clamp is used to hold the reduction (TECH FIG 3D).
- Verify the reduction with an image intensifier (TECH FIG 3E).

**TECH FIG 2** • A. A longitudinal incision is made over the first dorsal extensor compartment. B. The first compartment is released and a longitudinal incision is made down to the radial styloid.

**TECH FIG 3** • A. 0.062-inch Kirschner wires are placed in the lunate and scaphoid to serve as joysticks. B. A side-cutting burr is used to remove the cartilage within the scapholunate joint. C. The joysticks are used to extend the scaphoid and to flex the lunate. D. A Köcher clamp is used to hold the reduction. E. The reduction is verified with an image intensifier.
**HERBERT SCREW PLACEMENT**

- The path of the Herbert screw should be through the center of rotation of both the scaphoid and the lunate.
- Introduce the Herbert jig through the radial incision and place the insertion point of the jig on the scaphoid waist.
- Through the dorsal incision, introduce the end of the jig and rest it on the proximal ulnar corner of the lunate.
- Do not violate the lunotriquetral interosseous ligament.
- The insertion angle of the screw should be roughly parallel to the radial inclination of the distal radius, 20 degrees (TECH FIG 4A).
- Once the jig is in proper position and both bones are properly measured, drilled, and tapped, insert the Herbert screw.
- Countersink the screw into the scaphoid so that it is not palpable.
- Correct screw placement should be confirmed by fluoroscopy (TECH FIG 4B,C).
- Remove the Köcher clamp and the joystick wires.
- Take the wrist through a full range of motion to assess for any restrictions in motion and to confirm that the scaphoid and lunate remain reduced.

**WOUND CLOSURE**

- Release the tourniquet and achieve hemostasis using Bovie or bipolar electrocautery.
- Close the dorsal and radial capsular incisions and extensor retinaculum (once the EPL and fourth compartment tendons are placed back into their respective compartments) using 3-0 absorbable monofilament suture.
- Close the skin using 5-0 nylon suture and apply a sterile bulky dressing and volar thumb spica splint.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Indications</th>
<th>Pearls and Pitfalls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsal and radial approaches</td>
<td>Carefully evaluate both radiographically and intraoperatively for the presence of significant arthrosis. Identify and protect all neurovascular structures, especially superficial radial sensory nerve branches through the radial incision. Identify the dorsal radial artery just distal to the screw insertion site before screw placement.</td>
</tr>
<tr>
<td>Radial styloidectomy</td>
<td>Avoid removing too much of the radial styloid since this may destabilize the radioscaphocapitate and long radiolunate volar ligaments. Remove just enough to prevent radioscaphoid impingement.</td>
</tr>
<tr>
<td>Kirschner wire joystick placement</td>
<td>Do not place the Kirschner wires in the centers of the scaphoid and lunate. Aim for the proximal ulnar corner of the lunate and the distal radial corner of the scaphoid to avoid interfering with the eventual path of the screw.</td>
</tr>
<tr>
<td>Bone preparation</td>
<td>When burring down the chondral surfaces of the scaphoid and lunate before screw placement, remove only the cartilage and dense subchondral bone. Removing too much bone will decrease the amount of bony contact between the scaphoid and lunate after reduction.</td>
</tr>
<tr>
<td>Screw placement</td>
<td>After placing the jig, inspect its position both visually and by fluoroscopy. The axis of the jig should cross the central portions of the scaphoid and lunate. The screw should be directed toward the proximal ulnar corner of the lunate.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE
- The wrist is kept immobilized for 4 to 6 weeks.
- After 4 to 6 weeks, the thumb spica splint is removed, a removable splint is applied, and range-of-motion therapy is initiated.
- Over time, therapy is advanced to strengthening exercises around 3 months postoperatively.

OUTCOMES
- Rosenwasser et al. reported on a series of 21 patients with a mean of 32 months of follow-up.
  - In this group, 95% of patients returned to their previous occupations. One-year postoperative scapholunate angles and intervals were corrected to within normal limits, with the scapholunate angle being corrected from 69 degrees preoperatively to 40 degrees postoperatively, and the scapholunate interval being corrected from 4.1 mm preoperatively to 1.4 mm postoperatively.
  - One patient was converted to a partial wrist fusion secondary to screw migration and failure of reduction. Another patient required removal of the screw 4 years postoperatively secondary to radial impingement and still demonstrated scapholunate stability after screw removal.

COMPICATIONS
- Residual instability
- Screw migration
- Superficial radial sensory nerve injury

REFERENCES
DEFINITION
- Isolated injury of the lunotriquetral interosseous ligament complex is less common and less well understood compared with the other proximal row ligament injury, scapholunate dissociation.
- Lunotriquetral ligament disruption can occur in isolation or in combination with other wrist pathology, such as a perilunate dislocation.
- It may result from acute trauma or chronic degenerative or inflammatory processes.
- Injuries to the lunotriquetral ligament occur in a spectrum of severity ranging from partial tears with dynamic dysfunction (most common) to complete dissociation with static collapse.
- Lunotriquetral instability can occur when the ligament complex is intact but incompetent or attenuated. If the ligament is stretched and attenuated from chronic or inflammatory degradation, instability can occur in the absence of ligament dissociation (complete disruption).

- When the lunotriquetral ligament is completely ruptured (both dorsal and volar regions), it is called a lunotriquetral dissociation.
- When the dorsal radiotriquetral ligament (and other secondary restraints) is also compromised and the entire ligament complex is disrupted, carpal collapse results. This deformity is termed volar intercalated segment instability (VISI). VISI carpal collapse cannot be reproduced by simply sectioning the dorsal and palmar subregions of the lunotriquetral ligament. Loss of integrity of the radiotriquetral ligament restraint is required to create static carpal instability (FIG 1).

ANATOMY AND KINEMATICS
- Like the scapholunate ligament, the lunotriquetral interosseous ligament is C-shaped, spanning the dorsal, proximal, and palmar edges of the joint surface.
- The palmar portion of the lunotriquetral ligament is the thickest and most biomechanically important region of the...
entire complex. In contrast, the dorsal component of the scapholunate ligament has been shown to be the strongest. The dorsal lunotriquetral ligament is important as a rotational constraint, while the palmar portion is the strongest and transmits the extension moment of the triquetrum as it engages the hamate. The membranous region has little effect on rotation, translation, or distraction. These findings illustrate the “balanced lunate” concept, which describes the lunate as torque suspended between the scaphoid and triquetrum. The scaphoid has a tendency to palmar flex, while the triquetrum has a tendency to extend. Through the lunotriquetral and scapholunate ligaments the two forces are balanced and the entire proximal carpal row is balanced about the lunate.

PATHOGENESIS

The exact mechanism of traumatic lunotriquetral ligament injuries is not fully understood. Many mechanisms may play a role.

Lunotriquetral ligament injuries can occur in Mayfield III and IV perilunate injuries (FIG 2A). An isolated traumatic lunotriquetral ligament injury may occur in a reverse perilunate injury (FIG 2B). In the absence of trauma, degenerative lunotriquetral instability can result from inflammatory arthritis. Positive ulnar variance may lead to lunotriquetral ligament degeneration by wear mechanisms or altered intercarpal kinematics (ulnar impaction syndrome).

NATURAL HISTORY

The natural history of these injuries has not been fully elucidated but they may lead to degenerative joint changes.

PATIENT HISTORY AND PHYSICAL FINDINGS

Lunotriquetral ligament injuries present as vague ulnar-sided wrist pain either acutely after trauma or as generalized ulnar-sided chronic wrist pain.
The examination should encompass the entire wrist, especially the ulnar side.
- Dorsal lunotriquetral joint tenderness should be elicited in lunotriquetral joint injuries.\(^8,11\)
- Ulnar deviation with pronation and axial compression may elicit dynamic instability with a painful snap “catch-up” clunk.
- A palpable wrist click is occasionally significant, particularly if painful and occurring with radioulnar deviation.
- Provocative tests that demonstrate lunotriquetral laxity, crepitus, and pain are helpful to accurately localize the site of pathology. Three useful tests to perform include:
  - Ballottement\(^11\): The test is positive if increased anteroposterior laxity and pain occur.
  - Compression: Pain with this maneuver may indicate pathology of the lunotriquetral or triquetral hamate joints.\(^1\)
  - Shear test\(^7\): Positive with pain, crepitance, and abnormal mobility of the lunotriquetral joint
- Other common findings on physical examination include limited range of motion and diminished grip strength.\(^8\)
- Comparison of findings with the contralateral wrist is essential.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Plain radiographs are often normal in lunotriquetral ligament injuries because the most common presentation is dynamic dysfunction that manifests only with loading or certain positions of the hand and wrist.
- Dissociation of the lunotriquetral ligament can lead to disruption of Gilula arcs I and II, demonstrating proximal translation of the triquetrum, with or without lunotriquetral overlap (FIG 3A,B). \(^6\)
- Often, no lunotriquetral gap occurs, in contrast to scapholunate injuries.
- A static VISI deformity indicates not only lunotriquetral interosseous ligament injury but also damage to the dorsal radiotriquetral ligament.
- Radial and ulnar deviation together with clenched-fist anteroposterior views are often helpful. Lunotriquetral dissociation leads to lessened triquetral motion and increased movement of the lunate, scaphoid, and distal row.\(^2\)

- Injection of local anesthetic into the midcarpal space can be useful to localize the cause of the patient’s pain.
- Addition of corticosteroid to the injection may provide temporary relief by decreasing local inflammation.
- Arthrographic dye pooling or leakage at the lunotriquetral interspace can indicate ligamentous injury (FIG 3C). However, age-dependent degenerative changes and asymptomatic lunotriquetral instability have been reported. Correlation with physical examination is required.
- Real-time videofluoroscopy can illustrate the site of a “clunk” that occurs with wrist deviation. This occurs in lunotriquetral injuries when the triquetrum “catches up” when the wrist is moved into maximal ulnar deviation.
- Technetium-99m diphosphate bone scan can aid in the localization of an acute injury but has been shown to be less specific than arthrography (FIG 3D).\(^6\)
- Magnetic resonance imaging is improving but is not yet reliable for imaging of lunotriquetral ligament injuries.

**DIFFERENTIAL DIAGNOSIS**
- The differential diagnosis of ulnar-sided wrist pain can be divided into six categories: osseous, ligamentous, tendinous, vascular, neurologic, and miscellaneous.
- Osseous injuries include the sequelae of fractures (ie, nonunion or malunion) and degenerative processes. Fracture nonunions can affect the hamate, pisiform, triquetrum, base of the fifth metacarpal, ulnar styloid process, and distal part of the ulna or radius.
- Degenerative processes at the pisotriquetral joint, midcarpal (triquetrohamate) articulation, fifth carpometacarpal joint, or distal radioulnar joint can also result in substantial ulnar-sided wrist pain. Ulnar impaction or abutment into the radius or carpus has been reported as well.
- Ligamentous injuries can occur in any of the ulnar-sided intrinsic (lunotriquetral or capitohamate) or extrinsic (ulnolunate, triquetrocapitate, or triquetrohamate) ligaments as well as the triangular fibrocartilage complex.
- Tendinopathy of the extensor carpi ulnaris or flexor carpi ulnaris
- Vascular lesions such as ulnar artery thrombosis or hemangiomas
- Neurologic processes such as entrapment of the ulnar nerve in Guyon’s canal, neuritis of the dorsal sensory branch of the ulnar nerve, and complex regional pain syndromes
- The miscellaneous group includes the very unusual etiologies such as tumors, including osteoid osteomas, chondroblastomas, and aneurysmal bone cysts.

**NONOPERATIVE MANAGEMENT**
- Initial care for most lunotriquetral ligament injuries is immobilization with a splint or cast with a pisiform lift. Initially the wrist is immobilized in a long-arm cast for 4 weeks and then a short-arm cast for an additional 4 weeks. Care should be taken to mold a pad underneath the pisiform (pisiform lift) to maintain optimal alignment as the ligament heals.
- Acute injuries without radiographic changes may be successfully treated nonoperatively.
- Symptoms of chronic injuries often improve with immobilization.
- Midcarpal injections with local anesthetic and corticosteroid often provide significant relief for a prolonged time.
If conservative management fails for either acute or chronic injuries, surgical treatment can be performed. A trial of nonoperative treatment does not seem to jeopardize the outcome of subsequent surgical intervention.

**SURGICAL MANAGEMENT**

- Operative management is indicated in acute or chronic injuries unresponsive to conservative treatment.
- The goal of surgery is to return rotational stability of the proximal carpal row and restore the natural alignment of the lunocapitate axis.
- Functional reconstruction of the lunotriquetral ligament can be accomplished with direct ligament repair, ligament reconstruction with a strip of extensor carpi ulnaris tendon graft, or arthrodesis.
- The choice of intervention should be discussed with the patient. Our preference, based on outcomes studies performed at our institution, is tendon repair or reconstruction.13
- Arthrodesis is avoided whenever possible secondary to higher complication rates and lower patient satisfaction.
- If significant degenerative changes have occurred in the lunotriquetral, radiocarpal, or midcarpal joints, partial or total carpal arthrodesis or proximal row carpectomy may be indicated.
- In the presence of significant VISI deformity that cannot be easily reduced (ie, static VISI), intercarpal arthrodesis is recommended.
- In cases of significant ulna-positive or ulna-negative variance, ulna shortening or lengthening may be indicated as well.

**DIRECT LUNOTRIQUETRAL LIGAMENT REPAIR**

**Incision and Dissection**

- A longitudinal incision is made over the third extensor compartment (TECH FIG 1).
- Alternatively, a curvilinear incision can be used.
- The dorsal sensory branch of the ulnar nerve is identified and protected.

**Preoperative Planning**

- The senior author’s preference is to perform diagnostic arthroscopy on patients with lunotriquetral ligament injuries to evaluate the articular surface and assess other intercarpal pathology.
- Anterior interosseous and posterior interosseous nerve neuroectomies can be performed at this time as well.
- The findings of the arthroscopy are discussed with the patient at a second meeting and a reconstructive or salvage procedure can then be performed 6 weeks later.
- Alternatively, a definitive surgical procedure can be performed at a single surgical setting following a thorough preoperative discussion with the patient.
- When a lunotriquetral dorsal ligament repair is planned, preparations should also be made to proceed with ligament reconstruction if the quality of the lunotriquetral ligament is poor.

**Positioning**

- The patient is positioned supine on a standard operating room table with the affected arm on a hand table.
- A long-acting axillary regional anesthetic block placed preoperatively is helpful with postoperative pain control.
- A nonsterile tourniquet is applied above the surgical drapes.
- Preoperative intravenous antibiotics are routinely administered before beginning the procedure.
- The hand and arm are prepared and draped in standard fashion.
- An examination under anesthesia is always performed initially to evaluate for “catch-up” intercarpal clunks and well as radioulnar clunks.

**TECH FIG 1**

A. Axial image of dorsal wrist compartments with arrow indicating location for skin incision over third compartment.
B. Skin incision centered over third dorsal compartment with superficial branch of the radial nerve (SBRN) and dorsal sensory branch of the ulnar nerve (DSBUN). Oval indicates tubercle of Lister. (Copyright © Mayo Clinic.)
**Chapter 47  LUNOTRIQUETRAL LIGAMENT REPAIR AND AUGMENTATION**

**TECH FIG 2**  •  **A.** Superficial dissection with extensor retinaculum visible.  **B.** Dotted line indicates incision of third compartment to release the extensor pollicis longus (EPL) tendon.  **C.** EPL released from third compartment.  **D.** Incision of extensor retinaculum over EPL.  **E.** Incision of extensor retinaculum over EPL. EPL tendon is visible distally.  **F.** EPL released from third compartment. (B,C: Copyright © Mayo Clinic.)

**TECH FIG 3**  •  **A.** Dissection of septa to create ulnar-based flap of extensor retinaculum.  **B.** Preparing to reflect extensor retinaculum.  **C.** Retinaculum has been reflected ulnarly and extensor tendons are released. (A: Copyright © Mayo Clinic.)
If not previously performed, a posterior interosseous neurectomy is performed to partially denervate the dorsal wrist capsule (TECH FIG 4).

The dorsal radiocarpal and intercarpal ligaments are identified and a ligament-splitting capsulotomy made as described by Berger and Bishop4 (TECH FIG 5A–D).

When elevating the capsule it is important not to dissect too deep over the region of the lunotriquetral area. The lunotriquetral ligament is intimately related to the radiotriquetral ligament and can be injured if attention is not paid during the capsulotomy.

The midcarpal and radiocarpal joint surfaces are exposed and examined for arthritic changes (TECH FIG 5E).

The scapholunate and lunotriquetral ligament are thoroughly examined.

The dorsal aspect of the lunotriquetral ligament is inspected to determine if it is suitable for repair. The midcarpal joint is also inspected.
The volar portion of the lunotriquetral joint is examined, and the integrity of the volar lunotriquetral ligament is indirectly inspected. If it is completely incompetent, then a direct repair of the dorsal lunotriquetral ligament is contraindicated and one should proceed to a ligament reconstruction as described later in this chapter.

Intra-articular step-off of the lunotriquetral articulation is also assessed, as well as the presence of a separate lunate facet (type II lunate).

Reattaching the Ligament

- The lunotriquetral ligament is reattached to the site of avulsion, usually the triquetrum.
- Two techniques for reattachment of the ligament exist: the use of drill holes or suture anchors. Multiple horizontal drill holes or suture anchors are placed in the dorsal, nonarticular, surface of the triquetrum (TECH FIG 6A).
- Numerous strands of nonabsorbable suture (size 2-0) are used to repair the avulsed ligament (TECH FIG 6B).
- Before tensioning and tying the sutures, the diastasis of the lunotriquetral joint must be reduced and the articular congruity at the midcarpal joint reduced. The reduction is secured by two 0.045-inch smooth Kirschner wires (TECH FIG 6C–E).
- The sutures are then tensioned and tied, but not cut short.
- Dorsal capsulodesis is then performed to augment the lunotriquetral ligament. A portion of the radiotriquetral ligament can be used to augment the lunotriquetral ligament repair by placing additional suture anchors into the lunate and triquetrum and sewing the radiotriquetral ligament to the lunotriquetral ligament.
- The ligament-splitting capsulotomy is repaired with nonabsorbable sutures (TECH FIG 6F).
- The extensor retinaculum is repaired with the extensor pollicis longus dorsally transposed.
- The skin is closed.
- A long-arm, bulky splint is applied.
Harvesting the Graft
- To avoid disrupting the extensor carpi ulnaris (ECU) sub-sheath, a 2-cm transverse incision is made through the skin and the ECU sheath 6 cm proximal to the ulnar styloid. The ECU tendon is identified (TECH FIG 7A).
- A small right-angle clamp or 90-degree retractor is used to isolate and elevate the ECU tendon (TECH FIG 7B).
- A 4-mm incision is made on the radial side of the ECU tendon to create a strip of tendon graft. A piece of 28-gauge wire is tied to the free end of the tendon graft (TECH FIG 7C).
- The ECU sheath is opened at the level of the carpometacarpal joint. The wire is looped and passed from proximal to distal through the sheath into the distal incision. The wire and tendon are gently pulled distally, creating a distally based tendon graft (TECH FIG 7D).
- The graft is passed deep to the extensor retinaculum.
- The 28-gauge wire is left tied to the end of the graft and a moist sponge is wrapped around the graft while the bone tunnels are prepared.

Bone Tunnel Creation and Graft Passage
- 0.045-inch Kirschner wires are advanced through the lunate and the triquetrum.
- The correct starting points for these Kirschner wires are the dorsal ulnar aspect of the triquetrum and the dorsal radial edge of the lunate.
- The holes should converge at the volar margin of the lunotriquetral joint and must not be intra-articular (TECH FIG 8A).
- If a reducible VISI deformity exists, it is important to place the Kirschner wires while the deformity is held reduced. Joysticks in the scaphoid and triquetrum are useful to maintain the reduction while the lunate and triquetral wires are placed (TECH FIG 8B).
- The position of the wires is checked with fluoroscopy to confirm the ability to safely enlarge the drill holes without fracture.
- The tunnels are created using a series of sharp awls or drill bits, gradually increasing the diameter until a 4- to 5-mm tunnel is created in both the lunate and triquetrum (TECH FIG 8C).
- Alternatively, a cannulated drill system can be used.
The wire previously secured to the end of the graft is looped and passed through the triquetral tunnel toward the lunate (TECH FIG 9A–C).
- An arthroscopic hook or probe is useful to hook the wire loop and pull it through the lunate bone tunnel (TECH FIG 9D,E).
- The wire is used to pass the tendon graft through the tunnels (TECH FIG 10A).
- While maintaining tension on the tendon graft, the articular surfaces of the lunate and triquetrum are reduced and two 0.045-inch Kirschner wires are passed percutaneously across the lunotriquetral joint.
- Reduction, pin position, and length are checked with fluoroscopy.
- The tendon graft is then woven through itself on the dorsum of the lunate and triquetrum and firmly secured with nonabsorbable suture (TECH FIG 10B,C).
- Excess tendon is trimmed, and the wound is irrigated with normal saline solution.
- The wound is closed as previously described in the ligament repair section.

TECH FIG 8 • A. Kirschner wires showing position of drill holes through triquetrum and lunate. The tips converge on the palmar, nonarticular surface of the joint. B. Dorsal exposure showing lunotriquetral ligament disruption and position of Kirschner wires for bone tunnels. C. Enlarging the bone tunnels to a diameter of 5 mm. (Copyright © Mayo Clinic.)

TECH FIG 9 • A–C. Straight Keith needle used to shuttle wire or heavy suture to assist in passing the extensor carpi ulnaris (ECU) tendon strip through bone tunnels—first through the triquetrum and then through the lunate. D,E. Arthroscopic hook used to pass wire or heavy suture through bone tunnels. (Copyright © Mayo Clinic.)
COMBINED REPAIR

- Ligament reconstruction with an ECU tendon strip can be combined with direct ligament repair to provide additional strength for the repair (TECH FIG 11).

- This is especially useful when the volar region of the lunotriquetral ligament is disrupted and the dorsal aspect of the ligament is attenuated.

TECH FIG 10 • A. Passing extensor carpi ulnaris (ECU) tendon strip through bone tunnels. B. ECU tendon has been passed through bone tunnels, tensioned, and sutured into itself. Kirschner wires placed percutaneously to maintain lunotriquetral joint reduction. C. Dorsal view of ligament reconstruction with ECU tendon strip. Ready for capsular repair. (Copyright © Mayo Clinic.)

TECH FIG 11 • A. Dorsal exposure before capsulotomy (fingers are to the bottom and the thumb is to the left). B. Lunotriquetral joint diastasis with dorsal lunotriquetral ligament disruption. The ligament remains attached to the dorsal lunate. C,D. Positioning Kirschner wires for drill holes. (continued)
**TECH FIG 11** (continued) **E.** 28-gauge wire passes through bone tunnels. **F, G.** The tendon graft is first advanced through the triquetrum and then through the lunate. **H.** The tendon graft is tensioned. **I.** Reduction should be verified and maintained with lunotriquetral Kirschner wires before final ligament tensioning and suture placement. **J.** Direct repair of dorsal lunotriquetral ligament utilizing suture form anchors placed into the triquetrum. **K.** Tensioning direct lunotriquetral ligament repair. **L.** Final view of the reconstruction after capsulotomy repair. Heavy nonabsorbable sutures secure the capsular repair.

**PEARLS AND PITFALLS**

**Direct repair**
- Position the drill holes in the triquetrum so that a strong bridge of bone remains to support the sutures and knots. Holes placed too close to the edge of the bone will allow the suture to pull through when tensioned.
- Pass the sutures through sufficient substance of the lunotriquetral tendon so that the suture does not tear or pull out of the tendon.
- The use of heavy, nonabsorbable suture is important for an adequate capsular repair.
- It is important to visualize and ensure the adequacy of the reduction before placing the Kirschner wires across the lunotriquetral joint.
- The senior author prefers to cut the Kirschner wire below the level of the skin. Other authors advocate percutaneous placement for easy removal.

**Ligament reconstruction with distally based ECU strip**
- Positioning the ECU tendon strip through the drill holes can be difficult. Stainless-steel wire or heavy monofilament suture can be passed first and used to shuttle the strip of tendon in the correct position.
- Tensioning the tendon and suturing it into itself can be challenging. A surgical clamp such as a Köcher or Allis can be attached to the proximal free edge of the tendon strip and used as a handle to apply traction to the tendon strip as it is being secured.
- Tension the tendon strip while the lunotriquetral joint is reduced.
- It is important to visualize and ensure the adequacy of the reduction before placing the Kirschner wires across the lunotriquetral joint.
- Adequate duration of postoperative immobilization is important to ensure a successful outcome.
POSTOPERATIVE CARE

- Edema control and range-of-motion exercises of the digits are initiated immediately postoperatively.
- Seven to 10 days after the procedure, the surgical splint is removed, sutures are removed, and a long-arm cast is applied for 6 weeks. A short-arm cast is then applied for an additional 4 to 6 weeks for a total period of immobilization of 10 to 12 weeks.
- The Kirschner wires are removed at 10 to 12 weeks and wrist range-of-motion exercises are commenced.

OUTCOMES

- A high-quality tendon repair is vital for a successful outcome of the lunotriquetral tenodesis.
- Several studies have shown that direct lunotriquetral ligament repair results in a successful clinical result.\(^5,9,11,15\)
- Reagan et al.\(^{11}\) reported that six of seven cases of direct lunotriquetral ligament repairs were successful.
- Favero et al.\(^5\) reported patient satisfaction of 90% with only one failure in 21 cases.
- In high-demand patients such as laborers and athletes, rupture or attenuation can occur and lead to late failure. Reconstruction with a strip of ECU tendon should be considered in this patient subgroup.
- A review of clinical outcomes comparing lunotriquetral ligament repair, ligament reconstruction, and lunotriquetral joint arthrodesis at our institution showed that patients treated with ligament reconstruction have the lowest reoperation rate.\(^13\)
- Rerupture after trauma and late attenuation appear to be common modes of long-term failure of direct repair.
- Review of the clinical outcomes at our institution showed that reconstruction with a strip of ECU tendon as described can be an effective treatment.\(^3\)

REFERENCES

DEFINITION

- The carpus is a complex, intercalated system of dual rows that allow paired motion within the radial–ulnar and flexion–extension plane. A disruption of the intrinsic ligaments of the carpus or a combination of ligamentous and osseous structures leads to a spectrum of injuries ranging from “wrist sprains” to complex perilunate injuries including lesser and greater arc injuries.
- Lesser arc injuries are purely capsuloligamentous.
- Greater arc injuries include a range of associated carpal fractures.
- Disruptions of the normal kinematics and stability of the carpal row lead to acute failure with a predictable pattern of posttraumatic degenerative changes.

ANATOMY

- There are eight carpal bones without tendinous insertions, whose motion is passively transmitted and guided by precise ligamentous architecture and bony geometry.
- Volar extrinsic ligaments are the prime stabilizers of the carpus and are oriented in a double-V arrangement with a relative weakness between these V’s called the space of Poirer.
  - The volar extrinsic ligaments include the inner-V ligaments: long radiolunate (LRL), radioscapulonate (RSL), short radiolunate (SRL), and ulnolunate (UL). The outer V consists of the radioscapulocapitate (RSC) and the ulnotriquetrocapitate complex (UTCC) (FIG 1A).
  - The dorsal extrinsic ligaments provide less structural stability and include the radiotriquetral (RT) and dorsal intercarpal (DIC) ligaments (FIG 1B).
- The intrinsic ligaments are direct intercarpal connections that provide intra-row stability.
  - These include the lunotriquetral and the scapholunate ligaments.
  - Complex, three-dimensional motion occurs with wrist movement: radial deviation and wrist dorsiflexion are paired, as are ulnar deviation and wrist volarflexion.

PATHOGENESIS

- These may involve high-energy injuries in which an axial load is applied to a hyperextended and ulnarly deviated wrist, placing the volar structures under tension and the dorsal structures under compression and shear.
- The energy dissipates in a radial to ulnar direction.
- Lesser arc injuries are purely ligamentous and advance through four progressive stages as originally described by Mayfield et al (FIG 2A):
  - Stage I: the scapholunate ligament
  - Stage II: the space of Poirer
  - Stage III: the UTCC and UL ligament
  - Stage IV: lunate dislocation
- Greater arc injuries proceed in the same direction but involve fractures through the radial styloid, scaphoid, lunate, capitate, triquetrum, and ulna, either solely or in combination (FIG 2B).
- Perilunate dislocations most commonly occur as dorsal dislocations of the capitate and surrounding carpus with respect to the lunate, which remains in the lunate fossa of the distal radius.
- A lunate dislocation often involves volar displacement of the lunate into the carpal tunnel, with the capitate articulating in the lunate fossa of the radius. Median neuropathy is common. The lunate is ousted from the wrist joint through the space of Poirer, creating a rent in the volar capsule that extends medially and laterally along the interval between the V ligaments. The rent is semilunar or crescentic in appearance.

NATURAL HISTORY

- Nonoperative management yields predictably poor results, with loss of reduction and progression to wrist deformity and pain.1,2

FIG 1 • A. Volar extrinsic carpal ligaments. LRL, long radiolunate ligament; SRL, short radiolunate; RSC, radioscapulocapitate ligament; UL, ulnolunate ligament; UTCC, ulnotriquetrocapitate complex; *, space of Poirer. B. Dorsal extrinsic carpal ligaments. RTq, radiotriquetral ligament; DIC, dorsal intercarpal ligament; *, scaphoid.
Typical instability patterns (depending on extent of injury) include scapholunate advanced collapse, scaphoid nonunion advanced collapse, and volar or dorsal intercalated segmental instability.

Definitive treatment is operative intervention.

PATIENT HISTORY AND PHYSICAL FINDINGS

A typical history may range from a fall and twist on an extended hand to a high-energy event with extreme forces transferred to the wrist. Patients complain of pain and stiffness.

Physical examination findings depend on the level of injury and the elapsed time from injury to presentation.

Stiffness, tenderness, crepitus, swelling, and resistance to motion are common findings. Deformity is usually minimal.

Depending on the severity of injury, the findings can be subtle and easily missed. The examiner must maintain a high index of suspicion.

DIFFERENTIAL DIAGNOSIS

Given the severity of this injury pattern and the frequency with which it is missed, greater and lesser arc injuries must be ruled out in any situation in which the wrist is traumatized.

- Wrist sprain
- Triangular fibrocartilage complex (TFCC) injury
- Extrinsic or intrinsic ligament disruptions
- Carpal fractures
- Distal radius or ulna fracture
- Median neuropathy
- Kienböck disease
- Ulnar impaction syndrome
- DeQuervain tenosynovitis
- Basal joint arthritis

NONOPERATIVE MANAGEMENT

Closed reduction of perilunate dislocations may be achieved by in-line traction and gentle wrist manipulation as described by Tavernier.6

In-line traction is helpful for muscle relaxation before reduction and can be applied using finger traps and weights suspended from the arm with the elbow flexed 90 degrees for 10 minutes.

The surgeon extends the wrist and applies gentle manual traction. The surgeon’s thumb stabilizes the lunate volarly.
and rotates the lunate into extension. The capitate is then translated up and over the lunate while simultaneously flexing the wrist. A snapping sound may be heard when the capitate reduces over the lunate.

- Closed reductions of lunate dislocations are frequently unsuccessful. As traction is applied to the wrist, the volar rent narrows to prevent reduction of the lunate into the wrist joint.
- Acute carpal tunnel syndrome in this scenario is a surgical emergency.
- Long-term outcomes of closed reduction have been shown to be suboptimal, and surgical treatment is warranted.

SURGICAL MANAGEMENT

Preoperative Planning

- All radiographs are reviewed.
- The surgeon should determine what ligaments are damaged and whether biosuture anchors are needed to augment repair.
- The surgeon should assess osseous structures and determine whether fractures need to be stabilized with hardware such as Kirschner wires or dual-pitch screws.
- If median neuropathy is present or impending, a carpal tunnel release should be performed.

Positioning

- Supine positioning with a well-padded pneumatic tourniquet on the upper arm
- The use of a radiolucent hand table with fluoroscopic imaging aids in repair and reduction.

DORSAL APPROACH

Incision and Dissection

- A universal dorsal skin incision is made under tourniquet control. The extensor retinaculum is exposed, raising medial and lateral skin flaps. Access to the dorsal capsule is gained through the 3–4 extensor compartment interval (TECH FIG 1A).
- The extensor pollicis longus (EPL) tendon is dissected distal to the extensor retinaculum and the third compartment is incised. The EPL is transposed radially to prevent injury to the tendon during manipulation and stabilization of the carpus (TECH FIG 1B).
- The fourth extensor compartment is incised longitudinally and the tendons are retracted. The dorsal capsule is now visible.
- One centimeter of the posterior interosseous nerve is excised as part of the procedure (TECH FIG 1C).
- A transverse rent extending through the dorsal capsule and radiotriquetral ligament is often found. This rent...
should be extended in both the radial and ulnar directions to allow visualization of the capitolunate interval.
- A more extensile ligament-sparing incision can also be used to gain considerable access to the carpus.
- Incise the capsule in a radial direction along the dorsal distal radial lip, leaving a small cuff of tissue attached to the radius for later repair.
- Incise ulnarly, along the dorsal radiotriquetral ligament and dorsal intercarpal ligament. This generates a radially based capsular flap (TECH FIG 1D).
- If the dislocation was not reducible closed, the capitate is prominent and the absence of the lunate is evident.
- The articular injury can now be assessed.

**Reduction and Fixation**
- Before reduction of the dislocation–subluxation, 0.045- or 0.062-inch Kirschner wire transfixation pins are inserted into the triquetrum and scaphoid through the dorsal incision in an in-to-out fashion. These pins are later driven back into the lunate to stabilize the reduction.
- The starting point for these pins is through the centroid of the aspect of the proximal pole of the scaphoid and triquetrum that articulates with the lunate (TECH FIG 2).
- Transfixation pins are unnecessary in the scaphoid if it is fractured since a screw in the scaphoid will stabilize the radial side of the carpus.
- In combination with manual traction and volar pressure on the lunate, insert a Freer elevator into the capitolunate

**TECH FIG 1** • A. Universal dorsal skin incision for the dorsal approach. B. The third extensor compartment is incised and the extensor pollicis longus (EPL) is transposed radially. The extensor digitorum communis (EDC) tendons are visible. (Thumb is at top left and wrist is to the right.) C. The fourth extensor compartment is incised and the EDC tendons are retracted ulnarly. The sensory branch of the posterior interosseous nerve to the wrist (vessel loop) is sacrificed. D. A ligament-sparing capsular incision may be made to visualize the carpus. Sc, scaphoid.

**TECH FIG 2** • Transfixation pins are placed through the scaphoid and triquetrum before reduction of the lunate. This facilitates placement of these Kirschner wires and advancement into the lunate after reduction. The entry point is the centroid of the intercarpal joint on the scaphoid and triquetrum. The tips of the Kirschner wires are seen slightly protruding from the scaphoid and triquetrum. The lunate is displaced volarly and is not visible.
joint around the proximal pole of the capitate and shoehorn the lunate into place.

- Reduce and stabilize carpal fractures.
- Attention is first directed toward fixation of an associated scaphoid fracture using proximal to distal (ante-grade) fixation.
  - The scaphoid is usually fractured at its waist or proximal pole.
  - In a noncomminuted fracture, stabilization is accomplished with a cannulated headless compression screw.
  - If comminution exists, autologous cancellous bone graft is applied before final tightening of the screw.

Ligament Repair

- Intercarpal ligament injuries may now be repaired.
- In a transscaphoid perilunate dislocation, the proximal pole of the scaphoid remains attached to the lunate with an intact scapholunate ligament. However, in lesser arc injuries, the scapholunate and the lunotriquetral ligament are disrupted.
- Before ligamentous repair, anatomic carpal realignment is ensured.
  - 0.045-mm Kirschner wires are introduced into the scaphoid, lunate, and triquetrum and used as joysticks to align these bones.
  - The previously set Kirschner wires used as transfixation pins are then advanced from the scaphoid and triquetrum into the lunate.

- Transfixation pins are also percutaneously introduced to stabilize the scaphoid and triquetrum to the capitate (TECH FIG 3A).
- Intraoperative fluoroscopy aids alignment and placement of Kirschner wires.
  - The scapholunate angle (40 to 60 degrees), capitolunate angle (less than 15 degrees), and radiolunate angle (less than 15 degrees) should be reduced and verified.
  - The C shape of the distal radius, lunate, and capitate should be concentric (TECH FIG 3B).
- Small (about 2 mm) suture anchors with nonabsorbable suture (2-0 to 3-0) are inserted for reattachment of the scapholunate and lunotriquetral ligaments, avoiding the Kirschner wires.
  - Most often the ligaments avulse from the scaphoid and the triquetrum; therefore, the anchors are placed in those locations.
  - When the intercarpal ligaments are beyond repair, suture anchors are unnecessary, and stability is established via extrinsic capsuloligamentous healing.
  - The dorsal capsular injury and extended capsulotomy is closed with nonabsorbable suture.
  - The EPL tendon is left transposed in a subcutaneous location (TECH FIG 3C).
  - The subcutaneous tissue and skin are closed in a standard fashion.

**TECH FIG 3** • Transfixation pins are in place protecting the ligament repairs and maintaining anatomic carpal alignment. Suture anchors were not required for repair in this case. The intercarpal ligament injuries were midsubstance.

- The PA radiograph shows the reduced trapezoidal shape of the lunate and restoration of the lines of Gilula. **A.**
- The lateral radiograph shows the reduced scapholunate, radiolunate, and capitolunate angles. The three concentric C’s are also visible. **B.**
- Repair of the extensor retinaculum and transposed extensor pollicis longus. **C.**
COMBINED DORSAL AND VOLAR APPROACH
(AUTHORS’ PREFERRED APPROACH)

Incision and Dissection
- A standard extended carpal tunnel approach is performed under tourniquet control (TECH FIG 4A).
- The median nerve is completely decompressed.
- The contents of the carpal canal are retracted and hematoma is evacuated.
- The volar capsuloligamentous injury, which is represented by an apex-distal, semilunar rent, is visualized (TECH FIG 4B).
- This rent courses between the RSC and LRL radially, and between the UTCC and ulnolunate ligaments ulnarly.
- In the case of a lunate dislocation, the lunate can be visualized within the carpal canal, having been extruded through the capsular tear.
- Next, the wrist is exposed dorsally as described above.
- The degree of injury is assessed.

Reduction, Fixation, and Repair
- Preset transfixation Kirschner wires as previously described.
- Reduce the carpus under direct visualization, with wrist extension and the aid of a Freer elevator to shoehorn the capitate into the lunate fossa.
- The volar approach facilitates the reduction by allowing direct access to the lunate.
- Surgical extension of the capsular tear between the RSC and LRL ligaments or between the UTCC and ulnolunate ligaments allows greater access to the wrist without further disruption of extrinsic ligaments.
- Through the dorsal incision, reduce, stabilize, and repair any associated carpal fractures and intercarpal ligament injuries in the manner described above.
- The volar capsuloligamentous rent is closed with nonabsorbable suture (TECH FIG 5).
- The flexor tendons may now be assessed. Often the tenosynovium surrounding the tendons within the carpal tunnel is thickened. A tenosynovectomy may be performed.
- The EPL should be left transposed dorsally.
- The subcutaneous tissue and skin are closed in a standard fashion.

TECH FIG 4 • A. Extended carpal tunnel incision used for the volar approach. B. A volar, semilunar, apex-distal, capsuloligamentous rent is visible at the space of Poirier. The lunate (Lu) is seen protruding from the rent.

TECH FIG 5 • The volar capsule is closed with nonabsorbable suture.
### POSTOPERATIVE CARE
- The immediate postoperative dressing includes a well-padded splint immobilizing the wrist and forearm in a neutral rotational position with about 20 degrees of wrist extension.
  - Edema control and prevention of skin maceration can be accomplished with the addition of sterile gauze dressings between the digits and a bulky dressing within the palm.
  - Active and passive digital range-of-motion exercises are encouraged immediately to prevent flexor tendon adhesions and digital stiffness.
  - Sutures are removed at 10 to 14 days and full-time cast or splint immobilization is continued for a total of 8 weeks postoperatively.
  - Pins may be removed at 8 weeks, and the patient may be converted to a removable splint to promote range of motion of the wrist.
  - At 12 weeks, strengthening is permitted with progressive resistance as tolerated.
  - Anticipated return to activities is 6 to 12 months.

### OUTCOMES
- Outcomes will vary with regard to stiffness and grip strength.
  - More accurate anatomic reduction will lead to improved results. Sotereanos et al\(^3\) used a dorsal–volar approach in 11 patients with perilunate dislocations and fracture-dislocations. Good to excellent results were achieved in 9 of 11 patients.
- Up to 50% loss of flexion–extension motion arc can be anticipated.\(^3\)
- Up to 60% diminished grip strength can be anticipated.\(^3\)

### COMPLICATIONS
- Missed diagnosis
- Postoperative pin-tract infections
- Median nerve injury
- Transient ischemia of lunate
- Chondral injury or chondrolysis
- Late carpal instability
- Nonunion or malunion of the scaphoid
- Posttraumatic arthritis

### REFERENCES
DEFINITION
- The triangular fibrocartilage complex (TFCC) is a complex anatomic structure located at the ulnar side of the wrist. It has several important biomechanical functions:
  - Extends the gliding surface of the radiocarpal joint
  - Cushions and stabilizes the ulnar carpus
  - Stabilizes the distal radioulnar joint (DRUJ)
- Disorders of the TFCC are responsible for the ulnar-sided wrist symptoms of pain, weakness, and instability that affect the patient’s function.
- The diagnosis and treatment of these injuries to the TFCC will restore stability, resulting in pain relief and a generally good prognosis for functional return.

ANATOMY
- The TFCC is a cartilaginous and ligamentous structure interposed between the ulnar carpus and the distal ulna (FIG 1A). It arises from the distal aspect of the sigmoid notch of the radius and inserts into the base of the ulnar styloid.17
- The TFCC attaches to the ulnar carpus via the ulnocarpal ligament complex (ulnolunate, ulnotriquetral, and ulnar collateral ligament) (FIG 1B).
- The radioulnar ligaments stabilize the DRUJ, limiting rotation as well as axial migration.7
- The dorsal and volar radioulnar ligaments are fibrous thickenings within the substance of the TFCC.
- As a result of this anatomic configuration, they function as a unit rather than as independent ligaments.
- The central, horizontal portion of the TFCC is the thinnest portion, composed of interwoven obliquely oriented sheets of collagen fibers for the resistance of multidirectional stress.
- The vascularity of the TFCC has been carefully studied.3 The TFCC receives its blood supply from the ulnar artery through its radiocarpal branches and the dorsal and palmar branches of the anterior interosseous artery. These vessels supply the TFCC in a radial fashion (see Bednar et al3 for a good image of TFCC vascularity).
- Histologic sections demonstrate that these vessels penetrate only the peripheral 10% to 40% of the TFCC. The central section and radial attachment are avascular.
- This vascular anatomy supports the concept that peripheral injuries can heal if injured and treated appropriately, whereas tears of the central portion do not heal if sutured and are usually debrided.

Biomechanics
- The TFCC has several important biomechanical functions: it transmits 20% of an axially applied load from the ulnar carpus to the distal ulna; it is the major stabilizer of the DRUJ; and it is a stabilizer of the ulna.1,6,18,19
  - The amount of the load transferred to the distal ulna varies with ulnar variance. A greater amount is transferred in positive ulnar variance than negative.
  - This results in a corresponding decreased thickness of the central portion of the TFCC in ulnar-positive wrists.
  - There is a variable load placed on the TFCC with forearm rotation. Supination causes a negative ulnar variance due to the proximal migration of the ulna. This is reversed with pronation as the ulna moves distally, causing it to become ulnar-positive.
  - The ulnar head also moves within the sigmoid notch in a dorsal direction with pronation and a volar direction with supination.
- The dorsal and volar radioulnar ligaments, which form the peripheral portion of the TFCC, serve as major stabilizers to translation at the DRUJ during forearm rotation.

PATHOGENESIS
- Traumatic injuries of the TFCC result from either the application of an extension, pronation force to the axially loaded wrist or a distraction force to the ulnar aspect of the wrist.

FIG 1 • A. Anatomic coronal section demonstrating the triangular fibrocartilage (TFC) and its relation to the lunate (L), triquetrum (T), distal ulna (U), and radius (R). B. Triangular fibrocartilage complex.
This will most commonly occur with a fall on the outstretched hand or a resisted torque force.

- The lesions are more common with ulnar-positive and neutral patients and are frequently found in patients with fractures of the distal radius.
- Several authors have examined the incidence of intracarpal soft tissue injuries associated with distal radial fractures.
- Geissler et al studied 60 patients, finding a TFCC injury in 26 (43%).
- In Lindau et al’s series of 51 patients, 43 had a TFCC injury (84%): 24 had a peripheral tear, 10 had a central perforation, and 9 had a combined central and peripheral tear.
- In a study of 180 wrist joints in 100 cadavers ranging in age from fetuses to 94 years, Mikic found that degeneration of the TFCC begins in the third decade of life.
- This degeneration increases in frequency and severity as people age.
- After the fifth decade of life, 100% of TFCCs appear abnormal.
- However, these age-related TFCC lesions are often asymptomatic.

**NATURAL HISTORY**

- The classification system described by Palmer is the most useful for describing TFCC injuries, dividing them into traumatic and degenerative.
- Traumatic lesions are classified according to the location of the tear within the TFCC. The traumatic class has been designated by Palmer as class 1, with subclasses of A, B, C, and D assigned to anatomic lesions within the TFCC (FIG 2A).
  - A class 1A lesion represents a tear in the horizontal or central portion of the TFCC. The tear is 2 to 3 mm medial to the radial attachment of the cartilage. It is usually oriented from dorsal to volar.
  - A class 1B lesion represents an avulsion of the peripheral aspect of the TFCC from its insertion onto the distal ulna. This can occur either with a fracture of the ulnar styloid or as a pure avulsion from its bony attachment. This type of injury disrupts the stabilizing effect of the TFCC on the DRUJ, resulting in clinical instability.
  - A class 1C lesion represents an avulsion of the TFCC attachment to the ulnar carpus by disruption of the ulnocarpal ligaments. These lesions result in ulnar carpal instability with volar translocation of the carpus.
  - A class 1D lesion represents an avulsion of the TFCC from its radial attachment. Isolated disc tears should be differentiated from disruption of the dorsal and volar radioulnar ligaments. Such global TFCC injury will result in DRUJ instability.
- Degenerative type 2 lesions are age-related, nontraumatic lesions to the TFCC, typically characterized by central perforations and positive ulnar variance. The natural history of such degenerative lesions, when and if they become symptomatic, is a progressive cascade of degenerative changes, as reflected in Palmer’s type 2 classification (FIG 2B).
  - The deterioration proceeds from TFC wear through central perforation (type 2C) to lunatotriquetral ligament tear and arthritic changes of the lunate, triquetrum, and distal ulna (type 2D or E).
  - Treatment is based on the stage of involvement.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Symptoms consist of ulnar-sided wrist pain, frequently with clicking, that typically occurs after a fall.
- The initial physical examination reveals swelling over the ulnar aspect of the wrist with inflammation of the tendon of the extensor carpi ulnaris.
- Point tenderness is present over the TFCC and distal ulna. The more isolated the point of maximal tenderness, the more specific the diagnosis.
  - A fovea sign (point tenderness directly over the ulnar TFC origin) indicates a type 1A or 1B TFCC injury or an ulnar extrinsic injury type [1C]).
  - Ulnar deviation and axial loading of the wrist (TFCC compression test) will elicit a painful response and a click with forearm rotation.
  - The DRUJ must be assessed for instability. Instability is best assessed with the forearm in neutral rotation, but it is also checked in full supination and full pronation.
  - The examiner stabilizes the distal radius with one hand and applies a force to the distal ulna, moving it dorsal and...
volar, looking for increased motion or subluxation of the distal ulna relative to the radius and comparing it with the opposite uninjured wrist.

- Significant instability can present as laxity of the distal ulna with a positive “piano key” sign and dorsal prominence of the distal ulna. This may be due to a significant tear or detachment of the dorsal or volar radioulnar ligaments.

- A click produced by ulnar deviation and supination over the extensor carpi ulnaris (ECU) sheath at the distal ulna indicates ECU instability with subluxation out of its sixth extensor compartment.

- A visual carpal supination deformity with ulnar prominence that can be passively corrected by a dorsally applied force to the pisiform indicates an ulnar extrinsic ligament tear.

- TFCC injuries do not occur in isolation; they are often a component of a spectrum of injury to the ulnar side of the wrist. The examiner must therefore evaluate all of the commonly injured structures on the ulnar side of the wrist.

- The lunatotriquetral joint must be assessed for instability due to a lunatotriquetral ligament tear. This would cause tenderness over the lunatotriquetral interval with a positive shock test (painful click as the lunate and triquetrum slide abnormally).

- Point tenderness over the triquetrum may signify a triquetral avulsion fracture.

- An audible clunk and visual subluxation of the carpus that occur with active ulnar deviation suggest that a midcarpal instability is present.

- Crepitus and pain over the pisotriquetral joint on the shear test may indicate pisotriquetral arthritis.

- The other soft tissue structures around the ulnar wrist should be examined, including the ulnar nerve, the dorsal ulnar sensory nerve branch, and the ulnar artery.

- Grip strength measurements using a Jamar dynamometer, while subjective, are helpful in quantitating patient effort and as a parameter to follow therapeutic progress.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- The diagnostic workup should include plain radiographs and a neutral rotation posteroanterior and lateral view.

- This will allow assessment for fracture, ligament instability resulting in carpal malalignment, and ulnar variance. It is important to determine ulnar variance because it will influence treatment options (FIG 3A).

- The DRUJ must also be examined radiographically to determine if subluxation, arthritis, or ulnar styloid abnormalities such as an acute or chronic nonunited fracture fragment are present.

- MRI is useful in the diagnosis of TFCC tears, especially the class 1A and D lesions.\textsuperscript{9,11} T2-weighted images in the coronal plane are of the greatest diagnostic value (FIG 3B).

- The TFCC has a homogenous low signal intensity. The synovial fluid of the joint appears as a bright image on T2 and will outline tears in the TFCC.

- A gadolinium arthrogram enhances the visualization of TFCC tears.

- The reported sensitivity and specificity of MRI in diagnosing injuries of the TFCC in the literature is variable.

- Golimbu et al\textsuperscript{9} reported a 95% accuracy of MRI in the detection of TFCC tears. MRI findings were verified arthroscopically.

- Schweitzer et al\textsuperscript{20} reported a sensitivity of 72%, a specificity of 95%, and an accuracy of 89%.

- Arthroscopic findings were correlated with the MRI and clinical examination in a series of patients with TFCC injuries reported by Bednar et al.\textsuperscript{2} The MRI sensitivity was 44% (the probability of a positive MRI when a TFCC lesion is present) and the specificity was 75% (the probability of a negative MRI when a TFCC lesion is absent). The clinical examination sensitivity was 95%. The MRI correlated with arthroscopic findings in 45% of the wrists studied.

- Joshy et al\textsuperscript{13} reported on a series of patients with a clinical suspicion of a TFCC tear studied by MR arthrography and then wrist arthroscopy. The MR arthrography sensitivity was 74% and its specificity was 80%. They caution that negative results of MR arthrography in patients with clinical suspicion of TFCC tear should be interpreted with caution.

- Wrist arthroscopy has recently become the criterion standard for both diagnosing and treating lesions of the TFCC.\textsuperscript{6}

- When compared to MRI and arthrography, arthroscopy most accurately determines the location of lesions and the size of tears and allows determination of whether a flap is unstable.

- Wrist arthroscopy can determine the coexistence of other lesions such as tears within the lunotriquetral interosseous ligament, ECU subsheath, or chondral lesions.

**DIFFERENTIAL DIAGNOSIS**

- ECU subluxation
- Ulnar extrinsic ligament tear
- DRUJ instability
- Triquetral avulsion fracture
- Lunatotriquetral ligament injury
- Pisotriquetral arthritis
- Ulnar artery thrombosis
- Ulnar neuropathy at the canal of Guyon
- Dorsal ulnar sensory neuritis
NONOPERATIVE MANAGEMENT

- The initial treatment of acute TFCC injuries includes immobilization of the wrist and DRUJ.
- The patient must be examined carefully to look for DRUJ instability or ECU subluxation.
- If the radiographs are negative and instability is not present, then immobilization for 4 to 6 weeks is recommended to allow healing of the TFCC disruption.
- A peripheral tear is expected to heal if the torn edges are held in close contact, due to the good vascularity of the periphery of the TFCC. Many central tears also become asymptomatic with immobilization even though there is no significant vascularity to the central portion.
- After immobilization, a therapy program involving range-of-motion exercises and gradual strengthening is initiated. Forceful grasp or torque is restricted for 8 weeks.
- If there is ongoing synovitis, a well-placed cortisone shot can further help to quiet this inflammation.
- Tears involving the ligamentous portion of the TFCC or those that heal with a flap of cartilage that impinges on the carpus or distal ulna will fail to respond to conservative treatment and will require operative intervention.
- It is reasonable to wait 3 to 4 months before proceeding to surgical treatment.
- Class 1B lesions without an ulnar styloid fracture and a stable DRUJ can be immobilized for 4 weeks in a cast. If an ulnar styloid fracture is present, closed reduction should be attempted. If adequate reduction is achieved, then cast immobilization is sufficient. If the styloid remains displaced, then open reduction and internal fixation is required.

SURGICAL MANAGEMENT

- Patients who remain symptomatic after adequate immobilization should undergo further workup, including MRI with or without gadolinium.
- The specific treatment for each traumatic class 1 lesion is determined by the type of tear found arthroscopically.
- Arthroscopic treatment has become increasingly the method of choice for many traumatic lesions.
- The treatment of traumatic radial detachment of the TFCC from the sigmoid notch of the distal radius is controversial. There appears to be no vascularity to this portion of the TFCC, so theoretically a reattached cartilage would not heal at this repair site. However, clinical experience with open repair of these tears has been positive.\(^5\,\,\,21\) This may be attributed to vascular ingrowth from the bony radial insertion site that occurs with abrasion of the attachment site, stimulating the formation of new vessels.
- If the radial tear includes disruption of one or both of the radioulnar ligaments, repair is required to prevent chronic DRUJ instability.
- The algorithm for the treatment of degenerative type 2 tears proceeds from arthroscopy to ulnar-shortening osteotomy (see Chaps. HA-94 and HA-95).
- Plain films should identify the ulnar variance, DRUJ alignment, abnormalities of the ulnar styloid, or the presence of arthritic changes. Positive ulnar variance has a strong association with degenerative tears.

Preoperative Planning

- All physical examination findings and radiographic study results must be reviewed.
- Examination under anesthesia is performed, including the tests discussed earlier, before positioning in the arthroscopy tower.

Positioning

- Wrist arthroscopy requires distraction, and the wrist is positioned in the traction tower (FIG 4).

WRIST ARTHROSCOPY

- Diagnostic wrist arthroscopy of the radiocarpal and midcarpal joints is completed and all pathology is identified.
- Recognize the appearance of a normal TFC (TECH FIG 1).
- The type of TFC injury is identified.
  - A trampoline test is positive when the surgeon’s probe sinks into the TFCC rather than bouncing off it like a drumstick on a snare drum. Such loss of disc compliance is often seen with a peripheral tear.\(^10\) However, laxity of the TFCC does not necessarily translate into DRUJ instability.
  - Loose bodies, if present, are removed.
  - Inflamed synovium is removed with a shaver or radiofrequency probe.
Peripheral TFC tears are well vascularized and amenable to repair using arthroscopic techniques. A two-needle method similar to that employed for the repair of a knee meniscus is described here (TECH FIG 2A).

Visualize the tear through the 3–4 portal.

Initial arthroscopic evaluation may not reveal a tear of the TFCC periphery, but often synovitis and a thin scar will be seen along the periphery of the TFCC at the location of the tear (TECH FIG 2B).

A probe placed through the 6R portal will demonstrate loss of the normal trampoline effect of the TFCC, indicating a peripheral tear and loss of mechanical function of the TFCC (TECH FIG 2C).

Débride the edges of the tear and undersurface scarring with a shaver to create mobile edges with fresh areas for healing.

Adhesions may be present between the undersurface of the TFCC and the distal ulna. These must be released and the TFC mobilized sufficiently to allow advancement to reattach it and to restore proper tension.

After débridement, a 1-cm longitudinal incision is made extending the 6R portal.

Avoid injury to branches of the dorsal ulnar sensory nerve.

Open the sixth extensor compartment radially for 1 cm and retract the extensor carpi ulnaris ulnarily, providing access to its subsheath.

The repair includes the subsheath of the ECU compartment as this is intimately associated with the peripheral TFC.

Two needles are passed across the tear under arthroscopic vision (TECH FIG 2D).

A wire loop is passed through one needle to retrieve a 2-0 PDS suture, which is passed through the other needle.

This allows the placement of a horizontal mattress suture across the tear (author’s preference) (TECH FIG 2E).

Alternatively, multiple simple vertical sutures placed at the periphery of the TFCC may approximate the torn edges and restore tension to the TFCC. The suture is tied either under the skin over the dorsal wrist capsule (preferred) or out of the skin over a bolster. Usually two or three sutures are placed.

Postoperatively, a short-arm splint is applied.

I have not found a significant difference between use of a short-arm splint and use of a long-arm or sugar-tong splint in regard to healing and outcome.

**TECH FIG 2**  
*A.* Meniscus repair needles with 2-0 PDS suture used for an out-to-in repair.  
*B,C.* Peripheral TFC tear with loss of compliance such that the probe sinks into the lax surface. Unlike a central tear, fibrous tissue and incomplete healing obscure the actual tear.  
*D.* Arthroscopic repair of a type 1B peripheral TFC complex tear. Two hollow needles are passed across the tear. A wire loop in one needle is used to pass 2-0 suture across the tear. The suture is tied over the capsule.  
*E.* The suture approximates the tear and restores tension to the TFCC.
OPEN REPAIR OF PERIPHERAL TFC TEARS WITHOUT ULNAR STYLOID FRACTURE

- If there is significant DRUJ instability and avulsion of the TFC from the ulna fovea, an open repair is preferred.
- Expose the fifth extensor compartment and retract the extensor digiti quinti minimi tendon.
- Create an L-shaped capsulotomy of the DRUJ and identify the foveal attachment site of the TFC (TECH FIG 3A).
- Reattach the TFC with a bone anchor or bone suture (TECH FIG 3B–D).
- Postoperative care mirrors that of arthroscopic TFC repair.10

TECH FIG 3 • Open repair of unstable TFCC avulsion. A. Dorsal exposure through the fifth extensor compartment. A DRUJ capsulotomy has been performed. B. Defining the foveal insertion site. C. Insertion of bone anchor at foveal attachment. D. Sutures in place.

OPEN REPAIR OF PERIPHERAL TFC TEARS WITH ULNAR STYLOID FRACTURE

- Expose the ulnar styloid using an incision just volar and parallel to the ECU tendon.
- Protect the dorsal ulnar sensory nerve and preserve the ECU sheath.
- Base the method of fixation (longitudinal Kirschner wire, screw, bone anchor, or tension band) on fragment size and surgeon comfort.
- If the ulnar styloid is comminuted and will not allow stable fixation, it can be excised and the TFCC attached to the ulna by a suture placed through drill holes in the ulna proximal to the fracture or using the suture anchor technique described earlier.
- The patient is immobilized in a short-arm splint or cast for 4 weeks before starting rotational motion.

Surgery for Radial-Sided TFC Avulsion Tears

- Assess the tear arthroscopically (TECH FIG 4A) and repair it in the manner detailed below if instability is present.
- Place a burr through the 6R portal to roughen the radial attachment of the TFCC (TECH FIG 4B).
- Drill two holes using a 0.062-inch Kirschner wire in a retrograde manner, starting at the TFC insertion site. These holes will allow placement of the repair suture.
- The wires must exit the radius on its radial border, just volar to the first extensor compartment.
- An incision is made over the exiting Kirschner wire to retract and protect the radial sensory nerve and the tendons of the first extensor compartment.
- A cannula is placed in the 6R portal, through which a meniscal repair suture (2-0 PDS suture with a long straight needle at each end) is passed through the torn radial aspect of the TFCC in a horizontal mattress fashion, with each needle passing through the predrilled holes in the radius. (TECH FIG 4C).
- The placement of the needles into the predrilled holes can be challenging since the holes are not visible by the scope in the 3-4 portal. Two 18-gauge spinal needles can be placed from the radial side of the radius through the bone until they can be seen in the joint at the attachment site for the TFCC. The needles provide a visible target for the meniscal repair suture needles.
- If the meniscal repair suture with long straight needles is not available, pass 18-gauge needles through the bone tunnels, then directly through the torn radial TFC. A 2-0 PDS suture is passed from one 18-gauge needle to the other using a wire retrieval loop.
- The suture is tied over the radius (TECH FIG 4D).
- A short-arm splint is applied.
TECHNIQUES

WRIST INSTABILITIES

TRAUMATIC RADIAL TFC TEAR
A. Traumatic radial TFC tear. Such an isolated tear can be débrided or repaired based on the degree of instability. B. Radial TFC tear repair. Burring of the attachment site along the sigmoid notch of the radius to bleeding bone is necessary to introduce additional vascularity and promote wound healing. C,D. Radial tears are repaired with suture on meniscal needles, tied over a bone bridge on the radial aspect of the distal radius.

PEARLS AND PITFALLS

Indications
- Traumatic and degenerative TFC lesions with sufficient symptoms
- If the DRUJ is stable, allow 3 to 4 months of nonoperative treatment.

Preoperative evaluation
- Assess ulna variance.
- Physical examination under anesthesia
- Complete diagnostic wrist arthroscopy of both radiocarpal and midcarpal joints
- A complete history and physical examination of ulnar wrist pain causes

Treatment options relate to type of TFC lesion
- 1A: arthroscopic débridement
- 1B without fracture: arthroscopic or open repair (DRUJ instability)
- 1B with ulna styloid fracture and instability: reattach ulna styloid
- 1C: Rare 1B repair plus ulnar extrinsic ligament repair
- 1D: If isolated, débrane; if unstable, repair
- Degenerative lesions: arthroscopic wafer or ulna-shortening osteotomy

Pitfalls
- Excise only unstable central TFC portion.
- Protect dorsal sensory nerves and extensor tendons.

POSTOPERATIVE CARE
- After open or arthroscopic TFC repair, a short-arm splint or cast is applied for 4 to 6 weeks.
- Range-of-motion exercises are then progressed, using a removable splint for protection initially.
- Forceful wrist use is restricted for 3 months.

OUTCOMES
- Arthroscopic limited débridement of the central portion of the tear will provide excellent relief of symptoms, with 80% to 85% of patients having a good to excellent result.15
- The biomechanical effect of excision of the central portion of the TFCC has been examined.1,6 The excision of the central two thirds of the TFCC with maintenance of the dorsal and volar radioulnar ligaments as well as the ulnocarpal ligaments had no statistical significant effect on forearm axial load transmission. The removal of greater than two thirds will unload the ulnar column, shifting load to the distal radius and destabilizing the DRUJ. Adams1 further emphasized that the peripheral 2 mm of the TFCC must be maintained during central débridement in order not to have a biomechanical effect on load transfer.
- The results of arthroscopic repair of 1B TFCC lesions are equivalent to those reported for open repair. Gratifying outcomes are reached 85% to 90% of the time.5,6,22
- The treatment of radial detachment of the TFCC from the sigmoid notch of the distal radius remains controversial.
- Débridement of an isolated radial tear not associated with joint instability, similar to that for 1A lesions, yields excellent results.15
- Clinical experience with open repair of radial TFC avulsion tears has also been good.5,21 Short21 reported 79% excellent and good results in his series, with return of grip strength to 90%, after arthroscopic repair of radial TFC tears.

COMPLICATIONS
- Failure to make a complete diagnosis (eg, associated ECU subluxation)
Chapter 49 ARTHROSCOPIC AND OPEN TRIANGULAR FIBROCARTILAGE COMPLEX REPAIR

- Failure to appreciate DRUJ instability
- Loss of wrist motion
- Injury to dorsal sensory nerves
- Nonunion of the ulnar styloid or ulnar osteotomy

REFERENCES

DEFINITION
 Distal radioulnar joint (DRUJ) instability may be classified as acute or chronic, unidirectional (volar or dorsal) or bidirectional, and isolated or in association with other injuries. There is no consensus regarding the definition of clinically significant instability, though various radiographic criteria have been used. In general, the key physical finding is the presence of increased anteroposterior translation of the DRUJ with passive manipulation when compared with the normal side. Although the radius actually rotates around the stable ulna, by convention DRUJ dislocation or instability is described by the position of the ulnar head relative to the distal radius.

ANATOMY
 The DRUJ consists of the articulation between the ulnar head and the sigmoid notch of the distal radius and the associated supporting soft tissues. The DRUJ is not a congruent joint. The shallow sigmoid notch has a radius of curvature that is on average 50% greater than the ulnar head. Joint surface contact area is maximized at neutral rotation. Though the sigmoid notch is relatively flat, the dorsal and volar rims, which are typically augmented by fibrocartilaginous extensions, do provide an important contribution to joint stability. The soft tissue structures that contribute to DRUJ stability are the pronator quadratus, extensor carpi ulnaris (ECU) and its sheath, interosseous membrane, DRUJ capsule, and several components of the triangular fibrocartilage complex (TFCC). Multiple structures must be injured to result in joint instability.

The palmar and dorsal radioulnar ligaments are the prime components of the TFCC that stabilize the DRUJ. They are thickenings at the combined junctures of the triangular fibrocartilage articular disc, DRUJ capsule, and ulnocarpal capsule. As each radioulnar ligament passes ulnarly, it divides in the coronal plane into two limbs. The deep or proximal limbs of the radioulnar ligaments attach at the fovea and the superficial or distal limbs attach to the base and midportion of the ulnar styloid (FIG 1B). The total pronation–supination arc in a normal individual varies between 150 and 180 degrees. Normal pronation and supination involves a combination of rotation and dorsal-palmar translation of the distal radius on the stable ulna.

PATHOGENESIS
 The most common cause of DRUJ disruption is a fracture of the distal radius. Distal radius angulation greater than 20 or 30 degrees creates DRUJ incongruity, distorts the TFCC, and alters joint kinematics. More than 5 to 7 mm of radial shortening results in rupture of at least one of the radioulnar ligaments. Fractures of the tip of the ulnar styloid are not typically associated with DRUJ instability. Fractures of the base of the ulnar styloid can result in disruption of the radioulnar ligaments, causing DRUJ instability. Most isolated DRUJ dislocations (not associated with a fracture) are dorsal and caused by forceful hyperpronation and wrist extension, such as with a fall on an outstretched hand or the sudden torque of a rotating power tool.

![Image](image1.png)

**FIG 1** • A. Distal radioulnar joint (DRUJ) cross-section. The radius of curvature of the sigmoid notch is much greater than the radius of curvature of the ulnar head. B. DRUJ ligaments. (The disk component of the triangular fibrocartilage complex has been removed to show the deep limbs of the radioulnar ligaments.) The volar and dorsal radiopalmar ligaments, the major soft tissue stabilizers of the DRUJ, insert at the fovea and onto the base of the ulnar styloid.
Isolated volar DRUJ dislocations occur with an injury to the supinated forearm or a direct blow to the ulnar aspect of the forearm.

**Natural History**
- Delayed diagnosis and treatment of DRUJ injuries associated with distal radius fractures results in worse outcomes.\(^7\)
- Chronic instability rarely improves spontaneously.
- Although there is no proven association between DRUJ instability and the development of symptomatic arthritis, some degeneration should be expected in recurrent dislocators.

**Patient History and Physical Findings**
- Patients may report falling on an outstretched hand or a forced rotation of the hand followed by ulnar-sided wrist pain and swelling.
- Patients with chronic instability may report a clunk at the wrist with forearm rotation.
- Pain and weakness is exacerbated by activities requiring forceful rotation while gripping, such as turning a screwdriver.
- Increased passive volar-dorsal translation of the ulna relative to the radius is evidence of DRUJ instability.
- When treating an acute distal radius fracture with evidence of DRUJ disruption, the fracture should be reduced and stabilized first, followed by assessment of the DRUJ, as the fracture management alone usually provides adequate treatment for the DRUJ.
- In the absence of DRUJ arthritis, patients with DRUJ instability typically have full or nearly full wrist range of motion, including flexion, extension, pronation, and supination.
- A thorough patient examination should include the following tests:
  - Passive translation (“piano key” sign). Perform the test and compare results to the unaffected side. A positive test result indicates DRUJ instability, which is seen in 14 of 14 patients treated by ligament reconstruction.\(^2\)
  - Modified press test. Increased depression of ulnar head on affected side (“dimple” sign) indicates instability.\(^2\) Pain without increased depression may indicate a TFCC tear.\(^6\)
  - Passive forearm rotation. A painful clunk indicates gross DRUJ instability. This should not be confused with more subtle ECU subluxation.

**Imaging and Other Diagnostic Studies**
- A zero-rotation posteroanterior view is obtained by abducting the humerus 90 degrees, flexing the elbow 90 degrees, and placing the forearm on a flat surface. Signs of DRUJ instability on this view include:
  - Displaced fracture at the base of the ulnar styloid
  - Fleck fracture from the fovea of the ulnar head
  - Widening of the DRUJ
  - Greater than 5 mm of acquired ulnar or positive variance compared to the opposite wrist
- A true lateral radiograph is performed with the arm at the patient’s side and the elbow flexed 90 degrees. Obtaining a true lateral radiograph is important to avoid inaccurate assessment of DRUJ alignment. Mino et al\(^9\) showed that only 10 degrees of rotation from neutral resulted in an inability to correctly diagnose DRUJ dislocation on the lateral radiograph.

On a true lateral wrist radiograph, the lunate, proximal pole of the scaphoid, and triquetrum should overlap completely and there should be no space between the triquetrum and pisiform.

**CT** must be performed on both wrists, with each image obtained with the forearm in identical rotation to allow comparison between the normal and symptomatic joints (Fig 2).

The addition of applied stress to the joint during imaging may aid in detection of subtle instability.\(^10\)

MRI (with or without intra-articular dye) may be used to detect TFCC tears, although the reported sensitivity and specificity for such injuries is variable. MRI can also be used instead of CT to assess the shape of the sigmoid notch and joint stability.

**Differential Diagnosis**
- ECU tendinitis or subluxation
- Ulnar impaction syndrome
- DRUJ arthritis
- Pisotriquetral arthritis
- Lunotriquetral ligament injuries
- TFCC disc tears

**Nonoperative Management**
- Patients with mild chronic instability may benefit from a course of nonsteroidal anti-inflammatories, a splint that limits forearm rotation, and a forearm strengthening program.
- Patients with generalized ligamentous laxity and bilateral DRUJ instability have less predictable results with operative reconstruction. In such patients, all attempts at conservative management should be exhausted before considering surgery.

**Fig 2** • CT of distal radioulnar joint (DRUJ). A. Well-reduced asymptomatic DRUJ. B. Subluxated DRUJ on the symptomatic side. (A, B: dorsal is left and volar is right.)
SURGICAL MANAGEMENT

- Distal radioulnar ligament reconstruction is indicated in cases of chronic DRUJ instability where tissues are inadequate for primary repair of the TFCC.
- The goal of ligament reconstruction is to restore DRUJ stability and provide a full, painless arc of forearm motion.
- The technique described creates stability by near-anatomic reconstruction of the dorsal and volar radioulnar ligaments.
- If present, osseous malalignment must be addressed at the time of ligament reconstruction to obtain a good result.

Preoperative Planning

- The surgeon should review imaging studies for evidence of osseous deformity or degeneration of the DRUJ articular surfaces. Soft tissue reconstruction in the presence of substantial residual bony deformity or arthritis will yield poor results.

Intra-articular radioulnar ligament reconstruction requires a competent sigmoid notch for success. A notch that is developmentally flat or that has posttraumatic deficiency of either rim should be treated with a sigmoid notch osteoplasty at the time of ligament reconstruction.
- The surgeon should determine the presence of suitable tendon graft. The palmaris longus (PL) tendon is typically used. Alternative graft sources include plantaris, extensor digitorum longus, or most commonly a strip of the flexor carpi ulnaris tendon.
- The PL tendon can be identified by having the patient flex the wrist while holding the tips of the thumb and small finger together.

Positioning

- The patient is positioned supine with the affected limb resting on a hand table. Additional positioning may be necessary to allow access to graft harvest sites.
- A well-padded tourniquet is placed on the upper arm.

PALMARIS TENDON GRAFT HARVEST

- The PL tendon is identified by palpation. It is one of the most superficial structures at the distal wrist crease and lies just ulnar to the flexor carpi radialis tendon (TECH FIG 1A).
- A single 1-cm transverse incision is made at the proximal volar wrist crease overlying the PL tendon (TECH FIG 1B).
- A shepherd's hook is used to pull tension on the tendon and absolutely confirm its identity.
- The tendon is clamped with a hemostat and transected just distal to the hemostat.
- A small tendon stripper is passed distal to proximal along the PL tendon in the forearm to complete the harvest.
- Alternatively, a strip of the flexor carpi ulnaris tendon can be harvested using a tendon stripper through the same volar incision for graft passage.

DORSAL APPROACH

- A 5-cm skin incision is made between the fifth and sixth extensor compartments overlying the DRUJ (TECH FIG 2A).
- The fifth compartment is opened and the extensor digiti minimi is retracted.
- An L-shaped capsulotomy is made in the DRUJ capsule with one limb in line with the sigmoid notch and the other just proximal and parallel to the TFCC (TECH FIG 2B). The ECU tendon sheath marks the ulnar limit of the capsulotomy.
- The ECU tendon sheath is not disrupted during this approach.

TECH FIG 1 • Graft harvest. A. The palmaris tendon can be brought into relief by having the patient touch the thumb and small fingers while flexing the wrist slightly. B. A small transverse incision is made at the proximal wrist crease.
BONE TUNNEL PLACEMENT

- Careful subperiosteal dissection is used to elevate the soft tissue from the dorsal edge of the sigmoid notch for several millimeters.
- A guidewire for a 3.5-mm cannulated drill bit is driven from dorsal to volar through the radius.
  - The tunnel should begin several millimeters proximal to the lunate fossa and about 5 mm radial to the articular surface of the sigmoid notch (TECH FIG 3A).
  - The tunnel should be parallel to the articular surfaces of both the sigmoid notch and lunate fossa.
- Fluoroscopy is used to confirm guidewire placement, and the tunnel is made with a 3.5-mm cannulated drill bit (TECH FIG 3B).
- If a corrective osteotomy of the radius is planned, it is easier to make the bone tunnels before performing an osteotomy, but the tendon graft should not be placed or tensioned until the osteotomy is completed.
- The ulnar flap of the DRUJ capsulotomy is elevated to expose the ulnar head and neck, being careful not to interrupt the ECU tendon sheath.
- The ulnar bone hole travels from the ulnar fovea to exit on the lateral ulnar neck just volar to the ECU tendon (see Tech Fig 3A). Flex the wrist pronate the forearm, and retract the TFCC remnant to reveal the ulnar fovea. Pass a guidewire retrograde from the ulnar fovea to exit on the lateral ulnar neck just volar to the ECU tendon. Confirm the guidewire position with fluoroscopy. If flexing the wrist does not provide adequate exposure, the tunnel may be created antegrade from ulnar neck to fovea, while carefully protecting any TFCC remnant and the ulnar carpus (TECH FIG 3C).
- Standard drill bits may be used to enlarge the bone tunnels to accommodate the previously harvested graft. The ulnar bone tunnel must accommodate both limbs of the tendon graft.
GRAFT PASSAGE

- A second exposure is made to visualize the volar aspect of the radius bone tunnel.
- A 3-cm longitudinal incision is made extending proximally from the proximal wrist crease (TECH FIG 4A).
- Dissection is carried down between the ulnar neurovascular bundle and finger flexor tendons to reach the volar surface of the radius.
- A suture passer is passed through the radius bone tunnel from dorsal to volar and used to pull one end of the tendon graft back through the distal radius (TECH FIG 4B).
- A straight hemostat is passed over the ulnar head, dorsal to volar, to bluntly pierce the volar DRUJ capsule just distal to the ulnar head. The other end of the graft is grasped and pulled back through the capsule.
- At this point, both tendon ends should be visible through the dorsal wound. The suture retriever is used to pass both tendon ends through the ulna bone tunnel from the fovea to exit at the ulnar neck (TECH FIG 4C).
- A curved hemostat is used to guide the tendon ends around a portion of the ulnar neck in opposite directions, with one limb of the graft passing deep to the ECU sheath and the other around the volar neck (TECH FIG 4D).
- Avoid entrapping any nearby neurovascular structures.

TECH FIG 4 • Graft passage. A. A small volar approach is necessary to allow graft passage. B. A suture passer travels through the radial bone tunnel (dorsal to volar) to retrieve one limb of the graft (indicated by a red vessel loop). C. In this dorsal view, the graft is brought through the volar capsule into the ulnocarpal joint then the two ends are fed into the ulna tunnel. D. In this axial drawing the course of the free graft is visualized. The graft provides a near-anatomic reconstruction of the volar and dorsal radioulnar ligaments. E. The graft (red vessel loop) exits the radial bone hole (short arrow) into the dorsal wound and then enters the ulnar bone hole through the fovea (long arrow). The ends of the graft are then wrapped around the ulna neck.
**Chapter 50 INTRA-ARTICULAR RADIOULNAR LIGAMENT RECONSTRUCTION**

**POSTOPERATIVE CARE**
- The patient is placed in a long-arm splint with the forearm in neutral to slight pronation or supination, depending on the most stable DRUJ position. At the first postoperative visit, the patient is transitioned to a long-arm cast for 3 weeks.
- At 4 weeks postoperatively, the patient is placed in a well-molded short-arm cast for an additional 2 weeks.
- At 6 weeks after surgery, the cast is changed to a removable splint, which is worn for an additional 4 weeks.
- The patient should be able to return to most activities by 4 months after surgery, but heavy lifting and impact loading are avoided until 6 months postoperatively.

**OUTCOMES**
- Patients with a deficient sigmoid notch are more likely to experience recurrent instability if the deficits are not corrected.
- Most patients experience decreased pain and improved strength and stability while maintaining near-normal range of motion. However, full recovery may require 6 to 9 months.
- The described technique effectively restored stability in 12 of 14 patients while providing about 85% of the strength and range of motion of the contralateral unaffected side. The two failures resulted from deficiencies of the sigmoid notch that were not recognized preoperatively.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Indications</th>
<th>Patients with chronic DRUJ instability in whom the TFCC cannot be repaired. Confirm the patient does not have DRUJ arthritis or a deficient sigmoid notch.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graft management</td>
<td>Harvest the graft early to determine bone tunnel size. Use a suture passer to facilitate graft passage.</td>
</tr>
<tr>
<td>Tunnel placement</td>
<td>Place the tunnel an adequate distance from the articular surfaces of the DRUJ and lunate fossa to prevent fracturing into the joint. If concurrently performing a corrective osteotomy, make the bone tunnels before completing the osteotomy.</td>
</tr>
</tbody>
</table>

**COMPLICATIONS**
- Joint stiffness
- Recurrent instability
- Persistent pain
- Weakness of grasp
- Infection
- Complex regional pain syndrome

**REFERENCES**

**GRAFT TENSIONING AND FIXATION**
- The forearm is held in neutral rotation and the DRUJ is manually compressed.
- The two graft limbs are pulled taut and a half-hitch knot is made against the dorsal aspect of the ulnar neck.
- While maintaining firm tension in the graft, the half-hitch is secured with 3-0 nonabsorbable sutures (TECH FIG 5).

**TECH FIG 5 • Graft tensioning. Tension is held on the graft while the knot is secured with a suture.**

- Teoh and Yam reported similar results, with restoration of stability in seven of nine patients using a similar reconstructive method.


DEFINITION

- The diagnostic and therapeutic challenge presented by instability of the ulnocarpal joint reflects the inherent biomechanical and anatomic incongruity of the articulation.
- The triangular fibrocartilage complex (TFCC) provides the majority of anatomic and functional stability of the distal radioulnar and ulnocarpal joints.\(^1,16\)
- As expected, the consequences of TFCC lesions reflect a disruption of its normal function. The Hui-Linscheid procedure and the modified Herbert reconstruction are two approaches to achieve surgical stabilization of the distal radioulnar joint (DRUJ). The Hui-Linscheid reconstruction stabilizes the DRUJ by augmenting function of the ulnocarpal ligament,\(^6\) while the modified Herbert reconstruction restores the radioulnar and ulnocarpal functions of the TFCC by ligamentotaxic constraint of the ulnar carpus.\(^3\)

ANATOMY

- The ulnar carpus does not directly articulate with the distal ulna; instead, the ulnar carpus is suspended from the ulnar head by the TFCC.
- The TFCC is a collection of soft tissue structures that stabilizes the radial-ulnar-carpal unit (FIG 1). It consists of fibers originating from the subsheath of the extensor carpi ulnaris, the ulnocarpal ligaments, the dorsal and palmar radioulnar ligaments, and the triangular fibrocartilage proper.
- The TFCC provides a continuous gliding surface that spans the distal surfaces of the radius and ulna, allowing carpal movements and acting as a dynamic stabilizer of the forearm during pronation and supination.\(^12,18\) In addition to its radioulnar function, the TFCC stabilizes the ulnar side of the carpus, aids in load transference from the ulnar carpus to the ulna, and cushions ulnocarpal forces.\(^16\)
- The dorsal and volar distal radioulnar ligaments, which are often referred to as the marginal ligaments, help to stabilize the radioulnar joint through its extremes of motion.
- While controversy exists concerning the exact role of each marginal ligament, several authors have agreed that the ligaments act in concert to stabilize the DRUJ during pronosupination.
- The extensor retinaculum is a thick fibrous band of tissue that holds the extensor tendons against the distal radius and ulna to prevent bowstringing and displacement of the tendons (FIG 2). It is continuous with the palmar carpal ligament and shares connecting fibers with the flexor retinaculum just proximal to the pisiform. The extensor retinaculum attaches to the pisiform and triquetrum medially and to the lateral margin of the radius laterally. It is positioned from a radial-proximal to ulnar-distal direction.\(^15,19\)

PATHOGENESIS

- Injuries to the TFCC can occur secondary to trauma, such as a fall on the outstretched hand, or from degenerative changes caused by repetitive loading, especially in patients with rheumatoid arthritis. Palmer has classified TFCC abnormalities by differentiating between traumatic and degenerative pathologies, with further specification within each group.\(^11\)
- Dorsal subluxation of the ulnar head, with or without supination deformity of the radiocarpal complex and ulnocarpal instability, can occur with attenuation or tears of the dorsal radioulnar ligaments.\(^16,18\) The Hui-Linscheid reconstruction repairs these defects through augmentation of ulnocarpal ligament

![FIG 1](image)

The soft tissue structures encompassing the triangular fibrocartilage complex of the wrist stabilizing the radial-ulnar-carpal unit. The triangular fibrocartilage proper originates from the radius medially and attaches to the base of the ulnar styloid. Fibers originating from the subsheath of the extensor carpi ulnaris dorsally cross paths with fibers originating from the ulnocarpal ligaments volarly and blend with the triangular fibrocartilage proper.
Ulnocarpal instability may also result from incompetence of the ulnocarpal ligaments, either secondary to acute trauma or from cumulative attrition. The modified Herbert reconstruction addresses ulnocarpal instability by using ligamentotaxis to stabilize both the ulnocarpal and radioulnar aspects of the DRUJ.

**Natural History**

Ulnocarpal instability is a relatively common finding in the general population. Approximately two thirds of asymptomatic volunteers were found to have some form of ulnocarpal instability on physical examination. Medical or surgical intervention is necessary if symptoms are present or are worsening.

The unstable ulnocarpal joint uses the radiocarpal joint as a pivot. The abnormal rotation in this pathologic state leads to increased pain, weakness, and loss of function during wrist supination. In addition, an ulnar-sided supination deformity may be present.

**Patient History and Physical Findings**

In both acute and chronic cases, the clinical presentation of the ulnocarpal instability consists of ulnar-sided wrist pain with or without clicking, especially with forearm pronation–supination activities, such as putting topspin on a tennis ball with a forehand shot.

> There may be demonstrable laxity during supination and weakness in passive or active pronation–supination movements. These symptoms may hinder range of motion and function of the wrist.
> On physical examination, patients often localize tenderness to the ulnar carpus on palpation.
> The examiner should palpate the ulnar styloid.
> The examiner should palpate between the ulnar styloid and triquetrum.
> Visual inspection of the ulnocarpal area is important, looking for swelling and alignment of the carpal area in relation to the ulna. Swelling may be the result of acute injury. Position of tissues indicates stability or instability.
> In the absence of concomitant pathology, provocative maneuvers such as Watson and shuck tests are negative.
> Watson test: Pain and movement of the scaphoid despite blocking its normal capacity to flex in radial deviation is an indication of scapholunate tear or laxity.
> The Shuck test is performed to evaluate lunotriquetral instabilities.
> A positive piano key test indicates a complete peripheral tear of the TFCC and/or dorsal radioulnar ligament tear.
> Midcarpal instability can be ruled out with a negative wrist pivot shift test, as first described by Lichtman et al.
> In patients with ulnocarpal instability, the wrist assumes an ulnar-sided supination deformity similar to that seen in rheumatoid arthritis.
> A key to diagnosing ulnocarpal instability is the supination test, which is a diagnostic maneuver developed by the first author. This examination is performed by stabilizing the affected DRUJ with a firm grasp while stressing the wrist in supination and volar translation.
> When the wrist is loaded axially and returned through neutral in ulnar deviation, the patient’s pain is reproduced. The wrist may also “clunk” back into reduction.
> The contralateral wrist is also tested for comparison.

**Imaging and Other Diagnostic Studies**

- Standard posteroanterior and lateral radiographs have poor diagnostic value for ulnocarpal joint instabilities but can be used to rule out scapholunate interosseous ligament (SLIL) and lunatotriquetral interosseous ligament (LTIL) tears. On a pure lateral view, if there is DRUJ instability, the ulna will be dorsally positioned relative to the radius instead of being seen superimposed on the radius.
- Computed tomography is useful for visualizing joint congruity and fractures as well as subluxation or dislocation of the DRUJ.
- Live fluoroscopy during the supination test allows the examiner to evaluate and visualize the presence and amount of ulnocarpal joint instability (FIG 3).
  - The changing appearance of the triquetrum, demonstrated by its decreased length while in a position of supination, indicates ulnocarpal instability.
  - The pisiform’s location in relation to the triquetrum may also indicate the type of ligamentous tear or laxity by either moving together with the triquetrum during the supination test or appearing to be stationary as the triquetrum is moving.
  - Triple-injection arthrography of the midcarpal row, radiocarpal joint, and DRUJ can be useful in showing SLIL or...
LTIL tears, TFCC tears, and ulnar-sided TFCC tears, respectively.
- The findings must correlate with symptoms for accurate diagnosis.\textsuperscript{8,17}
- Standard magnetic resonance (MR) imaging effectively demonstrates the normal anatomy of the TFCC as well as the intrinsic and extrinsic ligaments of the wrist.
- Abnormalities of these structures can be detected with experience, but the radiographic literature has reported shortcomings of standard MR in diagnosing peripheral TFCC tears.
- MR arthrography, with injection of contrast into the DRUJ, has been shown as an adequate way of diagnosing peripheral TFCC tears, with a sensitivity of 85\% and specificity of 76\% when compared to wrist arthroscopy.\textsuperscript{14}
- Wrist arthroscopy is widely considered the gold standard of diagnostic studies of the wrist. Arthroscopic visualization allows for the determination of the size, location, and extent of ligamentous injuries of the wrist.
- Comparison of arthroscopy to arthrography by Cooney\textsuperscript{2} revealed arthroscopy to be the superior method of diagnosing injuries of the TFCC and interosseous ligaments.

**DIFFERENTIAL DIAGNOSIS**
- Fracture
- DRUJ instability
- Extensor carpi ulnaris subluxation
- TFCC lesions
- Ulnar impaction syndrome
- Degenerative changes of DRUJ and ulnar carpus
- Carpal instability, scapholunate tear (dorsal intercalated segment instability [DISI]), lunotriquetral tear (volar intercalated segment instability [VISI])
- Tendinitis
- Chondromalacia
- Ligament injuries
- Ulnocarpal instability

**NONOPERATIVE MANAGEMENT**
- Conservative treatment includes the use of a removable soft leather splint that minimizes motion of the wrist, such as those originally designed for use by gymnasts.
- If the patient wishes to return to athletic activities, he or she should proceed with cautious limitation while wearing a sports splint.
- Although these splints allow for motion of the wrist and for the use of athletic tools, the patient must understand that he or she must reduce the intensity of activity to a level that the wrist will tolerate.
- When activity levels are limited or more support is needed, such as while sleeping, a static splint is advised.
- Physical or occupational therapy, including training to increase range of motion and to strengthen the muscles spanning the ulnocarpal and distal radioulnar joints, may be beneficial.
- Nonsteroidal anti-inflammatories are also recommended before deciding on surgery, with an initial trial of 4 to 6 weeks.

**SURGICAL MANAGEMENT**
- The main indication for surgery is a painful ulnocarpal joint with diminished grip or pronosupination strength (or both) that does not respond to conservative treatment.
- Individuals with high demand for strong wrist function in weight-bearing supination (eg, golfers, tennis players, certain skilled labor professions) may be considered for surgery even without first receiving conservative treatment.

**Preoperative Planning**
- The surgeon should review all imaging studies to identify any concomitant pathology of the wrist joint.
- Arthroscopic examination of the wrist is generally undertaken immediately before ulnocarpal reconstruction to address any concomitant lesions or synovitis within the wrist.
- Diagnostic physical examination maneuvers are repeated while the patient is under anesthesia. These maneuvers include the piano key test and ulnocarpal supination test, as described earlier.
Positioning
- Using an arm board, the patient is positioned with the forearm in pronation and the elbow flexed at 45 degrees. The dorsal aspect of the wrist joint is prepared in a sterile manner.

Approach
- Modified Herbert reconstruction
  - Exposure of the dorsal surface of the wrist joint is the only surgical approach needed for the Herbert sling repair.
  - The Herbert sling procedure consists of the development of an ulnar-based flap of the extensor retinaculum, advanced at a 30- to 40-degree angle from distal ulnar to proximal radial by securing into the distal radial retinacular attachments.
  - This reduces the radioulnar joint and the carpus to the ulna with a single advancement of the extensor retinaculum (FIG 4).
- Hui-Linscheid reconstruction
  - A standard incision on the dorsal surface of the wrist is used to access the ulnocarpal articulation, the ulnar head, and the flexor carpi ulnaris.
  - A tendon graft is harvested from the flexor carpi ulnaris and passed through the tunnel in the ulnar head and looped back to its proximal insertion on the pisiform.

MODIFIED HERBERT RECONSTRUCTION
- Create a longitudinal incision over the fifth extensor compartment at the level of the wrist (TECH FIG 1A).
- Incise the extensor retinaculum between the fourth and fifth compartments, taking care not to enter the fourth compartment (TECH FIG 1B).
- Raise an ulnarly based flap of the distal two thirds of the retinaculum, and prepare the extensor digiti quinti (EDQ) for transposition dorsal to the retinaculum flap (TECH FIG 1C).
INCISION AND DISSECTION
- Start the incision at the level of the fifth carpometacarpal joint. Curve the incision over the ulnocarpal joint to reach the far ulnar border and continue to the middorsal forearm for exposure of the dorsal carpal ligament (TECH FIG 2A).
- Locate and protect the dorsal sensory branch of the ulnar nerve (TECH FIG 2B, C).
- Incise the extensor retinaculum over the sixth extensor compartment, taking care to protect the underlying extensor carpi ulnaris tendon and subsheath.
- Retract the extensor retinaculum medially to expose the capsule over the ulnocarpal joint and the subluxated ulnar head, creating an ulnarily based flap of retinaculum (TECH FIG 2D).

HUI-LINSCHEID RECONSTRUCTION

Incision and Dissection
- Place the wrist in neutral and apply downward force on the distal ulna to reduce the DRUJ.
- Translate the retinacular flap proximally and suture it to the periosteum of the ulnar border of the distal radius using 2-0 PDS absorbable sutures (TECH FIG 1D).
- Carefully imbricate the extensor retinaculum in an oblique fashion (30 to 40 degrees) from distal-ulnar to radial-proximal (TECH FIG 1E).
- The EDQ is relocated dorsally of the imbricated extensor retinaculum flap.

TECH FIG 1 • (continued) C. Raise an ulnar-based flap. Prepare the extensor digiti quinti to be transposed dorsal to the extensor retinaculum. D. The retinacular flap is sutured to the periosteum of the ulnar border on the distal radius. E. Imbricate the extensor retinaculum obliquely in a distal-ulnar to radial-proximal direction. The extensor digiti quinti should remain dorsally of the imbricated extensor retinaculum flap.

TECH FIG 2 • Hui-Linscheid reconstruction. A. Make a slightly curving incision over the ulnocarpal joint to reach the lateral ulnar border and continue it to the middorsal forearm for exposure of the dorsal carpal ligament. (continued)
Part 6  HAND, WRIST, AND FOREARM • Section V  WRIST INSTABILITIES

TECH FIG 2 • (continued) B. Take care not to injure the dorsal branch of the ulnar sensory branch during the incision and throughout the procedure. C. The ulnar nerve is located volar to the incision. The extensor retinaculum is incised at the fifth dorsal compartment. Protect the underlying extensor carpi ulnaris tendon and subsheath. D. Retract the extensor retinaculum medially to expose the capsule over the ulnocarpal joint and the subluxated ulnar head, creating an ulnar-based flap. E. Incise the capsule to expose the distal radioulnar joint while preserving the dorsal radioulnar ligament and taking care not to injure the extensor carpi ulnaris. F. Drill a 0.625-inch Kirschner wire through the ulnar head in a distal-to-proximal direction. The guidewire should be inserted obliquely starting from the base of ulnar styloid and aiming toward the synovial reflection proximally.

- Make a longitudinal incision in the capsule to expose the DRUJ while preserving the dorsal radioulnar ligament (TECH FIG 2E).
- Drill a 0.0625-inch Kirschner wire obliquely through the ulnar head beginning near the base of ulnar styloid to the ulnar fovea proximally (TECH FIG 2F).
- Placement of the Kirschner wire is confirmed visually and sequential hand awls are used to create a 4- to 5-mm bone tunnel.

Tendon Graft Harvest

- Locate the flexor carpi ulnaris (FCU) in the incision distally and trace it to the musculotendinous junction. This will allow about 10 cm of tendon graft for harvest (TECH FIG 3A).
  - If needed, a separate longitudinal incision on the palmar area of the wrist can be used.
  - Alternatively, a free tendon graft from the palmaris longus or other donor area may be used if the FCU tendon is inadequate.
- Split the FCU tendon longitudinally and cut the graft proximally at the musculotendinous junction. Leave the distal portion still attached at its insertion onto the pisiform (TECH FIG 3B).
- Perforate the pisotriquetral capsule in a dorsal to volar direction (TECH FIG 3C).

TECH FIG 3 • Hui-Linscheid tendon harvest. A. The flexor carpi ulnaris (FCU) is located distally and traced into the muscle belly to obtain about 10 cm of tendon graft. (continued)
The FCU tendon is passed intracapsularly using a tendon passer or by placing a Kessler suture into the tendon edge and using the suture to pull the tendon through the capsular perforation.

- Ensure that the graft does not place any tension on the ulnar artery or nerve (TECH FIG 3D,E).
- The FCU tendon graft is passed through the TFCC if it is perforated or through an enlargement of the prestyloid recess of the TFCC and through the drill hole in the distal end of the ulna.

**Completion of the Reconstruction**

- The carpal supination and the ulnar head dorsal subluxation is reduced by pulling the FCU tendon graft taut from its pisiform insertion.
- Hold this reduction by placing the forearm in supination and transfix the distal ulna to the distal radius with two parallel 0.062-inch Kirschner wires.
- Close the DRUJ capsule incision using a 3-0 nonabsorbable suture.
- The FCU tendon graft is pulled taut through the drill hole and then secured to the periosteum adjacent to the ulna bone tunnel using a 2-0 nonabsorbable suture.
- The FCU graft is doubled back superficially to the radioulnar capsule (TECH FIG 4A) and sewn to its pisotriquetral insertion (TECH FIG 4B).
- If the dorsal radioulnar ligament is found to be attenuated, imbrication of the ligament is performed.
- The extensor retinaculum is imbricated using a nonabsorbable 3-0 suture.


**PEARLS AND PITFALLS**

**Modified Herbert Reconstruction**

| Orientation of the capsulorrhaphy | Imbricate the extensor retinaculum in an oblique fashion (distal-ulnar to proximal-radial) to maximize the ulnocarpal ligamentotaxis effect of the repair. This will minimize the risk of postoperative supination deformity. If imbrication occurs at 90 degrees perpendicular to the DRUJ, only the DRUJ will be stabilized, not the ulnocarpal instability. |
| Placement of sutures in extensor retinaculum | Avoid injury to surrounding tissues or nerve structures (the dorsal branch of the ulnar nerve and the posterior interosseous nerve, terminal branch) when placing sutures in the extensor retinaculum (FIG 5). This will minimize the risk of postoperative wrist pain and dysesthesia. |
| EDQ tendinitis | The tendinitis usually resolves within 6 months. |
| Postoperative therapy | Advise the patient to avoid aggressive strengthening too soon after surgery, which may lead to loosening of the extensor retinaculum imbrication and failure of the Herbert sling repair. |

**Hui-Linscheid Reconstruction**

| Preservation of the nerve | The risk of damaging the dorsal branch of the ulnar nerve can be minimized by being aware of the dorsal ulnar nerve’s location during surgical incision, manipulation, and drilling. |
| Postoperative ulnar fracture | In the postoperative period, the FCU tendon graft may migrate within the ulnar tunnel, which may predispose the distal ulna to fracture. This risk can be minimized by sewing the FCU tendon graft to the ulnar periosteum and local soft tissues around the drill hole, decreasing the chance of the tendon gliding within the tunnel. |
| Nerve adherence | The ulnar nerve may adhere to surrounding scar tissue at the closing site of soft tissue. |

**POSTOPERATIVE CARE**

**Modified Herbert Reconstruction**

- Six weeks in a thumb spica Muenster cast with the forearm and wrist both positioned in neutral, followed by 6 weeks in a removable thumb spica splint

**Hui-Linscheid Reconstruction**

- Long-arm plaster cast for 6 weeks with the forearm and wrist both positioned in neutral. The cast and Kirschner wire are removed after 6 weeks.
- After 6 weeks, an ulnar gutter splint with “boost” padding is applied to the ulnar head dorsally and pisiform palmarly to support the wrist between mobilization exercises (FIG 6).
General Suggestions

- Gentle active rotatory motion during temporary splint removal is introduced at 6 weeks postoperatively at the patient’s discretion. Passive motion with a physical or occupational therapist is not necessary at this point.
- No heavy lifting or aggressive motion is permitted until 3 months postoperatively.
- Vigorous strengthening exercises to regain pronation are begun 3 months after the operation with a physical or occupational therapist at a pace with which the patient is comfortable, with exercise intensity increased gradually.
- A warm, moist wrap can be used around the wrist to provide additional stretching of the wrist before activities. Ice and nonsteroidal anti-inflammatory agents can be used to provide relief after each session.
- Examples of exercises:
  - Pronation and supination: Stretching can be achieved by holding a hammer or frying pan as a weight during the motions.
  - Wrist flexion and extension: Stretching can be achieved using bucket exercises. The patient places his or her arm on a table with the wrist hanging off the edge while holding an empty bucket. The bucket is filled with water until the point of discomfort. The patient holds the bucket for 2 to 3 minutes and repeats the exercise twice daily in flexion and extension.
  - If the patient’s preoperative activities included sports such as golf and tennis, these activities should be gradually incorporated into the strengthening program.
  - A Silastic sheet can be applied to aid scar remodeling. Scar massage may be started after the first 6 weeks.

OUTCOMES

- Modified Herbert reconstruction
  - A recent long-term follow-up study, ranging from 1 month to 13 years, of 39 wrists showed that 85% of the wrists remained stable at the ulnocarpal joint (in preparation for publication).
- Hui-Linscheid reconstruction
  - Successful short-term clinical outcomes have been reported in a small patient series by Hui and Linscheid, with patients reporting satisfactory and excellent outcomes.6
  - Mild limitations in pronation may be expected.

COMPLICATIONS

- The sling repair can loosen if aggressive strengthening occurs too quickly.
- If imbrication of the extensor retinaculum is not performed in an oblique direction, the ulnocarpal effect of the sling is lost, and a supination deformity of the wrist may occur or recur.
- Pain and dysesthesias at dorsal branch of ulnar nerve: Care must be taken when placing sutures for imbrication of the extensor retinaculum to avoid injury to surrounding tissues or nerve structures.
- EDQ tendinitis usually resolves 6 months after the operation.
- Damage to the ulnar nerve during the surgical procedure is concerning because of its anatomic location. The nerve is immediately exposed after the opening incision and is vulnerable during drilling of the ulnar tunnel. Dorsal ulnar nerve damage ranging from irritation to neurona may occur.
- Additionally, the nerve will be passing directly over an area of soft tissue closure and may be affected by the surrounding scar tissue.
- A protective covering (such as those used for recurrent nerve entrapments) to protect the dorsal ulnar nerve may minimize damage to the nerve.
- Other potential complications may occur as a result of the Kirschner wire, such as migration, infection, and nerve injury.

REFERENCES

DEFINITION
- Tears of the dorsal radiocarpal ligament (DRCL) are more common than previously suspected. They are best seen through a volar radial portal and are amenable to arthroscopic repair.
- Tears of the DRCL have been implicated in both volar and dorsal intercalated segmental instabilities, and they also have a role in midcarpal instability.3,5
- DRCL tears appear to be part of a spectrum of radial- and ulnar-sided carpal instability, as evidenced by the frequent association with scapholunate and lunotriquetral ligament injuries as well as triangular fibrocartilage (TFC) tears.
- Isolated DRCL tears can be solely responsible for wrist pain. The presence of an associated DRCL tear when seen in combination with a scapholunate, lunotriquetral, or TFC tear connotes a greater degree or duration of carpal instability and portends a poorer prognosis after treatment.12
- Good results are obtained after arthroscopic repair of isolated DRCL tears. Results of DRCL repairs are less predictable when seen in combination with other types of carpal pathology.11
- Recognition of this condition and further research into treatment methods is needed.

ANATOMY
- The DRCL is an extracapsular ligament on the dorsum of the wrist. It originates on the tubercle of Lister and moves obliquely in a distal and ulnar direction to attach to the tubercle of the triquetrum. Its radial fibers attach to the lunate and lunotriquetral interosseous ligament.4
- The dorsal intercarpal (DIC) ligament originates from the triquetrum and extends radially to attach onto the lunate, the dorsal groove of the scaphoid, and then the trapezium.
- The lateral V configuration of the DRCL and the DIC functions as a dorsal radioscapohoid ligament.
- It can vary its length by changing the angle between the two arms while maintaining its stabilizing effect on the scapholunate joint during wrist flexion and extension.
- This would require changes in length far greater than any single fixed ligament could accomplish.14
- When viewed from a volar radial portal, the DRCL is seen immediately ulnar to the 3-4 portal, just underneath the lunate (FIG 1A).
- The actual fibers of the DRCL may not be seen unless there is a tear present, since it is normally covered by an epiligamentous sheath (FIG 1B).

PATHOGENESIS
- It is instructive to consider the wrist as having a number of primary and secondary stabilizers.
- The scapholunate interosseous ligament (SLIL), the lunotriquetral interosseous ligament (LTIL), and the triangular fibrocartilaginous complex (TFCC) are the primary stabilizers.
- The capsular ligaments, including the radioscapohoid, radiolunotriquetral, ulnolunate, ulnotriquetral, dorsal radiocarpal, and dorsal intercarpal ligaments, can be thought of as secondary stabilizers.6
- A chronic tear of a primary stabilizer may culminate in the attenuation or tearing of the secondary stabilizer.
- This is seen in patients with a triquetrolunate dissociation of more than 6 months’ duration, in whom arthroscopy often reveals fraying of the ulnolunate ligaments and ulnotriquetral ligaments.17
- DRCL tears appear to be part of a spectrum of radial- and ulnar-sided carpal instability, as evidenced by the frequent association with SLIL, LTIL, or TFC tears. They have also been associated with midcarpal instability.10
- The DRCL tear may occur after or precede these injuries.
- In a recent study, 35 of 64 patients who underwent arthroscopy for the diagnosis and treatment of refractory wrist pain were noted to have associated DRCL tears, for an overall incidence of 55%.9
- Five patients had an isolated DRCL tear.
- 13 patients in this series had SLIL instability, tear, or both; 7 of 13 (54%) also had a DRCL tear. Of this subgroup four
patients had Geissler stage 1 or 2 instability and three had a Geissler stage 3 or 4 tear.
- Seven patients had LTIL instability, tear, or both; 2 of 7 (28%) also had a DRCL tear. Of this subgroup one patient had Geissler stage 2 instability and one had a Geissler stage 3 or 4 tear.
- Two patients had a capitohamate ligament tear; one of these patients also had a DRCL tear.
- Seven patients had a solitary TFCC tear; 6 of 7 (86%) were in association with a DRCL tear. One patient had a chronic ulnar styloid nonunion and a DRCL tear. There was TFCC fraying but no tear or detachment.
- Two or more lesions were present in 23 patients; DRCL tears were present in 12 patients (52%). Sixty-two percent of the combined lesions that were associated with a DRCL tear also included a TFCC tear.


dressing of dorsal wrist pain.
- Each successive stage denotes a longer standing or more severe condition, and this has a negative impact on the prognosis.
- An isolated DRCL tear does not necessarily lead to other intracarpal ligament or TFCC tears.

### PATIENT HISTORY AND PHYSICAL FINDINGS
- A typical patient with an isolated DRCL tear presents with complaints of intermittent dorsal midline wrist pain that may be sporadic but last 2 or 3 days; the pain is precipitated by repetitive loading or torquing movements of the wrist.
- When there is an underlying SLIL or LTIL tear or instability or TFCC tear, the pain may be more persistent and localized to the radial or ulnar side of the wrist.
- There are no physical findings that are pathognomonic of a DRCL tear. When there is no other associated wrist pathology, the diagnosis can be made only at the time of arthroscopy.
- Patients with isolated DRCL tears tend not to have localizing carpal tenderness and typically have a normal wrist examination, although some are mildly tender over the tubercle of Lister.
- Positive physical findings are usually related to any associated wrist pathology. In patients who have scapholunate instability, scaphoid tenderness and a positive scaphoid shift test are usually present.
- When there is an associated TFC tear, the patient will often have tenderness over the ulnar capsule and may have crepitus and pain with ulnar loading of the pronated wrist.
- If midcarpal instability is present, the patient may have a positive midcarpal shift test.

### IMAGING AND OTHER DIAGNOSTIC STUDIES
- Imaging studies are of mostly of value for ruling out associated carpal pathology since they are ineffective at making the diagnosis of an isolated DRCL tear.
- Plain radiographs and arthrograms are normal.
- The MRI is typically normal, although in one patient in the author’s series an MRI was wrongly interpreted as showing a dorsal ganglion due to a high fluid signal intensity over the dorsal capsule (FIG 2).

### Table 1 Classification of Dorsal Radiocarpal Ligament Tears

<table>
<thead>
<tr>
<th>Stage*</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Isolated DRCL tear</td>
</tr>
<tr>
<td>2</td>
<td>DRCL tear with associated SLIL or LTIL (Geissler stage 1 or 2) or TFCC tear</td>
</tr>
<tr>
<td>3A</td>
<td>DRCL tear with associated SLIL and/or LTIL (Geissler stage 3) and/or TFCC tear</td>
</tr>
<tr>
<td>3B</td>
<td>DRCL tear with SLIL and/or LTIL (Geissler stage 4) and/or TFCC tear</td>
</tr>
<tr>
<td>4</td>
<td>Chondromalacia with widespread carpal pathology</td>
</tr>
</tbody>
</table>

*The ligament with the highest Geissler grade determines the stage.

DRCL, dorsal radiocarpal ligament; LTIL, lunotriquetral interosseous ligament; SLIL, scapholunate interosseous ligament; TFCC, triangular fibrocartilage complex.

DIFFERENTIAL DIAGNOSIS
- Dynamic scapholunate instability
- Scapholunate ligament tear
- Dorsal wrist syndrome

NONOPERATIVE MANAGEMENT
- Patients should be treated with at least 1 month of wrist splinting, nonsteroidal anti-inflammatories, and activity modification with avoidance of repetitive gripping and lifting.
- Failure to respond is an indication for a radiocarpal corticosteroid injection followed by 1 additional month of splinting.
- Patients who continue to have wrist pain should then undergo imaging studies to rule out associated intra-articular pathology.

SURGICAL MANAGEMENT
- An arthroscopic repair is especially indicated for stage 1 (ie, isolated) DRCL tears, since the results are quite favorable.
- Repairs may also be considered in stage 2 and 3A DRCL tears, where the associated interosseous ligament tear or TFCC tear is treated arthroscopically.
- Stage 3B and stage 4 tears will likely be unresponsive to a DRCL repair since the outcomes are quite variable in the face of combined pathologies (Table 2).

Preoperative Planning
- Preoperative investigations should include plain radiographs to rule out a static carpal instability pattern.
- A double-row wrist arthrogram or an MR arthrogram is performed to assess the intracarpal ligaments and TFC.

Positioning
- The patient is positioned supine on the operating table with the arm abducted.
- Some method of overhead traction is useful. This may include traction from the overhead lights or a shoulder holder along with 5- to 10-lb sand bags attached to an arm sling. A traction tower such as the Linvatec tower (Conmed, Linvatec Corp, Largo, FL) or the ARC wrist traction tower designed by Dr. William Geissler (Arc Surgical LLC, Hillsboro, OR) greatly facilitates instrumentation.
- A 2.7-mm 30-degree angled arthroscope with a camera attachment is necessary.
- A fiberoptic light source, video monitor, and printer are also standard equipment.

Table 2 Treatment of DRCL Tears

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Arthroscopic DRCL repair</td>
</tr>
<tr>
<td>2</td>
<td>Arthroscopic DRCL repair, SLIL or LTIL debridement ± shrinkage, TFCC repair or débridement</td>
</tr>
<tr>
<td>3A</td>
<td>Arthroscopic DRCL repair, SLIL or LTIL shrinkage ± pinning, TFCC repair or débridement ± wafer (consider STT shrinkage)</td>
</tr>
<tr>
<td>3B</td>
<td>Open SLIL repair or reconstruction ± capsulodesis, LTIL repair or reconstruction, TFCC repair or débridement ± wafer or ulnar shortening</td>
</tr>
<tr>
<td>4</td>
<td>Partial carpal fusion versus proximal row carpectomy</td>
</tr>
</tbody>
</table>

DRCL, dorsal radiocarpal ligament; LTIL, lunotriquetral interosseous ligament; SLIL, scapholunate interosseous ligament; TFCC, triangular fibrocartilage complex; STT, scaphotrapeziotrapezoidal.

VR PORTAL
- A 2-cm longitudinal incision is made in the proximal wrist crease, exposing the flexor carpi radialis (FCR) tendon sheath (TECH FIG 1A).
- The sheath is divided and the FCR tendon retracted ulnarily.
- The radiocarpal joint space is identified with a 22-gauge needle and the joint inflated with saline (TECH FIG 1B).

A blunt trocar and a cannula are introduced through the floor of the FCR sheath, which overlies the interligamentous sulcus between the radioscaphocapitate ligament and the long radiolunate ligament.
- A 2.7-mm 30-degree angled arthroscope is inserted through the cannula (TECH FIG 1C).
The repair is performed by inserting a curved 21-gauge spinal needle through the 4-5 portal while viewing through the arthroscope, which is inserted in the VR portal (TECH FIG 2A–C).

A 2-0 absorbable suture is threaded through the spinal needle and retrieved with a grasper or suture snare inserted through the 3-4 portal (TECH FIG 2D, E).

A curved hemostat is used to pull either end of the suture underneath the extensor tendons, and the knot is tied either at the 3-4 or 4-5 portal (TECH FIG 2F).

With dorsal traction, the encircling suture pulls the torn DRCL up against the dorsal capsule, preventing it from impinging into the joint.

The repair may be augmented with thermal shrinkage if the torn edge of the DRCL is voluminous (TECH FIG 2G).
**Pearls and Pitfalls**

Procedural tips
- Use the hook probe in the 3-4 portal to palpate the DRCL. Tears may not be evident until the free edge is pulled into the joint.
- Be sure to assess the scapholunate and lunotriquetral intervals from the midcarpal joint to assess any dynamic instability. Consideration may be given to thermal shrinkage of the palmar aspect of the scapholunate ligament when there is an associated dynamic scapholunate instability.
- To ensure that the extensor tendons are not entrapped, use a hemostat to thread either end of the suture underneath the extensor compartment. Tie the suture under the skin only after the wrist traction is backed off.
- When performing capsular shrinkage, use copious irrigation to prevent thermal chondral damage. Monitor the temperature of the outflow fluid.

**Postoperative Care**
- After an isolated DRCL repair the patient is placed in a below-elbow splint with the wrist in neutral rotation.
- Finger motion and edema control are instituted immediately. At the first postoperative visit the sutures are removed and the patient is placed in a below-elbow cast for a total immobilization time of 6 weeks.
- Wrist motion with use of a removable splint for comfort is instituted after cast removal.
- Gradual strengthening exercises are added after 8 weeks.
- Dynamic wrist splinting is instituted at 10 weeks if needed.

**Outcomes**
- The five patients who underwent an isolated DRCL repair graded their pain as none or mild.9
- No patient required pain medication and all had returned to their previous occupation without restriction.
- The pre- and postoperative wrist motion was unchanged in four of these patients, with less than 15% loss of motion in the fourth patient.
- Grip strengths were 90% to 130% of the opposite side.
- A dorsal capsulodesis was performed in the seven patients with scapholunate instability.
Three of these patients graded their pain level as none or mild, with both returning to full duty.

Four graded their pain as moderate or severe, with all four changing their occupation.

Four patients underwent DRCL repair or shrinkage and LTIL pinning.

Two patients had no pain, and two had chronic, moderate pain.

Seven patients underwent DRCL repair and TFCC repair or debridement, wafer resection, or both.

Two had no pain (with wafer resection), two had occasional mild pain, and three had chronic moderate pain.

Of the patients with combined injuries who underwent a DRCL repair and treatment for associated tears of the SLIL, LTIL, or TFCC, seven of nine had chronic moderate pain.

COMPLICATIONS

There were no complications related to the DRCL repair as described.

Potential complications from use of a volar radial portal would include injury to the radial artery or the palmar cutaneous branch of the median nerve.

Use of capsular shrinkage is still unproven and cannot as yet be considered a standard of care of the treatment of intercarpal ligament injuries.

REFERENCES

DEFINITION

- Disruption of distal biceps tendon at its insertion

ANATOMY

- Distal tendon inserts into the biceps tuberosity on the proximal radius.
- A relatively avascular zone exists just proximal to the tendon’s insertion site.  

PATHOGENESIS

- Injury typically results from an eccentric muscle contraction. The forearm is forced into extension from a flexed position as the biceps muscle fires
- Avascular changes in the distal tendon and possible impingement in the interosseous space between the tuberosity and the proximal ulna may contribute to rupture.  

NATURAL HISTORY

Complete ruptures

- Distal biceps tendon ruptures usually occur in middle-aged men, similar to pectoralis major tendon ruptures and Achilles tendon ruptures.
- The initial pain subsides quickly but there is usually a noticeable deformity in the anterior brachium as the biceps muscle contracts and retracts. The degree of the retraction can be mitigated by the lacertus fibrosus, which may remain intact.
- The patient usually reports loss of flexion and supination strength. This is especially noted in patients who require repetitive supination, such as mechanics and plumbers. Pain is usually not a predominant complaint, although some patients will experience fatigue-type pain and cramping in the retracted muscle belly.
- Studies have revealed a 25% reduction in flexion strength and a 40% loss of supination strength.  

Partial ruptures

- Partial distal biceps tendon injuries are usually more painful than complete tears. Patients usually present with pain in the antecubital fossa, especially with resisted flexion and supination. There is an absence of clinical deformity.
- Partial tears can progress to complete tears.

PATIENT HISTORY AND PHYSICAL FINDINGS

- History of a rapid eccentric load on the involved extremity
- In acute cases of a complete distal biceps tendon rupture, there is usually a significant amount of ecchymosis in the antecubital fossa, distal arm, and proximal forearm.
- The distal biceps tendon is not palpable in the antecubital fossa. Comparison to the uninvolved side is helpful.
- Local edema can make the diagnosis a little more difficult, but the “hook test” has been found to be a very reliable diagnostic tool. To perform the test, the patient actively supinates the forearm while the examiner attempts to “hook” the distal biceps tendon from the lateral side.  
- The degree of proximal retraction of the tendon can be mitigated by the lacertus fibrosus.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- MRI is usually not necessary to make the diagnosis. The only caveat is that if the examiner feels that the distal biceps tendon is intact, the injury might be more proximal at the myotendinous junction or only a partial tear at its insertion.
- It is important to make the distinction between the common complete avulsion from the radial tuberosity and an injury at the myotendinous junction, as the more proximal injuries are best treated nonoperatively.  
- Partial tears occur at the radial tuberosity, are usually not associated with ecchymosis, and demonstrate no proximal retraction. They present late with pain with resisted flexion and supination. The distal biceps tendon is palpable and frequently tender.
- MRI can aid in the diagnosis of partial tendon ruptures.

NONOPERATIVE MANAGEMENT

- Nonoperative management of complete distal biceps tendon ruptures entails the use of modalities to reduce pain and swelling and simply allowing the patient to use the extremity as tolerated. Strengthening should focus on elbow flexion and supination.
- The surgeon should discuss with the patient that complete distal biceps tendon ruptures are not usually associated with residual pain but rather loss of flexion (30%) and supination (40%) strength.  
  If that is compatible with the patient’s job and lifestyle, nonoperative management is acceptable.
- Partial biceps tendon ruptures and ruptures at the myotendinous junction are treated in a similar manner. The patient should proceed to strengthening when full painless range of motion is obtained.
- Operative intervention is considered when nonoperative management fails for partial ruptures. Usually a minimum 3 to 4 months of observation is appropriate. Patients should be counseled that pain is more of a predominant complaint with these partial injuries.

SURGICAL MANAGEMENT

Complete and Partial Ruptures

- The EndoButton (Smith & Nephew, Andover, MA) method of fixation has been shown to have the highest ultimate tensile load.  
  Clinical studies with the EndoButton have also demonstrated good results with few complications.  
- Other methods are suture anchor and interference screw fixation.
Chapter 53  DISTAL BICEPS TENDON DISRUPTIONS: ACUTE AND DELAYED RECONSTRUCTION

Chronic Disruptions

- The definition of “chronic” is vague. Some authors have stated that greater than 8 weeks is chronic and that a graft is needed in these situations. However, we have been able to primarily repair distal biceps tendon ruptures out to 3 months. In these situations the elbow might not extend beyond 60 degrees on the table, but within 3 months after the repair the patient’s range of motion is full. The biceps brachii, like the pectoralis major, has a significant ability to stretch back out over time.

- The surgeon should discuss with the patient that a more chronic rupture might require graft and should discuss the type of graft to be used. Semitendinosus (either autograft or allograft),16 Achilles tendon allograft13 (with the bone plug inserted into the radial tuberosity or just soft tissue repair), flexor carpi radialis autograft,9 and fascia lata6 have been described.

Positioning

- The patient is placed in the supine position on an armboard with a sterile tourniquet on the upper arm.

Approach

- The approach depends on the surgeon’s preferred method of fixation.

Classic two-incision techniques had complications such as heterotopic ossification and posterior interosseous nerve palsy. Therefore, single-incision anterior approaches were developed with various methods of fixation, including suture anchors, interference screws, and the EndoButton.

ENDOBUTTON

- A longitudinal 4- to 5-cm anterior incision starting at the antecubital fossa and extending distally along the ulnar border of the brachioradialis is used. The lateral antebrachial cutaneous nerve and superficial radial nerve are identified and protected.

- The distal biceps tendon is retrieved into the wound. This can be accomplished by flexing the elbow and using a retractor to lift the skin of the distal arm for exposure.

- The tendon can be adherent to the adjacent tissues or the lacertus fibrosus. This may require a limited tenolysis to mobilize the tendon stump. Protect and isolate the lateral antebrachial cutaneous nerve and the brachial artery.

- On occasion, the biceps tendon cannot be retrieved through the anterior incision. In that case, an incision can be made medially along the distal aspect of the arm. The tendon is isolated and prepared and then passed into the distal wound.

- Once the tendon is isolated, a no. 2 nonabsorbable suture is woven into the distal biceps tendon using a locking Krackow technique or other locking suture technique. The locking sutures should extend 4 to 5 cm above the stump. The goal is to create a locking stitch proximally and allow about 1 cm of the distal biceps tendon to be unlocked.

- The two sutures extending from the tendon stump are then passed through the two central holes of the EndoButton.

- The sutures are tied, leaving no space between the end of the tendon and the EndoButton (TECH FIG 1A).

- Alternatively, one suture from the tendon can be passed through one of the central holes of the EndoButton and then back through the other central hole and the knot is then tied, thus placing the knot between the EndoButton and the tendon stump.

- Passing sutures (kite strings) are placed in the other two holes of the EndoButton.

- The radial tuberosity is exposed, and a burr is used to create an oval cortical window roughly the same dimension as the distal tendon stump. This is performed while an assistant holds the forearm in full supination. Two small Bennett retractors can be placed on either side of the radial tuberosity. Then, the EndoButton drill is used to create a hole in the far cortex to pass the button.
Keith needles or a Beath needle are used to pass the passing sutures (kite strings) through the bicortical hole and are retrieved as they pass through the skin on the dorsal side of the forearm (TECH FIG 1B).

One of the passing sutures is independently pulled, drawing the tendon into the radial tuberosity. Continued tension on this kite string draws the EndoButton in its vertical orientation through the hole in the far cortex of the radius (TECH FIG 1C).

Once the EndoButton is on the far side of the radius, the other suture is pulled to flip it and lock it in its horizontal orientation on the far side of the radius (TECH FIG 1D).

We use fluoroscopy to confirm placement of the button. The passing sutures are then pulled completely out after anatomic tendon placement is visually confirmed.

TECH FIG 1 • (continued) C. The tendon is pulled into the proximal radial hole as the EndoButton is advanced through the distal hole. D. The EndoButton is flipped to secure it on the other side of the radial cortex.

SUTURE ANCHOR OR INTERFERENCE SCREW FIXATION

- The same anterior approach is used, and the tendon is retrieved in a similar manner with both suture anchor and interference screw fixation. However, the radial tuberosity is prepared differently.
- In the case of interference screw fixation, a hole is drilled in the radial tuberosity. The diameter of the hole depends on the system (and the size of the screw) being used.
- In the case of suture anchor fixation, the radial tuberosity is lightly decorticated and suture anchors of choice are placed. Some authors use two suture anchors, and most use some kind of a sliding knot to advance the tendon onto the bone.

TWO-INCISION TECHNIQUE

- The anterior incision is made transverse in the antecubital flexion crease and used to locate the distal tendon stump. A second longitudinal incision is made 1 cm radial to the subcutaneous border of the radius in the proximal forearm at the level of the biceps tuberosity.
- Dissection is initially made in the extensor carpi ulnaris muscle and then through the supinator muscle. Take great care to avoid subperiosteal dissection on the ulna to decrease the risk of synostosis.
- The forearm is placed in maximal pronation and an oval cavity is created in the biceps tuberosity with a burr. Drill holes are then placed into this cavity with the forearm in supination.
- A no. 2 Fiberwire suture is then placed in the distal tendon in a Krackow technique.
- The sutures are then passed from anterior to the posterior incision with a long hemostat and retrieved. It is critical to pass the sutures in the interosseous space.
- The sutures are then passed through the drill holes and tied over bone with the forearm in supination.

CHRONIC DISTAL BICEPS TENDON RECONSTRUCTIONS

- More exposure of the biceps tendon and the myoten- denous junction is required for the chronic reconstructions. This can be accomplished by creating a second incision at the medial aspect of the distal arm.
- One could connect the two anterior incisions, but this risks creating additional scarring.
- A more meticulous dissection is required to protect the lateral antebrachial cutaneous and musculocutaneous nerves. Invariably there will be considerable scarring and adhesions, especially between the biceps tendon and lacertus fibrosus. Some of the lacertus can be used in the reconstruction.
- We have used semitendinosus autograft, which is harvested in a fashion similar to that used with anterior cruciate ligament reconstructions.
The tendon is doubled up and the two free ends are woven into the remaining distal biceps tendon and the myotendinous junction (TECH FIG 2A).

A Bunnell tendon passer is very effective at passing the tendon ends.

The length of the graft is chosen so that the reconstruction is tight at 60 degrees of elbow flexion. This can be accomplished by fixing it distally first and then performing the weave, or vice versa.

A nonabsorbable suture is passed through the graft–tendon construct, and this is secured to the radial tuberosity (TECH FIG 2B).

### Pearls and Pitfalls

<table>
<thead>
<tr>
<th>One-incision technique</th>
<th>Avoid excessive retraction on the radial side to avoid injury to the lateral antebrachial cutaneous nerve.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prepare the biceps tendon before the radial tuberosity.</td>
</tr>
<tr>
<td></td>
<td>Use fluoroscopic guidance to pass the EndoButton.</td>
</tr>
</tbody>
</table>

| Two-incision technique | Avoid subperiosteal dissection on the ulna.                                                             |

### Postoperative Care

- Radiographs are obtained at the time of surgery and at the first postoperative visit to ensure that the fixation (EndoButton or anchors) is in good position.
- For the EndoButton repair we remove the splint at 2 weeks and allow active and passive range of motion but no lifting greater than a cup of coffee for 6 weeks. Strengthening is then started, but rarely is formal physical therapy necessary.
- Other authors have reported good results with early range-of-motion therapy.\(^1\)
- Others use a more conservative approach and limit full extension until 6 to 8 weeks after surgery.

### Outcomes

- Patient-weighted outcome measures such as the DASH and the MEPS have been used in many studies and have demonstrated excellent results with primary repair.\(^1,5\)
- Objective data including strength testing have also demonstrated good results with anatomic repair, especially with regard to restoring supination strength.\(^5\)
- Chronic repairs or reconstructions have also performed well.\(^17\)

### Complications

- Certain fixation methods have been associated with a higher occurrence of certain complications.
- Classic two-incision technique: Heterotopic ossification, radioulnar synostosis, and posterior interosseous nerve palsies. Heterotopic ossification and radioulnar synostosis rates have been decreased by avoiding the ulnar periostheum.\(^3,7\)
- Single-incision technique: Lateral antebrachial cutaneous and superficial radial nerve palsies
- Loss of motion

### References


DEFINITION
- Flexor tendon injuries can occur in any of the five described zones within the finger, hand, wrist, or forearm. All such injuries require surgical repair to restore active finger flexion.
- The most challenging injuries to manage are those in zone II, where two flexor tendons occupy a narrow fibro-osseous sheath. Successful repair requires meticulous technique and a careful postoperative therapy regimen balancing the risks of adhesion formation versus rupture.

ANATOMY
- The flexor tendons form two layers in the forearm (zone V; FIG 1A), with the thumb’s flexor pollicis longus (FPL) and the fingers’ flexor digitorum profundus (FDP) muscles deep to the flexor digitorum superficialis (FDS) muscle. At the wrist the FPL and FDP tendons remain deep, with the index and small FDS tendons above, and the middle and ring FDS tendons most superficial.
- The median nerve runs down the forearm beneath the fascia of the FDS on its undersurface, becoming superficial within the carpal tunnel just proximal to the volar wrist crease (zone IV), with the flexor tendons closely packed together.
- Exiting the carpal tunnel, the flexor tendons cross the palm (zone III) toward the individual digits.
- The two tendons of each non-thumb digit (the thumb has just the FPL) enter the fibro-osseous sheath (zone II) at the level of the metacarpophalangeal (MP) joint. The FDS then divides into two slips to form the decussation termed the chiasm of Camper, through which the FDP passes from deep to superficial (FIG 1B).
- The two slips of the FDS insert along the proximal aspect of the volar surface of the middle phalanx, and the FDP proceeds distally to insert along the volar surface of the base of the distal phalanx.
- The flexor sheath extends from the level of the MP joint to the distal interphalangeal (DIP) joint. Multiple condensations of discrete fibers are found along its course and are named as either annular or cruciate pulleys, reflecting the orientation of the fibers forming the pulley (FIG 1C).
- The thicker, annular (A1 through A5, from proximal to distal) pulleys hold the tendons close to bone while the more slender cruciate (C1 through C3) pulleys collapse with digit flexion, allowing the sheath to shorten without buckling. Zone II is that part of the sheath where both FDS and FDP tendons are present, and zone I is distal to the FDS insertion.
- Tendon nutrition within the sheath is provided indirectly via synovial fluid and directly via vascular inflow through mesenteric folds called vinculae, with one vinculum longus and one vinculum brevis to each flexor tendon.

PATHOGENESIS
- Most acute flexor tendon injuries are the result of open trauma, with sharp transection of the tendon. In such cases, other structures are often injured as well. In particular, examination should include assessment of sensibility and capillary
refill to identify injury to the digital nerves and vessels that would affect preoperative planning.

- A less common injury mechanism is closed avulsion of the FDP from its distal attachment to bone. The term “jersey finger” is sometimes used for this injury, as it is often the result of an athlete’s fingers forcibly flexing to grab an opponent’s jersey, followed by sudden and forceful extension of the DIP joint against resistance as the opponent pulls away. This avulsion injury is addressed elsewhere.

### NATURAL HISTORY

- Flexor tendon injuries require surgical repair to restore active digit flexion. Early repair is crucial, with several studies pointing to better results when repairs are performed within the first 7 days after injury.3,7

- Outcomes aside, as a practical matter it is easiest to repair the tendon before proximal tendon retraction occurs, requiring additional incisions. Late repair with tendon retraction and muscle shortening can also result in tension at the repair site, leading to gapping of the repair (which increases the failure rate) or influencing the surgeon to splint the wrist or digits in excessive flexion, leading to joint contractures.

### PATIENT HISTORY AND PHYSICAL FINDINGS

- Methods for examining the hand or upper extremity with an acute flexor tendon injury
  - Isolate FDP: While maintaining the injured digit’s proximal interphalangeal joint extended, the examiner asks the patient to actively flex the DIP joint (FIG 2A).
  - Isolate FDS: While maintaining all uninjured digits in full extension, the examiner asks the patient to actively flex the injured digit’s proximal interphalangeal joint (FIG 2B).
  - Uncooperative or unresponsive patient
  - Tenodesis effect: The examiner extends the wrist; flexion is observed at the interphalangeal joints if the flexor tendons are intact.
  - Forearm compression: Pressure applied to flexor tendon muscle bellies results in interphalangeal joint flexion if flexor tendons are intact.
  - The examiner inspects for normal flexion cascade (FIG 2C).
  - Examination of the digit to rule out associated digital nerve injury is required.

### PHYSICAL FINDINGS

- Laceration
- Affected digit held in unopposed extension
- Inability to actively flex interphalangeal joints (if both tendons are cut), isolated DIP joint (if FDP only is cut) or isolated PIP joint (if FDS only is cut)

### IMAGING AND OTHER DIAGNOSTIC STUDIES

- The sudden loss of active flexion after a laceration overlying the flexor sheath almost always represents a tendon injury. Radiographs should be obtained to rule out associated fractures that would require treatment at the time of tendon repair. Lacerations due to glass, metal fragments, and so forth should be imaged to localize any residual foreign bodies for removal.
- In the setting of a closed injury with the sudden loss of active flexion, one must consider the possibility of a tendon avulsion from its insertion. Radiographs may demonstrate an avulsed fleck of bone. In the more common cases of an FDP avulsion, this bone fragment may remain in the region of the distal phalanx or may be pulled proximally into the flexor sheath. If no bony fragment is seen on a plain radiograph and the diagnosis is still in doubt, ultrasound may help.

### DIFFERENTIAL DIAGNOSIS

- Pain after injury may cause a patient (especially a child) to hold a digit or hand immobile, mimicking tendon injury.
- Testing for the tenodesis effect (digits passively flex with wrist extension) or compressing the flexor musculature in the forearm should help with diagnosis in these situations.

### NONOPERATIVE MANAGEMENT

- There is no nonoperative means of restoring active flexion to a digit whose flexors have been cut, as the tendon ends retract and do not heal to one another.
- If a flexor tendon laceration is encountered within the first 4 weeks after injury, it is probably worthwhile attempting primary repair. After that time, discussion should be held with the patient regarding other options.
- For late presentation of an isolated FDP laceration in zone I, it may be practical to do nothing, as full proximal interphalangeal motion should still be present. If the DIP joint is or

---

**FIG 2** • **A.** Isolation of distal interphalangeal flexion to test flexor digitorum profundus integrity. **B.** Isolation of proximal interphalangeal flexion to test flexor digitorum superficialis integrity. **C.** Loss of normal flexion cascade after tendon laceration in palm.
becomes unstable, a DIP joint fusion or tenodesis of the distal FDP stump can be performed. One large series reported successful primary tendon grafting for isolated FDP lacerations even in zone II, but this is not widely performed.

- For late presentation of zone II injuries involving both tendons, staged tendon reconstruction (see Chap. HA-55) may be an option.

### SURGICAL MANAGEMENT

- The goal of flexor tendon surgery is a repair that will allow early motion, will not fail due to gap formation or suture pullout, and will not develop adhesions limiting final range of motion.
- Several variables under control of the surgeon contribute to repair strength:
  - Number of strands (most important determinant; a four-strand repair with an epitenon suture added has been shown in laboratory studies to withstand limited early active motion)\(^6\),\(^{11}\)
  - Suture size (3-0 or 4-0 is sufficient; larger suture increases resistance to gliding)
  - Configuration of repair (cruciate repair requires only one knot, buries the knot within the repair site, and allows for equal distribution of force across all four strands)\(^5\)
  - Use of locking stitches (adds resistance to suture pullout)
  - Addition of an epitenon suture (increases repair strength and decreases gap formation and gliding resistance)\(^6\)
  - Presence of a gap (greater than 3 mm at any point will likely result in rupture)
  - Bunching of repair (due to taking too large a “bite” of tendon end; increases gliding resistance and therefore risk of rupture)
  - Integrity of pulleys (at least half of both A2 and A4 should be preserved to maintain tendon excursion and allow tip-to-palm contact)
  - Repair of one versus both tendons (if repair of both FDS slips impedes gliding, one slip should be resected, or the FDS not repaired at all)
  - It is well accepted that core suture strength is directly related to the number of suture strands crossing the repair site between proximal and distal tendon ends; all else being equal, using more strands means a stronger repair.\(^{11}\)
  - This concept must be balanced against other factors: too many sutures crossing the repair site limits the available surface area for exposed tendon ends to heal; more sutures and knots increase the gliding resistance of the tendon; and the more sutures placed, the longer the surgical time, which is associated with risks such as infection and anesthesia-related issues.

- Strickland\(^6\) showed that a four-strand zone II repair with an epitenon suture is strong enough to tolerate an immediate light active range-of-motion protocol, which allows for early gliding of the repair and decreases the risk of adhesion formation.
- Suture size contributes to repair strength, but one study showed 3-0 and 4-0 suture to resist repair rupture equally well and 2-0 suture to increase gliding resistance significantly.\(^1\)
- Adding at least one locking stitch (making an additional pass to capture more tendon fibers) has been shown to increase repair strength and minimize gap formation.
- Multiple studies suggest that when both tendons are cut in zone II, repair of the FDP and only one slip of FDS rather than both slips results in decreased gliding resistance and improved range of motion.\(^9\),\(^10\),\(^13\)

### Preoperative Planning

- As noted previously, it is usually preferable to perform tendon repair early (if other circumstances allow).\(^3\),\(^7\) The upper limit of time past which proximal stump contracture is likely to cause technical difficulty is variable. Although 3 to 4 weeks is a commonly cited limit for primary tendon repair, in rare cases the vinculae may prevent retraction and allow repair even later.
- Patients presenting late should be fully counseled regarding other options, including the potential for intraoperative changes in plan.

### Positioning

- Flexor tendon surgery, like most hand surgery, is generally performed with the affected extremity on a hand table, with the shoulder abducted 90 degrees and the elbow extended. The forearm is supinated, exposing the volar surface of the digits.
- A positioning device such as a lead hand can be helpful in stabilizing digits for surgery (once tendon ends have been delivered into the wound) and keeping other digits out of the way.

### Approach

- Incisions should be planned so as to incorporate the laceration into the exposure.
  - Zigzag (Bruner) or midlateral approaches both work well; they can be combined if needed.
  - Midlateral incisions extending proximally on one side of the digit and distally on the other can give large flaps and excellent exposure.
  - The chief concern is not to cross a flexion crease at a right angle since the resultant scar will tend to contract and limit extension.

### PRIMARY REPAIR IN ZONE II

#### Retrieval of Tendon Ends

- A zigzag or Bruner incision is made, sometimes in combination with mid-lateral incisions (TECH FIG 1A).
- Often some manipulation is needed to bring the tendon ends into the wound; for the proximal tendon end, wrist flexion and “milking” of the forearm may succeed. The distal stump is best exposed by extending the incision so that the repair can be performed without holding the digit flexed.

- Initial exposure should include both digital neurovascular bundles, whether or not they were injured along with the tendon or tendons.
- If digital nerve or artery repair is needed, this should be done after the tendon repair so that the more delicate microsuture used is not disrupted with manipulation of the digit. Exposure of these bundles even when uninjured allows much more freedom for manipulating the cut tendon ends.
Once the neurovascular bundles are exposed and protected, the sheath should be cleared of overlying soft tissues and inspected. The sheath laceration can be extended with a sidecut to form an L-shaped flap, always preserving as much as possible of the A2 and A4 pulleys. Creating such flaps can facilitate retrieving the tendon ends.

Because most flexor tendon injuries occur with the digit in flexion, the skin laceration is generally more proximal than the tendon laceration. This means that exposure of the distal stump often requires considerable distal extension of the incision, often to the level of the DIP joint and obliquely across the pulp of the distal phalanx.

The proximal tendon end may be held in place near the laceration by its vinculae, but it will often have retracted well proximally.

It is reasonable to make several attempts to retrieve the proximal tendon end through the sheath with an appropriately small instrument (curved tendon passer, small hemostat, etc.), keeping in mind that the less damage to the tendon end, the easier the repair and the less scarring that will result. Flexing the wrist and “milking” the forearm will sometimes encourage a proximally migrated tendon to protrude into the wound.

If these measures fail, a short transverse incision along the distal palmar crease can be made, as if exposing the A1 pulley for a trigger finger release, and the tendon exposed at this level.

A pediatric feeding tube can be threaded from one wound to the other and sutured to the tendon in the proximal wound (TECH FIG 1B).

The tube and flexor tendon can then be retrieved into the distal wound and the tube and suture cut free.

Once the proximal end is in the planned repair site, the tendon can be pinned with a 25-gauge needle to prevent retraction back into the sheath (TECH FIG 1C).

Often the distal location of the distal stump requires that the proximal tendon end be threaded past the original laceration site to a more distal “window” made in the sheath for tendon repair. This, coupled with flexion of the DIP joint, should allow for apposition of the tendon ends and repair under minimal tension.

**Tendon Repair**

- Four-strand cruciate repair is effected using 3-0 nonabsorbable suture, with a 6-0 Prolene running locking epitendon suture, and repair of one slip of FDS (TECH FIG 2).

**Epitenon-First Repair**

- For very oblique lacerations it may be easier to perform an epitenon-first repair, coapting the cut tendon ends smoothly, and then performing the core stitch beginning through a slit on the outside of the tendon, burying the knot in this same slit (TECH FIG 3).

- The repair is otherwise the same as a four-strand cruciate repair.
TECH FIG 3 • A–D. The hand is to the right and the fingertips to the left. 
A. Oblique laceration of flexor tendons in zone II; tendon ends retrieved and 
pinned in place for repair. B. Epitenon repair performed first. C. Core suture 
begun via small incision in tendon proximal to repair; otherwise similar to stan-
dard cruciate repair. D. Core stitch completed and knot buried in small incision 
used for starting point.

PEARLS AND PITFALLS
- Early repair is easiest and gives best results.
- Midlateral incisions give wide exposure.
- Hold tendon ends in place with 25-gauge needles to allow tension-free repair.
- A four-strand locking cruciate repair using 3-0 nonabsorbable suture combined with a 6-0 absorbable running epitenon stitch will 
  allow protected early active motion and has been shown to maximize the outcome.
- Limiting repair of FDS to one slip minimizes overcrowding in zone II and allows better tendon gliding.
- For partial lacerations, no repair is necessary unless greater than 60% of the cross-sectional area of the tendon has been divided.
- Any flap of tendon should be trimmed to prevent later triggering.24,12

POSTOPERATIVE CARE
- If a primary repair has been performed as described above, 
an immediate light active “place and hold” therapy regimen 
can usually begin safely as long as the patient is reliable.

OUTCOMES
- A recent meta-analysis of multiple studies over the past 15 
  years found a rupture rate of 4% to 10% and good to excellent 
  results in about three quarters of patients.5 Present-day tech-
  niques should allow for continued improvement in these results.
- Injury mechanism is a predictor of outcome and is beyond 
  the surgeon’s control. An uncomplicated, isolated sharp flexor 
  tendon laceration that is treated acutely represents the best 
  possible scenario for a highly functional digit. Additional in-
  jury to bone, tendon, or nerve negatively affects outcome.

COMPLICATIONS
- Two extremes of bad outcomes are tendon rupture and ten-
  don adhesions. Ruptures are rare, but adhesions, and resultant 
  limited motion, are common.
- If ruptures are noticed immediately, a repeat repair should 
  be performed, although the patient and surgeon should be pre-
  pared for the need to proceed intraoperatively with other 
  reconstructive options.
The management of tendon adhesions is discussed in Chapter HA-55.

REFERENCES
DEFINITION

- Flexor tendon trauma and repair are commonly complicated by adhesions, limiting the gliding capacity of the tendons.
- These injuries have long been highly challenging.
- The extracellular matrix, which is composed of collagen, is often covered by mesothelium, and no further improvement with therapy is seen, surgical treatment should be considered.
- The spectrum of treatment of flexor tendon adhesions ranges from nonoperative treatment to different surgical modalities, from tenolysis to a two-stage tendon reconstruction.
- The operative decision is based on different factors, such as the quality of the tendon involved and the integrity of the surrounding sheath. Some of these factors can be evaluated only during the operation.
- All treatment options should be discussed preoperatively and the surgeon should be prepared to make the final decision based on operative findings.
- Tenolysis consists of surgical release of tendon adhesions to restore tendon gliding and digital motion. This can be a very satisfying procedure in selected cases, particularly when adhesions are localized to just a portion of the sheath.
- Proper patient selection is crucial and several questions must be asked: Will the patient cooperate with extensive hand therapy? Is the functional improvement after this complex and time-intensive process likely to be better and more rapid than with fusion of an interphalangeal (IP) joint or even with amputation of the digit?

ANATOMY

- Refer to Chapter HA-54.

PATHOGENESIS

- Injury (or repair) of the tendon and its synovial sheath is the basis for the development of adhesions.
- The initial mode of inflammatory reaction is similar to that after any tissue injury. Initiation of adhesion formation begins with deposition of a fibrin matrix that typically occurs during the coagulation process.
- This matrix is gradually replaced by vascular granulation tissue containing macrophages, fibroblasts, and giant cells.
- The clots are slow to achieve complete organization. In this process, they consist of erythrocytes separated by masses of fibrin that are covered with layers of flattened cells and contain a patchy infiltrate of mononuclear cells.
- The adhesion matures into a fibrous band, often containing small nodules of calcification.
- Mature adhesions are often covered by mesothelium, are vascularized, and contain other connective tissue fibers, such as elastin. The extracellular matrix, which is composed of collagen, proteoglycans, fibronectin, and elastin, plays a central role in the management of tendon healing as well as the development of adhesions. Degradation products in the matrix are chemotactic for fibroblasts, leukocytes, and endothelial cells.
- During the first few days after trauma, T cells and macrophages accumulate in the location of injury and stimulate the synovial cells to produce fibronectin. Collagen types 1 and 3 accumulate between tenocytes and around the tendon by 1 week after trauma. Adhesions between the tendon and its sheath can be seen by this time as a thickening of the epitenon to five to seven cell layers. Fibronectin is present as well and serves as scaffolding for the developing scar.
- The process described occurs to a lesser extent in the proximal zones of the flexor tendons. Zone II tendon injuries occur in the milieu of two tendons gliding in a constrictive fibro-osseous tunnel. In other zones, this potential for development of adhesions exists to a much lesser extent.
- Three types of adhesions have been described:
  - Loose adhesions arising from subcutaneous tissue and allowing some glide of the tendons
  - Moderately dense adhesions from the synovial sheath or pulleys that are remarkably restrictive of tendon motion
  - Dense adhesions arising from the bony floor or volar plate, penetrating the dorsal aspect of the tendon
  - Both dense and moderately dense adhesions prevent tendon motion and jeopardize healing.
  - The role of different cytokines has been evaluated in the pathogenesis of adhesions in general and tendon adhesions in specific.
  - Transforming growth factor-beta (TGF-β) has been shown to be a prominent regulator of tendon healing, although its precise role is still unclear and under extensive research. In the laboratory, these factors have been shown to be regulated by physical factors such as shear stress as well as by specific neutralizing antibodies or chemical modulators such as 5-fluorouracil.

NATURAL HISTORY

- Symptomatic adhesions result in substantial morbidity such as decreased range of motion, joint contracture, decreased strength, and substantial decrease in hand and upper extremity function. Adhesions occur with every tendon injury and depend on the extent of injury, the mobilization of digits after the injury, and the treatment applied. They are especially severe and symptomatic in injuries in zone II. Before the widespread use of early and intensive mobilization protocols after injury and repair, limited success was achieved and tenolysis was frequently required.
- Strickland and Glogovac reported in 1980 on the advantage of early mobilization of zone II flexor tendon injuries.
In their report, by 160 days after repair, 10 of 25 patients achieved less than 70% of the expected range of motion of the proximal and distal IP joints. Although there are limited reports regarding the natural history of these injuries when untreated, this report gives us a sense of the typical outcome of flexor tendon repair in the era before early motion protocols.

- Tenolysis is by far the most common secondary procedure performed after digit replantation, according to a recent meta-analysis. Although stiffness of a replanted finger is a result of multiple causes, the adhesion of tendons is a leading cause of this problem.
- Tang estimates that 10% of repaired flexor tendons will need surgical treatment of adhesions. Moderately dense adhesions of the synovial sheath or pulley and dense adhesions of the bone to tendon are difficult to alter once they have formed. These adhesions should be treated surgically.
- Proximal to zone II, the limitation in range of motion and need for flexor tenolysis are less common, even in the setting of a severe injury.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Evaluate both passive and active range of motion.
- Note the skin integrity and the location and condition of scars and previous surgical incisions.
- Look for other deforming conditions, such as maligned fractures.
- The examiner should search for other factors limiting range of motion, such as intra-articular pathology, scar contracture of the skin, extensor tendon contracture or adhesions, interosseous muscle contractures, or capsular and collateral ligament contractures.
- The neurovascular status of the digit is documented.
- The continuity of both flexor tendons in all digits is evaluated:
  - Continuity of the flexor digitorum superficialis (FDS) tendon
  - Active flexion of the proximal interphalangeal (PIP) joint is evaluated for each digit separately. The adjacent digits are held in full extension by the examiner at the metacarpophalangeal (MP), PIP, and distal interphalangeal (DIP) joints to assess for intact fibers of the FDS inserting into the middle phalanx. This does not exclude a partial tear of the tendon.
  - Continuity of the flexor digitorum profundus (FDP) tendon
  - Active flexion of the DIP joint with the examiner grasps the mid-dle phalanx to assess for intact fibers of the FDP inserting into the distal phalanx. This does not exclude a partial tear of the tendon.
- Range of motion (ROM): If passive ROM exceeds active, the pathology is at least partly musculotendinous (tendon adherent, incompetent, or both).
  - The “seesaw effect”: The examiner should passively extend and flex the DIP, PIP, and MP joints. Extend one joint followed by the other to assess for the seesaw effect. Nonarticular contracture is revealed when one joint is flexed, the other can be extended, and vice versa.
  - The Bunnell intrinsic tightness test is performed to evaluate flexion of the PIP joint with the MP joint extended and then flexed. With intrinsic tightness, there is less passive flexion of the PIP joint when the MP joint is held extended than when the MP joint is flexed (therefore, the surgeon may need to release the intrinsics as part of treatment).
  - Evaluate for lumbrical contracture: An intrinsic tightness test is performed with the fingers radially or ulnarly deviated. With lumbrical contracture, there is less passive flexion of the PIP joint with the finger deviated or with the DIP joint flexed in comparison to intrinsic testing. If present, this suggests lumbrical muscle contracture as part of the pathology.
  - Alternatively, the test is performed with the DIP joint flexed as well as the PIP joint.
  - Evaluate for extensor contractures: The examiner flexes the wrist and MP joints and examines flexion of the PIP and DIP joints. With extensor contractures there will be limited flexion of the digit IP joints with flexed wrist and MP joints.
  - Evaluate for flexor contractures: The examiner extends the wrist and MP joints and examines extension of the IP joints. With flexor contracture, there will be limited extension of the digit IP joints with extension of the wrist and MP joints.
  - The Landsmeer test is performed for evaluation of contracture of the oblique retinacular ligament (extending from the volar aspect of the PIP joint to the dorsal aspect of the DIP joint). In a positive test, passive extension of the PIP joint will result in extension of the DIP joint as well. Continued shortening of the ligament will result in a boutonniere deformity.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Radiographs of the hand are taken to evaluate for bony and articular pathology as well as the presence and location of implants. Skeletal deformity secondary to avulsion injuries may be seen.
- CT scans may be helpful in selected cases for bony and articular pathology.
- Magnetic resonance imaging (MRI) or ultrasound may be useful in identifying tendon or capsular injury as well as aiding in the differential diagnosis of severe tendon adhesions versus rupture.

**DIFFERENTIAL DIAGNOSIS**

- Intrinsic muscle contracture
- Capsular or collateral ligament contractures
- Malalignment of fracture
- Extensor tendon adhesions
- Rheumatoid arthritis
- Dupuytren’s disease
- Neurologic causes
- Burns
- Congenital anomalies
- Complex regional pain syndrome

**NONOPERATIVE MANAGEMENT**

- ROM exercises as well as pain management play a role in several clinical situations:
  - During the period after repair of the injury
  - When the functional results are satisfactory to the patient and meet his or her needs
  - Delayed healing of soft tissue or bony injury
  - Limited passive range of motion
  - When the patient is uncooperative with perioperative care and therapy
  - The therapy should include full active as well as resistive exercises designed at maximizing the active ROM achieved, before surgical treatment.
Surgical Management

- Tenolysis of the flexor tendon requires intact tendons and pulleys in order to succeed. Patients for whom tenolysis is appropriate have reached a plateau in function despite appropriate therapy, and have significantly greater passive than active range of motion.
- Prerequisites for tenolysis also include healing of all fractures and wounds with soft, pliable skin and minimal inflammatory reaction around scars.
- The timing of tenolysis is the subject of debate. Recommendations range from 3 to 9 months after the tendon repair or grafting. Strickland recommends waiting at least 3 months after repair, with 4 to 8 weeks without measurable improvement in active motion with intensive therapy.
- Concomitant procedures should be considered carefully and limited to those procedures that will not affect postoperative therapy.
  - Capsulotomies of the PIP or DIP are often necessary in these cases and may be performed, although some authors warn of inferior results with this addition.
  - Pulley reconstruction with tenolysis should be avoided if possible, although successful combined procedures have been described.
  - Procedures requiring immobilization should not be performed concomitantly with the tenolysis. Examples include tendon lengthening or shortening, free skin grafts, or osteotomies.
  - Local anesthetic supplemented by intravenous analgesia and tranquilizing drugs was popularized by Schneider. This allows the surgeon to evaluate the extent of adhesiolysis achieved by having the patient actively flexing the digit during surgery. The patient can also see the results, motivating him or her to achieve a similar range of motion postoperatively.
  - Anesthetic options include local infiltration into the palm and a wrist block.
  - The use of local anesthesia is limited by the use of a tourniquet, which causes paralysis of the muscles after 30 minutes and may be difficult for the patient to tolerate past that time. To deal with these problems, a sterile forearm tourniquet may be elevated 30 minutes into the procedure, releasing the arm tourniquet.
  - Regional and general anesthesia are additional techniques suitable for a tenolysis procedure. General anesthesia is necessary in cases of questionable patient cooperation, tolerance to pain or other contraindication to local or regional anesthesia, or where time to completion of tenolysis (and any associated procedures) is expected to exceed the likely duration of a local or regional block.
  - Foucher et al report that they have abandoned local anesthesia or “selective sensory blocks” except in late tenolysis where they have doubts about the performance of the muscle. Instead, they use a separate incision in the palm or forearm to test flexion at the end of the procedure.

Preoperative Planning

- Surgical supplies including implants necessary to perform a staged tendon reconstruction should be available.

Positioning

- The patient is positioned supine with the upper extremity on a hand table. A lead hand splint is recommended.

Approach

- Wide exposure of the flexor tendon is necessary. This may be accomplished either by a zigzag (Brunner-type) incision or by a midlateral incision (Fig. 1). The Brunner zigzag incision provides the best exposure of the tendon and pulley system.
- A midlateral exposure will protect the neurovascular structures dorsally and will cause less scar directly over the tendon. It may also cause less wound tension during early therapy.

Flexor Tenolysis

- Expose the flexor tendons starting from the unaffected region and proceeding to the involved areas (Tech Fig 1A).
- Define the borders of the tendons (Tech Fig 1B).
- Raise both flexor tendons as one, carefully lysing the adhesions around them.
  - This may be performed using a scalpel, tenotomy scissors, or a Freer elevator (Tech Fig 1C).
- Retraction and manipulation of the elevated tendons should be accomplished in as atraumatic a fashion as possible using a Penrose drain or blunt instrument.
- If possible, separate FDS from FDP tendons.
- The FDS tendon may need to be sacrificed if the scarring is extremely severe in order to achieve adhesiolysis under the pulleys and smooth gliding of the tendon.
- Resection of a slip of FDS has been shown to improve FDP gliding after repair in zone II injuries.
- In some cases it may be preferable not to separate severely adhered tendons, allowing them to act as one, where a single combined tendon is mobilized to its insertion.
Adhesiolysis may be facilitated using these instruments and techniques:

- A modified 69 Beaver blade (McDonough and Stern 45-degree Beaver blade) with an angle of 45 degrees (TECH FIG 2A).
- Schreiber knee arthroscopy blades.
- Braided suture (0 Mersilene, 2-0 Prolene) or dental wire may be inserted between the tendon and phalanx and used as a Gigli saw to separate the tendon from bone by pulling on the suture ends back and forth along the tendon (TECH FIG 2B).
- Alternatives to collect and pass the suture include use of a blunt elevator with a hole at its distal tip, which may be inserted under the pulley from a proximal to distal direction, and a wire loop or a needle inserted backward in the gutter between the phalanx, the tendon, and the sheath.
- Meals developed a set of instruments specifically designed for tenolysis (George Tiemann & Co, Hauppauge, NY).

- Débride the tendons free of previous suture material or frayed edges.

The necks of these tenolysis knives follow the natural curvature of the finger and have semisharp blades that conform to the circumference of the tendon sheath with either a convex or a concave edge (TECH FIG 2C).
### ADDRESSING THE PULLEY SYSTEM

- Preserve as much of the pulley system as possible. It is crucial to preserve the A2 and A4 pulleys to prevent bow-stringing and loss of tip-to-palm contact in full flexion. This may be performed by creating transverse windows along the course of the tendon. Some resection of the pulleys is possible (TECH FIG 3).

- In case sacrifice of part of these pulleys is crucial to achieve better tendon excursion or to facilitate the release of adhesions, about half of a pulley can be incised.\(^\text{17}\)

- Widening of the pulleys may be performed with small pediatric urethral dilators or cardiac coronary artery dilators.

### EVALUATION OF ADEQUACY OF RELEASE

- Adequacy of release must be evaluated and may be assessed using several techniques.

- If the patient is awake, he or she can actively flex the digit. Otherwise a traction flexion check should be performed for each of the flexor tendons separately.

- Through the palmar extension of the exposure, pull on the tendon with a blunt tendon hook or retractor (TECH FIG 4A).

- If the expected excursion cannot be tested through the palmar incision, proximal exposure of the tendon may be necessary through a separate incision proximal to the wrist (TECH FIG 4B).

- An Allis clamp may be placed around the tendon and pulled gently to examine the tendon’s excursion.
POSTOPERATIVE CARE

- Hand therapy is initiated the day of surgery in the postanesthesia care unit if an isolated tenolysis is performed without pulley reconstruction.
- A detailed referral note or discussion with the therapist is necessary to plan the rehabilitation program for each patient. Patient history, type of injury, surgical intervention and intraoperative findings, motivation, and pain tolerance should be discussed. The condition of the tendon and pulley system and the vascularity of the digit may alter the course of therapy and should be reported.
- It is crucial that the patient be motivated and understand the therapy protocol, the need for frequent meetings with the therapist, and the daily exercises to be performed independently.
- Adequate pain control is ensured.
- Local blocks may be used in selected cases to allow early mobilization.15
- Transcutaneous nerve stimulators are recommended by some for postoperative pain reduction in combination with oral medication.
- Wound care education should be part of the first therapy meetings.
- Edema control is frequently necessary. The patient should be instructed to elevate the hand during the first days after surgery as well as to perform hourly fist pumps with the hand elevated. Gentle compression with a glove, Coban wrap, or elastic bandages should be considered.
- Early mobilization of the tendon is crucial to the success of the procedure, although the quality of the tendon should be taken into account. A weak tendon should limit the therapy to
A limited exercise protocol, although this may be an indication in itself for staged reconstruction or grafting rather than simple tenolysis.

- Various protocols have been described that balance the maintenance of active flexion ROM achieved in the operating room, maintaining the mobility of the joints as well as the full ROM of active extension. The common protocols achieve a small differential gliding of the FDS versus the FDP tendon.
- Blocking and strengthening exercises should be added at a later date. This may depend on the quality of the lysed tendon, although usually after 4 to 6 weeks these exercises are considered not to endanger the tendons' continuity.
- Trumble and Sailer begin light resistive exercises at 6 weeks and add progressively more resistance after 8 weeks.
- Continuous passive motion (CPM) is under investigation. There have been reports of increased risk of tendon rupture and force required for passive ROM. CPM should not be used in place of active ROM exercises. However, it may be of value if passive ROM is limited or the patient is apprehensive about moving actively. It may also minimize edema and scar formation.
- A protective resting wrist-based splint may be necessary in cases with a thin or damaged tendon. A closely supervised therapy program is important in these cases. Static–progressive or dynamic splints may be needed to treat patients with joint stiffness or contractures.
- A fabricated pulley ring may be used during active motion exercises if the pulleys are tenuous.
- In patients with a weak tendon, therapy should begin with “place and hold” exercises. In these exercises, the digit is passively flexed and then actively held in place by the patient.
- This minimizes the tensile forces on the weak tendon while passing it through its maximal excursion. Further protection may be added when the exercises are performed with the wrist or MP joints flexed. This program should be carried out for 4 to 6 weeks. Active ROM exercises may be added later on.
- Hourly exercises by the patient should be part of any protocol.

OUTCOMES

- Good outcomes after flexor tenolysis have been reported, but outcome measures have varied across reports (Table 1).
- Significant complications have been reported in all series, including a significant number of patients with either no improvement or with postoperative worsening. Less information is available but poorer results have been reported after tenolysis in children (under 11) and for the thumb.
- Strickland reported that 64% of tenolysed digits after zone II injury had at least 50% improvement in active ROM. Twenty percent of the patients had no improvement and 8% had rupture of the tendon.
- Jupiter et al. used the Strickland formula (Table 1) for the evaluation of 37 replanted digits and 4 replanted thumbs treated with flexor tenolysis. They reported good to excellent results with 24 of the 37 digits. Only poor or fair results were found after thumb flexor tenolysis.
- Several factors negatively influenced the final results: classification of injury, inferior results of tenolysis with avulsion or crush injuries, number of amputated digits, capsulotomy, level of injury (inferior results with zone II injuries), digit injured (inferior results with thumb procedures), and multiple tenolysed digits.
- The authors recommend tenolysis of digit flexors when indicated, but not of the thumb flexor.
- Foucher et al. reported their results after the treatment of 78 digits, 9 of which were thumbs, and excluding replanted digits. They implemented both their technique of pulley reconstruction and of therapy. The therapy included the use of percutaneous catheters for additional pain control for 3 weeks and passive extension exercises beginning 2 days following the tenolysis surgery. A splint providing some flexion (of MP and IP joints) was removed hourly for exercise. The result after a mean period of 21.5 months was graded both by total active motion (TAM) measurement and the Swanson method for functional evaluation (Table 1). Of the 78 digits, 3% were unimproved and 13% were made worse by the tenolysis. For the remainder of the cases, the TAM improved from 135 degrees to 203 degrees. Using Swanson’s assessment the functional deficit improved from 41% to 20%. The thumbs achieved less success, with two cases unimproved, while the rest resulted in an improvement of 65 degrees to 115 degrees, or a decrease in deficit from 12% to 2% according to Swanson. The authors did not separate the results according to the zone of injury and did not report the results for the entire group of patients.
Eggi et al.6 evaluated the change in ROM of each joint of the digit in 8 digits treated with flexor tenolysis out of a group of 32 digits with varying zone II injuries requiring tenolysis. They found a decrease of 5 degrees of MP active ROM and an increase of 25 and 35 degrees of PIP and DIP active ROM, respectively. TAM improved by 55 degrees. They found an additional improvement in TAM when the tenolysis was combined with PIP capsulolysis. The authors compared the results of flexor tenolysis with patients treated with flexor and extensor tenolysis in the same digit and found better total active motion (63-degree improvement) and better extension with the second group. The five patients with palmar injury alone achieved 80% good to excellent results according to the Buck-Gramcko scoring system, while only 55% good to excellent results were seen in digits tenolysed after replantation.

Reports of tenolysis in children are rare. Birnie and Idler4 compared treatment of children under and over the age of 11 after repair of zone II and III flexor tendon injuries. They concluded, by using Strickland’s method (Table 1) that under age 11, tenolysis was of no significant benefit. Of the 21 digits of children between the ages of 11 and 16, 13 had good to excellent results, 5 were graded poor, and 2 suffered rupture of the tendon. Of the eight digits of children ages 10 and under, two had fair results and six had poor results. They explained that under the age of 11, the cooperation of the patient necessary for the success of the procedure cannot be expected. Early therapy was more difficult in this group, resulting in inferior results. Within a group of 12 children after flexor tendon repair, Kato et al.13 described one successful tenolysis after zone II injury in a child age 3 years 10 months. They reported that the tenolysis was performed 9 months after the initial injury and repair and that the result of the tenolysis was excellent.

**COMPPLICATIONS**

- Rupture of the flexor tendon may be the result of poor-quality tendon or aggressive therapy as well as patient non-compliance. It may be prevented by limiting tenolysis only to tendons of good quality. Eggi et al.6 reported rupture in 3 of 16 flexor tendons tenolysed that were treated successfully with two-stage reconstruction. Jupiter et al.13 reported 2 ruptured tendons of 37 replanted digits, both in zone II injuries. Others have claimed this to be a rare yet disastrous complication.1

- Rupture of a pulley, more significantly A2 or A4 pulleys, may result from narrowing or fraying of the pulleys as part of the trauma or further compromise with surgical intervention.

- Multiple surgical treatments of the digits involved in various trauma mechanisms may result in significant scarring, decreased vascularity, delayed wound healing, and infection, further compromising the functional results. Adherence to careful surgical technique, including atraumatic handling of tissue, is crucial to minimize these complications.1,19

- Foucher et al.18 reported eight complications in 72 patients (78 digits): two with delayed healing, two with flexor tendon exposure, two with rupture, and two diagnosed using bone scan to have a localized form of reflex sympathetic dystrophy.

**Prevention of Recurrence**

- Bathing the tendon in a steroid solution to prevent recurrence of adhesions has been suggested but has only anecdotal evidence of efficacy. Others have reported that corticosteroids...
REFERENCES

DEFINITION
- Staged flexor tendon reconstruction is required in the settings of delayed diagnosis of a flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) disruption or failed previous attempt at primary repair within zone II of the digital tendon sheath.
- During the first stage of the reconstruction process, a silicone rod is placed within the flexor tendon sheath. The role of this implant is to help re-establish a frictionless inner lining of the sheath that will accommodate the placement of a tendon graft in the second stage.

ANATOMY
- Flexor tendons can be divided into five zones (FIG 1A).
- Bunnell originally described the region between the A1 pulley and the FDS insertion, zone II, as “no man’s land” because the initial results after attempted primary tendon repair were so poor he felt that no one should attempt this procedure.
- In the limited confines of zone II the two flexor tendons function together and rely on the digital sheath and its frictionless synovial interface for gliding and proper function.
- Another complicating anatomic characteristic of zone II is the chiasm of Camper. Here FDP passes through the slips of FDS, creating another potential region for adhesions (FIG 1B).

PATHOGENESIS
- Zone II has the highest probability of developing adhesions and the poorest prognosis after repair.
- Violation of the sheath, the lining, or the blood supply to the tendons by trauma or infection may lead to dense scar and adhesion formation and can compromise the results after either a primary repair or an attempt at single-stage reconstruction with a tendon graft.

NATURAL HISTORY
- Flexor tendon injuries that are not reconstructed can progress to a stiff and sometimes painful digit.
- If both tendons are not functional, no active proximal (PIP) or distal (DIP) interphalangeal motion will be possible, but if only the FDP tendon is disrupted, active PIP flexion will be present.
- If a digit with incompetent flexor tendons is subjected to repeated extension stress, as in pinch, the volar supporting structures will become lax over time, leading to hyperextension and an unstable joint.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The examiner should elicit information about the initial injury, such as when it occurred and if there were...
The flexor tendon sheath is incised, taking care to preserve the A2 and A4 pulleys. An L-shaped flap can be made within the flexor sheath to aid in access to the flexor tendons and protect the A2 and A4 pulleys (TECH FIG 1A).

The scarred tendon is excised, leaving a portion of the distal stump of the FDP intact at its insertion. This is useful in securing the tendon rod in stage 1 and the tendon graft in stage 2.

Isolated chronic disruption of the FDP tendon with an intact FDS tendon is best treated nonoperatively. Attempts at reconstruction of the FDP tendon risk function of the FDS tendon.

Buddy taping or trapping of the injured finger by an adjacent figure during finger flexion may allow concealment of the functional deficit between stage 1 and stage 2 or in the patient who is not a candidate for staged-tendon reconstruction.

Indications for two-stage flexor tendon reconstruction include:

- Loss of FDP and FDS
- Protective sensation
- Nearly full passive range of motion
- Good quality skin in the region of zone II
- A cooperative patient willing to participate fully in rehabilitation

The patient will need to have access to a good hand therapist before and after each of the stages of this complex reconstructive process.

For the second stage of the procedure a tendon must be harvested to use for the reconstruction. Often, a palmaris longus graft is used. If the patient does not have a palmaris longus, then a long toe extensor or plantaris tendon can be used. In this situation, the lower extremity must also be prepared out into the surgical field.

For both stages of the procedure the patient is placed supine on the operating table with the arm abducted on a hand table. A nonsterile tourniquet is placed around the upper arm for hemostasis.

Stage 1: A volar Brunner incision is made over the flexor tendon sheath and extended proximally into the palm. A second incision is made in the distal forearm to ensure placement of the rod within the carpal tunnel.

Stage 2: A limited Brunner incision is made at the level of the distal junction of the repair. A separate incision is made at the level of the proximal junction of the repair. This can be the same incision in the distal forearm as in stage 1 if the tendon graft is long enough. Alternatively, the proximal junction will be in the palm with shorter tendon grafts. A third incision or set of incisions will be made for the tendon harvest.

If a digital nerve laceration is identified, it should be repaired at this stage.

Release any adhesions within the sheath.

Release any flexion contractures of the joints by releasing the volar plate and accessory collateral ligaments.

Be sure to preserve the proper collateral ligaments.

If the A2 or A4 pulleys are absent or have been excised with the scar release, they need to be reconstructed. A tendon graft can be used to reconstruct the pulleys (TECH FIG 1B).
The tendon should be passed between the proximal phalanx and the extensor tendon for A2 reconstruction. For A4 reconstruction, the tendon can be passed dorsal to the extensor tendon. A silicone Hunter rod is inserted into the sheath. Distally, it is secured to the remnant of the FDP tendon with non-absorbing suture. If there is not enough of the tendon remnant, it can be secured to surrounding tissue at the base of the distal phalanx. Some Hunter rods can be secured using a screw placed in the distal phalanx. Proximally, the silicone rod is passed through the carpal tunnel and allowed to glide free with the flexor tendons in the distal forearm (TECH FIG 1C). All skin incisions are closed with 4-0 nylon after ensuring hemostasis. The patient is then placed into a dorsal blocking splint holding the fingers into an intrinsic plus posture. Rehabilitation is started early after surgery, often within 1 week, to ensure that the patient regains full passive range of motion. The scar tissue must be soft and supple before the patient is scheduled for the second stage of tendon reconstruction. On average this takes 3 months.

TECH FIG 1 • A. Creating a L-shaped flap can aid in accessing the underlying flexor sheath contents while preserving the important A2 and A4 pulleys. B. Tendon weaves for reconstruction of A2 and A4 pulleys. C. A “passive” silicone implant running under A2 and A4 pulleys is secured distally to the flexor digitorum profundus stump and extends proximally to the distal forearm.

STAGE 2

Incisions and Graft Harvest

A limited Brunner incision is made distally at the level of the DIP joint so that the distal FDP stump can be located within the sheath. The sutures securing the silicone rod to the profundus stump are released. Do not extend the incision or dissection into zone II, as this will compromise the re-established tendon sheath that has been created by the body’s reaction to the silicone rod. A second incision is made in the distal forearm so that the proximal portion of the silicone rod can be localized. A third set of incisions is then made for tendon graft harvest. This is typically from the palmaris longus, long toe extensor, or plantaris tendon (TECH FIG 2). Plantaris often makes the best donor if a long segment of tendon is needed.

Graft Placement

The tendon graft is then sutured to the proximal end of the silicone rod. The silicone rod is then retrieved from the distal wound, pulling the tendon graft into the tendon sheath (TECH FIG 3A). The distal end of the tendon graft is secured to the distal phalanx with bone anchors. The anchors should be inserted in the footprint of the FDP stump and angled slightly proximally. The proximal angle will ensure that the anchor stays within the bone rather than penetrating the dorsal cortex. It is important to ensure that the anchor does not penetrate the DIP. Alternatively, the tendon graft can be secured to the distal phalanx with a pullout suture tied over the nail, as in a zone I flexor tendon repair. This has been associated with deformities to the nail after suture removal and has no proven biomechanical advantage over suture anchors. Additional fixation can be provided by using the remaining FDP stump and securing this to the tendon graft with a nonabsorbable suture in figure 8 fashion. The distal incision is closed at this point. It will become difficult to gain access to this incision after graft tension is set.
Chapter 56  STAGED DIGITAL FLEXOR TENDON RECONSTRUCTION 2573


TECH FIG 3 • A. Technique for using the silicone rod to draw the tendon graft into the flexor tendon sheath and out through the distal incision. B. Re-creation of the normal finger cascade. C. A Pulvertaft weave is used for the proximal junction between the tendon graft and the flexor digitorum profundus or superficialis in the forearm.
Tendon graft tension is set from the proximal wound. The correct amount of tension is determined with the wrist in a neutral posture and is set by evaluating digital flexion cascade (TECH FIG 3B).

- It may be wise to exaggerate the cascade slightly so that as the graft relaxes and lengthens, the normal flexion cascade is created.
- If the cascade is significantly exaggerated, however, a quadriga effect will result.
- The proximal end of the tendon graft is then woven into the proximal recipient tendon stump with a Pulvertaft weave (TECH FIG 3C).

- The recipient stump proximally can be either the FDS or the FDP to the injured finger. If the initial injury is more than a few months old, the muscle belly of the injured FDP or FDS may be atrophic or scarred proximally in the forearm, which would limit postoperative results. In this setting, the recipient tendon can be a side-to-side anastomosis to the neighboring FDP, which will provide the appropriate excursion.
- All skin incisions are closed after ensuring hemostasis. The patient is then placed into a dorsal blocking splint with the wrist slightly flexed and the MP and IP joints flexed.
- Rehabilitation is started within a few days (see Postoperative Care).

PEARLS AND PITFALLS

**Pulley preservation**

Both the A2 and A4 pulleys must be maintained or reconstructed at stage 1 to prevent bowstringing and maximize the amount of active flexion (FIG 2; see Tech Fig 1B).

**TENOLYSIS**

- This is often necessary after stage 2 of tendon reconstruction. Tenolysis is indicated when passive range of motion is greater than active range of motion. This surgery should not be performed until 3 to 6 months after stage 2.
- The tendon must be exposed within zone II of the tendon sheath and tenolysis performed within the flexor sheath, taking care to preserve the A2 and A4 pulleys. If residual resistance is noted after tenolysis in the finger, an additional incision may be made at the level of the proximal junction to address any adhesions at that level.
- Immediate hand therapy must be initiated postoperatively and can be easier on the patient if a wrist block is performed with a long-acting local anesthetic to preserve motor function while producing an effective sensory block.

**ALTERNATIVE TO STAGE 1**

- The silicone rod that we use is considered “passive” and has no attachment to the proximal flexor motor.
- An "active" alternative exists in which the rod can be secured to the tendon proximally and function as a graft. This can eliminate the need for stage 2 (TECH FIG 4).
- These implants have been associated with a higher rate of complication in the limited number of studies that have examined them.

**TECH FIG 4** • In an active tendon rod, the motor tendon is looped through the ring in the proximal rod, woven through itself, and fixed with nonabsorbable suture so that active motion can be performed.

**FIG 2** • Sagittal MRI showing bowstringing of a flexor tendon (arrow) over the proximal phalanx due to an incompetent A2 pulley.
Chapter 56  STAGED DIGITAL FLEXOR TENDON RECONSTRUCTION

POSTOPERATIVE CARE

- The pre- and postoperative hand therapy is perhaps the most important component of this reconstruction procedure.
  - Patients must be motivated and compliant.
  - Therapists must be knowledgeable.
  - Before stage 1 and stage 2, the patient must have nearly full passive range of motion and a soft tissue envelope that will accommodate the subsequent stages of the process.
  - Stage 1 postoperative therapy is initiated within 48 hours and continues until the patient is ready for stage 2.
    - If pulley reconstruction was performed, the therapist can make ring splints for the patient to wear to protect the pulleys.
    - In general, the patient needs to be monitored for signs of infection. Edema should be controlled with elevation and compressive dressings as needed.
    - A custom splint is used when not exercising. This splint should hold the injured fingers in an intrinsic plus posture, with the MP joints in 70 degrees of flexion and the IP joints held in full extension. The wrist is held at neutral.
    - Passive range of motion of all involved digits is initiated, with emphasis on obtaining full composite flexion and full PIP extension.
    - Active range of motion exercises are also used to establish full active extension of all digits and full flexion of the uninvolved digits. Buddy-taping can be employed to facilitate motion of the operated digit.
    - The protocol for postoperative therapy after stage 2 is as follows:
      - 0 to 3 weeks postoperatively
        - Precautions: No active finger flexion, no passive finger extension
        - The patient is splinted with a dorsal extension block splint holding the involved digits in an intrinsic plus posture and the wrist at neutral. The splint should be worn at all times.
      - Therapist-directed exercises begin with passive flexion and active extension in the splint. The PIP and DIP joints are secured to the splint in extension between exercise sessions.
      - Wound care and edema control are also incorporated and the patient must be observed for signs of infection.
      - 3 to 6 weeks postoperatively
        - Precautions: Monitor closely for PIP flexion contractions, no passive finger extension, no splint removal
        - Active range of motion is initiated with “place and hold” exercises and progressed to full active range-of-motion exercises by 4 weeks after surgery while still in the splint.
        - Once the surgical wounds have healed, soft tissue massage should be incorporated to soften the volar tissues.
      - 6 to 9 weeks postoperatively
        - Precautions: No resisted active motion, light functional activities only
        - Reliable patients can be weaned from the dorsal blocking splint.
        - The active flexion and extension exercises should be continued. Blocking exercises are initiated for PIP and DIP flexion to facilitate tendon glide and pull-through. Combined finger extension exercises are slowly initiated with the wrist in slight flexion. If the patient is a heavy scar former, this begins at 6 weeks; if average, at 7 weeks; if light, at 8 weeks.
      - 9 to 12 weeks postoperatively
        - Precautions: No lifting or uncontrolled use
        - Splinting should be modified to correct any residual joint contractures and increase soft tissue excursion.
        - The patient can be allowed to begin progressive strengthening and should continue active range-of-motion and tendon gliding exercises as well as scar management as needed.
      - 12 to 14 weeks postoperatively
        - Precautions: No heavy lifting

Full passive range of motion should be achieved before stage 1 and again before stage 2. Less than maximum passive range of motion preoperatively will markedly worsen the functional result after stage 2.

Establishing the correct cascade with the appropriate amount of tension on the tendon graft in stage 2 is important. The graft will likely relax and lengthen as the patient goes through rehabilitation. A slight exaggeration of the cascade at the time of surgery may ultimately produce the normal cascade as the tendon graft lengthens. Gross exaggeration of the cascade, however, will produce a quadriga effect. The uninjured digits will be less than fully flexed when the injured digit has reached full flexion in the palm (FIG 3).

Hand therapy

A good therapist and a motivated patient are critical for a good outcome for this surgery.

FIG 3 • Clinical photograph of the quadriga effect. The long finger, in which the flexor digitorum profundus has been repaired with too much tension, is maximally flexed into the palm and the adjacent fingers cannot be actively flexed further.
Splinting is continued as needed to address contractures. Active range-of-motion and strengthening activities are continued. Resistance is gradually increased up to about 30 lbs by week 14.

14 to 16 weeks postoperatively
- The patient progresses to full resistive strengthening exercises and activities.
- A work-hardening program is initiated if needed to prepare for return to work.
- If the patient is less reliable, the above protocol is followed except that dorsal blocking splinting is continued for up to 9 weeks and active motion is delayed at least 4 weeks.

OUTCOMES
- Because there are few alternatives to this staged process of reconstruction, there are limited articles comparing this treatment to another. Most of the investigations in the literature are retrospective reviews documenting overall postoperative motion and outcome ratings based on objective and subjective rating systems.
- The larger studies have shown good and excellent results in the 70% to 80% range, depending on the grading system used.
- Final total active motion is about 70% of the contralateral uninjured digit.
- Typically a significant discrepancy exists between ultimate total passive motion and total active motion. A flexion contracture of about 20 degrees at the DIP joint is common.
- The most common reported complication, seen in 30% of patients, was the need for a tenolysis.
- Other common complications that resulted in the need for further surgery included infection, tendon rupture, pulley rupture with bowstringing, and incorrect tendon tensioning.

COMPLICATIONS
- The most common complication is the development of adhesions that limit active motion. This can be assessed by a discrepancy between the active and passive range of motion. If there are significant discrepancies after at least 3 months of therapy after stage 2, then a tenolysis is recommended. This is followed immediately by a rigorous course of therapy to regain active motion. By 3 months, the tendon graft and junction sites should be strong enough to allow for unrestricted active motion.
- Bowstringing is common if the A2 and A4 pulleys are compromised by initial trauma or released with the scar and adhesions during stage 1. In this setting, these pulleys should be reconstructed during stage 1. If they are found to be incompetent during the stage 2, then pulley reconstruction must be performed and the tendon graft must be delayed until the patient has healed from the pulley reconstruction and once again demonstrated nearly full passive range of motion.
- Infection should be monitored for closely, given the previous history of a penetrating wound that caused the tendon laceration in the first place and the implantation of a synthetic material during stage 1 of the procedure. Infections should be managed aggressively because the local inflammation can produce further contractures and adhesions.

REFERENCES
DEFINITION

- Traumatic disruptions of the extensor mechanism represent a broad spectrum of injuries, frequently seen because of the tendons’ superficial location, and frequently associated with concomitant injury to bone, skin, and joint.\textsuperscript{15}
- Repair can be technically demanding. The extensor tendons are thin, have limited excursion, and are intolerant of shortening, especially in the digits.
- Reconstruction of subacute and chronic extensor tendon injuries are more challenging and less effective than early repair, underscoring the importance of appropriate treatment of an acute injury.

ANATOMY

- Extensor tendon zones of injury (Verdan) (FIG 1A)\textsuperscript{13}
  - The extensor mechanism is divided into eight zones in the fingers and five in the thumb, numbered from distal to proximal.
- Even-numbered zones are over bones and odd-numbered ones are over joints.
- Extrinsic extensors (FIG 1B and Table 1)
  - Digital and wrist extensor muscles originate from the lateral epicondyle and condyle, with musculotendinous junctions 3 to 4 cm proximal to the wrist joint. The extensor indicis proprius (EIP), extensor pollicis longus (EPL), abductor pollicis longus (APL), and extensor pollicis brevis (EPB) all originate more distally from the ulna, the radius, or both and have more distal extension of muscle fibers.
  - The four extensor digitorum communis (EDC) tendons originate from a common muscle belly and have progressively limited independence moving from the index to small fingers.
  - The fascia over the extensor tendons thickens at the wrist to form the extensor retinaculum, with vertical septa separating the six extensor compartments (FIG 1B).
  - Juncturae tendinum provide interconnections between the EDC tendons just proximal to the metacarpophalangeal (MCP) joints.

FIG 1 • A. Extensor tendon zones of injury. B,C. The digits are to the left and the wrist is to the right. B. The top of the figure is radial and the bottom is ulnar. Wrist and hand extensor tendon anatomy, with numbers to identify the extensor tendon compartments. R is the reflected extensor retinaculum and J is a junctura tendonum. Note the combined extensor digitorum communis (EDC) tendon to the ring and small finger. In the fourth compartment, the extensor indicis proprius (EIP) tendon is deep to the EDC tendons and has more distal muscle fibers. In the hand, it is just deep and ulnar to the index EDC tendon. See Table 1 for more details. C. The digital extensor mechanism. 1. Terminal tendon. 2. Triangular ligament. 3. Proximal interphalangeal (PIP) joint. 4. Central slip tendon. 5. Sagittal band. 6. Lateral band, which will become the terminal tendon distally. 7. Conjoined lateral band, with fibers to base of middle phalanx and to the lateral band. This patient has an unusual proprius tendon to the long finger (*), passing ulnar to the EDC tendon and beneath the junctura.
The EIP and extensor digiti minimi are ulnar and deep to the EDC in the hand and at the MCP joint. The EIP passes beneath the junctura tendinum.

There can be considerable variability of the extensor tendons on the dorsum of the hand, with less than 50% of people having a separate EDC tendon to the small finger. Duplicated, interconnected tendons are common.

The sagittal band holds the extensor tendon over the metacarpal head at the MCP joint, and, through its connection to the volar plate, extends the joint.

Intrinsic extensors (FIG 1C)

Intrinsic extensors originate in the hand and include the four dorsal interossei, three palmar interossei, and four lumbricals. The thenar and hypothenar muscles also contribute to interphalangeal extension.

The intrinsic tendons join to form the conjoined lateral bands volar to the axis of the MCP joint, and continue dorsal to the axis of the proximal (PIP) and distal (DIP) interphalangeal joints. This allows them to simultaneously flex the MCP joint and extend the PIP and DIP joints, in addition to providing digital adduction and abduction.

PATHOGENESIS

Zone I

Disruption of the extensor tendon over the DIP joint will result in a terminal extensor lag after an open or closed injury (FIG 2).

Sudden forced flexion of the extended DIP joint can lead to an avulsion of the tendon from its insertion on the distal phalanx (mallet finger), possibly with an associated distal phalanx fracture.

The long, ring, and small fingers are most frequently involved, although closed mallet injuries can also be seen in the index finger and thumb.

Zone II

Laceration over the middle phalanx can give the clinical appearance of a zone I injury.

Injury to the periosteum and middle phalanx can lead to increased swelling, extensor tendon adherence, and DIP stiffness.

Zone III

Disruption of the central slip at the PIP joint may occur as a closed rupture (with or without an associated bone injury) or be associated with traumatic arthrotomy.

Central slip avulsion is seen with volar PIP joint dislocations.

Early closed injuries may present with swelling, pain, and little extension loss but can progress to a boutonnière deformity as the lateral bands migrate palmarly and become flexors of the PIP joint in the weeks after injury. Close follow-up is warranted for suspicious injuries.

Zone IV

Injuries occur over the proximal phalanx and typically involve only a portion of the extensor mechanism.

Lacerations are usually partial as the extensor “hood” covers almost 75% of the circumference of the digit. With a complete central slip laceration, PIP extension may be maintained (through the lateral bands) initially, although a boutonnière deformity may develop later.

Differentiation between complete and incomplete injury can be difficult, but pain or weakness with resisted PIP extension (especially from an initially flexed position) can be suggestive. As above, close follow-up is warranted for suspicious injuries.

Zone V

Tendon injury occurs over the MCP joint.

There may be an open laceration or a closed injury to the sagittal band with extensor tendon subluxation.

Most frequently, the radial sagittal band is disrupted in closed injuries allowing ulnar subluxation of the extensor tendon.

The surgeon should assume there is an open MCP joint injury with any tendon laceration around the joint.

Zone VI

Disruption of extensor tendon is over the dorsum of the hand.

Single tendon and partial tendon lacerations may be difficult to identify due to maintenance of some digital extension though an intact junctura tendinum and EDC tendon from an adjacent digit (FIG 3).
Zone VII
- Lacerations occur over the wrist and through the extensor retinaculum.

Zone VIII
- Pathology is located in the forearm at the musculotendinous junction or muscle belly.
- It may be difficult to detect concurrent posterior interosseous nerve injury in the presence of proximal extensor muscle lacerations.

Thumb
- The terminal extensor tendon is thicker than in other digits—mallet injury is rare.
- Tendon lacerations at, and distal to, the MCP joint are not associated with retraction of tendon ends, and primary repair is straightforward. Lacerations proximal to the MCP joint are associated with EPL retraction (often of the wrist).

### NATURAL HISTORY

- Untreated complete tendon lacerations at and distal to zone V will lead to persistent (and sometimes progressively worsening) digital deformity, often with continued pain and development of a flexion contracture.
- Untreated terminal tendon injuries may lead to a swan-neck deformity due to proximal migration of the digital extensor mechanism and increased extension force at the PIP joint.
- Delayed treatment of central slip injuries may lead to boutonnière deformity and PIP flexion contracture as the lateral bands migrate palmarly.
- Untreated tendon lacerations proximal to zone V will heal in lengthened fashion with pseudotendon formation. There may be a persistent extensor lag, weakness, or pain. Gradual loss of muscle length and elasticity (sometimes within as little as a week or two) can make delayed primary repair more difficult.
- EPL tendon lacerations proximal to the MCP joint may be difficult to primarily repair as little as 2 weeks after the injury, requiring tendon grafting or EIP transfer.
- Partial tendon lacerations involving less than 50% of the tendon width, longitudinal lacerations, and single lateral band lacerations will generally function well without repair.

### PATIENT HISTORY AND PHYSICAL FINDINGS

- Assessment and documentation of skin and soft tissue injury is important to aid in planning for débridement and extension of the skin incision for exposure and determining the need for soft tissue coverage.
- A complete neurologic and tendon examination is critical to rule out concurrent or remote injury that will alter treatment or outcome.
  - The EIP is examined. It is deep to other extensor tendons, with the most distal musculotendinous junction.
  - The extrinsic extensor tendons are examined with the wrist in neutral, testing MCP extension against resistance. (Isolated PIP extension can be performed by the intrinsic muscles even in the presence of complete extrinsic extensor tendon lacerations.)
  - Examination of the digits may identify extensor lag, weakness, or pain with resistance to extension at the PIP or DIP joints.
- Active and passive range of motion and strength are assessed. Active motion loss helps determine tendon deficits, while loss of passive motion may be pain-related or represent remote injury or arthritis. Lacerations proximal to the juncture of the DIP joint may have nearly full motion, but with weakness on strength testing (FIG 3).

### IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs are necessary to evaluate for any fractures, foreign bodies, preexisting injury, or arthritis that may alter treatment or affect the final result.
- Ultrasound or MRI are occasionally useful for suspected radiolucent foreign bodies. While both studies can be used to more fully evaluate tendon injuries, treatment decisions are usually based on history and physical examination.

### DIFFERENTIAL DIAGNOSIS

- Radial nerve or posterior interosseous nerve injury
- Extensor tendon subluxation at the MCP joint
- Chronic PIP flexion contracture and “pseudo-boutonnière” deformity
- Physiologic swan-neck deformity or DIP joint osteoarthritis with apparent mallet deformity
- Underlying joint deformity and arthrosis

### NONOPERATIVE MANAGEMENT

- Disruption of the terminal extensor tendon (mallet finger)
  - Treatment consists of full-time static DIP splinting for 6 to 8 weeks, followed by an additional 6 weeks of protective splinting at night and with high-risk activities.
  - Patients must be counseled as to the importance of maintaining full DIP extension, even during splint changes.
  - A dorsal splint (FIG 4A) can allow the patient nearly full use and sensibility of the digit, although palmar or thermoplastic splints can be used in some cases (provided that full DIP extension can be ensured). A good fit without excessive DIP hyperextension which can cause skin injury is critical.
  - The PIP is generally left free and motion encouraged. For patients with moderate PIP hyperextension, the PIP may be flexed 30 degrees and incorporated in the splint for the first 3 weeks of treatment.
  - Treatment can be initiated as late as 4 months after the original injury and still lead to a good result, although a couple more weeks of full-time splinting may be necessary.
Final results: About 80% of patients should regain full flexion with less than a 10-degree extensor lag. Patients with a greater extension lag after 6 weeks may benefit from 2 or 3 more weeks of full-time splinting. Swelling around the DIP joint can persist for months.

Central slip avulsion
- This is treated with full-time static PIP splinting in extension, with active and passive DIP flexion encouraged for 6 weeks, followed by 6 weeks of night splinting.
- Intermittent use of dynamic extension splint is warranted for PIP flexion contracture.

Closed sagittal band rupture
- The patient is placed in a below-elbow cast with the MCP joints supported in full extension (to allow no more than 10 degrees of flexion) for 6 weeks.
- Compliant patients can be switched to a hand-based splint after 3 weeks of casting with the MCP joint supported in 30 degrees of flexion (FIG 4B).
- Surgical treatment is indicated for closed ruptures presenting more than 2 weeks after injury or those that do not respond to conservative treatment.

Partial extensor tendon lacerations
- Conservative treatment is indicated if the laceration is known to involve less than 50% of the tendon width and in longitudinal tendon lacerations.
- If the degree of injury is unknown, conservative treatment should be considered in patients with full active extension, minimal or no pain with resisted extension, and good extension strength. Surgical exploration and repair is indicated if there is an extensor lag, weakness, or pain with resisted extension.
- Partial digital extensor tendon lacerations are treated in the manner described earlier, with splinting for 2 to 3 weeks, followed by a monitored gradual exercise program to ensure that an extensor lag does not develop.
- Partial hand and forearm extensor tendon injuries are treated similarly. A splint or cast is used for 3 weeks with mild wrist extension and 30 degrees of MCP flexion. The PIP joints are left free.

SURGICAL MANAGEMENT

Preoperative Planning
- A careful examination is performed to determine the structures that are injured or will need repair (eg, open joint injuries, fractures, flexor tendon or nerve injuries) and to inform the patient of the extent of the procedure, anticipated rehabilitation, need for occupational and non-occupational restrictions, and expected outcome.
- If the wound is infected at the time of presentation, irrigation and débridement should be followed by a course of antibiotics. Delayed primary tendon repair can be carried out 7 to 14 days later (sooner for EPL lacerations proximal to the MCP joint and EDC lacerations proximal to the juctura).
- The surgeon should anticipate the need for tendon graft or transfer for subacute injuries or those with tendon loss.
- Local anesthesia and a digital tourniquet can be used for injuries distal to the PIP joint. The need for an upper arm tourniquet for more proximal injuries may necessitate a general or regional anesthetic, unless the anticipated surgical time is less than 30 minutes. Regional anesthesia can offer extended postoperative pain relief and muscle relaxation during the initial recovery period.

Positioning
- Standard positioning is used with the hand on a hand table and the surgeon at the head.
- Preparation and draping is done above the elbow to allow dressing and splint application before removal of drapes.
- A carefully padded tourniquet is applied, set to 100 mm Hg above systolic blood pressure (sometimes more for obese patients, and less for children or those with small arms).

Approach
- Wound exploration and débridement are performed in a bloodless field, with appropriate light and magnification. Injuries over a joint usually require joint exploration and irrigation.
- The skin laceration can be extended to improve exposure, allow retrieval of retracted tendons, provide access to place sutures, and to decrease skin tension during retraction. Long, narrow skin flaps are avoided. Longitudinal incisions on the dorsum of the hand and fingers can cross over joints (unlike on the digital flexor surface).
- Bipolar electrocautery is used as needed, with care taken not to injure dorsal cutaneous nerves. If there is any doubt regarding hemostasis, the tourniquet is deflated before closure. Drains are seldom needed.
- Only the skin in the fingers, hand, and distal forearm is closed, with limited subcutaneous sutures more proximally if needed.
SUTURE TECHNIQUES

- Suture technique is determined by the thickness and shape of the tendon and the nature and character of the laceration (TECH FIG 1).
  - Thin tendons (e.g., in digits) can be repaired with a horizontal cross-stitch suture (Silfverskiöld), simple running, figure 8, or horizontal mattress suture using 4-0 or 5-0 braided or monofilament nonabsorbable material.
  - Thicker tendons can support a two- or four-strand grasping repair with a 2-0, 3-0, or 4-0 nonabsorbable braided suture (e.g., Ethibond, Ticron, or Fiberwire), optionally reinforced with a 5-0 or 6-0 monofilament epitendinous suture placed in a simple running or cross-stitch fashion.
- In general, repair strength is related to number of suture strands crossing the repair site, the thickness of the suture, and the locking style of the stitch.

TECHNIQUES
SUTURE TECHNIQUES

A B C D E F G

TECH FIG 1 • Some suture techniques for extensor tendon repair. The strongest repairs are the Silfverskiöld cross-stitch for flat tendons, and the four-strand cruciate suture for tendons able to accept a core suture. A. Running suture. B. Horizontal mattress. C. Silfverskiöld cross-stitch (which can also be used as a circumferential epitendinous tidying suture over a core suture). D. Modified Kessler. E. Modified Bunnell. F. Krackow. G. Four-strand cruciate suture.

REPAIR IN THE FINGERS

Zone I (DIP Joint)

Soft Tissue Mallet Treatment

- In patients with closed tendon disruptions who cannot tolerate a splint for occupational reasons, pinning across the DIP joint with a 0.045-inch Kirschner wire exposed at the tip or buried under the skin may be indicated. Pin removal is performed 6 weeks later, followed by motion exercises and 6 weeks of splinting at night and during vigorous activity.
- Lacerations in zone I are treated with primary surgical repair.
  - A figure 8 or running cross-stitch with a 5-0 nonabsorbable suture can be placed in the tendon, taking care to avoid shortening the tendon. This is supported with a 0.045-inch Kirschner wire across the DIP joint for 6 weeks. The DIP should be in neutral extension, without hyperextension.
  - An easier and often better alternative is use of a "tenodermodesis" stitch of 4-0 nylon through both the tendon and skin (TECH FIG 2). This can be especially useful in cases treated in the emergency room, or in children, where the small tendon is difficult to accurately repair.
    - Full-time extension splinting (as in a closed mallet finger) or a 0.045-inch Kirschner wire across the extended DIP joint is required.
    - The suture can be removed in 2 to 3 weeks, but the splinting should continue for a total of 6 weeks full time and another 6 weeks at night.

Bony Mallet Treatment

- It remains controversial whether mallet fractures with greater than 50% of the distal phalanx involved or with DIP joint subluxation should be treated surgically or by splinting alone. Surgery is more likely warranted in younger patients and those with greater amounts of subluxation. If conservative management is being considered, be sure to obtain a good lateral radiograph with the digit in the DIP splint, as DIP extension to neutral may demonstrate subluxation that was not apparent when the joint was flexed.
  - A large bone fragment is present, with subluxation of the DIP joint (TECH FIG 3A-B).
  - Place a 0.045-inch Kirschner wire down the shaft of the distal phalanx, almost to the DIP joint.
  - Maximally flex the DIP and place a 0.035-inch Kirschner wire at the anticipated location of the reduced dorsal fragment of the distal phalanx. The skin entry point is
Zone III (Over PIP Joint)
- Use a running 4-0 or 5-0 suture to repair the central slip in the manner detailed earlier (TECH FIG 4).
- Repair the lateral band or bands with single 4-0 or 5-0 monofilament suture in a figure 8 fashion.

Reconstruction in Cases with Tendon Loss
- Consider V-Y advancement of the central tendon or a “turndown” of the central slip proximal to the laceration to cover the defect.20
- Extend the skin incision proximally, almost to the MCP joint.
- Incise a V in the central slip, with the apex just distal to the MCP joint, and the distal end the width of the tendon, taking care not to damage the overlying epitenon (TECH FIG 5A, red line).
- Advance the tendon distally. Disrupt the loose alveolar tissue between the tendon and periosteum as little as possible.
- Close the V into a Y with a 4-0 or 5-0 suture, and repair the distal end of the advanced central slip as described earlier (TECH FIG 5B).
- An alternative method involves creating a rectangular flap of central slip proximally and turning it up to attach distally (TECH FIGS 5A–D).20
- Suture anchors or small holes drilled in the middle phalanx are occasionally needed to secure the tendon to the...
dorsal base of the middle phalanx, especially if the dorsal margin of the base of the phalanx is lost.

**Postoperative Management**

- Postoperative rehabilitation for children, less compliant adults, and cases with a tenuous repair involves static splinting or pinning of the PIP joint in full extension for 4 weeks, followed by a protected motion program.
- For compliant adults, an early motion protocol can be initiated.6
  
  - 0 to 30 degrees of active PIP flexion and extension is allowed starting a few days after surgery, using a palmar flexion block splint with a free wrist and MCP joint.
  - 10 to 20 repetitions are performed each hour, with a static PIP splint in full extension when not exercising.
- DIP flexion exercises are performed in the static PIP extension splint.
- If no extensor lag develops, PIP motion can be increased to 40 degrees after 2 weeks, 50 degrees after 3 weeks, and 70 degrees after 4 weeks. The splinting is discontinued at 6 weeks.
- Results are often less than perfect, especially in cases with tendon loss, where some loss of motion should be expected.

**Zone IV (Over Proximal Phalanx)**

- The tendon at this level may be thicker and support a grasping or locking core stitch with a 4-0 braided nonabsorbable suture, reinforced with a running 5-0 monofilament suture.
- If the tendon is too thin, repair as in zone III.
- Postoperative management is as in zone III.

**Zone V (Over the MCP Joint)**

- The tendon is much thicker at this level and can sometimes support a 3-0 or 4-0 braided nonabsorbable core suture with a running simple or cross-stitch suture over the repair, incorporating any laceration of the sagittal band.
- An abnormal resting cascade of the digits suggest a tendon laceration (TECH FIG 6A).
- Lacerations over the MCP joint often extend into the joint. The skin laceration is extended and débrided and the wound explored. Large capsular rents (arrow in TECH FIG 6B) can be repaired with a simple running 5-0 absorbable monofilament suture. Small capsular lacerations are left open.
- The tendon end is retrieved, and a 3-0 nonabsorbable core suture is placed. The first loops of the cruciate stitch are shown (TECH FIG 6C).
The distal locking stitch is placed on one side of the tendon but not pulled tight until the tendon ends are accurately approximated. The limbs of the X are individually tightened (TECH FIG 6D).

The core suture is completed and will not slide (TECH FIG 6E).

The repair is reinforced with a 5-0 nonabsorbable monofilament suture. This can be circumferential proximal to zone V, but only over the dorsal surface of the tendon distally (TECH FIG 6F).

The resting cascade of the digits shows the repaired finger to be slightly “tighter” than normal immediately after the repair (TECH FIG 6G).

A forearm-based splint is applied with 30 degrees of wrist extension, less than 30 degrees of MCP flexion, and fully extended PIP and DIP joints (TECH FIG 6H).

After 8 to 10 days, this splint is converted to a short-arm cast supporting the MCP joints in extension (including all fingers for index lacerations and the ulnar three for other lacerations) but leaving the PIP joints free for another 3 weeks before institution of a therapy program.

Alternatively, an early protected motion program can be initiated.3,9

**Repair of Distal “Compromised” Zone V Lacerations**

In this clinical situation a standard end-to-end repair may be tenuous or may not be possible secondary to contracted or lost tendon substance. A tendon interpositional graft may be required.

- Partially incise the distal tendon transversely 5 mm distal to the cut edge.
- Weave tendon graft in a volar to dorsal direction through this transverse incision in the distal stump.
- Sew the graft to the proximal stump to the distal tissue and back to itself using nonabsorbable material (TECH FIG 7).
- Sew the proximal stump to the tendon graft using a Polvartaft weave.
**TECH FIG 7** • Tendon graft is woven volar to dorsal through the transverse incision in the distal tendon stump. A Polvertaft weave is used to secure the graft to the proximal tendon stump.

**Zone VI (Metacarpal Level)**
- The tendon is thicker and repair is similar but technically easier than in zone V.
- Use a 3-0 or 4-0 braided nonabsorbable suture, reinforced with a circumferential running cross-stitch 5-0 or 6-0 monofilament suture.
- Rehabilitation is as for zone V.

**Zone VII (Wrist and Extensor Retinaculum)**
- Suture repair and postoperative management are as in zone VI.
- The extensor retinaculum is incised for repair and retrieval of the proximal tendon stump.
- Retinacular closure is performed with a 4-0 absorbable suture to prevent tendon bowstringing. A portion of the retinaculum may need to be excised to allow the repair site to glide smoothly.
- The EPL can be repaired outside of the retinaculum and left in the subcutaneous tissue.
- Postoperative management is the same as for Zone V injuries.

**Zone VIII**
- Make a generous incision to determine the resting orientation of the tendons before débridement and repair. It may be helpful to tag proximal tendon ends with labels to define them before further dissection changes their position.
- In the distal forearm, conventional repair with grasping sutures is possible. EDC tendons can be repaired as a group if necessary.
- Proximally, repair can be much more difficult. 3-0 interrupted absorbable sutures can be used in fibrous septa within muscle along with repair of epimysium.
- Postoperative management is as for zones V to VII.

**PEARLS AND PITFALLS**

**Tetanus prophylaxis**\(^{16}\)
- Tetanus toxoid “booster” should be given to patients with at least three previous doses, but last dose more than 5 years ago for tetanus-prone wounds (>1-cm laceration, crush, burn, high-energy injury, or with infection, devitalized tissue, or gross contamination) or more than 10 years ago for wounds not prone to tetanus.
- Tetanus immune globulin should be given for tetanus-prone wounds in patients with unknown or incomplete vaccination history. It is not clear, however, that “tetanus-prone wounds” are more likely to cause tetanus.
- The greatest protection against tetanus is a completed childhood vaccination series.
- A tetanus booster at the time of injury does not change the likelihood of developing tetanus.

**Lacerations proximal to juncturae tendinum**
- Extensor lag may be more subtle, sometimes noted only with lack of active MCP hyperextension, pain with resisted range of motion, or lack of palpable EDC tendon on dorsum of hand.
- Full PIP extension may be possible through the lateral bands even in the presence of a complete tendon laceration.

**Subacute lacerations**
- Be prepared for EIP transfer or free tendon graft for delayed treatment of EPL lacerations.
- Side-to-side repair to adjacent extensor tendons or use of a free tendon graft is occasionally needed for treatment of chronic injuries involving other tendons.

**Clenched-fist injuries**
- Extensor tendon injury may be well proximal to the skin injury.
- Associated MCP joint injuries are common.

**Shortened repair**
- Digital extensor mechanism is very sensitive to shortening, with resulting loss of flexion.

**Distal forearm extensor tendon lacerations**
- Before exploring proximal injury, locate and label individual tendon ends (based on location).
- Detailed exploration (for incision and drainage, foreign body removal, etc.) may distort tendon position, making it impossible to determine correct proximal motor to attach to each distal tendon end.

**Proximal forearm lacerations**
- Associated nerve injury (especially the posterior interosseous nerve) can make diagnosis and treatment difficult.
POSTOPERATIVE CARE

Postoperative care is detailed under the surgical technique for each individual location.

OUTCOMES

Good or excellent results can be anticipated in most patients, with worse outcomes seen in the digits and with concomitant soft tissue or bone injury. Loss of digital flexion is a greater problem than small losses of extension.\(^2\)\(^,\)\(^16\)

Stronger suture techniques and early dynamic postoperative protocols may result in better functional outcomes earlier,\(^17\) although few controlled studies show improvement in long-term results when compared to static splinting programs, which are easier, more predictable, and less expensive.\(^12\),\(^14\)

Early motion programs may be most beneficial in zones III and IV.

COMPLICATIONS

Infection
Rupture of repaired tendons
Stiffness
Primary joint stiffness after immobilization
Adherence of repaired tendon to surrounding skin, bone
Extensor lag

REFERENCES

DEFINITION

- Traumatic injury to the extensor tendons of the hand and forearm results in the disruption of tendon substance, causing a loss of active wrist or digital extension.
- Primary repair of the extensor tendon usually can be performed within 7 days after appropriate irrigation and débridement of wounds and stabilization of any fractures.\(^5\)
- Late reconstruction of extensor tendon injuries presents an operative challenge and often requires the use of tendon transfer and grafting techniques.

ANATOMY

- The extensor mechanism of the hand and wrist is a complex system involving balanced interplay between extrinsic and intrinsic components (FIG 1).
- The extrinsic extensor tendons are divided into superficial and deep groups in the forearm:
  - Superficial: extensor carpi radialis longus and brevis (ECRL and ECRB), extensor digitorum communis (EDC), extensor digiti minimi (EDM), extensor carpi ulnaris (ECU), and anconeus
  - Deep: abductor pollicis longus (APL), extensor pollicis brevis and longus (EPB and EPL), extensor indicis proprius (EIP), and supinator
- Wrist extension is provided by the ECRB, ECRL, and ECU.
- Finger and thumb extension is provided by the APL, EPB, EPL, EDC, EIP, and EDM.
- The radial nerve innervates all extensor muscles of the hand, except the intrinsics, which are innervated by the median and ulnar nerves. The radial nerve’s deep motor branch becomes the posterior interosseous nerve (PIN).

![Diagram of the extensor mechanism of the hand and wrist](image_url)
There are six fibro-osseous dorsal compartments at the level of the wrist covered by the extensor retinaculum. The contents of each compartment are as follows:
- I: APL, EPB
- II: ECRL, ECRB
- III: EPL
- IV: EDC, EIP
- V: EDM
- VI: ECU

The intrinsic system of the hand consists of the seven interosseous muscles (three palmar and four dorsal) and four lumbrical muscles.

The intrinsic muscles pass volar to the axis of the metacarpophalangeal (MP) joints and dorsal to the interphalangeal (IP) joints; thus, the intrinsic system will flex the MP joints and extend the IP joints.

On the dorsum on the hand, the fibrous bands of the juncturae tendinum connect the extensor digitorum tendons of the long, ring, and small fingers.
- This interconnection is what allows grouped extension of the fingers.
- The EIP and EDM are ulnar to their respective EDC tendons and function as independent extensors of the index and small fingers.

Over the MP joints, tendons are held in a central position by the sagittal bands, which envelop the MP joint and attach to the volar plate.

The dorsal extensor apparatus is formed distal to the MP joint from contributions of both extrinsic and intrinsic tendons.
- The central slip, the continuation of the extrinsic extensor tendon, inserts into the dorsal base of the middle phalanx.
- The lateral bands are formed from the intrinsic muscles on either side of the finger and send fibers to the middle phalanx as well as contributions to the central slip.
- The lateral bands combine dorsally over the middle phalanx to form the terminal extensor tendon, which inserts on the dorsal base of the distal phalanx.
- The transverse and oblique retinacular ligaments stabilize the tendons of the dorsal apparatus.

Traumatic injuries to the extensor tendons can be described in terms of nine anatomic zones (Table 1).³

<table>
<thead>
<tr>
<th>Zone</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Distal interphalangeal</td>
</tr>
<tr>
<td>II</td>
<td>Middle phalanx</td>
</tr>
<tr>
<td>III</td>
<td>Proximal interphalangeal</td>
</tr>
<tr>
<td>IV</td>
<td>Proximal phalanx</td>
</tr>
<tr>
<td>V</td>
<td>Metacarpophalangeal</td>
</tr>
<tr>
<td>VI</td>
<td>Metacarpal</td>
</tr>
<tr>
<td>VII</td>
<td>Wrist</td>
</tr>
<tr>
<td>VIII</td>
<td>Distal forearm</td>
</tr>
<tr>
<td>IX</td>
<td>Proximal forearm</td>
</tr>
</tbody>
</table>

Even-numbered zones overlie bones and odd-numbered zones overlie joints.

Vascular supply⁵
- Forearm: nutrition via small arterial branches from the surrounding fascia
- Wrist: derived from mesotenon; nutrition via diffusion
- Hand: derived from paratenon; nutrition via perfusion

PATHOGENESIS
- Extensor tendons are susceptible to traumatic injury because of their relatively superficial location and thin tendon substance.
- Acute repair within 7 days is recommended, but direct repair of acute injuries is occasionally impractical in cases with extensive soft tissue damage or segmental tendon loss.
- In these cases, skeletal stabilization is obtained first (Fig 2), followed by soft tissue coverage, and finally late reconstruction of the disrupted extensor mechanism.
- Also, late presentation of traumatic disruptions of an extensor tendon makes direct repair difficult because of tendon retraction and subsequent extrinsic tightness.
- Traumatic injury to the extensor tendons can also occur after upper extremity fractures.
- Acute rupture of the EPL tendon has been associated with displaced distal radius fractures.
- Delayed EPL rupture has been associated with minimally displaced distal radius fractures. These attritional ruptures are generally attributed to compromise of the tendon’s vascular supply by soft tissue damage and hemorrhage after fracture with an intact third extensor compartment.⁴
- Delayed extensor tendon ruptures of the EPL, EDC, and EIP have been reported as a complication after volar and dorsal plate fixation of distal radius fractures.²

Table 2 Extensor Tendon Zones of Thumb

<table>
<thead>
<tr>
<th>Zone</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-I</td>
<td>Interphalangeal</td>
</tr>
<tr>
<td>T-II</td>
<td>Proximal phalanx</td>
</tr>
<tr>
<td>T-III</td>
<td>Metacarpophalangeal</td>
</tr>
<tr>
<td>T-IV</td>
<td>First metacarpal</td>
</tr>
<tr>
<td>T-V</td>
<td>Wrist</td>
</tr>
</tbody>
</table>

FIG 2 • Preoperative picture of a patient with severe soft tissue loss, including extensor muscle, after a motorcycle accident, which required extensor tendon reconstruction.
NATURAL HISTORY

- Without treatment, complete extensor tendon disruptions will result in a persistent loss of active extension or incomplete extension of the wrist or digits (or loss of active abduction and extension of the thumb, depending on which tendon or tendons are involved).
- A late tendon imbalance resulting from pull of the flexor tendons against a disrupted or weakened extensor mechanism with or without fixed joint contracture may develop if reconstruction is not performed.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient most commonly has a history of penetrating or blunt trauma to the dorsal forearm or hand with resultant loss of active extension of the wrist, fingers, or thumb (FIG 3). Loss of soft tissue may be associated with the original injury.
- In cases of attritional rupture of the EPL tendon, the patient may have a recent or remote history of a distal radius fracture, usually only minimally displaced.
- Physical examination methods include the following:
  - MP extension. Incomplete MP extension indicates extensor tendon disruption in zones proximal to the MP. If the other fingers are not kept flexed, the patient may be able to fully extend the affected finger in the presence of a completely lacerated tendon.
  - EPL test. An EPL rupture manifests as a loss of extension of the thumb IP and MP joints.
  - Tenodesis test. A loss of extensor tendon continuity will result in loss of the tenodesis effect. Wrist flexion will have no effect on finger extension.
  - A complete evaluation of the elbow, forearm, wrist, or hand begins with a thorough inspection of all open wounds and an assessment of the extent of soft tissue compromise.
  - Local or regional anesthesia can assist with patient comfort during the examination.
  - A comprehensive neurovascular examination must be performed before using any anesthetic. Special attention is directed to the status of the radial nerve, specifically the PIN.
  - Compromise in PIN function may result from compression neuropathy, direct injury, or underlying elbow pathology.
  - If there is a suspicion of joint violation, then injection of sterile saline with or without methylene blue into the joint can verify whether the joint capsule has been disrupted.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- AP, lateral, and oblique plain radiographs of the affected area (elbow, forearm, wrist, or hand) are obtained to rule out the presence of a foreign body, underlying fracture, or bony deformity or pathology.
- In cases of late presentation of suspected extensor tendon rupture, MRI is occasionally useful to confirm the diagnosis and identify the location of the retracted tendon ends.

DIFFERENTIAL DIAGNOSIS

- Radial nerve or PIN palsy
- Flexor tendon injury
- Intrinsic tightness
- Tendon adhesions
- Tendon subluxation (MP joint level)
- Joint contracture, subluxation, or deformity
- Soft tissue contracture

NONOPERATIVE MANAGEMENT

- Conservative treatment of injuries proximal to the metacarpals usually is not possible because of tendon retraction and muscle contracture and will result in persistent loss of extension of the wrist or digits.4
- Chronic extensor mechanism disorders distal to the metacarpals without fixed deformity will respond to splinting and intensive therapy. Such conservative management may result in an acceptable functional outcome for select patients.

SURGICAL MANAGEMENT

- Most extensor tendon lacerations are amenable to direct primary repair if treated relatively early.
- Indications for reconstruction of extensor tendon injuries include loss of extension of the wrist, fingers, or thumb resulting in a functional deficit.
- When delay or loss of tendon substance precludes a direct repair, tendon grafting or transfer may restore function successfully.

Preoperative Planning

- The patient must be provided with a realistic assessment of the potential gains from surgery as well as details of the treatment plan.
- Any fixed joint contractures should be identified and treated with therapy and splinting before extensor tendon reconstruction to optimize outcomes.
- In cases of severe soft tissue loss, coverage must be obtained before proceeding with extensor system reconstruction.
  - This may include free or island muscle, fascial, or skin flaps in addition to full- or split-thickness skin grafts.

Positioning

- The patient is positioned supine with a hand table attached to the operative side.
- A tourniquet is usually used to operate in a bloodless field

Approach

- The approach depends on the tendon transfer or grafting technique required and is detailed in the Techniques section.
END AND SIDE WEAVE JUNCTURES

- Tendon transfer or graft junctures are often best secured using an end weave technique (TECH FIG 1).
- The Pulvertaft method is a common weave used.
  - A pointed tendon-grasping and -passing instrument is invaluable and allows one tendon to be brought through the substance of the other tendon with minimal trauma.
  - The tendon weave is performed at right angles. For example, the first entry is horizontal, the next vertical, and then the third horizontal. At least three weaves are needed.

**TECH FIG 1** • End weave technique. The smaller tendon is passed through and sutured.

EIP TO EPL TRANSFER

- The distal EIP tendon is identified through a 1-cm incision over the index finger MP joint. The EIP is ulnar to the EDC II.
- A second incision is made just distal to the extensor retinaculum at roughly the radiocarpal joint level, and the EIP tendon is identified in the radial aspect of the fourth extensor compartment.
  - The EIP is readily identified by its distal muscle belly.
  - The EIP tendon is separated from the EDC II and transected through the incision over the MP joint.
  - The tendon is then brought through to the proximal incision.
- A third incision is centered over the scaphotrapezial trapezoid joint and the distal stump of the disrupted EPL tendon is identified (TECH FIG 2A).

**TECH FIG 2** • Extensor indicis proprius (EIP) to extensor pollicis longus (EPL) transfer. **A.** After the EIP tendon is identified, it is brought through the proximal incision. The distal stump of the EPL tendon is identified as well. **B.** The EIP tendon is passed through and is woven into the EPL tendon. **C.** After proper tensioning, the thumb should extend as the wrist flexes.

- A subcutaneous tunnel is created to connect the incision at the wrist and the incision near the base of the thumb.
- The EIP tendon is passed through the tunnel and attached to the distal stump of EPL using an end weave technique (TECH FIG 2B).
- Tension should be set so that when the wrist is extended, the thumb IP joint flexes, allowing the tip of the thumb to touch the tip of the index finger. The thumb IP joint should fully extend when the wrist is flexed (TECH FIG 2C).
- The thumb is immobilized with the wrist extended about 20 degrees and the thumb IP joint at 0 degrees for 4 weeks.

END-TO-SIDE SUTURING FOR EDC DISRUPTIONS

- A longitudinal incision is made on the dorsum of the hand over the appropriate area.
- The disrupted tendon end is identified and isolated.
- An end-to-side repair is performed to the adjacent intact tendon.

- Tension must be set so that the fingers are in extension when the wrist is flexed and the MP joints are flexed 20 to 30 degrees when the wrist is extended about 20 degrees. The normal flexion cascade must be re-established.
**EIP TO EDC (FOURTH/FIFTH) TRANSFER**

- The EIP tendon is isolated and freed in a manner similar to that described for the EIP-to-EPL transfer.
- An incision is made dorsally on the hand, over the disrupted extensor tendons of the ring and small fingers.
- The EIP is mobilized and inserted into the distal stump of the disrupted tendon of the small finger.
  - If disrupted, the extensor digiti quinti (EDQ) is sewn side to side to the transfer.
- The distal stump of the ring finger is attached to the adjacent intact common extensor tendon of the long finger. If the EDC to the long finger is also ruptured, it is sewn to the intact EDC to the index while the EDC to the ring is sewn to the EIP transfer (TECH FIG 3).

**FLEXOR CARPI ULNARIS TO EDC TRANSFER**

- A longitudinal incision is made over the flexor carpi ulnaris (FCU) in the distal forearm.
- The FCU tendon is transected just proximal to the pisiform and is freed up proximally.
- A second oblique incision is made 5 cm below the medial epicondyle in the proximal forearm.
- The FCU fascial attachments are incised to free up the entire muscle belly.
- A third incision begins on the dorsal-ulnar mid-forearm and angles distally toward the tubercle of Lister to expose the disrupted EDC tendons.
- A tendon passer or Kelly clamp is passed subcutaneously around the ulnar border of the forearm to pull the FCU tendon into the dorsal wound.
- Muscle may be excised from the FCU to reduce bulk.
- The FCU tendon is woven through the EDC tendons at a 45-degree angle just proximal to the dorsal retinaculum.
- The FCU is secured under maximum tension, with the wrist and MP joints in neutral.

**FLEXOR CARPI RADIALIS TO EDC TRANSFER**

- A longitudinal incision is made over the flexor carpi radialis (FCR) in the distal forearm.
- The FCR tendon is identified and transected near its insertion.
- The tendon is freed up proximally to allow additional excursion.
- A second longitudinal incision is made on the dorsal forearm, extending from the mid-forearm to just distal to the dorsal retinaculum.
- The FCR is then passed subcutaneously around the radial border of forearm and delivered into the dorsal wound.
- The FCR tendon is then inserted into the EDC tendons and positioned superficial to the retinaculum.
- The transfer is secured with the FCR under maximum tension and wrist and MP joints in neutral (TECH FIG 4).
Pronator Teres to ECRB Transfer
- An incision is made over the volar-radial aspect of the mid-forearm.
- The pronator teres (PT) tendon is identified and followed to its insertion into the radius.
- A strip of perioesteum is kept intact when freeing up the insertion to ensure sufficient length of the transferred tendon.
- The PT muscle is freed up proximally to improve excursion.
- The PT muscle and tendon is then passed subcutaneously around the radial border of the forearm.
- The tendon is inserted into the ECRB just distal to the musculotendinous junction through a second incision if needed (TECH FIG 5).
- The transfer is secured with PT in maximum tension and the wrist in 45 degrees of extension.

Flexor Digitorum Superficialis Transfer for Multiple Extensor Disruption
- A transverse incision is made in the distal palm to expose the long and ring superficialis tendons.
- The flexor digitorum superficialis (FDS) tendons to III and IV in the distal palm are divided proximal to the chiasma.
- A longitudinal incision is made on the volar-radial mid-forearm and the interosseous membrane is exposed.
- The two tendons are then delivered into the proximal wound.
- Two openings are excised from the interosseous membrane, large enough to pass the muscle bellies through to minimize adhesions.

TECH FIG 4 • (continued) C–F. Patient demonstrating restored digital and hand extension.

TECH FIG 5 • FCR to EDC and pronator teres to extensor carpi radialis brevis tendon transfer.

TECH FIG 6 • A. Flexor digitorum superficialis (FDS) III and IV transferred to reconstruct segmental injuries of extensor digitorum communis (EDC) II, III, IV, and V. B. FDS III and IV to EDC II–V tendon transfers. The FDS is transferred through a rent created in the interosseous membrane.
In patients with loss of soft tissue over the dorsum of the hand and forearm, appropriate soft tissue coverage is obtained first. At the time of coverage, the proposed path of the tendon transfer or graft is preserved with the use of a silicone tendon rod. Once maturation of soft tissue has occurred, the appropriate tendon transfer or graft may be performed 2 to 3 months after silicone rod placement (TECH FIG 7).

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Preoperative issues</th>
<th>In patients with severe soft tissue compromise, skeletal stabilization is obtained first, followed by soft tissue coverage. Reconstruction of the extensor mechanism is addressed later.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Joint contractures should be addressed before surgery.</td>
</tr>
<tr>
<td>Selection of transfer</td>
<td>The type of transfer performed depends on the tendon to be reconstructed and on surgeon preference. We generally prefer using the FCR.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- Initial splinting should immobilize the wrist in about 30 degrees of extension, the MP joints in about 15 degrees of flexion, and the IP joints in full extension.
- If transferred tendons originate proximal to the elbow, the elbow should be immobilized in 90 degrees of flexion with appropriate forearm rotation.
- The thumb IP and MP joints should be immobilized in full extension.
- After 4 weeks, active range of motion is started under the supervision of a certified hand therapist and with a protective splint. Active-assisted and passive range of motion follows 2 weeks later.

**OUTCOMES**

- Staged extensor tendon reconstruction using a silicone implant followed by tendon grafting for restoration of PIP joint extension was reported to have good results in six fingers with severe dorsal soft tissue injuries, improving hand function in all cases.¹

**COMPPLICATIONS**

- Extrinsic tightness
- Intrinsic tightness
- Rupture
- Donor deficits
- Joint stiffness

**REFERENCES**

DEFINITION
- Instability of the extensor digitorum tendons at the metacarpophalangeal (MCP) joint has been subdivided into two categories: subluxation and dislocation.
- Subluxation of the extensor digitorum tendons at the MCP joint is defined as lateral displacement of the tendon with its border reaching beyond the midline, but remaining in contact with the condyle during full MCP joint flexion.
- Dislocation describes the condition in which the extensor tendon is located in the groove between the metacarpal heads.\(^\text{12}\)
- Instability of the extensor digitorum tendons at the MCP joint usually occurs in patients with underlying inflammatory conditions (ie, rheumatoid arthritis).
- Traumatic injury to the sagittal bands, particularly the radial sagittal band, can cause instability of the extensor tendon. Although ulnar-sided injuries have been reported, the overwhelming majority of injuries occur to the radial sagittal band.
- Instability of the extensor tendon is relatively rare in non-rheumatoid patients.
- The sagittal bands are sometimes referred to as the “shroud” ligament because of the way they cover, or wrap, the MCP joint.
- Sagittal band injuries are classified as type I, II, or III depending on the degree of extensor tendon instability.\(^\text{12}\)
- Traumatic extensor tendon subluxation at the MCP joint level is classified as type II injury; dislocation is type III. These injuries have been given the eponym “boxer’s knuckle.”\(^\text{5}\)
- Not all injuries to the sagittal bands result in extensor tendon subluxation. Clinical examination will identify those patients in which extensor tendon instability has occurred.
- Factors influencing treatment include symptoms and time elapsed since injury.

ANATOMY
- The digital extensor mechanism at the level of the MCP joint consists of the extensor tendon, sagittal bands, and volar plate. The sagittal bands are part of a complex extensor retinacular system that includes the triangular ligament between the lateral bands, the transverse retinacular ligament, and the oblique retinacular ligament at the proximal interphalangeal (PIP) joint level (FIG 1A).
- The sagittal bands are dynamic structures that envelop the extensor tendons, centering them over the MCP joint during flexion, preventing bowstringing during hyperextension, and controlling tendon excursion. The sagittal bands insert onto the volar plate overlying the MCP joint (FIG 1B).\(^\text{13}\)
- The sagittal bands are the primary stabilizers of the extensor digitorum tendons at the MCP joints, and their integrity is essential for normal extensor tendon function.\(^\text{10,13,15,18}\)
When the MCP joint is maintained in neutral extension, the sagittal bands are oriented perpendicular to the tendon.
- The sagittal bands are anatomically and physiologically distinct from the deeper collateral ligaments.
- The radial sagittal band is often thinner and longer than its ulnar counterpart.
- The greatest tension on the sagittal bands occurs with wrist and MCP flexion and radioulnar deviation.
- The lumbrical muscles function to flex the MCP joint and extend the interphalangeal (IP) joint through the lateral bands. They originate on the flexor digitorum profundus (FDP) tendon and traverse on the radial aspect of the digit inserting into the extensor expansion.
- The intermetacarpal ligaments are stout ligaments that originate and insert on adjacent metacarpal necks. These ligaments pass dorsal to the lumbrical tendons and volar to the interosseous tendons.

PATHOGENESIS
- The mechanism of sagittal band injury commonly involves a direct blow to a flexed MCP joint.
- Injury may result indirectly from forced flexion or directly from shear forces across the sagittal band.
- Other described mechanisms include forceful deviation of the digit against resistance, usually with the MCP joint extended.
- In open injuries, the sagittal band is usually lacerated.
- Sometimes laceration of the junctura tendonum can also lead to extensor tendon subluxation.
- Extensor tendon subluxation typically occurs with at least 50% disruption of the proximal sagittal band. The extensor tendon no longer remains centralized over the MCP joint through flexion, but rather subluxates ulnarly.
- It has been suggested that frequency of injury among the digits is related to the cross-sectional diameter of the sagittal band, the extent of distal attachment, and the length of the sagittal band. The long finger is most commonly injured.
- It has been suggested that traumatic subluxation occurs when there is tearing of both the superficial and deep layers of the sagittal band enveloping the extensor tendon.
- When underlying inflammatory conditions are present, the sagittal bands become attenuated and atrophic, allowing for atraumatic subluxation of the extensor tendons into the troughs (usually ulnar) between metacarpal heads.

NATURAL HISTORY
- Symptoms from acute injuries typically resolve within 3 weeks with appropriate treatment. However, pain can persist for up to 9 months before fully dissipating.
- When sagittal band injuries associated with discomfort, swelling, and subluxation are neglected, patients will experience ongoing symptoms that may worsen over time. The extensor tendon may become fixed in the valley between the metacarpal heads, leading to loss of extension and deviation of the digit. These patients will require surgical treatment for resolution of their symptoms.

PATIENT HISTORY AND PHYSICAL FINDINGS
- This chapter deals with traumatic subluxation. Treatment protocols for inflammatory subluxation differ and are beyond the scope of this chapter.
- A critical aspect of treatment involves understanding the circumstances surrounding the injury. This information will help identify those at risk for infection in open injuries (eg, clean laceration, fight bite), or the possibility of underlying systemic disease contributing to closed injuries caused by low-energy trauma.
- Shortly after injury soft tissue swelling may obscure the alignment of the tendon over the MCP joint.
- Initially after traumatic injury to the sagittal bands with subsequent extensor tendon instability, symptoms and signs include the following:
  - Localized pain
  - Swelling over the involved MCP joint
  - Limited motion (FIG 2A)
  - Limited or deviated MCP joint extension, or both (FIG 2B)
  - Weak MCP extension
  - A potentially painful snapping of the tendon over the MCP joint with active flexion (FIG 2C)
  - Ulnar deviation deformity and difficulty adducting (or abducting in the case of the index) the affected finger early or late
  - Chronic cases of tendon instability often exhibit pain during MCP joint flexion, such as during grip, along with localized tenderness and swelling over the injured sagittal band.
- MCP extension can be actively maintained when the joint is passively placed into extension; however, difficulty is usually encountered when attempts are made to extend the MCP joint from flexion or when flexing the MCP joint from full extension.

![FIG 2](image)

**FIG 2**

- **A.** Lack of complete active digital extension at the metacarpophalangeal joint associated with a sagittal band disruption.
- **B.** Ulnar deviation of the long finger associated with a radial sagittal band disruption.
- **C.** Dislocation of the long finger extensor tendon into the ulnar trough of the fourth web space (arrow). (A,B: Courtesy of Brian Hartigan.)
Methods for examining extensor tendon instability over the MCP joint include the following:
- Assess sagittal bands throughout MP range of motion.
- Assess swelling, open injuries, and so forth. Determine location of pathology.
- Palpate over the MCP joints and in the groove between the metacarpal heads.
- Sagittal band injuries will exhibit pain with superficial palpation. In contrast, pain associated with collateral ligament injury is usually deeper, within the groove between the metacarpal heads.
- Perform tendon instability examination.
- Ask the patient to flex the MCP joint and wrist. This position places the maximum amount of ulnar force on the extensor tendon at the MCP joint. This will help to determine the amount of instability.
- Pain provocation test: With the distal and proximal IP joints extended and the MCP joint flexed, ask the patient to try to extend the MCP joint against resistance.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- A standard radiographic series, including posteroanterior, lateral, and oblique views of the MCP joints, is obtained.
- These views will exclude any mechanical or bony pathology limiting extension of or predisposing the sagittal band to dislocate.
- A Brewerton view (AP view with dorsal surface of the fingers touching the cassette and the MCP joints flexed 45 degrees) or stress views may be needed to rule out collateral ligament avulsion injury.
- Magnetic resonance imaging (MRI) has been used with success to identify patients with sagittal band injuries, especially when the physical examination is obscured by swelling and patient discomfort. MRI with the injured MCP joint flexed facilitates the diagnosis.
- Acute injuries demonstrate morphologic and signal intensity abnormalities within and around the sagittal bands on axial T1- and T2-weighted images, together with poor definition, focal discontinuity, and focal thickening.4
- Dynamic ultrasound has been reported as a useful modality for diagnosis of extensor tendon subluxation when swelling obscures the physical examination.9

**DIFFERENTIAL DIAGNOSIS**
- MCP joint collateral ligament injury
- Trigger finger
- Ulnar nerve palsy
- Congenital sagittal band deficiency
- Extensor digitorum communis tendon rupture
- Radial nerve injury
- Junctura tendinum disruption
- MCP joint arthritis

**NONOPERATIVE MANAGEMENT**
- In our experience, most symptomatic patients presenting within 3 weeks of injury with acute sagittal band disruptions and extensor tendon instability can be treated successfully nonoperatively with a splint.12
  - Success in the literature varies, however. Studies have shown that 44% to 100% of patients treated conservatively will be asymptomatic at an average of 13.5 months.2,3,6,12
  - Certainly, except in special circumstances such as the professional athlete, conservative therapy should initially be attempted.
  - Although several different protocols and splints have been described, most share one common objective: maintaining the MCP joint in neutral (full extension) for a period of weeks. In all situations, motion of the IP joint should be accommodated and encouraged.
  - A hand-based, custom orthoplast splint holding the involved digit in 0 to 20 degrees of MCP joint flexion (FIG 3) is worn for 4 to 6 weeks, depending on the patient’s progress at the 2- and 4-week follow-up visits.
  - After 6 weeks of MCP immobilization in extension, the splint is weaned except for sporting endeavors and other heavy activities, in which case the splint is used for another 2 weeks. Buddy taping can provide long-term support as may be indicated.
  - Active range-of-motion activities are initiated and slowly progressed to gentle passive flexion of the involved MCP joint.
  - Thereafter, unrestricted use of the hand is promoted. It is unusual to need formal hand therapy; however, when excessive joint stiffness is present and radiographs fail to document any bony pathology, a short course of therapy along with modality use can be helpful.
  - If the injury clearly is not responding to immobilization, surgery is recommended.

**SURGICAL MANAGEMENT**
- Operative indications
  - Patients with painful extensor tendon instability more than 3 weeks after the injury
  - Patients whose injury has failed to respond to nonsurgical management and have persistent, painful tendon instability beyond 6 weeks of conservative care
  - Professional athletes5 and other high-demand individuals

**FIG 3** Typical splint used for the conservative treatment of sagittal band disruption. The interphalangeal joints are free and no more than 30 degrees of metacarpophalangeal joint flexion is allowed.
When possible, direct repair of the sagittal band should be performed.
- Although we believe that this is usually not possible more than 8 weeks after injury, Hame and Melone\(^5\) reported on 11 direct repairs at an average of 3.3 months out from time of injury. No patient had prior splinting. All patients were asymptomatic with full recovery of range of motion and return to professional sports at an average of 5 months.
- Carroll et al\(^2\) reported on five patients who underwent reconstruction after failed conservative management. All patients regained full, asymptomatic range of motion.
- If tissue deficiency or scarring exists, reconstruction as opposed to primary repair will be required.

**Preoperative Planning**
- With open injuries, the surgeon should determine if the cause was related to a bite. In this situation, MCP joint contamination is likely and surgical irrigation and débridement as well as antibiotic treatment is warranted. When severe contamination is present, delayed sagittal band repair is indicated.
- Concomitant MCP joint capsular injury is possible. Once surgically exposed, methylene blue injection into the joint, out of the zone of injury, can help to reveal any rents in the MCP joint capsule. These defects should be débrided with subsequent irrigation of the joint. Afterward, no capsular repair is necessary.\(^5\)
- The surgeon should be prepared to perform either a repair or a reconstruction.
- Local anesthesia with sedation is preferred, but regional or general anesthesia is acceptable.

**Positioning**
- The patient is placed supine on the operating table with the affected hand outstretched onto a hand table.
- A tourniquet is applied to the arm and inflated to the appropriate pressure before starting the procedure.

**EXPOSURE**
- A curvilinear incision is placed dorsally over the ulnar aspect of the affected MCP joint.
  - This is used for primary sagittal band repair.
- A longitudinal incision is centered dorsally over the affected MCP joint.
  - This is used for reconstructive cases requiring greater exposure.
- Sensory branches of the radial or ulnar nerves, or both, are identified and protected.

**PRIMARY REPAIR**
- The sagittal band disruption is identified and the extensor tendon centralized (TECH FIG 1A, B).
- Excess tissue is excised from the area between the torn sagittal band and the common extensor tendon.
- The extensor tendon is exposed, the tear identified, and scar tissue débrided.
- The MCP capsule, which is deep to the extensor tendon, is usually left undisturbed; however, when MCP joint pathology needs to be addressed, the capsule may be incised.
- The sagittal fibers are then repaired using 4-0 or 5-0 non-absorbable suture (Ethibond). The knots are buried where possible.
- The repair is performed with the joint in 60 to 70 degrees of flexion to avoid tension on the repair and stiffness of the joint.
- The joint is flexed and extended to ensure midline stability (TECH FIG 1C–E).
- The wound is closed with interrupted 4-0 nylon sutures.

**TECH FIG 1**
- A. Traumatic extensor tendon dislocation (ulnar) over the metacarpophalangeal (MCP) joint (arrowhead) with the MCP joint extended. B. Extensor tendon subluxation over the MCP joint with the joint flexed. (continued)
Release of the ulnar sagittal band may be necessary to mobilize the scarred tendon dorsally and radially (TECH FIG 2A,B).

A distally based radial or ulnar slip of extensor tendon (about one third) is fashioned and routed deep to the intact extensor tendon (TECH FIG 2C).

In a distal-to-proximal direction, the tendon graft is then looped around the radial collateral ligament (if subluxed ulnarly) (TECH FIG 2D).

Once proper tension is determined, the slip is then sutured back to the main tendon with interrupted, nonabsorbable suture or woven through the tendon in a Pulvertaft fashion (TECH FIG 2E,F).

As with all reconstruction techniques, tension is determined by taking the joint through a full range of motion and documenting stability dorsally.

The wound is closed with interrupted 4-0 nylon sutures.
TECH FIG 2 • (continued) E. The distally based slip of extensor tendon has been secured to the extensor tendon proximal to the MCP joint (black arrowhead). The remaining ulnar sagittal band was repaired to prevent radial subluxation of the extensor tendon (red arrowhead). F. Reconstruction of the sagittal band using a distally based radial slip of extensor tendon wrapped around the radial collateral ligament (RCL) and reattached to the extensor tendon (with a weave).

DYNAMIC LUMBRICAL MUSCLE TRANSFER (SEGALMAN\textsuperscript{16})

- The lumbrical muscle is identified on the radial side of the joint and mobilized (TECH FIG 3A,B).
- Begin proximally by separating the lumbrical muscle from the more dorsal interossei.
- Once the lumbrical muscle is separated, continue distally to identify its tendinous insertion.
- The lumbrical tendon is harvested just proximal to its insertion into the lateral band (TECH FIG 3C).
- With the extensor tendon reduced, an isometric point in the extensor tendon must be identified. This is achieved by gently ranging the finger or asking the patient to flex. Once it is identified, a small longitudinal slit is made and the lumbrical tendon is passed through from volar to dorsal (TECH FIG 3D).
- Tension is set appropriately while gently ranging the finger to confirm the absence of subluxation. The tendon is sutured back to itself using interrupted, nonabsorbable suture.
- The wound is closed with interrupted 4-0 nylon sutures.

TECH FIG 3 • Technique using the lumbrical muscle for dynamic extensor tendon stabilization. A. Ulnar dislocation of the extensor tendon over the long finger metacarpophalangeal (MCP) joint (arrow). B. Surgical exposure identifying the extensor dislocation (black arrow) with a large chronic defect in the radial sagittal band (white arrow). (continued)
**SAGITTAL BAND RECONSTRUCTION TO THE DEEP TRANSVERSE INTERMETACARPAL LIGAMENT (WATSON)**

- A 4-cm, distally based slip of extensor tendon consisting of no more than one-third the tendon width is harvested starting proximal to the MCP joint on the affected side (TECH FIG 4A).
- This segment of tendon is then passed through a small slit in the remaining tendon at the level of the deep transverse metacarpal ligament to prevent further propagation of the tendon split.
- The segment is then passed around or through the deep transverse intermetacarpal ligament using a curved clamp (TECH FIG 4B).
- The free end of the tendon graft is then woven through and sutured to the remaining extensor tendon once it has been centralized and properly tensioned using non-absorbable suture (TECH FIG 4C).
- Wounds are closed with interrupted 4-0 nylon sutures.

**CENTRALIZATION USING JUNCTURA TENDINUM**

- A longitudinal incision is centered dorsally over the affected MCP joint.
- The extensor tendon is identified and held in a centralized position.
- The MCP joint is flexed to reveal the more proximal, ulnar-sided junctura tendinum to the adjacent tendon.
- The junctura tendinum is released from its ulnar-sided insertion into the adjacent tendon.
- It is then brought over to the radial side of the affected finger, still in continuity with the tendon, and sutured to the palmar portion of the remaining sagittal band after correct tension has been set to centralize the tendon.
- Wounds are closed with interrupted 4-0 nylon sutures.
PEARLS AND PITFALLS

| Range of motion | - Preoperatively, ensure that there is good passive range of motion of the MCP joint.  
| - Avoid overtensioning and malpositioning of the repair or reconstruction. A reconstruction too proximal will limit extension. A reconstruction too distal will lead to recurrent subluxation. |
| Anesthesia | - Local anesthesia will enable the patient to actively flex the MCP joint during the procedure, allowing the surgeon to intraoperatively assess centralization after the repair or reconstruction.  
| MCP joint capsule | - Identify and débride rents in the MCP joint capsule. Repair is unnecessary. Also be aware of any injury to the junctura tendinum; this should be repaired.  
| MCP flexion | - Range the MCP joint once the tendon is exposed, both before and after repair or reconstruction. The repair or reconstruction should be performed with the MCP joint in 60 to 70 degrees of flexion.  
| Additional releases | - Sometimes the sagittal band, as well as the junctura tendinum, on the uninjured side will require release to centralize the tendon. |

POSTOPERATIVE CARE

- Wounds are sterilely dressed immediately after the procedure and a splint is applied.
  - A volar and dorsal splint is used with the wrist slightly extended, the MCP joints at 0 to 30 degrees flexion, and the IP joints extended.
  - On postoperative day 5, the patient is seen in the office. Sutures are removed and a short-arm cast is applied with the wrist slightly extended, the MCP joints at 0 to 30 degrees of extension, and the IP joints free.
  - Sometimes, in the compliant elderly patient, we favor a hand-based splint fabricated to include the MCP joints in 30 degrees of flexion and the IP joints free.
  - Several postoperative protocols have been described for nondynamic reconstructions.
    - Inoue and Yukihsia placed the involved finger in a plaster cast for 3 weeks with the MCP joint in neutral or slightly flexed, allowing active IP joint motion.
    - Carroll et al splinted the MCP joint neutral for 6 weeks. At 2 weeks after surgery they began PIP joint range of motion, and at 6 weeks active range of motion at the MCP was initiated.
    - Watson et al used a splint and Kirschner wire to immobilize the MCP joint at 15 to 20 degrees of flexion for 3 weeks.
    - Hame and Melone used cast immobilization of the MCP joint in 60 to 70 degrees of flexion for 6 weeks, with active flexion, but not extension, allowed.
  - For dynamic transfers, the patient is immobilized for 4 weeks in a short-arm cast with the wrist in neutral, MCP joints in extension, and the PIP joints free. Active motion is begun 4 weeks after surgery and strengthening at 6 weeks. Therapy is then continued for 6 to 8 weeks.

OUTCOMES

- Rayan et al treated three type II injuries nonoperatively with 3 weeks of splinting the MCP joint at 0 degrees of extension, followed by 2 to 3 weeks of protected range of motion out of the splint three times a day, with a final 4 weeks of buddy splinting. They reported full range of MCP joint motion and no tenderness or pain with resisted digital abduction in all three patients. However, one patient did experience residual painless subluxation.
  - Carroll et al treated nine subluxed extensor tendons. Four were treated nonoperatively with 6 weeks of splinting the MCP joint in 0 degrees of extension, followed by range-of-motion therapy. Five were treated operatively using a slip of extensor tendon looped around the collateral ligament. After splinting and therapy, all patients were pain-free with full extension and active flexion to 90 degrees or more. There were no recurrences of symptoms in either group and no complications in the surgical group.
  - Watson et al described 16 patients treated operatively with a slip of extensor tendon looped through the deep transverse metacarpal ligament. They reported an average MCP joint flexion of 90 degrees postoperatively, with no subluxation of the tendon. All patients were pain-free. There were no complications and no need for further surgery.
  - Hame and Melone reported on eight professional athletes who underwent immediate repair of sagittal band injuries with subluxation of the extensor tendon. There were 11 injured fingers in total. Seven of the 11 had capsular injuries; they were all debrided but not repaired. Each athlete demonstrated full range of motion postoperatively and all returned to professional sport at 5 months on average. No additional intervention was necessary and there were no complications.

COMPLICATIONS

- Complications are rare. Most series in the literature do not report any complications.
  - With nonoperative therapy, possible complications include joint stiffness, skin irritation from splinting, and failure of treatment.
  - With operative therapy, possible complications include infection, joint stiffness, injury to neurovascular structures, and failure of treatment with recurrent subluxation or dislocation either in a radial or ulnar direction.

REFERENCES

DEFINITION
- Synovium lines the joint spaces and tendon sheaths.
- It secretes lubricant (synovial fluid) needed for tendon gliding and reduces friction in synovial joint motion.
- Tendons may be both extra- and intrasynovial.
- Flexor tendons in the carpal tunnel have the added feature of subsynovial connective tissue, which can become inflamed.
- Tenosynovitis is inflammation of the tendon sheath in extrasynovial tendons, and inflammation of the synovial lining in intrasynovial tendons.³

ANATOMY
- The extensor tendons lie under the dorsal retinaculum in six separate compartments. These may be divided into the extensor tendon zones. The portion of the extensor tendon that lies under the dorsal retinaculum is lined with a synovial sheath (FIG 1A).
- The first extensor tendons originate as outcropper muscles from the distal third of the forearm and cross over the second extensor compartment tendons—the extensor carpi radialis longus (ECRL) and the extensor carpi radialis brevis—distally at the level of the wrist about 4 cm proximal to the radial styloid.
- The extensor pollicis longus (EPL) in the third extensor compartment makes an acute angle at the Lister’s tubercle at the level of the wrist.
- The fourth extensor compartment tendons—the extensor digitorum communis and the extensor indicis proprius—lie under a broad retinaculum. The deep branch of the posterior interosseous nerve courses deep to the fourth extensor compartment.
- The extensor digitorum quinti in the fifth extensor compartment often is the only tendon to motor the small finger metacarpophalangeal (MCP) joint in the act of extension.
- The extensor carpi ulnaris (ECU) tendon in the sixth compartment lies in a fibro-osseous tunnel and is intimately held in the ulnar groove by a subsheath that is critical for distal radioulnar joint stability.
- The wrist flexor tendons—the flexor carpi radialis (FCR), the palmaris longus, and the flexor carpi ulnaris—are extrasynovial tendons.
- The FCR passes through a tight fibro-osseous tunnel in the trapezium before inserting on the base of the second metacarpal (FIG 1B,C).
- The digital flexor tendons lie under the transverse carpal ligament in the carpal tunnel. Unlike digital extensor tendons, flexor tendons are almost entirely intrasynovial.
- The flexor tendons in the digits lie in a fibro-osseous canal formed by the annular and cruciate ligaments.²

PATHOGENESIS
- Rheumatoid arthritis is a disease of synovial tissue that can lead to inflammatory tenosynovitis.
- Flexor and extensor tenosynovitis is most commonly a sequela of rheumatoid arthritis.
- Rheumatoid arthritis causes formation of hypertrophic synovium in the joint spaces, thereby destabilizing joints. The hypertrophic synovium invades the tendon sheaths and synovial lining of all tendons.³

NATURAL HISTORY
- Inflammatory tenosynovitis usually is painless and can be the first sign of rheumatoid arthritis.
- The dorsal and volar wrist, as well as the volar digits, are most commonly affected.
The synovial tissue proliferates in the tendon sheath and eventually may invade the tendon. The end result is weakening and rupture of the tendon.\(^3\)

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Tenosynovitis of the first extensor compartment reveals thickening of the extensor pollicis brevis and abductor pollicis longus tendon sheaths at the radial styloid.
  - This thickening can produce a positive Finkelstein’s test: ulnar wrist abduction of a hand in a fist position, causing pain along the first extensor compartment.
  - Second compartment extensor tenosynovitis presents with painless swelling of the dorsum of the wrist 4 cm proximal to the radial styloid. There is focal tenderness to palpation with swelling and positive Tinel sign of the sensory branch of the radial nerve.
  - Third extensor compartment tenosynovitis usually presents with rupture of the EPL tendon.
    - This results in inability to raise the thumb when the hand is placed flat on a table.
  - Fourth extensor compartment tenosynovitis presents with focal swelling in extensor zone 7 along with multiple tendon ruptures (FIG 2).
  - Fifth extensor compartment tenosynovitis usually is accompanied by dorsal distal ulna instability and tendon rupture.
  - Sixth extensor compartment tenosynovitis is manifested as ECU instability in addition to significant intrasynovial inflammation at the level of the ulnar styloid.
  - Pain at the wrist indicates that the radiocarpal or radioulnar joint is affected.
  - Flexor tenosynovitis at the wrist can cause median nerve compression in the carpal tunnel, as well as decreased active and passive range of motion of the fingers.
  - Flexor tenosynovitis of the digits can cause triggering.\(^2\)
  - The flexor tendon that most commonly ruptures due to rheumatoid arthritis is the flexor pollicis longus. This is termed the Mannerfelt lesion and results in loss of thumb interphalangeal joint flexion.
  - The following examinations, all of which may detect weakness or rupture, are graded on a scale of 0 to 5:
    - First dorsal compartment (abductor pollicis longus and extensor pollicis brevis): abduct the thumb radially.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- MRI may be useful to evaluate low-grade tenosynovitis and mechanical dysfunction of the fibro-osseous digital pulley system.
- In general, flexor or extensor tenosynovitis is a clinical diagnosis made on physical findings.

**DIFFERENTIAL DIAGNOSIS**

- Extensor tendon weakness
- Rupture of sagittal bands
- Posterior interosseous nerve palsy
- Intrinsic muscle tightness or contracture
- Extensor tendon rupture
- Flexor tendon weakness
- Flexor tendon rupture
- Nerve palsy (median nerve, anterior interosseus nerve, ulnar nerve)

**NONOPERATIVE MANAGEMENT**

- Medical control of rheumatoid arthritis
- Splinting
- Cortisone injections are only very rarely indicated due to the risk of tendon rupture.
SURGICAL MANAGEMENT
- Tenosynovectomy is indicated if no improvement is observed after 4 to 6 months of adequate medical treatment or if tendon ruptures are detected.⁵
- Flexor tenosynovectomy is relatively indicated if active digit motion becomes worse than passive motion.³

Preoperative Planning
- Consider withholding rheumatoid medications (e.g., methotrexate, Etanercept, Imuran) 1 week before and 1 week after surgery.³

Positioning
- The patient is positioned supine with an armboard.

Approach
- For an extensor tenosynovectomy, the wrist dorsal midline approach is used (FIG 3A).
- For a flexor tenosynovectomy, the wrist volar approach to the carpal tunnel is chosen (FIG 3B).
- A digital tenosynovectomy is done using the volar zigzag approach to the digits (FIG 3C).

EXTENSOR TENOSYNOVECTOMY
- A straight longitudinal incision is made.
- Full-thickness skin flaps are created, exposing the extensor retinaculum (TECH FIG 1A).
- A straight longitudinal incision is made of the extensor retinaculum over the third compartment.
- Transverse incisions are made over the proximal and distal borders of the retinaculum, creating a radially based flap.
- Divide the vertical septum, opening each extensor compartment.
- Remove hypertrophic synovium from each tendon sheath with a rongeur or by sharp dissection (TECH FIG 1B).
- Frayed tendons are repaired with fine interrupted sutures.
- Tendons at risk for rupture are sutured to adjacent tendons.
- If synovitis of the wrist is encountered, wrist synovectomy is performed, and, if possible, the capsule is closed.
- The distal ulna is resected if it is prominent dorsally or if significant distal radioulnar joint arthrosis is noted.
- The retinaculum is passed deep to the extensor tendons and sutured (TECH FIG 1C,D).
  - Suturing a portion of the retinaculum over the extensor tendons prevents bowstringing.²
FLEXOR TENOSYNOVECTOMY

- Use a standard carpal tunnel approach with a mid-palm incision parallel to the thenar crease in line with the long finger.
- Extend the incision proximally 4 cm in a zigzag fashion when crossing the wrist crease.
- Protect the palmar cutaneous branch of the median nerve at the wrist flexion crease.
- Divide the volar antebrachial fascia and protect the median nerve in the forearm.
- Divide the palmar fascia and transverse carpal ligament longitudinally.
- Excise hypertrophic synovium surrounding the flexor tendons (TECH FIG 2).
  - A complete synovectomy is not required when the excess synovium involves more than half of the tendon diameter. Synovectomy in this case would lead to loss in function.

DIGITAL FLEXOR TENOSYNOVECTOMY

- Use a volar zigzag incision to explore the flexor tendons in the digit.
- Extend the incision proximally and distally for more exposure.
- Excise all hypertrophic synovium (TECH FIG 3).
- Carefully preserve the annular second and fourth pulleys to prevent bowstringing.
- Excise nodules in the tendon and close defects with fine suture.
- Check tendon excursion for smooth gliding.
- Passive flexion of the finger should equal the flexion obtained when pulling on the tendon (simulating active flexion).
  - If passive and active flexion are not equal, additional synovectomy is required.²

Inspect the floor of the carpal tunnel. Any bony spicules (commonly originating from the scaphoid) are removed with a rongeur.

Check flexor tendons for decreased excursion, indicating digit tenosynovitis.²
PEARLS AND PITFALLS

### Indications
- Failed adequate medical management for 4–6 months

### Extensor tenosynovectomy
- Débride radiocarpal synovitis if present.
- Resect the distal ulna if prominent or dislocated.

### Flexor tenosynovectomy
- Débride bony spicules on the carpal tunnel floor (ie, scaphoid).

### Digital flexor tenosynovectomy
- Preserve annular pulleys to prevent bowstringing.
- Passive flexion of the finger should be the same as the flexion observed when the surgeon pulls on the tendon.

POSTOPERATIVE CARE
- Splint the wrist in neutral position.
- Early (within 48 hours) active and passive digit range of motion exercise is key to maintaining motion.¹

OUTCOMES
- Long-term studies show less than 10% tendon rupture and recurrent tenosynovitis at 5 years.

COMPLICATIONS
- Wound dehiscence
- Tendon adhesions
- Tendon rupture¹

REFERENCES
Rheumatoid arthritis is a progressive disease that, if uncontrolled, leads to joint destruction, secondary to progressive synovitis, ligament instability, joint dislocation or subluxation, and attrition of adjacent tendons either by bony erosion or direct tenosynovial infiltration. When tendon rupture occurs on the dorsum of the hand or wrist, patients cannot extend their fingers and have difficulty grasping objects. The most common tendon ruptures on the dorsum of the hand begin on the ulnar side and usually are a result of subluxation of the distal radial ulnar joint (DRUJ), the so-called Vaughan-Jackson or caput ulnae syndrome.

On the volar side of the wrist, the most common tendons to rupture are the flexor pollicis longus and the adjacent flexor digitorum profundus (FDP) tendon to the index finger or possibly the long finger. This is referred to as Mannerfelt syndrome.

DEFINITION

Rheumatoid arthritis is a progressive disease that, if uncontrolled, leads to joint destruction, secondary to progressive synovitis, ligament instability, joint dislocation or subluxation, and attrition of adjacent tendons either by bony erosion or direct tenosynovial infiltration.

When tendon rupture occurs on the dorsum of the hand or wrist, patients cannot extend their fingers and have difficulty grasping objects.

The most common tendon ruptures on the dorsum of the hand begin on the ulnar side and usually are a result of subluxation of the distal radial ulnar joint (DRUJ), the so-called Vaughan-Jackson or caput ulnae syndrome.

On the volar side of the wrist, the flexor pollicis longus may become involved in the pathology of rheumatoid arthritis.

PATHOGENESIS

Tendon rupture on the dorsum of the wrist is usually the result of instability in the DRUJ, leading to secondary subluxation and bony erosion through the capsule of the joint and then the tendon.

The tendon initially affected is the EDQ. As the carpus supinates and subluxates volarly, causing the distal ulna to be more dorsal, tendons typically rupture sequentially in an ulnar to radial direction.

The tendons may also be compromised by direct infiltration from the tenosynovium.

While the ulnar tendons are involved most commonly, it is possible for all of the tendons crossing the dorsum of the wrist to rupture, making reconstruction more difficult.

On the volar side of the wrist, the flexor pollicis longus may become compromised through erosion by osteophytes and rough bony surfaces at the level of the trapeziometacarpal joint of the thumb or the scaphotrapezial articulation. The adjacent profundus tendon to the index and occasionally the long finger can rupture as well.

While the ulnar tendons are involved most commonly, it is possible for all of the tendons crossing the dorsum of the wrist to rupture, making reconstruction more difficult.

Tendons of the flexor surface of the wrist and forearm are also subject to rupture via direct tenosynovial infiltration, but this is less common.

ANATOMY

The extensor tendons of the hand and forearm pass beneath the extensor retinaculum at the wrist. The retinaculum is divided into six separate compartments lined by tenosynovium, which can become involved in the pathology of rheumatoid arthritis.

The first compartment contains the tendons of the abductor pollicis longus and the extensor pollicis brevis. The former tendon often contains multiple slips, which can contribute to limited space in its respective compartment and secondary De Quervain tenosynovitis.

The second compartment consists of the extensor carpi radialis longus (ECRL) and brevis (ECRB), the former tendon inserting at the base of the index metacarpal and the latter at the base of the long finger.

The third compartment contains only the tendon of the extensor pollicis longus (EPL), which passes around the tubercle of Lister at a fairly sharp angle. While frequently involved in tendon ruptures in rheumatoid arthritis, the EPL may also present as an isolated tendon rupture after nondisplaced fractures of the distal radius.

The fourth compartment contains the extensor indicis proprius (EIP) and the extensor digitorum communis (EDC), sending tendons from the common extensor muscle in the forearm to each of the fingers. The EIP is a separate muscle tendon unit located within the fourth compartment. It can be differentiated by its distal muscle belly.

The fifth extensor compartment contains the extensor digiti quinti (EDQ), often consisting of two slips and passing almost directly over the DRUJ.

The sixth compartment contains only the extensor carpi ulnaris.

On the palmar side of the wrist, the flexor pollicis longus is located most radially and passes over the radiocarpal joint adjacent to the trapeziometacarpal joint of the thumb. The flexor pollicis, along with the median nerve and the profundus and sublimis tendons to each digit, passes beneath the deep transverse carpal ligament and represents the contents of the carpal canal.

Tenosynovial proliferation can exist within the carpal tunnel, arising from the undersurface of the ligament but more commonly proliferating along the tendons themselves.

The worst-case scenario is secondary rupture of all of the wrist extensors, with subluxation of the extensor carpi ulnaris volar to the axis of wrist motion such that it becomes more of a wrist flexor and ulnar deviator than a wrist extensor. The radial wrist extensors may also rupture; however, in part as a result of the more robust nature of the tendons themselves, they tend to remain intact even with progressive disease.

NATURAL HISTORY

Before the advent of treatment for rheumatoid arthritis, the natural history was one of relentless progression. The disease would occasionally “burn itself out,” however, with the radiocarpal joint subluxing in a volar and radial direction, leading to instability and loss of function.

Also, before the development and routine use of antitumor necrosis factor drugs, patients were occasionally refractory to nonsteroidal medication, corticosteroids, and stronger anti-inflammatory drugs such as methotrexate. When these drug combinations failed, proliferative tenosynovitis occasionally occurred on the dorsum of the wrist, leading to direct tendon rupture as a result of tenosynovial ingrowth into the tendon and collagen destruction and rupture (FIG 1).

The worst-case scenario is secondary rupture of all of the finger extensors, with subluxation of the extensor carpi ulnaris volar to the axis of wrist motion such that it becomes more of a wrist flexor and ulnar deviator than a wrist extensor. The radial wrist extensors may also rupture; however, in part as a result of the more robust nature of the tendons themselves, they tend to remain intact even with progressive disease.
The French Impressionist painter Pierre Auguste Renoir was said to have had such severe rheumatoid arthritis that in his later years he would tape a brush to his hand to paint.

PATIENT HISTORY AND PHYSICAL FINDINGS

Patients often note a spontaneous loss of finger motion, but there may be minimal swelling and discomfort. Patients occasionally report a snap or twinge of discomfort as the tendon ruptures.

With an extensor tendon rupture, patients cannot actively extend the metacarpophalangeal (MCP) joints of the involved digit.

In the case of isolated rupture of the extensor digiti quinti, an intact EDC to the small finger may make it difficult to confirm the diagnosis.

The proximal and distal interphalangeal joints of the finger may be extended through the intrinsics even when the extensors are ruptured.

Wrist flexion should result in MCP joint extension through tenodesis if the extensor tendons are intact. When the finger extensors are ruptured, this tenodesis effect is absent (FIG 2A,B).

On the volar side of the wrist, the examiner should check closely for the possibility of associated tenosynovial proliferation proximal and deep to the transverse carpal ligament.

Active digital motion may cause palpable crepitance at this level.

Such proliferation may result in coexisting carpal tunnel syndrome (CTS). The examiner should question the patient regarding symptoms of CTS and should assess for signs of CTS.

The patient should also be examined carefully for active flexion at the distal interphalangeal joints of the index and long fingers as well as the interphalangeal joint of the thumb.

Absence of flexion should alert the surgeon to the possibility of rupture of the flexor pollicis longus and the FDP to the index and occasionally the long finger.

These tendons are particularly vulnerable when subluxation and spur formation are present at the trapeziometacarpal or scaphotrapezial joints as well as the volar radiocarpal joint.

Tendon rupture at this level is referred to as Mannerfelt syndrome (FIG 2C) and needs to be differentiated from an anterior interosseous nerve palsy.

Direct pressure on the flexor pollicis longus muscle in the forearm should lead to passive flexion in the interphalangeal joint of the thumb if the tendon is intact.

The tenodesis test also is effective for the flexor pollicis longus and profundus and sublimis tendons to the fingers; however, in patients with progressive rheumatoid arthritis, the radiocarpal joint and the interphalangeal joints may become arthritic, making passive motion of the wrist and fingers somewhat more difficult and therefore the test more unreliable.

FIG 1 • Exposure of the extensor tendons of the wrist shows proliferative tenosynovitis originating from the tenosynovial lining of the extensor retinaculum. If left unchecked, such proliferative tenosynovitis can contribute to extensor tendon rupture at the level of the wrist.

FIG 2 • A. Passive wrist extension results in passive finger flexion with intact finger flexors. B. Passive wrist flexion should result in passive finger extension when the finger extensor tendons are intact. In this situation, however, those tendons are not intact and passive wrist flexion results in the long, ring, and small extensor fingers remaining in a flexed position. C. In a patient with Mannerfelt syndrome, attempted active flexion of the thumb and fingers results in absent flexion of the interphalangeal joint of the thumb and in this situation the distal interphalangeal joint of the index finger. Clinically this is similar to anterior interosseous nerve syndrome and must be distinguished clinically and often by electromyography.
IMAGING AND OTHER DIAGNOSTIC STUDIES

- AP and lateral radiographs of the hand and wrist should be obtained to look for subtle changes of the DRUJ, such as subluxation or a small osteophyte (FIG 3), which may be consistent with the physical findings of tendon rupture (FIG 4).
- Similar attention should be paid to the volar surface of the radiocarpal joint and the trapeziometacarpal joint of the thumb as well as the scaphotrapezial and trapezoidal joints.
- Radiographs may reveal arthrosis and deformity in the digits themselves responsible for motion loss.
- Radiographs of the cervical spine may reveal subluxation, possibly causing nerve compression and secondary digital motion loss or weakness.
- CT and MRI are not routinely needed.
- Electromyography and nerve conduction studies are crucial in the evaluation of the patient with potential tendon ruptures, particularly if tenodesis testing is normal in the face of a loss of active finger extension or flexion.
- Compression of both the anterior interosseous and posterior interosseous nerves can occur in rheumatoid arthritis, usually secondary to ganglion cyst formation at the level of the elbow joint.

DIFFERENTIAL DIAGNOSIS

- In the case of tendon ruptures on the dorsum of the hand and wrist, the differential diagnosis is primarily with that of posterior interosseous nerve compression or posterior interosseous nerve syndrome.
- Compression of the posterior interosseous branch of the radial nerve, or the radial nerve itself more proximally, needs to be considered as the cause of the patient’s inability to extend the fingers. Diagnosis can be suspected by history and clinical examination. Electrophysiologic testing may also prove helpful.
- Cervical disc disease or rheumatoid arthritis of the cervical spine with subluxation or instability may also be the cause for weakness of the finger or wrist extensors, and the cervical spine should also be imaged.
- With respect to Mannerfelt syndrome, absence of flexion at the interphalangeal joint of the thumb and the distal interphalangeal joints in the index and long fingers should be differentiated from the anterior interosseous nerve syndrome, which when present in rheumatoid arthritis is usually due to a large ganglion originating on the volar surface of the elbow.

NONOPERATIVE MANAGEMENT

- Nonoperative management probably is more feasible with respect to Mannerfelt syndrome than with the Vaughn-Jackson or caput ulnae syndrome. While the functional deficit is generally greater with loss of finger extensors than loss of active flexion of the interphalangeal joint of the thumb and distal interphalangeal joints of the index and long fingers, some patients may still function remarkably well.
- Supportive measures in patients who for one reason or another are not deemed suitable surgical candidates may be provided by a certified hand therapist or occupational therapist able to assist the patient with his or her activities of daily living.
- With median nerve entrapment and compression from the proliferative tenosynovitis at the level of the radiocarpal joint, disability becomes more progressive and nonsurgical treatment more difficult. There may be a role for corticosteroid injection at the level of the radiocarpal joint, and certainly referral to a rheumatologist is crucial for the control and management of the disease before any surgical intervention.
- In the case of wrist or finger extensor tendon rupture, non-surgical treatment may be beneficial in terms of resting the radiocarpal joint and interphalangeal joints of the fingers to prevent further tendon rupture by attrition. Splinting the wrist or hand may prove beneficial, particularly if motion in the radiocarpal joint or fingers is painful.
SURGICAL MANAGEMENT

Extensor Tendon Rupture

A variety of tendon transfers are available for reconstruction of single and multiple extensor tendon ruptures.

It is important for the surgeon to locate the site of tendon rupture, and identify as well as treat the cause.

Usually, rupture is secondary to the distal ulna subluxing dorsally through the attenuated fibers of the DRUJ. When subluxation occurs at this level, it erodes through the floor of the fourth and fifth extensor compartments.

Tendon reconstruction is therefore not complete unless it involves removal of the dorsal osteophyte by a modified Darrach procedure and coverage of the distal ulna with a flap of extensor retinaculum.

When the distal ulna is unstable, the pronator quadratus may be brought dorsal to stabilize the bone.

Small finger extension loss

Single tendon rupture of the EDQ may go unnoticed, particularly if there is a strong EDC to the small finger. Often, however, this common extensor to the small finger is hypoplastic or absent and all that is present is a junctura tendinosa from the small finger to the adjacent ring finger. Isolated loss of function in the EDQ is manifest by weakness or lack of extension of the small finger.

The distal stump of the ruptured tendon is sewn end to side to the intact ring finger EDC tendon. The risk of this transfer, however, is excessive abduction of the small finger when the distal tendon is short (FIG 5A).

Alternatively, an EIP transfer may be performed (FIG 5B, C).

Ring and small finger extension loss (FIG 4)

In addition to the EDC tendons to the ring and small fingers, the EDQ usually will have ruptured.

The EIP is transferred to the EDQ.

The distal ring finger EDC tendon is transferred end to side to the adjacent intact long finger EDC tendon (FIG 6).

Long and ring finger extension loss (FIG 7A)

Although two fingers are seemingly involved, the EDC tendon to the small finger is usually ruptured as well. The EDQ remains intact.

In cases of double rupture in the ring and small fingers, transfer of the extensor indicis proprius to the distal extensor digiti quinti, with end-to-side transfer of the distal extensor digitorum communis of the ring finger to the adjacent extensor digitorum communis to the long finger, is a standard transfer.
If the index finger EDC tendon is intact, EIP transfer to the long and ring finger EDC tendons is performed (FIG 7B).

If the EDC tendon to the index finger has ruptured, end-to-side transfer of the distal tendon of the long finger EDC to the adjacent intact EIP and transfer of the distal tendon of the ring finger EDC to the adjacent intact EDQ may be considered (FIG 7C).

Long, ring, and small finger extension loss

- If the EIP and EDC tendons to the index finger are intact, the EIP can be transferred to the distal stumps of the ring and small finger EDC tendons using end-to-end or end-to-side techniques, depending on the length of the distal stumps.

- The EDC to the long finger is transferred end to side to the adjacent intact index EDC tendon (FIG 8).

- If only the EIP is intact and all remaining tendons on the dorsum of the wrist have ruptured, transfer of the flexor digitorum sublimis (FDS) of the ring finger around the radial or ulnar border of the forearm is the next logical choice.

- In patients with partial or complete wrist fusion, or in patients with limited wrist motion, transfer of the ECRL may be considered. Although not “in phase” with the finger extension, the line of pull matches reasonably well.

- Index, long, ring, and small finger extension loss

- The two most common transfers are the FDS around the radial and ulnar sides of the forearm or through the interosseous membrane (FIG 9A,B).
Chapter 61  TENDON TRANSFERS USED FOR TREATMENT OF RHEUMATOID DISORDERS 2613

Transfer of one of the radial wrist extensors is a suitable alternative (FIG 9C).

Loss of thumb extension
- EPL rupture is common and often results in minimal loss of function.
  - If diagnosed early, an interposition graft may be used.² The palmaris tendon, a strip of the flexor carpi radialis, and a slip of the EDQ are suitable choices.

Late or chronic ruptures require transfer of the EIP to the distal end of the EPL. The proximal muscle will usually begin to atrophy and become nonfunctional by 6 months after the injury.
- If the EIP is not available, transfer of the FDS from the long or ring finger can be considered. The FDS can be routed through the interosseous membrane or around the radial side of the forearm as described for transfer to restore finger extension.⁷
- Chronic synovitis at the thumb MCP joint may lead to attritional rupture of the dorsal capsule and the extensor pollicis brevis.
  - This boutonnière deformity of the thumb is a type I as described by Nalebuff⁴ and Nalebuff and Millender⁵ (FIG 10).
  - The deformity usually progresses after extensor pollicis brevis rupture. The EPL shifts ulnarward, the collateral ligaments weaken, and the thumb metacarpal becomes abducted radially. The interphalangeal joint hyperextends as a reciprocal response to the MCP joint flexion.
  - Transfer of the EPL to the extensor pollicis brevis and dorsal capsule is performed. Local anesthesia is typically adequate.

Flexor Tendon Rupture
- Tendon transfer for the treatment of flexor tendon disruption in the rheumatoid patient is much less common than for extensor tendon rupture.
- Mannerfelt syndrome should be treated by transfer of the brachioradialis tendon to the flexorpollicis longus.
- Associated disruption of a FDP tendon is usually treated by transferring the distal stump end to side to the adjacent digit’s FDP tendon.

FIG 8 • Rupture of the common extensors to the long, ring, and small fingers with extensor digiti quinti rupture can be treated, as shown here, with transfer of the extensor indicis proprius to the distal stumps of the ring and small finger with distal end-to-side transfer from the extensor digitorum communis to the long finger to the adjacent index extensor digitorum communis.

FIG 9 • A. Rupture of all four finger extensors may be treated alternatively with transfer of the flexor digitorum superficialis (FDS) to the long and ring fingers, harvested in the distal palm and transferred around the radius and ulna, with the two forearm bones serving as pulleys for the transferred tendon. B. Alternatively, both FDS tendons may be transferred around the radial side of the forearm and sutured to the distal stumps of the extensor digitorum communis tendons. C. With rupture of all common extensor tendons to the fingers as well as the extensor indicis proprius and the extensor digiti quinti, extension may be restored through transfer of one of the radial wrist extensors. This is ideal when a partial wrist fusion is being planned, as shown.
Preoperative Planning

- All patients with rheumatoid arthritis require a thorough general physical examination as well as careful evaluation of their cervical spine, including posteroanterior and lateral radiographs, often with flexion and extension views to evaluate cervical spine instability.
- Limited joint mobility is a contraindication to tendon transfer.
- Brachioradialis tendon transfer to the flexor pollicis longus is an ideal transfer and is likely to yield an excellent result, but only if there is adequate passive motion at the interphalangeal joint and MCP joint as well as the basal joint and the thumb. If these joints are stiff, the brachioradialis might be better saved for other needs as the patient’s arthritis progresses.
- The carpus should be examined for stability. In particular, the DRUJ on the ulnar side of the wrist should be checked for dorsal instability and subluxation and the volar, radial side of the wrist for palmar subluxation.

EXTENSOR INDICIS PROPRIUS TENDON TRANSFER

- Isolate the EIP through a 1-cm longitudinal or curvilinear incision on the dorsal ulnar aspect of the index MCP joint.
- The EIP is usually the ulnar tendon of the two located dorsal to the MCP joint of the index finger.
- Make a second 2- to 3-cm incision over the mid-dorsal wrist (unless a dorsal wrist incision has already been made for another procedure).
- Incise the retinaculum overlying the fourth extensor compartment and locate the EIP tendon ulnar and deep to the EDC tendons.
- The EIP muscle belly is the most distal in the fourth extensor compartment.
- Once the identity of the EIP is confirmed proximally and distally, suture the index EIP and EDC tendons together as far distal as possible using 4-0 nonabsorbable, usually braided nylon, suture.
- Invert or bury the knot to void prominence under thin rheumatoid skin.
- Incise the EIP just proximal to the stitch, then free any tendinous interconnections over the dorsum of the hand.
- Use a blunt instrument or Penrose drain to pull the EIP tendon into the wrist wound.
- Transfer the EIP to the exposed recipient tendon using a Pulvertaft weave.
- A single weave, while usually sufficient for smaller tendons, should be supplemented with an additional one or two weaves if possible. This will significantly strengthen the repair site.
- If insufficient distal tendon is present for a weave, either an end-to-end repair or a weave in which the transferred tendon is brought through a transverse incision in the distal recipient stump from volar to dorsal is an effective option.
- Skin incisions are closed and a splint is applied.

FLEXOR DIGITOTORUM SUPERFICIALIS TENDON TRANSFER

- In the case of rupture of all of the extensor tendons on the dorsum of the wrist, and when wrist motion is still intact, tendon transfer of the FDS, as suggested by Boyes,¹ is a reliable method to restore finger extension.
- The FDS and FDP to each of the donor fingers must be intact.
- Pre-existing swan-neck deformity in a donor digit may worsen after harvest of the FDS tendon.
- Long and ring FDS tendons are used most often.
Chapter 61  TENDON TRANSFERS USED FOR TREATMENT OF RHEUMATOID DISORDERS

Make a transverse incision in the distal palm and divide the FDS tendon proximal to the bifurcation, leaving the chiasm of Camper intact to provide proximal interphalangeal stability and help prevent development of a swan-neck deformity (TECH FIG 1).

Splinting the proximal interphalangeal joint in flexion postoperatively will also help to minimize the risk of developing a swan-neck deformity.

Isolate the FDS tendon proximally through a Henry-type incision in the distal forearm and atraumatically deliver it into that incision.

Pass the tendon deep to the median nerve, the FDP, the flexor carpi radialis, the flexor pollicis longus, and the radial artery and the nerve at the wrist with a blunt tendon passer, hemostat, or Kelly clamp.

The transferred tendon sits on the radius using the bone as a pulley to enhance the effectiveness of the transfer.

If the FDS to the ring finger is too short to pass around the radial side of the wrist, an alternative route is beneath the FDP, flexor carpi ulnaris, and ulnar artery and nerve around the ulnar side of the forearm using the ulna as the pulley.

In general the radial path is preferred to minimize ulnar deviation of the digits.

Alternatively, the FDS tendon is passed volar to dorsal though an incision in the interosseous membrane just proximal to the DRUJ.

The membrane functions as the pulley.

Weave the smaller distal tendon stumps through the larger transferred FDS tendon in the manner described by Pulvertaft.

Adjust tension such that with slight wrist flexion, the fingers are maintained in full extension.

Immobilize the hand and wrist with the wrist in 40 degrees of extension and the fingers flexed until tension is noted at the suture line (TECH FIG 2).

Ideally, this should be close to the “safe position” with slight MCP joint flexion and relative interphalangeal joint extension.

TECH FIG 1 • Transfer of the flexor digitorum sublimis to the long and ring fingers. The distal incision in the palm is used to isolate the sublimis tendon as far distal as possible by flexing the finger so that the chiasm of Camper is visible in the wound. The tendon is divided just proximal to the chiasm, leaving enough distal tendon to contribute to the stability of the proximal interphalangeal joint in extension and thereby avoiding a secondary instability of that joint and possible swan-neck deformity.

TECH FIG 2 • The ideal splint for transfer to the extensor tendons of the finger immobilizes the wrist in the so-called safe position. With wrist extension, tension at the site of transfer is usually minimal. Finger flexion at the metacarpophalangeal joint is ideal to prevent scarring of the collateral ligaments and secondary loss of finger flexion. The amount of flexion possible is judged in the operating room by passive flexion of the finger until a minimum amount of tension is seen at the repair site. (From Williams DP, Lubahn JD. Reconstruction of extensor tendons. Atlas Hand Clin 2005;10:209–222.)

EXTENSOR CARPI RADIALIS LONGUS OR BREVIS TRANSFER

When all of the finger extensors have ruptured, wrist motion is severely limited (ie, after a partial or complete wrist fusion), and the radiocarpal joint is stable, the wrist extensors become potential muscles for use as transfers.

The ECRL and the ECRB are located in the second dorsal compartment of the wrist adjacent to the fourth compartment and are separated only by the tubercle of Lister and the EPL.

Expose the ECRL or ECRB using a straight dorsal incision or a limited transverse incision over the base of the index and long metacarpals, at their respective insertion sites.

Divide the tendon selected for transfer, usually the ECRL, at its insertion and transfer it ulnarward to the recipient tendon stump.
BRACHIORADIALIS TENDON TRANSFER (RECONSTRUCTION OF MANNERFELT SYNDROME)

- Expose the forearm muscles and the brachioradialis tendon insertion on the distal radial aspect of the radius through a Henry-type incision.
- Confirm the tendon rupture by direct exposure of the slightly more distal and radial tendon of the flexor pollicis longus.
- Mobilize the distal tendon stump and perform a tenolysis to remove adhesions.
- Weave the distal flexor pollicis longus through the brachioradialis in a Pulvertaft fashion. Sharp tendon passers facilitate this technique (TECH FIG 3).
- Adjust tension such that with wrist flexion, the MCP and interphalangeal joints of the thumb extend fully, and with wrist extension, they flex 30 to 40 degrees.
- Secure the weaves with 3-0 or 4-0 braided nonabsorbable sutures.
- If the index or long FDP tendons also are ruptured, isolate the distal tendon stumps and repair them end to side.

EXTENSOR POLLICIS LONGUS TENDON TRANSFER (RECONSTRUCTION OF THUMB BOUTONNIÈRE DEFORMITY)

- Make a longitudinal incision to expose and identify the EPL tendon at its insertion onto the base of the distal phalanx.
- Incise the tendon at that level and mobilize it proximally (TECH FIG 4A).
- Carefully protect the intrinsic tendon, which will now be the sole extensor for the thumb interphalangeal joint.
- Expose the dorsal base of the proximal phalanx and weave the EPL tendon through the dorsal capsule, securing it using a 3-0 or 4-0 nonabsorbable braided suture (TECH FIG 4B).
- Alternatively, secure the EPL tendon in place using drill holes or a suture anchor in the proximal phalanx (TECH FIG 4C,D).
- The thumb is splinted or casted for 4 weeks and a protective splint is worn for strenuous activities for 6 to 8 weeks.
TECH FIG 4 • Extensor pollicis brevis rupture. A,B. Tendon transfer of the extensor pollicis longus proximally to the site of insertion of the extensor pollicis brevis, allowing the hyperextended interphalangeal joint to drop into a more flexed position and allowing active extension at the level of the metacarpophalangeal joint. C,D. Extensor pollicis longus is anchored through drill holes to the base of the proximal phalanx. (From Lubahn JD, Wolfe TL. Surgical treatment and rehabilitation and tendon ruptures in the rheumatoid hand. In: Mackin EJ, Callahan AD, Skirven TM, et al, eds. Rehabilitation of the Hand and Upper Extremity, ed 5. St. Louis: Mosby, 2002:1598–1607.)

PEARLS AND PITFALLS

EIP harvest

■ Obtain the EIP transfer by tracing the ulnarmost inserting tendon in the MCP joint region of the index finger proximally at the level of the wrist. In a certain percentage of patients, the ulnarmost tendon is in fact the EDC rather than the EIP. The EIP, however, is always the deeper, more volar tendon at the level of the wrist. Tracing this independent muscle tendon unit from the wrist to the index finger MPJ will help assure the surgeon that the correct tendon is being released for transfer.

■ Distal repair of the dorsal apparatus at the site of EIP harvest is somewhat controversial. While some experts recommend repair, others feel confident that the defect can be left with no risk of extensor lag. The surgeon needs to be aware of the potential risk of extensor lag, and we recommend attention to the defect by suture repair.

EDQ transfers

■ Sufficient length of the distal segment of the EDQ should be available to allow tendon transfer to the adjacent EDC without abducting the small finger. If this transfer is tight, the side-to-side transfer of EDQ to the EDC of the ring finger should be abandoned and tendon transfer to the EIP or another suitable donor pursued.

Unstable DRUJ

■ At the time of tendon transfer, inspect the DRUJ to be certain that any osteophytes have been débrided and a localized flap rotated to cover the exposed bone created. If the DRUJ is deemed unstable, transfer of the pronator quadratus dorsally may be used to stabilize the distal ulna.

Suturing

■ When suturing tendon grafts at the site of tendon weave (ie, where a graft or transfer is passed through another tendon), one or two sutures should be sufficient. Take care that the needle does not pass through the tendon near the thread from another suture. If this occurs, the suture is weakened or possibly cut in two by the needle, and the graft or transfer is predisposed to rupture. Cutting needles should never be used as they place both the suture and the tendon at risk.
POSTOPERATIVE CARE
- Postoperative care for each of these tendon transfers is similar.
- In the case of tendon transfer to restore loss of finger extensors, the hand and wrist are immobilized with the wrist extended about 40 degrees. More may be desirable in certain instances, but too much extension could damage already fragile joints.
  - The MCP joints are brought into flexion until tension is noted at the suture line. Forty degrees or more is ideal to maintain the desired length of the collateral ligaments and prevent MCP joint extension contractures.
  - Immobilization is continued for 3.5 to 4 weeks, and gentle active motion is begun, maintaining the hand in a splint for protection.
  - At 6 weeks, some resistive exercises may be added to the program. By 12 weeks, the patient should be able to resume normal activities.
- In the case of flexor tendon rupture, the hand and wrist are immobilized with the wrist in 60 degrees of flexion, the MCP joints in 40 degrees of flexion, and the interphalangeal joints allowed to extend until tension is noted at the suture line. Immobilization is continued for 6 weeks, at which time a gentle active range-of-motion program is begun without resistance.
  - At 12 weeks resistive exercises are added and the patient is permitted to gradually resume normal activity.

OUTCOMES
- Outcomes in tendon transfer surgery in rheumatoid arthritis are highly dependent on the patient’s medical condition and ability to cooperate with the postoperative splinting and rehabilitation program. Most patients who are supervised by a therapist achieve a better result than those who try to make it on their own.
  - With good medical management of rheumatoid arthritis, when the disease is well controlled, and in cooperative patients who are motivated to improve, good results should be expected.
- Tendon transfer should always be delayed in patients with active disease as results will be poor.
- The only surgical procedure to be performed in poorly controlled patients is synovectomy, and with the caveat that success hinges on eventual good medical control of the disease.

COMPLICATIONS
- Infection
- Skin or surgical wound breakdown
- Attenuation of the transferred tendon
- Rerupture of the tendons
- Loss of motion due to improper tensioning of the transferred tendon
- Joint stiffness

REFERENCES
DEFINITION
- Rheumatoid arthritis is a poorly understood systemic disease affecting the synovium of joints and tendon sheaths. The synovial tissue in rheumatoid arthritis is characterized by a proliferation of synovial lining cells, angiogenesis, and relative lymphocytosis.\textsuperscript{14}
- A combination of cartilage degeneration, synovial expansion and periarticular erosion, and ligamentous laxity creates an imbalance within the extrinsic and intrinsic tendon systems of the digit to cause progressive deformity.
- A boutonnière (“buttonhole”) deformity involves disruption of the central slip. It results in a characteristic deformity involving hyperextension at the metacarpophalangeal (MCP) joint, flexion at the proximal interphalangeal (PIP) joint, and hyperextension at the distal interphalangeal (DIP) joint.
- Swan-neck deformity is characterized by hyperextension of the PIP joint and flexion of the DIP joint. MCP joint flexion may also be present.
- In the posttraumatic setting, it results from laxity of the PIP joint volar plate and inability of the terminal slip to extend the DIP joint.
- Chronic deformity may be associated with progressive digital contracture.

Classification
- Rheumatoid thumb deformity\textsuperscript{26,33}
  - Type I: Boutonnière deformity: MCP joint flexion and interphalangeal joint hyperextension. Carpometacarpal (CMC) joint is not primarily involved.
  - Type II: Rare; a combination of types I and III involving MCP joint flexion and interphalangeal joint hyperextension and associated CMC joint subluxation or dislocation
  - Type III: Swan-neck deformity: MCP joint hyperextension, interphalangeal joint flexion, and thumb metacarpal adduction, resulting from progressive CMC joint pathology
  - Type IV: Gamekeeper’s deformity. Attenuation of the ulnar collateral ligament of the thumb MCP joint results in radial deviation through the MCP joint and secondary metacarpal adduction deformity or contracture.
  - Type V: Results from attenuation of the MCP volar plate with progressive MCP joint hyperextension and secondary interphalangeal joint flexion. There is no metacarpal adduction deformity.
- Boutonnière deformity
  - Stage I—mild: PIP joint synovitis and a mild, fully correctable extension lag
  - Stage II—moderate: Marked flexion deformity of the PIP joint, either flexible or fixed
  - Stage III—severe: PIP joint articular destruction
- Swan-neck deformity
  - Type I: PIP joint is fully mobile and flexible.
  - Type II: Active and passive motions of the PIP joint are limited, with the MCP joint held in extension due to intrinsic tightness.
  - Type III: Decreased PIP joint motion in all positions of MCP joint flexion and extension
  - Type IV: Fixed PIP joint hyperextension with advanced destruction of the PIP joint articular surfaces

ANATOMY

Bone and Joint
- The MCP joint is a condyloid joint with average range of motion from 15 degrees hyperextension to 90 degrees flexion.
- A cam effect for collateral ligaments is due to the shape of the metacarpal head; collateral ligaments are taut with MCP joint flexion and lax with MCP joint extension.
- The PIP joint (FIG 1A) is a hinge joint with greater inherent osseous stability than the MCP joint due to the configuration of the two condyles of the head of the proximal phalanx, which articulates with the median ridge at the base of the middle phalanx.
- The collateral ligaments are taut throughout the joint arc of motion.
- The volar plate is a thick, fibrocartilage structure that serves to resist PIP joint hyperextension; the volar plate originates within the A2 pulley on the proximal phalanx and inserts into the “rough area” at the base of the middle phalanx.
- The DIP joint is stabilized by the collateral ligaments, the terminal extensor tendon insertion, the flexor digitorum profundus insertion, and the volar plate.

FIG 1 • A. Proximal interphalangeal (PIP) joint relationships. The flexor tendons (flexor digitorum superficialis [FDS] and profundus [FDP]) have been removed from the proximal digital flexor sheath at the A2 pulley. The FDP and FDS tendon orientation is demonstrated before they re-enter the flexor sheath at the A4 pulley. The PIP joint collateral ligament (cl) and the insertion of the central slip (cs) at the dorsal base of the middle phalanx have been reflected distally to highlight the volar plate (vp) and its proximity within the flexor sheath. P1, proximal phalanx; P2, middle phalanx. (continued)
Dorsal Restraining Structures of the Digit (FIG 1B-D)
- The sagittal bands originate on both sides of the MCP joint, from the volar plate and the base of the proximal phalanx, and insert into the lateral margins of the extensor tendon over the dorsal MCP joint.
  - They stabilize the extrinsic extensor tendon over the MCP joint to prevent lateral subluxation.
  - They contribute indirectly to MCP joint extension and prevent extensor bowstringing.
- The triangular ligament stabilizes the two conjoined lateral bands over the dorsal aspect of the middle phalanx and prevents volar subluxation of the conjoined lateral bands.
- The transverse retinacular ligament is composed of fibers oriented in a volar–dorsal direction at the level of the PIP joint. It prevents dorsal subluxation of the conjoined lateral bands.
  - The oblique retinacular ligament (ORL) is a static restraining ligament, linking the PIP and DIP joints. It runs from the fibro-osseous gutter at the A2 flexor pulley and the middle third of the proximal phalanx to insert into the terminal extensor tendon and couples PIP joint and DIP joint extension.

Flexor Tendon: Digit
- At the level of the A1 pulley, the flexor digitorum superficialis (FDS) tendon flattens and bifurcates to allow the more dorsal flexor digitorum profundus (FDP) tendon to pass distally within the flexor sheath to insert at the volar base of the distal phalanx.
- The FDS tendon slips rotate laterally and dorsally around the FDP and then divide again into medial and lateral slips. The medial slips rejoin dorsal to the FDP tendon and insert into the distal aspect of the proximal phalanx. The lateral slips continue distally to insert into the base of the middle phalanx.

Extensor Tendon: Digit
- At the base of the proximal phalanx, the extrinsic extensor tendon trifurcates with the central portion inserting into the dorsal base of the middle phalanx as the central slip.
- The lateral slips are joined by the oblique fibers of the lumbrical tendons to form the conjoined lateral band. The conjoined lateral bands converge over the middle phalanx to form the terminal tendon, which inserts at the dorsal base of the distal phalanx, where it functions to extend the DIP joint.
- The interosseous muscles contribute to the dorsal extensor apparatus through their deep muscle belly, which travels superficial to the sagittal band as the lateral tendon, becoming the transverse fibers of the extensor hood (MCP joint flexion).
PATHOGENESIS

Posttraumatic Boutonnière Deformity
- Disruption of the central slip is the inciting pathology in the development of the boutonnière deformity.
- Injury patterns can be grouped into two broad categories, closed and open.
  - Closed injuries: Forceful hyperflexion of the PIP joint may result in a detachment of the central slip from its insertion. An associated avulsion fracture involving the insertion of the central slip may be identified from the dorsal base of the middle phalanx.
  - Volar dislocations of the PIP joint or digital crush injuries may disrupt the central slip.
  - Open injuries: Dorsal laceration or deep abrasions over the PIP joint may disrupt the central slip.
- Disruption of the central slip and attenuation of the triangular ligament allows for the migration of the lateral bands volar to the PIP joint axis of rotation. This results in flexion at the PIP joint and extension at the DIP joint through the action of the displaced lateral bands.
- The displaced lateral band becomes a flexor of the PIP joint and an extensor of the DIP joint.

Posttraumatic Swan-Neck Deformity
- Unrecognized volar plate injury at the PIP joint may result in volar plate insufficiency. This leaves the action of the central slip unchecked by the volar plate, resulting in a progressive PIP joint hyperextension deformity.
- Recurrent dorsal dislocation of the PIP joint is an example of an injury pattern that may result in volar plate incompetence.
- Avulsion of the terminal tendon from its insertion at the base of the dorsal distal phalanx results in an imbalance in the extensor mechanism. Extension forces are concentrated at the central slip, producing a progressive hyperextension deformity of the PIP joint.
- Patients predisposed to volar plate laxity (such as from generalized ligamentous laxity, inflammatory conditions, and collagen vascular disorders) are particularly susceptible to the development of deformity.
- An extension malunion of the middle phalanx or periteninous adhesions secondary to previous digital fracture or injury may contribute to the development of a swan-neck deformity.
- Hyperextension of the PIP joint and attenuation of the transverse retinacular ligament permits dorsal migration of the lateral bands relative to the PIP joint axis of rotation. The displaced lateral bands act to extend the PIP joint and to flex the DIP joint.

Rheumatoid Boutonnière Deformity

Fingers
- Boutonnière (“buttonhole”) deformity results from pathologic synovitis of the PIP joint that causes progressive attenuation of the central slip, transverse retinacular ligaments, and triangular ligament. The PIP joint essentially “buttonholes” through the extensor mechanism. Characteristic flexion of the PIP joint and hyperextension deformities of the MCP and DIP joint prevail due to the extensor imbalance (FIG 2A).
- Subluxation of the lateral bands, volar to the axis of PIP joint rotation, occurs due to the loss of these restraints. The lateral bands become flexors of the PIP joint rather than extensors.
- It is important to differentiate this pathologic involvement of the extensor mechanism from a flexion contracture of the PIP joint.
- Due to persisting PIP joint flexion, the volar plate, collateral ligaments, and oblique retinacular ligaments become increasingly contracted, resulting in a stiff and subsequently fixed boutonnière deformity.

Thumb
- Type I boutonnière deformity is the most common rheumatoid deformity of the thumb. It is characterized by MCP joint flexion and interphalangeal joint hyperextension (FIG 2B).
- The pathologic changes affecting the thumb typically involve synovitis of the MCP joint with resulting attenuation of the extensor mechanism (dorsal joint capsule, extensor pollicis brevis tendon insertion, extensor hood). This relative extensor imbalance results in MCP joint flexion and possible joint subluxation.
- Attenuation of the sagittal band permits ulnar and volar subluxation of the extensor pollicis longus (EPL) tendon, which accentuates MCP joint flexion and interphalangeal joint hyperextension as it translates volar to the axis of MCP joint rotation.
- The destructive influence of prolific MCP joint synovitis can cause progressive articular erosion and altered joint surface mechanics, resulting in progressive joint instability and deformity.
As the MCP joint flexion posturing increases in severity, compensatory radial abduction deviation of the thumb metacarpal ensues.

- Rupture of the EPL tendon at the wrist can result in a similar “extrinsic-minus” deformity of the thumb.20,25
- Boutonnière deformity can result, also, from a hyperextension deformity of the thumb interphalangeal joint secondary to joint synovitis with attenuation of the volar plate or to rupture of the flexor pollicis longus tendon.19
  - Generally, these primary interphalangeal joint etiologies present with less dramatic MCP joint flexion deformity.33

**Rheumatoid Swan-Neck Deformity**

**Fingers**

- Swan-neck deformity may result from pathologic rheumatoid synovitis of the MCP, PIP, or DIP joints and is characterized by PIP joint hyperextension and MCP and DIP flexion deformities.
  - Progressive attenuation of the volar plate, collateral ligaments, and insertion of the FDS tendon results in the development of a PIP hyperextension deformity.
  - Attenuation of the transverse retinacular ligaments may occur from synovitis, thereby resulting in a loss of the normal restraints to dorsal translocation of the lateral bands. As the lateral bands subluxate dorsal to the axis of PIP joint rotation, they become a constant hyperextension force on the PIP joint.
  - The DIP joint may be the primary cause of swan-neck deformity where synovitis results in the attenuation and possible rupture of the terminal extensor tendon. This leads to a concentration of the extensor forces at the PIP joint and a resultant hyperextension deformity.
  - Pathologic alterations in MCP joint mechanics may initiate the development of a swan-neck deformity. Progressive flexion deformity and ulnar drift of the digit results in an imbalance of the extensor mechanism whereby the lateral bands are drawn dorsally, concentrating an extension–hyperextension force at the PIP joint. Flexion deformity at the MCP joint may be secondary to several causes (**FIG 3A,B**):
    - Chronic synovitis and associated attenuation of the sagittal bands
    - Articular destruction with associated joint deformity and volar joint subluxation
    - The influence of intrinsic tightness or contracture
    - Persisting PIP hyperextension results in contracture of the extensor apparatus, particularly the triangular ligament, as well as the skin. These progressive changes result in a stiff and subsequently fixed PIP joint hyperextension contracture.
    - Digital flexor tenosynovitis may contribute to poor initiation of digital flexion and an increased extension imbalance at the PIP joint.
    - Chronic synovitis of the PIP joint, combined with altered joint mechanics, may result in progressive articular destruction that leads to greater joint deformity, a progressively fixed contracture, and, potentially, painful dysfunction of the digit.

**Thumb**

- Type III rheumatoid thumb deformity is the second most common thumb deformity after boutonnière deformity.25,29
  - The deformity occurs as the result of CMC joint synovitis and associated alterations in thumb mechanics.
  - Progressive dorsal and radial subluxation of the thumb CMC joint occurs with the deleterious effects of chronic synovitis, including capsular attenuation and articular erosions.
  - The force vectors associated with pinch and grasp activities accentuate the CMC deformity and accentuate a progressive thumb metacarpal adduction contracture due to a loss of thumb abduction.
  - As the adduction contracture worsens, hyperextension of the MCP joint (permitted by volar plate laxity) and interphalangeal joint flexion becomes a functional compensation (**FIG 3C,D**).
NATURAL HISTORY

Traumatic Injury
- Early diagnosis is critical for achieving satisfactory outcomes. Reconstructive options become limited as the deformity becomes rigid.

Boutonnière Deformity
- Deformity may not be evident immediately after injury but may develop over 2 to 3 weeks.
- The pathologic finger posture develops through five stages:1
  - Disruption of the central slip results in resting flexion of the PIP joint and weak extension of the middle phalanx via the lateral bands.
  - Attenuation of the triangular ligament and contracture of the transverse retinacular ligaments results in volar migration of the lateral bands. Active PIP joint extension is absent.
  - Extension forces are transmitted through the lateral bands, causing hyperextension at the DIP joint.
  - Progressive contracture of the PIP joint volar plate and the oblique retinacular ligament results in fixed flexion contracture at the PIP joint.
  - Progressive articular degeneration occurs after prolonged and untreated pathology.

Swan-Neck Deformity
- The deformity may be subclassified into four groups that describe the natural history:2
  - Presence of full passive range of motion at the PIP joint
  - Prolonged hyperextension of the PIP joint results in intrinsic tightness. The PIP joint exhibits full range of motion when the MCP joint is flexed. However, with the MCP joint extended, PIP flexion becomes limited.
  - As the transverse retinacular ligament attenuates and the triangular ligament contracts, the subluxated lateral bands become fixed dorsal to the PIP joint axis of rotation. Hyperextension of the PIP joint becomes fixed regardless of MCP joint position.
  - Progressive PIP joint articular degeneration occurs with chronic, fixed deformity.

Rheumatoid Deformity
- The rate of progressive rheumatoid arthritis-related upper extremity deformity appears to be slowing due to improved medical management of this systemic disease process.
- The incidence of uncorrectable boutonnière and swan-neck deformities during the first 2 years after the onset of systemic disease is about 16% and 8%, respectively.7
- The prevalence of finger deformities in patients with established rheumatoid arthritis is about 36% for boutonnière and 14% for swan-neck deformities.7
- The wrist, MCP, and PIP joints are the most commonly affected joints of the upper extremity, and pathologic proliferation of the flexor and extensor tenosynovium may influence digital function and deformity.

PATIENT HISTORY AND PHYSICAL FINDINGS

Posttraumatic Injury

Boutonnière Deformity
- A history of blunt trauma to the digit with swelling and tenderness over the PIP joint should arouse suspicion as to the condition. Often, patients report “jamming” or spraining the digit. History of a dorsal digital laceration is similarly concerning.
- Deformity may not develop until 10 to 21 days after the injury, making early diagnosis challenging and diligent follow-up imperative. Laceration, ecchymosis, or tenderness over the dorsum of the PIP joint may be diagnostic when a PIP joint extension lag is present.
- If the examination is limited due to pain, a digital block should be considered to facilitate a comfortable examination.
- The following physical findings are supportive in confirming an early diagnosis:
  - 15- to 20-degree PIP joint extension lag with the wrist and MCP joint fully flexed8
  - Weak extension of the middle phalanx against resistance18
  - Elson test: Effort to extend the PIP joint accompanied by rigidity of the DIP joint suggests that the central slip is ruptured and forces are being transferred by the lateral bands.
  - The Elson test is most reliable in diagnosing early boutonnière deformities.31
  - Boyes test: When the central slip is disrupted, passive extension of the PIP joint causes tension across the lateral bands, resulting in loss of active flexion at the DIP joint. When flexion at the PIP joint is restored, motion at the DIP joint returns.

Swan-Neck Deformity
- A history of unrecognized or undertreated trauma or multiple dorsal PIP joint dislocations is common. A patient who presents with a longstanding “mallet” deformity should arouse suspicion, particularly if there is associated hypermobility in the PIP joint of unaffected digits.
- Physical examination begins with inspection of the involved digit.
  - Typically, the PIP joint is hyperextended and the DIP joint is flexed. MCP joint flexion may be present also.
  - Active and passive range of motion of the PIP joint should be assessed.
  - In the presence of a flexible deformity, a Bunnell test for intrinsic tightness should be performed.
  - This test assists the examiner in determining the relative contribution of intrinsic tightness to the deformity.
  - Increased resistance to passive PIP flexion with the MCP joint in extension compared with flexion indicates a relative shortening of the intrinsic muscle–tendon units.

Rheumatoid Deformity
- Diagnostic criteria for rheumatoid arthritis are based on the American College of Rheumatology’s 1988 recommendations.2
- Current medications and medical comorbidities may influence decision making for treatment and the timing for surgical intervention.
- The evaluation of digital deformities associated with rheumatoid arthritis requires careful global assessment, including neurologic assessment (cervical spine, peripheral compressive neuropathy); appreciation for shoulder, elbow, and wrist involvement; and the awareness of lower extremity deformities that will need reconstructive surgery for which the use of ambulatory aids might be necessary.
- As progressive deformity of the wrist occurs, its pathologic influence on digital function and deformity should be recognized.
- The carpus typically collapses into supination, with concomitant volar translation and ulnar translocation.4

Relative dorsal prominence of the distal ulna may involve a loss of distal radioulnar joint (DRUJ) congruity and may be associated with ruptures of the extensor carpi ulnaris tendon and extensor tendons to the small and ring fingers (caput ulnae syndrome). Inspection of the extrinsic digital extensors, including the EPL, should be done, particularly in the presence of active synovitis of the radiocarpal joint and DRUJ (FIG 4).

The MCP joint should be assessed for active synovitis and for characteristic volar subluxation and ulnar drift.

Just as pathologic changes to both the wrist and MCP joints may influence the development of swan-neck and boutonnière deformities of the digits, these changes may adversely affect the outcomes of digital reconstruction if they are not addressed.

Evaluation of the digits should be performed individually with inspection of the resting posture of each digit, assessment of the active and passive motion of each digital joint, and inspection for joint synovitis or tenosynovitis. Skin integrity is assessed for attenuation and for its contribution to joint contracture.

Flexor tenosynovitis may be identified by a palpable fullness in the distal volar forearm or along the digital flexor sheath. Swelling, palpable crepitus along the digital flexor sheath, and a discrepancy between active and passive digital motion are hallmarks of flexor tenosynovitis of the digit.

Flexor tendon rupture may be present, often secondary to attenuation at the volar carpus, and should be addressed in the presence of a loss of active digital joint flexion.

Extensor tenosynovitis at the wrist may be determined by palpable tenosynovial hypertrophy, or fullness, and crepitus along the dorsal extensor compartments, proximal and distal to the extensor retinaculum.

Tendon ruptures may be identified by a lack of active digital extension despite active muscular contraction, by palpable tendon deficit, and by a lack of digital extension through tenodesis with passive wrist flexion.

The adhesion of a ruptured tendon to the surrounding tissues and the influence of the junctura tendinea may limit the accuracy of these evaluations.

As described above, the Bunnell intrinsic tightness test should be performed for all fingers of patients with rheumatoid arthritis, particularly for patients with swan-neck deformity of the digits. This test assists the examiner in determining the relative contribution of intrinsic tightness to the development of the deformity.

Tightness of the oblique retinacular ligament, often appreciated in digits with early boutonnière deformity, is evaluated by assessing the relative degree of resistance to passive DIP joint flexion with the PIP joint held by the examiner in maximum extension.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs (three views) are the mainstay of hand and wrist evaluation in the patient with either a traumatic or rheumatoid cause for deformity.
- Staging of arthritis-related joint pathology and identification of joint subluxation or dislocation, important for diagnostic and management considerations, is performed using plain radiographs (FIG 5A).
- Avulsion fractures from the dorsal base of the middle phalanx, volar subluxation of the PIP joint, or both suggest a central slip injury (FIG 5B).
In the presence of a fixed PIP joint flexion deformity, concomitant avulsion fracture of the volar plate suggests pseudo-boutonnière pathology.

Fluoroscopic imaging or stress views may be helpful in differentiating collateral ligament injury from disruption of the central slip.

Avulsion fractures from the dorsal base of the distal phalanx suggest terminal tendon injury.

The presence of volar plate avulsion fractures in the setting of PIP joint hyperextension suggests volar plate incompetence.

MRI may be useful in assessing for soft tissue pathology such as tenosynovitis and tendon rupture, especially in rheumatoid patients.

**DIFFERENTIAL DIAGNOSIS**

**Posttraumatic Injury**

- Pseudo-boutonnière deformity
- Collateral ligament injury
- Mallet finger
- Volar plate avulsion fracture

**Rheumatoid Deformity**

- Osteoarthritis
- Psoriatic arthritis
  - Similar deformities as seen in rheumatoid arthritis, but skin lesions are common and DIP joint “pencil-in-cup” deformities may be present
- Connective tissue disorders (scleroderma, systemic lupus erythematosus)
  - Systemic lupus erythematosus primarily affects soft tissue structures (ligamentous laxity, tendon subluxation) rather than joint destruction. Radiographs typically demonstrate joint deformities with well-preserved joint spaces. The thumb may be the first digit affected; lateral subluxation of the interphalangeal joint and flexion deformity of the MCP joint (secondary to extensor tendon subluxation) are common.
- Patients with scleroderma often develop PIP joint flexion contractures and compensatory hyperextension posturing of the MCP joints.
- Crystal-induced arthropathy (gout, calcium pyrophosphate deposition disease)
- Hemochromatosis
- Remitting symmetric seronegative synovitis

**NONOPERATIVE MANAGEMENT**

**Posttraumatic Injury**

**Boutonnière Deformity**

- Nonoperative management is indicated if correction of the deformity restores the anatomic length relationship between the central slip and the lateral bands. It is most appropriate in those with closed injuries who present within 8 to 12 weeks of injury. It may be attempted in those with central slip avulsion fractures or volar dislocation if satisfactory reduction and PIP joint stability can be obtained.

- For patients with full passive extension of the PIP joint, PIP joint extension splinting is the treatment of choice.
  - A transarticular Kirschner wire maintaining the PIP joint in full extension is an alternative or adjunct to external splinting.
  - For patients with a PIP joint flexion contracture without secondary joint degenerative changes, progressive static or dynamic extension splinting should be pursued.

- Full passive extension of the PIP joint should be sought before surgical intervention is considered.
- Active and passive DIP joint range of motion should be emphasized while the PIP joint is being treated. Restoration of active DIP joint flexion while the PIP joint is extended suggests successful treatment. Restoration of full active extension at the PIP joint is the goal.
- For most injuries, PIP joint extension splinting should be maintained for 6 to 8 weeks at all times, transitioning to protective buddy straps for daily activity and nighttime extension splinting for an additional 4 to 6 weeks.

**Swan-Neck Deformity**

- Once the deformity has developed, nonoperative treatment is rarely effective.
- Some patients with flexible deformities are capable of initiating PIP joint flexion with little impairment. They may complain of “snapping” or “cogwheeling” as the lateral bands relocate volarly during PIP joint flexion. These patients may benefit from a digital splint, such as a figure 8 ring splint, to prevent continued PIP joint hyperextension and to maintain the lateral bands in their anatomic position (**FIG 6**).

**Rheumatoid Deformity**

**Boutonnière Deformity**

- Nonoperative management of an early boutonnière deformity includes low-profile PIP joint extension splinting.
- Oral anti-inflammatory medications, intra-articular corticosteroid injection of the PIP joint, or both are used to minimize joint synovitis.

**Type I Swan-Neck Deformity**

- The goals of treatment for the flexible swan-neck deformity are prevention of PIP joint hyperextension and improvement in PIP joint flexion.
- In the presence of minimal PIP joint synovitis, use of digital splints, such as a figure 8 ring splint, is advocated to prevent PIP joint hyperextension (**Fig 6**).

**SURGICAL MANAGEMENT**

**Posttraumatic Injury**

**Boutonnière Deformity**

- Surgical intervention is indicated for patients who fail to respond to at least 3 months of extension splinting, patients with open injuries, and patients with fixed deformity with associated degenerative joint changes.

**FIG 6** A figure 8 ring splint (Silver Ring Splint; Charlottesville, VA) used to prevent proximal interphalangeal joint hyperextension in a mild, flexible swan-neck deformity. (Photographs © Copyright of Fraser J. Leversedge, Charles A. Goldfarb, and Martin Boyer.)
Surgical decision making should be tempered by the observations of Burton and Melchior:

- Boutonniere reconstructions are most successful on supple joints. If necessary, joint contracture release can be performed as a first stage. If the release is followed by an intensive exercise and splinting program, the second stage may be avoided.
- An arthritic joint usually precludes soft tissue reconstruction. The surgeon should consider either a PIP joint fusion or arthroplasty with extensor reconstruction.
- Boutonniere deformities rarely compromise PIP joint flexion and grip strength. The surgeon should not trade extension at the PIP joint for a stiff finger and a weak hand.

Swan-Neck Deformity

- Surgery is indicated for patients with a flexible deformity who cannot actively initiate PIP joint flexion and in those with fixed deformities.
- Patients with flexible deformities benefit from volar mobilization of the lateral bands and tenodesis to prevent PIP joint hyperextension.
- Patients with fixed deformities have difficulty grasping objects. Often, functional contact is limited to the volar surface of the hyperextended PIP joint.
- If the articular surfaces are well preserved, PIP joint release with concomitant procedures to restore flexion may be beneficial.
- If the articular surfaces are damaged, PIP arthrodesis is a practical option.

Rheumatoid Deformity

- Principles of surgical correction of rheumatoid deformities in the hand should be guided by the relief of pain and the improvement of function.

Boutonniere Finger Deformity

- Stage I—mild
  - For progressive boutonniere deformity associated with persistent PIP joint synovitis unresponsive to oral medication and intra-articular corticosteroid injection, PIP joint synovectomy may be considered. Concomitant slip reconstruction and lateral band repositioning may be indicated due to soft tissue attenuation over the dorsal PIP joint.
  - Functional limitation due to DIP joint hyperextension may be treated by sectioning the terminal extensor tendon over the dorsal middle phalanx.
- Stage II—moderate
  - For patients with moderate boutonniere deformity and preservation of the articular cartilage of the PIP joint, central slip reconstruction and terminal extensor tendon release may be indicated.
- Stage III—severe
  - If articular destruction is evident or if a severe fixed flexion contracture of the PIP joint is present, even without articular changes, then arthrodesis of the PIP joint is a reliable option for reducing pain and for improving function.
  - Implant arthroplasty of the PIP joint and concomitant terminal extensor tendon release is a less reliable option, particularly when there is attenuation of the dorsal extensor apparatus.

Swan-Neck Finger Deformity

- Type I
  - The primary cause of the flexible swan-neck deformity must be determined before proceeding with surgical inter-
MCP joint through EPL attachment to the dorsal MCP joint capsule.26

- **Moderate: Fixed MCP joint deformity**
  - The condition of the adjacent CMC and interphalangeal joints must be considered to determine whether to proceed with MCP arthrodesis or arthroplasty. Often, treatment at this stage of disease reduces the progression of thumb deformity.
  - If the extent of interphalangeal joint involvement warrants intervention, treatment of the interphalangeal joint is limited to arthrodesis. Therefore, preservation of motion at the MCP joint may be optimal through MCP implant arthroplasty, although function after MCP and interphalangeal arthrodesis is generally good.
  - Arthroplasty of the thumb MCP joint involves resection of the involved joint surfaces and prosthetic placement, most commonly with a flexible silicone implant. Extensor reconstruction, including EPL rerouting, is considered to augment extensor forces acting at the MCP joint. Postoperatively, the thumb MCP joint is splinted in extension for 4 to 6 weeks, allowing for controlled CMC and interphalangeal joint exercises. Good functional results with minimal progression of CMC or interphalangeal joint arthritis have been reported.33
  - Arthrodesis of the MCP joint is accomplished by one of several methods, including tension band wire fixation, crossing Kirschner wires, a headless compression screw, or plate and screw fixation. The joint is typically placed in 15 degrees of flexion and the arthrodesis site may be augmented with bone graft as needed to maximize bone surface contact area. The arthrodesis site is protected in a splint until radiographic union is confirmed. Early interphalangeal joint range of motion is encouraged to minimize extensor adhesions and stiffness.

- **Severe: Fixed deformities of MCP and interphalangeal joints**
  - In this advanced stage, the treatment rationale is similar to that for moderate deformity, except that interphalangeal joint contracture or joint deterioration requires intervention. Rarely, interphalangeal joint capsular release may be indicated to improve motion, in the absence of articular deterioration. For cases involving interphalangeal joint instability or progressive arthritis, interphalangeal arthrodesis is indicated.

- **Carpometacarpal joint involvement**
  - As rheumatoid arthritis has the potential to involve greater numbers of joints, motion-sparing procedures of the CMC joint are preferred compared to arthrodesis.
  - While total trapezial implant arthroplasty is relatively contraindicated in the rheumatoid patient due to the higher risk for implant failure or dislocation, resection or hemiresection arthroplasty with ligament reconstruction and soft tissue interposition arthroplasty should be considered.33

- **Type III: Swan-neck deformity**

  - **Mild: Isolated CMC joint involvement**
    - In the absence of symptomatic relief from conservative treatment, CMC hemi-trapeziectomy or trapeziectomy and ligament reconstruction with soft tissue interposition arthroplasty is indicated.
  - **Moderate: CMC joint pathology with mild MCP joint involvement (flexible deformity)**
    - For CMC joint pathology with progressive MCP joint hyperextension deformity, CMC hemi-trapeziectomy or trapeziectomy and ligament reconstruction with soft tissue interposition arthroplasty and simultaneous MCP joint volar plate capsulodesis, sesamoidectomy, or volar tenodesis are considered. Temporary transarticular pin stabilization of the MCP joint in 20 degrees of flexion for 3 to 4 weeks postoperatively permits early motion of the interphalangeal joint.
  - **Severe: CMC joint dislocation with metacarpal adduction contracture and fixed MCP joint hyperextension deformity**
    - Treatment for this advanced stage requires:
      - CMC joint reconstruction with resection arthroplasty and ligament reconstruction or tendon interposition arthroplasty
      - Correction of the metacarpal adduction contracture
      - MCP arthrodesis
    - Often, addition contracture of the thumb metacarpal may be adequately treated with resection of the thumb metacarpal base and release of the restraining ligaments of the CMC joint during resection arthroplasty. If the aduction contracture persists, then fasciotomy of the first dorsal interosseous and adductor muscles may be completed.33 Web space reconstruction with Z-plasties is rarely indicated.

### Preoperative Planning

- The surgeon must plan ahead. Extended procedures associated with multiple digital reconstructions or the combined treatment of multiple joints should warrant careful and efficient use of tourniquet time.
  - Regional anesthesia (axillary block, IV regional) may be preferred for the reconstruction of digital deformities. This form of anesthesia may provide a greater duration of postoperative pain control and may minimize the systemic effects of general anesthesia.
  - Avoidance of general anesthesia may minimize the potential risks of cervical spine positioning in patients with cervical instability secondary to rheumatoid arthritis.
  - Procedures that may require the use of bone grafting should involve preoperative discussion with the patient to explain the potential need for bone grafting and to identify potential sources for the graft (i.e., iliac crest, olecranon, distal radius, allograft or synthetic bone substitutes).

### Posttraumatic Injury

- A detailed history and physical examination should be performed.
  - Active and passive PIP joint range of motion should be assessed. Chronic, rigid deformities may require staged procedures with surgical release of the PIP joint before subsequent reconstructive procedures.
  - Radiographs should be reviewed for fractures, joint subluxation or dislocation, and degenerative joint changes.
  - Adjacent joint injuries and pre-existing degenerative changes should be considered during surgical planning.

### Rheumatoid Deformity

Before surgical reconstruction of rheumatoid swan-neck or boutonnière deformities of the digits, a global assessment is completed to characterize the systemic involvement of rheumatoid disease.

- Coordination of medical clearance and perioperative care may be pertinent for patients with medical comorbidities and for patients taking perioperative medications such as corticosteroids.
Preoperative cervical spine evaluation may be indicated to confirm stability of the spine for safe anesthesia administration.

Timing of rheumatoid swan-neck or boutonnière reconstruction should account for other musculoskeletal pathology as reviewed above. Postoperative protocols and anticipated prognosis for recovery should be reviewed carefully with patients to minimize potential conflicts with other medical or surgical management.

**Positioning**

- Surgical reconstruction of the hand is performed typically in a supine position with the upper limb placed on a well-padded hand table.
- A brachial tourniquet is used.
- Preoperative shoulder and elbow assessment will minimize potential difficulties with surgical positioning, particularly for patients with severe limitations to joint mobility or joint instability.

**Approach**

- Careful soft tissue handling is observed to minimize the risk of wound or soft tissue complications. Full-thickness skin flaps are raised during operative exposure.
- A longitudinal midline or curvilinear incision from the proximal phalanx to the DIP joint provides excellent visualization of the extensor mechanism.

**Dorsal Approach**

- For smaller fragments inappropriate for Kirschner wire or screw fixation, the fragment may be excised and the central slip repaired directly into the dorsal base of the middle phalanx using a pullout suture or suture anchor method.
- If the fracture fragment is larger, reduce the fragment, preserving the attachment of the central slip.
- The lateral bands must be restored to their anatomic location, dorsal to the axis of rotation of the PIP joint. Mobilize them by excising the triangular ligament and incising both transverse retinacular ligaments as necessary.
- Approximate the lateral bands distal and dorsal to the axis of rotation of the PIP joint and suture them together using 4-0 nonabsorbable, braided suture.
- The repair is protected and the PIP joint is held fully extended, usually using a transarticular Kirschner wire, for 6 weeks.

**Volar Approach**

- Access to volar structures may be necessary to release the PIP joint. This can be accomplished via a midlateral or a Brunner incision centered at the PIP joint.
- Dissection is carried down to the flexor sheath, elevating full-thickness flaps and preserving the digital neurovascular bundles.
- Between the A2 and A4 pulleys, the membranous portion of the flexor sheath can be elevated to expose the flexor tendons and the underlying volar plate of the PIP joint.
- Arthrodesis and arthroplasty techniques are detailed in separate chapters.

---

**BOUTONNIÈRE RECONSTRUCTION**

**Primary Central Slip Repair**

- Primary repair is accomplished through a dorsal approach.
- After isolating the central slip, assess the redundant tissue with the PIP joint held in full extension.
- Excise a chevron-shaped segment of redundant fibrous tissue, permitting repair of the free tendon edges with 4-0 braided suture using a multistrand, grasping or locking repair method.
- V-Y advancement may be necessary to facilitate repair.
- In the case of an avulsion fracture, identify and carefully elevate the fragment, preserving the attachment of the central slip.
- For smaller fragments inappropriate for Kirschner wire or screw fixation, the fragment may be excised and the central slip repaired directly into the dorsal base of the middle phalanx using a pullout suture or suture anchor method.
- If the fracture fragment is larger, reduce the fragment anatomically and stabilize it using appropriate fixation such as small screws or two small Kirschner wires.
- The lateral bands must be restored to their anatomic location, dorsal to the axis of rotation of the PIP joint. Mobilize them by excising the triangular ligament and incising both transverse retinacular ligaments as necessary.
- Approximate the lateral bands distal and dorsal to the PIP joint and suture them together using 4-0 nonabsorbable, braided suture.
- The repair is protected and the PIP joint is held fully extended, usually using a transarticular Kirschner wire, for 6 weeks.

**Central Slip Reconstruction Using Local Tissue**

- Central slip reconstruction using local tissue may be considered for patients with a flexible deformity and insufficient central slip for direct primary repair. Several methods have been described using a dorsal approach to the extensor apparatus.

**Snow’s Technique**

- Identify the proximal stump of central slip and dissect it free of the surrounding tissues.
- Elevate a distally based flap of extensor tendon sharply, preserving sufficient length to span the tendinous defect.
- Turn the flap down on itself and suture it to any distal tissue as well as the lateral bands using 4-0 braided, nonabsorbable suture.
- After repair, passive PIP joint flexion of no less than 60 degrees must be possible without excessive tension across the repair site.

**Aiche’s Technique**

- Isolate the radial and ulnar lateral bands and divide them longitudinally from the trifurcation of the extrinsic tendon to the triangular ligament.
- Mobilize the dorsal half of each lateral band dorsally and suture them together using 5-0 nonabsorbable, braided suture.
- Lateral band relocation is recommended when the lateral bands are fixed volar to the PIP joint axis of rotation.
Littler and Eatron’s Technique\(^{17}\)
- Carefully isolate the radial and ulnar lateral bands.
- Incise the lateral bands over the middle phalanx. Preserve at least one ORL; otherwise, DIP joint extension will be compromised.
- Mobilize the incised lateral bands dorsally and suture them into the insertion of the central slip.
- If excessive attenuation of the central slip precludes suture stabilization, this repair method is contraindicated.

Matev’s Technique\(^{22}\)
- After isolating the lateral bands from the surrounding soft tissue, incise the ulnar lateral band at the level of the DIP joint and incise the radial lateral band at the mid-point of the middle phalanx.
- Suture the proximal stump of the ulnar lateral band to the distal stump of the radial lateral band over the dorsal digit, thereby lengthening the terminal slip (TECH FIG 1).
- Weave the proximal stump of the radial lateral band into the remnants of the central slip and suture it to the base of the middle phalanx to restore PIP joint extension.
- Postoperatively, the PIP joint is held in full extension for 6 weeks. A temporary transarticular Kirschner wire may be placed to protect the repair.

Central Slip Reconstruction Using Tendon Graft
- When a flexible deformity is present but there is insufficient local tissue for use in central slip reconstruction, a tendon graft reconstruction may be considered.

Extensor Tenotomy
- Hyperextension deformity of the DIP joint may be addressed with extensor tenotomy.\(^{23}\)
- Tenotomy is indicated in the presence of mild, flexible deformities and for patients who have failed prior surgery directed at the PIP joint.
- Extensor tenotomy may be considered as an adjunct to PIP joint arthrodesis performed for chronic boutonnière deformity with associated PIP joint arthritis.
- Make a dorsal incision over the distal two thirds of the middle phalanx.
- Identify the terminal tendon and elevate it proximally over a distance of 1.5 cm from the underlying phalanx and DIP joint.
- Incise the terminal tendon distal to the triangular ligament.
- Preserve the radial ORL so that DIP joint extension is not compromised.
- Passively extend the PIP joint and passively flex the DIP joint to separate the incised tendon ends.

Oblique Retinacular Ligament Reconstruction\(^{16,39}\)
- Reconstruction of the ORL is indicated when a flexible swan-neck deformity develops secondary to an untreated mallet finger. This procedure is suited for patients with a well-preserved DIP joint.
- Make an incision from the ulnar margin of the MCP joint flexion crease and continue it volarly and distally along the radial midaxial line before curving it dorsally to end over the DIP joint.
- Isolate the radial neurovascular bundle from the surrounding tissue. Proximally, identify the A2 pulley. Distally, identify the terminal slip.

TECH FIG 1 • Boutonnière reconstruction using Matev’s technique of lengthening the terminal tendon and reconstructing the central slip using the lateral bands. The ulnar lateral band is incised slightly proximal to the distal interphalangeal joint and the radial lateral band is incised more proximally, at the level of the mid-aspect of the middle phalanx. The proximal stump of the ulnar lateral band is then sutured into the distal stump of the radial lateral band as shown here. The free proximal stump of the radial lateral band (rlb) is then repaired into the dorsal base of the middle phalanx. (Photographs © Copyright of Fraser J. Leversedge, Charles A. Goldfarb, and Martin Boyer.)

TECH FIG 2 • Boutonnière reconstruction using a tendon graft. The tendon graft is passed through a transverse osseous tunnel in the dorsal base of the middle phalanx (P2) and the limbs of the graft are woven into the lateral bands (lb). (Photographs © Copyright of Fraser J. Leversedge, Charles A. Goldfarb, and Martin Boyer.)
Proximal Interphalangeal Joint Flexor Tenodesis

- Creation of a check-rein to PIP joint hyperextension can be accomplished by PIP joint flexor tenodesis or by lateral band tenodesis (described below).
- Via a Brunner or midaxial incision, elevate full-thickness skin flaps to expose the digital flexor sheath, protecting the digital neurovascular bundles.
- Raise as a flap the membranous portion of the flexor sheath, from the distal aspect of the A2 pulley to the proximal edge of the A4 pulley, to expose the underlying flexor tendons.
- Identify one slip of the FDS tendon and divide it proximally at the level of the decussation, leaving its insertion into the base of the middle phalanx intact (TECH FIG 4A,B).
- Pass the divided tendon end from dorsal to volar through a transverse incision in the A2 pulley, about...
3 mm from the pulley’s distal margin, and suture it back onto itself with the PIP joint held in about 20 degrees of flexion (TECH FIG 4C,D).

- Postoperative immobilization with a dorsal block splint maintains the joint in more than 20 degrees of flexion for 6 weeks. Flexion exercises for the PIP and DIP joints are started at 3 weeks postoperatively.

**Lateral Band Tenodesis**\(^{42,45}\)

- The lateral band is rerouted so that it lies volar to the PIP joint axis of rotation and forms a restraint to PIP hyperextension.
- Approach the extensor apparatus via a dorsal curvilinear incision. Expose the Cleland ligament and divide it to access the flexor sheath with preservation of the digital neurovascular bundles.
- Leaving its proximal and distal attachments intact, dissect the dorsally subluxated lateral band free from the central slip and from its distal attachment to the triangular ligament overlying the base of the middle phalanx. Translocate the lateral band volar to the PIP joint axis of rotation, assisted by flexion of the PIP joint.
- At the level of the PIP joint, elevate a dorsally based flap of the flexor sheath 0.5 to 1 cm wide and place the mobilized lateral band volar to the flap. Repair the flap to its anatomic position, restraining the lateral band as an effective pulley.
- Alternatively, the lateral band may be detached from its insertion into the terminal tendon slip and rerouted within a roughly 0.5- to 1-cm segment of the flexor sheath at the A2 pulley before repairing it to the terminal tendon distally (Tech Fig 4A,B).
  - Confirm unimpeded gliding of the lateral band beneath the flexor sheath by gentle proximal and distal traction on the translocated lateral band.\(^{45}\)
  - Postoperatively, a dorsal block splint maintains the joint in more than 30 degrees of flexion. Digital flexion exercises are encouraged early in the postoperative period. Full active PIP joint extension is not allowed for 6 weeks.

**Type III Swan-Neck Reconstruction**

- Reconstruction of a type III swan-neck deformity must address the fixed translocation of the lateral bands dorsal to the PIP joint rotation axis and the associated PIP joint soft tissue contracture.
- Management of these pathologic changes includes lateral band release from the central tendon and from the triangular ligament; translocation of the lateral bands to a position volar to the PIP joint rotation axis; dorsal PIP joint contracture release, with dorsal capsulectomy and collateral ligament release; extensor tenolysis of the digit; and possible limited flexor tenolysis, as indicated, for flexor tenosynovitis.
- Via a dorsal curvilinear incision, raise full-thickness skin flaps to expose the underlying extensor apparatus.
- Release the lateral bands along their dorsal attachment to the central tendon, from the proximal phalanx to their confluence over the dorsal aspect of the middle phalanx.
- Complete a dorsal PIP joint capsulectomy and gradually release the radial and ulnar collateral ligaments, from dorsal to volar, until the PIP joint can be passively flexed to 90 degrees.
- Because the mobile lateral bands will passively translate volar to the PIP joint axis of rotation with passive joint flexion, the lateral bands do not require stabilization.
- After soft tissue releases, the PIP joint is stabilized in 20 degrees of flexion with a temporary transarticular Kirschner wire. The digital reconstructions are protected in a forearm-based splint, removed to permit MCP and DIP joint motion. The wire is removed 2 to 3 weeks postoperatively.

**PEARLS AND PITFALLS**

**Patient selection**

- The PIP joint should be assessed for flexibility.
- Reconstructive options are limited in the presence of PIP joint degenerative changes. Arthrodesis may be the only practical solution.
- Assess for intrinsic tightness in all patients with digital deformity.
- In rheumatoid patients, carefully evaluate the wrist and MCP joint before surgical reconstruction of the interphalangeal joints.
- Tendon ruptures may not be clinically apparent in rheumatoid patients with severe deformity.

**Boutonnière deformity**

- The deformity develops from injury to the central slip.
- Delayed development of the deformity may occur after injury to the central slip.
- Early diagnosis is important. The Elson test is useful in confirming early diagnosis.
- Extension splinting is effective treatment in those who present within 2 to 3 months from the time of injury. A transarticular Kirschner wire holding the PIP joint in extension may serve as an effective internal splint.
- It is important to differentiate boutonnière deformity from PIP joint contracture (pseudo-boutonnière deformity).

**Swan-neck reconstruction**

- In rheumatoid patients a swan-neck deformity can arise from any of the MCP, PIP, or DIP joints. It is critical to identify which type of deformity is present in order to guide treatment.

**Thumb CMC reconstruction**

- Implant interposition arthroplasty may have an increased failure rate due to poor soft tissue restraints and an increased risk of implant dislocation.

**PIP joint implant arthroplasty**

- Avoid implant arthroplasty in patients with a severe PIP joint flexion contracture (more than 45 to 50 degrees).
- Consider arthrodesis for the index PIP joint due to lateral stresses on the joint with pinch.
OUTCOMES

Traumatic Deformity Reconstruction

- Surgery for established boutonnière and swan-neck deformities is technically challenging.
- A variety of surgical options exist; there is little consensus regarding a preferred technique.
- There are relatively few studies evaluating the long-term results after surgery for posttraumatic boutonnière and swan-neck deformities. Direct comparisons may be difficult due to the variations in clinical stage at the time of presentation.

Boutonnière Deformity

- Towfigh and Gruber reported on the results of surgical treatment of 114 flexible posttraumatic boutonnière deformities. The central slip was repaired directly, with local tissue, or reconstructed with a tendon graft. Follow-up averaged 40 months. Seventy-eight patients report good or excellent results. Satisfactory results were observed in 22 patients and poor results in 14 patients.
- Meadows et al. reported on the results of extensor tenotomy performed on 14 fingers with posttraumatic boutonnière deformity. The average preoperative PIP joint flexion contracture was 36 degrees. All the digits had DIP joint extension contractures with an average arc of motion from 6.5 degrees of hyperextension to 4.2 degrees of flexion. Postoperatively, DIP flexion improved to 44 degrees. Ten of the digits had an extension lag averaging 13 degrees. Seven digits had improved extension at the PIP joint by an average of 27 degrees.

Swan-Neck Deformity

- Tonkin et al. reported outcomes of lateral band tenodesis for swan-neck deformity. Thirty digits with swan-neck deformity of various causes were included. Preoperative PIP joint deformity averaged 16 degrees of hyperextension; this was improved to 11 degrees of flexion postoperatively.
- Reconstruction of the oblique retinacular ligament was first described by Thompson et al. They reported improvement in PIP joint hyperextension and DIP joint flexion with this technique. Kleinman and Peterson described similar results with reliable correction of DIP joint flexion and secondary PIP joint hyperextension.

Rheumatoid Deformity Reconstruction

- There is a relative lack of clinical outcomes studies evaluating the long-term results of surgical management for swan-neck and boutonnière deformities in patients with rheumatoid arthritis.
- Kiefhaber and Strickland reported on the results of surgical treatment for type III swan-neck and stage II boutonnière deformities. In 92 patients undergoing lateral band release, extensor tenolysis, and PIP joint dorsal capsulotomy for type III swan-neck deformity, the authors reported an initial increase of 55 degrees flexion at the PIP joint; however, of 15 fingers assessed at 3 and 12 months postoperatively, there was a 17-degree loss of the early postoperative motion gains. Despite this deterioration of postoperative results, the arc of PIP motion shifted toward flexion, improving functional grasp.
- In 19 patients undergoing central slip reconstruction for stage II boutonnière deformity, the authors found unpredictable results and reported that the deterioration of postoperative correction was greater with time. Four of 19 patients were able to extend the PIP joint beyond 20 degrees of flexion and 11 of 19 patients had a PIP joint extension deficit of greater than 45 degrees.
- Tonkin et al. published two separate studies assessing the outcomes of treatment for swan-neck deformities with lateral band translocation and with synovectomy and lateral band release and translocation. While these studies are limited in their conclusions because of the varying stages of disease and their small patient populations, the trend toward positioning the arc of motion into flexion was observed, similar to the study results of Keifhaber and Strickland.
- Several long-term clinical outcomes studies of PIP and MCP joint implant arthroplasties have demonstrated poor correction of preoperative swan-neck or boutonnière deformities and in general have reported poorer results with respect to pain relief and range-of-motion recovery as compared to arthroplasties done for conditions of osteoarthritis or posttraumatic arthritis.
- A review of surgical treatment of varying stages of thumb boutonnière deformity by Terrono et al. concluded that MCP joint synovectomy and EPL rerouting for early, correctable boutonnière deformity had a high rate of deformity recurrence (64%). The authors recommend MCP joint arthrodesis for cases of moderate severity with isolated joint involvement, but in severe cases, MCP joint arthroplasty and interphalangeal arthrodesis is considered.

COMPLICATIONS

- Perioperative complications in the treatment of posttraumatic boutonnière and swan-neck deformities can be avoided by careful patient selection, appropriate intervention, and adherence to proper surgical technique.
- Thorough perioperative patient counseling and education is imperative to avoid unrealistic patient expectations and unanticipated outcomes.
- A successful operative result and the avoidance of perioperative complications in the treatment of a boutonnière or swan-neck deformity in the rheumatoid hand is largely dependent on a thorough preoperative evaluation, correct staging of the pathologic condition, and appropriate timing of operative intervention. While the goals of reducing pain and improving function are primary, patient education is critical for avoiding unrealistic expectations and unanticipated results.

REFERENCES

Chapter 62 OPERATIVE RECONSTRUCTION OF BOUTONNIÈRE AND SWAN-NECK DEFORMITIES


DEFINITION
- Medial epicondylitis involves tendinosis at the origin of the flexor–pronator mass.
- It is commonly referred to as “golfer’s elbow,” although there is a stronger association with racquet sports and manual labor.4

ANATOMY
- The common flexor–pronator origin is primarily on the anterior aspect of the medial epicondyle.
- The common flexor–pronator origin includes the humeral head of the pronator teres, the flexor carpi radialis (FCR), the flexor carpi ulnaris, and a small portion of the flexor digitorum superficialis.
- The palmaris longus also shares the origin, although this is not likely to be clinically relevant.

PATHOGENESIS
- Epicondylitis results from repetitive microtrauma followed by an incomplete reparative response that results in tendinosis, a pathologic state in which the degenerative tendon cannot heal itself effectively.
- Epicondylitis can be seen with medial collateral ligament instability whereby myotendinous overload occurs in an attempt to dynamically stabilize the ulnohumeral joint. In this scenario, ulnar neuropathy often is part of a trio of pathology.

NATURAL HISTORY
- Most patients improve with conservative treatment.
- However, a greater percentage of patients with medial epicondylitis go on to surgical treatment when compared to patients with lateral epicondylitis.3

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients commonly complain of forearm pain rather than elbow pain. At times the inflammation is significant enough to cause irritation of the ulnar nerve as it enters the flexor carpi ulnaris, causing ulnar nerve symptoms (eg, local irritability and distal numbness and tingling).
- Onset usually is insidious, but the patient may recall an inciting event.
- Medial epicondylitis can be present simultaneously with lateral epicondylitis.
- Examination methods include the following:
  - Palpation of the medial epicondyle for tenderness, a universal finding in medial epicondylitis
  - Resisted pronation is highly sensitive for medial epicondylitis.1
  - A decreased ROM suggests intra-articular pathology such as arthritis.
  - If resisted wrist flexion reproduced symptoms, it supports a diagnosis of medial epicondylitis.
  - Tap the ulnar nerve in the cubital tunnel and along its path into the ECU. Presence of a tingling sensation locally prompts further nerve investigation.
  - Flex patient’s elbow maximally, then compress the ulnar nerve just proximal to the cubital tunnel. Presence of hand numbness or tingling prompts further nerve investigation.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs may show calcifications at the flexor–pronator origin.
- MRI will reliably demonstrate increased intratendon signal on T2-weighted sequences. Most will also show increased intratendon signal and/or tendon thickening on T1-weighted sequences.
  - A small percentage of patients may show increased T2 signal in the medial epicondyle or anconeus edema.2
  - Periosteal reaction is not commonly seen on MRI.2
- Electrophysiologic testing (electromyography and nerve conduction studies) are warranted if patients have ulnar nerve symptoms, but with mild ulnar neuropathy these tests have a very low sensitivity.

DIFFERENTIAL DIAGNOSIS
- Pronator syndrome
- Medial collateral ligament injury
- Ulnar neuropathy
- Arthritis
- Cervical radiculopathy
- Malingering

NONOPERATIVE MANAGEMENT
- Appropriate initial treatment includes avoidance of painful activities and symptomatic relief with nonsteroidal anti-inflammatory drugs and ice.
- Daytime wrist bracing for exertional activities
- Physical or occupational therapy to supervise and instruct on stretching and strengthening protocol for patients not otherwise inclined to comply with those instructions
- Although corticosteroid injection at the medial epicondyle has been shown to provide temporary symptomatic relief, it does not affect the natural history.2 Repeat injections should be avoided to avoid tendon weakening and rupture.
- Ulnar nerve injury has been reported with injection, so careful attention should be paid to the location of the nerve and whether or not it is subluxed.

SURGICAL MANAGEMENT
- A minority of patients fail nonoperative management.
- Careful patient selection will ensure an excellent outcome with surgical management.
Preoperative Planning
- Be prepared to address concurrent ulnar nerve pathology. If necessary, ulnar nerve decompression should be performed in situ, using subcutaneous or submuscular transposition.
- In thin patients, and especially those who have lifestyles in which the inner elbow is struck frequently, we prefer submuscular transposition with flexor pronator lengthening, which definitively treats epicondylitis as well.
- Be prepared to address flexor pronator tears or avulsion. These typically will present more abruptly, with acute or chronic pain, ecchymosis, and swelling.
- It will be necessary to débride the ruptured degenerative tissue (Fig 1) and repair it by retensioning it close to the origin and closing the gap with healthier medial and lateral portions of the flexor pronator origin down to the medial epicondyle (as shown in Tech Fig 2D).

Positioning
- The patient is placed in the supine position.
- The arm is externally rotated at the shoulder and padding is placed under the elbow.
- The arm should rest in a position allowing ready access to the medial aspect of the elbow without requiring constant holding by an assistant.

Approach
- The elbow should be examined after the administration of anesthesia to ensure stability, and the result documented in the operative note.
- The goal of surgery is to débride the degenerative tissue at the flexor–pronator origin and create an environment conducive to proper healing of the tendon.

Incision and Dissection
- A 3- to 5-cm incision through the skin only is made beginning just proximal to and in the center of the medial epicondyle and extending distally along the axis of the forearm (Tech Fig 1A).
- Blunt dissection with scissors is carried through the subcutaneous tissues, taking care to preserve medial antebrachial cutaneous nerve branches, which commonly cross the field (Tech Fig 1B).
- The subcutaneous tissues are gently swept away, exposing the fascia of the flexor–pronator mass.
- The ulnar nerve is palpated, and the elbow is put through a range of motion to check for ulnar nerve subluxation. The result is documented in the operative note.
- The fascia overlying the interval between the pronator and FCR is then incised in line with the fibers to expose the tendon origin (Tech Fig 1C). The exact location can be altered depending on clinical examination and the point of maximal tenderness.

**FIG 1** The common flexors can be seen ruptured and retracted distal to the medial epicondyle.
TECH FIG 2 • A. Degenerative tissue is excised. The remaining healthy tendon is stable and cannot be scraped away with a no. 15 blade. B. The anterior portion of the medial epicondyle is scraped or rongeured to remove any remaining degenerative tendon. C. The bony cortex is not violated, however. D. The muscle interval is closed with a running size 0 Vicryl suture and tied with inverted knots. E. Skin closure is done with a running 3-0 Prolene suture.

The pronator is reflected anteriorly and the FCR posteriorly, exposing the abnormal, deeper tendon tissue (TECH FIG 1D).

**Fasciectomy and Partial Ostectomy**

- The abnormal tissue is excised. It can be identified by its grayish, unorganized mucoid appearance. Abnormal tissue will scrape away with a no. 15 blade, but normal tendon will remain attached (ie, Nirschl scratch test).
- The pathologic tissue is débrided to margins showing an organized, tendinous appearance.
- The area of excision usually is 1 to 1.5 cm long and 3 to 5 mm wide (TECH FIG 2A).
- A rongeur is used to roughen the anterior portion of the medial epicondyle to a bleeding surface without removing cortical bone (TECH FIG 2B,C).
- The defect in the tendon is closed with a running absorbable suture, using 0 or 1-0 suture material with a tapered needle (TECH FIG 2D).
- The subdermal layer is closed with buried, interrupted absorbable sutures, followed by a subcuticular skin closure and Steri-strips (TECH FIG 2E).
POSTOPERATIVE CARE

- Postoperatively, the patient is placed in a soft dressing and a removable cock-up wrist brace.
- The elbow is not immobilized, and gentle ROM is allowed immediately.
- The dressing is removed in 3 to 5 days. The patient may perform activities of daily living as tolerated with the wrist brace, removing the wrist brace several times daily for ROM.
- Exertion is avoided.
- A strengthening program is initiated in 6 weeks with a counterforce brace.
- All restrictions are removed at 3 months, but impact activities are not allowed until 4 to 6 months postoperatively. Return of full, pain-free activity can take 6 to 24 months.

OUTCOMES

- Over 85% of all patients will have return to full activities with no pain or only mild, occasional pain. Among high-level athletes, 75% to 85% will return to their previous level. In patients with mild or no ulnar nerve symptoms, the success rate is greater than 95%.1,6
- In patients with more than moderate ulnar nerve symptoms, there is a trend toward less favorable and less predictable outcomes, although a satisfactory result still is possible.
- It is uncommon for a patient to have absolutely no improvement in pain after surgery, even if the subjective outcome is unsatisfactory. Such a result should prompt consideration of incorrect diagnosis or the possibility of secondary gain issues.

COMPLICATIONS

- Medial antebrachial cutaneous nerve injury
- Grip weakness
- Weakness with wrist flexion or pronation
- Hematoma
- Infection
- Ulnar nerve injury
- Medial collateral ligament injury

REFERENCES

DEFINITION
- Lateral epicondylitis involves tendinosis at the origin of the common wrist extensors.
- It is commonly referred to as “tennis elbow” and is likely more correctly termed “lateral elbow tendinopathy.”

ANATOMY
- The common extensor origin is located on the lateral epicondyle.
- The common extensor origin includes the extensor carpi radialis brevis (ECRB), extensor digitorum communis (EDC), extensor digiti minimi, and extensor carpi ulnaris.
- The ECRB is the primary muscle–tendon unit affected, followed by the EDC, but an isolated origin does not exist.

PATHOGENESIS
- Epicondylitis results from repetitive microtrauma followed by an incomplete reparative response, resulting in chronic tendinosis.
- Functionally, this condition can more correctly be described as “gripper’s elbow,” as synergistic wrist extension increases finger flexion strength. Patients afflicted with lateral epicondylar tendinopathy commonly engage in repetitive forceful gripping activities as they lift, pull, twist, and push objects.

NATURAL HISTORY
- Lateral epicondylitis is a self-limiting condition that resolves in over 80% of patients over the course of 1 year.
- Most patients receiving active treatment (eg, anti-inflammatory medication, orthotics, ultrasound, physical or occupational therapy, injections) improve with nonoperative treatment.
- Typically, fewer than 10% of patients require surgical intervention.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Acute phase: lateral elbow pain or ache with activities that typically resolves with rest, ice, or anti-inflammatory medication
- Intermediate phase: lateral elbow pain or ache occurs at rest and may not resolve without prolonged activity restriction
- Chronic phase: pain or ache occurs with sleep and often is unresponsive to rest, medication, and injections.

Examination methods include the following:
- Palpation of the lateral epicondyle for tenderness, a universal finding in lateral epicondylitis
- Pain either at the epicondyle or radiating distally along the ECRB is a positive finding in any of these circumstances:
  - Passive stretch test: With the elbow in full extension, the wrist is flexed and the forearm is pronated.
  - Mill’s test: With the elbow flexed, the forearm slightly pronated, and the wrist slightly dorsiflexed, the patient actively supinates against the examiner, who resists this rotation.

Thompson test: With the elbow extended, the wrist in slight dorsiflexion, and making a fist, the patient dorsiflexes against the examiner, who resists this motion.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs may show calcifications at the extensor origin.
- MRI
  - Increased intratendon signal is reliably demonstrated on T2-weighted sequences.
  - Most also show increased intratendon signal or tendon thickening on T1-weighted sequences.
  - A small percentage of patients may show increased T2 signal in the lateral epicondyle or anconeus edema.
  - Periosteal reaction is not commonly seen on MRI.
- Lateral collateral ligament tears often are overcalled on MRI, but this possibility must be ruled out by an accurate history and pre- and intraoperative examinations.

DIFFERENTIAL DIAGNOSIS
- Synovial plica
- Lateral collateral ligament tear
- Radial tunnel syndrome
- Loose bodies
- Degenerative joint disease (typically early radiocapitellar joint)
- Avascular necrosis of the capitellum

NONOPERATIVE MANAGEMENT
- Appropriate initial treatment includes avoidance of painful activities and symptomatic relief with nonsteroidal anti-inflammatory drugs (NSAIDs) and ice.
- Daytime strapping is biomechanically and clinically effective.
- Nighttime wrist bracing to prevent palmar wrist flexion and prolonged tension on the extensor tendons
- Physical or occupational therapy to supervise and instruct on stretching and strengthening protocol for patients not otherwise inclined to perform these exercises
- Corticosteroid injection has had good response in the early stages of the condition.
- Platelet-rich plasma or blood clot tendon injection and botulinum toxin muscle injection currently are under investigation.

SURGICAL MANAGEMENT
- A minority of patients fail nonoperative management.
- Careful patient selection is critical to ensure an excellent outcome following surgical management.
- No prospective randomized studies have yet been done to examine the advantages of open versus arthroscopic techniques for the treatment of lateral epicondylitis. However, I choose arthroscopic treatment if there are any signs of a plica or synovial irritation (endpoint pain) that will allow direct examination and treatment.
Preoperative Planning
- Be prepared to address concurrent extensor tendon rupture.
- Be prepared to address lateral collateral ligament rupture.

Positioning
- The patient is placed in the supine position.
- The arm is internally rotated at the shoulder, and padding is placed under the elbow.
- The arm should rest in a position that allows ready access to the lateral aspect of the elbow without requiring constant holding by an assistant.
- The elbow should be examined after the administration of anesthesia to ensure stability, and the result documented in the operative note.
- The goal of surgery is to débride the degenerative tissue at the extensor origin and create an environment conducive to proper healing of the tendon.

OPEN LATERAL EPICONDYLAR FASCIECTOMY AND PARTIAL OSTECTOMY
- A 3- to 5-cm incision through skin only is made beginning at the proximal edge of the center of the lateral epicondyle and extending distally through the mid-radiocapitellar joint plane along the axis of the forearm (TECH FIG 1A).
- Blunt dissection with scissors is carried out through the subcutaneous tissues to expose the EDC aponeurosis and the ECRL.
- The more anterior and reddish ECRL and the more tendinous EDC originating on the epicondyle are identified (TECH FIG 1B).
  - The interval between the ECRL and the EDC aponeurosis is then split in line with the mid-radiocapitellar joint plane. Distally, a fat stripe along the aponeurosis typically is seen along this dissection plane.
  - A small posterior EDC flap is created for later closure and the ECRL is elevated anteriorly revealing the underlying ECRB origin. The origin may be obliterated by degenerative tissue.
- The abnormal tendon tissue to be excised can be identified by its grayish, unorganized mucoid appearance and should be sharply excised. Care is taken to dissect the ECRB off the underlying capsule.
- Abnormal tissue typically will scrape away with a no. 15 blade, but normal tendon will not (Nirschl scratch test). Sometimes the ECRB tissue cannot be dissected free from the underlying capsule or it has already ruptured from its origin, and the underlying joint becomes exposed (TECH FIG 1C). This will not affect outcome.
- If exposed, the joint should be inspected for degenerative change, which, if present, typically is found beneath a plica. The plica should be removed (TECH FIG 1D).
- The pathologic tissue is débrided to margins showing an organized, tendinous appearance. Complete resection of the ECRB origin is not necessary if healthy viable portions remain (TECH FIG 1E).
- The proximal stump of the ECRB should not be repaired, because it has ample attachments and will not retract significantly.
- The area of excision usually is 1 to 2 cm long and 5 to 10 mm wide.
- The undersurface of the EDC often is affected, and degenerative tissue should be similarly removed.
- A rongeur is used to roughen the anterior portion of the lateral epicondyle to a bleeding surface without removing cortical bone.
- In some cases, patients have a significantly prominent epicondylar tip. This can be removed, especially if patients are focused on this finding and they are very thin, but the early recovery period will be more painful (TECH FIG 1F).
- The defect in the tendon is closed with a running absorbable suture, using 0 or 1-0 suture material with a tapered needle. If a capsular rent occurs, there is no need to make a separate capsular closure, but the proximal tendon repair should be close to the epicondyle and watertight to avoid a postoperative ganglion (TECH FIG 1G).
- The subdermal layer is closed with buried, interrupted absorbable sutures, followed by a subcuticular skin closure and Steri-strips.

**TECH FIG 1** • A. Surgical approach uses a 3-cm incision over the lateral epicondyle and can be extended in line with the forearm axis to avoid injury to the lateral collateral ligament. B. The interval between the tendinous EDC aponeurosis and the darker muscle of the ECRL is entered, and the ECRL is elevated off the underlying ECRB. (The patient’s hand is to the right.) (continued)
TECH FIG 1 (continued) C. The degenerative ECRB is sharply excised. At times, as in this example, it is not possible to separate the ECRB and capsule, and a portion of the capsule also is excised. Neighboring tendon of the EDC is scraped with a no. 15 blade to remove loose degenerative tissue. D. In this example, it was possible to excise the degenerative portion of the ECRB without the underlying capsule. E. The anterior portion of the lateral epicondyle is scratched clean of degenerative tissue with a no. 15 blade or rongeur but not decorticated. F. Some intact, normal ECRB fibers are left if they are present. G. Closure is done with an inverted-stitch size 0 Vicryl suture on a tapered needle in a running fashion.

TECH FIG 2A

ARTHROSCOPIC LATERAL EPICONDYLAR FASCIECTOMY AND PARTIAL OSTECTOMY

- The patient is positioned according to surgeon preference for elbow arthroscopy.
- We prefer the lateral decubitus position with the aid of the Tenet Spider Arm Holder (Smith & Nephew Inc., Andover, MA).
- If prone or lateral, it is advantageous to keep the elbow well above the plane of the chest wall to optimize anterior superomedial portal camera positioning.
- The elbow is filled with 30 to 50 mL of irrigating solution until distended. An anterior superomedial portal is established.
- A small longitudinal portal incision is made about 2 cm proximal to the medial epicondyle and just anterior to the medial intermuscular septum. A curved hemostat is used to spread underlying tissues and feel the medial intermuscular septum, and then is slid along its anterior surface to the lateral, then anterior humerus.
- This is repeated with the scope trocar, which is then passed distally along the anterior humerus toward the radiocapitellar joint, piercing the capsule and entering the joint.
- Documentation of intra-articular (eg, loose bodies, plica [TECH FIG 2A], osteochondritis dissecans, arthritis) and lateral capsular or tendon pathology (TECH FIG 2B) is made, and they are treated appropriately.
- A 25-gauge needle is placed from outside in to choose an optimal radiocapitellar portal at the upper rim of the radial head at or just proximal to the joint level (TECH FIG 2C).
- A shaver is used to débride the abnormal capsule lining the EDC origin. Abnormal ECRB is débrided until normal superficial tendon fibers are identified and protected. If ruptured, all degenerative portions of the ECRB are excised. Normal, shining ECRL fibers can be seen superficially as well as the dark muscular appearance (TECH FIG 2D).
- Débridement should not proceed posterior to the mid-radiocapitellar plane, to avoid injury to the lateral collateral ligament.
- A bone-cutting shaver or a less aggressive burr used in reverse will roughen, but not decorticate, the anterior aspect of the lateral epicondyle from the capitellum back to the portal entry site (TECH FIG 2E).
- A hooked electrocautery probe is useful to divide a plica to facilitate its resection.
- Lateral and posterior portals are closed with 3-0 Prolene sutures, and the medial portal is left open for rapid resolution of fluid distention and pain relief.
POSTOPERATIVE CARE

- Postoperatively, the patient is placed in a soft dressing and a removable cock-up wrist brace.
- The elbow is not immobilized, and gentle range of motion is allowed immediately.
- The dressing is removed in 2 to 5 days. The patient may perform activities of daily living as tolerated with the wrist brace, removing the wrist brace several times daily for range of motion exercises.
- Exertion is avoided.
- A strengthening program is initiated at 6 weeks.
- All restrictions are removed at 3 months, but impact activities are not allowed until 4 to 6 months postoperatively. Pain-free full activity may require 6 to 12 months.
OUTCOMES

- Over 85% to 90% of all patients will have return to full activities with no pain. The remaining 10% to 15% have significant pain relief and strength, but do not return to normal preinjury levels. These outcomes hold true for both short follow-up and more than 10 years of follow-up.\textsuperscript{4,5,7} Future prospective randomized trials will elucidate whether the reported more rapid recovery of the arthroscopic treatment is realized.

- It is uncommon (\(<5\%\) of cases) for a patient to have absolutely no improvement in pain after surgery, even if the subjective outcome is unsatisfactory. Such a result should prompt consideration of incorrect diagnosis or the possibility of secondary gain issues.

COMPLICATIONS

- Hematoma
- Infection
- Lateral collateral ligament injury
- Weakness in grip strength

REFERENCES

DEFINITION
- Extensor carpi ulnaris (ECU) subluxation occurs when the separate subsheath of the sixth dorsal compartment is torn or attenuated.
- Incompetence of the ECU subsheath permits subluxation or dislocation of the ECU tendon out of the ulnar groove of the ulna, with a painful click noted on resisted supination, ulnar deviation, and palmar flexion.

ANATOMY
- The dorsal extensor retinaculum of the wrist is composed of two primary layers (FIG 1).
  - The supratendinous retinaculum originates 2 to 3 cm proximal to the radiocarpal joint and ends distinctly at the carpometacarpal joints. The most radial attachment on the distal radius forms the radial septum for the first extensor compartment. The supratendinous retinaculum courses medially, surrounding the ulna.¹⁰
  - The supratendinous retinaculum participates as a block to tendon subluxation for the first through fifth extensor compartments but does not function to prevent subluxation of the ECU.
  - The infratendinous retinaculum runs from the radiocarpal to the carpometacarpal joints. It is found deep to the fourth and fifth extensor compartments on the radius. The ECU lies in its own separate fibro-osseous subsheath, which represents a duplication of the infratendinous retinaculum.
  - The ECU sheath is separated from the supratendinous retinaculum by loose areolar tissue.
- The fibro-osseous subsheath of the sixth dorsal compartment overlies 1.5 to 2.0 cm of the distal ulna and arcs from the radial to ulnar wall of the ECU osseous groove. It ensheathes the ECU and maintains the tendon tightly in the groove (FIG 2).
  - The ECU subsheath contributes to the dorsal portion of the triangular fibrocartilage complex (TFCC).

PATHOGENESIS
- The mechanism of a traumatic injury most commonly is active ECU contraction combined with forced supination, palmar flexion, and ulnar deviation.
  - Injuries resulting from trauma can range from simple attenuation to complete rupture of the ECU fibro-osseous sheath.
  - Traumatic ECU subluxation is commonly reported in association with racket sports, baseball, and golf.

NATURAL HISTORY
- Chronic subluxation of the ECU tendon over the ulnar prominence of the groove in the distal ulna can lead to painful snapping of the tendon with supination and pronation. This can progress to ECU tendinopathy.
  - An injury to the ECU sheath resulting in volar dislocation of the ECU tendon can result in distal radioulnar joint (DRUJ) instability. This joint laxity may cause pain and dysfunction, eventually leading to degenerative changes.
  - Dislocation of the ECU tendon removes a dynamic stabilizer of the DRUJ.
The subsheath of the sixth extensor compartment represents a component of the dorsal peripheral TFCC. Disruption can result in static instability of the DRUJ.

Some patients may experience relatively minor ECU subluxation and related symptoms that do not progress and often improve with minimal intervention.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

Patients may present following an acute injury or, more commonly, in the subacute phase, complaining of persistent ulnar wrist pain aggravated by activities requiring pronation and supination. They may relate the sensation of a “click.”

A complete physical examination of the patient’s ulnar-sided wrist complaints should be conducted to elucidate associated pathology and rule out confounding conditions in the differential diagnosis.

- Palpation and inspection of sixth dorsal compartment and ECU tendon helps to localize the area of discomfort and focus the physical examination. Most acute sheath ruptures and tendinopathies will be tender to palpation at the level of the distal ulna and groove. Tenderness at the joint line may indicate an associated TFCC tear.
- In range-of-motion testing, an inflamed ECU tendon usually will be most painful with full passive radial wrist flexion, although motion most often is full except in the acute setting.
- If the tendon dislocates with passive supination, palmar flexion, and ulnar deviation, the ECU is grossly unstable. If the addition of ECU contraction is required for frank dislocation, some inherent stability remains. Pain with subluxation is a critical finding when contemplating surgical treatment.
- In resisted finger abduction, pain over the wrist and ECU tendon signifies an inflammatory ECU condition, possibly due to subluxation or overuse.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Routine anteroposterior (AP), lateral, and oblique radiographs in neutral rotation are important.
- Pronated grip views and other specialized plain radiographs of the wrist can provide information on other pathologies that contribute to ulnar-sided wrist pain (see Differential Diagnosis).
- MRI is the most sensitive and specific imaging modality to detect ECU subluxation (FIG 3A).
  - The sensitivity increases in studies with both wrists positioned in pronation, neutral, and supination. This allows side-by-side comparison with the asymptomatic wrist and adequately shows the position of the ECU relative to the ulnar osseous groove in all three positions.
  - The actual subsheath tear may or may not be visualized.
  - Often, inflammation and partial interstitial tendon disruption are visualized.
- An MRI arthrogram may depict a subsheath tear and, therefore, an injury to the peripheral TFCC.
  - Contrast may extravasate into the sixth extensor compartment (FIG 3B).
  - The study will also provide additional information concerning the remainder of the TFCC and the integrity of the intercarpal ligaments.
- Ultrasound allows dynamic assessment of ECU stability and can be useful in quantifying the degree of ECU tendon subluxation.

**DIFFERENTIAL DIAGNOSIS**

- ECU tenosynovitis
  - Fullness and pain with palpation of the sixth dorsal compartment
  - The patient often can reproduce a painful snap or click with supination and ulnar deviation, even in the absence of ECU subluxation.
- TFCC injury
  - Tenderness with direct palpation of the TFCC
  - Pain with axial loading and rotation of the ulnar-deviated wrist (TFCC compression test)
  - Instability of the DRUJ with manual manipulation when compared to the contralateral wrist
- Lunotriquetral ligament injury
  - Tenderness to palpation over the dorsal lunotriquetral articulation
  - The patient may also describe pain and crepitance with ulnar deviation of the wrist.
  - Provocative maneuvers for lunotriquetral ligament injuries (ie, ballottement test, ulnar sniff box test) have sufficient sensitivity but poor specificity.
- Ulnocarpal impaction syndrome
  - More common in patients with ulna-positive variance
  - Usually a dynamic phenomenon occurring during forceful activity or pronated gripping
The physical examination findings will be similar to those of TFCC injury, with pain on forced ulnar deviation of the wrist (TFCC stress test) that increases with rotation through the loaded ulnocarpal articulation. Tenderness will be elicited along the ulnar border of the triquetrum and the distal ulna.

Ulnar styloid nonunion
- Uncommon; occurs more commonly with widely displaced styloid fractures at the time of injury
- The intimate relationship with the ulnar TFCC attachment means that symptomatic nonunion can be associated with TFCC dysfunction and DRUJ instability.

DRUJ arthrosis
- Patients present with complaints of pain, swelling, and stiffness. The pain is exacerbated by forearm rotation, particularly when performed with manual compression of the DRUJ.

NONOPERATIVE MANAGEMENT
- In the acute setting (less than 3 weeks since injury), immobilize the patient in an above-elbow cast. The wrist should be in neutral to slight pronation, neutral to slight radial deviation, and neutral to slight extension.
- The cast is removed about 4 to 5 weeks later, and therapy is initiated. A sugartong splint is fabricated with the forearm in slight pronation, and a progressive active and active-assisted ROM protocol is initiated.
- Three weeks later, a forearm-based splint is provided and the patient slowly progresses back to activities.
- Unprotected, full activity is allowed 3 to 4 months after the initiation of treatment.

The literature does not agree on the efficacy of nonoperative treatment. Rowland produced a compelling case report of surgical treatment in acute, traumatic ECU subluxation.

In this case, the intraoperative findings showed the edges of the ruptured subsheath to be separated by a minimum of 7 mm, regardless of the position of the wrist.

These findings suggest that nonoperative treatment could routinely lead to clinical ECU subluxation and persistent symptoms.

SURGICAL MANAGEMENT
- Surgical reconstruction of the ECU subsheath should be considered in patients with clinically significant symptoms related to painful subluxation of the ECU tendon, especially if the injury is more than 3 weeks old. Treatment must be individualized based on the needs and expectations of the patient.
- The guiding principles for surgical repair depend on the essential osteofibrous sheath lesion present at the time of surgery.
- Inoue and Tamura classified three distinct patterns of injury (TABLE 1).

<table>
<thead>
<tr>
<th>Lesion Type</th>
<th>Illustration</th>
<th>Description of Pathology</th>
<th>Recommended Surgical Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>The fibro-osseous sheath is disrupted from the ulnar wall. The tendon may lie beneath the disrupted sheath.</td>
<td>If injury is fairly acute and if adequate tissue is present, a direct repair may be attempted. If nonreconstructable, a sheath reconstruction with retinacular free graft or retinacular sling is employed.</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>The fibro-osseous sheath is disrupted from the radial wall. The tendon may rest on top of the sheath and prevent healing.</td>
<td>A sheath reconstruction with retinacular free graft or retinacular sling is suggested.</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>The fibro-osseous sheath is stripped from the periosteum but remains in continuity, forming a false pouch.</td>
<td>Imbrication of false pouch reinforced with suture anchors or drill holes.</td>
</tr>
</tbody>
</table>

Inoue and Tamura classified three distinct patterns of injury (TABLE 1).

<table>
<thead>
<tr>
<th>Lesion Type</th>
<th>Illustration</th>
<th>Description of Pathology</th>
<th>Recommended Surgical Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>The fibro-osseous sheath is disrupted from the ulnar wall. The tendon may lie beneath the disrupted sheath.</td>
<td>If injury is fairly acute and if adequate tissue is present, a direct repair may be attempted. If nonreconstructable, a sheath reconstruction with retinacular free graft or retinacular sling is employed.</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>The fibro-osseous sheath is disrupted from the radial wall. The tendon may rest on top of the sheath and prevent healing.</td>
<td>A sheath reconstruction with retinacular free graft or retinacular sling is suggested.</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>The fibro-osseous sheath is stripped from the periosteum but remains in continuity, forming a false pouch.</td>
<td>Imbrication of false pouch reinforced with suture anchors or drill holes.</td>
</tr>
</tbody>
</table>
Treatment of type C lesions
- Separation of the fibro-osseous sheath from bone necessitates repositioning of the tissue at the ulnar margin of the groove (see False Pouch Reconstruction and Imbrication for Type C Lesions).
- Stretching and attenuation of the sheath without separation from bone may be effectively treated by suture imbrication, depending on the quality of the tissue.

Although this chapter describes reconstruction of traumatic ECU subluxation, reconstruction also may be considered in the patient with inflammatory arthropathy and secondary volar dislocation of the ECU tendon. The opportunity to stabilize the ulnar wrist and DRUJ while forestalling progression of deformity may lead the patient and surgeon toward surgical care even in the absence of pain.

Preoperative Planning
- All preoperative information obtained from the history, the physical examination, and imaging studies should be thoroughly reviewed and synthesized into the operative plan. For example, a patient with joint line tenderness and an MRI indicating a TFCC injury might benefit from wrist arthroscopy before any open procedure is done.
- Dorsal synovitis or tenosynovitis requiring débridement
- The existence of a shallow ulnar osseous groove and the need to deepen the groove surgically for added stability
- The paucity of soft tissue for reconstruction and the need for another graft choice for subsheath reconstruction. Graft options include the palmaris and flexor carpi ulnaris tendons.

Positioning
- The patient is positioned supine on the operating table with the injured extremity extended on an armboard in the usual manner.
- Initially, the procedure is performed with the arm extended and pronated. If the wrist must be placed in a neutral or supinated position, the elbow is flexed.

Approach
- A precise incision is chosen to allow for the predetermined method of reconstruction.
- Make a Brunner zigzag incision over the sixth extensor compartment.
- The incision begins 1 to 2 cm distal to the ulnocarpal joint and is carried proximally 5 cm.
- Identify and protect the dorsal cutaneous branch of the ulnar nerve in the distal incision.
- Incise the extensor retinaculum on its far ulnar border and carefully separate it from the underlying sixth extensor compartment fibro-osseous sheath (see Fig 2).
- Conservation of and planned incision in the extensor retinaculum is critical to allow for its use as a sling to stabilize the ECU tendon (see Retinacular Sling Reconstruction for Type A and B Lesions)
- Following exposure, inspect the separate fibro-osseous sheath of the ECU and note the position of the tendon through pronosupination.
- Perform a tenosynovectomy as indicated.

RETINACULAR SLING RECONSTRUCTION\(^2\) FOR TYPE A AND B LESIONS
- Retinacular sling reconstruction\(^2\) is performed when the sheath is ruptured and not repairable.
- At the level of the ulnar groove, create a rectangular flap of tissue, 2 to 3 cm wide, based on the septum separating the fifth and sixth extensor compartments (TECH FIG 1A).
- Pass this radially based sling in an ulnar direction, volar to the ECU tendon, then fold it back radially over the tendon and secure it to the ulnar portion of the fifth compartment (TECH FIG 1B).
- This places the superficial surface of the retinaculum in contact with the ECU tendon.
- Avoid constricting the ECU tendon by ensuring that the sling is wide and loose, which still prevents subluxation of the tendon.
- The portion of the extensor retinaculum not used for the sling is repaired anatomically.
ALTERNATE RETINACULAR SLING RECONSTRUCTION FOR TYPE A AND B LESIONS

- An alternate retinacular sling reconstruction\(^9\) requires the development of an ulnarly based, rectangular flap, 2 to 3 cm wide, of supratendinous retinacular tissue, beginning at Lister’s tubercle or over the second extensor compartment if more length is required (TECH FIG 2A).
  - The flap is based on the ulnar septum of the fifth extensor compartment.
- Pass the tissue ulnarly, deep to the ECU tendon, then back over the tendon to create the sling.
- This places the deep surface of the retinaculum in contact with the ECU tendon.
- Insert suture anchors on the radial and ulnar margins of the ulnar groove, and use this suture to stabilize the flap (TECH FIG 2B).
- Avoid constricting the ECU tendon, as discussed previously.

RETINACULAR GRAFT AUGMENTATION FOR TYPE A AND B LESIONS

- Retinacular graft augmentation\(^4\) is performed when the sheath is ruptured and not repairable.
- Harvest a 2 × 2-cm square graft from the distal supratendinous retinaculum (TECH FIG 3A).
- Secure this graft to the periosteum on the ulnar and radial borders of the ulnar osseous groove to maintain the ECU tendon within the groove.
- Roughen the bone surface to encourage attachment, and place suture anchors at the anatomic attachment sites along the radial and ulnar borders of the ulnar osseous groove.
- Secure the harvested graft to the margins of the ulnar groove, allowing bony contact between the graft and the ulna (TECH FIG 3B).
  - Place the deep surface of the graft against the tendon.
  - This provides secure fixation and does not rely on questionable soft tissue for early fixation.

FALSE POUCH RECONSTRUCTION AND IMBRICATION FOR TYPE C LESIONS

- False pouch reconstruction and imbrication\(^6\) is done when the fibro-osseous sheath of the ECU tendon is attenuated and stretched, but intact. The tendon subluxates out of the ulnar groove during forearm rotation (TECH FIG 4A, B).
- Incise the sheath on its ulnar margin (TECH FIG 4C).
- If the sheath has separated from the deep periosteum, roughen the medial surface of the ulna deep to the false pouch (TECH FIG 4D).
Insert suture anchors at the site of the true ulnar attachment of the sheath (TECH FIG 4E).

- Use suture from the bone anchors to capture and repair the fibro-osseous sheath, securing it to the prepared bone bed (TECH FIG 4F).

- The effect is to imbricate the attenuated sheath and obliterate the false pouch.

- Place additional permanent sutures to complete the repair (TECH FIG 4G).

TECH FIG 4 • Type C lesion. A. The supratendinous retinaculum has been incised, revealing the ECU subsheath. The subsheath is inflamed, stretched, and attenuated, allowing tendon subluxation. B. Diagrammatic representation of a type C lesion in which the sheath has pulled away from the bone. C. An incision is made in the attenuated subsheath, allowing visualization of the tendon. Despite MRI findings that indicate potential intrasubstance injury (see Fig 3A), the tendon itself appears normal. D. The bone underlying the ulnar subsheath flap is roughened with a rasp. E,F. Mini–bone anchors are used to secure the tissue to the ulnar border of the groove and imbricate the subsheath. G. Additional permanent sutures complete the repair.

DEEPENING OF THE ULNAR OSSEOUS GROOVE

- Deepening of the ulnar osseous groove is an optional technique that may be used to address all lesion types.
- This technique is added to the reconstruction when preoperative studies or intraoperative findings suggest that a shallow ulnar osseous groove contributes significantly to subluxation of the ECU tendon (TECH FIG 5A).
- Retract the ECU tendon out of its groove.
- Carefully elevate the periosteum and a thin layer of bone along the ulnar 2 to 3 cm of the ulnar osseous groove using a sharp, curved osteotome (TECH FIG 5B).
  - The radial border is used as a hinge to expose the underlying cancellous bone.
  - Precise elevation of the osteoperiosteal flap ensures adequate coverage of the raw bony surfaces.
- Remove cancellous bone using a small curette (TECH FIG 5C), no deeper than 2 to 3 mm.
- The cortical bone flap is then returned to its position and tamped down using a small bone tamp (TECH FIG 5D).
  - The periosteum is repaired (TECH FIG 5E).
- Treat any remaining exposed bony surface with bone wax.

TECH FIG 5 • Deepening of the ulnar osseous groove. A. ECU tendon in a shallow ulnar groove. B. A sharp curved osteotome is used to create an osteoperiosteal “trapdoor” with a hinge of periosteum radially. C. A curette is used to remove cancellous bone. D. A bone tamp is used to close the trapdoor gently and deepen the osseous groove. E. The periosteum is then secured using 4-0 suture if feasible.
CLOSURE AND SPLINTING
- Perform passive motion testing to ensure that the ECU tendon is stable in its groove following reconstruction or repair.
- Close the extensor retinaculum in a side-to-side fashion using absorbable suture.
- Deflate the tourniquet and obtain hemostasis.
- Following routine skin closure and dressing placement, place a sugartong splint with the forearm mildly pronated and the wrist in mild extension and radial deviation.

PEARLS AND PITFALLS

| Indications | Symptomatic subluxation of the ECU tendon at the ulnar osseous groove
| Acute injuries often are effectively treated with immobilization. |
| Approach | Protect against injury to the dorsal cutaneous branch of the ulnar nerve.
| Incise the supratendinous retinaculum along its ulnar border, remembering that the sixth extensor compartment is a separate, deeper structure. |
| Carefully inspect the ECU subsheath for rupture or attenuation, and adjust the reconstruction based on those findings. |
| Evaluate the ECU subsheath looking for a concomitant TFCC disruption. |
| Inspecting the ulnar osseous groove | Consider deepening the ulnar groove to augment stability. |
| Subsheath repair versus reconstruction | Repair the subsheath if the tissues appear substantial. |
| Reconstruct the sheath if in doubt. |
| Perform passive motion testing in the extremes of supination mild wrist flexion and ulnar deviation following the procedure to ensure that the problem has been addressed. |
| Pitfalls | Avoid injury to the dorsal cutaneous branch of the ulnar nerve. |
| Do not repair the supratendinous retinaculum to the ulna, because this will limit forearm rotation. |
| If creation of an ulnar extensor retinaculum sling is required, avoid making it overly tight, inhibiting ECU tendon gliding. This can be easily accomplished by placing a pediatric feeding tube beside the ECU during the sling construction. |
| Return to activity | Full activity is not considered until 3 to 4 months following surgery. |

POSTOPERATIVE CARE
- The sutures are removed 2 weeks after surgery, and an above elbow cast is applied with the forearm and wrist positioned in the manner described.
- This cast is removed 2 weeks later, and therapy is initiated with use of a fabricated sugartong splint and progressive range of motion as described in Nonoperative Management.

OUTCOMES
- No large conclusive studies on which to base outcomes have yet been published.
- A few case reports and smaller series have reported good results following surgical treatment for ECU subluxation.1-4,6,7,9 Our experience mirrors these reports.

COMPICATIONS
- The uncommon nature of ECU subluxation, the uniformly acceptable surgical outcomes, and the lack of large surgical case series result in a sparse list of postoperative complications. Trends with which to define “routine” postsurgical complications are simply not present.
- Complications that have been reported in the literature include the following:
  - Complex regional pain syndrome
  - Decreased wrist motion
  - Decreased grip strength

REFERENCES
A1 Pulley Release for Trigger Finger With and Without Flexor Digitorum Superficialis Ulnar Slip Excision

Alexander M. Marcus

DEFINITION
- Trigger finger is an entrapment of the digital flexor tendon(s) by the flexor tendon sheath.
- Trigger finger progressively causes inflammation, pain, catching, locking, and reduced range of motion (ROM).

ANATOMY
- The flexor digitorum profundus and superficialis (flexor pollicis longus in the thumb) pass under (dorsal to) the flexor sheath, which consists of annular and cruciate pulleys.
- The A1 pulley, which is volar to the metacarpophalangeal joint (MCP), is the most proximal pulley (except for a thickening known as the palmar aponeurotic pulley), and is almost always the primary site of entrapment (FIG 1).

PATHOGENESIS
- High angular loads at the A1 pulley and often, other causes of local inflammation result in a flexor tendon sheath whose inner diameter is too narrow to accommodate the flexor tendon(s).
- This size mismatch causes hypertrophy (thickening) of the A1 pulley and tendinous swelling.
- These changes exacerbate the size discrepancy, setting up a cycle in which entrapment causes hypertrophy and hypertrophy causes entrapment.

NATURAL HISTORY
- Trigger digits may develop spontaneously or may occur after swelling, from either trauma or a period of heavy use.
- Trigger digits may:
  - Resolve spontaneously (especially in mild cases)
  - Persist with the same level of symptoms
  - Advance to passively correctable locking
  - Become indefinitely locked in either flexion or extension

PATIENT HISTORY AND PHYSICAL FINDINGS
- The history may include any of the following:
  - Pain in the distal palm, often radiating proximally along the path of the flexor tendon
  - Pain occurring with use, and difficulty grasping objects or flexing the digit
  - Clicking or locking with digital flexion and extension, which is often perceived to be at the proximal interphalangeal joint (PIP)
  - The finger being stuck in flexion, often in the morning, requiring the other hand to straighten it
  - Being unable to flex or extend the digit fully, or at all (FIG 2)
- The history should elicit the following information:
  - Whether the patient has had a trigger finger before, in either the currently involved or any other digit
  - Previous treatments for trigger finger, and the extent and duration of the result

FIG 1 • To understand trigger finger and its release, an appreciation of the flexor tendon pulley system of the finger (A) and thumb (B) is required.

FIG 2 • Reduced flexion caused by ring finger triggering.
A1 PULLEY RELEASE FOR TRIGGER FINGER

Chapter 66

Whether the condition began after a particular incident or period of increased hand use
The patient’s medical history should be evaluated for conditions that may cause trigger fingers and alter treatment, as well as commonly associated conditions, including:
- Diabetes
- Rheumatoid arthritis and other inflammatory arthropathies
- Amyloidosis, most commonly secondary to renal disease requiring dialysis
- Lysosomal storage diseases
- Carpal tunnel syndrome (often seen in patients with trigger finger, but not causally related)

The history and physical examination should exclude other conditions that cause overlapping symptoms, including:
- Nerve compression
- Muscle weakness
- Tendon interruption from laceration (partial or complete) or rupture
- Pulley rupture and bowstringing
- Joint or soft tissue contracture or swelling, or both
- Extensor tendon laceration or subluxation, especially at the MCP joint
- Joint dislocation

The physical examination should include the following:
- ROM test, which is the most objective measure of severity. If the patient has absolutely no active motion at the PIP (or thumb IP), consider tendon interruption.
- Palpation of the palm. If the A1 pulley is not tender, strongly consider other diagnoses. Examine for other causes of the patient’s symptoms, including Dupuytren’s contracture, tendon sheath ganglion, PIP joint injury, and A3 pulley triggering.
- Examination of the extensor apparatus. Rule out extensor mechanism abnormalities that may cause overlapping signs or symptoms, including a popping sensation with ROM.
- Perform a neurovascular examination. Carpal tunnel syndrome often is associated with trigger finger. Muscle weakness may cause similar findings. Any neurovascular deficit should be documented before treatment.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographs can exclude some unusual causes of trigger finger symptoms and can assess for arthritis, but are not required to make the diagnosis of trigger finger.
- If other pathology is suspected, MRI can be useful.
- Nerve conduction studies can evaluate for anterior interosseous nerve (AIN) compression, which may mimic a trigger thumb or concomitant carpal tunnel syndrome.

DIFFERENTIAL DIAGNOSIS
- Extensor tendon subluxation at the MCP joint
- Joint contracture or injury, including MCP locking due to collateral ligaments and a swollen PIP joint
- Soft tissue swelling or contracture, including Dupuytren’s contracture
- Partial tendon laceration
- Triggering at the A3 pulley (rare)
- Muscle weakness, including flexor pollicis longus weakness secondary to AIN palsy
- Masses (especially tendon sheath ganglions), which may cause A1 pulley tenderness

NONOPERATIVE MANAGEMENT
- Observation and splinting
  - Mild, early cases often resolve spontaneously or do not bother the patient significantly.
  - Use of a night extension splint may help alleviate swelling and morning locking.
  - Unless the PIP joint remains locked, in either flexion or extension, for several weeks, delayed treatment usually does not significantly change either the options available or their results.
- Injection
  - Long-term relief in most affected digits with one to three injections.²
  - Results in diabetic patients are not as good,¹⁴ but it still is worth trying.
- Injection technique (FIG 3)
  - 1 mL of 2% plain (no epinephrine) lidocaine and 1 mL of a soluble corticosteroid solution (eg, betamethasone or

FIG 3 • Technique for trigger digit injection.
dexamethasone) in a single syringe with a 25-gauge needle is given.
- The A1 pulley area is prepped with an antiseptic solution such as alcohol or betadine.
- A topical spray may be used to reduce discomfort.
- 1 to 2 mL is injected in the sheath and subcutaneously. Avoid injecting into the tendon itself; if increased resistance is encountered, this may be the cause.

**SURGICAL MANAGEMENT**

- Indications for surgical treatment include:
  - Symptoms that persist despite conservative management
  - Inability to flex or extend the finger even passively: this is an indication for earlier release to prevent secondary joint contracture.
- Open A1 pulley release is indicated for any routine trigger finger.
- Percutaneous trigger finger release:
  - Requires an actively triggering digit so the patient can flex to confirm needle placement and pulley release.
  - Is used primarily for the middle and ring fingers. Use in other digits may place digital nerves in jeopardy.
  - In patients with very extensive synovitis, such as that seen in rheumatoid arthritis, lysosomal storage diseases, or amyloidosis associated with end-stage renal disease, releasing the A1 pulley percutaneously or through a routine, small incision is contraindicated. A more extensive tenosynovectomy and sometimes ulnar slip of the flexor digitorum superficialis (FDS) resection (USSR) is required.

**Preoperative Planning**

- Clinical notes and any studies obtained preoperatively should be reviewed.

**Approach**

- Anesthesia is obtained by injecting 2% plain (no epinephrine) lidocaine subcutaneously around the incision and in the tendon sheath.
  - Sedation will mitigate the discomfort associated with the injection and the tourniquet. If sedation is used, the patient should be allowed to wake up in time to demonstrate complete active digital flexion and extension without locking, documenting successful pulley release.
  - A standard volar approach to the A1 pulley is made with either an oblique, transverse, or longitudinal incision.
  - For resection of the ulnar slip of the sublimis, a Bruner-type or midaxial longitudinal incision is used over the distal portion of the proximal phalanx.

**OPEN A1 PULLEY RELEASE**

**Incision and Exposure**

- A 1-cm incision is placed over the A1 pulley.
  - Longitudinal (TECH FIG 1A)
  - If a transverse incision is used, it is placed in a palmar skin crease (TECH FIG 1B):
    - Distal palmar crease for small and ring fingers
    - Proximal palmar crease for index finger
    - An incision between creases may be required for middle finger release
  - Oblique or Bruner-type
  - Avoid crossing palmar skin creases at a right angle with any incision type.
  - Incise only the skin and dermis with a no. 15 blade.
  - Bluntly spread subcutaneous tissue to avoid injury to the digital nerves.
  - The digital neurovascular structures adjacent to the A1 pulley must be retracted and protected.
  - Extensive dissection and exposure of these structures is not required.
  - The radial digital nerve of the thumb is at the greatest risk because it typically crosses the surgical field (TECH FIG 1C).
Chapter 66 A1 PULLEY RELEASE FOR TRIGGER FINGER

**TECHNIQUES**

**Begin the A1 pulley incision with a knife, taking care not to cut deep into the tendon.**

**Complete the release with scissors until the pulley leaflets can be spread completely apart (TECH FIG 2B).**

**Avoid cutting any significant portion of the A2 pulley (or the oblique pulley in the thumb).**

---

**Performing the Release**

- Clear off the A1 pulley with sponge dissection.
- The A1 pulley is not incised until it is clearly visualized (TECH FIG 2A).
  - Use of small right-angle retractors helps provide needed visualization.
- Begin the A1 pulley incision with a knife, taking care not to cut deep into the tendon.
- Complete the release with scissors until the pulley leaflets can be spread completely apart (TECH FIG 2B).
- Avoid cutting any significant portion of the A2 pulley (or the oblique pulley in the thumb).

---

**TECH FIG 1 • (continued)**

B. Position of transverse incisions for trigger finger release in relation to the palmar skin creases and the A1 pulley. C. The digital neurovascular structures are right next to the A1 pulley and must be protected. This schematic demonstrates the proximity of the digital nerves and arteries. Because the radial digital nerve of the thumb may cross at the level of the A1 pulley, it is particularly vulnerable.

**TECH FIG 2 • A.** The digital neurovascular structures are retracted, and the A1 pulley has been cleared of all overlying soft tissue. B. The A1 pulley has been completely released. C. The palmar pulley remaining after A1 release. D. The flexor tendons are bluntly separated and pulled out of the wound, which then flexes the digit. (A–D. Top is proximal.)
The A2 pulley is separated from the A1 pulley either by a space (where there is no sheath) or a section of very thin sheath tissue.9

If the tendons appear constricted by the palmar aponeurotic pulley proximal to the A1 pulley, it should also be released (TECH FIG 2C).

Bluntly separate the tendons (in the fingers) and pull the tendon(s) out of the wound (TECH FIG 2D). Minimize any direct handling of the tendons.

Completion

A limited tenosynovectomy may be performed if required (TECH FIG 3A). Any unusual resected tissue or mass is sent to the pathology department for analysis (TECH FIG 3B).

Confirm that the patient can actively flex and extend the finger (TECH FIG 3C,D). If the active ROM is not full or significantly improved, or if the tendons are not passing under the remaining pulleys, consider ulnar slip of the flexor digitorum superficilias resection (USSR) as well as etiologies other than standard trigger finger.5,7,8,10

Release the tourniquet, and irrigate the wound.

Obtain hemostasis, usually with manual compression. Reinspect the wound, check for any arterial bleeding, and confirm the finger has brisk capillary refill.

Close the skin with interrupted sutures and place a mildly compressive dressing.

PERCUTANEOUS A1 PULLEY RELEASE

- The patient must have active triggering.
- The procedure is performed with a sterile prep in either the office or operating room.
- Hyperextend the MCP joints over a towel to help displace the neurovascular structures dorsally.
- Palpate the A1 pulley.
- Inject the local anesthetic (with or without corticosteroid) as described for nonoperative treatment.
- An 18- or 19-gauge needle is placed through the A1 pulley, centered radial to ulnar, and into the tendon (TECH FIG 4).

Open A1 Pulley Release With FDS Ulnar Slip Excision (USSR)

- The patient actively flexes the finger which moves the needle, confirming location.
- The needle is pulled back slightly so that it remains in the A1 pulley, but not the tendon.
- The needle is rotated so that the bevel is in line with the longitudinal axis of the pulley.
- Sweep the needle proximally and distally until grating is no longer felt.
- The patient should be able to actively flex and extend the finger without triggering, confirming release.

The initial steps are performed in the same manner as described for an open A1 pulley release.

A Bruner-type or ulnar midaxial incision is made over the proximal phalanx.

For a Bruner-type incision, a zigzag skin incision is made with the points over the finger flexion creases (TECH FIG 5).

The skin only is opened with a no. 15 blade, and blunt dissection is used to separate the neurovascular bundles as a unit. Formal dissection of the nerve and artery, or separating them from each other, is not required.

Care should be taken to stay more centrally as the incision proceeds distally (over the PIP and distal interphalangeal joints) because the neurovascular bundles can become less radial and ulnar on the digit.

The skin only is opened with a no. 15 blade, and blunt dissection is used to separate the neurovascular bundles as a unit. Formal dissection of the nerve and artery, or separating them from each other, is not required.

Care should be taken to stay more centrally as the incision proceeds distally (over the PIP and distal interphalangeal joints) because the neurovascular bundles can become less radial and ulnar on the digit.
Inspect the tendon distal to the A2 pulley, confirming that there is no catching under the A3 pulley and that an enlarged, bulbous flexor digitorum profundus is not catching under the distal end of the A2 pulley. In either of these cases, USSR may or may not relieve the problem.

Ulnar slip excision is then performed in either distal-to-proximal fashion or with a proximal-to-distal technique.

**Distal-to-Proximal Ulnar Slip Excision**

- Just distal to the A2 pulley, incise the tendon sheath, creating a radially based flap. This flap may be repaired later with 6-0 Prolene if desired.
- With the PIP joint maximally flexed, isolate and cut the ulnar slip of the flexor digitorum superficialis distally, taking care to preserve the vinculum brevis.
- Pull the tendon into the proximal wound and cut it as far proximal as can be reached safely.
- Confirm that the tendons now pass smoothly under the pulley system through a complete ROM.
- Release the tourniquet. Irrigate the wounds.
- Obtain hemostasis, usually with manual compression. Reinspect the wound, check for any arterial bleeding, and confirm the finger has brisk capillary refill.
- Close the skin with interrupted sutures and place a mildly compressive dressing.

**TECH FIG 5** • A Brunner-type incision. (Courtesy of Dominique Le Viet.)

**Proximal to Distal Ulnar Slip Excision**

- Examine the part of the tendon meant to glide under the A1 and A2 pulleys for enlargement, degeneration, longitudinal splitting, or loss of its smooth surface (**TECH FIG 6A**).
- Fully flex the finger, identify the ulnar and radial slips of the FDS distally, and split them longitudinally in a proximal direction (**TECH FIG 6B**).
- With the finger and wrist flexed, cut the ulnar slip of the FDS as far proximal as possible. Pull the ulnar slip distally, carefully separating it through the chiasm, and, with the PIP joint flexed, cut it distally at the edge of the A3 pulley. The tendon slip is than removed from either direction; a loop of 3-0 wire can be used to separate adhesions if necessary (**TECH FIG 6C**).
- Release the tourniquet. Irrigate the wound.
- Obtain hemostasis, usually with manual compression. Reinspect the wound, check for any arterial bleeding, and confirm the finger has brisk capillary refill.
- Close the skin with interrupted sutures and place a mildly compressive dressing.

**PEARLS AND PITFALLS**

| Satisfactory release | ▪ Confirm that the tendon glides freely after release. |
| ▪ If there was no joint contracture preoperatively, the patient should have significantly improved active (or passive, if the patient is under general anesthesia) ROM. |
| ▪ If not, assess the cause and correct. |

| Avoid injury to A2 pulley | ▪ Release of more than 25% of the A2 pulley may cause bowstringing, reducing flexion ROM, and require pulley reconstruction. |

**POSTOPERATIVE CARE**

- A soft dressing is applied with all of the digits free (**FIG 4**). Active ROM as tolerated is encouraged. Minimize dressing bulk to avoid inhibiting motion.
- Formal therapy is required only if the patient has difficulty regaining ROM.
- Patients whose digits were locked preoperatively are more likely to need therapy. This may be started within the first week.
- Scar massage is encouraged after the wound is sealed.

**OUTCOMES**

- Surgical release of trigger digits has a high success rate with a low complication and recurrence rate.\(^1\),\(^12\)

**COMPlications**

- Injury to digital nerve or artery
- Bowstringing
- Wound infection or dehiscence resulting in a flexor sheath infection

**REFERENCES**

DEFINITION
- Carpal tunnel syndrome (CTS) is the most common nerve compression condition in the upper extremity.
- Carpal tunnel release (CTR) is one of the most commonly performed procedures in the United States.
- CTS is a compressive neuropathy of the median nerve at the wrist.
- Early stages of CTS are reversible with treatment.
- Later or more severe stages of CTS may not be (fully) reversible.

ANATOMY
- The carpal tunnel or carpal canal is a space bounded by the carpal bones dorsally, the trapezium and scaphoid radially, the hook of the hamate ulnarly, and the transverse carpal ligament palmarly (FIG 1A).
- The carpal canal contains the median nerve and nine digital flexor tendons, along with the accompanying tenosynovium (FIG 1C).
- Anatomic anomalies include the following:
  - A persistent median artery
  - Muscle anomalies
  - Median nerve branching anomalies (FIG 1B)
  - Extraneous masses or structures may be found within the carpal canal, including sarcoïd and ganglion cysts.

PATHOGENESIS
- Most cases of CTS are idiopathic.⁹
- Some cases are associated with systemic conditions, such as rheumatoid arthritis, diabetes, thyroid disease, chronic renal failure, and sarcoïdosis. CTS is associated with pregnancy.
- There is an association of CTS with cumulative trauma and repetitive use.⁹
- Increased pressure within the carpal canal is associated with CTS.²,⁶,¹¹
- Peripheral neuropathy and CTS have also been associated with shear forces on the nerve, such as with a traction injury.⁷

FIG 1 • A. Cross-section of the carpal tunnel. B. The carpal tunnel has been fully released and the median nerve motor branch is seen branching from the nerve proximally and penetrating the radial portion of the transverse carpal ligament. C. Cross-section of the carpal tunnel with the ulnar artery and nerve superficial to the TCL. (B: Copyright Thomas R. Hunt III, MD.)
NATURAL HISTORY
- CTS may have a variable course. It can improve, remain stable, or get more severe.
- Patients with severe CTS have motor and sensory changes and may have muscle weakness and atrophy.9
  - Patients with extremely advanced CTS frequently have little pain but constant numbness and weakness.

HISTORY AND PHYSICAL FINDINGS
- Presenting symptoms can be variable: some patients with mild CTS present with moderate to severe pain, numbness, and paresthesias, whereas other patients have minimal symptoms until their syndrome is severe and there is thenar muscle atrophy.
  - A common finding that drives patients toward a remedy is nocturnal waking.
- The surgeon should obtain a full medical history to identify for risk factors for CTS such as hypothyroidism and diabetes.
- The surgeon must understand the patient’s occupational and recreational hand activities and any antecedent trauma that might contribute to symptoms.
  - The surgeon should inquire about activity triggers for the CTS.
- The surgeon should obtain a sense of symptom progression and severity.
  - Questions should be asked about sensory and motor function, pain pattern, and nocturnal waking.
- The physical examination includes the neck and shoulder girdle; the supraclavicular, infraclavicular, and axillary area; the humerus and elbow; the forearm; and the wrist and hand.
  - It is important to generate a list of findings that may be responsible for the pain or paresthesias other than CTS.
  - In addition to the standard joint evaluation with range of motion and assessments of stability, it is important to palpate the course of the nerves and elicit the Tinel sign along the course of the paracervical, brachial plexus, median, ulnar, and radial nerves.
  - The Tinel sign is mild, moderate, or severe subjective findings of radicular pain. The mechanical external stimulus threshold for depolarization–repolarization is lowered in a nerve that has a peripheral neuropathy. Anatomic distribution also is important.
  - Phalen’s sign: Wrist flexion decreases the anatomic volume of the carpal canal and raises pressure in patients with CTS. The pattern of paresthesia can be important.
  - Carpal tunnel compression test: The mechanical external stimulus threshold for depolarization–repolarization is lowered in a nerve that has a peripheral neuropathy.
  - Two-point discrimination: In peripheral neuropathy the ability to distinguish one or two points is diminished.
  - Decreased range of motion and palmar wrist swelling can be indirect indications of tenosynovium in the carpal canal, and also any intra-articular wrist pathology.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- AP, lateral, and oblique radiographs are not mandatory in the workup if the wrist examination is completely normal. If there is any possibility of wrist pathology, these studies should be obtained.
  - Other imaging studies are not indicated in routine cases. In cases of recurrent CTS, MRI should be obtained to gain further information regarding a complete versus incomplete release of the transverse carpal ligament (TCL) or evidence of median nerve compression, tenosynovitis, and scarring.1
- Electrodiagnostics: Nerve conduction studies (NCS) and electromyography (EMG) are important. CTS can be graded based on NCS and EMG findings:
  - CTS mild: Increased sensory or motor distal latency; may see decreased amplitude
  - CTS moderate: Increased nerve conduction velocity
  - CTS severe: EMG shows signs of chronic denervation with positive fibrillations and sharp waves or unobtainable recordings on the electrodes to median innervated muscles.
  - Although some experts believe the absence of any of the above electrodiagnostic findings means that there is no CTS, others believe that false-negatives exist due to sensitivity issues with NCS and EMG.4

DIFFERENTIAL DIAGNOSIS
- Cervical radiculitis
- Cervical pathology, joint disease, disc disease, facet disease with foraminal stenosis
- Thoracic outlet syndrome
- Brachial plexopathy
- Syringomyelia, motor neuron disease, myelopathy
  - “Double crush syndrome”
- Shoulder pain related to instability, intra-articular pathology, subacromial impingement
- Acromioclavicular joint pathology
- Medial epicondylitis
- Lateral epicondylitis
- Cubital tunnel syndrome
- Radial tunnel syndrome
- Pronator syndrome
- Elbow pathology instability or contracture
- Forearm or wrist tenosynovitis
- Wrist tenosynovitis, extensor, flexor, or De Quervain tenosynovitis
- Digital tenosynovitis (trigger finger)
- Guyon canal syndrome
- Hypothenar hammer syndrome
- Wrist or carpal fracture
- Intra-articular wrist pathology

NONOPERATIVE MANAGEMENT
- Mild CTS can often be modulated through conservative means.5,16
- Any systemic conditions should be identified and treated.5,16
- Activity modification can be attempted, especially if the activity includes highly repetitive loading of the hand, wrist, and upper extremity.
- Wrist splints can be introduced.
- The physician can recommend or prescribe nonsteroidal anti-inflammatory drugs (NSAIDs).
- Corticosteroid injection into the carpal canal can be considered (FIG 2).
  - Temporary relief from such an injection indicates that surgical decompression is likely to be successful.
- Hand therapy can be considered.
- Some believe oral vitamin B12 treatment can be helpful in some cases.
SURGICAL MANAGEMENT

- The diagnosis of CTS is confirmed by either the presence of classic clinical symptoms and signs or positive NCS or EMG studies.
  - If the NCS or EMG findings are negative, at least one trial of corticosteroid injection should be given to evaluate the clinical response.
  - The surgeon should confirm that a trial of conservative treatment has been undertaken without a cure.
  - The surgeon should confirm that differential diagnoses have been considered.
  - The surgeon should understand that the presence of other diagnoses and conditions will affect the overall results of CTS treatment; this needs to be discussed with the patient before, not after, surgery. In fact, one should strongly consider delaying CTS treatment to control or improve other conditions that may be amenable to nonoperative treatment.
  - If the above conditions are met, CTR should have good to excellent results in more than 90% of cases.\(^\text{14}\)
  - In the case of recurrent CTS, the key to success is patient selection. Although there are scant data to correlate the preoperative evaluation with results, the patient’s clinical course, response to conservative treatment, and interpretation of electrodiagnostic studies and MRI should be carefully considered before revision surgery.

Positioning

- CTR surgery is performed with the arm outstretched on a hand table.
- Pneumatic tourniquet use facilitates accurate identification of critical anatomic structures.
- Loupe magnification is recommended.
- Anesthesia can be by general anesthesia or regional anesthesia such as an axillary block or Bier block.

- Experienced surgeons can perform CTS safely under wrist block or local infiltration.

Approach

- The goal of CTR surgery is to decompress the median nerve at the carpal canal by complete division of the TCL to allow the carpal tunnel to expand.
- A volar exposure is used, but incision position and length vary.
- The locations of critical deep structures are defined using superficial landmarks and a line drawn down the axis of the fourth ray and another drawn obliquely across the palm in line with the ulnar border of the abducted thumb (Kaplan cardinal line) (FIG 3).

OPEN CARPAL TUNNEL RELEASE

Exposure

- Mark the skin incision location, beginning at the intersection of the Kaplan cardinal line and a line drawn along the radial border of the fourth ray, and ending at the wrist flexion crease (TECH FIG 1A).
  - Use a longitudinal hypothenar crease if available.
  - The incision may be placed anywhere along this mark (TECH FIG 1B), depending on the surgeon’s preference. I prefer the midpoint of the proximal third of the palm.
- The incision should be long enough to allow full access to the proximal to distal extent of the TCL to ensure full TCL division. This generally can be achieved without having the incision extend proximal to the wrist flexion crease.
Dissect in line with the incision using a scalpel or scissors, through the subcutaneous fat and the palmar fascia down to the TCL (TECH FIG 1C).

Frequently, the palmaris brevis muscle is encountered directly superficial to the TCL. It is incised and “feathered” from the ligament for adequate visualization of the TCL.

Incise the TCL over a small segment, avoiding injury to deep structures (TECH FIG 1D).

Contents of the carpal canal will have a characteristic appearance due to the tenosynovium.

Place an instrument such as a mosquito clamp or Carroll elevator into the carpal canal, just deep to the TCL (TECH FIG 1E).

This defines the undersurface of the TCL, the location of the hamate hook, and the proposed direction for release.

Visualize the superficial surface of the TCL along its course and place a right-angle retractor to protect the critical structures located between the skin and the ligament (TECH FIG 1F,G).

**TECH FIG 1** • **A.** A longitudinal incision is marked for an open carpal tunnel release. **B.** Either all or a limited portion of this incision may be used, depending on the surgeon’s preference. **C.** The palmar fascia has been incised, the deep fat retracted ulnarily, and the palmaris brevis muscle fibers dissected revealing the transverse fibers of the TCL. **D.** The distal portion of the TCL is carefully incised with a no. 15 knife blade. **E.** A mosquito clamp is placed deep to the TCL in a distal to proximal direction. **F.** A right angle retractor is utilized to visualize the proximal TCL and the distal forearm fascia. **G.** The same retractor is then utilized to visualize the distal TCL to allow complete release. (B–G: Copyright Thomas R. Hunt, III, MD.)
Transverse Carpal Ligament Release

- Staying ulnar in the canal but still leaving a 2-mm cuff of TCL attached to the hamate hook, release the TCL under direct vision proximally and distally with a scalpel, scissors, or mini-meniscotome Beaver blade.
  - Keep a radially based TCL leaflet over the median nerve.
- Release the distal forearm fascia proximally (see Tech Fig 1F).
  - This tissue may be a secondary compression site, especially in patients with two wrist flexion creases.
- Completely divide the TCL and inspect the median nerve and canal contents (see Tech Fig 1G).
  - In rare instances a space-occupying lesion will require removal (ie, “billowing” synovium in a patient with rheumatoid arthritis).
- In primary CTR procedures without systemic disease, there is no role for internal neurolysis or tenosynovectomy (TECH FIG 2).3,8,10
- The wound is closed and sterile dressings are applied.
- Use of a splint is based on the surgeon’s preference.

SINGLE-INCISION ENDOSCOPIC CARPAL TUNNEL RELEASE (MODIFIED AGEE TECHNIQUE)14

Exposure

- Mark out the palmaris longus, the flexor carpi radialis, and the flexor carpi ulnaris.
- Make a transverse 1- to 2-cm incision in a wrist flexion crease centered over or just ulnar to the palmaris longus (TECH FIG 3A).
  - If the palmaris longus is not present, incise halfway between the flexor carpi radialis and the flexor carpi ulnaris.
- Expose the palmaris longus and retract it radially with a Ragnell retractor.
- Identify the flexor retinaculum deep to this structure (TECH FIG 3B).
- Incise the flexor retinaculum and create a distally based U-shaped flap 1 cm wide. Elevate and retract it with a mosquito clamp.
  - On the undersurface of the retinaculum adherent tenosynovium is frequently seen.
  - Visible deep to the opening should be the tenosynovium-covered digital flexor tendons and median nerve.
- Pass small and large hamate finders down the carpal canal in an antegrade manner to evaluate the space and the location of the hamate (TECH FIG 3).
- Palpate the tip of the instruments as they become subcutaneous distal to the distal edge of the TCL at the Kaplan cardinal line.
  - Make sure these instruments are not palpable subcutaneously in the proximal third of the palm, which would indicate incorrect placement superficial to the TCL and carpal canal and probably within the canal of Guyon.
- Use the tenosynovial elevator and pass it proximally and distally a dozen times along the axis of the fourth ray to dissect tenosynovium from the undersurface of the TCL.
  - A “washerboard effect” should be felt with this maneuver.

Device Insertion

- Introduce the assembled Agee endoscopic carpal tunnel release (ECTR) device into the carpal canal, with the scope directed palmarly.
- The undersurface of the TCL with its characteristic transverse striations is visible.
- While viewing the monitor, advance the instrument until the distal edge of the TCL is identified.
- The distal edge is noted by a transition from the white, transverse fibers of the TCL to the yellow amorphous midpalmar fat, which often contains visible vessels and nerves.
- Using your nondominant hand on the palm, perform a ballottement maneuver to help distinguish the transition between the midpalmar fat and the distal edge of the TCL while viewing the signal from the endoscope within the carpal canal on the monitor.
- In the palm, palpate the tip of the ECTR device as it emerges into the subcutaneous space just distal to the TCL. Drive the device with the other dominant hand (TECH FIG 4).
- The transillumination pattern from the ECTR device light source changes from underneath the TCL to the midpalmar fat.

### Transverse Carpal Ligament Release
- Elevate the blade and withdraw the device slowly, cutting the TCL from distal to proximal. Keep the device pressed up against the undersurface of the TCL so no structures come between the blade and the TCL; cut only the TCL (TECH FIG 5).
- Cut only when visualization is excellent. If needed, withdraw the device and redefine the undersurface of the TCL in the manner detailed above until visualization is ideal.
- Repeat the above step as needed until there is a full release of the TCL, with good separation of radial and ulnar leaflets from proximal to distal.
- With a full release, it should not be possible to visualize the radial and ulnar leaflets simultaneously.

**TECH FIG 4** The surgeon’s nondominant index and long digits palpate the tip of the endoscopic carpal tunnel release device as it emerges into the subcutaneous space just distal to the transverse carpal tunnel ligament. The transillumination pattern from the device light source changes from underneath the transverse carpal ligament to the midpalmar fat.

**TECH FIG 5** After careful identification of the distal edge of the transverse carpal ligament (A), the ligament is released from distal to proximal (B). (continued)
Chapter 67 CARPAL TUNNEL RELEASE: ENDOSCOPIC, OPEN, AND REVISION 2663

TECH FIG 5 • (continued) C. This is the start of the TCL division using the Agee device. The blade is elevated (center) and is shown starting to divide the TCL from distal to proximal. The median nerve is just seen radial to the blade. (Copyright Ekkehard Bonatz, MD.)

TWO-INCISION ENDOSCOPIC CARPAL TUNNEL RELEASE (CHOW TECHNIQUE)

- Make the proximal incision and create the distally based U-shaped flap of antebrachial fascia in the manner described for the single-incision ECTR technique.
- Introduce a clamp, elevator, or trocar under the TCL.
- Advance the instrument until it is palpable in the palm subcutaneously distal to the TCL.
- Make a second small incision to expose the tip of the instrument, usually at the junction of the middle and proximal thirds of the palm.
  - Take care to identify the superficial arch, common digital nerves, and fibers of the distal TCL in the area.
  - A variety of techniques (open or scope-assisted) can be used at this point, including slotted trocars for two-incision endoscopic release, or use of a mini-meniscotome blade or scissor or other cutting instrument with a retractor or elevator to protect the median nerve and flexor tendons from the TCL cutting instrument.
- The complete distal TCL division can be ascertained by direct visualization, also taking note that the vessels and nerves have not been injured.
- A pitfall of the two incision techniques, aside from the potential injury to the palmar arterial arch and/or the branches of median or ulnar nerve, is incomplete release of the TCL distally. Therefore, inspection of the operative site with magnifying loupes at the distal incision is important.

REVISION RELEASE FOR RECURRENT OR RESIDUAL CARPAL TUNNEL SYNDROME

- If the recurrent CTS is due to prior incomplete release, revision surgery can be attempted using an ECTR technique; otherwise, open release is indicated (TECH FIG. 6A,B).
- Use a generous skin incision, incorporating previous incisions as needed.
- Perform the release using a similar technique to that described for primary open CTR.
  - Scarring often requires scalpel dissection, and separation of superficial tissues from the TCL is difficult.
- Carefully separate the TCL (in the area of its previous division) from the underlying median nerve.
  - Dense scarring of the median nerve to the TCL is expected and will place the nerve in jeopardy during this exposure.
- Completely release the TCL and the scarred median nerve, taking great care to protect the median nerve motor branch.
- Use an operating microscope to inspect the median nerve for signs of damage or scarring.
Part 6  HAND, WRIST, AND FOREARM  •  Section VII  NERVE COMPRESSION AND INJURY

POSTOPERATIVE CARE

- Traditionally, CTR patients were managed in wrist splints for 1 to 3 weeks after surgery. However, multiple studies have shown that faster recovery occurs when the wrist is not splinted postoperatively.
- Temporary postoperative splints may still be indicated in specific clinical scenarios, such as open revision surgery.
- Hand therapy is helpful in the postoperative period, especially if the patient is having difficulty with full digital active and passive motion.
- Grip and pinch strength, subjective symptom measures, and functional evaluations are helpful to manage the postoperative course.
- Some patients have prolonged periods of tenderness under the TCL, or pillar pain on the thenar or hypothenar side of the proximal palm, and require extended hand therapy and periods of time to gradually increase hand strength and endurance for hand activities.

OUTCOMES

- There should be greater than 95% good or excellent results. This randomized, double-blinded multicenter study compared open and single portal endoscopic CTR and showed statistically significant improvements in the endoscopic group between 6 weeks and 3 months postoperatively in terms of pain and hand strength compared to that of the open group, and equivalent good results in both groups at 1 year.
- Stutz et al reported on a retrospective series of 200 patients who underwent a secondary exploration during a 26-month period at a single institution for persistent or recurrent CTS symptoms after CTR. There were 108 cases of incomplete release of the TCL. Twelve patients had evidence of median nerve laceration during the index procedure. Forty-six patients had scarring of the nerve to surrounding tissues. In 13 patients the cause of their problem could not be determined.
- Varitimidis et al reviewed 22 patients (24 wrists) who underwent revision open CTR after an initial ECTR and who had

TECH FIG 6 • (continued) C. Revision carpal tunnel release with NeuraGen tube around scarred branch of median nerve.

- Create a TCL flap through Z-lengthening and tissue rearrangement if flexor tendon prolapse or palmar migration of the median nerve seems likely.

Hypothenar Fat Pad

- When revision CTR reveals median nerve scarring, surgical tactics to improve the environment around the nerve after the neurolysis to reduce rescarring are attractive. Strickland has described this technique in several publications. The tissue is readily available and has been shown to be of benefit. In a 1996 article, 62 patients were reviewed. Results were good based on pre- and postoperative patient satisfaction scores, with only three transient minor complications.
- Dissect the fat pad to the level of the ulnar nerve and artery, and advance the radial edge to cover the median nerve.
- Sew this edge to the radial flap of the TCL.

Palmaris Brevis Flap

- Rose et al described this flap in 1991.
- Expose the thin palmaris brevis muscle on the ulnar side of the CTR incision.
- Divide it from its insertion in the subcutaneous space and transpose or rotate it into a position covering the median nerve.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Poor patient selection</th>
<th>Perform a full history and physical examination and contemplate the entire list of differential diagnoses.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incomplete release of TCL</td>
<td>Whatever technique is used, make sure it is performed in a technically proficient manner. Confirm complete TCL division, especially distally.</td>
</tr>
<tr>
<td>Damage to median nerve</td>
<td>The surgeon must be able to identify the various anatomic structures and distinguish them. The median nerve must be protected during CTR. In techniques where the median nerve is visualized, inspection should be performed after TCL release and before skin closure.</td>
</tr>
</tbody>
</table>

An external epineurotomy to expose the bands of Fontana on the surface fascicles of the median nerve is recommended in the case of significant nerve scarring.

If there is minimal nerve scarring or damage, the wound can be closed in the usual manner.

If nerve injury is dramatic and rescarring seems likely, cover the damaged nerve with a hypothenar fat pad flap, palmaris brevis muscle flap, vein wrapping, or neural conduit (TECH FIG 6C).
persistent CTS. Twenty-two patients had incomplete TCL release. One patient had a partial and another a complete median nerve transection. One patient had a Guyon canal release instead of a CTR. Twenty patients returned to work, 15 at the previous level and 5 at lighter duty. The two patients with nerve injuries continued to do poorly, one requiring a vein-wrapping procedure.

**COMPLICATIONS**
- Incomplete TCL release
- Median nerve scarring or damage (especially the common digital nerve to the third web space and the thenar motor branch)
- Ulnar nerve or artery damage
- Sympathetically mediated pain syndrome
- Damage to palmar arterial arch

**REFERENCES**
2. Diao E, Shao F, Liebenberg E, et al. Carpal tunnel pressure alters median nerve function in a dose-dependent manner: a rabbit model for carpal tunnel syndrome. J Orthop Res 2005;23:218–223.
DEFINITION

- Pronator syndrome and anterior interosseous syndrome are compression neuropathies of the median nerve and its main branch, the anterior interosseous nerve (AIN), at the elbow and proximal forearm.

ANATOMY

- The median nerve passes in the distal upper arm between the brachialis and the medial intermuscular septum, with the brachial artery sitting lateral to it.
- A rare supracondylar process may arise from the distal aspect of the humerus, giving origin to a fibrous band extending to the medial epicondyle. This is the ligament of Struthers.
- If a ligament of Struthers is present, the median nerve passes underneath it.
- At the elbow, the median nerve sits underneath the lacertus fibrosus and then typically passes between the superficial (humeral) head and the deep (ulnar) head of the pronator teres.
- In 20% of individuals, the deep head is absent or consists of a small fibrous band.
- Motor branches to the palmaris longus, flexor carpi radialis, flexor digitorum superficialis, and flexor digitorum profundus typically branch from the median nerve in an ulnar direction proximal to the pronator teres.
- Under the pronator teres, the AIN branches in a radial direction from the median nerve, and both pass underneath the fibrous arcade of the flexor digitorum superficialis.
- The surgeon should be cognizant of the cutaneous nerves passing over the antecubital and proximal forearm region. Damage to these nerves can result in numbness and paresthesia, as well as symptomatic neuromas in the forearm.
- Anomalous muscles and nerve branches may be present, the most common of which is the so-called Martin-Gruber anastomosis.
- The surgeon should also be aware of more proximal or distal branching of the AIN from the median nerve.
- The Martin-Gruber anastomosis, which occurs in about 15% of the population, consists of branches from either the median nerve or AIN to the ulnar nerve.

PATHOGENESIS

- Compression of the median nerve in the proximal forearm is rare compared with carpal tunnel syndrome.
- Median nerve compression in the proximal forearm has been labeled as either pronator or anterior interosseous syndromes.
- The true incidence of median nerve compression in the proximal forearm is difficult to ascertain, as is the relative contribution of the various potential impinging structures.
- Numerous studies have shown that the most common causes of median nerve compression in the region of the elbow and proximal forearm seem to be fascial bands and muscular anomalies of the pronator teres and the fibrous arcade of the flexor digitorum superficialis.
- Less common sites of nerve compression include the lacertus fibrosus and the ligament of Struthers (in cases with an existing supracondylar process).
- A large number of additional structures have been identified as potential sources of compression of the median nerve. These include an accessory bicipital aponeurosis and a variety of anomalous muscles, the most frequently cited of which is the accessory head of the flexor pollicis longus muscle, or Gantzer’s muscle.
- A persistent median artery penetrating the median nerve also has been described.
- Space-occupying lesions such as lipomas or scarring from trauma can result in nerve compression.
- Anterior interosseous syndrome caused by nerve compression must be differentiated from Parsonage-Turner syndrome, or mononeuritis.

NATURAL HISTORY

- Compression of the median nerve in the forearm often is transient, due to excessive physical activity or swelling from injury.
- Recovery from Parsonage-Turner syndrome can be prolonged, but the prognosis usually is good without surgical decompression.
- The natural history and prognosis of pronator syndrome is not well understood.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Classically, pronator syndrome presents as paresthesia in the median nerve distribution with minimal or no weakness. The patient also may complain of pain localized to the proximal forearm that is increased with activities. There may be a focal area of increased pain localizing to the specific area of compression.
- In severe cases, weakness of the anterior interosseous innervated muscles—the flexor pollicis longus, the index and long flexor digitorum profundus, and the pronator quadratus—might be seen, as well as select thenar muscles.
- Theoretically, patients may have paresthesia in the distribution of the palmar cutaneous branch of the median nerve, in contrast to carpal tunnel syndrome.
- AIN syndrome presents as diminished motor function of the index (and long) flexor digitorum profundus, flexor pollicis longus, and pronator quadratus without injury or specific known cause.
- The patient typically complains of spontaneous loss of dexterity and voices specific complaints related to flexion of the thumb IP joint and/or index DIP joint.
- Decreased sensation is not a common presenting symptom.
  - In cases of space-occupying lesions or scarring from trauma compressing the nerve, one would expect to see sensory symptoms as well as motor abnormalities.
  - Patients suffering from Parsonage-Turner syndrome often will experience a prodromal viral-type illness together with significant pain for several days or weeks before the onset of weakness.

- Physical examinations to perform include:
  - **Pronator compression test.** Paresthesia in the median nerve distribution within 30 seconds is considered a positive test. The test is nonspecific and can be seen with carpal tunnel syndrome.
  - **Resisted PIP flexion of long finger.** Paresthesia in the median nerve distribution and pain in the forearm are considered a positive test. The test is thought to be consistent with compression of the median nerve at the fibrous arcade of the flexor digitorum superficialis.
  - **Resisted pronation test.** Paresthesia in the median nerve distribution and pain are considered a positive test. A positive finding is consistent with compression of the median nerve by the pronator teres.
  - **Elbow flexion test.** Paresthesia and pain are considered a positive test. A positive test is thought to be consistent with lacertus fibrosis compression of the median nerve.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Electrodiagnostic studies are often not helpful in pronator syndrome. Numerous studies have shown that symptoms and outcome of surgery do not correlate well with electrodiagnostic studies.
- In anterior interosseous syndrome, electrodiagnostic studies will confirm denervation of the anterior interosseous muscles.
- Electrodiagnostic studies are most valuable in the diagnosis of proximal median nerve compression for ruling out carpal tunnel syndrome.

- Ultrasonography and MRI are valuable tests for identifying space-occupying lesions such as lipomas or ganglions.
- Plain radiographs of the proximal forearm and elbow may reveal a supracondylar process or anatomic variation.

**DIFFERENTIAL DIAGNOSIS**

- **Carpal tunnel syndrome**
- **Mononeuritis, or Parsonage-Turner syndrome**
- **Other form of neuritis**

**NONOPERATIVE MANAGEMENT**

- In the acute phase, rest, immobilization, and avoidance of aggravating activities, such as repetitive pronation and heavy gripping, should be recommended.
- Forearm stretching exercises can be tried in chronic cases.
- Modalities such as ultrasound and electrostimulation have been advocated, although there is limited validation of their usefulness.
- Nerve gliding and nerve mobilization remain controversial.

**SURGICAL MANAGEMENT**

**Approach**

- The greatest variation in surgical technique concerns the skin incision.
- For decompression of both pronator and anterior interosseous syndromes, extensile exposures using a modification of Henry’s approach allows for safe and thorough exposure of the median nerve and decompression of all sites of potential compression.
  - This incision sometimes is associated with unsightly scarring and injuries to the cutaneous nerves.
  - Lesser incisions have been described, therefore; these include a lazy S-shape incision in the proximal volar forearm, as well as two longitudinal, oblique, and transverse incisions.
  - Limited incisions require significant retraction to ensure decompression both proximally and distally.
  - The surgeon’s experience and comfort level may be the determining factors in deciding on the type of incision.

**EXTENSILE EXPOSURE**

- The incision is made on the medial aspect of the distal arm proximal to the elbow flexion crease (TECH FIG 1A). It is brought across the elbow flexion crease and extended distally for approximately 10 cm.
- Cutaneous nerve branches, including branches of the lateral brachial and medial antebrachial cutaneous nerves, are identified and atraumatically mobilized.
- The median nerve is identified proximal to the elbow flexion crease and then is traced distally, releasing the lacertus fibrosus (TECH FIG 1B).
  - The existence of a ligament of Struthers and supracondylar process can then be ascertained.
- Motor branches of the median nerve to the muscles originating from the medial epicondyle must be protected throughout the operation. These include the palmaris longus; the flexor carpi radialis; and the flexor digitorum superficialis as well as the pronator teres (TECH FIG 1C).
  - It will be necessary to ligate some vessels, but it will be possible to retract most of them.
  - The radial artery lies radial to the nerve and must be protected throughout the procedure.
  - The median nerve will be adherent to the pronator teres. Retracting the proximal portion of the pronator muscle mass identifies the median nerve and the pronator teres tendon (TECH FIG 1D).
  - The larger, superficial pronator head is identified.
  - It sometimes is possible to retract the entire muscle mass and follow the median nerve into the superficialis arcade. Frequently, however, it is necessary to release the tendinous portion of the pronator teres (TECH FIG 1E).
  - Considerable variation exists within the pronator teres.
  - The median nerve can either pass between the superficial and deep pronator heads or, less commonly, pass underneath both heads.
Up to 20% of the time the deep head is absent.

In the most uncommon variation, the median nerve pierces the humeral head.

It is critical for all tendinous portions of the pronator teres potentially compressing the nerve to be released in the procedure.

If scarring of the pronator teres is present as a result of trauma, a Z-lengthening of the pronator teres tendon is advisable.

This will improve exposure by allowing the humeral head to be reflected in an ulnar direction, exposing the AIN, the median nerve, and the flexor digitorum superficialis arcade (see Tech Fig 1E).

The superficialis arcade can then be released, and the median nerve and AIN visualized distally by gentle retraction of the muscle fibers.

Anterior interosseous nerve branches to the flexor pollicis longus and flexor digitorum profundus must be protected.

Use of atraumatic technique with careful hemostasis is important to prevent postoperative scarring, with resultant pain and potential weakness.

If the pronator teres tendon has been released, it should be repaired in a lengthened fashion.

We prefer to use subcutaneous closure and subcuticular suturing.
LIMITED INCISION

■ An oblique or transverse incision can be made in the proximal forearm just distal to the elbow flexion crease (TECH FIG 2A).
■ Retractors are placed proximal and distal to identify the cutaneous nerve fibers.
■ The lacertus fibrosus is released first, and then the median nerve is identified, as previously described.
■ Retractors are placed to allow visualization and palpation of the median nerve proximally, to permit identification of proximal lesions such as a ligament of Struthers (TECH FIG 2B).
■ Distally, the pronator teres is identified and the muscle and tendon mobilized.
■ If required, the superficial or deep tendons (or both) are released.
■ Fascial impinging structures are identified and released as needed.
■ The superficialis arcade is identified and released, protecting the median nerve and AIN.

PEARLS AND PITFALLS

Anatomy

■ Tendinous portions of the pronator teres and the fibrous portions of the arcade of the flexor digitorum superficialis are the most common causes of compression.
■ Motor branches that go from the median nerve to the muscles originating from the medial epicondyle branch from the ulnar side of the nerve.
■ The AIN originates from the radial side of the median nerve and under the pronator teres.
■ Considerable variation occurs within the pronator teres. Tendinous portions of the pronator impinging on the median nerve should be released, with preservation of the muscle fibers when possible.
■ The humeral or superficial head of the pronator teres is the largest portion of the muscle. The ulnar head or deep head is far smaller, sometimes absent, and most commonly is deep to the median nerve. Both heads, however, have tendinous insertion sites, which may be sources of impingement. In addition, fascial connections between the heads may be present, impinging on the median nerve.

Surgical technique

■ The fibrous portion of the superficialis arcade can be released with preservation of the muscle.
■ Palpation and visualization proximally and distally can be obtained by appropriate retraction.
■ Extensile exposures result in easier surgery but at the expense of potential unsightly scarring and dysesthesia from cutaneous nerve injury.
■ Judicious release of the pronator teres limits the postoperative morbidity and decreases the recovery time.

Relation to carpal tunnel syndrome

■ Patients often may have both carpal tunnel syndrome and a more proximal compression, resulting in the so-called double crush phenomenon.
■ Some authors have implied that failed carpal tunnel syndrome is due to a misdiagnosis in which the more proximal compression of the median nerve in the forearm was not identified.
■ In cases, however, where electrodiagnostic studies clearly show carpal tunnel syndrome even when proximal forearm symptoms are present, it is wise to merely decompress the carpal canal, because the carpal tunnel procedure has a more predictable outcome with less morbidity than proximal forearm median nerve decompression.
POSTOPERATIVE CARE

- Splinting or casting is avoided.
- Early elbow range of motion is encouraged.
- If the pronator tendon has been released, lifting and forearm rotation are restricted for 4 weeks.

OUTCOMES

- Outcome following surgical treatment of proximal forearm median nerve compression has been inconsistent compared to the more uniformly good outcomes associated with carpal tunnel release.
- Many, if not most, patients continue to be at least somewhat symptomatic after surgical decompression.
  - This may reflect persistent compression due to inadequate release or scarring from the surgery itself.
  - It is more likely, however, that it reflects the difficulty in making the diagnosis due to the lack of objective criteria.
- Few studies have evaluated outcome following median nerve decompression in the forearm. Most such studies report results of decompression for pronator syndrome.
- Olehnik et al\(^4\) and Hartz et al\(^2\) both reported results for decompression of pronator syndrome.
- Olehnik et al\(^4\) showed surgery to be of benefit in 30 of 37 extremities, but 9 of 39 were unchanged and 20 had only partial relief.
  - Hartz et al\(^2\) showed 28 good or excellent results in 36 operations, but a majority of patients still had symptoms.

COMPLICATIONS

- Persistent symptoms due to incorrect diagnosis
- Damage to cutaneous nerve branches with subsequent dysesthesias
- Damage to or scarring of motor branches of median nerve or interosseous nerve
- Scarring of pronator teres and forearm musculature

REFERENCES

DEFINITION
- The site of compression must be identified to determine the appropriate treatment for symptoms of ulnar nerve dysfunction. Guyon’s canal at the wrist is the second most common site of ulnar nerve entrapment.
- Symptoms may be purely motor, purely sensory, or mixed, depending on the site and cause of compression.

ANATOMY
- In the distal half of the forearm, the ulnar nerve is joined on its lateral side by the ulnar artery. Proximal to the wrist, the nerve gives off a large dorsal sensory branch, which supplies sensation to the dorsum of the wrist and the ulnar side of the hand. The ulnar nerve continues into the hand through Guyon’s canal.
- Guyon’s canal is a triangular tunnel at the base of the ulnar side of the palm. It is 4 cm in length, extending from the proximal edge of the palmar carpal ligament to the fibrous edge of the hypothenar muscles. The space functions as a physiologic anastomosis with discrete anatomic landmarks (FIG 1A).
- Both the ulnar nerve and artery pass through the canal to enter the hand.
- The dorsal cutaneous branch of the ulnar nerve usually branches before the nerve enters Guyon’s canal.
- It is bordered laterally by the hook of the hamate and the transverse carpal ligament. The medial wall is formed by the pisiform and the attachments of the pisohamate ligament.
- Dividing the tunnel into three zones helps in correlating the clinical symptoms with the specific pathologic cause4,13 (FIG 1B).
- Zone 1, about 3 cm in length, is the area proximal to the bifurcation of the ulnar nerve into motor and sensory branches. Compression in zone 1 results in combined motor and sensory loss. It is most commonly caused by a fracture of the hook of the hamate or a ganglion cyst.
- Zones 2 and 3 are located next to each other, from the point where the ulnar nerve divides into a superficial or sensory branch and a deep motor branch, to the region just beyond the fibrous arch of the hypothenar muscles.
- Zone 2 encompasses the motor branch of the nerve, located in the dorsoradial portion of the tunnel. The deep motor branch, along with the deep branch of the ulnar artery, passes between the abductor digiti quinti and the flexor digiti quinti brevis, perforating the opponens digiti quinti. The motor branch then follows the deep volar arch across the palm to innervate the interossei.
- The nerve supplies the three intrinsic muscles of the small finger, the third and fourth lumbricales, the volar and dorsal interossei, the adductor pollicis, and the deep head of the flexor pollicis brevis.
- Compression in this area causes pure motor loss to all of the ulnar-innervated muscles in the hand. Ganglions from the pisotriquetral joint and fractures of the hook of the hamate are the most common etiologic factors (FIG 1C). Due to the nerve’s proximity to the hamate, it is unfortunately easy to damage the nerve while excising the hook of the hamate.
- Zone 3, located ulnar to zone 2, encompasses the superficial or sensory branch of the bifurcated ulnar nerve. Compression here causes sensory loss to the hypothenar eminence, the small finger, and part of the ring finger, but does not usually cause motor deficits. Common causes are aneurysm of the ulnar artery, thrombosis, and synovial inflammation.
- The superficial branch of the ulnar nerve in Guyon’s canal supplies the palmaris brevis and the skin of the hypothenar eminence and forms the digital nerves to the small and ulnar side of the ring finger.
- Two specific nerve anomalies can confuse the diagnosis.
- Martin-Gruber anastomosis in the forearm: fibers that supply the intrinsic muscles are carried in the median nerve to the middle of the forearm, where they leave the median nerve to join the ulnar nerve. Functioning intrinsic muscles can be observed when the ulnar nerve is injured proximal to this anastomosis.
- Riche-Cannieu anastomosis: the median and ulnar nerves are connected in the palm. Even with an injury at the wrist, some intrinsic function remains.

PATHOGENESIS
- Causative factors of compression or injury of the ulnar nerve in Guyon’s canal include repeated blunt trauma from power tools and gripping or hammering with the palm of the hand, which may result in thrombosis or aneurysm of the ulnar artery compressing the nerve (hypothenar hammer syndrome)2,6,10 (FIG 2A,B, Table 1). Direct pressure on the ulnar nerve may occur during activities such as cycling.
- Fractures of the hook of the hamate can impinge on the nerve.
- Idiopathic compression may occur secondary to thickening of the proximal fibrous ligament at the entrance to the canal.
- Compression also may occur as a result of swelling after distal radius fracture.
- Compression of the ulnar nerve at Guyon’s canal also has been shown to occur in conjunction with carpal tunnel syndrome. It typically resolves after surgical decompression of the carpal canal.5,16
- Other etiologies include tumors, such as ganglia or lipomas (FIG 2C,D), anomalous muscle bellies,8,15 or hypertrophy of the palmaris brevis.
- Ganglia and other soft-tissue masses are responsible for 32% to 48% of cases of ulnar tunnel syndrome. Another 16% of cases are due to muscle anomalies.12
- Synovitis secondary to rheumatoid arthritis may encroach upon the canal and the nerve.
FIG 1 • A. Anatomic landmarks of the distal ulnar tunnel (Guyon’s canal). **Zone 1**: Ulnar nerve in the region proximal to the bifurcation. **Zone 2**: Ulnar nerve motor segment, following bifurcation. **Zone 3**: Ulnar nerve sensory segment, distal to the bifurcation. B. Location of the three zones. **Zone 1** is proximal to the bifurcation; **zone 2** encompasses the motor branch; **zone 3** is the region surrounding the sensory branch. C. The proximity of the motor branch of the ulnar nerve to the hook of the hamate as seen during excision of the hook.

FIG 2 • A. Ulnar artery thrombosis. B. Resected thrombosed segment. C. Hypothenar mass as a cause of compression of the ulnar nerve at the wrist. D. Lipoma causing compression of the nerve.
A careful clinical history is imperative, noting the time of occurrence of symptoms. Determine whether symptoms are transient or continuous. Determine whether symptoms are related to work, sleep, or recreation. Elicit duration of symptoms and possible relation to trauma.

Table 1 Causes of Compression or Injury of the Ulnar Nerve in Guyon's Canal

<table>
<thead>
<tr>
<th>Causes of Compression or Injury of the Ulnar Nerve in Guyon’s Canal</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ganglia</td>
</tr>
<tr>
<td>• Soft tissue masses</td>
</tr>
<tr>
<td>• Abnormal muscle bellies</td>
</tr>
<tr>
<td>• Hook of hamate fracture</td>
</tr>
<tr>
<td>• Distal radial fracture</td>
</tr>
<tr>
<td>• Thickening of proximal fibrous hypothenar arch</td>
</tr>
<tr>
<td>• Hypertrophic synovium</td>
</tr>
<tr>
<td>• Iatrogenic (after opponensplasty)</td>
</tr>
<tr>
<td>• Physiology</td>
</tr>
<tr>
<td>• Inflammatory conditions</td>
</tr>
<tr>
<td>• Tenosynovitis</td>
</tr>
<tr>
<td>• Rheumatoid arthritis</td>
</tr>
<tr>
<td>• Edema secondary to burns</td>
</tr>
<tr>
<td>• Gout</td>
</tr>
<tr>
<td>• Coexistent carpal tunnel syndrome</td>
</tr>
<tr>
<td>• Vascular conditions</td>
</tr>
<tr>
<td>• Ulnar artery thrombosis</td>
</tr>
<tr>
<td>• Ulnar artery pseudoaneurysm</td>
</tr>
<tr>
<td>• Neuropathic conditions</td>
</tr>
<tr>
<td>• Diabetes</td>
</tr>
<tr>
<td>• Alcoholism</td>
</tr>
<tr>
<td>• Proximal lesion of ulnar nerve (double-crush syndrome)</td>
</tr>
<tr>
<td>• Occupation-related</td>
</tr>
<tr>
<td>• Vibration exposure</td>
</tr>
<tr>
<td>• Repetitive blunt trauma</td>
</tr>
<tr>
<td>• Direct pressure on ulnar nerve with wrist extended</td>
</tr>
<tr>
<td>• Typing</td>
</tr>
<tr>
<td>• Cycling</td>
</tr>
</tbody>
</table>

Metabolic or infectious diseases such as diabetes, thyroid disease, or leprosy may also mimic the symptoms of nerve compression.

Iatrogenic causes must also be recognized, such as compression by tendon or muscle transfer (Huber opponensplasty).11

NATURAL HISTORY

Untreated compression may result in permanent dysfunction, weakness, and numbness.

PATIENT HISTORY AND PHYSICAL FINDINGS

Clinical History

Presenting symptoms can vary from mild, transient paresthesias in the ring and small fingers to clawing of these digits and severe intrinsic muscle atrophy.

The patient may report severe pain at the elbow or wrist with radiation into the hand or up into the shoulder and neck.

Patients may report difficulty or clumsiness when opening jars or turning doorknobs.

Early fatigue or weakness may be noticed if work requires repetitive hand motions.

Depending on the climate and work conditions, cold intolerance in the ring and small fingers may be present.7

A careful clinical history is imperative, noting the time of occurrence of symptoms. Determine whether symptoms are transient or continuous. Determine whether symptoms are related to work, sleep, or recreation. Elicit duration of symptoms and possible relation to trauma.

Physical Examination7,17

It is important to determine the level of pathology of the ulnar nerve, because compression commonly occurs at four points: the cervical spine, the thoracic outlet, the elbow (cubital tunnel syndrome), or the wrist (Guyon’s canal).

Begin the clinical examination at the neck and shoulder and move down the affected extremity to the elbow.

Pain on neck movement mimicking the patient’s symptoms could indicate cervical disc disease.

Pain on palpation of the plexus or with shoulder motion could indicate a pathologic condition in the brachial plexus or lung. Results of provocative maneuvers for thoracic outlet syndrome should be assessed.

Masses on the medial side of the arm could indicate a soft tissue tumor or hemorrhage compressing the nerve.

At the elbow, note any deformity, palpate the nerve, and determine whether abnormal mobility is present.

The course of the nerve is palpated in the forearm all the way to the wrist.

A positive Tinel or Phalen’s sign is often found at the wrist over the ulnar nerve.

Tenderness over the hook of the hamate is particularly important.

Sensory function is assessed.

Semmes-Weinstein monofilament testing may be abnormal, but often is normal early in the course of the compression.

Two-point discrimination of the ring and small fingers usually becomes abnormal only late in the course of the disease.

To help differentiate cubital tunnel syndrome from compression of the ulnar nerve at the wrist, assess flexor carpi ulnaris and flexor digitorum profundus strength.

Intrinsic muscle function is tested by asking the patient to cross the long finger over the index finger (ie, crossed finger test).

Only two muscles can be tested accurately in the hand—the abductor digiti quinti and the first dorsal interosseous. The tendons or bellies of these muscles can be palpated or visualized.

Weakness of thumb pinch may be elicited by the Froment sign. Froment’s sign is ruled positive if the person must flex the thumb interphalangeal joint to maintain grasp.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Radiographs of the elbow and wrist are mandatory in ulnar nerve compression, because entrapment of the ulnar nerve may occur at more than one level.

Radiographs of the hand and wrist should include carpal tunnel views as well as standard anteroposterior (AP), lateral, and oblique views. Radiographs of the wrist may reveal fractures of the hook of the hamate, dislocations of the carpal bones, or, less commonly, soft tissue masses and calcifications.

Radiographs of the elbow may reveal abnormal anatomy, such as a valgus deformity, bone spurs or bone fragments, a shallow olecranon groove, osteochondromas, or destructive lesions (eg, tumors, infections, abnormal calcifications).

Radiographs of the neck should be obtained if cervical disc disease is suspected and to rule out cervical ribs.

Obtain radiographs of the chest if a Pancoast tumor or tuberculosis is suspected.
MRI is not usually necessary unless further delineation of soft tissue masses such as lipomas or ganglions or visualization of fractures, aneurysms, congenital abnormality, or other abnormalities in the nerve is required. MRI also may detect structural abnormalities along the course of the ulnar nerve accounting for compression (eg, fibrous bands).

Ultrasonography may be used to detect cysts or masses in Guyon’s canal and to assess ulnar nerve diameter at the elbow.

Electromyography (EMG) and nerve conduction studies are helpful to confirm the specific area(s) of entrapment as well as document the extent of the pathology.

Motor and sensory conduction velocities are more useful in a recent entrapment, whereas conduction velocities and EMG are useful in chronic neuropathies (EMG shows axonal degeneration).

Conduction velocity short-segment stimulation (also known as the inching technique) can increase the sensitivity of this method and can improve localization by helping the examiner determine exactly where a blockage is occurring.

EMG evaluation of motor unit morphology and recruitment patterns ascertain ongoing loss of muscle fibers via detection of abnormal spontaneous activity (eg, fibrillation potentials and fasciculations). It also checks the integrity of the muscle membrane to expand differential diagnosis (eg, myotonia, paramyotonia, periodic paralysis) as manifested by increased insertional activity such as complex repetitive discharges, myokymia, and (para)myotonic discharges.

DIFFERENTIAL DIAGNOSIS
- Cervical disc disease
- Brachial plexus abnormalities, thoracic outlet syndrome, Pancoast tumor
- Elbow abnormalities, epicondylitis
- Infections, tumors, diabetes mellitus, hypothyroidism, rheumatoid diseases, alcoholism
- Wrist fractures
- Ulnar artery aneurysms or thrombosis at the wrist

NONOPERATIVE MANAGEMENT
- Conservative treatment of ulnar nerve compression is most successful when paresthesias are transient. Patient education and insight are important.

SURGICAL MANAGEMENT
- Surgical intervention is indicated if paresthesia increases despite adequate conservative treatment combined with abnormal nerve conduction studies or EMGs, and at the first sign of motor changes.

Prospective Planning
- The diagnosis should be confirmed with EMG and nerve conduction velocity or imaging studies (eg, MRI) before planned surgery.

Positioning
- Patients are operated on in the supine position with the arm extended on an armboard.
- A tourniquet is placed above the elbow and inflated to 250 to 265 mm Hg before the incision is made.

Approach
- Operative treatment is aimed at exploring and decompressing the nerve from the distal forearm into the hand throughout all three zones.

ULNAR NERVE EXPLORATION AND DECOMPRESSION OF GUYON’S CANAL

- Palpate and mark the pisiform.
  - The hook of the hamate can be found 1 cm distal and lateral to the pisiform.
  - Make a curvilinear incision beginning distally in the interval between the pisiform and the hook of the hamate. Cross the wrist, extending proximal to the distal wrist flexion crease, along the radial border of the flexor carpi ulnaris (TECH FIG 1A).
  - The wrist should be crossed in a zigzag fashion to prevent longitudinal contracture of the scar.
  - Perform the dissection proximal to distal. Identify the ulnar nerve proximal to the distal wrist flexor retinaculum and follow it distally through Guyon’s canal by reflecting the flexor carpi ulnaris and the pisohamate ligament.
  - The neurovascular bundle is traced distally to the point at which it enters Guyon’s canal beneath the palmar carpal ligament.

- Incise the ligament, palmaris brevis muscle, and fibrous tissue, decompressing the nerve along its entire course through the canal.
  - The branches of the ulnar nerve to the hypothenar muscles and palmaris brevis, as well as the deep branch of the nerve, can be identified and protected with this approach.
  - The incision should not be carried ulnarly over the hypothenar eminence, to avoid injury to the palmar cutaneous branch of the ulnar nerve.
  - The ulnar artery should be examined for areas of thickening or thrombosis, and the ulnar nerve should be examined along its course for intra- or extraneural tumors (eg, schwannoma, neurolemmoma).
  - Further exploration of the floor of the canal should be done to identify masses, ganglions, anomalous muscles,
fibrous bands, osteophytes, or fracture fragments. The motor branch is followed into the interval between the flexor digiti minimi and abductor digiti minimi muscles and through the origin of the opponens digiti minimi (TECH FIG 1B).

PEARLS AND PITFALLS

**Pearls**
- Differentiation between proximal and distal nerve compression:
  - Weakness of the small finger profundus points to ulnar nerve compression at the elbow.
  - Involvement of the dorsal sensory branch indicates compression proximal to Guyon’s canal.
  - Clawing is seen more commonly in distal (wrist) than proximal (elbow) lesions.

**Pitfalls**
- Inadequate preoperative evaluation, resulting in:
  - Inaccurate or incomplete diagnosis
  - Inadequate decompression

POSTOPERATIVE CARE
- Postoperatively, patients are placed into a protective splint for about 2 weeks to prevent excessive wrist flexion and extension.
- Sutures are removed at 10 to 14 days after surgery, at which time gentle active range of motion is started, as well as scar care.
- The wrist splint should be continued for 2 to 3 more weeks to prevent scar thickening, which is common in this area.
  - Silicone or otoform is helpful to prevent hard, firm scars.

OUTCOMES
- Symptoms can be expected to improve in all cases, with fewer than 20% of patients complaining of slight persistent numbness after the surgery.
  - The most common cause of failure of surgery is failure in diagnosis, followed by inadequate decompression of all of the branches of the ulnar nerve.

COMPlications
- Laceration of the ulnar nerve or artery (or both)
- Inadequate decompression
- Injury to the ulnar artery

REFERENCES
DEFINITION
- Cubital tunnel syndrome is a compression neuropathy of the ulnar nerve that occurs at or around the level of the elbow (cubis is Latin for “elbow”).
- Cubital tunnel syndrome is the second most common compression neuropathy of the upper limb requiring treatment, after carpal tunnel syndrome.

ANATOMY
- The ulnar nerve is the terminal branch of the medial cord of the brachial plexus, with contributions from C8 and T1 nerve roots.
- The ulnar nerve traverses the cubital tunnel, a fibro-osseous tunnel at the elbow. The medial epicondyle, the olecranon, the medial collateral ligament of the elbow (which forms the floor), and the fibrous retinaculum extending from the medial epicondyle to the olecranon make up the anatomic landmarks (FIG 1).
- Any of several possible sites of compression of the ulnar nerve around the elbow can result in cubital tunnel syndrome. All of these sites should be considered when selecting the type of surgical decompression.
  - The arcade of Struthers is a controversial site of compression, because it is found in only a minority of patients. If present, it is found approximately 8 cm proximal to the medial epicondyle and consists of a fascial band running from the medial head of the triceps to the intermuscular septum.
  - The medial intermuscular septum is a fascial band from the coracobrachialis to the medial humeral epicondyle, especially thick at its attachment to the epicondyle. The ulnar nerve may rest or scissor over the septum as it crosses from the anterior to the posterior compartment, as it approaches the medial epicondyle, or after an anterior transposition if it is not adequately excised.
- The arcuate ligament of Osborne at the cubital tunnel, which is the fibrous band extending from the medial epicondyle to the olecranon, can cause stenosis of the cubital tunnel and, thus, ulnar nerve compression.
- Distally, the nerve can be compressed as it passes between the two heads of the flexor carpi ulnaris, especially if each muscle head from the medial epicondyle and the olecranon converge close to the elbow joint.
- The presence of an anconeus epitrochlearis (FIG 2), an anomalous thin muscle extending from the triceps or olecranon to the medial epicondyle, also can cause ulnar nerve compression.
- The medial antebrachial cutaneous nerve and the medial brachial cutaneous nerve both emanate directly from the medial cord and are thus not ulnar nerve branches, but they importantly may lie in the surgical field. They are usually found deeper than expected, along the fascia of the triceps, brachialis, and flexor carpi ulnaris.

PATHOGENESIS
- Cubital tunnel syndrome is a compressive neuropathy. Several anatomic factors make the ulnar nerve susceptible to compression at the elbow.
  - The nerve is superficial at the level of the elbow, making it susceptible to minor and major trauma, ranging from mild repetitive contusion to high-energy injury.
  - The bony tunnel and its soft tissue support between the olecranon and medial epicondyle may be shallow, either inherently or traumatically, promoting subluxation, “perching” on the epicondyle, and microtrauma.
  - Elbow flexion increases pressure on the nerve and decreases the volume of the cubital tunnel, resulting in compression of the nerve.
NATURAL HISTORY

- Without operative intervention, about half of mild cases can resolve with activity modification.\(^{10}\)
- No long-term studies have been done of the natural history for severe disease.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Subjective complaints include numbness in the small and ring fingers, often with accompanying burning pain around the medial epicondyle. Symptoms may be worse at night.
- As the disease progresses, patients may complain of weakness or clumsiness of their hands. More advanced disease will demonstrate wasting of the intrinsics and clawing of the ring and small fingers.
- Systemic diseases such as diabetes, amyloidosis, or alcoholism may cause peripheral neuropathy, which can mimic the symptoms of a compressive neuropathy.
- A smoking history is important, not only for impaired vascularity, but because it may point to the rare Pancoast tumor, an apical lung tumor, which causes plexus compression, mimicking the symptoms of cubital tunnel syndrome.
- Elbow trauma can create deformity, causing ulnar nerve compression. Deformities include a cubitus valgus, cubitus varus, or malunion. The elbow trauma can be remote and result in tardy ulnar nerve palsy.
- Look for atrophy of the intrinsic muscles of the hand or a clawed posture of the ring and small fingers. Check for masses around the elbow.
- Palpate the elbow and hand to evaluate for tender masses or other anomalous elbow anatomy.
- Put the elbow through its range of motion and assess whether the ulnar nerve subluxates or perches at the medial epicondyle with elbow flexion (FIG 3A).
- Visible atrophy of the first dorsal interosseous nerve correlates with significant ulnar nerve compression and can indicate significant motor impairment (FIG 3B).
- Perform a sensory examination of the hand, using Semmes-Weinstein monofilaments to obtain threshold measurements. Evaluate sensation on the ulnar dorsum of the hand. If sensation is normal, it suggests the problem may be distal, at the level of Guyon’s canal.
- Clinical tests that can help with diagnosis include the following:
  - Tinel’s test. This test may not be specific, because many normal individuals will have a positive Tinel’s response to percussion.
  - Elbow flexion test. This test is sensitive for cubital tunnel syndrome.
  - Crossed finger test. This test demonstrates weakness of dorsal and palmar interossei.
  - Froment’s sign. A positive Froment’s sign indicates weakness of the adductor pollicis.
  - Wartenberg’s sign (in which the small finger assumes an abducted posture with finger extension). This sign is the result of weakness in the palmar interossei, resulting in unopposed ulnar pull of the extensor digiti quinti.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiographs of the elbow define the bony architecture and its alterations: masses, erosions, arthritis, and previous trauma. An axial view is helpful to evaluate the cubital canal (FIG 4).
- Normal results on electrodiagnostic studies (eg, nerve conduction and electromyography) do not exclude the diagnosis of cubital tunnel syndrome; the syndrome may be present but not severe.
- These tests localize the area of compression if the nerve conduction is measured at short segment intervals.
- Several positive electrodiagnostic findings suggest ulnar compression:
  - Motor conduction across the elbow less than 50 m/sec.\(^{13}\)
  - Focal slowing of nerve velocity across the elbow
Fibrillation potentials or positive waves suggest axonal degeneration, representing a poorer prognosis for complete recovery.

MRI and CT may occasionally be helpful as ancillary imaging studies to define soft tissue aberrancies and localize bone abnormalities such as osteophytes in the cubital tunnel.

DIFFERENTIAL DIAGNOSIS
- Cervical spine disease affecting C8 and T1
- Compression of the inferior aspect of the brachial plexus from shoulder trauma
- Apical lung tumor (Pancoast tumor)
- Thoracic outlet syndrome
- Entrapment of the ulnar nerve at the wrist (Guyon’s canal)

NONOPERATIVE MANAGEMENT
- Activity modification
  - Ulnar nerve protection limiting microtrauma to the nerve through elbow padding and limiting direct pressure on the nerve
  - Minimize prolonged elbow flexion, especially at night, through sleep modifications or splints.
- Splinting
  - Splints to prevent elbow flexion; rigid splints are more effective but are less tolerated by patients. If persistent paresthesias exist, a trial of temporary full-time use is recommended. For milder cases, the splint is worn only at night.
  - Nonoperative treatment requires a trial of several months before determining its success.

SURGICAL MANAGEMENT
- Surgical intervention should be considered for patients presenting with motor involvement or permanent sensory changes, or for those who have failed nonoperative treatment.

Preoperative Planning
- Review the history and physical examination.
- Review plain radiographs for evidence of old trauma, valgus or varus deformity, or loose bodies.
- Electrodagnostic testing and examination may correlate with postoperative results.
- Body habitus, especially the presence of abundant adipose tissue around the elbow, may help the surgeon select a subcutaneous transposition—a procedure with less dissection—rather than a more extensive but protective procedure such as an intramuscular transposition.
- A patient with a visible and symptomatic subluxating nerve may be considered for a medial epicondylectomy.
- Patients with severe disease with muscle wasting are less likely to have complete recovery.

Positioning
- The patient usually is placed in the supine position.
- If a sterile tourniquet is preferred, drape out the forequarter. A standard tourniquet may be used, but position it high in the axilla, with good padding. A proximally placed tourniquet can be challenging to position in the obese arm in either circumstance, because the tourniquet tends to gap distally. It is worth the extra time to position it properly, because adequate hemostasis and visualized proximal dissection are important aspects of ulnar nerve surgery.
- The patient’s shoulder is externally rotated and abducted on an arm table.
- The tourniquet is inflated after exsanguination of the arm.
- Folded towels stabilize and elevate the elbow (FIG 5).
- An obese patient with sleep apnea under peripheral nerve block (most commonly supra- or infraclavicular block) may require slight truncal elevation, which may be vexing for the surgeon.

Approach
- The choice of technique depends on the severity of symptoms, the patient’s body habitus, the presence of elbow anatomic pathology, and the surgeon’s preference.
- The three general types of release are in situ release, in situ release with medial epicondylectomy, and anterior transposition (subcutaneous, intramuscular, and submuscular).
- Table 1 summarizes the surgical options for treating cubital tunnel syndrome.
### Table 1  Techniques for Cubital Tunnel Release

<table>
<thead>
<tr>
<th>Technique</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Contraindications</th>
<th>Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>In situ release</td>
<td>Simplest dissection</td>
<td>Keeps nerve in same tissue bed</td>
<td>Subluxating ulnar nerve</td>
<td>Diabetic patient</td>
</tr>
<tr>
<td></td>
<td>Does not devascularize the nerve with circumferential dissection</td>
<td>Does not address subluxation of the nerve</td>
<td>Abnormal elbow anatomy</td>
<td>Frail patient</td>
</tr>
<tr>
<td></td>
<td>Early mobilization</td>
<td></td>
<td>Abnormal elbow anatomy</td>
<td>Mild disease</td>
</tr>
<tr>
<td>In situ release with medial condylectomy</td>
<td>Preserves vascular supply to the nerve</td>
<td>Keeps nerve in same tissue bed</td>
<td>Not for throwing athletes</td>
<td>Patient with focal compression distal to medial epicondyle</td>
</tr>
<tr>
<td></td>
<td>Early mobilization</td>
<td>Risk of destabilizing the medial elbow by damaging the medial collateral ligament of the elbow</td>
<td></td>
<td>Patients with mild compression to moderate symptoms</td>
</tr>
<tr>
<td>Anterior subcutaneous transfer</td>
<td>Places the nerve in a fresh tissue bed</td>
<td>Nerve is superficial and may be more susceptible to trauma.</td>
<td>Very thin patient</td>
<td>Patient with a poor ulnar nerve bed from tumor, osteophyte, heterotopic bone</td>
</tr>
<tr>
<td>Anterior intermuscular transposition</td>
<td>Tension with elbow range of motion is minimized.</td>
<td>Greater dissection</td>
<td>Throwing athlete</td>
<td>Failed in situ release</td>
</tr>
<tr>
<td>Anterior submuscular transposition</td>
<td>Tension with elbow range of motion is minimized.</td>
<td>Need for longer immobilization</td>
<td></td>
<td>Throwing athlete, patients with severe compression</td>
</tr>
</tbody>
</table>

### IN SITU RELEASE

- Center the longitudinal incision just anterior to the medial epicondyle, making an incision about 8 cm long (TECH FIG 1A).
- Dissect through the fat, down to the level of the medial epicondyle.
- Preserve the branches of the medial brachial and antebrachial cutaneous nerves. Although the course is variable, branches can be found from 6 cm proximal to 6 cm distal to the medial epicondyle and often are at the level of the fascia (TECH FIG 1B,C).
- Identify the ulnar nerve and dissect it free proximally until it pierces the medial intermuscular septum. Release any areas of constriction.
- Take the dissection distal to the level of the medial epicondyle and release the band spanning from the medial epicondyle to the olecranon.
- Preserve the branches of the ulnar nerve: the first is the articular sensory branch, followed by the motor branches to the flexor carpi ulnaris (FCU) and flexor digitorum profundus (FDP). The FCU branches are found proximally with appearance of the muscle.

**TECH FIG 1** A. The standard incision, centered just anterior or posterior to the medial epicondyle. B,C. Preservation of crossing medial brachial and antebrachial nerves. The cutaneous nerves lie deep in the fat, typically on the fascia. Here two branches are encountered before and after fasciotomies to expose the nerve. (Copyright Amy Ladd, MD.)
IN SITU RELEASE WITH MEDIAL EPICONDYLECTOMY

- The incision and dissection are the same as the in situ release.
- Excise a strip of the tough fascial intermuscular septum as it attaches to the medial epicondyle to minimize the nerve “scissoring” over the firm edge.
- Once the nerve is free of all areas of entrapment, a longitudinal incision is made slightly anterior to the medial epicondyle with a knife or electrocautery, reflecting the periosteum to reveal the bony prominence of the epicondyle. Carefully protect the ulnar nerve; gentle retraction with a saline-lubricated ¼-inch Penrose drain on a short hemostat is sufficient.
- Expose the medial epicondyle subperiosteally.
- Remove the prominence of the epicondyle, which is most acute in its posterior position, removing 2 to 3 mm of prominence and 6 to 8 mm in length. Use a small, sharp osteotome and smooth with a file while protecting the nerve (TECH FIG 2A).
- Place bone wax over the raw bone. This minimizes postoperative hematoma.
- The periosteum is closed with buried sutures, either braided absorbable or nonabsorbable, minimizing contact with the nerve.
- Check that the nerve glides, rather than perches, when the elbow is flexed and extended before closure of the skin (TECH FIG 2B).
- Because of potential bony bleeding, a drain is recommended.
- Apply a posterior plaster splint for 10 to 14 days, with protected mobilization thereafter.

ANTERIOR SUBCUTANEOUS TRANSFER

- The incision and dissection are the same as for the in situ release, except that the incision may have to be slightly longer.
- Release the nerve at every potential level of entrapment.
- Range the elbow and check for smooth ulnar nerve excursion. If perching (snapping) over the medial epicondyle occurs, consider medial epicondylectomy. This is often a preclinical determination.
- Close the soft tissues using the surgeon’s preferred technique.
- Typically, no drain is placed.
- Place the arm in a bulky supportive dressing or a posterior plaster elbow splint with flexion of about 60 degrees. Remove the splint according to wound care and the surgeon’s mobilization preference.

TECH FIG 2 • Medial epicondylectomy. A. The medial epicondyle is exposed, and the most prominent aspect is removed. We recommend removal of the most prominent and inferior portion, 2 to 3 mm in depth, to avoid disruption of the medial collateral ligament. B. Once the epicondylectomy is performed and the fascia closed, the elbow is flexed to visualize smooth movement of the nerve. The nerve no longer perches on the medial epicondyle. (Copyright Amy Ladd, MD.)

Circumferentially dissect the nerve to allow it to be moved anterior to the medial epicondyle. Free all posterior attachments to allow for maximal anterior excursion.
- Excise the intermuscular septum from the crossover of the ulnar nerve, anterior to posterior in the proximal dissection, all the way to its tough attachment at the medial epicondyle.
- Preserve the longitudinal vasculature accompanying the nerve to prevent devascularization of the nerve. Use caution around the medial epicondyle and the most fibrous part of the intermuscular septum, where lies an external but vulnerable large venous leash.
- Develop the interval between the skin and the fascia overlying the flexor pronator muscle mass anterior to the medial epicondyle, about 4 cm.
- Transpose the nerve to lie anterior to the medial epicondyle (TECH FIG 3A).
- The nerve should lie in its new position without any tension or areas of compression. An intraneural dissection to release the motor branches to the FCU may be required proximally.
- To prevent the nerve from subluxating, a 1-cm fasciodelmal sling is constructed from the fascia overlying the flexor pronator mass (ie, the FCU, FCR, and the pronator teres) (TECH FIG 3B). This flap is sutured to the skin. This flap prevents the nerve from sliding back to its old position.
- Care must be taken to ensure that this flap does not become a new area of compression.
- No drain is required.
- Apply a posterior plaster splint for 10 to 14 days, with protected mobilization.
- The nerve is fully released, as described for the subcutaneous transposition.
- The interval between the skin and the fascia is developed anterior to the medial epicondyle, to about 4 cm.
- Transpose the nerve so that its rests along the flexor pronator mass (ie, FCU, FCR, and the pronator teres).
- A trough slightly bigger than the nerve is carved out of the muscles along this anterior course (TECH FIG 4). Release any fascial bands found within the muscle substance.
  - Flex the elbow and place the nerve in the trough.
  - Suture fascia over the nerve, creating a tunnel.
  - Range the elbow to ensure that there is no kinking or tethering of the transposed nerve.
  - The arm is immobilized with a pronated forearm in an elbow splint for 2 to 3 weeks at 45 to 60 degrees of flexion with progressive protected mobilization.
- The nerve is fully released as described with the preceding procedures, and the skin flap is developed similarly to the intramuscular procedure.
- Divide the flexor pronator mass about 1 cm distal to its insertion on the medial epicondyle, either as a straight incision or in a V-Y fashion (TECH FIG 5A).
Chapter 70  SURGICAL TREATMENT OF CUBITAL TUNNEL SYNDROME

TECHNIQUES

TECH FIG 5  • Submuscular transposition. The flexor pronator mass is incised (A), and the nerve is passed deep to the flexor pronator muscle mass (B). Sutures are in place to repair the muscle origin following use of a simple straight incision. (A: Copyright Amy Ladd, MD. B: Courtesy of Thomas R. Hunt, III, MD.)

PEARLS AND PITFALLS

Dissection

- Avoid cutting the medial brachial and antebrachial nerve. Damage to this nerve is the most common cause of pain after cubital tunnel release.8,14
- Make an adequate proximal dissection: follow the nerve to the crossover of the anterior-to-posterior compartment, where a thin or thick fascial band is present at the septum, or rarely, the arcade of Struthers. Make certain the tourniquet is high enough to reach this spot, usually 5 to 8 cm above the epicondyle.
- Make an adequate distal dissection: follow the nerve several centimeters into the muscle bellies to ensure a full release, including the fascia of the FCU encasing its branches.

Transposition

- Preserve the longitudinal blood supply to the nerve.
- If transposing the nerve, ensure that a new point of compression is not created. Compression may be created at the following sites: proximally at the crossover from anterior to posterior; the intermuscular septum just proximal to the medial epicondyle; the flexor pronator mass if submuscular or intramuscular transposition is performed; and the entrance to the FCU muscle bellies.

POSTOPERATIVE CARE

- Postoperative care instructions are given individually with the discussion of each technique. In general, the more extensive the dissection, the more protected postoperative splinting and mobilization is required. Strengthening may begin a few weeks after an in situ decompression, for example, and 6 to 8 weeks following a submuscular transposition.

OUTCOMES

- Overall, all procedures have a success rate of about 90% for mild cases. The rate of total relief decreases as severity of disease increases.5
- Postoperative outcomes are proportional to disease severity: ic, severe disease is less likely to achieve full recovery.3
- Recent studies suggest that outcomes are similar for the different procedure types.1,4,10

COMPLICATIONS

- Pain at the elbow
- Decreased sensation around the scar
- Incomplete symptom relief
- Painful neuroma of cutaneous nerves
- Symptomatic subluxating nerve
- Injury to motor branches to the FCU

REFERENCES


DEFINITION
- Radial tunnel syndrome was first described by Michele and Krueger in 1956 as radial pronator syndrome.
- It was described as a compression neuropathy involving primarily the posterior interosseous nerve (PIN), associated with a predominant symptom of pain.

ANATOMY
- The radial nerve pierces the lateral intermuscular septum 10 to 12 cm above the lateral epicondyle. It travels along the lateral border of the brachialis muscle and is covered laterally and anteriorly by the brachioradialis (BR), extensor carpi radialis longus (ECRL), and extensor carpi radialis brevis (ECRB) muscles (see Fig. 1B, Chap. 76).
- It divides into the PIN and the superficial radial sensory nerve 3 to 5 cm distal to the lateral epicondyle.
- The PIN then enters the “radial tunnel.”
  - The floor of the tunnel begins at the anterior capsule of the radiocapitellar joint and continues as the deep head of the supinator.
  - The roof begins as inconstant fibrous bands between the brachialis and BR, and then continues as the medial border of the ECRB. Distally, the roof of the tunnel consists of the superficial or oblique head of the supinator.
  - The radial tunnel ends with the distal edge of the supinator.
- Proximal to the supinator, the nerve is crossed superficially by branches of the radial recurrent artery known as the vascular leash of Henry.

PATHOGENESIS
- Roles and Maudsley described the concept of radial nerve compression in 1972, suggesting that it could result in a wide spectrum of symptoms. Radial tunnel syndrome, defined as localized pain over the mobile wad, is thought to be a result of compression of the PIN.
- If the primary complaint is weakness, the symptom complex is referred to as posterior interosseous syndrome, even though the pathogenesis in both conditions is thought to be due to a compression neuropathy.
- The compression may rarely be due to space-occupying lesions such as ganglion, neoplasm, or florid synovitis of the proximal radioulnar, radiocapitellar, or ulnotrochlear joints.
- The sites of compression of the PIN most often cited are the fibrous proximal border of the supinator (arcade of Frohse), the medial border of the ECRB, fibrous bands passing volar to the radial head, and the vascular leash of Henry.
- The arcade of Frohse and the medial border of the ECRB are thought to be the most common sites of compression.
- Werner recorded pressures from 40–50 mm Hg exerted on the nerve with passive stretch of the supinator muscle. Pressures exceeding 250 mm of Hg have been recorded on the nerve with stimulated tetanic contraction of the supinator muscle. Ischemia of the nerve has been demonstrated at 60–80 mm of Hg, and blockade of axonal transport at 50 mm of Hg.
- The documented changes in pressure due to positioning of the forearm in conjunction with the observation that symptoms often are associated with repetitive pronation and supination have led to the theory that the clinical syndrome may be provoked by dynamic and intermittent compression on the radial nerve.
- Although the PIN is considered a motor nerve, it has been well documented that afferent sensory fibers run within the nerve. The muscles innervated by the PIN contain nerve endings corresponding to group IIA fibers. These fibers are commonly thought to be responsible for the pain from muscle cramps, and, therefore, could likely be mediators of pain in radial tunnel syndrome.
- Because of the common association with (or difficulty in distinguishing it from) lateral epicondylitis, some authors have suggested that referred pain from lateral epicondylitis or intra-articular pathology may contribute to radial tunnel syndrome.
- In 1984, Heyse-Moore suggested that radial tunnel syndrome may be an analogue of a musculotendinous lesion of the common extensor tendon, causing lateral epicondylitis in the supinator.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The diagnosis of radial tunnel syndrome is based on clinical findings. Historically, it was described as a cause of treatment-resistant lateral epicondylitis. The two disorders may have similar and overlapping symptoms.
- Symptoms can be variable, but the classic history described by the patient with radial tunnel syndrome is of pain over the lateral forearm musculature distal to the lateral epicondyle (along the course of the radial nerve) that is exacerbated by activity.
- The pain is often described as a constant “aching” that is aggravated by or prevents activities.
- Pain is most pronounced with active supination, and less severe with activities involving extension of the fingers.
- Lesser symptoms of weakness of the finger and wrist extensors also may be present, as may dysesthesias over the distal lateral forearm and wrist.
- Other symptoms include writer’s cramp, paresthesias, night cramps, and radiation of pain proximally and distally in the arm and forearm. Some patients complain of a “popping” sensation over the elbow during pronation.
- The most specific finding on physical examination is pain with digital pressure placed over the course of the radial nerve at the radial neck, or the proximal edge of the supinator.
- Two other pathognomonic signs (described by Lister et al) are pain in the lateral forearm with resisted extension of the middle finger, and pain with resisted supination.
Posterior interosseous nerve palsy

Differential Diagnosis

- Electromyographic or nerve conduction studies. Symptoms of radial tunnel syndrome and the findings of either conduction velocity have shown no consistent relation between the EMG and causing increased pressure on the PIN.
- Injection of lidocaine into the radial tunnel has been described as a diagnostic tool for radial tunnel syndrome.
- MRI can be helpful in identifying possible cervical degenerative disc disease of the cervical spine.
- Multiple studies using electromyography (EMG) and nerve conduction velocity have shown no consistent relation between symptoms of radial tunnel syndrome and the findings of either electromyographic or nerve conduction studies.
- In 1980, Rosen and Werner demonstrated that static motor nerve conduction at rest was not significantly different between symptomatic patients and a nonsymptomatic control group. They did find, however, that active supination of the forearm produced an increase in the conduction time of the PIN across the supinator muscle more often in patients with radial tunnel than in control subjects.
- Verhaar and Spaans tested patients while holding the forearm in active supination and found that 14 of 16 patients with radial tunnel syndrome had no abnormal latency on nerve conduction studies or abnormality of the EMG.
- Kupfer et al found that differential latency (ie, different latency measurements recorded in the same nerve in different positions) may be more significant in identifying “pathologic” latency than comparing a measured latency to a standard “normal “ latency measurement. Differential latencies were higher in patients with radial tunnel syndrome than in the control group and improved after surgical decompression, correlating with clinical results.

Imaging and Other Diagnostic Studies

- If the patient’s clinical examination is suggestive of elbow arthritis or cervical radiculopathy, radiographs of the elbow and a cervical spine series may be helpful in elucidating associated pathology that may contribute to a neuropathy of the radial nerve caused by an anterior osteophyte of the elbow or degenerative disc disease of the cervical spine.
- MRI can be helpful in identifying possible cervical degenerative disc disease or elbow ganglia.
- Injection of lidocaine into the radial tunnel has been described as a diagnostic tool for radial tunnel syndrome.
- Because it is difficult to reliably contain the anesthetic within the radial tunnel, the main criticism of this technique is the lack of specificity in differentiating pathology of the radial nerve from other sources of pain.
- Multiple studies using electromyography (EMG) and nerve conduction velocity have shown no consistent relation between symptoms of radial tunnel syndrome and the findings of either electromyographic or nerve conduction studies.
- In 1980, Rosen and Werner demonstrated that static motor nerve conduction at rest was not significantly different between symptomatic patients and a nonsymptomatic control group. They did find, however, that active supination of the forearm produced an increase in the conduction time of the PIN across the supinator muscle more often in patients with radial tunnel than in control subjects.
- Verhaar and Spaans tested patients while holding the forearm in active supination and found that 14 of 16 patients with radial tunnel syndrome had no abnormal latency on nerve conduction studies or abnormality of the EMG.
- Kupfer et al found that differential latency (ie, different latency measurements recorded in the same nerve in different positions) may be more significant in identifying “pathologic” latency than comparing a measured latency to a standard “normal “ latency measurement. Differential latencies were higher in patients with radial tunnel syndrome than in the control group and improved after surgical decompression, correlating with clinical results.

Differential Diagnosis

- Lateral epicondilitis
- Posterior interosseous nerve palsy
- Cervical radiculopathy C5–6
- Neuritis of the lateral antebrachial cutaneous nerve
- Waardenburg syndrome
- Myofascial pain syndrome

Nonoperative Management

- A course of nonoperative treatment should always be attempted.
- Activity modification may be helpful, particularly in patients whose vocation or avocation involves frequent repetitive supination and pronation of the forearm.
- The patient should attempt stretching exercises of the supinator and the ECRB, with pronation of the forearm and wrist flexion with the elbow in extension. Gentle strengthening exercise also may be helpful in improving symptoms.
- An injection of local anesthetic and corticosteroid in the radial tunnel may provide relief in some patients.

Surgical Management

- Surgical management should be considered in the patient who has failed nonoperative treatment. A 4- to 6-week trial of nonoperative treatment should be sufficient to determine whether there is any improvement.
- There is no consensus as to which anatomic structures should be released at the time of surgery. It is agreed, however, that this is typically a clinical decision. Electrodiagnostic studies have not been shown to locate the area of pathology reliably.
- Most authors recommend releasing the PIN as it passes under the superficial head of the supinator by dividing the fibrous arcade of Frohse and the tendinous border of the ECRB, as needed.
- Lister and others emphasize release of the fibrous bands of the radial tunnel anterior to the radial head.
- Sponseller has reported cases where the PIN is compressed by the distal aspect of the supinator muscle.
- Some surgeons advocate the release of the common extensors as well as structures compressing the PIN to address all potential causes of pain. Ritts et al stated that the pathology of radial tunnel syndrome and that of lateral epicondylitis appear to be interrelated.
- Little literature has been published supporting release of the superficial sensory branch of the radial nerve. It has been associated with neurapraxia and complex regional pain syndrome.
- The surgeon should remain mindful of less common causes of pain over the radial tunnel, including radial nerve compression proximal to the supinator.
- When the diagnosis is not clear on physical examination, and the patient has symptoms and examination findings suggestive of lateral epicondylitis, surgical treatment of lateral epicondylitis can be done concomitantly.

Preoperative Planning

- A tourniquet should be placed on the arm to facilitate visualization. If it is thought that more proximal release or exploration of the radial nerve into the arm may be necessary, a sterile tourniquet is used.

Positioning

- The patient is placed in the supine position, with the arm and forearm rotated as needed to facilitate the preferred approach.
Approach

- The most direct dissection path to the radial nerve may be established by palpating the radial nerve through the mobile wad and rolling the PIN under a thumb with enough force to cause an extension flicker of the digits.
- Multiple surgical approaches are possible. Determination of which structures require decompression may influence the approach chosen.
- Anterior approach
  - Advantages: it can easily be extended proximally to decompress the radial nerve in the arm if indicated. This exposure may be of benefit in cases of compression on the nerve by rarer causes such as elbow synovitis or ganglia.
  - Disadvantages: in muscular patients it can be difficult to retract the BR radially well enough to obtain adequate visualization of the radial tunnel. Distal compression sites often are difficult to release.

- Transbrachioradialis approach
  - Advantage: provides a more direct approach to the radial tunnel, improving exposure
  - Disadvantage: some surgeons find the intramuscular dissection unappealing given the relative paucity of definable landmarks.
- Posterior and posterolateral approaches (the author’s favored approaches)
  - Advantage: dissection between the ECRB and the extensor digitorum communis (EDC), or between the BR and ECRL, allows direct exposure to the entire radial tunnel with relatively less dissection and a bloodless field.
  - Disadvantage: the ECRB–EDC interval is limited in that it does not allow easy extension of the incision to expose the radial nerve more proximally.

POSTERIOR APPROACH AND NERVE DECOMPRESSION (EDC–ERCB INTERVAL)

Exposure

- The forearm is held in pronation. The radial nerve is palpated just posterior to the mobile wad (TECH FIG 1A).
- A 5-cm longitudinal incision is made over the proximal lateral forearm along Thompson’s cardinal line from Lister’s tubercle to the lateral epicondyle (TECH FIG 1B).
- The posterior cutaneous nerve of the forearm is identified and protected (TECH FIG 1C).
- The interval between the EDC and ECRB is located. The overlying fascia is first incised, beginning distally where the structures are better identified. The incision is extended proximally to the lateral epicondyle.
- The EDC and ECRB muscles are separated bluntly, using finger dissection, or with scissors, as required (TECH FIG 1D).
- Opening of this interval will reveal the superficial fascia of the ERCB, to which the fibers of the EDC often are securely attached and from which they must be carefully released.

TECH FIG 1 • A. The points of maximal tenderness help delineate the course of the nerve and isolate areas of compression. B. Standard positioning, use of a sterile tourniquet, and placement of the 5-cm posterior proximal forearm incision. C. The posterior cutaneous nerve of the forearm is consistently seen crossing the proximal incision, superficial to the fascia. It must be protected. D. The fascia between the EDC and ECRB has been divided, and the supinator is exposed.
Releasing the Compression

- The leading edge of the ECRB often is thickened and taut (TECH FIG 2A). This potential site of nerve compression is incised.
  - Release of the origin of the ECRB simultaneously treats coexisting lateral epicondylitis.
  - Further blunt dissection in the EDC–ECRB interval reveals fibers of the superficial head of the supinator distally and fat more proximally over the radial neck (TECH FIG 2B).
  - The PIN will be found within this fat.
  - Gentle dissection of the nerve is performed through this proximal fat as necessary for complete visualization of the nerve.
  - Proximally, the leash of Henry usually is seen running transversely, superficial to the nerve.
    - Typically the vessels are not large or obviously constricting.
    - If any of the vessels of the leash are substantial enough to appear to cause compression, or if they impede full decompression of the supinator, they are separated and coagulated with bipolar cautery.
    - Once the nerve is well visualized proximally, the superficial fascia of the supinator is released in a proximal-to-distal direction to the most distal border of the supinator.
  - A white crescent-shaped band of fibers represents the proximal border of the superficial head of the supinator; this is termed the arcade of Frohse (TECH FIG 2C).
  - This arcade can be observed to tighten over the PIN as the forearm is pronated.
  - These fibers of the superficial head of the supinator are then carefully released. Protect the small motor branches to the ECRB (TECH FIG 2D).
  - This release generally results in significant stretching of the remaining underlying supinator muscle fibers and appears to reduce tension over the nerve.
  - The nerve is inspected and palpated along its entire course for any other sites of compression.
    - During palpation, special attention is paid to the proximal nerve in the interval between the brachialis and BR.
    - A thin fascial layer occasionally is present. This layer is confluent with the fascia of the superficial supinator that extends proximally, causing compression of the nerve. If this is present, it is carefully released.
    - Before completion, visualize and palpate the nerve over its entire course to make sure there are no further sites of compression, especially proximally (TECH FIG 2E).
    - The fascial layer between the ECRB and the EDC is closed with absorbable suture, the skin is closed in the usual manner, and an above-elbow splint is applied with the elbow at 90 degrees and the wrist extended 20 to 30 degrees.
Chapter 71 RADIAL NERVE DECOMPRESSION

POSTEROLATERAL APPROACH AND NERVE DECOMPRESSION (ERCL–BR INTERVAL)

- A 5- to 7-cm incision is made starting at the lateral epicondyle and heading distally along the posterior border of the BR with protection of the sensory nerve branches.
- The fascial interval between the BR and the ECRL is defined.
  - The BR is a deeper red compared with the ECRL due to its thinner overlying fascia.
- The interval is further developed using blunt finger dissection.
  - Difficulty in dissection usually indicates that the muscular interval is not correct.
  - The remainder of the procedure mirrors that detailed for the EDC–ERCB interval.

BRACHIORADIALIS MUSCLE-SPLITTING APPROACH AND NERVE DECOMPRESSION

- A 4- to 6-cm longitudinal incision is made over the proximal, anterolateral surface of the forearm, starting distal to the elbow flexion crease and 3 cm radial to the biceps tendon and extending over the radial head.
  - A 4-cm transverse incision just distal to the radial head also may be used.
- The deep fascia is divided in the line of the skin incision, and the BR is exposed. Its fibers are parted by blunt dissection.
- Immediately deep to this muscle, the vivid white of the superficial branch of the radial nerve is seen. Inspection at the level of the radial head reveals the fat overlying the PIN.
- The transverse branches of the radial recurrent artery and accompanying veins are divided as they pass between the PIN and radial sensory nerve.
- The radial nerve and its branches are now more fully exposed by dividing adhesions and fibrous bands overlying the nerve as well as the proximal fibrous edge of the ECRB.
  - The superficial branch is followed distally anterior to the extensor carpi radialis brevis.
  - The PIN is traced as it disappears beneath the fibrous edge of the superficial proximal border of the supinator, easily distinguished by its prominent oblique striations.
  - This fibrous edge and the muscle are divided longitudinally.
  - The nerve is carefully inspected for untreated sites of compression before closure and splinting.

MODIFIED ANTERIOR APPROACH OF HENRY AND NERVE DECOMPRESSION

- A 5-cm longitudinal incision is made beginning at the antecubital flexion crease and proceeding distally along the medial border of the BR.
  - More proximal and extensile exposure may be obtained by extending the incision obliquely across the elbow flexion crease in the interval between the brachialis and the BR.
- The deep fascia is incised, and the BR is retracted radially. The proximal radial tunnel can be visualized over the capitellum.
  - Any constricting vessels are ligated and divided.
  - The superficial sensory branch of the radial nerve and the PIN are identified.
- The PIN is traced distally.
  - Significant retraction of the BR is required for adequate exposure.
  - The medial border of the ERCB is released to aid in exposure and to eliminate a potential site of compression.
  - The arcade of Frohse is visualized, and the supinator muscle is divided to its distal border.
  - The arm is supinated and pronated to identify constricting structures, and the course of the PIN is carefully inspected.
  - Despite closure and splinting, as detailed previously, the scar often is conspicuous.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Surgical indications</th>
<th>Attempt a course of nonoperative treatment for at least 3 months.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Take care to differentiate radial tunnel syndrome from other pathology using a thorough history and multiple physical examinations.</td>
</tr>
<tr>
<td>Surgical approach</td>
<td>Dictated by inciting pathology, coexistent diagnoses, and surgeon comfort</td>
</tr>
<tr>
<td>Decompression</td>
<td>At the time of release, make sure that the PIN is released from the proximal radiocapitellar joint to the distal border of the supinator.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE
- Patients are splinted for 7 to 10 days.
- Gentle active range of motion exercises are initiated and progressively advanced. Nerve gliding exercises are emphasized.
- Patients are allowed to resume normal activities in a progressive and graded fashion over the next few weeks.

OUTCOMES
- The efficacy of surgical treatment for radial tunnel syndrome is widely variable.
  - This variability in results may be due to heterogeneous patient populations and varying diagnostic criteria.
  - Lister et al, Roles and Maudsley, and Ritts et al all reported high cure rates after release of the PIN.
  - Sotereanos et al reported more modest results (11 of 38 good or excellent), although their population did have a high proportion of worker’s compensation patients.
  - Verhaar and Spaans reported even more modest results (1 of 10 patients had good results; 3 of 10 had fair results). Their diagnostic criterion was limited to tenderness over the radial nerve where it passes under the arcade of Frohse.

COMPLICATIONS
- The incidence of PIN palsy following the procedure is reported to be low.
- Sotereanos et al reported a 31% incidence of paresthesias of the superficial radial nerve.
- Paresthesias of the lateral cutaneous nerve of the arm have also been reported.

REFERENCES
DEFINITION

- **Complete transection** of a peripheral nerve is defined as interruption of all of the axons within the nerve.
- **Primary nerve repair** is the tension-free reapproximation of severed nerve ends performed within a week of injury.
- **Delayed primary repair** is performed up to 3 weeks from injury when local soft tissue injuries do not permit primary wound closure.
- The healing of an injured peripheral nerve is different from the healing of other tissue types.
- Injury is followed by an immediate degeneration, followed by incomplete recovery.
- Irreversible changes in the motor and sensory end-organs make timing of repair critical to achieve useful recovery.

ANATOMY

- The anatomy of the peripheral nerve can be simplified by examining its component parts (FIG 1).
- **Axon.** The basic unit of a nerve is composed of a cell body, dendrites, and longer axons.
  - All axons are surrounded by Schwann cells, which produce the myelin sheath surrounding the axon.
  - Interruptions in the myelin sheath are referred to as **nodes of Ranvier.** Impulse propagation is faster in myelinated axons, because the depolarization potential “jumps” between nodes.
  - Myelinated fibers are between 2 and 22 μm in diameter. The larger the fiber, the faster the conduction speeds.
  - Axonal transport of cytoskeletal elements and neuronal factors is oxygen-dependent. Antegrade transport along the axon occurs at roughly 1 to 4 mm per day. The transport is the rate-limiting step in nerve regeneration.
- **Endoneurium.** Delicate connective tissue that supports and surrounds each axonal fiber and associated Schwann cells
  - Consists of longitudinally arranged collagen fibrils and intrinsic blood vessels
- **Perineurium.** The connective tissue that surrounds groups of axons, creating bundles referred to as **fascicles.** The fascicle is the smallest visible unit of the nerve at surgery.
  - The fascicle is several layers thick and acts as a protective membrane and a barrier to diffusion.
- **Epineurium.** Surrounds groups of fascicles to form the superstructure of a peripheral nerve
  - Forms a sheath about the entire nerve and also supports the fascicular structure by passing between all the fascicles
  - Forms 60% to 85% of the cross-sectional area of a peripheral nerve
  - Composed of longitudinally oriented collagen fibers, fibroblasts, and intrinsic vessels
- **Paraneurium or mesoneurium.** Loose areolar tissue surrounding the epineurium
  - Limited to the outer surface of the nerve
  - Location for the extrinsic vascular supply of the nerve
  - Makes up the gliding apparatus of a peripheral nerve
  - Fascicles have a definite topographic arrangement within a peripheral nerve.
  - Fascicular segregation into motor and sensory components is important when aligning a sectioned nerve before repair.
  - This concept of functional segregation allows for use of part of a donor healthy nerve for nerve transfer with minimal functional deficit.

PATHOGENESIS

- Injuries involving peripheral nerves can be simply classified as tidy or untidy.
- **Tidy wounds** involve sharp transections with minimal to no tissue loss:
  - Sharp lacerations from glass or knife wounds
  - Most iatrogenic nerve injuries
- **Untidy wounds** involve maceration of all tissues in the area:
  - Bony injury may be present.
  - Surrounding soft tissue may have been lost or rendered nonviable and is expected to heal with significant scarring.

NATURAL HISTORY

- Complete transection of a nerve results in retraction of the nerve ends. The nerve will not heal without surgical intervention to approximate the nerve ends.
- Wallerian degeneration occurs in the nerve segment distal to the level of transection.
  - The axon distal to the injury degenerates and does not directly contribute to repair. The axonal and myelin debris are
cleared by macrophages. Schwann cells proliferate, releasing nerve growth factors or neurotrophic factors. The distal stump does produce a complex protein, neurotropic factor, that attracts regenerating axons from the proximal stump. The cell body swells, Nissl granules in the cytoplasm diminish, and its dendritic processes retract. Several cells rupture and die, especially with more proximal nerve injuries (FIG 2).

Regenerating axons sprout from the surviving axons and migrate toward the empty tubules in the degenerate distal stump at a rate of 1 to 3 mm/day.

Proliferating Schwann cells myelinate the newly regenerated axons.

In an unrepaird nerve, the random proliferation of axons from the proximal stump forms a tender mass or neuroma.

PATIENT HISTORY AND PHYSICAL FINDINGS

- History of trauma
  - Penetrating, ballistic, burn, stretch, blunt, fracture, or previous surgery
  - Timing of onset of symptoms: at initial presentation; after procedure, eg, manipulation and casting or internal fixation of a fracture
  - Depth and location of the injury
  - Severity of bleeding-associated blood vessel injury

- Patient reports
  - Paresthesias (pins and needles) or absent sensation (numbness) in fingers
  - Weakness
  - Paralysis due to nerve or associated tendon injury
  - Pain: neurogenic type; can be constant and severe
  - Rarely, a sensation of warmth or anhydrosis

- Physical examination
  - Note the distribution of sensory loss. The area of sensory loss varies with the nerve that is injured (FIG 3).
  - Examine the skin for trophic changes or dry skin. Dry, warm skin implies sympathetic interruption.
  - Perform thumb abduction test to check for paralysis of the abductor pollicis brevis from median nerve injury.
  - Perform the Froment’s sign test. The test is positive if paper is held by flexing the thumb interphalangeal joint (IP), indicating recruitment of the flexor pollicis longus, which implies paralysis of the adductor pollicis from ulnar nerve injury.
  - The thumb IP hyperextension test may indicate paralysis of the extensor pollicis longus due to posterior interosseous palsy.
  - Perform the Tinel sign test. The test is positive if the patient notes a tingling sensation in the sensory distribution of the nerve. Serial progression of Tinel sign distally is useful to monitor axon progression after repair.
  - When performing physical examinations, it is helpful to use motor function grading according to the Medical Research Council system. This grading allows for quantitative measurement of function and allows the physician to chart recovery objectively:
    - M0: no contraction
    - M1: palpable contraction with only a flicker of motion
    - M2: movement of the part with gravity eliminated
    - M3: muscle contraction against gravity
    - M4: ability to contract against moderate resistance
    - M5: normal function

- Sensory grading is also useful in evaluation. Sensory function is evaluated within the anatomic distribution of the nerve in question. Sensation is quantified using two complementary tests—(1) Semmes-Weinstein monofilaments, which measure innervation threshold, and (2) two-point discrimination, which measures innervation density. Vibratory, pain, and temperature sensation should also be evaluated. Semmes-Weinstein filaments demonstrate subtle and early sensory loss and are more useful in evaluation of compressive neuropathy. Two-point discrimination measurements help gauge the severity of nerve injury, with two-point discrimination of less than 12 mm indicating neurapraxic injury and readings greater than 15 mm suggesting complete disruption. Used together, the various sensory tests allow for quantitative measurement of function and allow for the physician to objectively chart recovery:
  - S0: lack of sensation
  - S1: recovery of deep cutaneous pain sensibility within the autonomous area of the nerve
  - S2: return of some degree of superficial cutaneous pain and tactile sensibility
  - S3: Return of function (S2) without evidence of hyper-sensibility
  - S3 plus: return of function (S3) with some return of two-point discrimination
  - S4: normal function

Sensory recovery classification on two-point discrimination alone:

- Normal: < 6 mm
- Fair: 6–10 mm
- Poor: 11–15 mm

FIG 2 • Comparison of a normal neuron cell body (A) with that of a nerve after transection (B). Note cellular swelling, dissolution of Nissl granules in the cytoplasm, and retraction of the dendritic processes.

FIG 3 • Distribution of sensory loss with nerve injury. Yellow, median nerve; blue, ulnar nerve; pink, radial nerve.
IMAGING AND OTHER DIAGNOSTIC STUDIES

- Diagnosis in acute injuries is usually based on history and clinical examination alone without need for additional investigations.
- Plain radiographs are of little use in evaluation of the nerves themselves, but may be helpful in cases of injury from fracture or projectiles.
- CT myelography is useful for evaluation of injuries to the brachial plexus. The formation of a pseudomeningocele is indicative of root avulsion.
- MRI is useful for evaluation of peripheral injury but is not routinely indicated for peripheral nerve injuries.
  - Short tau inversion recovery (STIR) MRI may show enhancement of the nerve near the site of injury or interruption of the nerve trunk on T1- and T2-weighted images.
  - MRI provides visualization of pseudomeningoceles at the spinal cord levels in root avulsion injuries.
- Electrodiagnostic testing
  - Nerve conduction velocity (NCV) and electromyography (EMG) are useful in evaluation of closed nerve injuries, eg, after fracture or multiple nerve injuries such as brachial plexus injury.
  - If stimulation distal to the suspected injury elicits a motor response about 3 days after injury, then the lesion is likely a conduction block. However, muscle action may be present in the case of complete transection for up to 9 days.
  - Fibrillation potentials on EMG appear after 2 to 3 weeks and indicate muscle denervation and a severe grade nerve injury.
  - Recovery is best evaluated with serial examination of compound muscle action potentials. Early recovery of only a few motor units may indicate reinnervation from adjacent intact nerves and should not be used as an indicator of recovery of the repaired nerve.

DIFFERENTIAL DIAGNOSIS

- Muscle or tendon injury in open lacerations
- Parsonage-Turner syndrome (brachial plexus neuritis)
- Peripheral nerve entrapment

NONOPERATIVE MANAGEMENT

- Nonoperative management of a completely transected nerve after an open injury is doomed to failure, because cut ends retract and scar tissue forms in the gap.
- Pending recovery of the nerve, splinting of the paralyzed joint maintains functional position and prevents contractures.

SURGICAL MANAGEMENT

- Nerves that have been completely interrupted require surgical measures to restore continuity.
- All open injuries with neurologic impairment must be explored expeditiously.
- With closed injuries or delayed presentation, consider the overall functional capacity of the injured limb.
- In a largely motor nerve, eg, the radial nerve, tendon transfers may restore function more reliably than nerve repair.

Preoperative Planning

- The cause of the peripheral nerve injury must be identified. The repaired nerve must have a favorable local environment if the repair is to be successful.
- Underlying fractures must be stabilized.
- Adequate soft tissue coverage of the nerve repair must be planned.
- Repair should be delayed when multiple debridements are necessary until the bed for the repaired nerve is optimal and wound can be primarily closed.
- If segmental loss is suspected, as with a crushing injury, the patient must give informed consent for additional options such as conduit repair or nerve grafting.
- Injuries that present late should be evaluated with electrophysiologic studies to look for signs of recovery.
- If intraoperative nerve stimulation is to be used, muscle relaxants should be avoided at induction of general anesthesia.
- If associated muscle or tendon lacerations are present, muscle relaxation facilitates their repair.
- Regional anesthetics such as supraclavicular block provide excellent muscle relaxation, and a supraclavicular catheter will help in administering postoperative analgesia.

Positioning

- The patient is positioned supine, with the arm positioned on a hand table.
- Use of a tourniquet facilitates dissection but will interfere with intraoperative nerve stimulation, because it results in ischemic conduction blocks after 15 minutes.
- Use of intraoperative magnification (eg, loupes) for the dissection and a surgical microscope during nerve repair is essential.
- Microinstrumentation is needed for nerve handling and repair.
- Alcoholic solutions should be avoided for the preparation of open wounds to avoid chemical damage to nerve tissue.

APPROACH

- The area of injury should be exposed both proximally and distally to allow for visualization of the proximal and distal nerve stumps using extensile approaches.
- After all injured structures have been assessed, repair fractures and tendons first to take tension off the nerve repair.
- Mobilize nerve ends for about 1 to 2 cm at either end, avoiding unnecessary stripping of the mesoneurium over long distances.
- Preserve the common sheath of neurovascular bundles to maintain nerve vascularity and minimize tension on nerve repair.
- Nerve end preparation is critical. Crushing is present even after sharp lacerations.
- Under an operating microscope, the nerve end is stabilized over a sterile wooden spatula and a fresh no. 11 blade is used to progressively cut back 2-mm segments of the nerve end until sprouting fascicles are seen (TECH FIG 1).
End-to-end repair should be attempted as long as this can be accomplished with minimal tension on the repair and with minimal mobilization of the nerve.

If a single epineurial stitch of 8-0 suture fails to maintain nerve approximation, tension is excessive. Additional mobilization or alternative options such as conduit repair or nerve grafting must be considered.

Posterior wall repair is completed with three or four simple epineurial sutures, as needed. The long tails are then cut short, and the nerve is examined carefully to ensure that a complete epineurial seal is achieved (TECH FIG 2B).

The distal and proximal joints are placed in minimal flexion. Excessive flexion is to be avoided, because it will result in flexion contractures or tension on healing nerve.

Additional length can be gained by transposition of the proximal nerve, eg, ulnar nerve at the elbow, or bone shortening, eg, during replantation surgery.

The distal and proximal joints are placed in minimal flexion. Excessive flexion is to be avoided, because it will result in flexion contractures or tension on healing nerve.

Additional length can be gained by transposition of the proximal nerve, eg, ulnar nerve at the elbow, or bone shortening, eg, during replantation surgery.

Epineurial repair, the most common type of nerve repair, consists of alignment and approximation of the nerve ends using sutures placed in the epineurium.

After clean, pouting bundles of fascicles are exposed, the epineurium is identified circumferentially by resection or pushing back of the mesoneurium.

Correct alignment of the nerve ends is critical. Line up blood vessels and other external markings in the epineurium, and match fascicular bundles in the two ends.

Suture must be monofilament (eg, nylon) on an atraumatic needle to minimize trauma to the nerve ends. Suture size varies with the size of the nerve. Usually an 8-0 suture is used in the arm and 9-0 in the fingers. Repair with larger suture dimensions does not add strength to the repair: sutures fail by pull-out of the neural tissue.

Two simple sutures are placed 180 degrees from one another. Care must be taken to avoid penetrating fascicles with the needle (TECH FIG 2A).

One tail of each suture is left long to stabilize the nerve during repair.

Three or four additional sutures are placed on the anterior face of the repair as necessary to approximate the epineurium and prevent fascicular extrusion.

By flexing the limb further to relax the nerve, the nerve is turned over, using the suture tails, to expose the posterior wall. Each suture tail can be weighted down with a small vascular clip.

Posterior wall repair is completed with three or four simple epineurial sutures, as needed. The long tails are then cut short, and the nerve is examined carefully to ensure that a complete epineurial seal is achieved (TECH FIG 2B).
GROUP FASCICULAR REPAIR

- Groups of nerve fascicles are approximated by perineurial sutures (TECH FIG 3).
- Group fascicular repair is indicated for partial nerve injury involving a few groups of fascicles or in a mixed nerve with distinct motor and sensory components, such as the median nerve proximal to the wrist.
- The advantage of improved fascicular alignment may be counteracted by increased intraneural scarring from the increased surgical dissection and manipulation of the group fascicular repair.
- After exposing clean, pouting bundles of fascicles, the epineurium is resected back for 5 mm to clearly expose groups of fascicles surrounded by perineurium.
- The internal arrangement of the fascicles is noted, and similarly sized fascicular groups are aligned.
- For partial nerve injury with a few injured fascicles, repair individual fascicles with 10-0 nylon simple sutures placed in the perineurium. Usually, two sutures per fascicle are adequate.
- In the case of a complete nerve injury involving a larger nerve, a group fascicular repair that approximates groups of fascicles is faster and less traumatic.
- When approximating larger groups of fascicles, four to six sutures are placed per group in a circumferential pattern. For additional stability, sutures at the external surface of the fascicular group should be passed through both the epineurium and perineurium. (These sutures are known as epi-perineurial sutures.)
- After completion of fascicular repair, four additional sutures of 9-0 nylon are placed in the epineurium to take tension off the repair.

CABLE GRAFT REPAIR

- Nerve grafting is indicated when end-to-end approximation is not possible, eg, after crushing of the nerve ends, retraction of nerve ends after delay in surgical intervention, or after neuroma resection.
- After the nerve ends are prepared back to pouting bundles of fascicles, the epineurium is identified circumferentially.
- The internal arrangement of the fascicles is noted, and a quick sketch of the fascicular arrangement helps to plan graft alignment (TECH FIG 4).
- Epineurium is resected to expose the perineurium of the fascicles.
- The gap between the prepared nerve ends is measured.
- When grafting a larger-diameter nerve such as the median nerve using a smaller diameter nerve such as the sural nerve, several strands of donor nerve are interposed in the gap as a cable graft.
- The length of nerve graft needed is calculated as follows: gap $\div 15\% \times$ estimated number of strands.
- Donor nerves include the sural (located midway between the lateral border of the tendo achilles and the lateral malleolus), posterior interosseous (located in the floor of the fourth extensor compartment), and the medial antebrachial cutaneous nerve (located in the anteromedial forearm along branches of the basilic vein).
- Each segment of graft is reversed and attached to a similar-sized group of fascicles at the proximal stump using two sutures of 9-0 nylon, 180 degrees from one another.
- Although the donor nerve allows growth of regenerating axons in either direction, reversing the nerve graft helps to minimize the possibility of regenerating axons growing out along branches of the donor nerve.
- Place the limb in a neutral position; then lay the graft in the defect and align it with a similar fascicular group in the distal stump. The graft is cut and sutured to the distal stump fascicles.
- Follow the same sequence, laying segments of graft across the gap until the gap is filled.
- The repair can be reinforced with fibrin glue placed at the anastomosis and between segments of the graft.

TECH FIG 3 • Technique of group fascicular repair. The epineurium is pulled back, and sutures are placed in the perineurium after fascicular groups have been aligned.

TECH FIG 4 • Nerve grafting using “cables” of nerve graft. After aligning the nerve ends, similar fascicular groups are bridged with segments of nerve graft.
VASCULARIZED NERVE GRAFT REPAIR

- Vascularized nerve graft repair may be indicated in cases when the gap is 6 cm or more, or in a scarred tissue bed in large proximal nerve reconstruction after brachial plexus injuries.
- The most common vascularized nerve graft donor is the ulnar nerve (following C8 and T1 root avulsion), along with its mesoneurium, containing the superior ulnar collateral vessels.
- For local nerve defects, the ulnar nerve segment is divided, preserving the vascular pedicle. The segment is transposed with its intact pedicle, and epineurial repair is performed.
- If a more remote defect is to be grafted, the vascular pedicle and nerve segment are divided. The nerve is reversed and placed in the defect. Following epineurial repair, microvascular anastomosis is performed between the artery and vein in the vascular leash to a local arterial and venous recipient vessel.

CONDUIT REPAIR

- Conduit repair is indicated for clinical use in nerve gaps up to 2 cm.
- Advantages over conventional repair are that it is tension free, less traumatic, permits no axonal escape, and allows spontaneous axonal orientation.
- Two types are in clinical use: reversed autogenous vein or artificial conduits.
  - Artificial conduits may be either manufactured using absorbable materials such as polyglycolic acid or made of collagen engineered from natural xenograft sources such as bovine tendon. Artificial conduits have obvious advantages over a vein conduit in regard to shelf availability, size variation, no additional dissection for harvesting, and resilience and elasticity. Collagen tubes degrade over time with natural processes and without any inflammatory reaction.
  - After nerve end preparation, the nerve diameter is measured. A conduit that is oversized by 1 mm is chosen to avoid constriction of the regenerating nerve.
  - The conduit is rehydrated in saline for 5 minutes.

- The aim of repair is to invaginate each end of the nerve into the tube for a distance of 5 to 8 mm using a mattress suture followed by a single anchoring suture for stability (TECH FIG 5).
- The suture is first passed through the tube from the outside in and about 5 mm from the tube edge. The suture is then passed transversely across the epineurium 3 mm from the edge of the nerve stump and then back through the tube in an inside-to-outside direction.
- Gently ease the nerve into the tube as the knot is tightened.
- Place a simple suture between the epineurium and the edge of the tube at a diametrically opposite point to anchor the tube and prevent rotation.
- Repeat the same steps for the distal stump, and fill the tube with saline using a fine cannula.

**TECH FIG 5** • Technique of conduit repair. A. A horizontal mattress suture is placed between the conduit and the epineurium of the nerve. B. As the suture is tightened, the nerve is drawn into the conduit. A simple stitch is placed anchoring the epineurium to the tube opposite the location of the mattress suture.
PEARLS AND PITFALLS

Intraoperative precautions
- If contemplating intraoperative nerve stimulation, avoid muscle relaxants and tourniquets.
- Repair bones and tendons before undertaking fragile nerve repair.
- Proceed with nerve repair only if the wound bed is clean and healthy and primary closure is possible.
- If delayed repair is planned, place a marking suture in the epineurium to facilitate later identification.

Nerve precautions
- Limit handling of nerve and use microsurgical instruments.
- Use operating microscope to prepare nerve ends and for fascicular alignment.
- Always be prepared to use graft or conduit rather than suture nerve under tension or with joints excessively flexed.
- Keep nerves (including grafts) moist.
- Repair should be tension-free.
- Soft tissue coverage is a must.

Instrumentation
- Make certain microinstrumentation is in good repair.
- Forceps should be free of spurs and should approximate correctly.
- Use 8-0 or 9-0 suture with atraumatic taper-point needles.

POSTOPERATIVE CARE
- Consider use of a local anesthesia infusion pump for postoperative pain control.
- Immobilization is very important to prevent tension across the repair:
  - The elbow should be held at 90 degrees of flexion.
  - Wrist flexion greater than 20 degrees should be avoided.
  - The metacarpophalangeal joints should be held at 70 degrees of flexion.
- Mobilization varies with associated tendon repair. After isolated nerve repair, gentle finger flexion and shoulder range of motion are started soon after surgery to promote nerve gliding and prevent finger stiffness.
- Remove skin sutures after 2 weeks and replace the splint.
- For nerve repairs around the elbow, allow motion in an extension blocking splint. Full extension is permitted after 6 weeks.
- For repairs in the distal forearm and wrist level, immobilize the wrist at 20 degrees flexion and block metacarpophalangeal hyperextension for 4 weeks. Allow active finger motion within the splint. Bring the wrist to neutral at 4 weeks, and then allow mobilization out of the splint at 6 weeks.
- Nerve regeneration is followed at regular intervals with clinical examination of motor and sensory recovery and Tinel sign.
  - The distal-most point at which the Tinel sign is observed is recorded at each visit and its distance from the suture line noted.
  - Expect distal progression of Tinel sign at the rate of about 1 mm per day, with a delay of 1 month after the date of repair.
  - Failure of Tinel progression over serial visits may indicate repair failure; consider re-exploration and grafting.
  - Sensory re-education is initiated early in the postoperative phase with the goal of teaching recognition of new input in a useful manner.
- Three stages to this process are introduced sequentially in the recovery period:
  - Desensitization: the patient is presented with graded stimuli to decrease unpleasant sensations.
  - Early-phase discrimination and localization: the patient works with static and moving touch, using visual reinforcement.
  - Late-phase discrimination and tactile gnosis: the patient works with varying shaped objects.

OUTCOMES
- The outcome after nerve repair is generally less favorable than that of repair of other tissues, such as bone or tendon injury.
- It is difficult to predict the outcome because of several variables, including type of nerve (pure sensory versus mixed), age of patient, type of injury—clean or crushed, associated soft tissue injuries.
- The single most important factor that correlates with outcome is patient age. The best results are seen in children younger than 10 years of age.
- Pure motor or pure sensory nerves fare better than mixed nerves.
- The outcome also correlates with level of injury. Injuries closer to the end organs fare better, because there is less distance for the regenerating axons to cover.
- Peripheral factors that are determined by the injury and cannot be modified by the treating surgeon include axonal cell death, end-organ atrophy, and extensive scarring from surrounding crush injury.
- The surgeon can control, to a limited extent, the scarring in and around the nerve repair.
- Central factors that account for poor results include cortical remapping and reorganization, with reduced and disorganized cortical representation of denervated areas.
- Children recover greater function than their adult counterparts with primarily repaired lesions at similar levels due to a combination of better axonal regeneration and cortical plasticity.
- Delayed repairs fare worse than those repaired acutely, with an estimated 1% decrease in performance for every 6 days of delay in the repair.
- The nature of the injury often determines the likelihood of recovery. Massive soft tissue injury or burns involving a peripheral nerve are less likely to regain function than injuries involving sharp or limited transection of a nerve.
- Median nerve outcome after high injuries usually is poor because of hand intrinsic atrophy. After low injuries, useful
motor function is regained in 40% to 90% of repairs, and useful sensation is restored in 53% to 100% of patients.

- Ulnar nerve injuries show similarly poor results for motor recovery, with functional restoration in 35% of cases and functional sensory recovery in 30% to 68% of cases.
- Because the ulnar nerve is largely a motor nerve, better results can be expected after acute radial nerve repairs, with functional return in 60% to 75% of patients. Poor results are noted with high injuries, however.
- After repair of digital nerves, about 50% of patients regain static two-point discrimination of less than 10 mm. Younger children demonstrate near-normal sensory recovery due to their cortical adaptability.
- Lingering symptoms of hypersensitivity and cold intolerance are common with sensory nerve injury in the upper extremity, resolving in most patients after 2 to 3 years. The cause is unclear.
- Complex regional pain syndrome is more likely to be present after untreated nerve injuries. If it does occur, significant joint contractures and atrophic changes can result, and the patient generally has a prolonged recovery period and a poor outcome.

**COMPlications**

- Causes for failure of repair include:
  - Tension on the initial repair
  - An unfavorable local tissue environment with excessive scarring
  - Noncompliance with protective measures or therapy and consequent joint contractures
  - Painful neuromas usually form in unrepaired or poorly repaired nerves close to the surface. These usually are treated with desensitization, local padding, etc. because surgical results are often disappointing.
  - Altered sensation is a result of axonal misdirection and cortical misrepresentation and can present as loss of temperature sensation or cold intolerance, hyperesthesia, or neuropathic pain.
  - Some amount of altered function is inevitable after all complete nerve injuries in the upper extremity except in young children. It is due to a combination of altered sensation and proprioception along with loss of motor strength.
  - Complex regional pain syndrome type II can occur after nerve injury especially in untreated cases or after delayed treatment or failure to control pain. Typical features include dramatic changes in the color and temperature of the skin accompanied by intense burning pain, skin sensitivity, sweating, and swelling. Early recognition is the key with referral to a pain management specialist for stellate blocks along with steroids, antiepileptic drugs, and therapy.

**SUGGESTED READING**


de Medinaceli L, Prayon M, Merle M. Percentage of nerve injuries in which primary repair can be achieved by end-to-end approximation: Review of 2,181 nerve lesions. Microsurgery 1993;14:244–246.


DEFINITION

■ A nerve injury in continuity occurs when there is loss of axonal function with preserved structure of the supportive connective tissue.
  □ By definition, the epineurium is preserved in a nerve injury in continuity.
  □ Because varying degrees of axonal interruption may occur, the extent of functional loss in terms of numbness and paralysis is variable.
  □ The severity of injury varies with degree of preservation of the endoneurium and the perineurium.

ANATOMY

■ The cross-sectional anatomy of the peripheral nerve is discussed in detail in Chapter HA-72.
  □ Endoneurial tubes form the basic conduit for the Schwann cell–encased axon.

PATHOGENESIS

■ Several mechanisms may cause a nerve injury in continuity, but the most common is nerve stretch.
  □ When a nerve is subject to blunt injury or stretch, axonal disruption can occur without externally visible injury to the nerve.
  □ Stromal elements are more resilient to stretch and remain preserved to a variable extent (FIG 1).
  □ The type of recovery seen after an injury depends on preservation of the endoneurial tube.

■ In the mildest forms of injury, with preserved endoneurial tubes, regenerating axons follow their original path. The destination is reached with good outcome. There is no axonal mismatch, and the recovery is termed uncomplicated regeneration.
  □ When the endoneurial tube is disrupted, axonal regeneration is disorganized. Axons sprout and grow in a different direction, and mismatch occurs. This form of repair, termed complex regeneration, is associated with a clinically less satisfactory outcome.
  □ With more severe forms of stretch injury, additional disruption of the perineurium occurs, resulting in a greater fibrotic response and resultant scarring of the nerve.
  □ The nerve trunk, which externally appears uninterrupted due to the intact epineurium, demonstrates an injured segment that is enlarged due to intraneural fibrosis surrounding a mass of disorganized axons. This is referred to as a neuroma in continuity (FIG 2).

NATURAL HISTORY

■ Pathoanatomy associated with the injury, pathologic changes resulting from this altered anatomy, and functional recovery are closely related.
  □ More anatomic disruption results in a stronger pathologic response and worse outcome.
  □ Sunderland’s classification of injury severity is useful to categorize injury and plan treatment.

□ Type I
  □ The mildest form of injury involves loss of axonal function without actual structural interruption: neurapraxia (FIG 3A).
  □ Type I injury is seen after mild stretch injuries, tourniquet palsy, and external compression of a nerve, as in radial nerve compression in “Saturday night palsy.”
  □ Although structurally intact, axons fail to conduct impulses, secondary to malfunction of ion channels along the injured segment.
  □ No visible change in the microscopic or macroscopic appearance of the nerve is present, and there is no wallerian degeneration of the distal segment.
  □ Electrophysiologic testing does not reveal a conduction block or denervation potentials.

FIG 1 • Pathogenesis of a nerve injury in continuity. The effect of increasing stretch is seen, from normal nerve at the top to complete rupture at the bottom. Neural elements fail first in response to stretch; epineurium fails last.

FIG 2 • Neuroma in continuity. The enlarged part of the nerve consists of a mixture of intact and damaged axons surrounded by scar tissue and regenerating axons.
Recovery starts within a few weeks and can be expected to be complete.
Because axons recover conductivity in a variable pattern, clinical recovery follows a random pattern.

Type II
There is structural disruption of the axon, but the endoneurium is preserved (FIG 3B).
Type II injury is seen after more severe stretch injuries, such as radial nerve palsy resulting from a closed humerus fracture.
Wallerian degeneration results and electrophysiologic tests reveal distal conduction block and denervation.
As regenerating axons progress distally, proximal muscles are reinnervated first. Clinically, recovery occurs in a proximal-to-distal direction.
Because there is no axonal mismatch, recovery usually is complete but takes longer, usually several months.

Type III
The axon, myelin sheath, and endoneurium are interrupted (FIG 3C).
Recovery is less predictable, because regenerating axons may not follow previous pathways (complicated regeneration).
With the perineurium preserved, recovery can take place without surgical intervention but usually is incomplete due to axonal misdirection.
Injury to small vessels within the endoneurium leads to an inflammatory response. Fibroblast activation results in a variable degree of interfascicular scarring that may impede nerve regeneration.

Type IV
In more severe stretch injuries, the internal nerve structure is completely disrupted, leaving only an intact epineurium (FIG 3D).
Retraction of fascicles and scarring within the nerve are present. Even though the nerve is in continuity, no clinically significant recovery can be expected without surgical intervention.

Type V
Complete rupture or laceration of the nerve with retraction of the nerve ends (see Chap. HA-93) (FIG 3E)

PATIENT HISTORY AND PHYSICAL FINDINGS
Stretch injuries that result in nerve injury in continuity usually are proximal. These injuries often take place as the nerve root exits the spinal cord or involve the brachial plexus in the neck or upper arm.
At more distal levels, nerve stretch injuries usually are the result of displaced fractures or dislocations.
There usually is a history of significant trauma, and patients complain of pain and paresthesias with a variable amount of functional loss distal to the site of injury.
Incomplete loss of function often indicates an incomplete nerve injury.
Severe pain or paresthesias after any closed fracture should alert the clinician to the possibility of an associated nerve injury.
Complete loss of function does not necessarily imply complete disruption of the nerve.
Documented lack of recovery on serial clinical examinations is essential to determine the severity of the injury and the need for surgical intervention.
Muscle strength is charted against a timeline at every visit. Progressive muscle recovery in a proximal-to-distal direction indicates spontaneous axonal regeneration.
Tinel sign and its gradual progression is also a useful measure of nerve recovery.
Recovery within a few weeks of injury and with a random pattern usually suggests a Type I injury or neurapraxia.

After incomplete injury to a peripheral nerve, function is lost in a predictable order: motor, proprioception, touch, temperature, pain, and sympathetic function.

Recovery usually occurs in the reverse order.

In a closed injury without any obvious fractures, the site of nerve injury is not always obvious.

Careful mapping of the motor and sensory deficit will help to distinguish the level of injury.

The pattern of sensory loss is a reliable way to determine the level of injury. A more proximal injury usually follows a dermatomal pattern, whereas a distal injury follows the distribution of the nerve.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- MRI done several weeks after injury may reveal an enlarged nerve segment, suggesting a neuroma in continuity.
- Neuropathologic studies are useful in evaluating and monitoring an injured nerve when there is no external injury.
- Conduction blocks usually reverse within 10 to 14 days; therefore, tests should be delayed until this time.
- Complete loss of muscle action potentials does not necessarily indicate a complete interruption of all axons.
- Electromyograms (EMGs) will show variable denervation of muscle groups innervated by the nerve in question.
- Fibrillation potentials on EMG usually appear within 10 to 40 days, indicating complete denervation of a muscle group.
- Electromyographic evidence of reinnervation may precede voluntary muscle contraction by several weeks and may be of use in tracking the progress of nerve regeneration.
- Return of a muscle action potential requires not only regeneration of the nerve to the level of the end organ but also re-establishment of a physiologic connection between the nerve and the target tissue. Re-establishment of the motor endplate is required before EMG provides evidence of functional return.
- Nerve conduction studies (NCSs) also are useful in the evaluation of a closed nerve injury.
  - In a closed injury, lesions may be localized using NCSs.
  - Continuity of the nerve also may be assessed, but should be undertaken at about 10 days after the injury to prevent erroneous results, because the axons distal to a complete transection may continue to conduct during this initial period after injury.
- Parameters evaluated include amplitude and latency.

**DIFFERENTIAL DIAGNOSIS**

- Complete transection
- Conduction block
- Partial axonal injury
- Compressive injury

**NONOPERATIVE MANAGEMENT**

- Lesions in continuity may improve spontaneously, especially in types I and II, in which recovery is complete without any surgical intervention.
- Type I through III injuries can be watched closely with serial mapping of the sensory and motor recovery.
- Type IV and V injuries usually require surgical repair of the nerve to restore axonal continuity.
- Preservation of some function distal to the suspected level of the injury within the distribution of the injured nerve suggests a partial injury, and observation is appropriate.
- If there is a complete palsy of a nerve after a closed injury, an initial period of observation may be best until signs of denervation appear in end organs.
- If signs of reinnervation appear, such as a Tinel sign distal to the level of injury, continued observation is prudent.
- If no signs of reinnervation appear, one should strongly consider electrophysiologic studies to evaluate the continuity of the axonal fibers.
- Physical therapy is very important to maintain mobility during the period of observation.

**SURGICAL MANAGEMENT**

- If no signs of recovery are present at 2 to 4 months, then surgical exploration may be indicated.
- Electrophysiologic testing should be used in this instance to define the level of injury.
- Longer delays may compromise the efficacy of surgical repair, secondary to end organ degenerative changes.
- Focal injuries are usually observed for shorter periods, because the extent of the injured nerve segment usually is smaller.
- Blunt or blast injuries may be observed for up to 6 months after the initial large segments of injured nerve undergoing repair.

**Preoperative Planning**

- Intraoperative nerve action potentials (NAPs) may provide information about lesions in continuity, including the degree and extent of interruption.
- If NAPs are not recordable across a lesion, then resection and direct repair rather than grafting will likely be required.
- Resection is performed from the point at which NAPs are lost to the point where they return.
- If NAPs are present, external neurolysis or nerve decompression may be adequate treatment.

**Positioning**

- The patient is positioned supine, with a hand table.
- If nerve grafts may be required, the opposite leg is prepared to allow access to the sural nerve. Rarely, if bilateral sural nerves are to be harvested, the patient initially is placed prone.
- Use of a tourniquet may result in ischemic conduction block, which will render intraoperative nerve stimulation ineffective.
- It generally is preferable to use a tourniquet for only the first 20 minutes of surgery, to facilitate initial dissection.
- The use of an operating microscope and fine soft tissue sets or microinstrumentation is necessary for nerve handling and repair.

**Approach**

- Surgical exposure should provide adequate access to the section of damaged nerve as well as proximal and distal to this site.
- Mobilization should be minimized to prevent additional vascular insult to the nerve.
- Sources of external compression should be identified and alleviated.
- The bed for repair should be free of scar tissue. Nerve transposition may be required.
EXTERNAL NEUROLYSIS

- External neurolysis is defined as the circumferential freeing of a peripheral nerve from surrounding scar tissue (TECH FIG 1A).
- Dissection proceeds from normal nerve (both proximal and distal) to the area of scarring (TECH FIG 1B).
- The nerve should be mobilized away from the scar tissue bed to prevent recurrence.

- Use of a xenograft nerve wrap or fat graft may be considered to prevent recurrence of scarring (TECH FIG 1C).
- External neurolysis may relieve neuropathic pain associated with compression, but results for sensory and motor recovery are variable.

EXTERNAL NEUROLYSIS

- Use of a xenograft nerve wrap or fat graft may be considered to prevent recurrence of scarring (TECH FIG 1C).
- External neurolysis may relieve neuropathic pain associated with compression, but results for sensory and motor recovery are variable.

INTERNAL NEUROLYSIS

- Internal neurolysis is defined as the resection of fibrotic tissue from within the structure of the nerve itself.
- This procedure is indicated for late management of incomplete injuries such as stretch injuries when the nerve has regained partial function that is clinically inadequate.

- Intraoperative recording of NAPs will indicate functioning fascicular groups and help guide the surgeon during this procedure.
- Internal neurolysis is performed along the fascicular segment that has lost NAPs (TECH FIG 2).

TECH FIG 1 • External neurolysis and xenograft nerve wrap. A. The median nerve at the wrist developed painful scarring after carpal tunnel release. B. External neurolysis has been performed by excision of all scar tissue and thickened epineurium. C. A xenograft collagen nerve wrap has been placed around the nerve to minimize scar tissue formation around the nerve.

TECH FIG 2 • A–C. Intraoperative microscope images of internal neurolysis of the ulnar nerve at the wrist. A. The ulnar nerve is surrounded by dense scar tissue. B. After external neurolysis, there is a persistent area of narrowing of the nerve (arrows) requiring internal neurolysis. (continued)
SPLIT REPAIR

- **Split repair** is defined as a procedure in which intraoperative NAP recordings are used to guide the resection of individual nonconducting fascicles.
- First, external neurolysis is performed to expose the injured segment of the nerve.
- The epineurium is excised circumferentially to expose the injured fascicles (TECH FIG 3A).
- Intraoperative NAP recordings are made to identify the injured fascicular segments (TECH FIG 3B).
- Resection of the nonconducting segments is performed using either a blade or sharp microvascular scissors (TECH FIG 3C).
- Repair is performed either directly or with autogenous grafting.

This procedure is performed in cases of incomplete functional loss distal to the site of injury.

Some loss of intact axons can be expected as a result of the dissection, so the patient should be advised that additional loss of function could be possible with this procedure.

TECH FIG 2 • (continued) C. Appearance after internal neurolysis—the constricting epineurium and scar between fascicles has been excised. D. Illustration of a neuroma in continuity treated by internal neurolysis. The segment of scarred epineurium is excised, and all scar tissue between fascicles also is excised.

TECH FIG 3 • Exploration and split repair of a partial injury of the posterior interosseous nerve 4 weeks after palsy following a dog bite at the elbow. A. The posterior interosseous nerve demonstrates a neuroma in continuity (white arrow). B. Internal neurolysis has been performed, isolating intact peripheral fascicles with a central neuroma (white arrow). C. A gap remains in the injured fascicular group after neuroma resection. Mobilization of the intact fascicles is limited because of their proximity to the motor branches, making end-end repair of the injured fascicles difficult. (continued)
If no conduction of NAPs is noted across a lesion after internal neurolysis is performed, then the entire lesion should be resected.

The proximal and distal portions of the nerve flanking the lesion should be mobilized to prevent undue tension on the repair. During mobilization, longitudinal blood vessels within the epineurium must be preserved.

The lesion is sharply excised using a fresh, sharp blade against a block (usually a moistened tongue depressor).

**Epineurial Repair**

- If the extent of the lesion is short, then direct end-to-end epineurial repair without tension often is possible.
- Direct epineurial repair is then performed as described in Chapter HA 93.

**Cable Graft Repair**

- Cable graft repair is useful when the extent of the lesion precludes direct repair because of either tension or a large gap (TECH FIG 4A).
- Cable graft repair is then performed as described in Chapter HA-93.
- Sural nerve graft can be harvested through a single longitudinal or multiple transverse incisions (TECH FIG 4B).

**Cable Grafting**

- Cable grafting is the more common technique, using donor nerve from either the sural or antebrachial cutaneous nerve.
- Grouped fascicular repair is then performed (TECH FIG 3D–F).
  - The internal arrangement of the fascicles is noted, and a quick sketch of the fascicular arrangement is made to allow alignment of the nerve ends.
  - Nerve grafts will not match the exact fascicular pattern—the aim is to place graft “cables” between groups of fascicles.
  - The gap between nerve ends is measured, and the length of graft needed is calculated.

- Length = gap + 15% × estimated number of grafts
- Grafts are attached to a group of fascicles using two sutures of 9-0 or 10-0 nylon, 180 degrees from one another.
- Each graft is sutured to the proximal and distal stumps before moving on to the next graft, thus allowing for more accurate fascicular matching.
- Check the repair to ensure that no stitches have pulled out. The repair may be reinforced with fibrin glue.
- Handling of the grafts should be minimized.
- Grafts should be kept moist from harvest to repair.

**RESECTION OF THE NERVE LESION IN CONTINUITY**

- If no conduction of NAPs is noted across a lesion after internal neurolysis is performed, then the entire lesion should be resected.
- The proximal and distal portions of the nerve flanking the lesion should be mobilized to prevent undue tension on the repair. During mobilization, longitudinal blood vessels within the epineurium must be preserved.
- The lesion is sharply excised using a fresh, sharp blade against a block (usually a moistened tongue depressor).

- The nerve is easily identified by careful spreading dissection in the subcutaneous tissue midway between the lateral malleolus and the tendo-achilles (TECH FIG 4C).
- Use of a tendon stripper to harvest the nerve is not recommended.
- This technique can result in stretch or laceration of the sural nerve.
- Additionally, the posterior tibial nerve may be inadvertently injured.
POSTOPERATIVE CARE

- General guidelines for splinting and postoperative care are detailed in Chapter HA-72.
- Serial examination is important to follow the progress after surgical repair.

OUTCOMES

- Neurolysis
  - If NAPs are recorded through a nerve segment, recovery is thought to be about 90%.
  - NAP recording and subsequent neurolysis without resection have been found to consistently result in better outcomes than direct or graft repair.
- Split repair
  - Outcomes are superior to complete repair when NAPs are recorded through some portion of the nerve.
  - Direct and graft repair of the injured fascicles yield similar results.
- Complete resection with direct repair or graft repair
  - The outcome of direct repairs appears to be superior to those requiring the use of a graft; however, injuries requiring a nerve graft often are more substantial and require regeneration along a greater distance.
  - In general, radial nerve repairs are more successful than median nerve repairs, and both are better than ulnar nerve repairs.
- Children generally have better overall outcomes than adults.
- Internal neurolysis or resection of any lesion in continuity may be related to a decrease in preoperative function as some intact axons may be transected.

COMPLICATIONS

- Infection
- Scarring
- Loss of function
- Increased neuropathic pain
  - Either distal to the lesion or in the form of a painful neuroma
- Failure of recovery of function

SUGGESTED READINGS

DEFINITION
- The median nerve can be compromised by any number of causes, including trauma, tumor, chronic compression, or synovitis.
- Palsy of the median nerve can result in motor or sensory deficits, or both, within the distribution of this nerve.

ANATOMY
- The median nerve enters the forearm between the two heads of the pronator teres muscle.
- The median nerve travels down the forearm between the flexor digitorum superficialis and profundus muscles to enter the carpal tunnel.
- Along its course, the anterior interosseous nerve branches from the median nerve to provide innervation to the flexor pollicis longus, flexor digitorum profundus (FDP) to the index, and the pronator quadratus muscles.
- The median nerve proper provides innervation to the flexor carpi radialis, pronator teres, flexor digitorum superficialis (FDS), palmaris longus, and FDP to the long finger.
- The palmar cutaneous branch arises from the median nerve 5 cm proximal to the wrist joint, crosses the wrist volar to the transverse carpal ligament, and supplies sensibility to the thenar eminence.
- Just proximal to the wrist, the median nerve becomes superficial and travels within the carpal tunnel.
- The recurrent motor branch originates from the central or radial portion of the median nerve during its passage through the carpal tunnel. The recurrent branch usually passes distal to the transverse carpal ligament to innervate the thenar muscles. The nerve can also pass through the transverse carpal ligament (occurs in 5% to 7% of individuals).6
- The thenar muscles are the opponens pollicis, flexor pollicis brevis, and abductor pollicis brevis. The flexor pollicis brevis muscle receives dual innervation from both the recurrent branch and the deep motor branch of the ulnar nerve.
- The median nerve terminates into multiple sensory branches, which supply sensibility to the thumb, index, long, and ring (radial side) fingers. The sensory branches to the radial side of the index and radial side of the long fingers possess a minor motor component that sends a small branch that innervates the adjacent lumbrical muscle.

PATHOGENESIS
- Most injuries to the median nerve occur at the wrist and affect the thenar muscles. The resultant functional loss is lack of thumb opposition.
- Compression injuries are most common and are usually attributed to prolonged carpal tunnel syndrome.
- Carpal tunnel compression may also be secondary to tumor, adjacent synovitis, or fracture-dislocation.
- Penetrating or perforating injuries may directly damage the median nerve.
- Pediatric causes include lipofibrohamartoma of the median nerve or Charcot-Marie-Tooth disease, a demyelinating process that has a preference for the median and ulnar nerves (FIG 1).6
- High median nerve injuries are rare. Similar causes exist, including trauma and nerve compression.

NATURAL HISTORY
- With a median nerve compression neuropathy (ie, carpal tunnel syndrome), palsy of the median nerve is insidious in onset and manifestation. Over a period of months to years, patients can progress to decreased median nerve function as well as sensory changes in the dermatome of this nerve.
- Acute injuries to the median nerve at the wrist or elbow have a traumatic onset followed by sensory or motor changes, or both.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Compressive neuropathy of the median nerve
- Patients report pain, numbness, and tingling in the thumb, index, middle, and sometimes ring ringer of the affected hand. They frequently describe problems with fine coordination of the hand, notably problems with pinch. Patients often report pain and numbness that awakens them at night.
- Physical examination findings include thenar muscle wasting and diminished thumb opposition (defined as the

FIG 1 • Left hand of 16-year-old boy with Charcot-Marie-Tooth disorder resulting in median nerve palsy. Note inability to oppose thumb with attempt to touch small fingertip. (Courtesy of Shriners Hospital for Children, Philadelphia.)
combination of palmar abduction, metacarpophalangeal [MCP] joint flexion, and thumb pronation).
- Additional signs include the Tinel sign, the Phalen sign, the carpal tunnel compression sign, and increased two-point discrimination in the thumb, index, and long fingers.
- High median nerve neuropathies have similar findings, in addition to loss of forearm pronation and flexion of the thumb, index, and long fingers.
- Acute median nerve injury
  - There is nearly always a wound on the upper extremity, usually on the volar wrist.
  - Physical findings include diminished sensibility in the thumb, index, and long fingers; increased two-point discrimination in those fingers; and an inability to touch the thumb tip to the small finger (ie, loss of opposition).
  - Depending on the level of injury, patients may display diminished sensibility of the thenar eminence of the thumb, signifying an injury proximal to the palmar cutaneous branch of the median nerve, or a concomitant injury to the palmar cutaneous branch.
  - Higher median nerve neuropathies have similar findings, in addition to loss of forearm pronation and flexion of the thumb, index, and long fingers.
  - Patients with median nerve palsy will not be able to oppose thumb to small finger. There may be some palmar abduction due to function of the abductor pollicis longus or extensor pollicis brevis muscles, but this will be minor. The ulnar-innervated deep head of the flexor pollicis brevis muscle will still function, creating MCP joint flexion but not true opposition.
  - Inability to make an “OK” sign indicates anterior interosseous nerve injury and high median nerve pathology.
  - The clinician should ask the patient to try to touch thumb to small finger with the wrist flexed. Due to median nerve palsy, the patient will likely not be able to fully touch the thumb to the small finger. However, if the palmaris longus is present, it will be visible as it tents up the skin over the volar wrist.
  - The patient is asked to spread his or her fingers apart and hold them against adduction pressure on the small finger. The examiner feels for resistance and palpates the hypothenar eminence at the same time. There should be resistance to adduction force on the small finger, and firmness of the hypothenar eminence should be appreciated.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Radiographs
  - Plain radiographs are helpful in determining the nature of fractures or dislocations after acute trauma to the upper extremity.
  - Specific carpal tunnel radiographic views may demonstrate osteophytes within the carpal tunnel, but they are not routinely performed.
- Electrodiagnostic studies
  - In the setting of compressive neuropathy of the median nerve, nerve conduction studies typically show increased motor and sensory latencies in the median distribution.
  - In advanced stages of compressive neuropathy, electromyography demonstrates fibrillation potentials in various muscles tested, most commonly the abductor pollicis brevis. These fibrillation potentials signify denervation of the tested muscle.
  - Advanced high median nerve neuropathy reveals fibrillation potentials in more proximal muscles, such as the flexor carpi radialis and the pronator teres.

**DIFFERENTIAL DIAGNOSIS**
- Carpal tunnel syndrome
- Anterior interosseous syndrome
- Pronator syndrome
- Wrist synovitis
- Direct injury to the median nerve
- Tumor compression of the median nerve
- Charcot-Marie-Tooth disease
- Brachial plexus injury
- Stroke or other brain injury

**NONOPERATIVE MANAGEMENT**
- Patients with demonstrable carpal tunnel syndrome can undergo a trial of splinting, wrist corticosteroid injection, or both.
- Work modification is indicated in patients with compressive neuropathy as a result of overuse for both carpal tunnel and pronator syndromes.
- Anti-inflammatory and immunomodulatory medications are indicated in patients with wrist synovitis secondary to inflammatory arthropathy.

**SURGICAL MANAGEMENT**
- The chief surgical modality for a low or high median nerve palsy that has not responded to surgery or other interventions is tendon transfer.\(^5\,^6\)
  - Typically, in a low median nerve palsy, the only function that requires restoration via tendon transfer is thumb opposition, which is a combination of palmar abduction, MCP joint flexion, and thumb pronation.
  - In a high median nerve palsy, the additional loss of flexion of the thumb, index, and long fingers requires tendon transfer. In addition, lack of pronation may require tendon transfer.

**Preoperative Planning**
- The surgeon must ensure that there is good passive range of motion of the joints to be mobilized.
  - In longstanding median nerve palsy, the thumb MCP and carpometacarpal joints can become quite stiff.
  - Physical therapy must be employed to loosen these joints and increase their range of motion.\(^5\) This can usually be accomplished in 3 to 6 weeks.
  - A thorough assessment of muscle function and strength is made before selecting a transfer, especially in the setting of combined nerve deficits.
- When performing an opponensplasty, the donor tendon and attachment site are individualized to the particular patient, his or her injury, his or her needs, and the donor muscle–tendon availability. As the attachment site moves more dorsal, the amount of pronation and thumb extension is increased.
- Donor options for opponensplasty include:
  - FDS
  - Abductor digiti minimi (Huber)
  - Extensor indicis proprius (EIP)
Palmaris longus (Camitz). The palmaris transfer is associated with more abduction and less opposition compared to other opposition transfers.3

Other less common donors include the extensor pollicis longus, extensor carpi ulnaris, extensor carpi radialis brevis, and extensor digitorum quinti.4

Opponensplasty attachment site options include the following:3

- Abductor pollicis brevis tendon. This yields a lot of thumb abduction and some opposition.
- Extensor pollicis brevis or longus tendons. This yields thumb abduction, pronation, and MCP joint extension.

Single attachment options

- Riordan’s technique involves interweaving the transferred tendon into the abductor pollicis brevis tendon, with continuation onto the extensor pollicis longus tendon distal to the MCP joint.
- Littler’s technique attaches the transferred tendon into the abductor pollicis brevis tendon.
- Bunnell’s method involves passing the tendon through a small drill hole made at the proximal phalanx base from the dorso-ulnar to palmar-radial direction to provide pronation of the thumb.

Dual attachment options

- These are designed to rotate (pronate) the thumb and either passively stabilize the MCP joint or minimize interphalangeal joint flexion.
- There is a theoretical benefit in patients with combined median and ulnar nerve deficits who lack all thumb intrinsic function.
- Some authors question the utility of dual insertion techniques since the transfer will only function predominantly on the tighter of the two insertions.

In Brand’s technique, one half is woven through the abductor pollicis brevis tendon and then passed distal to the MCP joint and attached to the extensor pollicis longus tendon.

In the Royle-Thompson method, a slip is passed through a drill hole made in the metacarpal neck, from radial to ulnar, with the metacarpal pulled into as much opposition as possible. This slip is tied to the other half that is initially passed dorsally over the extensor hood at the MCP joint and through a small tunnel in the fascia and periosteum at the base of the proximal phalanx.

High median nerve palsy requires additional restoration of thumb, index, and long finger flexion. On occasion, re-establishment of pronation is required.

Flexion of the index and long fingers can be accomplished by side-to-side transfers of the FDP tendons of the index and long to the ring and small. We transect the recipient tendons proximal to the wrist and weave them into the donor tendons.

Thumb flexion can be restored by transfer of the brachioradialis to the flexor pollicis longus.

Loss of pronation can be overcome by rerouting the biceps around the radius, which converts the biceps from a supinator into a pronator.

Positioning

- The patient is positioned supine on the operating table.
- The affected limb is abducted at the shoulder and placed on an attached hand table or armboard.

Approach

- The approach to opponensplasty for median nerve palsy depends on two factors: the donor tendon and the site of attachment.

TECHNIQUES

**Flexor Digitorum Superficialis Transfer (Authors’ Preferred Technique)**

- Make a palmar transverse skin incision over the first annular pulley of the ring finger.
- Identify the A1 pulley and incise it longitudinally. Isolate the FDS tendon.
- Apply traction to the FDS tendon to flex the proximal interphalangeal joint (TECH FIG 1A), and divide the FDS tendon transversely just proximal to its bifurcation while protecting the FDP tendon.
- Make a second zigzag incision at the volar ulnar distal forearm in the region of the flexor carpi ulnaris (FCU) tendon insertion.
- Isolate the FCU and the ring finger FDS tendons and protect the ulnar neurovascular bundle.
- Divide the radial half of the FCU tendon transversely about 4 cm proximal to its insertion onto the pisiform.

**LOW MEDIAN NERVE TRANSFERS**

TECH FIG 1 • A. Isolation of ring finger flexor digitorum superficialis (FDS) to be transferred for thumb opposition. (continued)
Pull the cut ring finger FDS tendon into the volar ulnar forearm incision and pass it through the constructed pulley (TECH FIG 1B).

- Make a third incision on the radial aspect of the thumb MCP joint.
- Create a subcutaneous tunnel between this incision and the wrist incision (TECH FIG 1C).
- Pass the ring FDS tendon through this tunnel to the thumb incision (TECH FIG 1D).
- Place the thumb into opposition with the small finger.
- Secure the FDS tendon to the thumb with a 3-0 or 4-0 braided polyester suture (TECH FIG 1E).
- The attachment sites usually include the abductor tendon plus or minus the dorsal capsule and extensor pollicis brevis tendon.
- Protect the ulnar sensory nerve to the small finger.
- Divide the ADM insertion sites, including a portion of the lateral band to increase its overall length.
- Dissect the muscle proximally to the pisiform (TECH FIG 2A).
- Release the origin from the pisiform; identify and protect the neurovascular bundle (on the dorsoradial side).
- Make a longitudinal incision on the radial aspect of the thumb MCP joint.
- Use blunt dissection to create a subcutaneous tunnel in the palm.
- Pass the ADM through the tunnel to the thumb MCP joint (TECH FIG 2B).
- Secure the ADM tendon to the thumb using 3-0 or 4-0 braided polyester suture (TECH FIG 2C).

**Abductor Digiti Minimi Transfer (Huber)**

- Make an oblique or zigzag incision beginning distally on the ulnar border of the small finger proximal phalanx, curving radially along the radial border of the hypothenar eminence.
- Separate the abductor digiti minimi (ADM) muscle from the flexor digiti minimi. Dissect the ADM distally to its insertion into the proximal phalanx and lateral band.

**TECH FIG 1 • (continued)**

B. Ring finger FDS passed through the flexor carpi ulnaris, which now serves as the pulley for the transferred tendon. C. Creation of the subcutaneous tunnel between the ulnar wrist and thumb incisions, through which the FDS tendon will be passed. D. Ring finger FDS tendon shown passing through both the flexor carpi ulnaris tendon and the subcutaneous tunnel. E. Suture fixation of the FDS tendon to the abductor tendon and extensor hood of the thumb. (Courtesy of Shriners Hospital for Children, Philadelphia.)

**TECH FIG 2 • A.** Isolated and dissected abductor digiti minimi (ADM) muscle-tendon unit, to be used for transfer for thumb opposition (Huber transfer). (continued)
Extensor Indicis Proprius Transfer\(^4\)

- Make a longitudinal incision on the dorsum of the index finger MCP joint.
- Locate the EIP tendon deep and ulnar to the extensor digitorum communis tendon to the index finger (TECH FIG 3A).
- Identify the EIP tendon along with the extensor hood.
- Divide the EIP tendon on the proximal edge of the extensor hood. The EIP tendon can be elongated by taking a 3- to 4-mm slip of extensor mechanism along the proximal phalanx. Repair the rent in the extensor hood with interrupted 4-0 braided polyester suture.
- Make a longitudinal incision on the dorso-ulnar aspect of the wrist, just proximal to the point where the dorsal sensory branch of the ulnar nerve crosses the ulnar styloid.
- Carry dissection from this incision radially until the proximal EIP tendon can be identified (just distal to the extensor retinaculum) (TECH FIG 3B).
- Divide the distal extensor retinaculum over the fourth compartment to release the EIP tendon.
- Bring the EIP tendon out through the ulnar wrist incision (TECH FIG 3C).
- Make another small longitudinal incision on the radial edge of the pisiform.
- Make a fourth incision over the thumb MCP joint.
- Create a subcutaneous tunnel from the ulnar wrist incision to the pisiform incision, then on to the thumb MCP joint incision, using blunt dissection.
- Pass the EIP tendon first through the pisiform incision, then on to the thumb incision (TECH FIG 3D).
- Suture the EIP tendon to the thumb using a 3-0 or 4-0 braided polyester suture.

**TECH FIG 2** (continued) B. Passage of the ADM muscle–tendon unit through the previously created subcutaneous tunnel to the thumb. C. Final position of thumb after suture fixation of the ADM to the thumb. Note opposition and palmar abduction. (Courtesy of Shriners Hospital for Children, Philadelphia.)

**TECH FIG 3**

A. Isolation of extensor indicis proprius (EIP) tendon ulnar and deep to the extensor digitorum communis tendon to the index finger. B. Wrist incision through which the proximal aspect of the EIP is found and isolated. C. The EIP tendon is brought out through the previously created ulnar wrist incision. D. Passage of EIP tendon through the subcutaneous tunnel between ulnar wrist incision and thumb incision.
Chapter 74 TENDON TRANSFERS FOR MEDIAN NERVE PALSY

HIGH MEDIAN NERVE TRANSFERS

Palmaris Longus Transfer (Camitz10)

- Confirm the presence of a palmaris longus (PL) tendon by having the patient attempt to oppose the thumb to the small fingertip with the wrist flexed.
- Make a longitudinal incision beginning at the distal wrist crease and continuing distally to the proximal palmar crease. This incision may be “zigzagged” at the wrist to prevent scar contracture.
- Dissect the PL tendon proximally to distally.

Brachioradialis Transfer

- Make a long radial incision from the radial styloid to the brachioradialis muscle belly.
- Release the brachioradialis tendon from the radial styloid and mobilize it along the forearm to optimize available excursion (TECH FIG 4).7
- Identify the flexor pollicis longus tendon deep to the flexor carpi radialis tendon.
- Weave the harvested brachioradialis tendon into the flexor pollicis longus using a tendon braider and multiple weaves.
- Determine proper tension of the transfer by placing the wrist in flexion and extension and judging tenodesis lateral pinch position and thumb release, respectively.

- Take a small (about 1 cm square) patch of palmar aponeurosis along with the PL tendon.
- Make an incision over the dorsum of the thumb MCP joint.
- Create the subcutaneous tunnel between the PL tendon and the MCP joint with blunt dissection.
- Pass the PL tendon through the tunnel to the thumb incision.
- Finally, secure the PL tendon to the thumb with 3-0 or 4-0 braided polyester suture.

Biceps Rerouting

- Biceps rerouting is our preferred technique for supple supination deformities of the forearm to correct the forearm position and to apply a pronation moment.
- Surgery is performed under general anesthesia and an upper arm tourniquet is used. The upper extremity is prepared and draped in the usual sterile fashion. The limb is exsanguinated and the tourniquet inflated.
- Design a Z-incision with a horizontal limb across the antecubital fossa (TECH FIG 5A).
- Identify the lateral antebrachial cutaneous nerve lateral to the biceps tendon and protect it (TECH FIG 5B).
- Isolate the biceps tendon and incise the lacertus fibrosis while protecting the underlying median nerve and brachial artery.

TECH FIG 4 • Brachioradialis harvested as donor for transfer to the flexor pollicis longus tendon (red loop) to restore lateral pinch. (Courtesy of Shriners Hospitals for Children, Philadelphia.)

TECH FIG 5 • A. Skin incision for biceps rerouting. B. Isolation of the biceps tendon and lacertus fibrosis. The lateral antebrachial cutaneous nerve is just lateral to the tendon. (continued)
Trace the biceps tendon to its insertion into the radial tuberosity by careful dissection and placement of the forearm into supination (TECH FIG 5C).

Plan a Z-plasty of the biceps tendon along its entire length to ensure sufficient tendon length for passage around the radius (TECH FIG 5D).

Leave the distal Z-plasty attached to the insertion site and leave the proximal Z-plasty attached to the muscle belly (TECH FIG 5E).

Carefully reroute the distal attachment around the radius through the interosseous space to create a pronation force. A curved clamp, such as a Deborah cast clamp or Castaneda pediatric clamp, facilitates tendon passage (TECH FIG 5F,G).

Protect the supinator muscle and posterior interosseous nerve to prevent injury.

Place the elbow in 90 degrees of flexion and the forearm in pronation. Repair the rerouted distal tendon back to the proximal tendon that is still attached to the biceps muscle using a tendon weave augmented by nonabsorbable suture (TECH FIG 5H).

Close the subcutaneous tissue and skin in routine fashion. Apply a long-arm cast with the elbow in 90 degrees of flexion and the forearm in pronation. The cast is worn for 5 weeks.
POSTOPERATIVE CARE

- A bulky hand dressing and short-arm plaster splint is placed with the wrist in flexion and the thumb in full opposition.
- Immediate hand therapy commences to maintain motion in the fingers, especially the ring finger after FDS harvest.
- If the ring finger tends to position into flexion, a proximal interphalangeal joint extension splint is fabricated for nighttime wear.
- In contrast, a ring finger that tends to swan-neck secondary to loss of the FDS tendon requires a silver ring splint to prevent deformity until the remaining FDS scars along the volar aspect of the proximal interphalangeal joint.
- After 2 to 3 weeks, the plaster splint is removed and therapy is initiated. Longer periods of immobilization may yield scarring of the FDS tendon within the reconstructed pulley.
- An Orthoplast splint is fabricated to maintain mild wrist flexion and thumb opposition. The splint is removed four to six times a day to encourage tendon gliding exercises and retraining of the transferred tendon.
- Similar occupational therapy principles are applied after other opposition transfers as described, including the palmaris longus, EIP, abductor digiti minimi, and other transfers.

OUTCOMES

- In general, opposition transfers are successful: most patients regain opposition adequate to perform normal daily activities such as writing, buttoning clothes, and other fine manipulation tasks (FIG 2).9
- Burkhalter et al2 reported excellent results in 57 of 65 cases of EIP opponensplasty; excellent results were defined as those with 75% function compared to the opposite normal thumb or those with less than a 20-degree difference between the plane of the opposite thumbnail and the plane of the palm with good power.
- Jacobs and Thompson,5 using a variety of donor tendons (mainly FDS IV and FDS III tendons), pulley designs, and insertion techniques, reported 77 good or excellent, 9 fair, and 17 poor results. Similar results were obtained with the FDS IV and FDS III tendons.
- In a comparison of FDS versus EIP opponensplasty, Anderson et al1 compared 50 EIP to 116 FDS ring finger opponensplasty cases. Their analysis demonstrated that the EIP opponensplasty was best in supple hands, while the FDS opponensplasty was more suitable in less pliable hands.

COMPLICATIONS

- Suboptimal transfer outcome due to stiff joints
- Selection of suboptimal or weak muscle–tendon unit for transfer
- Incorrect vector of pull due to lack of or poor selection of pulley
- Rupture of transferred tendon
- Tendon adhesions
- Loss of grip strength after FDS ring finger transfer
- Difficulty with muscle–tendon re-education, especially with tendon transfers that are not synergistic. For example, EIP transfer is more difficult to learn compared to FDS tendon transfer.

REFERENCES

DEFINITION
- Ulnar nerve palsy refers to loss of sensory and motor function after injury to the ulnar nerve above or below the wrist (high vs. low ulnar nerve palsy).

ANATOMY
- The ulnar nerve is the terminal branch of the medial cord (C8 and T1).
- The ulnar nerve consists of motor and sensory fibers. There are no muscles innervated by the ulnar nerve in the arm. In the forearm, the flexor carpi ulnaris receives its nerve branches after the ulnar nerve passes through the cubital tunnel. The other muscles innervated in the forearm are the flexor digitorum profundus of the ring and small fingers.
- The muscles innervated in the hand (by order of innervation) are:
  - Hypothenar muscles
    - Abductor digiti minimi
    - Flexor digiti minimi
    - Opponens digiti minimi
  - Ring and small lumbricals
  - Dorsal and palmar interosseous muscles
  - Adductor pollicis
  - Deep head of flexor pollicis brevis
  - First dorsal interosseous (last muscle innervated by the ulnar nerve)
- The sensory fibers of the ulnar nerve supply the small finger and the ulnar half of ring finger over the entire palmar surface and the dorsal surface distal to the proximal interphalangeal (PIP) joint. The dorsal surface proximal to the PIP joint of the small finger and the ulnar half of the ring finger and ulnar dorsal of the hand is innervated via the dorsal sensory branch of the ulnar nerve, which arises from the ulnar nerve 7 cm proximal to the wrist. The sensory branch crosses from volar to dorsal at the level of the ulnar styloid.

PATHOGENESIS
- Ulnar nerve palsy can arise from a laceration anywhere along its course. Proximal injuries to the medial cord may present with additional sensory loss in the distribution of the medial brachial or antebrachial cutaneous nerves. Nerve compression typically occurs either at the cubital tunnel at the elbow or the canal of Guyon at the wrist.
- A variety of systemic conditions may mimic ulnar neuropathy, including Charcot-Marie-Tooth disease, syringomyelia, and leprosy. In Charcot-Marie-Tooth disease and syringomyelia, there is weakness involving other nerves. In leprosy, there is a profound loss of sensation in the ulnar nerve distribution in addition to the claw deformity of the fingers.

NATURAL HISTORY
- The severity of the nerve palsy depends on the degree of the nerve lesion and the presence of anomalous innervation patterns (Martin-Gruber, Riche-Cannieu) in determining the number of muscles involved and the extent of palsy. Anomalous innervation patterns can confuse the examiner.
- Martin-Gruber anastomosis patterns are divided into four types:
  - Type I (60%): motor branches from the median nerve are sent to the ulnar nerve to innervated “median” muscles
  - Type II (35%): motor branches from the median nerve are sent to the ulnar nerve to innervated “ulnar” muscles
  - Type III (3%): motor branches from the ulnar nerve are sent to the median nerve to innervated “ulnar” muscles
  - Type IV (1%): motor branches from the ulnar nerve are sent to the median nerve to innervated “median” muscles
- With prolonged nerve palsy, secondary abnormalities of the hand occur, such as stretching of the central slip of the extensor mechanism at the PIP joint or fixed joint flexion contractures.

PATIENT HISTORY AND PHYSICAL FINDINGS
- An important point is to identify the cause and timing of palsy to determine whether the pathology can be reversed. Treatment is first addressed at improving nerve function by procedures such as decompression of a compressed nerve or acute repair of a lacerated nerve. Recovery can be gauged by progression of symptoms, such as advancing Tinel sign, return of muscle function, and return of sensation. Tendon transfers are indicated when nerve recovery is not expected or possible.
- Loss of sensation in the medial arm or forearm indicates a proximal lesion. Loss of sensation to the dorsal side of the ulnar hand indicates a lesion proximal to the wrist to affect the dorsal sensory branch.
- The following specific tests of motor dysfunction are used to determine the functional loss of the hand:
  - Froment sign: hyperflexion of thumb interphalangeal joint (FIG 1A); indicates substitution of flexor pollicis longus (median nerve) for adductor pollicis (ulnar nerve)
  - Jeanne sign: reciprocal hyperextension of thumb metacarpophalangeal (MCP) joint (Fig 1A); indicates substitution of flexor pollicis longus for adductor pollicis
  - Wartenberg sign: abduction of small finger at MCP joint; indicates paralyzed palmar intrinsic muscle (ulnar nerve) with abduction from extensor digiti minimi (radial nerve)
  - Duchenne sign: clawing of ring and small fingers, hyperextension of MCP joints, and flexion of PIP joints (FIG 1B); indicates paralysis of interosseous and lumbrical muscles of the ring and small fingers (low ulnar nerve), more pronounced in low rather than high ulnar nerve palsy secondary
to functioning flexor digitorum profundus of ring and small fingers (high ulnar nerve)
- Bouvier maneuver: inability to actively extend PIP joint when MCP joints are hyperextended and ability to actively extend PIP joint when MCP joints are blocked from hyperextension (FIG 1C,D). When active PIP joint extension is possible with the MCP joints blocked, this indicates competence of the central slip (positive test). When PIP joints cannot actively extend (negative test), this implies central slip attenuation. In this case, tendon transfers will need to block MCP joint hyperextension and provide PIP joint extension.
- Andre-Thomas sign: clawing of ring and small fingers, hyperextension of MCP joints and flexion of PIP joints, flexion of wrist (Fig 1C). An increase in the claw deformity as the patient tries to extend the fingers by flexing the wrist indicates a poor prognosis for tendon transfer surgery.
- Masse sign: flattening of the metacarpal arch (Fig 1B); inability to oppose the small finger carpometacarpal joint
- Pollack sign: inability to flex the distal interphalangeal joint of the ring and small fingers; used to differentiate high from low ulnar nerve palsy
- In assessing for tendon transfers in ulnar nerve palsy, the primary functional concerns are:
  - Lack of thumb adduction and lateral pinch
  - Claw deformity of fingers that impairs object acquisition and grip
  - Loss of ring and small finger flexion (high palsy)

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Electromyographic and nerve conduction velocity studies are used to isolate the ulnar nerve pathology and rule out other diagnoses. Serial studies may demonstrate the potential for recovery.

**DIFFERENTIAL DIAGNOSIS**
- Cervical radiculopathy
- Lower brachial plexopathy
- Charcot-Marie-Tooth disease

**NONOPERATIVE MANAGEMENT**
- When the Bouvier test is positive (active PIP joint extension is possible when MCP joint hyperextension is prevented), a dorsal MCP blocking splint for the ring and small fingers is fabricated to preserve the integrity of the PIP joint central slips.
- If a fixed flexion contracture of more than 45 degrees occurs at the PIP joint, a supervised hand therapy program consisting of serial casting is required.
- If the fixed flexion contracture does not respond to therapy, preliminary surgical joint release is necessary before tendon transfers.

**SURGICAL MANAGEMENT**
- Tendon transfers address the primary functional concerns listed above:
  - Lack of thumb adduction and lateral pinch
  - Claw deformity of the fingers that impairs object acquisition and grip
  - Loss of ring and small finger flexion (high palsy)

**Considerations**

**Restoring Thumb Adduction**
- The first factor to consider in performing a transfer to restore thumb adduction is what donor muscle to use.
  - The extensor carpi radialis brevis (ECRB) and the flexor digitorum superficialis (FDS) are the most commonly used.
  - The FDS of the ring finger can be used in low ulnar nerve palsy when the flexor digitorum profundus of the ring finger is functioning.
  - In high ulnar nerve palsy, the FDS of the middle finger can be used instead of the FDS of the ring finger.
  - The brachioradialis can be used if the ECRB is required for an intrinsic reconstruction of the fingers.
  - Alternatively, the extensor indicis proprius or abductor pollicis longus can be used.
The second factor to consider is placement of the pulley.
- For transfers coming from the dorsum of the hand, the pulley is either the index or middle finger metacarpal. Passing the transfer through the third web space, using the middle metacarpal as the pulley, allows the transferred tendon to lie palmar to the adductor pollicis but dorsal to the flexor tendons and neurovascular bundles.
- For transfers originating from the palm of the hand (FDS), the vertical septum of the palmar fascia attached to the third metacarpal forms the pulley.
- The third factor is attachment of the transfer to the thumb.
  - The transfer can be inserted directly into the thumb metacarpal, into the adductor pollicis tendon, or into the abductor pollicis brevis tendon.
  - This last technique, favored by Omer, allows the tendon to be sewn to the strong fascia abductor pollicis longus tendon and improves pronation of the thumb to aid in pinch.
- The last factor to address is stability of the MCP and interphalangeal joints.
  - For patients with a persistent Froment sign and mild hyperextension of the MCP joint, the split flexor pollicis longus to extensor pollicis longus tenodesis will stabilize the interphalangeal joint without fusion.
  - When the MCP joint shows substantial instability or arthritic changes, it should be fused.

**Correcting Claw Deformity of Fingers**
- Procedures to correct MCP hyperextension may be either static or dynamic.
  - A static procedure prevents hyperextension of the MCP joint, improving extension of the fingers. The Bouvier maneuver must be positive. The disadvantage of static procedures, either the MCP volar capsulodesis or tenodesis procedure, is that they tend to stretch with time.
  - A dynamic transfer uses the FDS, extensor carpi radialis longus, ECRB, or flexor carpi radialis as a donor muscle.
  - If the Bouvier maneuver is positive, there is no need to restore PIP joint extension.
  - If the Bouvier maneuver is negative, the procedure must address both MCP joint flexion and PIP joint extension. The insertion site of the tendon transfer determines which joints are affected by the transfer.
- FDS transfers for finger clawing
  - Advantages
    - No need for tendon graft
    - Not passing tendon through interosseous spaces or through carpal tunnel
  - Disadvantages
    - Does not increase grip strength
    - High incidence of swan-neck deformities
    - Cannot use FDS of ring and small fingers in high ulnar nerve palsy
    - Wrist motors for transfers for finger clawing
      - Advantage: increases grip strength
      - Disadvantages
        - Requires tendon graft, either palmaris longus, plantaris, fascia lata, or toe extensor
        - Passes tendon through interosseous spaces or through carpal tunnel

**Restoring Ring and Small Finger Extrinsic Muscle Function**
- In patients with high ulnar nerve palsy, it is important to restore extrinsic flexion power before performing intrinsic transfers.
- Claw deformity of the ring and small fingers will worsen after these transfers.

**Preoperative Planning**
- Tendon transfers are indicated when no further nerve recovery is anticipated.
- In evaluating a patient for tendon transfer procedures, the examiner assesses the number of functions lost, determines the number of muscles available for transfer, and assesses the strength and excursion of each of the donor and recipient muscles.
- When there are insufficient donor muscles to substitute for all functions that are lost, tenodesis and arthrodesis procedures may partially substitute for the lost function.
- There should be no fixed flexion contractures of the joints affected by the transfers.
- The transferred tendons need to be placed in a smooth, scar-free bed to glide.
- The principle of “one muscle and one function” should apply to each tendon transfer.

**Positioning**
- The patient is supine with the arm abducted on an arm table.

**Approach**
- All transfers for thumb adduction must pass distal to the pisiform.
- All transfers for intrinsic reconstruction must pass palmar to the axis of rotation of the MCP joint and dorsal to the axis of the PIP joint.

### TRANSFERS TO RESTORE THUMB ADDUCTION

**Brachioradialis Extended With Tendon Graft, Through Third Web Space, Inserted into Abductor Pollicis Brevis Tendon**
- Make an incision between the flexor carpi radialis tendon and the radial artery beginning at the wrist crease and extending to the proximal third of the forearm.
- Dissect free of fascia the brachioradialis tendon and its muscle 7 to 10 cm proximal to the musculotendinous junction.
- Extend the tendon with a palmaris longus graft. Use a three-pass Pulvertaft weave to secure the palmaris longus graft to the brachioradialis tendon (TECH FIG 1A).
- Make incisions over the radial thumb MCP joint and in the third web space, both palmar and dorsal.
- Sew a tendon graft, using one slip of the abductor pollicis longus tendon, in a three-pass Pulvertaft fashion into the abductor pollicis brevis tendon.
Pass the tendon palmar to the adductor pollicis but dorsal to the flexor tendons and neurovascular bundles, as identified through the palmar incision over the third web space (TECH FIG 1B).

Use the tendon passer to bring the graft from palmar to dorsal, using the proximal metaphysis of the third metacarpal as the pulley (TECH FIG 1C).

Bring the tendon graft from the brachioradialis to the dorsum of the hand and perform the final Pulvertaft weave (TECH FIG 1D).

Set tension to allow the thumb to rest palmar to the index finger when the wrist is in neutral.

Take care to weave the tendons proximally enough on the hand such that the weave does not enter the third web space.

Tension on the graft will pull the thumb into adduction (TECH FIG 1E,F).

**Split Flexor Pollicis Longus to Extensor Pollicis Longus Tenodesis**

Make an incision along the radial proximal phalanx of the thumb. Identify the flexor pollicis longus (FPL) and extensor pollicis longus tendons. Take care to preserve the oblique pulley.
Identify the natural cleft between the radial and ulnar fibers of the FPL and split the tendon (TECH FIG 2A).

Weave the radial half of the FPL tendon into the extensor pollicis longus tendon (TECH FIG 2B, C).

Pin the interphalangeal joint in extension with a 0.045-inch smooth pin.

**TENDON TRANSFERS FOR CLAW DEFORMITY OF FINGERS**

**Zancolli Lasso**
- This operation is indicated when there is a positive Bouvier maneuver.
- Make a midpalm Bruner zigzag incision.
- Incise the tendon sheath between the A-1 and A-2 pulleys. Identify the FDS tendon and transect it just proximal to the bifurcation. Leaving the bifurcation intact will decrease the incidence of PIP hyperextension.
- Zancolli recommends using the FDS of each finger, but Anderson recommends using the FDS of the middle finger, split into four tails, to control MCP flexion of all four fingers.
- Pull the FDS tendon out of the tendon sheath distal to the A-1 pulley, bring it palmar to the A-1 pulley, and sew it to itself proximal to the A-1 pulley. If insufficient MCP flexion is attained, the tendon exits the pulley sheath in the middle of the A-2 pulley to improve the lever arm of the transfer.
- Set tension so the MCP joint is in 40 to 50 degrees of flexion with the wrist in neutral.
- When one FDS tendon is used for all four fingers, transect the FDS middle tendon distal to the A-2 pulley through an oblique incision on the finger.
- Make a transverse midpalm incision, retrieve the tendon, and split it into four tails.
- Pass each tail down the lumbrical canal, palmar to the deep transverse metacarpal ligament and into the flexor sheath proximal to the A-1 pulley. Pass the tendon around the pulley and sew the distal end of the tendon back to itself proximal to the A-1 pulley, tensioning it while the MCP joint is in 40 to 50 degrees of flexion with the wrist in neutral.
- For either the Zancolli or Anderson technique, the tendon may be sewn to the proximal metaphyseal-diaphyseal junction of the proximal phalanx via suture anchors or pullout drill holes.

**Stille Bunnel Transfer**
- This technique is indicated when the Bouvier maneuver is negative.
- One FDS tendon is used to motor two digits. Make radial midaxial incisions over the proximal phalanges of the digits. Make a midpalmar incision to retrieve the tendon. Cut the FDS ring tendon just proximal to its bifurcation between the A-1 and A-2 pulleys.
- Split the tendon and pass each half down the lumbrical canal. Pass the tendon passer from distally to proximally, going palmar to the deep transverse intermetacarpal ligament.
- Sew the tendon to the lateral band to restore PIP extension. Set tension with the MCP joint in 40 to 50 degrees of flexion and the PIP joints in full extension with the wrist in neutral. Excessive tension will cause PIP hyperextension.

**Dorsal Route Transfer of Extensor Carpi Radialis Brevis**
- Make radial midaxial incisions over the proximal phalanges of the digits.
- Pass the tendon passer from distally to proximally, going palmar to the deep transverse intermetacarpal ligament.
- For the ring and small fingers, make an incision in the dorsal fourth web space to retrieve the tendon grafts (TECH FIG 3A).
- Sew the distal end of the tendon graft to the proximal metaphyseal-diaphyseal junction of the proximal phalanx via suture anchors or pullout drill holes if the Bouvier maneuver is positive. Tension on the tendon graft will produce MCP flexion (TECH FIG 3B).
If the Bouvier maneuver is negative, attach the graft to the radial lateral band of the middle, ring, and small fingers and the ulnar lateral band of the index finger.

Retrieve the ECRB tendon through a dorsal incision. Bring the tendon grafts through the same wound. First sew the grafts to each other, synchronized to obtain even pull through the grafts. Then sew the grafts to the ECRB tendon with the wrist in 30 degrees of extension and the MCP joints in 60 degrees of flexion.

TRANSFER OF FLEXOR DIGITORUM PROFUNDUS RING AND SMALL TO FLEXOR DIGITORUM PROFUNDUS MIDDLE (HIGH ULNAR NERVE PALSY)

Make a longitudinal incision over the distal third of the forearm. After synchronizing the long, ring, and small tendons, place two rows of horizontal sutures between the three tendons.

PEARLS AND PITFALLS

**Evaluation**

- Differentiate high from low ulnar nerve palsy.
- Determine the potential for nerve and muscle recovery.
- Critically assess the strength of the donor muscles.
- Determine the integrity of the PIP central slip (Bouvier maneuver).
- Have the patient prioritize functional impairment.

**Adductorplasty**

- Assess both adduction and opposition.
- Dorsal transfers passed through the third web space allow for strong adduction using a wrist extensor or the brachioradialis muscle.
- Hyperextension of the MCP joint and hyperflexion of the interphalangeal joint must be addressed with either a capsulodesis and fusion of the MCP joint or a split FPL tenodesis. Both the MCP and interphalangeal joints should not be fused.

**Claw finger deformities**

- Determine the integrity of the PIP central slip (Bouvier maneuver).
- When the Bouvier maneuver shows that the PIP central slip is competent, the tendon transfer should be sewn to the proximal phalanx or the pulleys. If the central slip is not competent, the tendon transfer is sewn into the lateral band.
- Transfers need to pass palmar to the axis of rotation of the MCP joints.

POSTOPERATIVE CARE

- A knowledgeable hand therapist plays an important role in the postoperative care of tendon transfers for ulnar nerve palsy. Protecting the transfers with well-made splints while mobilizing uninvolved joints requires strict adherence to postoperative protocols.
- For most procedures, the hand is immobilized for 3 weeks, followed by a blocking splint to allow motion within the restraints of the splint for the next 3 weeks.
Passive exercises are begun at 6 weeks and strengthening at 8 weeks for the adductorplasty and at 10 to 12 weeks for the intrinsic tendon transfers.

OUTCOMES

- After tendon transfers for thumb adduction, pinch strength usually improves to 25% to 50% of normal.
- Tendon transfers to improve intrinsic function maintain good to excellent correction of the claw deformity in 80% to 90% of patients.
- Only the ECRB transfer improves grip strength.

COMPLICATIONS

- More complications occur after intrinsic muscle transfers than adductorplasty because of the delicate balance of the extensor hood mechanism.
- Transfer not strong enough
  - Problems include choice of a muscle with insufficient strength or excursion, use of a soft tissue pulley that stretched, or elongation at the tendon transfer site.
  - Elongation is a particular problem with sewing the transfer into the lateral bands of the extensor hood.
  - Patients with this transfer must be instructed on not hyperextending the MCP joints.
  - Transfers that are not strong enough can be treated with a therapy program to strengthen the muscle but often require surgical revision.
- Transfer too strong
  - Problems include choice of a muscle that is too strong or with too short of an excursion, or sewing the transfer in with too much tension.
  - When the transfer is sewn too tightly into the lateral band, it can produce a swan-neck deformity of the digit.

- Transfers that are too tight can be treated with passive range of motion in therapy, trying to stretch the transfer.

REFERENCES

DEFINITION
- Radial nerve palsy that is distal to the triceps innervation affects the forearm musculature. A lesion that does not recover results in predictable wrist, finger, and thumb extensor deficits.

ANATOMY
- The brachioradialis and forearm extensor musculature originate in the lateral humeral epicondyle and the interosseous membrane (FIG 1A).
  - Each of the extensor muscles has a relatively flat muscle belly before forming a flat, broad tendon.
  - The myotendinous junction for the wrist extensors is in the mid-forearm, whereas the myotendinous junction of the finger and wrist extensors is the distal forearm.
- The radial nerve arises from the posterior cord of the infraclavicular brachial plexus (FIG 1B). Multiple triceps motor branches are present as the nerve courses in the posterior compartment of the upper arm. The nerve traverses into the anterior compartment through the intramuscular septum. The nerve then lies between the brachialis and brachioradialis before it enters the forearm. The brachioradialis (BR), extensor carpi radialis longus (ECRL), and extensor carpi radialis brevis (ECRB) are innervated as the nerve divides into the deep radial nerve, the posterior interosseous nerve (PIN), and the superficial radial nerve. The PIN innervates the extrinsic extensors after exiting the supinator musculature.
  - The motor point for each nerve is fairly consistently located just proximal to the myotendinous junction. In most cases, there is one larger motor branch from the radial nerve or PIN to each muscle.
  - The sequence of muscle innervation is an important distinction when considering the anatomy of the radial nerve. Whereas some nerves distribute their nerve branches in a tree-like fashion, the radial nerve innervates the extensor compartment...
musculature in an orderly pattern, from proximal to distal. The proper radial nerve supplies the BR, the ECRL, and occasionally the ECRB. The PIN innervates the ECRB, the extensor digitorum communis (EDC), the extensor carpi ulnaris (ECU), the extensor indicis proprius (EIP), and the extensor pollicis longus (EPL).

- The order of innervation is important in differentiating a radial nerve injury from a mechanical myotendinous injury or muscle disruption after a forearm laceration.
- Understanding the innervation also is helpful while observing and assessing the clinical recovery after radial nerve injury or repair.

PATHOGENESIS
- Most radial nerve deficits result from traumatic injuries. Idiopathic and neoplastic etiologies are less common.
- Radial nerve injury is most commonly associated with mid-to-distal shaft humerus fractures.1,4,24,25,28

NATURAL HISTORY
- The type of traumatic injury is an important predictor of recovery after humerus trauma.
- Neurapraxic lesions typically result from low-energy injuries. Recovery can be expected over the course of 3 months. The clinical recovery can be followed by observing the advancing Tinel sign and the reinnervation sequence.
- Conditions that persist after 3 months can be further evaluated with electrodiagnostic studies. In the clinical setting of a nonadvancing Tinel sign and electromyographic findings of axonal loss, exploration with intraoperative electrophysiologic testing is warranted. Nerve grafting across the injury is indicated in lesions that do not demonstrate improvement after external neurolysis.18,24,25
- Exploration of open and penetrating injuries is recommended. The choice of primary repair or nerve grafting depends on the injury zone. Recent evidence warrants exploration of high-energy injuries, because these lesions have not demonstrated recovery. It is difficult to determine the injury at the acute setting. Interposition nerve graft is often necessary.18

PATIENT HISTORY AND PHYSICAL FINDINGS
- A deficit in radial nerve innervation of the extrinsic wrist and finger extensors results in no active wrist, finger, and thumb extension.
- The clinical presentation of radial and PIN palsies is differentiated by the fact that the brachioradialis and ECRL are preserved in PIN palsies.
- The brachioradialis can be palpated during resisted, neutral position elbow flexion, and the wrist assumes a radial deviated position during attempted active extension.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Electrodiagnostic studies (eg, nerve conduction studies and electromyography) are used initially for assessment and for determining subsequent treatment.
- Axonal loss injuries are evident about 4 weeks after the injury; therefore, the initial study is obtained 4 to 6 weeks after the injury.
- The electrodiagnostic study also can identify other nerve injuries that were not as evident on the initial evaluation.
- Recovery can be followed by clinical examination or with supplemental studies.
- A final study is obtained before tendon transfer at 12 to 18 months.

DIFFERENTIAL DIAGNOSIS
- Muscle or tendon laceration
- Closed myotendinous rupture
- Cervical spinal disease
- Joint or tendon subluxation (especially if there is lost digital extension)

NONOPERATIVE MANAGEMENT
- Splint
- Active and passive motion exercises to maintain motion and prevent contracture28

SURGICAL MANAGEMENT
- Tendon transfer is the mainstay of treatment. Microvascular repair and nerve graft are discussed in another chapter.
- The goal of treatment is independent wrist, finger, and thumb extension with thumb abduction. Donor muscles include the pronator teres (PT), flexor carpi ulnaris (FCU), flexor carpi radialis (FCR), flexor digitorum superficialis (FDS) 3 and 4, and palmaris longus (PL).
- Timing of surgical intervention is controversial. Conventional surgical recommendations are to proceed after the patient has reached a documented clinical and electromyographic plateau of useful radial nerve regeneration. This typically occurs 1 year after the nerve lesion.25
- Tendon transfer primarily for wrist extension may be performed early, at the same setting as nerve surgery, to improve function and minimize brace reliance as the nerve regenerates.

Preoperative Planning
- Prerequisites
  - MHC grade 4+ or 5 median or ulnar nerve–innervated donor musculature
  - Maintained passive motion in wrist and finger extension with no contracture
  - Controlled systemic disease processes

Positioning
- The patient is positioned supine with arm table support and a tourniquet.

Approach
- Three general exposures are used:
  - Radial incision with volar exposure for FCR and PT and dorsal exposure for the ECRB and ECRL
  - Distal, dorsal incision for EDC exposure
  - Individual approaches for harvest of the FCU, FCR, and FDS
- The ideal tendon transfer tension is based on the individual muscle properties. In general, the optimal tension is established at the peak of the length–tension curve for the donor muscle, while the wrist and fingers are maintained in the ideal position. Because this donor muscle position is difficult to determine intraoperatively without specialized equipment, this point reasonably corresponds to the midpoint of the passive muscle excursion. The ideal joint position for each transfer is discussed with the individual transfers.
WRIST EXTENSION RESTORATION THROUGH PT TO ECRL AND ECRB²,⁸,²⁷

- Make a longitudinal radial incision over the midshaft of the radius.
  - This allows exposure of the PT and the wrist extensors through a single incision.
- Identify and expose the PT volarly while protecting the radial artery and superficial radial nerve (TECH FIG 1A).
- Extend the pronator insertion by harvesting a strip of periosteum distally (TECH FIG 1B).
- Release the proximal muscle to improve its excursion (TECH FIG 1C).
- Develop the dorsal subcutaneous flap and identify the ECRB and ECRL.
- Deliver the PT dorsally, deep to the brachioradialis (TECH FIG 1D).
- Perform a Pulver-Taft weave into the ECRL and ECRB, and then secure the transfer with 2-0 or 3-0 nonabsorbable braided suture (TECH FIG 1E, F).

FINGER EXTENSION THROUGH FCU TO EDC TRANSFER⁷,¹⁶,¹⁹,²⁰

- Make a distal, volar longitudinal incision to expose the FCU insertion at the pisiform (TECH FIG 2A).
- Identify the ulnar neurovascular structures.
- Extend the exposure proximal to a point 8 cm from the humeral insertion and release the FCU periosteal attachments as necessary to improve excursion (TECH FIG 2B).
- Develop a broad subcutaneous dorsal flap to improve the ECU line of pull to the EDC (TECH FIG 2C). The ECU may be placed beneath the most superficial subcutaneous fascial layer.
Chapter 76 TENDON TRANSFERS FOR RADIAL NERVE PALSY

TECHNIQUES

■ Trim distal muscle and, if necessary, the tendon to enable passage of tendon into the EDC (TECH FIG 2D,E).
■ Make a dorsal longitudinal incision 5 to 7 cm long in the retinaculum of the distal forearm.
■ Release the proximal extensor retinaculum to permit excursion after transfer.
■ Perform a single or double weave into the EDC tendons. Locate the point of insertion into each slip that recreates the normal finger cascade (TECH FIG 2F).

■ The final transfer tension is set with the metacarpophalangeal joints in full extension while the wrist is in 30 degrees of extension.
■ Secure finger extensor transfers with 3-0 or 4-0 nonabsorbable braided sutures.

FINGER EXTENSION THROUGH FCR TO EDC TRANSFER7,9,12

■ Use volar radial exposure to identify the radial artery and the FCR (TECH FIG 3A).
■ Incise the FCR sheath and transect the tendon while maintaining the wrist in flexion.
■ Two different passage techniques may be chosen.
  ■ In the first, a subcutaneous tunnel to the dorsal incision (similar to the FCU transfer) is developed (TECH FIG 3B,C), and the FCR is passed beneath the superficial radial nerve to the EDC.
  ■ In the second, the FDS and median nerve are retracted ulnarly to identify the anterior interosseous nerve and the interosseous membrane proximal to the pronator quadratus (TECH FIG 3D–F), and the FCR tendon is passed volar-to-dorsal through an enlarged opening in the IOM (TECH FIG 3G,H). Be cautious of the anterior interosseous nerve.
  ■ Do not violate the central band.
■ Tension, weave, and suture into EDC, as with FCU transfer (TECH FIG 3I,J).
THUMB EXTENSION THROUGH PL TO EPL

- Identify the palmaris longus at the wrist crease through the same incision described for exposure of the FCR (TECH FIG 4A).
- Dissect and divide the proximal fascial bands to facilitate harvest (TECH FIG 4B).
- Develop a subcutaneous tunnel to the dorsal thumb below the cutaneous nerves.
- The EPL may be addressed in either of two ways:
  - Release the EPL from the third compartment to facilitate transfer location. This technique permits the muscle-tendon connection to remain intact if radial nerve recovery is possible (TECH FIG 4C).
  - Divide the EPL proximally (only if recovery is not possible) and perform the transfer in a more volar location. The thumb extension vector is improved with the transfer in this location.
- Set the tension at the level of the thumb metacarpal with the wrist in neutral and close to maximum tension on the PL and EPL (TECH FIG 4D,E).
- Secure the weave with 3-0 or 4-0 nonabsorbable braided suture.
Chapter 76  TENDON TRANSFERS FOR RADIAL NERVE PALSY

TECH FIG 4  •  A. This approach was combined with a FCR–EDC transfer with identification of the PL through the same exposure. B. Adhesions are released allowing tendon mobilization. C. The EPL is left intact, transposed volarly, and prepared for transfer at the level of the thumb metacarpal. D, E. The Pulvertaft weave is initiated and completed once proper tension is set.

MODICATION: FINGER EXTENSION AND THUMB ABDUCTION THROUGH LONG FINGER FDS TO EIP/EPL; RING FINGER FDS TO LONG, RING, AND SMALL EDC; AND PL TO ABDUCTOR POLLICIS LONGUS

- Perform oblique palmar incisions to harvest the FDS of the long and ring fingers.
- Include both slips for transfer.
- Suture the remaining distal tendon to the volar plate or soft tissue to prevent proximal interphalangeal hyperextension.
- Use the volar incision to retrieve the FDS tendons and to harvest the PL.
- Precisely expose the interosseous membrane (IOM) and make preparations for tendon transfer as discussed in the preceding section.
- Perform a dorsal incision and exposure similar to that detailed in the preceding section. Transfer the two FDS tendons dorsally through the IOM.
- The long finger FDS is transferred to the EIP and the EPL. The ring finger FDS is transferred to the long, ring, and small EDC tendons.
- Set tension at the wrist at 30 degrees and at the MP joint at full extension.
- Secure the transfer with 3-0 or 4-0 suture.
- The PL is harvested as detailed for the EPL transfer.
- The radial subcutaneous route also is used to transfer the PL to the abductor pollicis longus (APL), proximal to the retinaculum.
- The location of this transfer is slightly more proximal to the PL than the EPL transfer due to the length available for the APL.
- Set tension in near-full thumb abduction at wrist 30 degrees; secure with 3-0 or 4-0 suture.

FINGER EXTENSION AND THUMB ABDUCTION THROUGH FCU TO EDC AND EPL, AND PL TO APL

- Although one donor muscle is not typically transferred to two recipients,3 an FCU transfer to the EPL and EDC has been described. This may be combined with a wrist extension transfer.
- The technique is similar to that discussed for the FCU to EDC transfer along the ulnar subcutaneous route. The tension is such that the thumb and index metacarpal are parallel.

PEARLS AND PITFALLS

| Donor muscle properties | In setting tendon transfer tension, the donor muscle length–tension properties are important to consider. A good clinical approximation of a muscle at the peak of the length–tension curve is to place the muscle near the 50% excursion point. The distal recipient tendon is then pulled proximally until the ideal position of the joints has been achieved.11 |
| Pulvertaft weave | In performing a Pulvertaft weave, a curved tendon passer is very helpful. The weaves should be placed at 90 degrees to each other and secured with multiple mattress sutures. The sutures should have small purchase into the donor and recipient tendons to prevent necrosis. At least three weaves should be used. |
The choice between the most common extensor transfers—FCR or FCU—is difficult. Usually, the FCU

With finger extension transfers, it is important to determine the preoperative goals for the FCU/FCR

REFERENCES

POSTOPERATIVE CARE

- Postoperative splint with wrist at 30 to 40 degrees and MP joints in 0 to 10 degrees of hyperextension
- Proximal and distal interphalangeal active and passive motion at 3 to 5 days
- Static immobilization for 3 weeks, then tenodesis motions with activation of wrist extension transfer
- Integration of finger and thumb active extension as wrist motion improves
- The most difficult motion to obtain is independent finger extension with the wrist in the extended position.
- Passive wrist flexion exercises are determined by the recovery of wrist flexion after splint removal. The arc of flexion can be expected to be less than the preoperative level.
- A dynamic splint may be applied so that finger extension may begin at 1 week postoperative. An articulated splint may be used to permit dynamic wrist motion, but the patient must be very adept and have a clear understanding of the therapy regimen.23,28

OUTCOMES

- Wrist extension of 40 to 50 degrees (80% M4), wrist flexion 20 to 40 degrees
- Finger extension: at wrist neutral, 0 to 10 degrees flexion; at wrist in 30 degrees of extension, 0 to 30 degrees
- Functional scores: 80% excellent to good23; no reported disabilities of the arm, shoulder, or hand

COMPLICATIONS

- If transfer adhesions occur, the therapy can be modified according to postoperative course. Tenolysis should be delayed until at least 9 to 12 months after surgery.
- Transfer attenuation

REFERENCES

DEFINITION

- The finger metacarpophalangeal joint (MCP joint) is commonly and characteristically involved in inflammatory arthritis.
- The MCP joint is often involved early in inflammatory arthritis and usually presents with ulnar extensor tendon subluxation resulting in ulnar deviation of the fingers.
- Occasionally in systemic lupus erythematosus (SLE) radial subluxation of the extensor tendon is seen.

ANATOMY

- The normal MCP joint is a condylar joint that allows flexion and extension as well as radial and ulnar deviation and a combination of these movements. Normally there is 90 degrees of flexion, although hyperextension can vary.
- The stability of the MCP joint is provided by the radial and ulnar collateral ligaments, the accessory collateral ligaments, the volar plate, the dorsal capsule, and the extensor tendon (FIG 1).
- The metacarpal head diameter increases in both the transverse and sagittal planes and therefore has a cam effect, making the collateral ligaments tight in flexion and lax in extension. This allows more radial and ulnar deviation of the MCP joint in extension.
- The MCP joint collateral ligaments are asymmetric.
  - The ulnar collateral ligament is more parallel to the long axis of the fingers.
  - The radial collateral ligament is more oblique.
  - This causes supination of the MCP joint with MCP joint flexion.
  - The collateral ligament also resists volar-directed forces.
  - The volar plate is fibrocartilaginous distally and has a membranous portion proximally. It limits MCP joint extension.
  - The transverse intermetacarpal ligament connects the volar plates to each other.
  - The accessory collateral ligament connects the collateral ligament and volar plate and keeps the volar plate close to the volar aspect of the MCP joint throughout motion.
  - The A-1 pulley of the flexor tendon sheath is attached to the volar plate.
  - The extensor digitorum tendon is maintained centrally over the MCP joint by the transverse fibers of the sagittal band that attach volarly to the volar plate and the intermetacarpal ligament. This forms a sling mechanism. The ulnar sagittal band is felt to be stronger and denser than the radial sagittal band.
  - There is usually no direct extensor tendon insertion into the proximal phalanx. The proximal phalanx is extended through the sling mechanism.
  - The lumbrical muscle originates from the tendon of the flexor digitorum profundus and is volar to the intermetacarpal ligament. It inserts into the lateral band.
  - There are three volar (which adduct) and four dorsal (which abduct) interossei that have tendons that all pass dorsal to the
transverse intermetacarpal ligament. They have variable insertions into the proximal phalanx and extensor mechanism.

- The first dorsal interosseous almost always inserts completely into the radial side of the proximal phalanx of the index finger.

### PATHOGENESIS

- The pathology of inflammatory arthritis begins with proliferative synovitis.
- Selective changes in static and dynamic stabilizers of the MCP joint occur, resulting in alteration in the equilibrium of the joint. The most common deformity produced is ulnar deviation of the fingers (FIG 2A).
- Which comes first, the changes to the dynamic or static stabilizers, is unclear and may vary.
- The capsule, radial collateral ligament, and radial sagittal band are stretched by the synovitis and allow the equilibrium to move toward ulnar deviation.

---

![FIG 2 • A. Radiograph of a patient with extensor tendon subluxation and ulnar deviation of the metacarpophalangeal (MCP) joints. The joint spaces are maintained and the joints are not subluxated. B. Radiograph of a patient with extensor tendon subluxation and ulnar deviation of the MCP joints with reducible MCP joint subluxation involving the index and middle MCP joints.](image)

- The accessory collateral ligament and the membranous portion of the volar plate become lax.
- The joint capsule becomes thinned and a defect in the dorsal capsule may occur.
- With increasing ulnar deviation, the ulnar intrinsic muscle shortens.
- The intrinsic muscle contribution to the deformity is unclear. It may be a primary or secondary change. There is a cycle that is set up as the MCP joint ulnarily deviates and the extensor tendon acts as an ulnar deviator and may even act as a flexor of the MCP joint.
- The laxity of the volar plate and accessory collateral ligament causes the flexor tendons to develop a mechanical advantage and increased flexion force. This results in an increase in the deformity.
- The combination of changes to the capsule, radial collateral ligament, radial sagittal band, accessory collateral ligament, and the membranous portion of the volar plate and increases mechanical advantage of the flexor tendon is magnified by the normal ulnar and volar slope of the metacarpal condyles and allows ulnar deviation and volar displacement of the proximal phalanx (FIG 2B).
- The wrist may be a contributing factor to the development of the MCP joint deformity, and this must be considered in each case before correcting the MCP joint.
  - Radial deviation of the wrist can be a compensatory position to the ulnar deviation of the MCP joints to allow the fingers to line up with the forearm.
  - Ulnar deviation of the digit is more common in patients with radial deviation of the wrist.
- At first the deformity is correctable passively, but gradually this mobility is lost and the deformity becomes fixed.
- Articular cartilage changes progress from softening of the cartilage to erosion with significant loss of cartilage and bone. This contributes to the deformity.
  - Once there are significant cartilage and bone changes, extensor tendon realignment alone, without joint resurfacing, is not indicated.
- The changes seen in SLE are secondary not to synovitis but rather to alteration in the collagen that results in a change in the equilibrium of the MCP joint and subsequent deformity.
  - The finger deformity in SLE is often ulnar deviation, but radial deviation is not uncommon.
  - In SLE it is easy to change one deformity to another (ie, ulnar drift into a radial deviation deformity after surgery) because of the global changes to the supporting structures.
  - Despite the MCP deformity becoming fixed, the articular cartilage is usually preserved.

### NATURAL HISTORY

- The natural history of the MCP joint changes in inflammatory arthritis is not known and is probably highly variable and influenced by the new disease-modifying medications.
- Mild ulnar deviation of the fingers is normal and increases with MCP joint flexion.
- In inflammatory arthritis, such as rheumatoid arthritis, deformity is initially passively correctable.
- Mild ulnar deviation of the fingers is seen in less than 10% of the patients in the first 5 years of having rheumatoid arthritis.
PATIENT HISTORY AND PHYSICAL FINDINGS

In a patient with inflammatory arthritis who is being considered for MCP joint surgery, the entire upper extremity is evaluated. Involvement of the lower extremities must also be considered, given that the upper extremities may need to assist in ambulation.

- The need to use the upper extremities for weight bearing can significantly affect the durability of the correction obtained after MCP joint surgery.
- Ideally MCP joint surgery is performed when the upper extremity is not needed for such support.
- The wrist is evaluated for the presence of a static deformity at the time of MCP joint surgery. Presence of a static radial deviation deformity will negatively affect the results of MP joint surgery.
- The skin over the MCP joint is evaluated; it should be in good condition.
- Motion of the MCP joint is assessed. The surgeon should specifically ensure that ulnar deviation and flexion deformities can be easily corrected passively.
- Proximal interphalangeal (PIP) joint motion and alignment must be critically evaluated.
  - If there is a significant boutonnière deformity, this should be corrected before the MCP joint surgery since the PIP flexion will influence the amount of MCP joint flexion obtained postoperatively.
  - If there is a swan-neck deformity, this can be treated at the same time or after the MCP joint. A stiff PIP joint in extension will cause the patient to flex the finger at the MCP joint and can help obtain better flexion postoperatively.
  - Any radial or ulnar deformity at the PIP joint must be corrected before the MCP joint surgery.
- The flexor and extensor tendons must be intact before any MCP joint surgery.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiographs of the hand and wrist are essential before MCP joint surgery to evaluate alignment, congruence, and joint integrity.

DIFFERENTIAL DIAGNOSIS

- The most common cause of inflammatory arthritis that affects the MCP joint is rheumatoid arthritis.
- SLE is more common in black women, and the deformity is secondary to a collagen abnormality causing ligament and tendon imbalance. Articular cartilage loss is a much less common problem in SLE. Soft tissue realignment can be performed even after the condition has been present for a long time.
- Psoriatic arthritis is more common in men and has a characteristic skin rash, although patients may have joint involvement before a clinically obvious skin rash. The patient with psoriatic arthritis often has an asymmetric deformity and more stiffness. The cartilage and bone are also affected.

NONOPERATIVE TREATMENT

- A team approach to patients with inflammatory arthritis is important.
- Splinting in a corrected position (FIG 3) and joint protection may decrease the forces that contribute to the deformity.
- This may be helpful, but the effect in the long term is unknown, and we have not noticed significant long-term benefit.

SURGICAL MANAGEMENT

- One of the most difficult operations to decide to perform is MCP joint synovectomy and realignment.
  - This is usually best performed early when there is minimal deformity.
  - However, at this time the patient often has minimal pain and only slight loss of function.
  - With the use of disease-modifying medications, if the anatomy can be restored and the mechanical problems corrected, salvage procedures may be prevented or significantly delayed.
- The ideal patient for surgery is one with increasing deformity and good medical management with control of his or her synovitis.
  - The deformity should be passively correctable with good active MCP joint motion.
  - Ideally the MCP joint is not volarly subluxated, since correction and maintenance of correction is more unreliable.
  - There should be a well-aligned wrist with good PIP joint function without deformity.
  - If the deformity is passively correctable but cannot be actively corrected, obtaining active ulnar deviation such as by an extensor carpi ulnaris tendon relocation or transfer should be considered.
  - The radiographs should reveal good preservation of the joint space without volar subluxation.
  - If all of these criteria are met and the joints are not passively correctable or there is volar subluxation of the MCP joint, surgery can be performed, although the results may not be as reliable.
  - A firm diagnosis can help with establishing a prognosis for the maintenance of correction obtained at surgery.
  - The effect of the new disease-modifying medication is not known.
It is possible that the soft tissue correction obtained at surgery may now last longer and therefore the procedure should be entertained earlier and more often.

Ideally, earlier surgery will solve the correctable mechanical problem and will end the cycle of deformity.

**Positioning**

- The procedure is performed using tourniquet control. The hand is supported by a hand table.

**Approach**

- The procedure usually is performed on all four fingers through a transverse dorsal incision over the MCP joint (FIG 4).
  - If a single digit is involved, a longitudinal incision should be used.
  - If not all of the fingers are going to be corrected, the fingers on the side of the deformity (ie, if there is ulnar deviation deformity, the radial involved digits) must be corrected first to limit recurrent deformity.

**EXPOSURE**

- Expose the extensor mechanism at each joint (TECH FIG 1A).
- Release the juncture tendineae as needed (TECH FIG 1B).
- Develop the interval between the extensor hood and capsule.
- Try to relocate the extensor tendon to the midline.
- Sometimes this can be done without releasing the ulnar sagittal band.

- If the extensor tendon can be relocated to the midline, expose the joint by incising the radial sagittal band.
- The radial sagittal band will be reefed at the end of the procedure.
- If the extensor tendon cannot be relocated to the midline, release the ulnar sagittal band to expose the capsule.
- A central defect in the joint capsule is often present. Open the capsule through this defect using a distally based dorsal capsular flap (TECH FIG 1C).
SYNOVECTOMY AND TENDON REALIGNMENT

- Perform a synovectomy using small rongeurs, curettes, and elevators (TECH FIG 2A).
- Evaluate the intrinsics after the extensor tendon is relocated and the joint is in neutral position. Perform an intrinsic tightness test. If positive and intrinsic tightness persists, release the ulnar intrinsics.
  - Incise the sagittal band and expose the intrinsic tendon on the ulnar side of the joint.
    - It is superficial to the collateral ligament and capsule.
  - Pass a curved hemostat beneath the ulnar intrinsic tendon as it inserts into the lateral band (see Fig 1) and divide the tendon.
    - A section of the oblique fibers may be excised.
- If intrinsic tightness continues, release the proximal phalanx insertion by grasping the proximal portion of the tendon with a clamp and sectioning (TECH FIG 2B).
  - A step-cut lengthening of the ulnar intrinsics may be preferred to complete intrinsic release in patients with SLE to avoid late radial deviation.
- If the joint still cannot be corrected, release the ulnar collateral ligament.
- If the ulnar intrinsic has been released, an intrinsic transfer can be performed, usually attaching it to the radial collateral ligament (TECH FIG 2C).
  - The advantage of using the radial collateral ligament as the attachment site is that it does not increase the extensor force at the PIP joint, which could result in a swan-neck deformity.
- If the joint was subluxated volarly preoperatively, pin the MCP joint in extension with a Kirschner wire.
- After the proximal phalanx is reduced, reef or advance the radial collateral ligament as needed (TECH FIG 2D).
- Close the capsule in a pants-over-vest manner so that the MCP joint is in extension (TECH FIG 2E).
- The extensor tendon is relocated onto the dorsal midline of the joint.
- Strip the periosteum from the dorsum of the proximal phalanx base and tenodese the central tendon to the proximal phalanx using a suture anchor (TECH FIG 2F,G).
  - Alternatively, place two drill holes in the proximal phalanx to suture the tendon directly to the bone.
  - 2-0 PDS suture is used. Nonabsorbable suture may result in prominent knots in this patient population with thin skin.
- Reef the radial sagittal band fibers with a 4-0 nonabsorbable suture to rebalance and support the extensor tendon directly over the joint.
- Repair the juncture tendineae.
- Traction on the central tendon should result in full MCP joint extension.
- A bulky dressing with fluffs between the fingers is applied, followed by a volar splint supporting the MCP joints in extension and in a slightly overcorrected position.

TECH FIG 2 • A. A metacarpophalangeal joint synovectomy is performed. B. The ulnar intrinsic tendon is sectioned and the ulnar collateral ligament is released. The central tendon is centralized and sutured to the proximal phalanx. (continued)
TECH FIG 2  * (continued) C. The contracted ulnar sagittal fibers are released and the radial sagittal fibers are reefed (red arrows) to rebalance and support the extensor tendon in the midline. The radial collateral ligament is advanced (green arrow) and the ulnar intrinsic muscle is transferred to the radial collateral ligament (blue arrow) of the adjacent digit. D. The radial collateral ligament is advanced, as in this case, or reefed. E. The capsule is closed in a pants-over-vest manner so that the metacarpophalangeal joint is supported in extension. F. The extensor tendon is sutured directly to the dorsal base of the proximal phalanx using absorbable suture. G. Postoperative radiograph of a patient showing suture anchors in place after extensor tendon centralization.

PEARLS AND PITFALLS

- Patient selection and control of the disease process are probably the most important factors.
- Joints with fixed deformities and cartilage loss are best treated with replacement arthroplasty.
- Proximal joint and distal joint correction must be performed before MCP joint surgery.
- Intrinsic transfers do not improve the long-term outcome of this procedure.
- Intrinsic lengthening is used only in patients with SLE.
POSTOPERATIVE CARE
- The postoperative dressing is removed at about 10 to 14 days and the sutures are removed.
- An Orthoplast splint with the MCP joints extended and slightly overcorrected, usually in slight radial deviation, is applied until 4 weeks postoperatively.
- At 4 weeks postoperatively, if Kirschner wires were inserted they are removed. Splinting is then continued for 2 additional weeks.
- At 6 weeks postoperatively, hand therapy is started, concentrating on active MCP joint extension. Active MCP flexion is also started. Protective splinting is continued for another 2 weeks in between exercises and at night.
- The fingers are splinted together as a unit to maintain alignment and concentrate flexion at the MCP level.
- To increase the postoperative flexion, the PIP joint is occasionally splinted in extension, concentrating the flexion force at the MCP joint.
- Dynamic splinting can be used to support extension and maintain digital alignment during the early healing stage but is usually not necessary.
- At 8 weeks postoperatively daytime splinting is decreased and gradual return to functional activities is encouraged.
- Nighttime extension splinting is continued for 3 months.

OUTCOMES
- MCP joint extension and ulnar drift are improved postoperatively.
- MCP flexion is usually slightly less than it was preoperatively.
- Strength is not significantly improved.
- Maintenance of correction is usually good with slight increase in ulnar drift, usually without recurrent subluxation.
- When the deformity is seen early and is still passively correctable with preserved joints, extensor tendon centralization and MCP joint synovectomy (as needed) is often beneficial, improving patient function.
- As with all joint procedures for deformities resulting from inflammatory arthritis, the procedure itself does not stop the progression of the disease. However, the new generation of disease-modifying medications combined with surgery may result in long-lasting correction of joint deformity.

COMPLICATIONS
- Infection
- Wound healing problems
- Loss of motion
- Recurrent ulnar drift with tendon subluxation
- Radial subluxation of the extensor tendon (seen in SLE)
- Progressive joint destruction from the arthritis and need for joint replacement

REFERENCES
DEFINITION

- Arthritis of the metacarpophalangeal (MCP) or proximal interphalangeal (PIP) joints may cause pain, deformity, and decreased motion. Rheumatoid arthritis (RA), osteoarthritis, and posttraumatic arthritis are common causes.
- Silicone implant arthroplasty may be considered as a surgical option after failure of nonoperative treatment in the patient with pain, functional disability, or both secondary to arthritis at the MCP or PIP joint.
- The primary function of the silicone implant is to serve as a dynamic spacer until the joint is encapsulated; thereafter, the joint can be expected to maintain alignment and provide a satisfactory range of motion.

ANATOMY

Metacarpophalangeal Joint

- The MCP joint is condyloid with motion in three planes: flexion–extension, abduction–adduction, and rotation.
- The head of the metacarpal is wider on its volar aspect, providing greater stability in flexion. The radial condyle is larger as well, contributing to the ulnar deviation posture most commonly seen in RA patients.
- Collateral ligaments arise dorsal to the center of rotation; this, together with the shape of the metacarpal head, contributes to the cam effect that is manifest by collateral ligament laxity in extension and tightness in flexion.
- Hyperextension of the MCP joints is common; however, the volar plate limits excessive motion.

Proximal Interphalangeal Joint

- The PIP joint is a hinge joint with an average arc of motion of 0 to 100 degrees of flexion.
- The bony anatomy is crucial to PIP joint stability in all positions; the base of the middle phalanx is wider volarly, thus helping to prevent dorsal dislocation. The PIP joint is more stable in all positions compared to the MCP joint.
- The proper collateral ligaments originate from the center of rotation of the proximal phalanx head and insert onto the volar base of the middle phalanx; they provide stability in all positions. The accessory collateral ligaments insert onto the volar plate and provide more stability in extension. There is no significant cam effect with the PIP joint.
- The volar plate resists hyperextension and is a key supporting structure of the joint.

PATHOGENESIS

- Arthritis of the MCP or PIP joints may be idiopathic, posttraumatic, or inflammatory (RA).
- Idiopathic osteoarthritis involves the distal interphalangeal joint most commonly, but the PIP joint is also affected; the MCP joint is less commonly involved.
- The PIP joint is the most frequently traumatized finger joint and, thus, has the highest incidence of posttraumatic arthritis.

Given the shortcomings of the salvage procedures for PIP joint arthritis, an anatomic joint reduction and aggressive restoration of the normal anatomy after trauma is critical as a means of prevention of arthritis.

- The bony congruity of the PIP joint makes it poorly tolerant of any loss of cartilage; deformity and loss of motion may progress quickly.
- Inflammatory arthritis (RA) most commonly affects the MCP joint but may also involve the PIP joint. In RA, a proliferative synovitis compromises the soft tissue support of the affected joint and may lead to the characteristic deformities at the MCP joint, including volar subluxation (and a flexed posture) and ulnar deviation. In the PIP joint, an attenuation of the volar supporting structures may lead to joint hyperextension, while compromise of the central slip insertion will lead to a joint flexion deformity.
- The efficacy of the disease-modifying antirheumatic drugs has dramatically decreased the need for joint arthroplasty in these patients.

NATURAL HISTORY

- The natural history of osteoarthritis or posttraumatic arthritis of the PIP joint is progression with loss of motion, pain, and in some patients deformity. The MCP joint is less commonly affected and is also more tolerant of arthritis, given its increased mobility in all planes.
- In the patient with severe RA not controllable by disease-modifying antirheumatic drugs, joint inflammation will lead to progression of the arthritis.
- The functional affect of the arthritis depends on both the degree of involvement of the specific joint and the involvement of the adjacent joints.

PATIENT HISTORY AND PHYSICAL FINDINGS

- It is vital that the surgeon understand how the arthritis specifically affects the function of a particular patient. This depends on many factors, including adjacent joint involvement, specific patient activities, and the degree of pain experienced.
- Physical examination methods include the following:
  - Palpation of the joint at the joint line: Confirms origin of the pain and allows evaluation for synovitis
  - Active and passive range of motion of the joint are measured with a goniometer. Joint motion is lost with arthritis. Pain with motion is noted.
  - Deformity of joint alignment is measured with a goniometer. Progressive arthritis leads to deformity.
  - Radial–ulnar stress testing: Evaluation of collateral ligaments. The MCP should be tested in flexion; the PIP joint may be tested in any position but is most commonly tested in extension. Attenuation of collateral ligaments may occur in RA or after trauma.
Integrity of tendon function: Most commonly abnormal in RA or after prior trauma.

Intrinsic tightness (Bunnell) test: If the intrinsics are tight, therapy or surgical intervention may be needed.

Elsen test: Integrity of the central slip is important when contemplating PIP joint arthroplasty.

The alignment and function of the adjacent joints (including the wrist) should be assessed, given the intimate relationship between the joints.

A complete examination of the hand includes an examination of adjacent joints. The ligamentous stability of all joints of the hand and the functioning of the extrinsic and intrinsic flexor and extensor musculature are evaluated.

In inflammatory conditions, the proximal joints, most importantly the wrist, must be examined. If wrist deformity is not corrected before surgical correction of distal disease, surgical correction (such as MCP arthroplasty) will have a higher incidence of failure due to the uncorrected deforming forces.

In patients with posttraumatic arthritis (especially affecting the PIP joints), the functioning of the flexor and extensor tendons must be understood. The presence of tendon shortening or lengthening (for example, after repair of an open injury) and the presence of tendon adhesions should be sought.

Intrinsic or extrinsic contractures after hand trauma are assessed before surgical intervention.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

Plain radiographs provide sufficient diagnostic information. AP and lateral radiographs are usually sufficient, although oblique radiographs may be helpful (FIG 1).

MRI and CT are of limited utility in the evaluation of the MCP and PIP joints.

**DIFFERENTIAL DIAGNOSIS**

- Acute fracture with or without joint subluxation
- Collateral ligament injury
- Joint infection
- Flexor or extensor mechanism injury

**NONOPERATIVE MANAGEMENT**

- Anti-inflammatory medications
- Steroid injections
- Splinting

**SURGICAL MANAGEMENT**

Surgery is considered if nonoperative management fails. Given the limitations of silicone implant arthroplasty as noted below, the decision for surgical intervention should be patient-driven.

The best outcome is expected in patients with a preserved arc of motion, minimal deformity, and pain. Patients without pain and presenting with deformity or a lack of motion are not ideal candidates for arthroplasty, especially if the adjacent joints are functioning well. Joint arthroplasty does not reliably increase motion at long-term follow-up.

In RA, an ulnar drift and volar subluxation of the MCP joints with a flexion posture of the joints may lead to weakness and a loss of the ability to grasp larger objects. These deformities are also unsightly. Surgical intervention in these patients can be expected to improve the aesthetic appearance and function of the hand.

**Preoperative Planning**

- All imaging studies should be reviewed.
- Involvement of adjacent joints should be assessed.
- Multiple MCP or PIP joints can be treated with silicone arthroplasty at the same surgical setting, but we do not typically recommend MCP and PIP joint silicone arthroplasty in the same finger.
- In patients with symptomatic disease at both the MCP joint and the PIP joint, the MCP is typically treated with silicone implant arthroplasty and the PIP joint is fused.
- An assessment of the ligamentous stability of the MCP and PIP joints should be performed under anesthesia.

**FIG 1** • A. Rheumatoid arthritis affecting hand, with most notable disease affecting metacarpophalangeal (MCP) joints. The wrist is also affected. B. Isolated osteoarthritis of the MCP joint of the long finger. C. Posttraumatic arthritis affecting the small finger proximal interphalangeal joint.
■ MCP and PIP arthroplasty is performed cautiously in the index (or long) finger as pinch forces may be problematic for joint stability.
■ Templating should be performed to ensure that appropriately-sized implants are available.

**Positioning**
■ The patient is placed supine with the extremity on an arm table.
■ A nonsterile arm tourniquet is used.
■ General or axillary block anesthesia is used.

**Approach**
■ The MCP joint is approached from dorsally with a midline incision.
■ The PIP joint may be approached from either the dorsal or volar approach.

---

**METACARPOPHALANGEAL JOINT SILICONE ARTHROPLASTY**

**Incision and Dissection**
■ If a single joint is being addressed (osteoarthritis or posttraumatic arthritis), make a longitudinal incision over the MCP joint. If multiple joints are being addressed, make a transverse incision over the metacarpal necks (TECH FIG 1A).
■ Protect the superficial veins (most importantly in RA patients).
■ Identify and protect the extensor tendons.
■ In RA, the tendons may be translocated in an ulnar direction. If so, divide the sagittal bands on the ulnar side to allow later centralization of the tendons.
■ If the tendons are centralized, the interval between tendons (index and small finger between extensor indicis proprius or extensor digit minimi and extensor digitorum communis) can be used to approach the joint (TECH FIG 1B).
■ In RA, the ulnar intrinsic tendon is often a deforming force. In fingers with marked ulnar deviation, bring the tendon into the surgical field with a blunt hook and divide it.
■ Divide the joint capsule longitudinally for later repair.
■ Débride the joint (TECH FIG 1C).
■ It may be necessary to recess the collateral ligaments off their origin from the metacarpal head. Carefully protect their insertion onto the base of the proximal phalanx.
■ In osteoarthritis or posttraumatic arthritis, the collateral ligaments need not be released if adequate exposure can be obtained.
■ If the joint is volarly subluxated, it may exhibit a flexion contracture that must be released.
■ Perform a soft tissue release using a Freer to elevate the volar plate off the volar distal metacarpal; this, together with bony resection, will allow joint reduction.
■ Once the proximal phalanx can be mobilized dorsal to the metacarpal head, a sufficient release has been obtained.

**Bone Preparation**
■ Using an oscillating saw, remove the metacarpal head just distal to the collateral ligament origin, staying perpendicular to the axis of the bone in the posteroanterior and lateral planes.
■ The amount of bone removed depends on the degree of deformity and contracture (TECH FIG 2A).
■ In severe cases it is necessary to elevate the collateral ligaments from their origins to resect more metacarpal. In these cases, radial collateral (and ulnar) ligaments are repaired during closure.
■ Prepare the base of the proximal phalanx by removing the articular cartilage using osteotomes or a rongeur. Carefully protect the collateral ligament insertions.
■ Use an awl to identify the metacarpal medullary canal first.
■ The awl typically enters the canal dorsal to the apparent center of the cut end of the metacarpal given the dorsal–volar bone curvature.
■ Use hand reamers to prepare the bone.
■ Use progressive broaches, taking care to ensure correct broach alignment and integrity of the cortex (TECH FIG 2B).
■ The ring finger metacarpal is frequently much narrower and may require more reaming, use of a burr, and potentially a smaller implant.
■ Once the metacarpal is prepared, initiate the same procedure for the proximal phalanx.
■ The base of the proximal phalanx can be reamed in slight supination for the index finger to improve pinch (TECH FIG 2C).

Implant Placement and Closure
■ Place a trial prosthesis, choosing the largest “comfortable” fit that allows full joint motion. Ensure proper clinical alignment (TECH FIG 3A).
■ If the prosthesis buckles, choose a smaller prosthesis or create more space through soft tissue release or additional bone resection.
■ If the prosthetic stem is too long and is contributing to buckling of the prosthesis, the stem may be trimmed using scissors.
■ If the origins of the collateral ligaments were disturbed, drill holes in the dorsal radial and the dorsal ulnar (in the case of osteoarthritis or posttraumatic arthritis) metacarpal and place 2-0 nonabsorbable suture for later repair of the collateral ligaments.
■ The radial collateral ligaments are typically attenuated in RA, especially if the joints have been ulnarly deviated. The ligaments are tightened when repaired through imbrication (TECH FIG 3B).
■ A distally based radial slip of the volar plate may be mobilized and integrated into the repair in the case of severely attenuated radial collateral ligaments.
■ Place the final implants using a “no touch” technique.
■ To minimize the risk of a reaction between the silicone implant and the sterile gloves, do not directly handle the implants; instead, insert them using forceps.
■ Grommets are not routinely used.
■ Insert the proximal stem first; then bend the implant and place the distal stem.
■ Once the implant has been placed in a stable position, the collateral ligaments are repaired.
■ The collateral ligaments are repaired, imbricated, or reconstructed as may be required to restore stability (especially against ulnar deviation).
■ If the capsule is sufficiently robust, repair it with interrupted 3-0 absorbable suture.
- Repair the extensor mechanism in a centralized position with nonabsorbable 2-0 suture. Use passive joint range of motion to ensure there is no tendon subluxation after repair.
- If the radial sagittal band is attenuated, imbricate or incise it and advance it deep to the extensor digitorum communis tendon in a pants-over-vest manner.
- Additional release of the ulnar sagittal band may also be required to centralize the extensor mechanism.
- Obtain C-arm or standard radiographs to confirm clinical alignment.
- Close the skin with 4-0 nylon suture. Once the wound is closed, deflate the tourniquet.
- A Penrose drain may be used if excessive bleeding is noted (uncommon). The drain is removed the next day.

PROXIMAL INTERPHALANGEAL JOINT SILICONE ARTHROPLASTY

Volar Approach for Proximal Interphalangeal Joint Arthroplasty

Incision and Dissection
- Use a volar, Brunner incision centered at the PIP joint (TECH FIG 4A).
- Raise full-thickness flaps with careful protection of the neurovascular bundles.
- Divide the C1, A3, and C3 pulleys at their insertion on one side and elevate them to expose the flexor tendons (TECH FIG 4B,C).
- Protect the A2 and A4 pulleys.
- Retract the flexor tendons to either side using a Penrose drain.
- Detach the volar plate proximally and divide the accessory collateral ligaments from their insertion onto the volar plate. Leave the volar plate attached distally (TECH FIG 4D).
- Detachment of the collateral ligaments at their insertion is required for optimal exposure and visualization (may be repaired back to volar plate at closure).
- Dislocate the joint in a “shotgun” manner to expose the articular surfaces.

Bone Preparation
- Using an oscillating saw, remove the condyles of the proximal phalanx head, staying perpendicular to the long axis of the bone in both the posteroanterior and lateral planes.
- Carefully prepare the base of the middle phalanx, taking great care not to injure the central slip insertion or proper collateral ligament insertion. Remove remaining cartilage with a rongeur or osteotome. Create a flat surface to accommodate the implant.
- Use awls, hand reamers, and broaches to prepare the medullary canals of the proximal and middle phalanges.
- The proximal phalanx is typically prepared before the middle phalanx.
- Use the rectangular shape of the broach base to ensure correct rotation of the final implant.

Implant Placement and Closure
- The trial should allow satisfactory joint range of motion without buckling or displacement.
- The trial and final implant should remain flush against the cut ends of the bones.
- The implant can be shortened or additional reaming can be performed as needed for the trial that buckles.

**TECH FIG 4 • A.** A volar skin incision is centered at the proximal interphalangeal joint in a Brunner fashion. **B, C.** The flexor tendon sheath is incised between the A2 and A4 pulleys to allow retraction of the tendons. **D.** The volar plate is released proximally for exposure.
Chapter 78  PIP AND MCP JOINT SILICONE IMPLANT ARTHROPLASTY

TECHNIQUES

■ The volar plate can be divided longitudinally and used to reconstruct the collateral ligaments if needed.
■ Obtain C-arm or standard radiographs to confirm clinical alignment (TECH FIG 5).
■ The flexor sheath need not be repaired.
■ Use 4-0 nylon sutures to close the skin.

Dorsal Approach for Proximal Interphalangeal Joint Arthroplasty

■ Make a straight or gently curved longitudinal incision centered over the dorsal PIP joint.
■ Raise full-thickness flaps at the level of the extensor mechanism.
■ Split the central slip longitudinally and elevate it radially and ulnarly, taking care not to injure the central slip insertion and create an iatrogenic boutonnière deformity. Other alternatives are as follows:
  ■ The longitudinal split of the extensor mechanism may be carried to one or both sides of the central slip insertion for its protection (TECH FIG 6A).
  ■ The Chamay approach may be used. A distally based triangular flap of the extensor mechanism is created; this provides excellent joint exposure and the extensor mechanism is later repaired (TECH FIG 6B).1
  ■ Recess the collateral ligaments off their origin from the proximal phalanx head for later repair. Before final implant placement, drill holes adjacent to the collateral ligament origin to allow suture passage for ligament repair (TECH FIG 6C).
■ The volar plate is protected with the dorsal approach.
■ The remaining portion of the procedure is similar to that described as part of the volar approach.

TECH FIG 5 • Postoperative radiograph of patient with diffuse osteoarthritis. Note the silicone implant arthroplasties for the proximal interphalangeal joints of the index and long fingers as well as the fusions of the distal interphalangeal joints of the long and ring fingers.

■ Create small drill holes at the radial and ulnar bases of the proximal phalanx before final prosthesis fitting to allow volar plate repair.
■ Create dorsal drill holes at the origin of the proper collateral ligaments to be used for repair.

TECH FIG 6 • A. Preservation of the central slip is crucial for successful postoperative rehabilitation. B. The Chamay approach may be utilized for PIP joint exposure. C. The collateral ligaments are recessed off the head of the proximal phalanx.
PEARLS AND PITFALLS

Indications
- Painless loss of motion is not an ideal indication; the operation does not reliably increase motion at long-term assessment.
- Osteoarthritis and posttraumatic arthritis are more common in the PIP joint than in the MCP joint. MCP arthroplasty has traditionally been performed for RA but has declined in frequency due to better control of disease in RA patients.
- PIP joint arthroplasty is helpful in maintaining motion in the ring and small fingers (for grip); PIP fusion is more acceptable in the index and long fingers (especially in workers).
- Avoid arthroplasty at both the MCP and PIP joints in one finger.

Technique
- Broaching should be carefully performed to avoid penetration of the cortex and rotation of the implant.
- The central slip insertion must be carefully protected at the PIP joint.
- The implant fit must be carefully assessed; buckling of the implant requires bony or soft tissue adjustments before final implant placement.

Rehabilitation
- Motion must be carefully allowed until joint encapsulation.
- Rotation or deformity after arthroplasty may be corrected with dynamic splinting.

POSTOPERATIVE CARE
- The patient is placed in a plaster splint after surgery for 3 to 5 days. The MCP and PIP joints are immobilized in extension.
  - Some surgeons advocate 3 to 4 weeks of immobilization after MCP joint implant arthroplasty before the initiation of hand therapy.
- Early joint motion is important for appropriate joint encapsulation.
- An engaged hand therapist is crucial in obtaining a satisfactory surgical outcome.
  - Early therapy emphasizes edema control and patient comfort through splinting.
  - Subsequent therapy focuses on range of motion.
- MCP joint arthroplasty, especially in the rheumatoid patient, requires meticulous postoperative hand therapy.
  - Dynamic extension (daytime) splints, static extension (nighttime) splints, or both are fabricated.
  - The alignment and motion of the fingers are carefully monitored. Adjustments to the splints are commonly required as the encapsulation process and the healing process progress.
  - Active and gentle passive motion are progressively allowed.
  - After PIP joint implant arthroplasty through a volar approach, the flexor and extensor mechanism need not be protected. Active and gentle passive motion may be initiated quickly, although the collateral ligament repairs should be protected for at least 6 weeks.
    - Dynamic extension splinting may be used during the first 6 weeks.
  - If the central slip was spared during a dorsal PIP joint approach and implant placement, early active motion is initiated with progression to gentle passive motion.
  - If the approach for PIP implant arthroplasty required central slip takedown and repair, the extensor mechanism should be carefully protected during the rehabilitation period.

OUTCOMES
- Pain is reliably improved in patients with MCP or PIP joint arthroplasty.2–7
- Most patients are improved functionally after silicone MCP arthroplasty. Patients with RA and a marked flexion and ulnar deviation posture of the MCP joints stand to benefit most.2,3 While the arc of motion may be improved in the early postoperative period, at long-term follow-up the arc of motion is not dramatically increased; however, the arc is moved to a more extended and functional position.2,3
- The ulnar drift of the MCP joints most commonly seen in RA is improved (although some recurrence in drift over time may also occur).2,3
- MCP arthroplasty for osteoarthritis can be expected to maintain or somewhat improve MCP range of motion and strength while decreasing pain. In contrast to RA patients, MCP joint flexion may be increased in patients treated for osteoarthritis.2,5
- PIP arthroplasty can be expected to place the PIP joint in a more extended and functional posture but should not be expected to increase range of motion at long-term follow-up. Total joint motion depends on the preoperative motion but typically averages about 45 degrees. Pain relief is reliable for most patients no matter what the diagnosis.4,6,7
- PIP arthroplasty for RA may have a lesser outcome compared for PIP arthroplasty performed for posttraumatic arthritis or osteoarthritis. Patients with a boutonnière or swan-neck deformity are most likely to be unchanged or worse in regard to their deformity.7
- PIP silicone implant survivorship decreases from 98% at 2 years to 80% at 10 years to 49% at 16 years (in a mixed population analysis).7

COMPLICATIONS
- Infection
- Implant fracture (which may or may not necessitate revision arthroplasty; if the encapsulated joint is stable, a fractured implant may not need to be addressed)
- Rotational malalignment
- Joint subluxation
- Silicone synovitis
- In RA patients, recurrent ulnar drift may occur.

REFERENCES


DEFINITION

- Rheumatoid arthritis is a disorder that can affect the hands and can cause fatigue, muscle pain, loss of appetite, depression, weight loss, anemia, and immunocompromise. The effect on the hands is a combination of tenosynovitis and inflammation of the metacarpophalangeal (MCP) synovial lining of the joints (synovitis).\textsuperscript{10,12}

- Rheumatoid arthritis less frequently involves the proximal interphalangeal (PIP) joints of the hand; more commonly, the PIP joints are affected by degenerative arthritis. Degenerative arthritis may occur after trauma or infection or may arise as an idiopathic process.\textsuperscript{1}

ANATOMY

- Anatomy of the extensor tendon mechanism is shown in FIG 1.

FIG 1 • Anatomy of the extensor tendon mechanism of the finger.

PATHOGENESIS

- Rheumatoid arthritis is a multifactorial entity and is poorly understood.
  - The disease is autoimmune mediated and may occur after a bacterial or viral infection.
  - There is a hereditary influence.
  - The B lymphocytes, T lymphocytes, and macrophages lead to proliferation and hypertrophy of synovial cells. The enzymes released by these cells can cause bony erosions, ligamentous laxity, and tendon ruptures.\textsuperscript{10}
  - MCP joint deformities in rheumatoid patients include ulnar deviation and volar subluxation or dislocation of the proximal phalanx on the metacarpal head (FIG 2).\textsuperscript{4,11}
  - These deformities occur after synovial proliferation in the recesses between the collateral ligaments and the metacarpal head, attenuating the collateral ligaments.
  - Radial inclinations of the metacarpals and wrist joint destruction often leads to an ulnar translation of the entire carpus. This translation can cause ulnar and volar extensor tendon subluxation between the metacarpal heads. Ulnar forces generated by the extensor apparatus and volar forces produced by the flexors lead to ulnar drift of the fingers and fixed MCP flexion deformities or volar dislocations of the MCP joints.
  - Degenerative arthritis affecting the PIP joints of the hand is a process whereby the articular cartilage develops irreversible wear changes, caused by an incompletely understood mechanism. Subchondral bone stiffens and periarticular new bone formation occurs, which leads to restricted joint motion and pain.\textsuperscript{9}
  - Less commonly, degenerative arthritis can affect the MCP joints of the hand. This can occur after trauma, infection, or osteonecrosis.\textsuperscript{9}

FIG 2 • Ulnar drift of the digits.
NATURAL HISTORY

- Rheumatoid arthritis has a variable prognosis based on the severity of the disease and the structures involved. Mild presentations may go undiagnosed for years, while severe presentations may progress to rapid joint destruction in the third or fourth decade of life.
- Three clinical stages of rheumatoid arthritis exist.
  - First, swelling of the synovial lining, which causes pain, warmth, stiffness, redness, and fullness around the joint
  - Second, synoviocyte hypertrophy and proliferation leading to synovial thickening
  - Third, enzymatic release causing bone and cartilage destruction, ligamentous laxity, and tendon ruptures
- Medical management as well as surgical synovectomy can halt or minimize progression of rheumatoid arthritis in the destructive stage.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough patient history and physical examination are important before implant arthroplasty of the fingers.
  - The surgeon should note the patient’s occupation, hobbies, and expectations.
  - The history of the patient’s condition is helpful in gauging the progression of the disease.
  - The primary indication for surface replacement arthroplasty of the MCP or PIP joints is pain relief. Correction of deformity and improvement in function are secondary considerations. Mild deformity may be painful for some, while profound deformity may be painless and functional for others.
  - Examination of the entire upper extremity should be performed. Although the order of reconstruction is controversial, deficits of the shoulder, wrist, and elbow should be addressed before addressing hand conditions.
- Particular attention should be paid to elements of radiocarpal instability or ulnar translation of the carpus. In some situations a wrist arthrodesis may be necessary before performing MCP arthroplasties.
  - Failure to correct carpal collapse and radial deviation of the metacarpals can result in recurrence of ulnar drift deformity after MCP arthroplasty.
  - Careful examination of flexor and extensor tendons of the hand and wrist should be performed. The extensor digiti quinti minimi, extensor pollicis longus, and flexor pollicis longus often rupture in more active forms of rheumatoid arthritis.
  - Extensor tendon or flexor tendon ruptures should be treated before considering implant arthroplasty of the hand.
- Examination of the PIP joint should include range-of-motion assessment of the joint, assessment of volar plate integrity, central slip integrity, and collateral ligament stability.
  - Normal range of motion of the PIP joint is 0 to 110 degrees.
  - Varus and valgus stability should be compared to the contralateral side.
  - Failure of volar plate integrity in rheumatoid arthritis can lead to swan-neck deformity, which is characterized by PIP joint hyperextension, dorsal subluxation of the lateral bands, and flexion of the distal phalangeal joint. The swan-neck deformity is considered a relative contraindication for surface replacement arthroplasty of the PIP joint (FIG 3A).
  - A boutonnière deformity is caused by failure of the central slip mechanism. This can occur in rheumatoid arthritis or after trauma (FIG 3B). It is characterized by flexion of the PIP joint due to central slip incompetence, volar subluxation of the lateral bands, and hyperextension of the DIP joint.
  - Normal MCP range of motion is between 0 and 90 degrees.
  - Instability testing: The individual MCP or PIP joints are tested by the examiner grasping the patient’s finger and then applying a valgus and then a varus stress. The resultant motion is compared to the contralateral side. Differences in laxity indicate ligamentous instability. Attempts at hyperextension of the digit at the PIP or the MCP joint can identify volar plate instability and the propensity of the digit to subluxate or dislocate. Surface replacement arthroplasty of either the MCP or the PIP joint is contraindicated in patients with ligamentous instability as these are minimally constrained devices.
  - Grade 1: No difference in joint line opening compared to the contralateral joint
  - Grade 2: Notable opening of the joint line compared to the contralateral joint, but a solid “endpoint” is reached
  - Grade 3: Complete opening of the radial or lateral joint line with valgus or varus stress. This can be demonstrated at either the MCP or the PIP joints. No endpoint can be discerned.
  - Bunnell test of intrinsic tightness of the PIP joints: The resistance encountered with the MCP joint in this position is compared with the resistance encountered with the MCP joint.
in the flexed position. An increase of resistance with the MCP joint in the extended position indicates intrinsic tightness of that digit.
- It is important to distinguish intrinsic tightness from extrinsic tightness. Extrinsic tightness is encountered when the long extensors of the digits are adherent to either the surrounding soft tissues or the metacarpals. The result is increased resistance to flexion of the PIP joint with the MCP in flexion. In either instance, the limitation of motion is important to clarify as it can affect the outcome of implant arthroplasty of the MCP or the PIP joint.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Posteroanterior, lateral, and oblique views of the hands will adequately image the MCP joints. Brewerton views may add additional information.
- Posteroanterior and lateral views are sufficient to image the PIP joints.

**DIFFERENTIAL DIAGNOSIS**
- Psoriatic arthritis
- Chronic septic arthritis
- Osteomyelitis
- Gout
- Calcium pyrophosphate dihydrate arthropathy
- Articular malunions of the MCP and PIP joints
- Scleroderma
- Lupus

**NONOPERATIVE MANAGEMENT**
- Nonoperative management in rapidly progressing rheumatoid arthritis is largely ineffective.
- In the quiescent forms of rheumatoid arthritis, nighttime wrist and hand splinting in conjunction with medical management may provide pain relief. Various combinations of methotrexate, prednisone, remitting agents, and nonsteroidal anti-inflammatory agents may prove effective for extended periods in certain cases.
- During periods of active rheumatoid arthritis of the MCP joints, corticosteroid injections into the joint may provide acute pain relief and improve function in the short term.
- The symptoms of MCP and PIP joint degenerative arthritis may come and go, successfully responding to nighttime wrist and hand splinting and nonsteroidal anti-inflammatory agents.
- Corticosteroid injection into the MCP and PIP joints for advanced degenerative arthritis seldom provides long-term benefits.

**SURGICAL MANAGEMENT**
- The indications for surface replacement or pyrocarbon MCP arthroplasty are similar to those for flexible MCP implants. These include pain in the face of deformity and worsening function.
- Surface replacement implants are designed to recreate the anatomy of a native joint, potentially resulting in greater stability than with flexible MCP implants.
- The enhanced stability of these implants is best demonstrated in the index and long fingers, where flexible MCP implants are prone to failure.
- Contraindications to surface replacement implant arthroplasty of the MCP joint include infection, lack of adequate bone stock, insufficient radial or ulnar collateral ligament support, lack of adequate soft tissue coverage, and excessively small metacarpal or proximal phalanx medullary canals.
- These implants rely on intact soft tissue elements. This includes functioning flexors and extensors as well as intact radial and ulnar collateral ligaments.
- Indications for PIP joint surface replacement arthroplasty are pain and diminishing function in the context of advanced radiographic articular degeneration. \(^1,7\)
- Contraindications to PIP joint surface replacement arthroplasty include inadequate bone stock of either the proximal or the middle phalanx, ulnar or radial collateral ligament insufficiency, acute or chronic infection, inadequate soft tissue coverage, insufficient digital flexor function, or disruption of the extensor central slip insertion on the middle phalanx.
- Relative contraindications include the presence of a static swan-neck\(^5\) or boutonnière deformity.
- In general PIP joint surface replacement arthroplasty is not indicated in patients with rheumatoid arthritis.
- The importance of postoperative therapy should be emphasized. To ensure that the implants heal with a stable and a functional range of motion the patient must wear a combination of static and dynamic splints for several weeks to months after. Patients must also be aware that heavy lifting or gripping must be avoided indefinitely.

**Preoperative Planning**
- Sizing templates with a 3% parallax enlargement are available for MCP and PIP joint systems and should be used preoperatively to give the surgeon an idea of the size implant required.

**Positioning**
- The patient is positioned supine with the arm placed on an armboard for either MCP or PIP joint surface replacement arthroplasty.
- A nonsterile tourniquet is placed proximal to the drapes on the arm.
- The hand is pronated to allow access to the dorsum.

**Approach**
- For MCP surface replacement arthroplasty, two different incisions can be used.
- A transverse incision across the dorsum of the hand, centered over the MCP joints, will facilitate access to multiple joints.
- Alternatively, multiple longitudinal incisions can be used to address all four MCP joints.
- If a single joint is being addressed, a longitudinal incision should be used.
- For PIP joint surface replacement arthroplasty, a midline longitudinal incision is preferred.
- Alternative approaches include the lateral approach and the volar approach.
Chapter 79  PIP AND MCP JOINT SURFACE REPLACEMENT ARTHROPLASTY

METACARPOPHALANGEAL JOINT SURFACE REPLACEMENT ARTHROPLASTY

Exposure
- Incise the extensor hood just ulnar to the extensor mechanism.
- Carry dissection down through the subcutaneous tissue to expose the extensor tendons.
  - Preserve the dorsal veins.
- Retract the extensor hood and extensor mechanism radiallyward.
- In the rheumatoid patient, the extensor tendon ulnarly translates with destruction of the radial sagittal band. If possible, dissect the sagittal bands from the capsule and preserve them so that the extensor tendon can be relocated and the sagittal bands imbricated at the end of the procedure in order to maintain a centralized extensor tendon position.
- Incise the remnants of the MCP joint capsule and use small Hohmann retractors to deliver the head of the metacarpal into the wound.
- After the joint is exposed, perform a synovectomy, carefully preserving the collateral ligaments.
- If the joint is irreducible, it may be necessary to release one or both collateral ligaments from their origins.
  - Tag the ends of the collateral ligaments for later repair to their tuberosity origins.

Joint Preparation and Trial Implant Insertion
- Use a metacarpal sizing template to identify the appropriate amount of metacarpal head to be resected.
- Remove the metacarpal head by first making a vertical saw cut distal to the collateral ligaments. A second cut oriented 45 degrees proximally and volarly removes the remainder of the metacarpal head, retaining the collateral ligament origins.
- Remove the articular surface along with a small portion of the base of the proximal phalanx, preserving the collateral ligaments (TECH FIG 1A).
- Contracture of the ulnar capsule may require detaching the ulnar collateral ligament to achieve alignment of the finger in some circumstances.
- Insert an awl into the dorsal aspect of the intramedullary canal of the metacarpal (TECH FIG 1B).
- Perform sequential broaching for the metacarpal until a proper fit has been attained.
  - For the index and long finger, the broaching is slightly ulnarly displaced. This provides a better moment arm for the radial intrinsic and extrinsic tendons to compensate for ulnar drift.
- Repeat the broaching in a similar fashion for the proximal phalanx.
- A plastic impactor with a concave surface aids insertion of the metacarpal proximal trial component.
  - The tip of the prosthesis should pass the midpoint of the metacarpal.
- Avoid forceful impaction in order to avoid fracture.
- A convex impactor aids insertion and seating of the distal component.
- Once the trial components are inserted and the joint is reduced, check component fit and position using an image intensifier. Then assess range of motion, component tracking, and stability.
  - Revisions of bone cuts may be necessary for soft tissue balancing and to ensure adequate range of motion.
  - If release of the collateral ligaments was required, drill two holes through the tuberosity at the dorsal radial and dorsal ulnar aspect of the remaining metacarpal head for reattachment of the ligaments.

TECH FIG 1 • A. Exposure of the metacarpophalangeal (MCP) joint demonstrating the bone cuts for preparation of MCP surface replacement arthroplasty. B. Broaching of the metacarpal preparing for MCP surface replacement arthroplasty. (Courtesy of Small Bone Innovations, Morrisville, PA.)
Insert sutures for repair of the collateral ligament (4-0 Ticron/Mersilene).

**Final Implant Insertion**
- Irrigate the intramedullary canal with saline and 0.5% neomycin solution, then dry it.
- Inject polymethylmethacrylate (PMMA) in a liquid state into the metacarpal and the proximal phalanx using a size no. 14 plastic angiocath catheter attached to a 10-cc syringe.
  - Under some circumstances “finger packing” may be necessary.
- Insert the distal component first. Convex and concave plastic impactors are provided to assist in implant insertion (TECH FIG 2).
  - Avoid impacting with metallic instruments, which can accelerate prosthetic wear.
- The joint is extended and viewed under the image intensifier before allowing the cement to harden so that last-minute corrections in alignment can be made.
- Cement fixation of one finger at a time is advisable if positioning is difficult.
  - If multiple MCP joints are to be implanted, it may be easier to do the distal components as a group, followed by the proximal components.
- After the cement has cured, check passive range of motion to ensure adequate range without impingement or prosthetic binding.

**Closure and Soft Tissue Balancing**
- After hardening of the cement, tighten the collateral ligaments or reattach them to the tuberosity of the metacarpal head with nonabsorbable suture.
- Ensure proper radial and ulnar stability as well as rotational alignment before securing the sutures.
- Close any remaining capsule with absorbable suture before extensor apparatus closure.
- Centralize the extensor tendon and imbricate the radial sagittal bands in rheumatoid hands using nonabsorbable suture.
  - A pants-over-vest centralization of the sagittal bands may be required in moderate to severe ulnar drift along with intrinsic releases or crossed-intrinsic transfers (TECH FIG 3).
  - With the finger held in slight overcorrection, imbricate the radial sagittal band over the extensor tendon.
- The skin is closed in a routine manner and a splint is applied with the MCP joints in slight flexion.

---

**PROXIMAL INTERPHALANGEAL JOINT SURFACE REPLACEMENT ARTHROPLASTY**

**Exposure**
- Through a midline longitudinal incision, reflect the extensor tendon distally by creating a distally based flap, as described by Chamay (TECH FIG 4A).
  - Identify and incise remnants of the dorsal PIP joint capsule.
  - Protect the radial and ulnar collateral ligaments using small Hohmann retractors while bringing the articular surface of the middle phalanx into view.
Chapter 79  PIP AND MCP JOINT SURFACE REPLACEMENT ARTHROPLASTY

TECHNIQUES

Joint Preparation and Trial Implant Insertion

- Resect the proximal phalanx head by an osteotomy performed 90 degrees to the long axis of the proximal phalanx, just proximal to the most proximal extent of the articular surface (TECH FIG 4A).
- During the osteotomy, protect the origins of the radial and ulnar collateral ligaments by using small retractors or by hyperflexing the joint.
- It may be necessary to release a small portion of the proximal phalangeal origin of the collateral ligaments to facilitate the proximal phalangeal osteotomy and prosthesis insertion.
- Minamikawa et al have shown that the PIP joint remains stable after removal of 50% of the collateral ligament substance.
- While protecting the volar plate with a small retractor, use a 2-mm burr to assist in making a small back cut (or chamfer cut) to accept the posterior aspect of the prosthetic condyles of the proximal phalangeal component.
- This can also be accomplished with the oscillating saw, but that can place the volar plate at risk.
- Make a perpendicular osteotomy at the base of the middle phalanx with a small rongeur and remove no more than 1 to 2 mm of bone.
- Protect the collateral ligament insertions with small retractors or by hyperflexing the digit.

- Broach the proximal and middle phalanges with specific and sequential instruments.
- Broach the proximal and middle phalanges to the largest size possible (TECH FIG 4B).
- Undersized components can result in limited motion due to bony impingement during flexion.
- Insert the trial components using proximal and middle phalanx-specific impactors.
- The components are not modular and are generally not interchanged. Under certain circumstances, such as revision surgery, it is permissible to implant unmatched sizes, but no more than one size up or one size down should be used.
- After trial component insertion, examine the digit for implant position, range of motion, and stability as detailed for the MCP joint. Make appropriate adjustments.

Final Implant Insertion and Closure

- Implant the permanent components by “press-fit” using the “no-touch” technique.
- Cementing is discouraged except perhaps in cases with capacious canals or in patients with substantial bone loss or articular erosion. In these circumstances, the prosthetic stems and flanges are simply coated with cement. Excessive cement packing into the medullary canal is not necessary.
- Another technique is to pack the canal with morselized allograft bone. This is analogous to
the Ling technique described for revision total hip arthroplasty.\textsuperscript{5}

- Using specific impactors, seat the permanent components (TECH FIG 5).
- Repair the extensor mechanism with 3-0 Surgilon suture.
- Release the tourniquet before skin closure.
- The patient leaves the operating room with a sterile dressing, splinted in extension.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th><strong>PIP joint surface replacement arthroplasty</strong></th>
<th><strong>MCP joint surface replacement arthroplasty</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Take care to preserve the insertion of the central slip.</td>
<td></td>
</tr>
<tr>
<td>- Osteotomy of the proximal phalanx must avoid the origin of the PIP joint collateral ligaments.</td>
<td></td>
</tr>
<tr>
<td>- Remove only a small amount of bone from the middle phalanx.</td>
<td></td>
</tr>
<tr>
<td>- Broach the proximal phalanx to the largest size that can be accommodated. Failure to use appropriate-sized implants may result in subsidence of the implants and posterior cortical impingement of the phalanges.</td>
<td></td>
</tr>
<tr>
<td>- Contracture of the ulnar capsule may require detaching the ulnar collateral ligament.</td>
<td></td>
</tr>
<tr>
<td>- Broaching of the index finger should be slightly ulnarly displaced.</td>
<td></td>
</tr>
<tr>
<td>- Centralization of the extensor tendon is generally necessary in rheumatoid hands; it can be achieved by imbricating the radial sagittal bands.</td>
<td></td>
</tr>
<tr>
<td>- Imbrication of the radial sagittal bands should be performed with the digit in radial deviation.</td>
<td></td>
</tr>
<tr>
<td>- “Water-tight” closure of the extensor mechanism is necessary to prevent PIP joint flexion lag or contracture.</td>
<td></td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- Postoperatively the MCP joints should be placed in slight flexion and the PIP joints in about 45 degrees of flexion. If there was ulnar deviation before surgery, the fingers should be placed in 10 degrees of radial deviation.
- The dressing is removed 2 to 4 days after surgery and a dynamic splint is applied for daytime exercises. A static rest or nocturnal splint capable of holding the fingers in the corrected position is used for 4 to 6 weeks.
- The rehabilitation program is enhanced by the close supervision of a hand therapist. The first week of therapy is best carried out with daily supervision.
- Follow-up examinations should include range-of-motion assessment for all the joints of the hand and wrist. Static deformities, grip strength, and pinch strength should also be assessed and recorded.
- Follow-up radiographic examination includes posteroanterior, lateral, and oblique views of the hand. Any residual deformity should also be assessed and recorded.
- For the PIP joint surface replacement arthroplasty, a controlled rehabilitation protocol is needed to prevent central slip failure.
- Initiation of formal postoperative rehabilitation is encouraged by postoperative day 5. A dynamic extension splint permitting active flexion is applied at this time and used for about 6 weeks. A static forearm-based digital extension splint is used at bedtime.
- During the first 2 weeks after surgery, PIP flexion is limited to 30 degrees.
- Flexion to 60 degrees is allowed beginning at 4 weeks.
- By 6 weeks, the extension outrigger splint is discontinued and unrestricted flexion and extension is permitted.
- The static bedtime splint is used for an additional 6 weeks. Heavy lifting or gripping is not permitted.

**OUTCOMES**

- Initial results after 76 PIP joint surface replacement arthroplasties were published.\textsuperscript{6}
- At a mean follow-up of 4.5 years, 32 joints had good results, 19 fair, and 25 poor.
- Better results were obtained with arthroplasties performed through a dorsal approach rather than the volar approach.
- Range of motion at follow-up averaged $-14$ degrees of extension and 61 degrees of flexion. There was a 12-degree
improvement in the flexion–extension arc compared to the preoperative examination.

- The MCP joint surface replacement arthroplasty (Small Bone Innovations, Morrisville, PA) has been available in Europe for 8 years and is under clinical trial in the United States. No series has been published reporting results of this implant. Although from a theoretical perspective there are advantages to the use of the MCPJ surface replacement arthroplasty, it currently cannot be considered a replacement for the Swanson Silastic MCP joint spacer.

- Previous primate studies have shown no evidence of debris or inflammatory reaction after implantation of the pyrolytic carbon MCP joint arthroplasty. Good bone incorporation of the prosthesis was also observed.

- In contrast to the Small Bone Innovations MCP joint surface replacement arthroplasty, a series of 151 pyrolytic carbon MCP prostheses (Ascension Orthopaedics, Austin, TX) implanted over an 8-year period, mostly in patients with rheumatoid arthritis, have been followed for an average of 11.7 years. The arc of MCP joint motion improved an average of 130 degrees.
- The 10-year survivorship was 81.4%.
- At follow-up, the degree of digital ulnar drift was the same as preoperative.
- Complications led to 18 implant revisions (12%).

**COMPLICATIONS**

- PIP
  - Failure of the central slip can occur, resulting in extensor lag or, more commonly, a flexion contracture or boutonnière deformity.
  - With the volar approach, failure of the volar plate may occur, leading to swan-neck deformity.
  - Tenodesis as well as joint instability and joint subluxation can occur.

- MCP
  - Postoperative infection or prosthesis loosening is seldom seen.
  - Stiffness
  - Loosening
  - Subluxation
  - Proliferative synovitis

**REFERENCES**

DEFINITION
- Conditions resulting in the need for arthrodesis in the hand include arthritis, unreconstructable soft tissue problems, and certain neurologic conditions.

ANATOMY
- The proximal (PIP) and distal (DIP) interphalangeal joint configurations are quite similar.
  - The condylar heads are biconvex but slightly asymmetric, being about twice as wide volarly as dorsally.
  - The reciprocal bases of the distal segment are biconcave, having a central ridge.
  - The volar plate extends from the neck of the phalanx to the volar base of the more distal phalanx, preventing joint hyperextension.
  - Radial and ulnar collateral ligaments provide additional joint stability. The “true” collateral ligaments have bony attachments at both ends, whereas the accessory collateral ligaments extend from the condylar head to the volar plate.
  - The axis of rotation and radius of curvature for a given interphalangeal joint are fairly constant. Consequently, the true collateral ligaments are effectively isometric, while the accessory collateral ligaments resist lateral translation when the joint is extended.
  - As a result of the ligamentous and bony architecture, the PIP and DIP joints normally function as highly constrained hinge joints.
  - The extensor tendon crosses the DIP joint dorsally as the terminal tendon, inserting slightly distal to the dorsal base of the distal phalanx.
  - The germinal matrix of the nailbed is close to the terminal tendon insertion (average of 1.3 mm distal).
  - The flexor digitorum profundus (FDP) tendon inserts broadly on the volar aspect of the distal phalanx, extending from the base to the midshaft.
  - Over the PIP joint, the extensor apparatus splits into thirds. Contributions from the extensor tendon, the interosseous tendons, and lumbricals form the central slip, which inserts onto the dorsal base of the middle phalanx. The lateral bands travel past the PIP joint along the lateral margins, and then combine to form the terminal tendon distally.
  - The flexor digitorum superficialis (FDS) tendon splits to insert on the volar lateral margins of the proximal shaft of the middle phalanx.
  - Unlike the interphalangeal joints, the metacarpophalangeal joints (MCP) are multiaxial, permitting motion in multiple planes.
  - The metacarpal head has a complex, convex shape. Viewed end-on, the metacarpal head is pear-shaped, being wider volarly. In the sagittal plane, the radius of curvature increases progressively from dorsal to volar.
  - The metacarpal attachment of the collateral ligaments is dorsal to the axis of rotation. The phalangeal and volar plate attachments are similar to the interphalangeal joint.
  - As a consequence of the metacarpal head shape and ligament attachments, the MCP joints are typically more lax in extension and tight in flexion.
  - Significant variability exists in the shape of the thumb metacarpal head. Some heads are more square than round, potentially limiting lateral translation and MCP flexion.
  - In the thumb, the extensor pollicis brevis (EPB) tendon inserts onto the dorsal base of the proximal phalanx. The size of the EPB tendon is variable.
  - For some patients, the extensor pollicis longus (EPL) tendon assumes the major role in MCP joint extension.
  - In the other digits, no direct extensor attachment exists. MCP joint extension occurs through a sling effect of the sagittal hood fibers lifting the proximal phalanx through the pull of the extensor tendon.
  - MCP joint flexion is produced through a combination of direct intrinsic tendon attachments to the volar-lateral phalangeal base and indirect actions of the intrinsics on the more distal transverse fibers of the extensor hood.

PATHOGENESIS
- Arthritis is the principal indication for small joint arthrodesis.
- Osteoarthritis (OA) most commonly affects the DIP joints. It is estimated that at least 60% of individuals over age 60 have DIP joint arthritis, which may not necessarily be symptomatic.
- In the early stages, the joints may be painful and swollen in spite of normal radiographs. As the arthritis progresses, osteophytes and mucous cysts may develop. Bony prominences (Heberden nodes) and angular deformities in both the coronal and sagittal planes (mallet appearance) may develop. In the final stages, DIP joint motion may be severely restricted.
- OA may also involve the PIP joints and the MCP joints, especially in the index and middle fingers.
- Inflammatory arthritis may also affect the small joints of the hand. About 70% of rheumatoid patients have hand involvement. Synovitis may result in deformity due to attenuation of supporting structures (collateral ligaments, extensor tendons) long before arthritic changes are evident.
- At the DIP joint, terminal tendon incompetence may result in a secondary swan-neck deformity.
- At the PIP joint, central slip attenuation results in a boutonnière deformity.
- At the MCP joint, collateral ligament involvement may contribute to ulnar drift. Persistent synovitis produces cartilage loss.
Hand involvement in systemic lupus erythematosus (SLE) may mimic rheumatoid arthritis. Supporting structures are affected principally in SLE, which may result in joint subluxation or dislocation with relatively normal-appearing articular cartilage. The capsuloligamentous problems may compromise attempts at joint salvage.

In contrast, psoriatic arthritis may produce a remarkable degree of bone loss as the arthritis progresses. Pencil-in-cup deformity is a characteristic feature of psoriatic arthritis of the interphalangeal joints. Severe bone resorption is the characteristic feature of arthritis mutilans, most commonly seen in patients with psoriatic arthritis. Arthrodesis is the most reliable method for halting this destructive process.

Scleroderma typically produces PIP flexion and MCP extension contractures. Impaired vascularity of the digits may result in dorsal PIP ulcer formation and central slip attenuation, compounding the PIP flexion deformity.

Presentations of crystalline arthropathy in the small joints of the hand may be varied. The process may be indolent, presenting as gouty tophi over the DIP joint, or acute, presenting as an exquisitely painful, swollen, tender joint. Untreated, gout results in a resorptive arthritis.

Infection is another cause of small joint arthritis.

A “fight bite” directly inoculates the MCP joint and, if undertreated, can result in rapid joint destruction.

Contiguous spread, for example, from a felon or a wound over the DIP or PIP joint, may destroy the adjacent joint.

Hematogenous spread is an uncommon cause of septic arthritis in the hand.

Trauma is another cause of unreconstructable problems in the small joints of the hand.

Intra-articular fractures and fracture-dislocations may result in arthritis, particularly in cases of residual joint incongruity. The PIP joint does not tolerate injury well.

Severe periarticular soft tissue injuries may cause severe joint stiffness, even if the underlying joint surface is not initially involved. Certain soft tissue injuries, such as central slip disruptions, may confound attempts at reconstruction.

Central or peripheral nerve injury may produce imbalances in the hand. Arthrodesis can potentially simplify reconstructions in an effort to improve function.

PATIENT HISTORY AND PHYSICAL FINDINGS

Pain is the most common complaint of patients who are candidates for arthrodesis. Ideally, the location of the pain should correlate with the joint in question.

In OA, multiple DIP joints may appear abnormal, although they may not necessarily be painful.

Polyarticular involvement is common in rheumatoid arthritis. A priority list should be elicited from the patient.

Handedness, occupation, and avocational activities should be documented.

The functional impact of the problem should be clearly defined.

When a single joint is involved, a history of trauma should be sought.

In cases of acute, painful swelling, a history of penetrating injury, gout, or recent infection should be considered.

The physical examination should include the appearance of joints and overlying skin, active and passive range of motion of the affected joints, stability, grip and pinch strength, and sensibility.

The status of adjacent joints should be evaluated.

For example, chronic DIP OA resulting in a DIP flexion deformity may produce a secondary hyperextension deformity of the PIP (swan-neck) that may be more disabling than the primary (DIP) problem.

Multiple DIP joint bumps (Heberden nodes) are a characteristic feature of OA.

Mucous cysts are suggestive of underlying DIP OA.

Onycholysis and eczema are suggestive of psoriatic arthritis.

Discrepancies between active and passive motion are indicative of an associated tendon problem.

Stress examination may demonstrate collateral ligament incompetence.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Plain radiographs (posteroanterior [PA], lateral, oblique) of the affected digit are usually sufficient to make the diagnosis.

In cases of suspected inflammatory arthritis, a collagen vascular screen is ordered. This blood panel includes a rheumatoid factor, ANA, complete blood count with differential, erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP).

A uric acid level may be drawn in cases of suspected gout.

Blood tests are not generally helpful in the setting of an acute finger infection.

MRI or ultrasound may rarely be ordered to evaluate tendon pathology if stiffness is associated with tendon abnormality.

DIFFERENTIAL DIAGNOSIS

OA

Inflammatory arthritis (rheumatoid, SLE, psoriatic arthritis)

Crystal arthritis

Posttraumatic arthritis

Infection

NONOPERATIVE MANAGEMENT

The mainstays of nonoperative treatment for unreconstructable small joint problems in the hand include oral medications, splints, and intra-articular corticosteroid injections.

For OA and posttraumatic arthritis, oral anti-inflammatory agents may reduce pain and stiffness.

Glucosamine and chondroitin sulfate appear to be of limited value for hand arthritis.

Rheumatoid patients can consider modifications in their medication regimen, supervised by a rheumatologist.

Resting splints may reduce pain and inflammation.

At the DIP and PIP joints, a simple padded aluminum splint may suffice.

Corrective splints, such as the safety pin static progressive or LMB dynamic splint (DeRoyal), will not be tolerated when the joint is inflamed.

For the thumb MCP joint, a hand-based thermoplast splint may lessen discomfort and improve function.

Buddy taping to the adjacent digit may be appropriate for some MCP joint problems. Dynamic MCP joint splints are usually reserved for postoperative protection.

Corticosteroid injections may provide temporary relief of pain and synovitis. The joint may be difficult to access and the joint capacity is quite small.
The surgeon should use a 27-gauge needle and inject 0.5 mL of Celestone Soluspan and 0.5 mL of 1% Xylocaine through a dorsal approach.

SURGICAL MANAGEMENT
Arthrodesis Versus Arthroplasty
- Arthrodesis is a reliable procedure for managing arthritis and instability of the DIP joint. The functional impairment from loss of motion at the DIP joint is minimal.
- At the PIP joint level, the surgeon and patient must weigh the potential benefits of stability and pain relief against the functional impairment resulting from the loss of PIP joint motion. For the index finger, PIP joint stability is critical for pinch. On the other hand, in the small finger, PIP joint mobility is necessary for grip.
- As a general rule, for isolated unreconstructable PIP problems, the index finger gets arthrodesis, the middle finger gets arthrodesis or arthroplasty, and the ring and small fingers get arthroplasty.
- Exceptions to the rule include associated unsalvageable tendon problems and soft tissue coverage issues, in which arthrodesis may be preferred.
- The status of the adjacent joints is an important factor in deciding whether to perform arthrodesis or arthroplasty. In the rheumatoid patient with both MCP and PIP involvement, the temptation is to perform arthroplasties of all involved joints. So-called double-row arthroplasties tend to compromise the results at both the MCP and PIP joints. In such instances, the goal is stability at the PIP joint (arthrodesis) and motion at the MCP joint (arthroplasty).
- Arthrodesis of the thumb MCP joint is a reliable procedure for managing arthritis and unreconstructable ligament problems. Arthrodesis is a far superior procedure to arthroplasty for the thumb. However, before undertaking this, it is important to ensure adequate motion and function of the adjacent joints (interphalangeal, carpometacarpal).
- The chronic radial collateral ligament tear with static volar-ulnar subluxation is a good indication for thumb MCP fusion.
- Arthrodesis of the digital MCP joints is not commonly performed. Indications include multiply failed arthroplasty or inadequate bone stock for arthroplasty, unremitting infection, refractory instability of the index MCP, and an unreconstructable extensor mechanism.
- Candidates for arthrodesis must understand that all motion in the affected joint will be eliminated, and that the principal goals are pain relief and stability.\textsuperscript{19}

Arthrodesis Position
- The fusion position varies with the digit and joint involved. Invariably, the decision is a compromise between appearance and function. The ideal posture should replicate the normal digital cascade (FIG 1).
- In general, the DIP joints and thumb interphalangeal joint should be fused in 0 to 10 degrees of flexion.\textsuperscript{14}
- For the PIP joint, some authors recommend a uniform 40-degree flexion position for all digits,\textsuperscript{9} while others recommend 40 degrees for the index finger, progressing ulnarward in 5-degree increments to 55 degrees in the small finger.\textsuperscript{17}
- Many prefer a slightly more extended position for the index PIP that will still allow functional tip-to-tip pinch.
- The recommended fusion angle of the MP joints is a cascade from 25 degrees of flexion in the index digit, progressing ulnarward in 5-degree increments to 40 degrees in the small finger.\textsuperscript{14}
- The recommended fusion angle of the MP joint of the thumb is 10 to 15 degrees of flexion.\textsuperscript{14}

Fixation Options
- The choice of surgical technique depends on a number of factors, including the affected joint to be fused, the availability and cost of implants, the adequacy of bone stock, and the comfort of the surgeon. The goal is to achieve a solid fusion of the affected joint in a timely manner. Bone preparation is essential.
- The specific method of fixation may be less important in obtaining union than specific patient factors such as bone quality. Certain constructs, such as the tension band, are more rigid but may be associated with more hardware-related problems.
- The biomechanical issues must be weighed against potential soft tissue problems when deciding on a form of fixation. Maintenance of motion in the adjacent joints is critical.
- Kirschner wire fixation has been associated with fusion rates of up to 99%.

Advantages
- Simplicity of the technique
- Ready availability of low-cost implants

Disadvantages
- Infection risk, including superficial pin site and deep wound infections, osteomyelitis; pin migration; minimal compression across the fusion site
- Less rigid fixation,\textsuperscript{9} requiring additional external immobilization to enhance stability, possibly leading to stiffness of surrounding joints\textsuperscript{8,15}
- Interosseous wiring has been found to be biomechanically stronger than Kirschner wire fixation.\textsuperscript{18} It is especially useful for PIP fusion and thumb interphalangeal fusion.

Advantages
- Biomechanically stronger than Kirschner wire fixation\textsuperscript{18}
- Readily available low-cost implants

Disadvantages
- Large amount of soft tissue stripping for appropriate placement of drill holes
- Higher rate of nonunion, up to 9%\textsuperscript{11}
Tension band fixation is a biomechanically stable method of fixation\textsuperscript{16} combining parallel Kirschner wires for rotational control and interosseous wiring for compression. This technique is especially useful for MCP, PIP, and thumb interphalangeal arthrodesis.

- The tension band construct converts the strong distracting force created by the finger flexors to a compressive force across the arthrodesis interface.
- This technique is relatively simple, with a high fusion rate and reliable outcomes,\textsuperscript{1,16} especially when used for arthrodesis of the MCP and PIP joints.
- Postoperative immobilization is necessary only in the immediate postoperative period to allow for healing of the incision.\textsuperscript{1,8}

**Advantages**
- Simplicity of the procedure
- Low rate of infection\textsuperscript{16}
- High fusion rates, reportedly 97\% to 100\%\textsuperscript{1,16}
- Readily available, low-cost implants
- Enhanced biomechanical stability and strength of the construct, allowing for early active range of motion\textsuperscript{16} The tension band construct for small joint arthrodesis has been shown to be biomechanically superior compared to crossed Kirschner wire fixation and intraosseous wiring, especially in anteroposterior bending and in axial torsion.\textsuperscript{9}

**Disadvantages**
- Increased soft tissue dissection to place the drill holes, with resultant increased risk of soft tissue and tendon scarring
- Difficult to remove fully internalized hardware if necessary

Plate fixation provides biomechanically strong fixation, especially useful for PIP and MCP joint arthrodesis.\textsuperscript{4,19}

**Advantages**
- Excellent fusion rate by 6 weeks, 96\% to 100\%\textsuperscript{1,16}
- Ability to correct deformity
- Useful in cases with segmental bone loss\textsuperscript{4}

**Disadvantages**
- Technically demanding
- Time-consuming
- Extensor tendon adhesions, possibly necessitating hardware removal and tenolysis\textsuperscript{16}; stiffness in adjacent joints
- Hardware prominence

Compression screw fixation is a biomechanically strong fixation technique\textsuperscript{20} that is especially useful for arthrodesis of the finger DIP and PIP joints, as well as the thumb interphalangeal joint.

**Advantages**
- Using a headless screw keeps the fixation hardware low profile and prevents the problems associated with prominent hardware.
- PIP joint fusion uses the same principles but has a slightly different surgical technique.\textsuperscript{2}

**Disadvantages**
- Fusion rates 85\% to 98\%\textsuperscript{2,3}
- Hardware is buried and low profile.
- Risk of penetration and fracture of the dorsal cortex,\textsuperscript{3} especially with screw fixation of the PIP joint, results in poor fixation
- Risk of nail irregularities from disturbance of germinal matrix\textsuperscript{3} in DIP fusion

**Complications**
- Risk of infection, hardware complications, nail irregularities secondary to penetration of the dorsal cortex of the distal phalanx by the screw, and fractures of the dorsal cortex from screw breakthrough\textsuperscript{3}
- Easily avoided by maintaining adequate space between the dorsal proximal entry site and the arthrodesis site
- For DIP arthrodesis, the nail-associated complications usually occurred in the small finger because of the large diameter of the screw used relative to the size of the small finger distal phalanx medullary canal.\textsuperscript{20} This is less of a problem in the distal phalanges of the other fingers or thumb.\textsuperscript{2,3}

**Preoperative Planning**
- Radiographs of the affected joint must be reviewed before operative management. Assessment of the bone stock, quality, and size is useful in helping to determine the optimal type of surgical fixation.
- Should a fusion screw be considered, templates may be used to determine the appropriate screw length and diameter.

**Positioning**
- The patient is placed in the supine position, with the affected limb resting on a hand table. Sterile preparation and draping is performed.
- For arthrodesis of the PIP and DIP joints, local anesthesia with or without sedation is adequate.
- Two percent mepivacaine provides a rapid rate of onset and lasts about 1 hour.
- For the PIP joint, a web space block is performed, including the dorsal cutaneous branches.
- For the DIP joint, the flexor tendon sheath is injected.
- For the MCP joint, either regional or general anesthesia is necessary.

---

**DIP JOINT ARTHRODESIS**

**Exposure**
- A digital tourniquet is used.
- Center a dorsal H-shaped incision over the DIP joint (TECH FIG 1A).
- Transect the terminal tendon (TECH FIG 1B).
- Release the collateral ligaments from the middle phalanx, using a no. 15 blade directed dorsally, parallel to the sides of the phalanx (TECH FIG 1C).

**Preparation of the DIP Joint**
- Hyperflex the DIP joint and remove peripheral osteophytes with a small rongeur.
- Remove the volar condyles of the head of the middle phalanx with the rongeur.
- Identify the periphery of the base of the distal phalanx with a no. 15 blade, protecting the germinal matrix and the neurovascular bundles.
- Remove bone necessary to correct any joint malalignment, but minimize loss of digital length.
- Dechondrify and decorticate the opposing surfaces until healthy-appearing bone is present.
- Contour the head of the middle phalanx into a transversely oriented cylindrical shape (TECH FIG 2A), and fashion the base of the distal phalanx into a reciprocal shape.
  - Alternatively, create flat opposing surfaces perpendicular to the shafts.
- On occasion, the base of the distal phalanx is eburnated. Multiple 0.035-inch drill holes may be placed (“pepperpot” technique), which may then be connected with a small rongeur to unveil subchondral bone (TECH FIG 2B,C).

### Reduction and Fixation

- The type of fixation depends on the size of the bone. An Acutrak fusion screw (Acumed, Hillsboro, OR) is preferred when the diameter of the middle and distal phalanges is sufficient to accommodate the screw.
- Insert a 0.062-inch Kirschner wire antegrade beginning at the base of the distal phalanx and exiting the tip of the distal phalanx, just volar to the nail plate (TECH FIG 3A).
  - If the Kirschner wire penetrates the nail plate, discard it and use another to minimize the likelihood of contamination.
- Drive a smooth 0.062-inch Kirschner wire retrograde into the center of the middle phalanx to create a pilot hole, and then remove it (TECH FIG 3B).
- Reduce and compress the joint and then advance the wire retrograde across the DIP joint into the middle phalanx (TECH FIG 3C).
- Assess the reduction and Kirschner wire position clinically and fluoroscopically (TECH FIG 3D).
- While manually maintaining the joint position, remove the Kirschner wire and replace it with the appropriate drill bit.
  - Proper drill bit size is based on preoperative templating as well as an estimate of the available space based on the lateral fluoroscopic image with the 0.062-inch Kirschner wire in place.
- While maintaining compression across the joint, advance the drill retrograde by hand along the path created by the removed Kirschner wire (TECH FIG 3E).
- Determine the proper depth by fluoroscopy, using the external drill bit markings as a reference.
- Remove the drill bit and insert the appropriate-sized fusion screw (TECH FIG 3F) while maintaining manual compression across the joint.
- Final seating of the screw is based on the external reference used for the drill bit.
Chapter 80  DIP, PIP, AND MCP JOINT ARTHRODESIS

TECHNIQUES

A B C D E

I

J

TECH FIG 3 • A. A 0.062-inch Kirschner wire is driven antegrade through the center of the distal phalanx. B. A second 0.062-inch Kirschner wire is driven retrograde down the center of the middle phalanx to prepare a path for the screw. C. The distal interphalangeal joint is reduced and the distal Kirschner wire is driven retrograde into the middle phalanx. D. Proper alignment is confirmed fluoroscopically. The diameter of the intramedullary Kirschner wire is used as a reference for determining the screw diameter, based on the lateral radiograph. E. The Kirschner wire is removed. While maintaining manual compression across the joint, the appropriate drill bit is advanced by hand retrograde through the Kirschner wire path under fluoroscopic control. External markings on the drill bit serve as a reference for depth. F. The appropriate-sized screw is selected and secured to the driver. External markings on the driver correlate with the drill bit. G,H. PA and lateral radiographs during screw insertion. I. An alternative method of fixation involves the use of two or three Kirschner wires. J. Clinical appearance after fixation and closure.

Avoid inadvertent malrotation of the distal segment as the screw is tightened.

Obtain final radiographs and evaluate the stability (TECH FIG 3G,H).

Insert a supplemental 0.035-inch oblique Kirschner wire if necessary for stability.

If Kirschner wires are used as the sole form of fixation, drive an appropriate-diameter pin antegrade into the distal phalanx, reduce the joint, and advance the pin retrograde, preferably into the subchondral plate at the base of the middle phalanx.

One or two additional Kirschner wires are inserted obliquely in a retrograde fashion.

Final radiographs are obtained, and the pins are cut beneath the skin (TECH FIG 3I).

Completion

Remove the digital tourniquet and achieve hemostasis using bipolar electrocautery.

Irrigate the wound copiously.

Approximate the skin with 5-0 nylon interrupted sutures (TECH FIG 3J).

Repair of the terminal tendon is unnecessary.

Apply a sterile dressing and dorsal aluminum DIP splint, leaving the PIP joint free.

Instruct the patient on PIP exercises.
PIP JOINT ARTHRODESIS

Exposure
- Make a longitudinal dorsal incision.
- The surgical approach is similar to the thumb MCP arthrodesis (discussed later).
- In the multiply operated finger, a pre-existing midaxial scar may be used.
- The central slip and capsule are split longitudinally and elevated subperiosteally.
- The collateral ligaments are released from the middle phalanx, using a no. 15 blade directed dorsally, parallel to the sides of the phalanx.

Preparation of the PIP Joint
- Hyperflex (shotgun) the PIP joint and prepare the joint in the manner detailed for the DIP joint.
- Correct joint malalignment but minimize loss of digital length.
- As for the DIP joint, contour the head of the proximal phalanx into a transversely oriented cylindrical shape, and fashion the base of the distal phalanx into a reciprocal shape.
- Alternatively, use a water-cooled sagittal saw to cut flat surfaces perpendicular to the phalangeal shafts in the coronal plane, and with an appropriate degree of flexion in the sagittal plane.
- The flexion angle is built into the proximal phalanx saw cut. The middle phalanx cut is perpendicular to the axis of the phalanx in the sagittal plane.
- There is little room for error with the bone cuts. Commitment to the final position of the arthrodesis is made when the bone cuts are made. Any change may result in excessive shortening of the bone.7
- On occasion, as with the DIP joint, the base of the middle phalanx is eburnated. Multiple 0.035-inch drill holes may be placed (“pepperpot” technique), which may then be connected with a small rongeur to unveil subchondral bone.

Kirschner Wire Fixation
- In patients with inflammatory arthritis, the overlying skin is quite thin and may not tolerate prominent hardware. In those instances, crossed 0.035- to 0.045-inch Kirschner wires are used.
- Preset the appropriately sized Kirschner wires into the sides of the middle phalanx.
- Reduce and compress the joint manually, then advance the Kirschner wires in a retrograde manner into the proximal phalanx.
- If the skin is very thin, it may be impossible to cut the Kirschner wires beneath the skin. In those instances, the Kirschner wires are simply bent and left exposed.

Tension Band Fixation
- A tension band technique is used for posttraumatic and OA cases, particularly those involving the index PIP joint (TECH FIG 4A).
- Use a 0.035-inch Kirschner wire to make a transverse hole in the middle phalanx, dorsal to the mid-axis, about 8 mm distal to the joint.
- Pass a 26-gauge surgical steel wire through the hole.
- With the joint manually reduced, drive parallel 0.035- to 0.045-inch Kirschner wires antegrade across the PIP joint into the subchondral head of the middle phalanx.
- Begin the Kirschner wires on the dorsoradial and dorsoulnar margins of the proximal phalanx, about 10 mm proximal to the fusion site.
- The Kirschner wires should remain intramedullary in the middle phalanx.
- Loop the 26-gauge wire into a figure 8 configuration around the Kirschner wires proximally and tighten carefully with a needle driver.
- A gentle distraction force on the needle holder as the device is used to turn the wire and compress the fusion site helps avoid wire breakage.
- Remove the excess knot and impact the knot into bone.
- Withdraw the Kirschner wires slightly, bend them as close to the bone as possible so they can capture the 26-gauge wire, cut the Kirschner wires just distal to the bend, and advance them using the needle holder.
- Obtain final radiographs (TECH FIG 4B) and assess stability.
- Remove the tourniquet, achieve hemostasis, and irrigate the wound.
- Reapproximate the extensor tendon using interrupted inverted 4-0 nonabsorbable sutures. Close the skin with 5-0 nylon interrupted sutures.
- Place a sterile dressing and dorsal aluminum splint, leaving the DIP joint free. Instruct the patient on DIP joint exercises.

TECH FIG 4 • A. Preoperative PA radiograph demonstrating advanced osteoarthritis of the index proximal interphalangeal joint. Note the angular deformity, joint space loss, and large subchondral cyst. B. Postoperative PA radiograph demonstrating proximal interphalangeal arthrodesis with tension band fixation.
THUMB MCP JOINT ARTHRODESIS

Exposure
- Make a longitudinal dorsal incision over the MCP joint (TECH FIG 5A).
- Incise the extensor apparatus longitudinally between the EPB and EPL tendons (TECH FIG 5B). This will reveal the joint capsule (TECH FIG 5C).
- Perform a longitudinal capsulotomy and subperiosteally dissect around the dorsal base of the middle phalanx (TECH FIG 5D).
- Release the collateral ligaments from the metacarpal head (TECH FIG 5E), and hyperflex the MCP joint (TECH FIG 5F).

Joint Preparation
- Dechondrify the articular surfaces and remove peripheral osteophytes as well as the volar condyles of the metacarpal head with a rongeur (TECH FIG 6A).
- Decorticate and prepare the fusion surfaces in a “cup-and-cone” configuration\(^5,12\) using Coughlin reamers (Howmedica, Rutherford, NJ) (TECH FIG 6B,C).
  - This method allows for maintenance of thumb length and subtle adjustments in joint position while still maintaining optimal bone contact.
  - The 14- and 16-mm sizes are most often appropriate. Size selection is usually based on the size of the metacarpal head in order to avoid notching.
  - The same dimensions must be used for both metacarpal and phalangeal reaming or the surfaces will be incongruent.

Fixation and Reduction
- Tension band fixation is performed to stabilize the thumb MCP joint fusion in much the same manner as detailed for arthrodesis of the PIP joint.
- Alternative methods of fixation include Kirschner wires alone, headed or headless screw fixation, and plate fixation.

---

TECH FIG 5 • A. A longitudinal incision is centered over the metacarpophalangeal joint. B. The extensor hood is incised between the extensor pollicis longus and brevis tendons (dotted line). C. The hood has been split, revealing the dorsal joint capsule. D. The capsule has been incised longitudinally and reflected subperiosteally from the dorsal base of the proximal phalanx. Note the full-thickness cartilage loss along the ulnar aspect of the metacarpal head and dorsal base of the proximal phalanx secondary to volar-ulnar subluxation. E. The collateral ligaments are released from the metacarpal head. F. The metacarpophalangeal joint is now hyperflexed.
The remaining articular cartilage is removed. Peripheral osteophytes and the volar condyles are trimmed with a rongeur. **B.** Coughlin cup and cone reamers. Care must be taken to ensure that the same-sized reamer is used for both sides to maximize bone contact. **C.** The metacarpal head is used as a reference in determining reamer size. The smallest reamer that will not notch the cortex is selected. **D,E.** A 0.062-inch Kirschner wire is advanced antegrade in the proximal phalanx to be used as a guidewire. The pin is positioned in the center of the bone in the coronal plane (dot in the center of the interphalangeal joint) and in slight flexion in the sagittal plane. **F.** The “cup” reamer is placed over the Kirschner wire under power with frequent irrigation until bleeding subchondral bone is revealed. The asymmetry of the base of the proximal phalanx due to chronic subluxation is corrected. **G,H.** A 0.062-inch Kirschner wire is then inserted retrograde into the metacarpal head. The pin is positioned in slight flexion and slight ulnar deviation. **I.** The matching “cone” reamer is placed over the Kirschner wire under power with frequent irrigation until bleeding subchondral bone is apparent. **J.** Appearance of the surfaces after joint preparation.

- The tension band construct is strong enough to allow for early motion with a hand-based splint.
- Plate fixation is reserved for cases of bone loss requiring supplemental grafting.
- Use a 0.045-inch smooth Kirschner wire to create a transverse hole in the proximal phalanx, about 1 cm distal to the joint and dorsal to the midline.
- Pass a 24- or 26-gauge surgical steel wire though the tunnel (**TECH FIG 7A**).
- Anticipating the ultimate position of the thumb fusion, advance parallel 0.054- or 0.062-inch Kirschner wires retrograde, exiting dorsally along the metacarpal shaft (**TECH FIG 7B**).
- Reduce the MCP joint in slight (less than 25 degrees) flexion, abduction (5 degrees), and pronation (5 degrees), and drive the preset Kirschner wires antegrade.
- Take care to avoid perforating the volar cortex into the flexor tendon sheath.
Loop the wire in a figure 8 configuration around the Kirschner wires, and tighten using a needle driver.

Trim excess wire and impact the knot into the bone.

Pull back, bend, cut, and advance the Kirschner wires (as detailed earlier) to secure the tension band wire (TECH FIG 7C).

Completion

- Remove the tourniquet, achieve hemostasis, and irrigate the wound.
- Close the capsule over the hardware using absorbable 4-0 suture and then close the extensor mechanism using 4-0 nonabsorbable interrupted inverted stitches (TECH FIG 8A).
- Approximate the skin using 5-0 nylon interrupted suture, and apply a sterile dressing and radial gutter splint.
  - The interphalangeal joint is left free, and the patient is instructed on interphalangeal motion exercises.
- Obtain final radiographs (TECH FIG 8B,C).

TECH FIG 7 • A. A 24-gauge wire is passed through a drill hole in the proximal shaft of the proximal phalanx, dorsal to the midline and parallel to the joint. B. A 0.062-inch Kirschner wire is then driven retrograde in the metacarpal head, exiting dorsally, anticipating the ultimate position of the metacarpophalangeal joint. C. The 24-gauge wire is looped around the base of the Kirschner wires in figure 8 fashion and tensioned. The Kirschner wires are cut short and the wire knot is tamped against the cortex.

Loop the wire in a figure 8 configuration around the Kirschner wires, and tighten using a needle driver.

Trim excess wire and impact the knot into the bone.

Pull back, bend, cut, and advance the Kirschner wires (as detailed earlier) to secure the tension band wire (TECH FIG 7C).

Completion

- Remove the tourniquet, achieve hemostasis, and irrigate the wound.
- Close the capsule over the hardware using absorbable 4-0 suture and then close the extensor mechanism using 4-0 nonabsorbable interrupted inverted stitches (TECH FIG 8A).
- Approximate the skin using 5-0 nylon interrupted suture, and apply a sterile dressing and radial gutter splint.
  - The interphalangeal joint is left free, and the patient is instructed on interphalangeal motion exercises.
- Obtain final radiographs (TECH FIG 8B,C).

TECH FIG 8 • A. The capsule and extensor hood are repaired in layers. B,C. Postoperative PA and lateral radiographs demonstrate good joint apposition and alignment.

INDEX THROUGH SMALL FINGER MCP JOINT ARTHRODESIS

- The approach and bone preparation mirror those described for the thumb.
- Fixation may be achieved with Kirschner wires alone, a tension band construct, screws, or plates (TECH FIG 9).
  - Keep in mind the anticipated deforming forces, which may be out of plane with the fixation.
- Immobilization should protect the fused joint from stress, while simultaneously permitting motion of the PIP and DIP joints. We prefer to apply a short-arm cast extending out to the PIP joints, allowing PIP and DIP motion.

TECH FIG 9 • A, B. PA and lateral radiographs showing chronic right index metacarpophalangeal volar-ulnar subluxation in patient who had undergone two previous attempts at radial collateral ligament reconstruction. (continued)
The surgical approach, bone preparation, and closure are performed as detailed earlier.

Most frequently, flat bone cuts are used with these fixation techniques.

### Interosseous Wiring
- Drill two parallel holes from dorsal to volar, each 3 to 4 mm away from the arthrodesis site, using a 0.035-inch Kirschner wire.
- Drill two additional holes, this time in the radioulnar plane, again about 3 to 4 mm on either side of the arthrodesis site.
- Thread two 26-gauge surgical steel wires through the drill holes.
  - A 20-gauge hypodermic needle may be used to facilitate wire placement.
- Pass one wire from dorsal to volar through one drill hole, and then volar to dorsal in the parallel drill hole, forming a loop.
- Pass the second 26-gauge steel wire through the drill holes in the coronal plane, forming a second loop.
- After the wires are placed, tighten the ends of the wires sequentially and shorten and bend them to decrease their profile.
- This configuration results in two perpendicular loops providing compression and fixation across the arthrodesis interface.

### Plate Fixation
- Fill bone defects with intercalary grafts as needed (TECH FIG 10A,B).
- Select the largest compression plate that will not be prominent.
  - These range in size from 1.5 to 2.7 mm.
- The plate is precontoured to match the angle of the fusion.
  - A slight increase in concavity is created to allow compression of the volar cortex when the plate is applied (TECH FIG 10C).
- Insert a bicortical screw through the plate into the distal fragment.
  - Be certain that this and other screws do not penetrate the volar cortex and impair the function of the flexor tendons.
- Using AO compression technique, place a screw through the plate into the proximal fragment.
  - Drill as proximally and eccentrically as possible within the plate’s screw hole so that when the screw is tightened, compression is obtained.
- Place the remaining screws (TECH FIG 10D).
  - Four to six cortices on either side of the fusion site provides adequate fixation.14

### Compression Screw Fixation
- In much the same manner as described for placement of Kirschner wires for tension band fusion of the
A B C

TECH FIG 10 • A,B. After silicone implant arthroplasty, rigid swan-neck deformities developed. Conversion to arthrodesis in a more functional position was complicated by large bone defects resulting from removal of the implants. C. A prebent 2-mm dynamic compression plate is applied to the dorsal surface for the proximal and middle phalanges. D. Lateral radiograph depicts placement of intercalary bone graft and compression plate fixation. Screw length is carefully determined to avoid irritation of the flexor tendons. (Copyright Thomas R. Hunt III, MD.)

D

TECH FIG 11 • PA and lateral radiographs demonstrating arthrodesis of proximal interphalangeal joints with cannulated, headless compression screws. (Copyright Thomas R. Hunt III, MD.)

A B

Chapter 80 DIP, PIP, AND MCP JOINT ARTHRODESIS

thumb MCP joint, the guidewire is introduced into the proximal fragment in a retrograde manner, exiting the dorsal cortex at least 5 mm proximal to the arthrodesis site.
- This protects against inadvertent fracture of the dorsal cortex.
- Manually reduce and compress the prepared joint.
- It may be helpful to place a small (0.028- to 0.035-inch) provisional Kirschner wire away from the anticipated screw site to provide rotational stability.
- Advance the guidewire antegrade from proximal to distal, perpendicular to the fusion interface, and into the medullary canal of the distal segment.
- Advance the wire just beyond the mid-diaphyseal region of the distal fragment.
- Evaluate clinically and fluoroscopically to ensure proper position (TECH FIG 11).
- Measure the guidewire and choose the appropriate-length screw to ensure that after compression, the distal screw threads will engage the endosteal cortex and the proximal aspect of the screw will be buried.
- Remove the derotation Kirschner wire.

A B
PEARLS AND PITFALLS

Bone end preparation
- If flat bone cuts are to be used, predetermine and create accurate flexion angles for the joint fusion. There is little room for error with this technique. Inaccurate cuts will result in excessive bone shortening.
- The cup-and-cone preparation technique is more forgiving, allowing for angular and rotational adjustments while maintaining bone contact.
- Ensure that there is no malrotation of fusion interface.

Surgical approach
- Preserve joint capsule for later repair to minimize extensor tendon adherence.

Tension band fixation
- To minimize hardware problems, position the Kirschner wires within the intramedullary canal and advance them into the subchondral plate.

Compression screw fixation
- In the PIP and MCP joints, ensure that the starting point is 5 mm from the bony end of the proximal fragment to prevent fracture of the dorsal cortex.

POSTOPERATIVE CARE
- Postoperative management depends on the involved joint and method of fixation. Early motion of the adjacent joints is critical to minimize stiffness.
- For DIP joint arthrodesis, protection with a simple aluminum splint is sufficient. PIP motion is encouraged. Splinting may be unnecessary if a fusion screw is used. Radiographs are taken at 6 weeks postoperatively. Buried pins may be removed once the fusion is radiographically solid (at least 8 weeks postoperatively).
- For PIP joint arthrodesis, tension band, screw, and plate constructs are usually strong enough to obviate the need for supplemental splinting. Early MCP and DIP motion is encouraged; however, the patient is advised against lateral stress or forceful grip with the affected digit. With simple pin fixation, a supplemental dorsal aluminum or thermoplast PIP splint is used until radiographs demonstrate union.
- For the thumb MCP joint treated with tension band fixation, a protective custom-molded thermoplast hand-based MCP splint is used for about 6 weeks. Early IP joint motion is encouraged.
- In general, arthrodesis of the other MCP joints must be protected with a hand- or forearm-based splint, regardless of the type of fixation. Significant flexion and lateral stresses must be neutralized while simultaneously allowing for PIP and DIP motion. It may be necessary to splint the PIP joint in extension part-time to prevent an extensor lag from developing.

OUTCOMES
- Multiple studies have evaluated the biomechanical advantages of one type of surgical technique versus another in order to establish the most rigid type of fixation that will allow a rapid and complete arthrodesis.
- A comparison between the failure load of a Herbert screw and the failure load of a tension band construct showed no significant difference between the two; the authors concluded that these two methods of fixation have similar biomechanical strength.
- A comparison of multiple fixation techniques showed that arthrodesis by screw fixation had a better fusion rate than Kirschner wires, tension band construct, and plate fixation.10
- A comparison of tension band constructs versus Kirschner wire fixation for PIP joint arthrodesis concluded that tension bands provide more rigid fixation.9
- Biomechanical testing comparing the Herbert screw and tension band construct for DIP arthrodesis showed that the Herbert screw has significantly higher bending strength as well as more rigidity against axial torsion, although no difference was noted in the bending stiffness between these two methods of fixation.20

COMPlications
- Pin tract infection
- Nonunion
- Malunion
- Vascular insufficiency
- Skin necrosis
- Cold intolerance
- Stiffness of adjacent digits
- Painful hardware

REFERENCES


DEFINITION
- When ligamentous restraint at the thumb carpometacarpal (CMC) joint is compromised, functional grip and pinch may result in painful synovitis and hypermobility long before the development of cartilage wear and arthritis.
- So-called Eaton stage 1 disease can be treated with an extension osteotomy at the base of the thumb metacarpal as an alternative to either ligament reconstruction or arthroscopic synovectomy and pinning.\(^7,8\)

ANATOMY
- The thumb metacarpal (TM) joint is a biconcave-convex saddle joint with minimal bony constraints, so ligamentous support is extremely important, especially considering the compressive forces transmitted across the joint during functional pinch. Eaton and Littler identified the anterior oblique “beak” ligament, so called for its attachment on the palmar beak of the thumb metacarpal, as the primary stabilizer of the TM joint.
- With the assistance of TM joint arthroscopy, Bettinger et al\(^1\) have further defined the anterior oblique ligament (AOL) into a superficial (sAOL) and deep ligament (dAOL). The dAOL, which is intracapsular, is, in fact, the beak ligament. The dAOL plays an important role in the kinematics of thumb opposition. It acts as a pivot point and becomes tight during pronation, opposition, and palmar abduction. The dAOL limits pronation in flexion and both pronation and supination in extension.
- In their comprehensive assessment of the ligamentous anatomy of the TM joint, Bettinger et al\(^1\) described a total of 16 ligaments that stabilize the trapezium and TM. Seven of these ligaments, including the sAOL, dAOL “beak” ligament, dorsoradial (DRL), posterior oblique, ulnar collateral, intermetacarpal, and dorsal intermetacarpal, are responsible for directly stabilizing the TM joint.
- The DRL’s role in joint stability has been debated, but Bettinger et al\(^1\) showed that the DRL is an important joint stabilizer. The DRL, which covers a large percentage of the posterior aspect of the joint, is a wide thick ligament that attaches to the trapezium and inserts on the dorsum of the metacarpal base. This ligament tightens with dorsoradial and dorsal translational forces in all positions except full extension. It also tightens in supination and in pronation with joint flexion.

PATHOGENESIS
- Functional incompetence of the basal joint’s AOL results in pathologic laxity, abnormal translation of the metacarpal on the trapezium, and generation of excessive shear forces between the joint surfaces, particularly within the palmar portion of the joint during grip and pinch activity. Histologic study has shown that attritional changes in the AOL at its attachment to the palmar lip of the metacarpal precede degeneration of cartilage.\(^2\)

NATURAL HISTORY
- Because the AOL appears to be the primary stabilizer of the TM joint, and since its detachment results in dorsal translation of the metacarpal, its reconstruction has been recommended to restore thumb stability not only in cases of end-stage osteoarthritis but also for early-stage disease.
- Pellegrini et al\(^5\) were the first to evaluate the biomechanical efficacy of extension osteotomy. Palmar contact area was unloaded with a concomitant shift in contact more dorsally so long as arthrosis did not extend more dorsal than the midpoint of the trapezium.
- Shrivastava et al\(^6\) studied the effect of a simulated osteotomy on TM joint laxity by flexing the metacarpal base 30 degrees, thus placing the joint in the relationship it would assume if an extension osteotomy was performed.
  - The simulated extension osteotomy reduced laxity in all directions tested: dorsal-volar (40% reduction), radial-ulnar (23% reduction), distraction (15% reduction), and pronation-supination (29% reduction).
  - They hypothesized that the beneficial clinical effects of a TM extension osteotomy may be partially due to tightening of the DRL, which might reduce dorsal translation.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Basal joint arthritis may present with mild symptoms beneath the thenar eminence at the level of the TM joint, particularly during pinch and grip. Ultimately, the greatest functional impairment occurs with advanced disease—limiting breadth of grasp and forceful lateral pinch activities such as brushing teeth, turning a key, opening a jar, or picking up a book.
- Complaints are directed toward the base of the thumb, and pain is frequently associated with a sensation of movement or “slipping” within the joint. An enlarging prominence, or “shoulder sign,” inevitably develops at the base as the clinical manifestation of dorsal metacarpal subluxation on the trapezium and metacarpal adduction.
- Early presentation may result in only pain with TM stress and palpation beneath the thenar cone, without deformity, instability, subluxation, or crepitance.
- Methods for examining the thumb CMC joint for hypermobility (stage 1 disease) include the following:
  - Trapeziiometacarpal stress test, which may cause pain or a slight shift or subluxation
  - Thenar CMC joint palpation test, which may cause pain...
IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographic evaluation includes a posteroanterior (PA) 30-degree oblique stress view, lateral view, and a Robert (pronated anteroposterior [AP]) view (FIG 1).
- Osteoarthritis may be confined to the TM joint, or it may involve the pan-trapezial joint complex. Indeed, the staging system described by Eaton and Littler describes four stages:
  - Stage 1: a normal joint with the exception of possible widening from synovitis
  - Stage 2: joint space narrowing with debris and osteophytes smaller than 2 mm
  - Stage 3: joint space narrowing with debris and osteophytes larger than 2 mm
  - Stage 4: scaphotrapezial joint space involvement in addition to narrowing of the TM joint

DIFFERENTIAL DIAGNOSIS
- CMC arthritis (stages 2 to 4)
- De Quervain tendonitis
- Flexor carpi radialis tendinitis

NONOPERATIVE MANAGEMENT
- Nonoperative treatment includes anti-inflammatory medication, intra-articular steroid injection, hand- or forearm-based thumb spica splint immobilization, and thenar muscle isometric conditioning.
- Although none of these measures may provide permanent or even long-lasting relief from symptoms, they may indeed provide temporary relief. This allows the patient to contemplate surgery, to gain acceptance, and to participate in the surgical decision-making process.

SURGICAL MANAGEMENT
- Until recently, surgical treatment has centered around reconstruction of the palmar beak ligament with a slip of flexor carpi radialis tendon, as described by Eaton and Littler.3
- The rationale for TM extension osteotomy involves dorsal load transfer and a shift in force vectors during pinch. Pellegrini et al5 showed that a 30-degree closing wedge extension osteotomy effectively unloaded the palmar compartment when eburnation involved less than half, and optimally only one third, of the palmar joint surfaces. Osteotomy in this setting shifted the contact areas to the intact dorsal articular cartilage.
- The most recent biomechanical assessment of metacarpal osteotomy suggested that joint laxity is reduced in lateral pinch because of obligatory metacarpal flexion and resulting increased tightening of the dorsal radial ligament.6

Preoperative Planning
- Radiographs should show a normal joint or slight widening from synovitis. A trapeziometacarpal stress test should elicit pain along with palpation of the joint beneath the thenars. Obviously, other causes of discomfort in the region should be excluded.

Positioning
- The extremity is placed on a standard hand table.

Approach
- A dorsal approach is used and subperiosteal exposure of the base of the metacarpal is provided.
- The osteotomy is made 1 cm distal to the base and is 5 mm wide, so the incision should extend 4 cm distal to the base.
- The base of the wedge is therefore 5 mm wide and is dorsal. Its apex is palmar.
EXTENSION OSTEOTOMY WITH STAPLE FIXATION

- Regional, axillary block anesthesia is performed and a nonsterile tourniquet is placed.
- After exsanguination with an Esmarch bandage and inflation of the tourniquet to 250 mm Hg, make a dorsal incision from the base of the TM distally for about 3 cm.
- In the subcutaneous tissue, identify and protect the sensory branches of the radial and lateral antebrachial cutaneous nerves. Obtain subperiosteal exposure without injuring the extensor pollicis longus, and identify the TM joint with a 25-gauge needle.
  - One centimeter distal to the TM joint, obtain near-circumferential access around the metacarpal in anticipation of the osteotomy.
- Visualize the volar extent of the metacarpal at this location to facilitate accurate resection of a dorsally based 30-degree wedge of bone (TECH FIG 1A).
- Use a microsagittal saw to score the metacarpal 1 cm distal to its base transversely, but do not make a complete cut through the volar cortex.
- Leave a new saw blade in that partial osteotomy site and use a second blade about 5 mm distal to the first cut at an angle of 30 degrees so that the two blades intersect at the volar cortex.
- Remove the wedge of bone, extend the distal metacarpal and compress it against the proximal fragment, and place one 11/10038 staple (OSStaple™ BioMedical Enterprises, Inc., San Antonio, TX).
- Typically, I maintain the reduced position of the metacarpal while my assistant predrills and then places the staple (TECH FIG 1B,C).
- Perform a layered closure of the periosteum and skin and place an overlying thumb spica splint.

TECH FIG 1 • A. Radiograph showing planned osteotomy. B,C. AP and lateral postoperative thumb radiographs.

EXTENSION OSTEOTOMY WITH KIRSCHNER WIRE AND TENSION BAND FIXATION

- The technique is as described for staple fixation except for the use of Kirschner wires.
- Use a microsagittal saw to score the metacarpal 1 cm distal to its base transversely, but do not make a complete cut through the volar cortex.
  - Leave a new saw blade in that partial osteotomy site and use a second blade about 5 mm distal to the first cut at an angle of 30 degrees so that the two blades intersect at the volar cortex.
- Remove the wedge of bone and use a 0.045-inch Kirschner wire to place a transverse hole on either side of the osteotomy.
- Pass a 22-gauge wire radial to ulnar and ulnar to radial.
- Place a 0.045-inch Kirschner wire retrograde through the distal osteotomy site, exiting out the ulnar aspect of the thumb, and compress the osteotomy by extending the distal metacarpal.
- With an assistant maintaining compression, tighten the wire, cut it, and bend it beneath the thenar musculature. Then advance the Kirschner wire anterograde.
- Cut the Kirschner wire external to the skin to facilitate removal, and repair the periosteal origin of the thenar musculature with absorbable suture.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Event</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-articular osteotomy</td>
<td>Accurately locate the CMC joint with a 25-gauge needle so that the osteotomy is made 1 cm distal to the base.</td>
</tr>
<tr>
<td>Accurate execution of a 30-degree osteotomy</td>
<td>Make the most proximal cut perpendicular to the metacarpal—with the metacarpal parallel to the table.</td>
</tr>
<tr>
<td></td>
<td>Make the second cut at an angle of 30 degrees—5 mm distal to the first cut—such that the saw blade intersects the volar cortex at the location of the first blade.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- A thumb spica splint is placed for 10 days.
- At that time sutures are removed, and a thumb spica cast with the interphalangeal joint of the thumb left free is placed for an additional 4 weeks.
- About 6 weeks after surgery a forearm-based thumb spica Orthoplast splint is placed, and the patient is instructed to begin gentle TM motion.
- Grip and pinch exercises are started at about 8 weeks after surgery unless union is delayed.

OUTCOMES

- In light of Pellegrini et al’s biomechanical data and my own relative dissatisfaction with Eaton ligament reconstruction for stage 1 disease, primarily related to a prolonged recovery period (8 to 10 months) and a stiff TM joint, I prospectively evaluated the efficacy of a 30-degree extension osteotomy in 12 patients (12 thumbs) between 1995 and 1998.8
  - TM arthroscopy allowed accurate intra-articular assessment and verified AOL detachment from the metacarpal rim in each case.
  - Follow-up averaged 2.1 years (range 6 to 46 months).
  - All osteotomies healed at an average of 7 weeks. Eleven patients were satisfied with outcome. Grip and pinch strength increased an average of 8.5 and 3 kg, respectively.
  - Since that study’s publication, I have become even more impressed by the efficacy of the procedure and believe, as Koff et al suggested, that osteotomy decreases laxity and shifts contact area more dorsally. It seems logical that the DRL participates in this effect, and this substantiates the contention that the DRL is an important stabilizer.

COMPLICATIONS

- Nonunion
- Persistent pain necessitating resection arthroplasty with trapezium excision
- Radial sensory nerve injury or dysethesia

REFERENCES

DEFINITION

- Osteoarthritis, or more appropriately termed osteoarthrosis, is a common problem in the hand.
- The trapeziometacarpal joint is frequently affected, second in frequency only to the distal interphalangeal joint, but much more disabling due to pain and weakness of grip and pinch strength.
- The surgical management of symptomatic basilar joint arthritis depends on anatomy, radiographic staging, and patient requirements, followed by intraoperative confirmation of the stage of disease.
- Arthrodesis of the thumb carpometacarpal (CMC) joint was initially described by Muller over 50 years ago. With refinements in arthroplasty procedures, arthrodesis of the basal joint of the thumb has become less popular, but the procedure still can provide an excellent result in the right circumstances; it is a valid treatment option for stage II or stage III disease only.

ANATOMY

- The thumb CMC joint is a biconcave joint, allowing for motion in three planes: flexion-extension, abduction-adduction, and pronation-supination.
- There are minimal osseous constraints, making the ligamentous structures extremely important stabilizers of the thumb base.
- A total of 16 ligaments have been described around the thumb CMC joint:
  - Seven are primary stabilizers of the thumb metacarpal:
    - Superficial and deep anterior oblique (sAOL and dAOL)
    - Dorsal radial
    - Posterior oblique
    - Ulnar collateral
    - Intermetacarpal
    - Dorsal intermetacarpal
  - The remainder stabilize the trapezium, providing a stable foundation for the thumb.

PATHOGENESIS

- The pathogenesis of CMC joint arthrosis is multifactorial, involving biochemical and biomechanical influences. The synovial fluid within the joints contains cytokines, which invariably play a role in cartilage degradation and decreased ability to withstand the loads generated at the joint during daily activities.
  - Although not clearly delineated, there probably is some protective role played by estrogen or estrogen-related compounds, which may explain the increased incidence of osteoarthritis in postmenopausal women (10 to 15:1).
  - The anterior (palmar) oblique ligament, or so-called beak ligament, has been shown to be the most important stabilizing ligament of the thumb, and its degeneration or functional incompetence leads to laxity, followed by abnormal translation of the metacarpal on the trapezium, resulting in increased shear forces and abnormal wear patterns. This eventually leads to eburnation of the articular cartilage, initially along the palmar aspect of the joint. With progression of disease, osteophytes develop and eburnation progresses throughout the entire joint surface.

- Osteoarthritis can also develop from disruption of the articular cartilage. Any fracture involving the articular surfaces (most commonly the base of the thumb metacarpal) will predispose to or accelerate the development of arthrosis.
  - Anatomic restoration of the joint surface can minimize this progression but not eliminate it completely.
  - Paradoxically, a Bennett fracture may protect the joint from the development of osteoarthritis (assuming subluxation is not present) by virtue of consequential unloading of the volar aspect of the joint.

NATURAL HISTORY

- Arthrosis of the thumb CMC joint begins along the palmar aspect of the metacarpal secondary to laxity of the AOL.
- The entire base of the metacarpal and the distal trapezium experience eburnation of the cartilage, which progresses to develop osteophytes.
- The thumb metacarpal assumes an adducted position and the metacarpophalangeal (MCP) joint may compensate by becoming hyperextensible, resulting in hyperextension.
- Finally, the entire surface of the trapezium becomes involved, resulting in degeneration between the proximal trapezium and the distal scaphoid.
- Disease can involve all the trapezial articulations as well as the scaphotrapezial joint.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Thumb CMC joint arthrosis will often present with pain at the base of the metacarpal.
  - The pain will be exacerbated with activities involving loading the thumb metacarpal base, such as turning a doorknob, twisting a lid off a jar, or turning a key.
  - Pain at rest may or may not be present.
  - Symptoms do not always correlate with the clinical or radiographic appearance. A patient may have advanced clinical and radiographic disease but be minimally symptomatic. Conversely, a patient may have significant symptoms with minimal radiographic changes and no clinical deformity at rest.
  - Physical examination of the patient with advanced disease reveals deformity.
    - The thumb subluxates in a dorsal direction and becomes fixed in adduction, manifesting as a prominence at the base of the thumb and decreased ability to abduct the thumb away from the palm.
    - In an effort to compensate for this limitation, the MCP joint will often hyperextend, creating a zig-zag deformity.
Asking the patient to place one finger on the point that is most symptomatic helps localize the point of maximal tenderness to the CMC joint or another area.

CMC grind test: Reproduction of symptoms confirms the CMC joint as a site of disease.

CMC distraction test: Reproduction of symptoms confirms the CMC joint as a site of disease.

Finkelstein maneuver: Maximal tenderness indicates that DeQuervain disease may be a greater source of symptoms.

Phalen test: Reproduction of symptoms indicates carpal tunnel syndrome as a more likely etiology.

Carpal tunnel compression test: Reproduction of symptoms indicates carpal tunnel syndrome as a more likely etiology.

Trigger evaluation: Reproduction of pain, triggering, or locking of the thumb indicates trigger thumb as an etiology.

Allen test: The radial and ulnar arteries are compressed and the hand is exsanguinated. The ulnar artery is released and the circulation of the hand is assessed. The process is repeated, releasing the radial artery while the ulnar artery is occluded. Surgical procedures often involve mobilization of the radial artery in the snuffbox. Damage to this artery will require reconstruction if the ulnar artery cannot compensate.

Other conditions causing pain at the base of the thumb must be eliminated, such as DeQuervain disease, trigger thumb, and carpal tunnel syndrome. Although more than one condition may exist, the physical examination can usually determine the most problematic area.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Plain radiographs are the imaging modality of choice for evaluation of thumb CMC joint arthrosis (FIG 1).

These include a pronated AP (Robert view), lateral, and a 30-degree posteroanterior stress view.

Eaton and Littler3 have described a radiographic staging system that is commonly used, but Tomaino et al11 have emphasized routine assessment of the scaphotrapezial joint, both radiographically and intraoperatively, to rule out scaphotrapezial arthritis, or what they termed “stage V disease.”

Stage I: normal-appearing or widened joint space secondary to synovitis

Stage II: joint space narrowing and osteophyte formation smaller than 2 mm

Stage III: joint space narrowing with osteophytes larger than 2 mm

Stage IV: stage III appearance with the addition of narrowing or osteophytes in the scaphotrapezial joint

The scaphotrapezial joint is not specifically addressed in this system and may be difficult to assess radiographically, but this joint should always be assessed at the time of surgery because it may be a source of continued pain.

DIFFERENTIAL DIAGNOSIS

- Thumb CMC arthrosis
- DeQuervain disease
- Trigger thumb or stenosing tenosynovitis
- Carpal tunnel syndrome
- Intramuscular (thenar) processes, such as vascular or tumor etiologies

NONOPERATIVE MANAGEMENT

- Most patients with symptomatic thumb CMC joint arthrosis benefit from a trial of conservative therapy, which may include corticosteroid injection, thenar isometric strengthening exercises, and splinting.3

- Although this will not eliminate the problem or alter the underlying disease process, it often reduces symptoms, at least transiently, allowing the patient the opportunity to plan for surgical treatment at the most opportune time.

- Steroid injections can also be helpful in determining how much of a patient’s symptoms are coming from the thumb CMC joint versus other areas (carpal tunnel or De Quervain disease).

SURGICAL MANAGEMENT

- The indications for surgical intervention for symptomatic thumb basilar joint arthrosis include pain and weakness not responsive to conservative treatments.

- There are multiple procedures used to treat symptomatic CMC thumb arthritis, many of which have merit depending on several factors. Consideration should be given to the age of the patient and the demands placed on the thumb (specifically looking at the patient’s occupation) as well as the radiographic stage and the condition of surrounding joints.

- The best candidates for thumb CMC arthrodesis are young, active patients who need to maintain power grip and pinch, and regularly place high demand on their thumb. These are typically young, male manual laborers with stage II or III disease.

- Special consideration should be given to the thumb MCP joint. If hyperextension and laxity are present, arthrodesis of the CMC joint is not an appropriate option, because fusion of both the thumb CMC and MCP joints will result in significant functional impairment.

- Pan-trapezial involvement represents a contraindication for CMC arthrodesis because of the risk of incomplete pain relief.

Preoperative Planning

- The patient should be made aware of the decreased mobility, inability to flatten the palm on the table, potential difficulty in placing the hand in tight confined spaces, and possible difficulty placing the hand in a glove.
Patients also should understand the risks of nonunion, potential for hardware complications, and potential for developing degenerative changes at adjacent joints.

Positioning
- The procedure is performed under regional or general anesthesia with the use of a pneumatic tourniquet.
- The patient is in supine position with the arm extended on an armboard.

Approach
- The procedure can be performed through a Wagner-type incision, along the junction of the glabrous and dorsal skin, or through a dorsal incision.
- The dorsal incision can be oriented in a longitudinal fashion, along the radial aspect of the first dorsal compartment tendons, or in a transverse direction, with the incision oriented in the resting skin tension lines centered over the trapeziometacarpal joint.

**THUMB CMC (TRAPEZIOMETACARPAL) ARTHRODESIS**

**Incision and Dissection**
- Make a dorsal longitudinal incision along the radial aspect of the first dorsal compartment tendons (TECH FIG 1A).
- Identify and protect sensory branches of the radial nerve and the lateral antebrachial cutaneous nerve (TECH FIG 1B).
- Identify the first dorsal compartment tendons and release the compartment along the ulnar aspect to allow for better exposure (TECH FIG 1C).
- Identify the dorsal branch of the radial artery deep to the abductor pollicis longus and extensor pollicis brevis tendons running in a dorsal and ulnar direction (TECH FIG 1D). Carefully mobilize and protect it.
- Identify the base of the metacarpal, and complete a longitudinal capsulotomy to expose the base of the metacarpal, the entire trapezium, and the distal aspect of the scaphoid.
- Fluoroscopy is used to confirm the location of the CMC joint if necessary.

**Preparation of the Joint**
- Inspect the scaphotrapeziotrapezoid joints (TECH FIG 2A).
  - If there is evidence of arthrosis, consideration is given to alternative procedures.
- Then inspect the CMC joint (TECH FIG 2B).
  - By freeing the surrounding capsular attachments, the base of the metacarpal can be flexed to allow better access to the joint.
- Use a rongeur to remove osteophytes (TECH FIG 2C), any remaining articular cartilage, and subchondral bone. Shape the metacarpal base in a cone fashion to provide a larger surface area and greater freedom for obtaining the ideal position for arthrodesis (TECH FIG 2D).
- Decorticate the distal aspect of the trapezium in a similar fashion, creating a cup for placement of the prepared metacarpal base.

**Positioning and Fixation**
- The position for arthrodesis should allow the tip of the thumb to rest against the radial aspect of the index middle phalanx when the hand is placed in the fisted position.
- The exact angles to accomplish this position are debated, but in general there should be about 45 degrees of palmar abduction and adequate pronation to allow positioning.
- Place three 0.045-inch smooth Kirschner wires through the decorticated metacarpal base in an antegrade manner,
exiting the dorsal aspect of the metacarpal until the tip of the wires are just beneath the prepared proximal metacarpal (TECH FIG 3A).

- The metacarpal is then aligned with the trapezium, properly positioned, and compressed with axially directed force (TECH FIG 3B).
- Advance the Kirschner wires retrograde across the joint into the trapezium, anchoring in the subchondral bone. The wires can be advanced into the carpus (TECH FIG 3C).
- Fluoroscopy is used to confirm reduction and Kirschner wire placement (TECH FIG 3D). If there is inadequate bony apposition, distal radius bone graft can be harvested and used to fill any voids.
- Close the capsule with a nonabsorbable suture and close the skin with buried absorbable sutures.
- Bend the Kirschner wires and cut them external to the skin.
- If mild thumb MCP joint hyperextension is noted at this juncture, pin the MCP joint in 20 degrees of flexion. If dynamic collapse accompanies pinch, then perform volar capsulodesis.
- Apply a well-padded short-arm thumb spica splint.

TECH FIG 2 • A. Inspection of the scaphotrapeziotrapezoid (STT) joint for arthrosis (probe is in the scaphotrapezial joint). B. Exposure of the carpometacarpal (CMC) joint (forceps are around trapezium and probe is in CMC joint). C. Close-up view of small dorsal osteophyte along base of thumb metacarpal. D. View of the CMC joint after removal of articular cartilage in preparation for arthrodesis.

TECH FIG 3 • A. Preliminary placement of Kirschner wire to check alignment before compression of the arthrodesis site. B. Final inspection of the prepared surfaces before compression and advancement of the Kirschner wires across site of arthrodesis. (continued)
Bony Preparation
- Rather than the “cup and cone” technique, an oscillating saw can be used to create two flat surfaces that can be apposed, allowing a large contact area.
- Make the cuts in the exact plane desired, or the position of the thumb will be compromised.
- This is a much less forgiving technique than the cup and cone method, which allows for correction by rotation of the metacarpal while positioning it on the trapezium.

Fixation Devices
- Single or multiple smooth Kirschner wires, tension band wiring, cerclage wiring, staples, compression screws, and plates and screws have all been used with documented success.
- Union rates are comparable for Kirschner wires and more rigid fixation devices, but plates and screws result in a higher rate of additional procedures, typically due to hardware prominence or tendon irritation.
- Kirschner wires are associated with the fewest complications and are the simplest method of fixation.

PEARLS AND PITFALLS

**Surgical approach**
- Take care to protect the cutaneous branches of the radial sensory nerve and the lateral antebrachial cutaneous nerve throughout the entire procedure.
- Protect the radial artery located under the abductor pollicis longus and extensor pollicis brevis tendons.

**Intraoperative joint inspection**
- Carefully inspect the scaphotrapeziotrapezoid joints, as arthritic involvement at these joints will preclude success with CMC arthrodesis.

**Judicious use of bone graft**
- Make sure there is good apposition of the bony surfaces before closure. Use bone graft to fill any voids, which may lead to nonunion.

**Treatment of MCP joint laxity**
- Consider pinning the MCP joint in 20 degrees of flexion if mild hyperextension exists.

**Radial sensory nerve injury**
- If there is inadvertent injury to the radial sensory nerve and this is recognized, it should be repaired with fine epineurial suture.

**Radial artery injury**
- If there is inadvertent injury to the radial artery, it should be temporarily clipped with temporary vascular clamps. After the arthrodesis is completed and the capsule is closed, the tourniquet is deflated. If there is good perfusion to all the digits, the artery can be ligated. If the perfusion is inadequate, microvascular repair must be accomplished.

**Nonunion or malunion**
- Inadequate preparation of joint surfaces may lead to nonunion.
- Improper positioning of thumb metacarpal on the trapezium may lead to malunion.
POSTOPERATIVE CARE

- The patient is seen in the office at 10 to 14 days to check the wound and the Kirschner wires and to obtain radiographs.
- If fixation is secure and the Kirschner wires are not advanced through the trapezium, a well-molded short-arm thumb spica splint is applied and removed for hygiene purposes only. If the Kirschner wires are advanced into the carpus, the patient is placed in a thumb spica cast.
- If there is any concern about fixation, a short-arm thumb spica cast is applied and the patient is seen at 2- to 3-week intervals until clinical tenderness subsides and there is radiographic evidence of fusion (FIG 2). This typically occurs by 6 to 8 weeks after surgery.
- Once healing is documented, the pins are removed and range-of-motion exercises are begun under the direction of a hand therapist. The splint is continued for protection.
- At 3 months, strengthening exercises are begun, the splint is discontinued, and the patient is allowed to return to unrestricted activities.

OUTCOMES

- The outcomes of trapeziometacarpal arthrodesis are generally good, with predictable pain relief and patient satisfaction.
- Hartigan et al\(^5\) retrospectively reviewed patients who had arthrodesis and compared them to those having trapezial excision and ligament reconstruction. At 6 to 9 months there were no significant differences in pain, function, patient satisfaction, or grip strength. The arthrodesis group had greater key pinch and three-point pinch but more difficulty with opposition and the ability to flatten the hand, all of which were statistically significant. The arthrodesis group also had a higher complication rate, most of which was attributable to nonunion. Interestingly, all patients with nonunion had improvement in their pain and were satisfied with their outcomes.
- Forseth and Stern\(^4\) compared the complication rate with Kirschner wire fixation to that with plates and screws and found similar nonunion rates (less than 10% in their small series), but there were higher rates of secondary procedures and lower patient satisfaction in the plate and screw group.
- Despite Hartigan et al’s report, which found that the ligament reconstruction and tendon interposition (LRTI) arthroplasty and arthrodesis resulted in high levels of patient satisfaction, Mureau et al\(^7\) found less subjective improvement with arthrodesis in comparison to arthroplasty and no significant differences in pinch strength. They also found a higher incidence of complications in the arthrodesis group.

COMPLICATIONS

- Complications from thumb CMC arthrodesis are generally related to nonunion or hardware problems, including malposition (screws in the trapeziotrapezoid joint), prominence and tendon irritation, and rupture.
- The patient should be made aware of the possible need for secondary procedures.

REFERENCES

DEFINITION
- Osteoarthritis, or more appropriately osteoarthrosis, is a common problem in the hand. The trapeziometacarpal joint is commonly affected, second in frequency only to the distal interphalangeal joint. Trapeziometacarpal joint osteoarthritis, however, can be much more disabling secondary to pain and weakness of grip and pinch strength.
- The surgical management of symptomatic basilar joint arthrosis varies according to the anatomy, radiographic staging, intraoperative confirmation of disease stage, and patient requirements.

ANATOMY
- The thumb carpometacarpal (CMC) joint is a biconcave joint, allowing for motion in three planes: flexion-extension, abduction-adduction, and pronation-supination.
- There are minimal constraints from an osseous standpoint, making the ligamentous structures extremely important in providing stability to the base of the thumb. A total of 16 ligaments have been described around the thumb CMC joint, 7 of which are primary stabilizers of the thumb metacarpal (TM).
- The superficial and deep anterior oblique, dorsal radial, posterior oblique, ulnar collateral, intermetacarpal, and dorsal intermetacarpal ligaments directly stabilize the TM, while the remainder serve to stabilize the trapezium, allowing for a stable foundation for the thumb to rest on (FIG 1).

PATHOGENESIS
- The pathogenesis of CMC joint arthrosis is multifactorial, involving biochemical and biomechanical influences. The synovial fluid within the joints contains cytokines that invariably play a role in cartilage degradation and decreased ability to withstand the loads generated at the joint during daily activities. Although not clearly delineated, estrogen or estrogen-related compounds probably play some protective role, which may explain the increased incidence of osteoarthritis in postmenopausal women (10 to 15:1).
- The palmar or anterior oblique ligament (AOL), or so-called beak ligament, has been shown to be the most important stabilizing ligament of the thumb. Degeneration or functional incompetence of this ligament leads to laxity, abnormal translation of the metacarpal on the trapezium, increased shear forces, and resultant abnormal wear patterns. This eburnation of the articular cartilage initially occurs along the palmar aspect of the joint. With progression of disease, osteophytes develop and eburnation progresses throughout the entire joint surface.
- Osteoarthrosis can also develop from damage and disruption of the articular cartilage. Any fracture through the metacarpal or trapezium joint surfaces yield arthrosis. Anatomic restoration of the joint surface can minimize this sequela but cannot eliminate the risk entirely. Paradoxically, however, a Bennett fracture may protect the joint from the development of osteoarthritis, assuming subluxation has been treated, by virtue of consequential unloading of the volar aspect of the joint.

FIG 1 • Carpometacarpal thumb joint.
NATURAL HISTORY

- Arthrosis of the thumb CMC joint begins along the palmar aspect of the metacarpal secondary to laxity of the AOL. As the process progresses, the entire base of the metacarpal and distal trapezium becomes involved.
- There is initial eburnation of the cartilage, which progresses to osteophyte formation. As the disease continues, the TM assumes an adducted position and the metacarpophalangeal (MCP) joint may compensate by becoming hyperextensible, resulting in varying degrees of MCP joint hyperextension.
- The disease can involve all the trapezial articulations as well as the scaphotrapezial joint.¹⁴

PATIENT HISTORY AND PHYSICAL FINDINGS

- Thumb CMC joint arthrosis often presents with pain at the base of the metacarpal. The pain may or may not be present at rest. It will be exacerbated with activities involving loading the TM base, such as turning a doorknob, twisting a lid off a jar, or turning a key.
- With advanced disease, the thumb subluxes in a dorsal direction and becomes fixed in adduction. This manifests as a prominence at the base of the thumb and decreased ability to abduct the thumb away from the palm. In an effort to compensate for this, the MCP joint will often hyperextend, creating a zig-zag deformity.
- Symptoms do not always correlate with the clinical or radiographic appearance, meaning that a patient may have advanced clinical and radiographic disease but be minimally symptomatic. Conversely, a patient may have substantial symptoms with minimal radiographic changes and no clinical deformity at rest.
- Other conditions causing pain at the base of the thumb must be eliminated, such as De Quervain disease, trigger thumb, and carpal tunnel syndrome. Although more than one condition may exist, the physical examination can usually determine the most troubled area.
- Physical examination includes the following:
  - Point tenderness assessment: With the TM adducted, the CMC joint is palpated beneath the thenars. Tenderness confirms the clinical significance of changes seen on radiographs.
  - Reproduction of symptoms on the CMC grind test confirms the CMC joint as a site disease.
  - Key pinch assessment: If dynamic collapse accompanies pinch, MCP joint fusion or capsulodesis is recommended (FIG 2).

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs are the imaging modality of choice for evaluation of thumb CMC joint arthrosis. These include a pronated AP (Robert view), lateral, and a 30-degree posteroanterior stress view (FIG 3).
- Eaton and Littler have described a radiographic staging system, which is commonly used, but Tomaino et al¹⁴ have emphasized routine assessment of the scaphotrapezial joint, both radiographically and intraoperatively, to rule out scaphotrapezial arthritis—what they termed stage V disease.
  - Stage I: normal-appearing or widened joint space secondary to synovitis
  - Stage II: joint space narrowing and osteophyte formation smaller than 2 mm
  - Stage III: joint space narrowing with osteophytes larger than 2 mm
  - Stage IV: scaphotrapezial joint space involvement in addition to narrowing of the TM joint

FIG 2 • Dynamic collapse of the thumb on key pinch testing.

FIG 3 • Preoperative PA stress and lateral radiographs of the right thumb.
- Stage V: stage IV appearance with the addition of narrowing or osteophytes in the scaphotrapezoid joint
- The scaphotrapezoid joint is not specifically addressed in this system and may be difficult to assess radiographically, but it should always be assessed clinically during operative intervention because it may be a source of continued pain.

**DIFFERENTIAL DIAGNOSIS**
- De Quervain disease
- Trigger thumb or stenosing tenosynovitis
- Carpal tunnel syndrome

**NONOPERATIVE MANAGEMENT**
- Most patients with symptomatic thumb CMC joint arthrosis benefit from a trial of conservative therapy, which may include corticosteroid injection, thenar isometric strengthening exercises, and splinting.
- Although this will not eliminate the problem or alter the underlying disease process, conservative treatment often reduces symptoms, at least transiently, allowing the patient the opportunity to plan for surgical treatment at the most opportune time.
- Differential injection of steroids can also be helpful to assess how much of a patient’s symptoms are coming from the thumb CMC joint versus other areas (carpal tunnel or De Quervain disease).

**SURGICAL MANAGEMENT**
- The indications for surgical intervention for symptomatic thumb basilar joint arthrosis include pain and weakness.
- There are multiple procedures used to treat symptomatic CMC thumb arthritis, many of which have merit depending on the extent of arthritic involvement.
- Pan-trapezial involvement contraindicates the use of arthrodesis or implant arthroplasty, in particular, because of the risk of incomplete pain relief.
- Arthrodesis may be preferable in younger, high-demand patients such as laborers.
- Resection arthroplasty can be performed with ligament reconstruction or without (hematoma distraction arthroplasty).4,6
- The flexor carpi radialis (FCR) and abductor pollicis longus (APL) are most commonly used when performing “suspensionplasty.”

**Preoperative Planning**
- Consideration should be given to the age of the patient and the demands placed on the thumb.
- Dynamic collapse of the MCP joint during key pinch necessitates MCP fusion or capsulodesis.
- Intraoperative evaluation of the scaphotrapezotrapezial (STT) joint is critical to ensure adequate pain relief after surgery. Thus, hemitrapeziectomy is rarely performed once the decision to proceed with conventional resection arthroplasty is made. If retention of the proximal trapezium is elected because of the absence of STT disease, Artelon resurfacing or joint arthroplasty may be elected.
- Intraoperative assessment of the scaphotrapezial joint is recommended, and if changes exist, a 2- to 3-mm resection of the proximal trapezium is performed.4 Care is taken not to injure the capitate.
- Suspensionplasty ensures stability of the TM during pinch and grip, resisting the cantilever bending forces that will potentially lead to subluxation and proximal migration compared to trapeziectomy alone.
- Intermediate-term outcome of the hematoma distraction arthroplasty suggests that this procedure may have a role in providing excellent pain relief in well-selected patients for whom grip strength is a less important issue.4

**Positioning**
- The patient is supine and the involved hand and arm are supported by a hand table.

**Approach**
- Trapeziectomy and ligament reconstruction and suspensionplasty can be performed using the Wagner (volar) approach or a dorsal approach. I prefer the dorsal approach except when performing an Eaton ligament reconstruction, in which case a volar approach is used. I have modified my technique since performing the ligament reconstruction and tendon interposition (LRTI) arthroplasty exclusively during the first 10 years of practice.11,12
- Over the past 5 years I have performed a suspensionplasty using a distally based slip of the APL tendon, which obviates the need for a bony channel. This is a variation of other suspensionplasty techniques.7,10,12 In addition, I no longer pin the joint or interpose tissue into the space remaining after trapezial resection. The procedure is performed more expeditiously and seems to be associated with equivalent outcomes.13

**LRTI ARTHROPLASTY USING THE FCR TENDON**

**Incision and Superficial Dissection**
- A triradiate is drawn before the tourniquet is inflated to allow palpation of the radial pulse in the vicinity of the anatomic snuffbox; this typically identifies the scaphotrapezial joint.
- When a substantial shoulder sign (prominence associated with dorsal subluxation of the proximal phalanx trapezium) exists, it can be difficult to identify the TM joint. In these cases, palpation of the scaphoid tuberosity is helpful to ensure that the incision is neither too distal nor too proximal.
- The triradiate incision facilitates dissection of the radial artery off the dorsal capsule; when first extensor compartment release is planned, however, a longitudinal incision may be preferred.
- At the outset, the radial sensory nerve must be identified and small branches must not be skeletonized or divided. This may cause postoperative sensory neuritis and even transient reflex sympathetic dystrophy.
- Place blunt retractors beneath the extensor pollicis longus (EPL) in a dorsal and ulnar position and the APL radially and volarly.
The radial artery courses within this interval, and deep perforators to the dorsal capsule must be coagulated and divided so the artery can be retracted dorsally and ulnarly.

**Capsular Incision and Trapezial Excision**

- With gentle traction on the thumb, perform a longitudinal capsulotomy and obtain subperiosteal exposure of the trapezium and the base of the metacarpal (TECH FIG 1A). Extend the capsulotomy proximally so the scaphotrapezial joint is identified.
- Either retractors or tag sutures of 3-0 Vicryl can be used to retract the capsule.
- Before the trapezium is excised, use a microsagittal saw to remove a thin sliver of bone at the base of the metacarpal. This facilitates exposure of the distal extent of the trapezium and, with further traction on the thumb, provides a safer window for sectioning of the trapezium.
- Cut the trapezium into quadrants, beginning with the limb that parallels the expected course of the FCR tendon. Injury to the tendon during this portion of the procedure is unlikely if the saw is not brought completely through the trapezium.
- After making perpendicular cuts in the trapezium, place an osteotome and twist it to break apart its four quadrants. Removal of the trapezium in pieces with a rongeur is facilitated by sharp dissection of the remaining capsule, particularly volarly and around loose bodies. Avoid inordinate ripping and pulling with the rongeurs because damage to the underlying capsule can increase postoperative discomfort, particularly where it abuts the carpal tunnel.
- Remove osteophytic bone between the base of the thumb and index metacarpal so that pain does not accompany key pinch after the procedure. Identify the FCR tendon at the base of the arthroplasty space so it is not injured; remember that the trapezium may encircle the flexor carpi radialis tendon at its volar extent.
- At this portion of the procedure, I routinely have an assistant place traction on the index and long finger to allow inspection of the scaphotrapezial joint. If there is cartilage fraying or eburnation, a motorized burr or rongeur is used to remove 2 to 3 mm of proximal trapezoid so that, with axial compression applied to the index and long finger metacarpals, there is no contact between the remaining trapezoid and scaphoid (TECH FIG 1B). I do not interpose soft tissue or FCR tendon into the space. Take care not to remove bone from the capitate.

**Creation of the Bony Channel Through the Metacarpal Base**

- One centimeter distal to the squared-off base of the metacarpal, in the plane of the nail, create a bone tunnel with a motorized 3-mm burr that exits at the volar base of the metacarpal (TECH FIG 2).
- This position is selected rather than central exit point in the metacarpal base because passage of the FCR tendon volarly more closely simulates the original attachment of the beak ligament.
- Enlarge the bony channel with two curettes of increasing size, but do not make it large enough for the entire width of the leading edge of the FCR tendon. Rather, trim the full width of the FCR tendon to its tip to facilitate passage with a Carroll tendon passer. In that light, the bony channel needs to be large enough only for the Carroll tendon passer to be used.

**FCR Harvest**

- Palpate the FCR tendon at wrist level during passive flexion and extension of the wrist, where it is clearly tendinous. More proximally in the forearm the tendon becomes less discrete. This generally correlates with the proximal one third to half of the forearm. At that location make a 1.5-cm transverse incision.
- Open the fascia, maximally flex the wrist, and identify the interval between the FCR tendon and muscle. Lift it into the wound via a curved clamp and divide it. Close this wound with 5-0 nylon sutures.
- Retract the capsular flaps to protect the overlying radial artery dorsally and ulnarly. Place a curved clamp beneath the FCR tendon and pull it. This typically delivers the entire tendon into the arthroplasty space.
- Grasp the tendon at its tip and mobilize it to its insertion at the base of the index metacarpal without violating the small blood vessels that perfuse the tendon insertion itself.
- If adhesions between the FCR and the volar capsule are not released, the vector of the ligament reconstruction is based more proximally and will not closely
simulate the original vector of the beak ligament. This, in my opinion, is a potential cause of early subsidence after ligament reconstruction.

- Taper the tendon for about 2 to 3 cm so the diameter of the tip of the tendon will easily fit through the bone tunnel via the Carroll tendon passer.
- Use a 4-0 Vicryl suture on a small needle to purchase the volar capsule for subsequent stabilization of the tendon interposition.
- If there are rents in the volar capsule, this same suture can be used to repair them, but I no longer am inordinately preoccupied with repairing small tears in the volar capsule because there is little risk of the tendon interposition extruding into the carpal canal or into the base of the metacarpal.

**Stabilization of the Thumb Metacarpal (Optional) and FCR Tendon Tensioning**

- Kirschner wire placement, when elected, is one of the more tedious parts of the procedure and must be performed skillfully so that the bony channel is not violated. If the Kirschner wire inadvertently purchases the FCR tendon within the bony channel in the metacarpal, it will impair the ability to pull it tight and properly tension the new ligament.
- Usually a 0.045- or 0.054-inch wire is used. It begins obliquely at the dorsoradial aspect of the metacarpal and purchases the ulnar carpus.
- I place the thumb in the “fisted” position as if engaged in key pinch. The TM is suspended at the level of the index metacarpal. Its base should be colinear with the scaphoid articular surface and the thumb tip should rest on the index finger, neither too extended nor flexed at its base.
- Ideally, this positions the thumb intrinsic muscles optimally on the Blix curve and ensures optimal restoration of pinch strength.
- Bend the wire external to the skin and cut it.
- A hand probe or the like is used to take the FCR tendon at the base of the metacarpal and pull it proximally (TECH FIG 3).
- When pinning has been performed, it should not prevent free excursion of the FCR through the bone channel. Pull the tendon tightly as it exits the dorsum of the TM and suture it to adjacent periosteum and soft tissue with 3-0 Vicryl suture.
- If pinning is not performed, at this point, ensure that you have suspended the metacarpal at the level of the index CMC joint.
- The extensor pollicis brevis (EPB) tendon is sutured more radially and divided distally. This completes the EPB tenodesis, rendering it an abductor of the metacarpal as opposed to a potential hyperextender of the MP joint.
- Place a second suture slightly more proximal to the tenodesis suture so that the ligament reconstruction is stabilized adequately, and perform tissue interposition.

**Tissue Interposition (Optional)**

- Although Burton’s original technique continues to “resurface” the metacarpal base to minimize the chance that interposition material may extrude through the channel, this is unlikely. Studies have suggested that interposition is not a critical element of the procedure if suspension of the metacarpal has been effectively executed. Furthermore, proximal migration, short of causing scaphometacarpal impingement, appears not to affect the functional outcome.
- In a higher-demand patient, however, residual length of the FCR is available for interposition as follows. The tendon is folded into the volar aspect of the arthroplasty space to ensure that it will sink into its depth. From that point distally, the tendon is folded back and forth about four times on a single Keith needle, like ribbon candy.
- A 4-0 Vicryl suture is used to stabilize each corner of the tendon anchovy, and then a second Keith needle is placed through it, parallel to the first. Apertures in each needle should be volar, the tip of each needle dorsal, and, with the previously placed volar capsular suture, each limb is threaded and the anchovy is slid down and delivered into the arthroplasty space. The two Vicryl limbs are tied, securing the tissue interposition (TECH FIG 4).

**Capsular Repair and Wound Closure**

- Tightly repair the capsule using 3-0 Vicryl sutures. If redundant capsule is present, a pants-over-vest closure can be performed.

![TECH FIG 3](image_url) **A.** The flexor carpi radialis (FCR) is passed through bony tunnel. **B.** A hand probe indicates FCR suspensionplasty.
Chapter 83  THUMB CARPOMETACARPAL JOINT RESECTION ARTHROPLASTY

TECHNIQUES

TECH FIG 4 • The tendon anchovy held in place with Vicryl sutures.

APL SUSPENSIONPLASTY

Incision and Deep Dissection

- Make a 6-cm curvilinear incision from two finger-breadths proximal to the radial styloid process to 1 cm distal to the base of the metacarpal (TECH FIG 5A). Expose and retract the radial artery and branches of the radial sensory nerve.
- Release the first extensor compartment retinaculum as would be performed for De Quervain disease, leaving the volar attachment intact.
- At the myotendinous junction of the APL, release the ulnarnest slip of APL and free it to the level of its insertion at the metacarpal base (TECH FIG 5B).
- Expose the EPL and APL tendons—in between is the capsule of the TM joint.
- Perform a capsulotomy to expose the trapezium (TECH FIG 5C), which is resected after being cut partially into four fragments with a saw and osteotome.
  - The base of the thumb metacarpal is not squared off; not resecting a small sliver from the metacarpal base may help to preserve the intermetacarpal ligament.
  - The FCR tendon is visualized in the base of the arthroplasty space. With traction on the index and long fingers, inspect the scaphotrapezoidal joint; if it is arthritic, resect the proximal trapezoid.

Creation of the APL Suspensionplasty

- Poke the APL slip through the capsule to within the arthroplasty space. Using a right-angle clamp, pass it through a slit in the FCR tendon or around the FCR, while grabbing some local capsule as well (TECH FIG 6).
- Position the thumb so that it rests on the index finger in the fisted position—distracted so that the metacarpal base is at the level of the index CMC joint. A Kirschner wire is not placed.
- Pull the APL slip taut and place a 3-0 Vicryl suture between the APL slip, at the level of the metacarpal base, and the EPB (radially) and the tissue deep to the EPL (ulnarily).

Capsular Closure and Rehabilitation

- The capsule is closed and a thumb spica splint is placed for 14 days.

TECH FIG 5 • Abductor pollicis longus suspensionplasty technique. A. Skin incision. B. Distally based slip of abductor pollicis longus. C. Trapezium excision (arrow identifies the trapezium).
TECH FIG 6 • Abductor pollicis longus slip is passed through and around flexor carpi radialis (arrow).

PEARLS AND PITFALLS

| Address MCP joint hyperextensibility | Static laxity is no longer viewed as an absolute indication for capsulodesis or fusion. Rather, dynamic collapse during pinch is a relative indication. |
| Address scaphotrapezial disease | If proximal trapezoid excision is not performed, pain at this articulation may persist. |
| Pinning is not essential; tissue interposition is not essential | Neither pinning for 4 weeks nor tissue interposition is required. Outcomes appear not to be compromised by modest proximal metacarpal migration. However, these elements of the procedure do have a role if concern about any potential for scaphometacarpal impingement exists. |
| Ensure stability of the APL suspension | The APL should be placed through the FCR or around it and should capture some capsule. This technical point will prevent the APL and thumb metacarpal from sliding proximally along the FCR. |
| Joint fusion timing | When necessary, concomitant MCP joint fusion should be performed after tendon harvest and passage to avoid thumb manipulation after fusion. |

POSTOPERATIVE CARE

- First month
  - At 2 weeks, the patient returns for suture removal, wound inspection, and placement of a fiberglass thumb spica cast that allows full motion of the thumb interphalangeal joint, unless MCP joint fusion has been performed.
  - At 4 weeks, the patient returns again, the Kirschner wire is pulled (if one has been placed), and a forearm-based thumb spica Orthoplast splint is fashioned by the hand therapist.
  - Gentle wrist and thumb MCP joint range-of-motion exercises are initiated, as well as thenar isometric exercises. The latter are performed with the thumb in the splint.
- Month 2
  - At 6 weeks, if the patient is comfortable, gentle pinch and grip strengthening exercises are initiated.
  - By 8 weeks, flexion-adduction and opposition exercises are begun.
- Month 3
  - By this time, the patient is usually doing well enough that the splint can be discarded.
  - Grip and pinch exercises are typically continued by the patient via a home program.

- No rigorous attempt is made for the thumb to reach the ring and small finger bases because there is no functional relevance to these activities and they risk stretching the ligament. In addition, passive range of motion is not a part of the postoperative regimen.
- During months 3 to 6, the patient is encouraged to use the hand and to push the exercises vigorously. Typically, patients return to normal activities, including golf and tennis.

OUTCOMES

LRTI Arthroplasty

- Improvements in grip strength typically exceed improvements in key pinch strength. In 1995, Tomaino et al. noted that key pinch strength took at least 6 years to equal preoperative measurements.
- At an average follow-up of 9 years (range 8 to 11), these authors reported on 24 thumbs in 22 patients and found that average grip strength increased 93%, average key pinch strength increased 34%, and tip pinch strength increased 65% compared with preoperative values.
- In contrast to many other studies, stress radiographs showed an average subluxation of the metacarpal base of only 11%
and subsidence of only 13%. This compares favorably with the radiographic outcomes after the hematoma distraction arthroplasty.\(^4,6\)

- Even in series in which proximal migration of the metacarpal base averaged greater than 20%, there has been no significant correlation between maintenance of arthroplasty space height and subjective clinical outcome (FIG 4).\(^5\)

**APL Suspensionplasty**

- My evaluation of outcomes after the APL suspensionplasty found a satisfaction rate and functional return equivalent to the LRTI procedure.\(^13\)

- Evaluation of 23 thumbs in 22 patients at a minimum of 1 year after surgery showed that grip and key pinch strengths were 82% and 77%, respectively, compared to the opposite side. Proximal migration of the metacarpal averaged 50% of the preoperative trapezial height. Experience and the literature show that modest proximal migration does not correlate with outcome.\(^5\)

- In summary, APL suspensionplasty is a simple yet effective treatment alternative for basal joint arthritis. The suspensionplasty technique uses our current understanding of the forces involved during pinch and grip,\(^2\) as well as the role of normal ligamentous anatomy.

**COMPLICATIONS**

- One cause of unsatisfactory outcome after basal joint arthroplasty is residual pain because of failure to address scaphotrapezial or scaphotrapezoidal disease.\(^14\)

- Unaddressed instability of the MCP joint can also impair functional outcome after ligament reconstruction. During lateral pinch, MCP joint hyperextension causes reciprocal deformity more proximally, imposing metacarpal adduction and stressing the reconstructed ligament. Accordingly, early identification of hyperextension in excess of 30 degrees during key pinch should prompt stabilization to protect the integrity of the basal joint ligament reconstruction. Even with a sound ligament reconstruction and appropriate stabilization of the MCP joint, it is theoretically possible to develop recurrent laxity at the basal joint due to stretching of the ligament reconstruction.

**REFERENCES**


DEFINITION
- Trapeziometacarpal joint (basal joint) arthritis is a debilitating condition that most commonly affects women in their 50s and 60s. The stage of arthritis dictates the treatment for this disorder.4,5,20
- Obviously, the perils of this alternative revolve around durability, survivability, and complication rate. Joint resurfacing with the Artelon implant (SBI) may have the most potential in terms of a biologic resurfacing procedure that avoids the use of a semiconstrained device—which has been associated with trapezial component loosening and failure.

ANATOMY
- The anatomy of thethumb metacarpal (TM) joint is extremely complex and has been well studied. The deep anterior oblique ligament (“beak ligament”) is the primary stabilizer of the TM joint.19 More recently, 16 ligaments have been described that stabilize the TM joint. Seven of these ligaments, including the superficial anterior oblique ligament (sAOL), deep anterior oblique (dAOL), dorsoradial, posterior oblique, ulnar collateral, intermetacarpal, and dorsal intermetacarpal directly stabilize the TM joint. The other nine ligaments indirectly stabilize the TM joint by directly stabilizing the trapezium.
- The TM joint is the most complex joint in the hand. It is a biconcave-convex saddle joint with minimal bony constraints. This joint allows flexion-extension, abduction-adduction, and pronation-supination of the thumb. For optimal treatment outcomes with joint replacement, normal kinematics—six degrees of freedom—should be restored as closely as possible.

PATHOGENESIS
- Degeneration of the AOL of the TM joint has been linked to the development of osteoarthritis.
- Pathologic laxity, abnormal translation of the metacarpal on the trapezium, and generation of abnormally high shear forces within the TM joint, especially on the palmar aspect of the joint during pinch and grip motions, occur when the AOL becomes incompetent.
- The base of the metacarpal tends to sublux dorsally with AOL detachment, emphasizing the importance of the AOL. In advanced osteoarthritis, adduction and flexion contractures tend to develop, producing further functional impairment and joint overload.

NATURAL HISTORY
- The vast number of described operations to treat osteoarthritis of the TM joint demonstrates the lack of consensus among treating surgeons as to the best way to approach this disorder. This chapter details the role of resurfacing and implant arthroplasty for the treatment of osteoarthritis of the TM joint.
- Various materials, techniques, and prostheses have been used in the past. Hemiarthroplasty and total joint arthroplasty of the TM joint have largely failed, with mediocre long-term results compared with soft tissue arthroplasty.1,2,5,7,14,20 However, the appeal of a replacement may lie with quicker recovery and more normal kinematics.
- Obviously, the perils of this alternative revolve around durability, survivability, and complication rate. Joint resurfacing with the Artelon implant (SBI) may have the most potential in terms of a biologic resurfacing procedure that avoids the use of a semiconstrained device—which has been associated with trapezial component loosening and failure.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Arthritis of the TM joint often presents with pain at the base of the thumb during pinch and grip (stressful activities for the TM joint). Women are 10 to 15 times more likely than men to develop this disorder. Asian and Caucasian populations have an increased prevalence as well.
- Common offending activities include brushing teeth, opening a jar, picking up a book, or turning a key. All of these activities involve increasing the breadth of grasp or forceful lateral pinch. Usually the pain is localized at the base of the thumb on the dorsal or volar radial aspect of the thenar cone. Patients often feel the joint slipping or subluxing radially.
- A “shoulder sign” is an enlarging prominence (the result of a dorsally subluxing proximal metacarpal on the trapezium and metacarpal adduction) that develops with progressive disease.
- Other causes of pain in the hand should be evaluated (see differential diagnosis list) as well. This is important because any concomitant disease, such as a trigger thumb, may hamper the postoperative therapy regimen and negatively affect the patient’s final outcome.
- The treating physician should also keep the diagnosis of carpal tunnel syndrome in mind, as it coexists in about 44% of patients with TM joint arthritis. Further, the postoperative swelling from a basal joint arthroplasty may exacerbate even mild cases of carpal tunnel syndrome.
- The Allen test should be performed on every patient who is undergoing surgery for basal joint arthroplasty, as the radial artery will be near or in the operative field and may need to be mobilized depending on the exact procedure performed. Any injury to the radial artery should be repaired immediately.
- The stability of the metacarpophalangeal (MCP) joint of the thumb is also critical, as this is a source of postoperative stress on the reconstructed beak ligament from either ligament reconstruction or suspensionplasty procedures.
- MCP joint fusion or volar plate capsulodesis should be performed when the MCP joint hyperextends to greater than 20 degrees.13
- Methods for examining the carpometacarpal (CMC) joint of the thumb include the following:
  - CMC grind test: A positive test is suggestive of degenerative disease.
CMC instability test: Laxity of the TM joint is common in early stages of degeneration, but as the joint degenerates, it usually becomes stiffer.

MCP joint stability test: If the MCP joint is actively hyperextending, this could put undue stress on a reconstructed TM joint and lead to failure. This hyperextendable metacarpophalangeal joint (MPJ) should be stabilized.

Metacarpal base compression test: Glickel11 believed this is more commonly painful in advanced stages rather than milder stages of TM joint disease.

Distraction test: A positive result from this maneuver is thought to be caused by traction on an inflamed TM joint capsule.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Imaging of the TM joint includes a true AP view of the TM joint (called a Robert view or pronated AP), lateral, and posteroanterior 30-degree oblique stress view (with thumb tips pressing against each other).

The most common staging system was originally described by Eaton and Littler:9,10 stage 1 shows slight widening of the joint, possibly from synovitis; stage 2 demonstrates some joint space narrowing and osteophytes smaller than 2 mm; stage 3, osteophytes larger than 2 mm; and stage 4 disease, scaphotrapezial joint space involvement along with TM joint narrowing.

The senior author of this chapter has described a “fifth stage” in which the disease process is pan-trapezial and there is TM, scaphotrapezial, and scaphotrapezial joint degeneration. Scaphotrapezial arthritis can be a source of continued pain and this joint should be evaluated intraoperatively in every patient because, unfortunately, preoperative radiographs are only 44% sensitive and 86% specific for diagnosing arthritis at this joint.23

DIFFERENTIAL DIAGNOSIS

- Scaphotrapezial arthritis
- Scaphotrapezial arthrosis
- Thumb sesamoid arthritis
- Carpal tunnel syndrome
- De Quervain tenosynovitis
- Stenosing flexor tenosynovitis (trigger finger)

NONOPERATIVE MANAGEMENT

- Initial management of TM joint arthritis is nonoperative and includes anti-inflammatory medication, thenar cone muscle isometric strengthening exercises, hand- or forearm-based thumb spica splint immobilization, steroid injections, and activity modification.
- These measures may not alleviate any or all of the patient’s symptoms, but they may help enough to provide temporary relief, allowing the patient ample time to educate himself or herself and to contemplate the treatment alternatives.
- The time afforded by the nonoperative measures may also allow the patient to schedule the operation at a more convenient time.

SURGICAL MANAGEMENT

- There are several options for surgical treatment of TM joint arthritis. Ligament reconstruction and tendon interposition (LRTI), suspensionplasty, and CMC joint fusion are discussed in other chapters. This chapter focuses on the role of resurfacing and implant arthroplasty. Resurfacing is an increasingly attractive option in younger, more active patients in whom one might prefer to avoid trapeziectomy to eliminate the risk of metacarpal subsidence with time. Subsidence can result in recurrent pain and weakness.
- The Artelon (SBI) spacer is a bioabsorbable implant (FIG 1A) that degrades and is replaced with scar tissue that protects the base of the thumb metacarpal and the distal aspect of the trapezium. This implant is ideal for a younger laborer with TM arthritis in whom grip and pinch strength are of critical importance. The attraction of this alternative is that it is a potentially definitive procedure that does not “burn the bridge” of resection arthroplasty in the future.17
- Pyrocarbon resurfacing using the “saddle” implant (Ascension Orthopaedics, Austin, TX; FIG 1B) is an alternative to Artelon. Its design mimics the articular shape of the metacarpal articulating surface, which may more closely restore CMC joint kinematics compared to Artelon implant use. Little information exists in the literature, however, regarding outcomes.
- Total joint arthroplasty, such as with the Avanta CMC implant (FIG 1C), is another option. This is designed to require less immobilization, leading to quicker return of functional abilities, and is ideal (theoretically) for an elderly, lower-demand patient. However, the literature is full of articles describing failures of innumerable prosthetic implants for the TM joint.

Preoperative Planning

- Many other hand pathologies can coexist with TM joint arthritis. These other diagnoses should be evaluated before the day of surgery.
If an Allen test had not been performed previously, it should be performed before the surgery.

**Positioning**
- The patient is positioned supine on the operating table with the affected hand placed on a hand table extension. A tourniquet is placed above the elbow.
- When using a dorsal approach, we tend to keep the hand in neutral pronation–supination, with an assistant holding the hand stable and at times pulling traction or directly stabilizing the thumb with the nail plate parallel to the floor.

**Approach**
- There are several different approaches for soft tissue arthroplasties, but for resurfacing or implant arthroplasties, a dorsal approach seems to work the best and to offer the best visualization.

### ARTELON RESURFACING ARTHROPLASTY

#### Exposure
- A dorsal approach is needed for placement of the Artelon implant between the distal trapezium and the proximal metacarpal of the thumb.
- Make a longitudinal incision centered over the CMC joint. Identify and protect branches of the superficial radial nerve throughout the case, along with the extensor pollicis longus (EPL) and extensor pollicis brevis (EPB).
- After mobilizing and protecting the radial artery, mobilize the EPL and EPB tendons enough to facilitate a longitudinal incision through the capsule. Reflect the capsule enough to completely visualize the joint (TECH FIG 1).
- Visualize the scaphotrapezial joint; if it is found to have substantial degeneration, this joint surface would need to be addressed as part of the procedure.

#### Joint Preparation
- Use a high-speed sagittal saw to remove the distal facet of the trapezium. Take care not to injure the flexor carpi radialis (FCR) or flexor pollicis longus (FPL) tendons, which lie on the volar side of the bony cut. Alternatively, a burr can be used to decorticate the trapezial surface while maintaining its native contour.
- Use a high-speed burr to slightly decorticate the dorsum of the proximal metacarpal to stimulate healing, but not enough to affect the suture anchor fixation (TECH FIG 2).

#### Implant Placement
- The implant (Fig 1A) comes in two sizes; pick the appropriate size to fill the void from radial to ulnar as well as dorsal to volar between the trapezium and the base of the metacarpal. The larger size may be able to be trimmed down to fit more anatomically.
- The Artelon implant is shaped similar to a T, with two wings for the dorsum of the trapezium and metacarpal, with the other part to be placed between the fresh bone edges of the trapezium and the base of the metacarpal.
- Bioabsorbable suture anchors (with 2-0 fiberwire or equivalent) are used to hold the dorsal wings down to the bone (TECH FIG 3). Although cortical bone screws were recommended to secure the implant early on, experience has shown that screws are a frequent source of complication and may pull through the mesh. Screws should be avoided. Suture anchors are much easier and quicker and provide better fixation of the implant.
- After this, close the capsule with absorbable suture and the skin with 3-0 nylon. At the end of the surgery, the patient is placed into a thumb spica splint and will follow up in 2 weeks for suture removal and placement into a thumb spica cast for 4 more weeks.
PYROCARBON RESURFACING ARTHROPLASTY

Exposure
- Make a dorsal longitudinal incision centered over the CMC joint. Identify and protect branches of the superficial radial nerve throughout the procedure, along with the EPL and EPB.
- After mobilizing and protecting the radial artery, mobilize the EPL and EPB tendons enough to facilitate a longitudinal incision through the capsule. Reflect the capsule enough to completely visualize the joint. Subperiosteal release allows the base of the metacarpal to be dislocated dorsal to the trapezium. Place a Hohmann retractor beneath the palmar surface to maintain exposure.

Joint Preparation
- First, place a sizing guide over the surface as a guide toward what the ultimate size implant is likely to be.
- Resect the base using the cutting guide, which is assembled after an intramedullary rod is inserted. Just the articular surface is removed.
- Start broaching. Ensure that the broach is started just volar to the central portion of the cut to ensure that the implant is not placed too dorsal (TECH FIG 4).

Implant Placement
- Check stability with the final implant in place (TECH FIG 5A). Gentle cross-palm pressure before capsular closure should not cause dislocation.
- The implant comes in four sizes. If the trial is not stable, upsizing the implant may be necessary.
- Close the capsule with absorbable suture and the skin with 4-0 nylon.
- At the end of the surgery, the patient is placed into a thumb spica splint and will follow up in 2 weeks for suture removal and placement into a thumb spica splint for 4 more weeks.
- Radiographs are checked at that time to ensure that the implant is reduced (TECH FIG 5B).

TECH FIG 3 • Appearance of the resurfacing arthroplasty after stabilization of the Artelon implant with suture anchors.

TECH FIG 4 • Extramedullary guide to plan placement of saddle implant.

TECH FIG 5 • A. Saddle implant in place. B. Postoperative lateral radiograph showing implant in place.
TOTAL JOINT REPLACEMENT

Exposure

- We use a technique and surgical approach similar to that described by Badia and Sambandam² for implanting a Braun-Cutter trapeziometacarpal joint prosthesis (or Avanta CMC implant; Small Bone Innovations, Morrisville, PA; Fig 1C) using bone cement.

Joint Preparation

- Make a 4-cm longitudinal incision over the dorsal aspect of the base of the thumb. Identify and protect branches of the superficial sensory radial nerve. Perform further dissection between the EPL and EPB tendons, isolating and protecting the dorsal branch of the radial artery.
- Open the dorsal capsule of the trapeziometacarpal joint longitudinally. Reflect the periosteum and the dorsal capsule radially and ulnarily as a single flap to be repaired later (TECH FIG 6).

Exposure

- We use a technique and surgical approach similar to that described by Badia and Sambandam² for implanting a Braun-Cutter trapeziometacarpal joint prosthesis (or Avanta CMC implant; Small Bone Innovations, Morrisville, PA; Fig 1C) using bone cement.

Joint Preparation

- Using a sagittal saw, remove about 8 mm of the thumb metacarpal base. This resection is necessary to provide enough exposure to the trapezium (TECH FIG 7A,B).
- Release the adductor pollicis if required to allow abduction of the thumb metacarpal away from the palm. At this point, longitudinal traction and flexion are applied to better expose the trapezial surface.
- Use a rongeur to remove the marginal osteophytes and flatten the joint surface of the trapezium.
- With imaging, identify the center of the trapezium with a small burr. Enlarge the center hole to create a deep channel within the trapezium where the polyethylene cup will be cemented (TECH FIG 7C).
- For the thumb metacarpal, use a guide to open the intramedullary canal, which is broached with a burr to allow for an ample cement mantle (TECH FIG 7D).

TECH FIG 6 • The first compartment is opened from the volar side and the strands of the abductor pollicis longus (APL) are inspected. A strand of the APL that inserts on the base of the metacarpal in the bone area that will be resected should be freed from its insertion and tagged for later repair. (Courtesy of Small Bone Innovations, Morrisville, PA.)
Implant Placement

- Place the implant and perform a trial reduction so that motion and fluoroscopic images can be assessed. If there is any bony impingement at the periphery of the residual trapezium, this can be addressed before placing the permanent prosthesis.
- For final placement, first cement the trapezial cup in the trapezium, taking care to impact the cement beneath the sub cortical bone.
  - Once the cup has been inserted but before the cement has cured, insert the thumb metacarpal component with bone cement (TECH FIG 8A).
  - The two components are linked, but because this stem is collarless, it is important to maintain adequate neck length (to prevent subsidence) until the bone cement has cured. Make sure the stem neck does not impinge on the edge of the trapezium (TECH FIG 8B).
- Assess stability and circumferential motion to ensure there is no impingement on the implant.
- Close the capsule–periosteal flap with absorbable suture.
- After inserting the implant and before closure, use intraoperative fluoroscopy to check proper alignment and placement of the prosthesis (TECH FIG 8C).
- Close the skin and subcutaneous tissue with a resorbable suture and place a well-padded short-arm thumb spica splint.

**TECH FIG 8 • A,B.** The components are cemented into place, the trapezium first and the metacarpal second. Compression should be maintained until the bone cement has completely set. C. Postoperative lateral radiograph showing implant in place. (A: Courtesy of Small Bone Innovations, Morrisville, PA.)

PEARLS AND PITFALLS

**Preoperative**
- Always do an Allen test before surgery.
- Always evaluate the thumb MCP joint for active instability–hyperextension.

**Intraoperative**
- Use extreme caution mobilizing the radial artery. Often bipolar electrocautery facilitates mobilization, especially of the deep perforators at the volar base of the TM joint.
- Evaluate the scaphotrapezial joint, as preoperative radiographs are not good at predicting disease.
- Be careful when sawing or drilling not to injure structures deep to the bone.
- After making the bone cuts on the trapezium and burring the proximal metacarpal, drill and place the suture anchors far enough away from the prepared bone to avoid inadvertent breakout in the fresh cancellous bone surfaces.
- Once the implant has been secured and the capsule repaired, do not manipulate by the thumb, as this may put undue stress on the soft tissue repair.
- After the procedure, before contaminating the sterile field, release the tourniquet and observe the reperfusion of the hand to ensure that no unexpected arterial injury occurred.

**Postoperative**
- Have a postoperative therapy protocol for patients to follow.
- The cast immobilization is discontinued at 6 weeks postoperatively if Artelon resurfacing has been used and at 2 weeks if CMC replacement has been performed. A custom Orthoplast thumb-based spica splint (Johnson & Johnson, New Brunswick, NJ) is worn full time for protection, except during showers and therapy.

POSTOPERATIVE CARE

- At the end of the surgery, the patient is placed into a thumb spica splint to keep the thumb in opposition. At 2 weeks postoperatively, the sutures are removed and placement into a thumb spica cast continues for 2 more weeks.
Formal therapy is usually not required after total joint replacement. In the case of resurfacing, therapy will focus on range-of-motion exercises only for postoperative weeks 4 to 6, advancing to thenar isometrics for weeks 6 to 8. At 8 weeks postoperatively, the patient will start grip and pinch strengthening exercises; the splint is also discontinued at this point.

**OUTCOMES**

Several long-term studies have shown better than 90% satisfaction and pain relief with soft tissue arthroplasties, but long-term outcome studies do not exist for the Artelon implant, and most of the literature for total joint arthroplasty for TM joint arthritis is not favorable.

**COMPlications**

- Superficial branch of the radial nerve injury
- Damage to flexor tendons during saw use
- Radial artery injury
- Dislocation or subsidence of total joint implant
- Subluxation of TM joint
- Continued pain or discomfort
- Failure to recognize other sources of pathology in the hand and wrist

**REFERENCES**

DEFINITION
- Arthrosis of the wrist often presents with functional movement, but with substantial disability due to pain. The purpose of wrist denervation is to decrease pain by surgically dividing the nerves that transmit the afferent pain signal from the wrist.

ANATOMY
- The posterior interosseous nerve (PIN) is considered to be the most important nerve innervating the wrist joint.
- Other nerves involved are branches from the anterior interosseous nerve (AIN), the radial nerve, the dorsal branch of the ulnar nerve, the palmar branch of the median nerve, and recurrent intermetacarpal nerve branches.

PATHOGENESIS
- Common causative conditions include scaphoid nonunion advanced collapse, scapholunate advanced collapse, degeneration secondary to crystalline arthropathy, inflammatory arthritis, and trauma.

NATURAL HISTORY
- The natural history of wrist arthrosis is slow progression, but the correlation between radiologic staging and symptoms is sometimes poor.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients with wrist arthrosis present with wrist pain, weakness of the grip, swelling, and stiffness.
- Often there is a sensation of grating during wrist movement, and occasionally clicking or clunking.

Some patients report a history of wrist injury years previously, but many do not recall any wrist trauma.
- It is important to inquire about neurologic symptoms to identify any associated compressive neuropathy at the carpal tunnel, the canal of Guyon, or both.
- Examination of the wrist usually reveals dorsoradial swelling, loss of movement, weak grip strength secondary to pain, and crepitation.

Local Anesthetic Blocks
- Although controversial in the literature, selective injection of a local anesthetic can be used to predict the results of wrist denervation.
- Local anesthetic is injected about 1 cm ulnar and 3 cm proximal to the tubercle of Lister, delivering 1 mL Marcaine 0.5% around the PIN (FIG 1A). The needle is pushed forward through the interosseous membrane to deliver 1 cc of local anesthetic adjacent to the AIN.
- One cc Marcaine is then injected under the branches of the radial nerve (FIG 1B), under the dorsal cutaneous branch of the ulnar nerve (FIG 1C), under the palmar branch of the median nerve (FIG 1D), and finally between the base of the second and third metacarpals to block the recurrent intermetacarpal branches.
- The wrist is examined before the injections and again 20 minutes afterward. Baltimore Therapeutic Equipment is used where available.
- A decrease in pain rating by 90% and an increase in work output of more than 200% indicate a significant improvement.
- Patients with these results are considered good candidates for surgical denervation.

FIG 1 • One mL of 0.5% bupivacaine is injected to block the posterior and anterior interosseous nerves (A), the branches of the radial nerve (B), the branches of the dorsal cutaneous ulnar nerve (C), the palmar branch of the median nerve (D), and the branches of the intermetacarpal nerve. (Reprinted from Hunt T, Herlas-Palou C. Wrist denervation. In Chunk K. Operative Techniques: Hand and Wrist Surgery. Philadelphia: Elsevier, 2008:209–230.)
IMAGING AND OTHER DIAGNOSTIC STUDIES
- Posteroanterior and lateral radiographs of the wrist confirm the degenerative changes in the wrist joint.
- If there is any doubt about the degree of degeneration, an advanced imaging study (eg, MRI) or wrist arthroscopy can provide more precise information, but these are seldom required.

DIFFERENTIAL DIAGNOSIS
- Wrist denervation is a good option for patients with wrist pain secondary to degeneration. It is important to rule out other causes of pain, such as infection.
- Patients with frank wrist instability and patients with active inflammatory arthritis are unlikely to benefit from wrist denervation.

NONOPERATIVE MANAGEMENT
- For patients with wrist degeneration, conservative management, including anti-inflammatory drugs and splints, should be tried before considering surgery.

SURGICAL MANAGEMENT
- Wrist denervation is indicated in a patient with considerable pain due to wrist degeneration, recalcitrant to conservative measures.
- Alternatives to wrist denervation include open or arthroscopic wrist débridement, radial styloidectomy, partial carpal arthrodesis, proximal row carpectomy, and wrist arthrodesis. Some of these procedures can be combined with a denervation.

Positioning
- The patient is positioned supine with the affected arm on a hand table, under regional block, with a high arm tourniquet, and the procedure is carried out under loupe magnification.

Approach
- Standard denervation of the wrist is carried out through four incisions: dorsal, dorsal–ulnar, volar–radial, and dorsal, over the base of the metacarpals.
- A partial denervation is carried out through one dorsal incision.

PARTIAL DENERVATION OF THE WRIST
- Partial denervation involves excision of the PIN with or without excision of the AIN just proximal to the radiocarpal joint.
- Make a 2-cm transverse dorsal incision 3 to 5 cm proximal to the wrist.
- Incise the fourth extensor compartment in a longitudinal direction and retract the extensor tendons ulnarward.
- Isolate the PIN on the radial floor of the fourth extensor compartment.
  - The PIN travels with the posterior interosseous artery and veins.
- Excise a 1-cm segment of nerve.²,³
- Retract the fourth compartment extensor tendons radially and make a small window in the interosseous membrane.
- Excise a segment of AIN just deep to the interosseous membrane.
- Close the extensor retinaculum with absorbable suture and close the skin in a routine manner.
- Apply a soft dressing with or without a temporary splint.

FULL DENERVATION OF THE WRIST
- A full wrist denervation involves four separate incisions (TECH FIG 1).

Incision 1
- Make the same transverse incision described for a partial denervation 3 to 5 cm proximal to the wrist on the dorsal forearm.
- If a more distal incision is used, some articular branches from the PIN may not be completely eliminated.
- Excise the PIN (TECH FIG 2A) and branches of the AIN (TECH FIG 2B) as discussed above.

Incision 2
- Make a 2- to 3-cm dorsal–ulnar incision over the wrist at the level of the ulnar head.
Dissect to the level of the extensor retinaculum.

In the subcutaneous flap, isolate the dorsal branch of the ulnar nerve along with its small articular branches to the wrist joint (TECH FIG 3).

Divide these small branches close to the point where they enter the extensor retinaculum.

**Incision 3**

- Make a 2- to 3-cm volar–radial incision centered over the radial artery at the level of the wrist and distal forearm.
- Resect a portion of perivascular tissue from around the radial artery.

**Incision 4**

- Make a 2-cm transverse incision over the dorsal base of the second and third metacarpals.
- Dissect through the fascia to expose and resect the recurrent intermetacarpal branches (TECH FIG 4).
- Close in standard fashion.
- Apply a soft dressing with or without a temporary splint.
PEARLS AND PITFALLS

| Indications | ■ Patients with wrist degeneration and substantial pain but some useful wrist movement  
|            | ■ Avoid denervation in patients with frank wrist instability or active inflammatory arthritis.  
|            | ■ Use local anesthetic blocks to help in patient selection.  |
| Options    | ■ Partial denervation  
|            | ■ Full denervation  
|            | ■ Denervation combined with other procedures  |
| Alternatives to denervation | ■ Arthroscopic or open wrist débridement  
|            | ■ Radial styloidectomy  
|            | ■ Partial carpal arthrodesis  
|            | ■ Proximal row carpectomy  
|            | ■ Wrist arthrodesis  |

POSTOPERATIVE CARE

■ Early range of motion is initiated but little formal therapy is required.  
■ A removable splint may be provided for comfort initially.  
■ Patients usually return to work 2 to 4 weeks after surgery.  

OUTCOMES

■ Wrist denervation is successful in providing pain relief in the long term in two thirds of patients.  
■ A partial wrist denervation seems to provide good results initially, but there is often deterioration after 12 months.  

COMPLICATIONS

■ Although there is a theoretical risk of causing a neuropathic Charcot joint, to our knowledge this has never been reported.  
■ This proves that a complete denervation of the wrist joint is never achieved.  
■ Neuroma formation has been reported in 2% of patients.  

REFERENCES

DEFINITION
- Arthritis between the radial styloid and the distal aspect of the scaphoid can lead to pain, weakness of grip, and limitation of motion. This arthritis can occur in the early stages of a variety of pathologic states of the radiocarpal joint.
- Radial styloidectomy is a technique that involves resection of the distalmost aspect of the articular surface of the distal radius.
- A radial styloidectomy can be performed as a distinct procedure via an open incision or by arthroscopic means. It is more commonly undertaken as an adjunct procedure with reconstructive or salvage procedures for scaphoid nonunions, carpal instabilities, Kienböck disease, or posttraumatic arthritis of the radiocarpal joint.9,17

ANATOMY
- The radial styloid is the distalmost projection on the lateral aspect of the terminal end of the radius (FIG 1A,B).
- When viewed from the lateral aspect, the styloid has a gentle slope volarly, placing it below the midcoronal longitudinal axis of the radius.
- The intra-articular component of the radial styloid encompasses part of the scaphoid facet.
- The extra-articular aspect of the styloid serves as the origin of several dorsal, palmar, and radial extrinsic ligaments that are vital to normal carpal kinematics (FIG 1C).
- The palmar radiocarpal ligaments serve as a constraint to radiocarpal pronation, ulnar translation, and distal pole scaphoid stabilization. Global disruption of this complex has been implicated in perilunate dislocation. The palmar radiocarpal ligaments are composed of the following structures:
  - The radial collateral ligament (RCL) is a thin structure that originates from the tip of the radial styloid and inserts into the waist and distal aspect of the scaphoid. The integrity of the ligament is always sacrificed with a radial styloidectomy, but no untoward effects have been reported.3,4
  - The radioscaphocapitate (RSC) ligament originates from the palmar cortex of the distal radius coursing distally and ulnarily, attaching to the waist and proximal cortex of the distal pole of the scaphoid and the body of the capitate.3,4
  - The long radiolunate ligament (LRL) originates from the palmar cortical margin of the distal radius immediately adjacent and medial to the RSC ligament. It is separated from the RSC by a distinct sulcus that serves an arthroscopic landmark.3,4
  - The dorsal radiocarpal (DRC) ligament originates broadly from the dorsal rim of the distal radius around the tubercle of Lister, coursing ulnarily, distally, and obliquely to insert on the dorsal tubercle of the triquetrum.
  - The radialmost fibers of this ligament also insert on the dorsal lunate.
  - The DRC ligament, in concert with the dorsal intercarpal ligament, has a crucial role in maintaining normal carpal kinematics and carpal stability and preventing ulnar translation of the carpus.3,4,15

FIG 1 • A,B. The radial styloid outlined on a standard PA and lateral wrist radiograph. C. Palmar and dorsal extrinsic ligaments of the radiocarpal joint. Note the broad origin of the dorsoradial ligament. The radial collateral ligament originates from the tip of the styloid. The radioscaphocapitate and long radiolunate ligaments are separated by a well-defined sulcus readily seen arthroscopically.
Siegel and Gelberman\textsuperscript{13} examined the effect of three different styloidectomy configurations on palmar radiocarpal ligament integrity in a cadaver model (FIG 2).

- The most conservative osteotomy (short oblique) removed only 9% of the RSC and none of the LRL ligaments.
- A vertical oblique osteotomy sacrificed 92% of the RSC and 21% of the LRL ligaments.
- A transverse styloidectomy was the most aggressive and resulted in loss of 95% of the RSC and 42% loss of the LRL ligaments.

Nakamura et al\textsuperscript{10} examined the effect of radial styloidectomy on carpal alignment and ulnar translation in cadaveric limbs. They demonstrated that as a larger segment of the radial styloid was resected (FIG 2), a greater tendency toward ulnar translation, as manifested by decreased stiffness, was observed. No frank ulnar translation with axial loading was observed.

- Based on their analysis, they recommended that no more than 3 to 4 mm of radial styloid should be resected. This correlated with a short oblique styloidectomy as described by Siegel and Gelberman.
- Although ulnar translation is a stated complication of overly vigorous styloidectomy, Viegas et al\textsuperscript{14} demonstrated in a cadaver model that ulnar translation can occur only with resection of the DRC, RSC, LRL, and SRL ligaments.

PATHOGENESIS AND NATURAL HISTORY

Scapholunate Instability

Watson and Ballet\textsuperscript{16} reviewed radiographs of individuals with scapholunate dissociation to establish the sequential progression of arthritis in the scapholunate advanced collapse (SLAC) wrist (FIG 3).

- SLAC I: Degenerative changes are confined to the radial styloid area.
- SLAC II: Changes are characterized by joint space narrowing involving the entire radioscapoid articulation.
- SLAC III: Changes involve additional arthritis between the capitate and lunate.

Several authors have examined the mechanics of scapholunate dissociation in cadaver models and have demonstrated that scapholunate instability leads to a shift in the contact pressures from the proximal pole of scaphoid articulation with the radial articular surface toward the distal pole of the scaphoid with the dorsal lip of the radial styloid.\textsuperscript{6,7} The pathomechanics of these changes can occur even before the frank radiographic appearance of scapholunate diastasis is present (ie, static scapholunate instability). Prolonged exposure to these abnormal contact stresses leads to the predictable arthritic changes described above.
■ Scaphoid nonunion
  ■ With an unstable scaphoid fracture, the proximal pole of the scaphoid remains firmly fixed to and extends with the lunate through an intact scapholunate interosseous ligament. The distal pole adopts a flexed posture, which can then impinge upon the radial styloid, leading to abnormal contact stresses and arthritic changes.
  ■ The natural history of scaphoid nonunion has not been established by rigorous prospective analysis. Nonetheless, most surgeons believe that unstable scaphoid fractures result in abnormal carpal kinematics with a dorsal intercalated segment instability (DISI) deformity and subsequent arthritis (scaphoid nonunion advanced collapse [SNAC] wrist).
  ■ Inoue and Sakuma reviewed 102 patients with scaphoid nonunions clinically and radiographically; they found that arthritis initially developed at the scaphoid–radial styloid articulation and subsequently the midcarpal joint. All patients had radiographic arthritis within 10 years of injury. They also demonstrated that although radiographic progression did not correlate with wrist pain, it did correlate with a decrease in grip strength and range of motion.

■ Impingement after triscaphe (scaphoid-trapezoid-trapezium) fusion
  ■ Rogers and Watson reviewed 93 patients after triscaphe fusion and found a 33% incidence of painful impingement between the fusion mass and the radial styloid that resolved after limited radial styloidectomy. They hypothesized that the fixed scaphoid could no longer be accommodated in the fossa and impacted upon the radial styloid.

■ Proximal row carpectomy
  ■ Although not all surgeons routinely perform a radial styloidectomy in the setting of a proximal row carpectomy, a recent cadaveric study demonstrated that radial deviation after proximal-row carpectomy was limited by impingement of the trapezoid on the radial styloid.

PATIENT HISTORY AND PHYSICAL FINDINGS

■ Patients with clinically significant radial styloid arthritis or impingement frequently complain of pain along the dorsal radial aspect of the wrist that is exacerbated by extension of the wrist or gripping activities. They may also note focal swelling or a decrease in the range of motion.
  ■ A complete physical examination of the radiocarpal, the midcarpal, and the first carpometacarpal joints is necessary to assess for associated conditions and to rule out alternative diagnoses.
  ■ Styloid impingement typically causes radial-sided wrist pain that is exacerbated by radial deviation, extension, and loading of the wrist.
  ■ Physical findings of styloid impingement are centered around the anatomic snuffbox (FIG 4).
  ■ The anatomic snuffbox is triangular, with its radial border formed by the extensor pollicis brevis tendon, its ulnar border by the extensor pollicis longus tendon, and its proximal border by the dorsal rim of the distal radius at the level of the styloid. The waist of the scaphoid and a small segment of the trapezium are palpable in the floor of the snuffbox, more readily with ulnar deviation.

IMAGING AND OTHER DIAGNOSTIC STUDIES

■ Plain radiographs of the wrist
  ■ To diagnosis and stage SNAC and SLAC (FIG 5)
  ■ To rule out scaphoid fracture or other acute injury
  ■ Stress radiographs (clenched fist and radial–ulnar deviation posteroanterior) of the wrist can yield information concerning dynamic impingement between the scaphoid and the radial styloid.
DIFFERENTIAL DIAGNOSIS

- DeQuervain stenosing tenosynovitis: Tenderness usually extends along the extra-articular component of the radial styloid, proximally and radially over the first dorsal compartment. A positive Finkelstein test is highly suggestive of this disorder.
- Scapho-trapezoid-trapezial arthritis: focal tenderness in the distal-ulnar aspect of the snuffbox under the extensor pollicis long tendon along the axis of the second metacarpal
- Thumb carpometacarpal instability or arthritis: tenderness distal to the anatomic snuffbox that is worsened by loading of the thumb ray (CMC grind test)
- Scaphoid fracture: After an acute injury, special imaging (bone scan or MRI) may be required to rule out an acute scaphoid fracture.
- Preiser disease
- Inflammatory arthritis (ie, rheumatoid)
- Radial sensory neuritis or neuroma
- Tenosynovitis of the extensor carpi radialis longus and brevis
- Not uncommonly, styloid impingement coexists with other diagnoses, especially basilar thumb arthritis and De Quervain stenosing tenosynovitis.

NONOPERATIVE MANAGEMENT

- Individuals with chronic SLAC or SNAC wrist arthritis frequently present with acute pain after a recent injury. After obtaining an accurate medical history of prior injury and radiographic assessment, the chronicity of the problem is usually evident. In this situation, a course of conservative treatment with activity modification, nonsteroidal anti-inflammatory drugs, rest in a forearm-based thumb spica splint, and selective corticosteroid injection in the radial styloid area is appropriate.
- If the arthritic changes are truly isolated to the area of articulation between the scaphoid and the styloid, the surgeon may elect earlier operative intervention with the theoretical goal of slowing or preventing progressive arthrosis and the need for a more extensive reconstructive procedure.

SURGICAL MANAGEMENT

- Isolated radial styloidectomy is a limited procedure to treat the early stage of progressive posttraumatic arthritis. It cannot be expected to prevent its pathologic progression. It can also be employed as a temporizing solution in a low-demand individual or in a patient unfit or unwilling to undertake a more extensive procedure and postoperative rehabilitative course.
- In that instance, patient expectations with respect to motion and pain relief must be assiduously managed.
- Arthroscopic radial styloidectomy has the theoretical advantages of being minimally invasive and allowing more precise control of the level of bony resection to minimize injury to the palmar radiocarpal ligaments. In addition, arthroscopic evaluation of the radiocarpal and midcarpal joints can allow for diagnosis and treatment of concomitant intra-articular pathology. In some cases, final staging of the severity of articular degeneration can be made only by direct visualization with diagnostic wrist arthroscopy (FIG 6). An isolated radial styloidectomy or a more extensive reconstructive procedure can be done at the time of arthroscopy or at a later time, after the implications of the arthroscopic findings are discussed with the patient.

Positioning

- The patient is positioned supine on a stretcher with an attached hand table and the arm centered on the hand table with the shoulder abducted 90 degrees. A mini-fluoroscopy unit is draped in a sterile fashion and placed in a plane perpendicular to the hand table.
- For arthroscopic procedures, the arm is stabilized to the hand table with a strap that allows countertraction.
- The shoulder is abducted 90 degrees, the elbow is flexed 90 degrees, and finger traps are placed on the index and middle fingers.
- The forearm is suspended in a standard wrist traction tower with 8 to 12 pounds of traction employed.
- A mini-fluoroscopy unit is draped in a sterile fashion and placed in a plane parallel to and above the hand table.
- Alternatively, the hand can be suspended via finger traps using a nonsterile overhead traction boom (ie, an arthroscopic shoulder holder); in this case, the wrist traction tower will not be an impediment to intraoperative fluoroscopic assessment.

Approach

- A radial styloidectomy can be performed in conjunction with other reconstructive procedures such as proximal-row carpectomy, intercarpal fusion, or bone grafting for a scaphoid nonunion. In these instances, the primary procedure usually requires wide exposure through a standard dorsal approach to the wrist.
- An isolated styloidectomy can be performed through a limited radial incision.
- An arthroscopic styloidectomy can be performed through standard arthroscopic portals.
OPEN RADIAL STYLOIDECTOMY

- Palpate the distalmost aspect of the radial styloid on the volar radial aspect of the wrist. Make an incision from that point for 2 or 3 cm proximally and obliquely between the first and second extensor compartments (TECH FIG 1A).
  - Alternatively, a transverse incision may provide a more cosmetically pleasing scar but also may limit exposure.
- At this level, there will be arborization of the terminal branches of the radial sensory and lateral antebrachial cutaneous nerves in the subcutaneous tissue. Use blunt dissection and gentle retraction to expose the first and second compartments.
  - Distal placement of the incision may place the dorsal branch of the radial artery at risk and should be recognized.
- Incise the extensor retinaculum in the 1–2 interval and expose the radial styloid by subperiosteal dissection. Alternatively, the radius can be approached through the floor of the first compartment (TECH FIG 1B).
- Expose the radial styloid by sharp dissection (TECH FIG 1C).
- Using a sharp osteotome, remove the distal 3 to 4 mm of radial styloid. The plane of the cut should be perpendicular to the articular surface (TECH FIG 1D).
- Fluoroscopic imaging of the level of resection can be useful at this point in the procedure.
  - A narrow malleable retractor can be placed in the radiocarpal joint to prevent damage to the scaphoid as the styloid is being resected (TECH FIG 1E).
- After styloidectomy, fluoroscopic examination with the wrist in radial and ulnar deviation to assess for impingement confirms adequacy of the resection level (TECH FIG 1F,G).
- Loosely reapproximate the periosteum with resorbable suture, allow the extensor compartments to fall back into their anatomic position, and suture the skin. A bulky dressing and volar splint holding the wrist is applied.

**TECH FIG 1** - Open radial styloidectomy. A. A 2- to 3-cm oblique skin incision is made between the first and second extensor compartments. Note the branches of the radial sensory and lateral antebrachial cutaneous nerves. B. The first dorsal compartment is then opened. C. The radial styloid is extraperiosteally exposed by sharp dissection. D. An osteotome is used to resect the distal 3 to 4 mm of radial styloid. The osteotome should be angled perpendicular to the joint surface. E. The resected radial styloid is removed. F,G. Preoperative and postoperative PA radiographs of the wrist with early scaphoid nonunion advanced collapse [SNAC] undergoing open radial styloidectomy. (Courtesy of Dr. John J. Fernandez.)
**ARTHRITIS**

**POSTOPERATIVE CARE**
- If the radial styloidectomy is performed concomitantly with another reconstructive procedure (PRC, four-corner arthrodesis, scaphoid bone grafting and fixation), the rehabilitation is dictated by the requirements of that additional procedure.

- After either open or arthroscopic radial styloidectomy, the postoperative dressing and sutures are removed in 7 to 10 days. Early active, active-assisted, and passive motion is initiated under the guidance of a hand therapist. Usually a removable splint is used initially for patient comfort. As the patient’s symptoms permit, graded strengthening and unrestricted activities are allowed.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Indications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A complete history and physical examination emphasizing clinical staging is essential. The final decision to proceed with styloidectomy may require staging arthroscopy.</td>
<td></td>
</tr>
<tr>
<td>Insufficient or excessive styloid resection</td>
<td></td>
</tr>
<tr>
<td>Arthroscopic visualization of the RSC ligament to prevent significant injury</td>
<td></td>
</tr>
<tr>
<td>Using the diameter of the burr as a gauge for the amount of bone resected</td>
<td></td>
</tr>
<tr>
<td>Intraoperative fluoroscopic evaluation</td>
<td></td>
</tr>
<tr>
<td>Poor arthroscopic visualization</td>
<td></td>
</tr>
<tr>
<td>Convert from arthroscopic to open procedure</td>
<td></td>
</tr>
</tbody>
</table>
OUTCOMES

- Stubbins and Barnard\(^1\) first described a radial styloidectomy as part of an operative treatment strategy for scaphoid nonunion in 14 patients in 1948. They thought that the styloidectomy removed impingement, enhanced exposure of the scaphoid, and provided material for bone grafting from the same operative field. Since that time there have been no series of outcomes in the indexed English literature for outcomes after isolated open radial styloidectomy. Several reports of radial styloidectomy performed with open reduction and internal fixation of scaphoid nonunion or with triscaphe fusion have demonstrated good pain relief but no significant improvement in range of motion.\(^{12,16}\)

- Page et al\(^{11}\) presented their experience with the arthroscopic technique in 22 patients to the European Federation of National Associations of Orthopaedics and Traumatology in 2003. In short-term follow-up, they reported 75% good and satisfactory results.

- Radial styloidectomy is most often performed as a limited procedure to address posttraumatic arthritis of the wrist early in its pathogenesis. While it can provide long-lasting symptomatic relief, it cannot be expected to halt the progression of the arthritis. A successful radial styloidectomy could be one in which a more extensive reconstructive procedure was delayed by several years.

COMPLICATIONS

- Incomplete resection leading to persistent pain
- Excessive resection leading to extrinsic ligament incompetence and wrist instability with ulnar translation
- Nerve injury to the terminal branches of the radial sensory nerve or lateral antebrachial cutaneous nerve
- Arthrofibrosis
- Infection
- Complex regional pain syndrome

REFERENCES

DEFINITION
- Proximal row carpectomy (PRC) involves removal of the proximal carpal row (scaphoid, lunate, and triquetrum).
- PRC has been described as a treatment option for a number of pathologic conditions:
  - Scaphoid nonunion advanced collapse (SNAC) wrist
  - Scapholunate advanced collapse (SLAC) wrist
  - Kienböck disease
  - Chronic or missed perilunate dislocation
  - Scaphoid osteonecrosis or Preiser disease
  - Wrist deformity or contracture

ANATOMY
- The proximal row of the wrist consists of three bones: scaphoid, lunate, and triquetrum.
- The proximal row moves as a single unit through intercarpal ligamentous attachments and bony congruity.
  - The proximal row flexes with radial deviation and extends with ulnar deviation.
- The capitate, in the distal row, articulates with the lunate.
  - The proximal capitate articular surface is relatively, although not completely, congruous with the lunate facet of the radius.

PATHOGENESIS
- A number of pathologies may eventually result in wrist degeneration requiring PRC. Patients experience progressive pain and limitation in motion, often requiring PRC to improve symptoms.
  - SNAC and SLAC
    - Stage I: Degenerative changes along the radial half of the radioscaphoid articulation. In SNAC wrists, the degenerative changes are typically limited to the articulation between the distal scaphoid fragment and the radius.
    - Stage II: Degenerative changes involving the entire radioscaphoid articulation (FIG 1). In SNAC wrists, the articulation between the proximal scaphoid fragment and the radius is preserved, and instead stage II degeneration occurs in the scaphocapitate joint.
    - Stage III: Degenerative changes at the capitolunate joint. The radiolunate joint is spared.
  - Kienböck disease
    - Stage I: Normal plain radiographs with wrist pain and positive MRI finding
    - Stage II: Sclerosis without collapse of the lunate
    - Stage IIIa: Lunate collapse without instability
    - Stage IIIb: Lunate collapse with carpal instability
    - Stage IV: Fixed carpal instability with pan-carpal degenerative changes
  - Missed perilunate dislocation
  - Scaphoid osteonecrosis (Preiser disease)
  - Congenital or spastic wrist and hand flexion contractures may be so severe that a PRC allows deformity correction that tendon-lengthening procedures alone would be unable to correct.

PATIENT HISTORY AND PHYSICAL FINDINGS
- It is important to seek the cause of the wrist degeneration.
- Mechanical wrist pain is aggravated by use and relieved by rest. The history must support this for the proposed treatment to be successful.
- The history defines the patient’s symptoms, level of severity, and progression over time, as well as any previous attempts at treatment.
- Limited and painful wrist motion with diminished grip strength tends to be a common denominator regardless of the initial source of pathology.
  - Normal range of motion: wrist extension, 70 degrees; wrist flexion, 75 degrees; radial deviation, 20 degrees; ulnar deviation, 35 degrees
  - Normal grip strength: Mean grip for males is 103 to 104 for the dominant extremity and 92 to 99 for the nondominant extremity. Mean grip for females is 62 to 63 for the dominant extremity and 53 to 55 for the nondominant extremity.
  - Radioscaphoid joint line tenderness on palpation implies radioscaphoid arthritis.
  - Swelling over the dorsal and dorsoradial aspects of the wrist can be associated with radiocarpal and intercarpal arthritis. Most often dorsoradial wrist swelling will be visible and palpable in cases of SLAC and SNAC.

FIG 1 • Intraoperative photograph showing wear at the dorsal half of the scaphoid fossa seen with SLAC wrist, as indicated by the black arrow. Cartilage integrity is preserved in the lunate fossa, as indicated by the red arrow.
IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs assist with making the underlying diagnosis (eg, SNAC wrist, SLAC wrist, Kienböck disease).
- The surgeon should evaluate the articular facets and surfaces, specifically of the proximal capitate and lunate facet of the radius.
- The surgeon should evaluate for other sources of limited wrist motion, diminished grip strength, and pain (eg, thumb carpometacarpal arthritis, scapholunate instability without degenerative changes, fracture).
- Although MRI may assist in making the underlying diagnosis (eg, Kienböck disease, Preiser disease, scaphoid avascular necrosis) and evaluating the joint surfaces, it is rarely used.

DIFFERENTIAL DIAGNOSIS
- Triangular fibrocartilage complex or distal radioulnar joint pathology
- Extensor carpi ulnaris, flexor carpi ulnaris, flexor carpi radialis tendinitis
- De Quervain tenosynovitis
- First carpometacarpal arthritis
- Scapholunate or lunotriquetral instability without degenerative changes
- Midcarpal arthritis

SURGICAL MANAGEMENT
- Regardless of the initial source of pathology when considering treatment via PRC, the integrity of the articular cartilage and the congruity between the proximal capitate and the lunate facet of the radius are critical. This determination is often made intraoperatively.
- Indications
  - SLAC and SNAC wrist degeneration: stage I, II, or III (only if the degenerative changes at proximal capitate are limited to thinning or minor fissuring)

Preoperative Planning
- Plain radiographs of the wrist should be reviewed. The surgeon should scrutinize the location of degenerative changes, should know the amount of radial styloid beaking (and potential need for radial styloidectomy), and should note any previous fractures or hardware (may need to be removed).
- The surgeon should discuss and obtain consent for alternative procedures from the patient (ie, if one should find excessive degenerative changes at the capitate, one might proceed with intercarpal arthrodesis).
- Regional anesthesia, general anesthesia, or a combination of the two (for postoperative analgesia) is suitable.

Positioning
- The patient is supine with the arm on a radiolucent armboard.
- A nonsterile tourniquet preset at 250 mm Hg is on the upper arm.
- The shoulder, elbow, and hand are positioned such that the hand rests in pronation at the center of the armboard (if a dorsal approach is planned).

INCISION AND EXPOSURE
- Make a dorsal longitudinal skin incision over the fourth dorsal compartment or a transverse incision across the dorsal wrist crease just distal to the tubercle of Lister.
  - The longitudinal incision is more extensile and versatile.
  - The transverse incision tends to be more cosmetic.
- Expose the extensor retinaculum.
  - Maintain full-thickness flaps when elevating soft tissues off the extensor retinaculum to minimize the risk of damage to the radial and ulnar sensory nerves (TECH FIG 1A).
  - Incise the extensor retinaculum in line with extensor pollicis longus (EPL) with scissors and transpose the EPL radially, dorsal to the retinaculum.
- Incise the radial septum of the fourth dorsal compartment and expose the wrist capsule by retracting the fourth compartment extensor tendons ulnarly and the EPL and radial wrist extensor tendons radially.
- Look for the distal extent of the posterior interosseous nerve (PIN) in the proximal portion of the incision on the radial floor of the fourth compartment. Perform a PIN neurectomy after coagulating the accompanying vessels. Create a distally based “inverted-U” capsular flap by first incising the wrist capsule transversely over the radiocarpal joint (from radial to ulnar) and then, at the margins, extending the incision distally (TECH FIG 1B).
  - Making a U-shaped capsular hood provides flexibility should one elect to add a dorsal capsular interposition arthroplasty in the setting of mild midcarpal arthroplasty.
  - The dorsal branch of the radial artery is radial to the second compartment, so take care at the radial aspect of the capsulotomy.
- Inspect the articular cartilage on the proximal capitate and lunate facet of the radius for any degenerative changes.
  - If the cartilage is in good condition, proceed with PRC; if not, consider alternative procedures (TECH FIG 1C).
ARTHRITIS

A. Superficial branches of the radial nerve and the dorsal cutaneous branch of the ulnar nerve. The dorsal branch of the radial artery is in danger deeper in the dissection as the wrist joint capsule is incised. B. Intraoperative photograph showing the distally based U-shaped dorsal capsular flap. This flap is centered over the capitate. The radial margin is just adjacent to the ulnar border of the extensor carpi radialis brevis tendon. The proximal margin is taken directly off the dorsal lip of the radius. (Red arrow points to distal articular surface of the hamate; the triquetrum has not yet been removed. Black arrow points to the dorsal lip of scaphoid fossa.) The ulnar margin is just radial to the extensor digiti minimi. C. Wear on the ulnar aspect of the head of the capitate is visualized in this case. (Arrow points to a cartilage defect on the capitate head.) Arthrosis affecting the non-weight-bearing portion of the capitate does not preclude the use of a proximal row carpectomy but one may want to include a capsular interposition. This is usually employed in older, lower-demand individuals.

TECHNIQUES

CARPECTOMY

- Precisely ensure the anatomy and which bones are to be removed.
  - Consider intraoperative fluoroscopy if there is any question.
- Note the location of the radioscaphocapitate ligament at the waist of the scaphoid. Protect it and the other volar extrinsic ligaments while removing the proximal carpal row.
- Avoid iatrogenic injury to the cartilaginous surfaces of the capitate head and lunate facet of the radius.
- Osteotomize the scaphoid at its waist with a straight osteotome to facilitate scaphoid excision.
  - Place the osteotome such that it parallels the flexor carpi radialis tendon to minimize the risk of transection (TECH FIG 2A,B).
- The distal pole of the scaphoid is particularly difficult to remove (especially with SNAC wrist deformities).
  - Consider using a threaded Kirschner wire (0.062 inch) or a large threaded Steinmann pin (5/32 inch) as a joystick to control the bone to be removed (TECH FIG 2C).
  - Try to create tension between the proximal carpal bones during dissection (a combination of no. 15 blade; Beaver blade; periosteal, Freer, or Carroll elevator; and small straight or curved curettes is valuable; TECH FIG 2D).
- If possible, remove the carpal bones whole rather than piecemeal. This facilitates removal when possible and ensures that no portions are left behind (TECH FIG 2E).
ASSESSMENT OF REDUCTION AND IMPINGEMENT

- Once the proximal row is removed, seat the capitate into the lunate facet on the radius to evaluate congruity.
- Check for impingement between the trapezium and radial styloid with extreme radial deviation.
- The trapezium has been shown to be volar to the styloid, making impingement less common than once thought.
- If radial-sided impingement is a concern, proceed with a radial styloidectomy.

RADIAL STYLOIDECTOMY

- See Chapter HA-86.
- Elevate the tendons of the second and then the first extensor compartments off the radial styloid through the same dorsal incision.
  - Take care to avoid injuring the dorsal branch of the radial artery just radial to the second dorsal compartment.
- The styloidectomy can be performed from proximal-radial to distal-ulnar with a straight osteotome (remove no more than 5 to 7 mm) (**TECH FIG 3**).

**TECH FIG 3** - The amount of radial styloid that is removed and the direction of the osteotomy. The origin of the radioscaphocapitate ligament is carefully preserved.
### TECHNIQUES

#### WOUND CLOSURE

- Close the capsule with nonabsorbable 2-0 suture.
- Plain radiographs or fluoroscopic images should be obtained in AP and lateral planes to ensure that the capitate is seated in the lunate fossae.
  - While uncommon, radiocarpal subluxation is possible with a PRC.
  - Maintenance of the volar ligaments (especially the radioscaphocapitate, which is most at risk during removal of the scaphoid) minimizes any risk of radiocarpal instability after PRC.
- Close the retinaculum with nonabsorbable 3-0 suture, leaving the EPL superficial to the retinaculum.
- Consider placing a drain in the subcutaneous tissues, to be removed in 24 to 48 hours.
- Close the skin with a 3-0 nonabsorbable running subcuticular Prolene stitch with “rescue loops” to facilitate removal at 10 to 14 days.
- Cover the incision with nonadherent gauze.
- Fashion a sugar-tong splint over a bulky dressing.
- Keep the fingers and the thumb free proximal to the metacarpophalangeal joints.
- Hold the wrist at neutral or slight extension (10 degrees).

#### PROXIMAL ROW CARPECTOMY WITH INTERPOSITION ARTHROPLASTY

- If mild to moderate chondral changes are noted on the capitate head, a PRC may still be indicated with the addition of an interpositional arthroplasty between the capitate head and lunate fossae.
- Use the previously created distally based inverted U-shaped capsular flap as the interpositional material.
- Place three simple stitches (2-0 PDS) connecting the dorsal capsular flap to the palmar capsule.
- Place and tag all stitches into the dorsal capsule (passing from deep to superficial) and into the palmar capsule (passing from proximal to distal) before tying them down to the palmar capsule (TECH FIG 4A).
- Loosely reapproximate the lateral margins of the dorsal flap to the residual dorsal capsule after interposing the dorsal capsule (TECH FIG 4B).
- Postoperative management is not altered.

### TECH FIG 4 • A. Sutures are passed in a mattress fashion through dorsal capsule, volar capsule, and then dorsal capsule to interpose the dorsal capsular flap between the capitate and lunate fossa. (Arrow points to the head of the capitate.) B. The dorsal capsule interposed between the capitate (shown above) and the radius (shown below) after the PDS sutures have been tied down.

#### PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Intraoperative pearls</th>
<th>Consider using finger traps with weights (or assistant traction) to open the radial carpal joint during proximal row excision. Mastisol can be used on the fingers to assist in holding the traps.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Threaded Kirschner wires (0.062 inch) or large threaded Steinmann pins (5/32 inch) in the scaphoid, lunate, or triquetrum can serve as a joystick or fulcrum to assist in removing the carpal bones.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Excessive styloidectomy</th>
<th>Removing more than 5 to 7 mm of the radial styloid has been associated with compromise of the radioscaphocapitate ligament, with resultant ulnar carpal translation and radiocarpal instability.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflex sympathetic dystrophy</td>
<td>Associated with prolonged immobilization (more than 2 weeks)</td>
</tr>
<tr>
<td></td>
<td>Thought to be minimized by accelerated rehabilitation (immediate finger and thumb passive range of motion and wrist motion at 2 to 3 weeks)</td>
</tr>
</tbody>
</table>

| Damage to the radial sensory and dorsal ulnar sensory branches | Dissect directly down to the extensor retinaculum and elevate subcutaneous fat in full-thickness flaps off the extensor retinaculum to minimize the risk of nerve injury. |
POSTOPERATIVE CARE

- PRC tends to be an outpatient procedure; an overnight stay may be necessary for postoperative pain or nausea.
- A short splint is applied in the operating room with the wrist in neutral and the fingers and thumb free at the metacarpophalangeal joints.
- Passive thumb and finger motion is encouraged immediately postoperatively, along with elevation and ice for the first 48 hours.
- At the first postoperative follow-up visit (in 10 to 14 days) the splint is removed, plain wrist AP and lateral radiographs are obtained to ensure the capitate is located in the radial lunate facet, and sutures are removed.
- At 2 weeks postoperatively, gentle active wrist extension and flexion and radioulnar deviation are added and a removable cock-up wrist splint or custom Orthoplast wrist splint is worn between exercises.
- Scar massage can begin once the incision is healed.
- Edema control may be necessary with compressive dressings.
- The removable splint can be removed as the patient feels comfortable (typically in 3 to 4 weeks).
- At 6 weeks, objective measurements of wrist extension, flexion, radioulnar deviation arcs, grip and pinch strength should be obtained.
- Therapy is initiated if the patient seems to be struggling to regain wrist or finger motion.
- At 3 months, full activities are encouraged.

OUTCOMES

- A broad range in grip strength outcome has been reported postoperatively.
- 60% to 100% grip strength of the contralateral wrist (and a 20% to 30% increase in postoperative grip versus preoperative grip) can be expected.3,7
- A decrease in postoperative wrist motion can be expected, as well as a decrease in flexion extension by 20%, a decrease in radioulnar deviation by 10%,3 and a 72- to 75-degree arc of motion in flexion and extension.2,7
- Satisfactory pain relief can be expected in 80% to 100% of patients.3,5
- Return to work for manual laborers after PRC has been unpredictable, varying from 20% in one series3 to 85% in another.5
- Age less than 35 years has been shown to be predictive of early failure with PRC.

COMPLICATIONS

- Incomplete removal of the carpal bones (typically distal scaphoid)
- Use of pins has been associated with pin site infections and rapid degenerative changes when placed through the radiocapitate articulation (because of this, pins are not routinely recommended as they once were).
- Reflex sympathetic dystrophy
- Excessive styloidectomy and compromise of the radioscaphocapitate ligament
- Compromise of the radioscaphocapitate ligament can lead to ulnar carpal subluxation.
- Conversely, failure to check intraoperatively for radial-sided impingement may lead to radial-sided wrist pain postoperatively.
- Damage to sensory nerves (radial sensory and dorsal ulnar branches)
- Progressive arthritis

REFERENCES

DEFINITION

- Limited wrist arthrodeses are salvage procedures for post-traumatic and degenerative conditions of the wrist as well as symptomatic instabilities.
- The goal is to reduce pain by selected fusion of the affected joints, thereby sparing motion, and improving the function of the remaining joints.

ANATOMY

- The carpus consists of four bones in the proximal row (scaphoid, lunate, triquetrum, pisiform) and four bones in the distal row (trapezium, trapezoid, capitate, hamate).
- The scaphoid and lunate bones are intimately joined by the scapholunate ligament both dorsally and volarly. This ligament is the keystone to the motion of the wrist.
- Numerous other named ligaments hold the carpal bones stable as the wrist moves through its five planes of motion (flexion, extension, radial and ulnar deviation, and circumduction).
- Most reconstructive wrist procedures require a dorsal approach to the wrist. The wrist and finger extensor tendons are separated into six compartments by the dorsal extensor retinaculum. The most common interval for exposure of the wrist is the 3–4 interval between the extensor pollicis longus and extensor digitorum communis tendons.

PATHOGENESIS

- Distraction forces across the joint and twisting motions while the wrist joint is being loaded can lead to a ligament injury.
- Failure of the scapholunate interosseous ligament, either by trauma or inflammatory arthritis, allows the scaphoid to flex and the lunate to extend, leading to dorsal intercalated segment instability.17,30 When this occurs, abnormal loading of the carpal bones results. This leads to degenerative arthritis, particularly at the radioscaphoid joint due to the abnormal distribution of force across this elliptical joint.7 This has been termed scapholunate advanced collapse (SLAC).
- Scaphoid nonunion advanced collapse (SNAC), perilunate dislocations, calcium pyrophosphate dihydrate deposition, and rheumatoid arthritis can also lead to this pattern of arthritis.
- Other ligament injuries, Kienböck disease, and localized arthritis can lead to wrist pain, instability, and deformity.

NATURAL HISTORY

- Much of our knowledge of the natural history of scaphoid nonunion was reported by Mack et al.18 We have learned that most ununited fractures of the scaphoid and SLAC wrists develop progressive osteoarthritis in a predictable pattern.
- Cyst formation and bony resorption are the hallmarks of arthritis and are usually seen 5 to 10 years after injury.
- Arthritis of the radioscaphoid joint can appear within a year after scaphoid nonunion. At that point most patients become symptomatic.12,28

PATIENT HISTORY AND PHYSICAL FINDINGS

- Typically, the patient describes a traumatic injury to the wrist. The absence of trauma should not exclude traumatic causes.
- Painful wrist motion and a limited arc of motion are common findings.
- Methods for examining the wrist include the following:
  - Finger extension test. The wrist is passively flexed while the examiner resists active finger extension. A positive test yields pain and may represent periscaphoid inflammatory changes, radiocarpal or midcarpal instability, or Kienböck disease. A negative test essentially excludes dorsal wrist syndrome, Kienböck disease, midcarpal instability, and SLAC as the cause of pain.
  - Anatomic snuffbox palpation. The examiner palpates the anatomic snuffbox with the index finger while moving the wrist from radial to ulnar deviation. A positive test yields severe pain at the articular–nonarticular junction of the scaphoid. Periscaphoid synovitis, scaphoid instability, and radial styloid arthrosis from SLAC are possible causes.
  - Triscaphe (scaphoid–trapezium–trapezoid [STT]) joint palpation. The examiner palpates the second metacarpal proximally until it falls into a recess, the triscaphoe joint. Pain with palpation indicates pathology of the distal scaphoid or the triscaphoe joint.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs, including AP, lateral, oblique, and scaphoid views, should be obtained.
- The stage of wrist arthritis, as seen on plain radiographs, helps to determine the treatment options. Watson and Ballet classified the radiographic findings into stages I–III.
  - Stage IV, not originally described, demonstrates arthritis in most all joints of the wrist. Fortunately, the radiolunate joint is rarely involved and serves as the basis for several treatment options.
  - Arthritis involving the radiolunate joint is usually seen only in patients with inflammatory wrist arthritis.

DIFFERENTIAL DIAGNOSIS

- SNAC
- SLAC
- Arthritis after perilunate dislocation
- Gout
- Pseudogout
- Rheumatoid arthritis
- Infectious arthritis
- Kienböck disease

NONOPERATIVE MANAGEMENT

- Nonoperative measures include rest, anti-inflammatory medications, splinting, occasional casting for flare-ups of arthritis, and cortisone injections.
SURGICAL MANAGEMENT

- **Indications**
  - Four-corner (capitate–hamate–lunate–triquetral [CHLT]) arthrodesis
  - Stage II or III SLAC wrist arthritis
  - Chronic symptomatic volar intercalated segmental instability (VISI) deformity or midcarpal instability
  - STT arthrodesis
    - Chronic static or dynamic scapholunate instability
    - Scapho–trapezium–trapezoid arthritis
    - Kienböck disease
    - Radiocarpal instability
  - Lunotriquetral arthrodesis
    - Lunotriquetral ligament tears
    - Posttraumatic instability
  - Scapholunate arthrodesis
    - Posttraumatic instability
    - Scapholunate instability
    - Dorsal intercalated segmental instability (DISI) deformity
  - Scaphocapitate arthrodesis
    - Scaphoid nonunion
    - Chronic DISI deformity with rotatory scaphoid instability
    - Kienböck disease
    - Lunate nonunion
  - Radiolunate arthrodesis
    - Rheumatoid arthritis primarily involving the radiolunate joint
    - Ulnar translocation of the carpus (relative indication)

Preoperative Planning

- The patient’s history and pertinent physical examination findings are reviewed.
- Any prior surgical scars are noted.
- All radiographs are reviewed, noting any associated pathology that might need to be simultaneously addressed to yield the best outcome.
- Postoperative pain control should be discussed with the patient and the anesthesia team, and a local or axillary block should be considered for prolonged pain relief after surgery.

Positioning

- The patient is placed in the supine position on the operating table with the arm draped to the side on a radiolucent armboard.
- A tourniquet is used to control bleeding during the procedure.

Approach

- The wrist is approached through a dorsal longitudinal incision between the third and fourth extensor compartments.
  - Alternatively, the 4–5 extensor compartment interval may be used to better visualize the lunate–triquetrum–capitate–hamate articulations.
  - The extensor pollicis longus (EPL) tendon sheath is opened and it is released both proximally and distally. The tendon is allowed to be transposed out of its compartment in a radial direction.
  - Although the EPL tendon is typically exposed and subsequently transposed, a more limited incision beginning just distal to the tubercle of Lister and proceeding distally may avoid significant exposure of the EPL tendon altogether.
  - All joints are exposed fully and a precise decortication is performed down to bleeding bone.
  - In almost every case, bone graft is harvested from the distal radius and used to augment the fusion.
  - Iliac crest graft may be substituted but is associated with higher morbidity.

FOUR-CORNER (CHLT) ARTHRODESIS USING KIRSCHNER WIRE FIXATION

- Make a standard dorsal longitudinal incision between the third and fourth extensor compartments using the tubercle of Lister as a landmark (TECH FIG 1A).
- Incise the retinaculum over the third extensor compartment.
- Incise the radial septum of the fourth extensor compartment and retract the tendons ulnarily.
- Perform a ligament-splitting dorsal approach to the carpus as described by Berger et al.4
  - This capsular incision allows access to the carpus while preserving the dorsal intercarpal ligament and dorsal radiotriquetral ligament (see Chap. HA-44).
  - Inspect the radiolunate joint for articular cartilage wear (TECH FIG 1B).

TECH FIG 1 • A. Skin incision is centered just ulnar to the tubercle of Lister. (Fingers are to the right or bottom in all intraoperative photos.) B. The radiolunate joint should be inspected for arthritis. If lunate cartilage is not preserved, a total wrist fusion may be required. (continued)
Identify and excise the scaphoid either piecemeal with a rongeur or sharply using a scalpel (TECH FIG 1C).
- Kirschner wires and tenaculum clamps facilitate the visualization and excision of the distal volar scaphoid.
- Take care to protect the volar radioscapophacitate ligament.
- Once the scaphoid is excised, decorticate the opposing joint surfaces of the lunate, triquetrum, capitate, and hamate (TECH FIG 1D).
- Longitudinal traction with fingertraps helps to distract these joints, making decortication easier.
- Thorough removal of the volar-third cartilage from the lunate and capitate facilitates correction of the pre-existing DISI deformity but shortens the intercarpal bone distances. This may restrict final wrist range of motion.
- Once these joint surfaces are denuded, harvest distal radius bone graft and place it into the fusion bed.

Use a 0.062 Kirschner wire to joystick the lunate into a more flexed position, and apply dorsal pressure to volarly translate the capitate on the lunate. Place one or two 0.062 Kirschner wires across this joint (TECH FIG 1E).
- Verify correction of the DISI deformity using fluoroscopy.
- Pin the lunotriquetral joint and the capitohamate joint with two 0.062 Kirschner wires (TECH FIG 1F).
- Intraoperative fluoroscopic images should reveal a stable triangular construct of Kirschner wires traversing the four bones (TECH FIG 1G,H).
- The Kirschner wires may be cut under the skin or left external, depending on the surgeon’s preference.
- After irrigation, close the capsule with absorbable suture, and repair the extensor retinaculum, leaving the EPL tendon transposed subcutaneously.
- Close the skin in a routine manner.
- Apply a large bulky dressing including a dorsal and volar forearm-based splint.

FOUR-CORNER ARTHRODESIS USING A CIRCULAR PLATE9,13,29

The approach, scaphoid excision, and joint preparation are analogous to those described above.
- Place a 0.062 Kirschner wire through the distal radius articular surface. Use a separate 0.062 Kirschner wire as a joystick to hold the lunate reduced in neutral alignment while advancing the Kirschner wire across the radiolunate joint in a dorsal to volar direction.
- Obtain fluoroscopic images to verify correction of the dorsally tilted lunate.
- After volarly translating the capitate (as described above) and fully correcting the DISI deformity, secure the triquetrum to the hamate and the lunate to the capitate with two additional Kirschner wires.
- Place these Kirschner wires as volar as possible to avoid interference during rasping and plate placement.
- Center the power rasp over the four bones in the AP and lateral planes and bury the rasp down to subchondral bone.
Ideal rasp placement does not always coincide with the central point between the four bones.
- Pack bone graft, obtained preferably from the distal radius or iliac crest, between the four prepared bones.
- Center the plate over the four bones in the AP and lateral planes and place the circular plate into the bony crater created by the rasp.
- Rotate the plate to maximize screw purchase into each of the four bones. Two screws should be planned for each of the four carpal bones.
- All screws must be placed in a unicortical fashion.
- Place the first screw through the plate into the lunate. Do not tighten this screw completely or it will cause the circular plate to tilt up and compromise screw fixation in the remaining bones.
- Place a second screw into the hole opposite the first screw. This sets the plate position.
- Check a lateral fluoroscopic image to ensure the plate is well seated and there is no impingement with wrist extension.
- Fill in the remainder of the holes with screws.
- Placing the screws opposite one another and tightening them sequentially helps prevent malpositioning of the plate.
- Obtain final images to check screw length and position, carpal reduction, and construct stability (TECH FIG 2).
- Close the wound as described above. Apply the dressing and splint.

### SCAPHOID–TRAPEZIUM–TRAPEZOID (STT) FUSION

- Make a transverse or dorsoradial incision centered over the STT joint.
- Protect the superficial radial nerve branches, and coagulate the small perforators from the dorsal branch of the radial artery (TECH FIG 3A).
- Make a longitudinal capsulotomy over the STT joint, and reflect the capsule to expose the bone surfaces (TECH FIG 3B).
- Verify scaphoid alignment with fluoroscopy. The ideal scapholunate angle is 41 to 60 degrees.
Failure to correct this malalignment could lead to persistent pain. Overcorrection of an increased scapholunate angle may limit postoperative motion.

C. Kirschner wire position in the trapezium and trapezoid bones before advancement into the scaphoid bone. A separate pin traversing the trapezio-trapezoidal joint is added for stability.

Remove only the dorsal 70% of the articular cartilage from the three bones. Preserving the volar 30% maintains the intercarpal bone distances but still ensures successful fusion. Perform a radial styloidectomy. Resect no more than 3 or 4 mm of the styloid to avoid iatrogenic injury to the origin of the radioscaphocapitate and long radiolunate ligaments. Fixation may be accomplished with Kirschner wires or a circular plate. Place two 0.045 Kirschner wires anterograde into the trapezium and trapezoid (TECH FIG 3C). Add a third 0.045 Kirschner wire in an ulnar to radial direction from the trapezoid toward the trapezium. The above wires are preset in place and should be advanced across the joints after bone graft placement. Harvest cancellous bone graft from the distal radius and pack it into the interstices of the STT joints. Reduce the joints and advance the preset Kirschner wires. The Kirschner wires can be cut and buried under the skin or left out of the skin to facilitate removal. Perform a routine closure and apply a well-padded forearm-based thumb spica splint.

TECH FIG 4

A. Lunotriquetral joint during decortication. (Fingers are at top in all images.) B. Lunotriquetral joint fusion construct with a partially threaded cannulated screw and a derotation pin.

LUNOTRIQUETRAL FUSION

Make a transverse incision over the dorsal and ulnar aspect of the radiocarpal joint. Retract the extensor tendons and incise the capsule transversely to expose the lunotriquetral joint. Remove any remaining lunotriquetral ligament with a small rongeur. Decorticate the lunotriquetral articulation, leaving the volar 25% of the joint surface intact to maintain intercarpal distances (TECH FIG 4A). Harvest distal radius bone graft and pack it into the void created. Place two cannulated screw guidewires through the triquetrum, and after reducing the joint, advance the pins across the lunotriquetral joint into the lunate. Verify pin position using fluoroscopy. Advance two partially threaded cannulated screws over the guide pins across the lunotriquetral joint (TECH FIG 4B). Make sure the thread length on the screw is short enough to allow compression across the lunotriquetral joint. Alternatively, headless screws, staples, or Kirschner wires may be used for fixation. Perform routine wound closure and apply a wrist splint.

SCAPHOLUNATE FUSION

Use a standard dorsal incision ulnar to the tubercle of Lister and perform a longitudinal capsular incision. Place two dorsal joystick Kirschner wires, one into the palmar-flexed scaphoid distally, directed proximally and ulnarly, and a second into the dorsiflexed lunate proximally, directed distally. When these two wires are brought together the joint is reduced.
Decorticate the bone surfaces and obtain bone graft from the distal radius.
Reduce the scaphoid and lunate with the Kirschner wires and hold them in place with a Köcher clamp.
Verify scapholunate reduction via fluoroscopy before proceeding.

SCAPHOCAPITATE FUSION^3,27

- Use the 3–4 extensor compartment approach followed by a longitudinal capsulotomy directly over the scaphocapitate interval between the second and fourth compartments.
- Denude the articulating scaphoid and capitate surfaces of articular cartilage down to bleeding cancellous bone.
- For cannulated screw fixation, make a V-shaped incision on the radial aspect of the wrist superficial to the radial styloid. A styloidectomy performed through this incision creates a superior view of the lateral aspect of the scaphoid. Preset two guidewires in the scaphoid, aimed toward the capitae (radial to ulnar).
  - A radial styloidectomy is an option to facilitate accurate positioning of the Kirschner wires.
  - Compression screws (our preference), Kirschner wires, or staples may be used for fixation.
- Harvest distal radius cancellous bone graft and place it between the two prepared bones.
- Reduce the articulation, advance the guidewires, and verify pin placement with fluoroscopy.
  - Obtain a scapholunate angle of about 45 degrees.
- Advance the threaded compression screws across the scaphocapitate joint (TECH FIG 5).

PEARLS AND PITFALLS

**Pearls**

<table>
<thead>
<tr>
<th>CHLT Kirschner wire arthrodesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>For excellent visualization of the wrist capsule, incise the distalmost aspect of the extensor retinaculum between the third and fourth compartments to the level of the tubercle of Lister.</td>
</tr>
<tr>
<td>Protect the volar radioscapohancapitate ligament when excising the scaphoid to prevent iatrogenic ulnar translocation of the carpus.</td>
</tr>
<tr>
<td>Preserve the dorsal intercarpal and radiotriquetral ligament during the capsulotomy.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CHLT circular plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place the screws opposite one another in the circular plate and tighten them sequentially to help prevent plate malpositioning.</td>
</tr>
</tbody>
</table>

**Pitfalls**

- A Kirschner wire inserted into the dorsal lunate may be used as a joystick to effect correction.
- Stabilize the lunate in the reduced position with provisional Kirschner wires from the radius into the lunate.
- Harvest bone graft from the distal radius or iliac crest and pack the graft tightly into the palmar radiolunate joint.
- Secure the lunate to the radius with Kirschner wires, headless screws, staples, or small blade plates.
- Pack the remaining bone graft into the dorsal radiolunate joint.
- Perform a routine closure and apply a splint.
POSTOPERATIVE CARE

- The sutures are removed from the wound in 10 to 14 days and a short-arm cast is applied.
- Immobilization is typically 8 to 12 weeks, but this period may be shortened if stable fixation is obtained with screws.
- Plain radiographs are taken at the first postoperative visit and at all subsequent visits until signs of consolidation at the fusion site are noted.
- At this time, the pins are removed and a functional brace is applied to support the wrist but still allow controlled range of motion of the wrist during supervised therapy.
- Strengthening begins about 12 to 16 weeks after surgery.

OUTCOMES

- Nonunion rates range from 4% to 63%, depending on the joints being fused and the stresses placed across the joints before fusion.\(^5,11,16,20\)
- For limited wrist fusions, a loss of grip strength on the order of 25% can be expected.\(^5,11,16,20\)
- About 50% of patients will have some chronic wrist pain.\(^5,11,16,20\)
- For stage I and II SLAC arthritis, four-corner arthrodesis yields clinical results comparable to those of proximal row carpectomy (FIG 1).\(^10,23,30\)
- Stage III SLAC arthritis can be managed with either a four-corner fusion or a proximal row carpectomy with dorsal capsular interposition.\(^23\)

---

**FIG 1** • Nine-year follow-up of four-corner fusion. A,B. Maximal active wrist extension and flexion. (continued)
In patients 35 years of age or younger at the time of proximal row carpectomy, subjective and objective function may decline over time, and they may eventually require a wrist fusion. Circular plate fixation for capitate–lunate–triquetrum–hamate fusion is a newer trend. Weiss et al reported a union rate approaching 100% and high patient satisfaction. However, several subsequent studies have documented higher nonunion rates, higher hardware failure rates, higher pain scores, and an overall lower rate of patient satisfaction compared to other traditional methods of fixation.

**COMPLICATIONS**

- Pin tract infections
- Osteomyelitis
- Avascular necrosis of the lunate
- Radiolunate arthritis
- Reflex sympathetic dystrophy
- Tendon ruptures
- Persistent wrist pain
- Nonunion
- Fracture through fusion
- Neuapraxia
- Hardware failure
- Neuroma
- Pseudarthrosis

**REFERENCES**


**FIG 1 (continued)** C, D. AP and lateral radiographs.


DEFINITION
- Wrist arthritis occurs when the codependent joints of the wrist lose the ability to rotate, thereby impairing normal wrist kinematics.
- Wrist arthritis can originate from many causes, including osteoarthritis, degenerative arthritis, and inflammatory arthritis.
- While sacrificing motion at the wrist, arthrodesis has been shown to reliably relieve pain.

ANATOMY
- The wrist is perhaps the most complex set of joints in the body.
- The eight bones of the wrist work together to provide motion in multiple planes, governed by the complex array of soft tissue ligaments that unite them.
  - Single ligament disruptions can cause degenerative change in nonadjacent bones and at times unlikely sites.
- In broad terms, the wrist is divided into two distinct rows of bones.
  - The distal row, including the trapezium, trapezoid, capitate, and hamate, is united to the hand and shows little gross motion relative to the metacarpals.
  - As such, the most significant articulations in the wrist occur in the proximal row bones, which are the scaphoid, lunate, and triquetrum. These proximal row bones allow the wrist to flex, extend, deviate both radially and ulnarily, and pronosupinate.

PATHOGENESIS
- Because of the many possible routes to the eventual destruction of the wrist joint, it is difficult to describe a single chain of events that leads to end-stage arthritis, most suitably treated by complete wrist fusion.

NATURAL HISTORY
- Causes of wrist degeneration and the often-predictable pattern and pace of wear are detailed in other chapters.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients describe pain and stiffness as their major reasons for presentation. Pain limits their function and their strength.
  - Most patients are less concerned with motion loss if their dominant extremity is not involved.
  - If their dominant wrist is involved, patients prefer to preserve some motion even if faced with low-grade persistent pain after treatment. In this clinical setting complete wrist fusions are less often performed as the index operation.
- Physical examination findings include tenderness, soft tissue swelling, loss of motion, and pain with motion. Pinch and grip strength are reduced compared with age-matched peers and the uninvolved contralateral extremity.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Wrist arthritis is best studied with standard posteroanterior and lateral radiographs of the wrist.
  - These images often reveal the cause of the degeneration together with its pattern and progression.
  - Special attention is paid to the alignment of the wrist and the bone stock available for fusion and fixation.
  - Computed tomography helps plan limited fusions or salvage procedures when arthritis may have spared areas of the midcarpal or proximal carpal rows.

DIFFERENTIAL DIAGNOSIS
- Limited wrist arthritis
- Extrinsic joint contracture (including calcific tendinitis)
- Inflammatory arthritis and synovitis (ie, rheumatoid, gout, or pseudogout)
- Infection
- Connective tissue diseases

NONOPERATIVE MANAGEMENT
- In most every case, the first form of treatment for wrist arthritis is nonoperative:
  - Nonsteroidal anti-inflammatory medications (NSAIDs)
  - Disease-modifying medications (if the cause of the degenerative process can be identified and is appropriate)
  - Splinting
    - A custom-made thumb spica splint allows interphalangeal motion of the thumb but limits painful wrist motion.
  - Local steroid injections placed in the wrist

SURGICAL MANAGEMENT
- Alternative motion-sparing procedures, including partial wrist fusions and proximal row carpectomy, should be considered before performing a complete wrist fusion, especially in patients who have at least 60 degrees of wrist flexion–extension and have isolated articular degeneration.
- Wrist arthroplasty remains in its infancy and is associated with high revision rates and frequent implant design changes.
- Wrist arthroplasty after arthroplasty is more difficult due to bone stock loss.
- Wrist arthrodesis after arthroplasty is the final treatment method for end-stage wrist degeneration due to multiple causes or as a salvage procedure in patients who have failed the more limited procedures mentioned above.
  - Arthrodesis can be obtained reliably and provides a stable wrist in a high-demand patient.1,2,11,13
  - In patients who have undergone lower extremity joint replacements and therefore require support for ambulation, fusion of the wrist is generally regarded as a reliable procedure.
The two most popular methods used to fuse a wrist are plate osteosynthesis and rod osteosynthesis.2,8,13

The chief considerations when choosing between these two options are the desired position of fusion, the quality of the bone and available soft tissue coverage, and the possibility of future infection.

The strongest grip is achieved when the wrist is fused in 20 to 30 degrees of extension. Advocates of fusion in this position favor the use of a plate and screw construct that is fabricated to reproduce this position.2,3,5,11 Straight wrist fusion plates are also available, and all these devices include screws and plates that match the size of the radius and the metacarpal.

A neutral wrist position obtained with rod osteosynthesis may be more favorable for activities of daily living, including perineal care.2,3,5,11

Plate and screw constructs rely on solid screw purchase and stable soft tissue coverage. If good-quality bone and viable soft tissues are not present, as might be the case in a patient with severe rheumatoid disease, intramedullary rod fixation may be a more effective means of fixation.

In patients taking aggressive disease-remitting medications, the possibility of late infection should be considered. These patients may benefit from metal removal, which is often more easily accomplished after rod osteosynthesis.

Preoperative Planning

While the use of aspirin may be continued, warfarin (Coumadin) and clopidogrel (Plavix) should be discontinued to avoid bleeding and flap complications.

Radiographs should be reviewed before performing a wrist arthrodesis. Specific attention should be paid to the amount of available bone stock and the bony alignment.

Intraoperative evaluation will require a fluoroscopic device. Appropriate alignment, reduction, and implant length should be confirmed before closure.

Positioning

Patients are placed supine with the operative hand extended on a hand table extension.

A tourniquet is applied to the proximal arm over padding.

Before anesthesia is induced, the patient’s comfortable shoulder position should be assessed. The armboard should not place the shoulder above this position. This test is especially important in rheumatoid patients with limited joint mobility.

Approach

Both arthrodesis procedures are performed through a standard dorsal approach to the wrist.12–14 A longitudinal midline dorsal incision ulnar to the tubercle of Lister is used.

The extensor pollicis longus tendon is released from its sheath and retracted radially.12

The fourth extensor compartment is subperiosteally elevated from the dorsum of the distal radius and retracted ulnarly.

The posterior interosseous nerve can be dissected free and excised.

The dorsal capsule is incised in line with the skin incision and elevated off the carpus.12

This exposure allows for performance of concomitant procedures such as a distal ulna excision and dorsal tenosynovectomy.

PLATE AND SCREW OSTEOSYNTHESIS

In addition to the approach described above, the proximal portion of the third metacarpal is exposed subperiosteally.

Expose the radioscaphoid, radiolunate, scaphocapitate, capitolunate, and third carpometacarpal joints (TECH FIG 1A), clean them of any remaining cartilage and soft tissue, and then fully denude them to below the subchondral bone.

Maintain the general bony geometry to allow the prepared carpal bones to interdigitate effectively.

A combination of a no. 15 blade, small curettes, and rongeurs is usually adequate for preparing the joint surfaces. Use of a water-cooled power Burr and repeated penetration of the articular surfaces with a 0.045-inch smooth Kirschner wire are sometimes helpful.

The triquetrolunate, triquetrohamate, scaphotrapezial-trapezoid, and capitohamate joints may be left undisturbed if not arthritic.

If one expects to remove the plate at a second surgery, the second and third carpometacarpal joints can be left intact. This limits the fusion mass to the radiocarpal and midcarpal joints, preserving motion at the carpometacarpal level.

Obtain autologous bone graft from the distal radius in two forms, a corticocancellous graft and cancellous bone chips.

Measure the distance from the base of the third metacarpal to the radius platform and harvest a cortico-cancellous bone graft of equal length from the dorsal radial surface of the distal radius.

Take care to avoid disrupting the radial cortex of the distal radius (and thereby destabilizing the bone) and removing the cortex on which the plate will eventually sit.

Outline the graft using a wire driver and a 0.045-inch Kirschner wire, and then harvest it with a sharp osteotome and mallet.

After removing this graft, harvest cancellous bone from the site and tightly pack it between the prepared bony surfaces.

In cases of severe deformity, the carpus may be held in general alignment with temporary Kirschner wires.

Key the corticocancellous graft into the space between the third metacarpal base and the radius platform.

This graft will be located directly under the plate (TECH FIG 1B).

Choose the desired wrist fusion plate and secure it distally to the third metacarpal with appropriately sized screws.

Plate options include a long bend, a short bend, and a straight plate (Synthes USA).

In selected instances, the second metacarpal may be used rather than the third metacarpal.

With the carpus aligned and the prepared joints reduced and grafted, apply the plate to the distal radius in a com-
Fusion with Steinmann rods is performed using a technique similar to that described above, typically in patients with advanced inflammatory arthritis.

- Because bone loss and deformity are substantive, precise joint preparation and reduction is not possible and the goal is generation of a fusion mass.
- Typically, cancellous autograft taken from the distal radius is used between the prepared bony surfaces.

Fixation may be accomplished using an intramedullary rod inserted through the head of the third metacarpal (TECH FIG 2A–D).

- As an alternative, two rods can be inserted between the second and third, and third and fourth metacarpals (TECH FIG 2E,F). These are usually smaller pins that produce an interference fit in the radius shaft.
- Placing an intramedullary rod through the third metacarpal head necessitates an incision in the dorsal web space and in the sagittal band.
  - Metacarpophalangeal joint replacement may eventually be required.
- Choose the largest pin that will fit within the metacarpal and advance it retrograde through the reduced carpus and into the radius.
- A second smaller derotation pin can be placed through the radial styloid into the carpus and metacarpals to prevent rotation.
- Alternatively, a figure 8 wire can be placed around the third metacarpal and through the radius to compress the construct.
- If the metacarpophalangeal joints have already been replaced, two Steinmann pins through the second and third and third and fourth intermetacarpal spaces.

**PEARLS AND PITFALLS**

- The third metacarpal should be aligned with the radius. This alignment is essential when applying a plate.
- Patients prefer to be in slight wrist extension without significant radial or ulnar deviation; significant deviation into flexion or radial deviation leads to problems and weakness. Patients already stiff at neutral may prefer a neutral position.
- Bilateral fusions may not be preferred but rarely affect function.²
- If the proximal row has displaced, proximal row carpectomy and fusion has been shown to be successful.³
- If the ulnar head appears arthritic or prominent, it will need to be addressed using a Darrach procedure, hemiresection techniques, or head replacement. If not addressed, it may be a source of pain postoperatively.

**TECH FIG 2 • A,B.** Complex wrist collapse secondary to rheumatoid arthritis treated with an intramedullary rod and wiring. Ulnar impaction symptoms developing at the distal radioulnar joint. C,D. Less severe wrist disease in a different patient was treated with a Darrach resection and wrist arthrodesis. E,F. PA and lateral radiographs after wrist arthrodesis in a different patient with rheumatoid arthritis was undertaken using two Steinmann pins inserted through the second and third, and third and fourth intermetacarpal spaces. (A–D: Courtesy of P.J. Stern, MD; E,F: Copyright Thomas R. Hunt III, MD.)
POSTOPERATIVE CARE

- Patients are placed into a removable brace 2 weeks after surgery and started on active finger flexion-extension exercises as well as pronation and supination.
- Patients with an extensor lag due to dorsal swelling are started on a program of dynamic extension with an outrigger splint until full active extension is regained.
- Strengthening is reserved for when the radiographs demonstrate union. Union usually takes 6 to 8 weeks but is prolonged in smokers. Comorbidities may also affect healing rates.
- If patient compliance is an issue, a cast may be used for the first 4 weeks to protect the construct with plate osteosynthesis.
- A cast is recommended for 4 to 6 weeks when using Steinmann rods until the patient’s wrist is nontender.
- Therapy may also need to be modified depending on any additional procedures performed.

COMPLICATIONS

- Infection
- Nonunion, delayed union, and malunion
- Dorsal wrist tenderness
- Tendon adhesions and ruptures
- Neurammas and complex regional pain syndromes
- Pin migration
- Wound breakdown

OUTCOMES

- Wrist arthrodesis boasts a high fusion rate, a high satisfaction rate, and a low complication rate.\(^1,5,7,8,9,13\) It is for this reason that fusion of the wrist is selected in patients who can tolerate fewer trips to the operating room for secondary procedures.
- While more satisfying than rod stabilization in rheumatoid patients (74% vs. 37%), plate fixation may require tenolysis or plate removal after arthrodesis.\(^1,11\) Satisfaction may be affected by the patient’s underlying disease.
- Housian and Schroder\(^6\) found that plate removal was common (15%) due to the complications listed above but was successful in relieving symptoms.

REFERENCES

DEFINITION

- In the past, the gold standard for the treatment of end-stage wrist degeneration and debilitating pain was fusion of the wrist joint. As a salvage procedure, arthrodesis can provide reasonable pain relief and relative preservation of upper extremity function. Unfortunately, fusion of the painful wrist does not guarantee pain relief, nor does it come without functional impairment.

- In contrast, total wrist arthroplasty provides an attractive motion- and function-sparing alternative to wrist arthrodesis. Pain relief is achieved, along with preservation of wrist motion and function.

- Multiple studies have demonstrated that patients consistently prefer motion-sparing procedures over arthrodesis.

- In much the same vein as arthroplasty efforts in the other major joints, early wrist replacement designs were successful in both relieving pain and maintaining function. Unfortunately, early wrist prostheses failed to achieve the long-term survivorship results provided by joint replacements in the shoulder, hip, and knee joints.

- Early prosthetic designs suffered from significant biomechanical design flaws. Difficulties arose with implant centering, balance, and fixation.

- Significant improvements in implant design have capitalized on modularity, better material considerations, and improved anatomic designs to provide improved longevity.

- Current designs strive to achieve the following:
  - A more anatomic wrist joint than previous wrist designs, either through component design or implant instrumentation
  - Stable distal fixation by using screw fixation into the carpus while at the same time avoiding the lever arm created by a stem inserted into the third metacarpal
  - The three most popular wrist designs in the United States today are the Universal 2 (KMI/Integra), the Re-Motion (Small Bone Innovations [SBI]), and the Maestro (Biomet) (FIG 1).
  - The Universal 2 Total Wrist prosthesis is an improved version of the original wrist of the late Dr. Jay Menon (FIG 1A). A great debt of gratitude is owed to Dr. Menon for popularizing distal screw fixation to the carpus.
  - The Uni2 design uses a flat carpal cut, screw fixation distally into both the second metacarpal and hamate, and a modular, distally based polyethylene cap that articulates with a proximal cobalt chrome radial component. The improved design attempts to preserve the distal radioulnar joint (DRUJ).
  - The Uni2 wrist is the prosthesis with which there is the greatest clinical experience to date. The results are encouraging.
  - The Re-Motion Total Wrist is essentially the prosthesis marketed initially by Avanta and then SBI with new and improved instrumentation (FIG 1B). It is fundamentally a prosthesis designed to resurface the distal radius.
  - A concave, cobalt chrome radial component articulates with a convex, distally based, polyethylene cap snapped over a flat carpal plate. The carpal plate is anchored to the carpus with a radial screw that does not penetrate the second metacarpal, and a second screw placed ulnarly. About 15 degrees of “wiggle” or intended motion is built into the
snap fit of the polyethylene cap with the carpal plate. No attempt is made to preserve the DRUJ with this implant.

- Many Re-Motion wrist replacements have been performed in conjunction with ulnar head replacement arthroplasty. Preliminary results with the Re-Motion wrist are encouraging.¹

- The Maestro Wrist is the most recent implant to enter the wrist joint replacement market (FIG 1C,D). It differs significantly in design from the Uni2 and the Re-Motion wrists, having been conceived to resemble successful total hip, knee, and shoulder designs, which use a metal convex component articulating with a concave polyethylene component.

- The convex metallic distal component articulates with the proximally based, concave polyethylene body. This UPMWPE body is direct compression molded onto a cobalt chrome (CoCr) alloy radial body with a modular titanium stem. The distal component is composed of a CoCr alloy carpal plate (with or without scaphoid augment) and carpal body and a titanium capitate stem. All components are modular.

- Unlike the Uni2 and the Re-Motion wrists, it is not always necessary to attempt fusion of the distal pole of the scaphoid to the surrounding carpus. The Maestro Wrist has a provision to replace the entire scaphoid using a carpal plate incorporating a modular radial augment.

- The modular radial stem component is designed to fill the distal radius canal to prevent loosening and provide stability. The instrumentation used to prepare the distal radius is designed to preserve the DRUJ.

- The excitement over these three wrist replacement systems has stimulated other investigators to work with companies in producing a total wrist replacement. These other wrist replacement systems are in various stages of design but offer promise for even further advancement of the technology.

**ANATOMY**

- The wrist joint consists of the distal radial articular surface, the distal ulna and triangular fibrocartilage complex, eight carpal bones arranged into proximal and distal rows, and five metacarpal bases.

- Four significant articulations exist: the radiocarpal joint, the midcarpal joint, the carpometacarpal joints, and the DRUJ. A combination of interosseous, intrinsic, and extrinsic ligaments provides stabilization (FIG 2).

- The proximal row of the carpus articulates with the distal radius to form the radiocarpal joint. The distal carpal row articulations with the metacarpal bases form the carpometacarpal joints. Within the distal carpal row, the center of wrist motion is located at the head of the capitate, slightly palmar to the center of the head. This center of rotation may or may not be colinear with the third metacarpal shaft, depending on each patient’s anatomy.

- Proximally, the center of wrist motion lies ulnar to the radial intramedullary canal. Normal anatomic parameters of the distal radial articular surface include a volar tilt of 11 degrees and a radial inclination of 22 degrees.

- The sigmoid notch of the distal radius provides the articulation for the DRUJ. Strong dorsal and palmar radioulnar ligaments provide DRUJ stability.

**PATHOGENESIS**

- End-stage wrist degeneration, a common endpoint of multiple pathways, involves loss of joint space and carpal collapse. The primary indication for total wrist arthroplasty is joint destruction secondary to the effects of rheumatoid arthritis.

- The classic pattern of deformity and destruction involves the radiocarpal and midcarpal joints and the DRUJ. Attenuation of the extrinsic wrist ligaments destabilizes the carpus, often resulting in an ulnar and volar translation of the wrist (FIG 3).²

- Joint replacement is also indicated to manage the pain, deformity, and loss of motion coincident with end-stage arthritis resulting from osteoarthritis, posttraumatic arthritis, or avascular necrosis. Total wrist arthroplasty can provide a salvage option for functional deformities such as scapholunate advanced collapse (SLAC) or irreparable trauma to the distal radius or carpus.
MAESTRO PROSTHESES

The senior author’s personal experience is primarily with the Maestro prosthesis, and thus the technique of the Maestro total wrist arthroplasty is presented here.

Although approved for implantation with cement, most wrists are implanted without cement fixation.

Cement is usually preferred in cases of significant absent bone stock and in revision situations.

Carpal Preparation

Position the carpal resection guide to allow resection of 2 to 3 mm of the capitate head. It is held in position with two 0.062-inch Kirschner wires (TECH FIG 1A, B).

Place the first wire into the capitate neck and the second into the metaphysis of the third metacarpal, ensuring that the guide is parallel to the third metacarpal axis.

TECHNIQUES
With proper placement, the ulnar guide wing will lie close to the triquetrum–hamate articulation and the radial wing will bisect the scaphoid at its distal third.

Loosen the thumbscrew on the carpal resection guide to allow insertion of the radial resection guide boom (TECH FIG 1C).

With the wrist in neutral, score the radius through the cutting slot in the guide to provide a reference for the distal radial resection (TECH FIG 1D).

Remove the radius resection guide and use the carpal resection guide handle to stabilize the carpal guide during carpal resection.
- Cut the scaphoid, capitate head, hamate edge, and triquetrum at a 90-degree angle to the axis of the forearm—jig (TECH FIG 1E,F).
- As an alternative, the scaphoid can be completely removed and a carpal plate incorporating a scaphoid augment used.

**Capitate Reaming and Selection of Carpal Plate**
- After removing the carpal resection guide and Kirschner wires, remove the proximal carpus.
- Place a guidewire into the capitate at the apex of the resection, directly into the center of the capitate (TECH FIG 2A). This may or may not coincide with the center of the third metacarpal. Attention is focused on the capitate and not the capitate–third metacarpal relation.
- Ream the capitate (TECH FIG 2B).
- The depth of reaming can be verified under fluoroscopy. A direct indication of the trial stem size is indicated by depth marks on the reamer.
- Provisionally determine the trial carpal plate by the curvature and width of the remaining proximal carpal surface. The plate should lie flush with the hamate and proximal capitate surfaces.
- Three separate scaphoid augments are available (TECH FIG 2C).
- Assemble the plate and stem and insert them into the reamed capitate and onto the resected carpal surface. (TECH FIG 2D).
- With adequate plate fitting, alignment is such that a radial screw will easily be inserted into the second metacarpal and an ulnar screw inserted into the hamate.

**Radius Resection**
- Insert a 0.062-inch Kirschner wire directly into the center of the medullary canal of the radius (TECH FIG 3A).
- The correct insertion point is in the lower corner of the dorsal-ulnar quadrant of the radius articular surface (TECH FIG 3B). This corresponds to a point near
the center of the radius and immediately below the
groove of the tubercle of Lister. Correct wire place-
ment is confirmed under fluoroscopy.
- The perfectly placed Kirschner wire is overdrilled
  with the cannulated drill bit to a minimum depth of
  40 mm.
- Remove the Kirschner wire and successively ream the ra-
dius by hand until the reamer chatters on the in-
tramedullary canal.
- The final reamer is left in the canal and the radius re-
section guide boom and guide are attached (TECH
FIG 3C,D).
- Align the proximal portion of the guide over the
score mark made on the dorsal cortex and secure it
with Kirschner wires.
- After removing the reamer and guide boom from the
medullary canal, cut the radius.
- The saw cut should follow exactly the contour of the
resection guide and should not enter the DRUJ, thus
maintaining its normal anatomy.
- Place the appropriate radius intramedullary guide into
the canal and insert the chisel guide until flush with the
resected surface (TECH FIG 3E).
- Insert the chisel into each side of the guide in sequence and gently tap it until fully seated.
- After removing the chisel and guide, remove the chiseled bone from the distal radius. Reinsert the intermedullary guide, and over this, broach the distal radius to the templated size desired (TECH FIG 3F,G).

**Trial of Carpal and Radial Components**

- Insert the previously assembled trial components for the carpal and the radial stem-body assembly (TECH FIG 4A).
- With the wrist in full flexion, a standard-size carpal head is snap fit to the carpal plate (TECH FIG 4B).
- The wrist is distracted and extended for reduction (TECH FIG 4C). About 2 to 3 mm of joint separation with distraction indicates appropriate tension. The carpal head may be adjusted to a +2 or +4 size until tension is appropriate. Satisfactory radial and ulnar deviation should be demonstrated.
- Excessive tissue tension can be remedied with additional radial resection. Distal ulnar impingement can be addressed with a Darrach-type resection of the distal ulna.
- Remove the trial components; if the proper tension has been achieved, perform final irrigation.

**Carpal Body Insertion and Fixation**

- Assemble the carpal implant and inject bone cement, if indicated, into the capitate. Insert the stem of the assembled prosthesis into the capitate and impact it.
- Insert a single 0.062-inch Kirschner wire into the ulnar screw hole using the drill guide. Verify under fluoroscopy that the wire is directed centrally into the central portion of the hamate.
- Insert a second Kirschner wire through the radial screw hole and verify that it is through the trapezoid into the intermedullary canal of the second metacarpal.
- Overdrill both Kirschner wires with the cannulated drill bit (TECH FIG 5). Screw depth can be measured directly from the score marks on the drill bit.
- Place the appropriate-size screws and verify placement fluoroscopically if needed.

**Radial Body Insertion and Fixation**

- Assemble the radial stem to the radial body. If indicated, inject bone cement into the radius, and impact the stem until fully seated.
- Reduce the wrist components and take final radiographs (see Fig 1C).

**Closure**

- Close the wrist capsule and dorsal retinaculum with non-absorbable sutures.
- If the distal ulna was resected, the capsular closure should include a secure closure of the DRUJ.
- The placement of a drain before closure is at the surgeon’s preference.
- Close the skin and place a sterile bulky dressing and palmar splint.

**TECH FIG 4** • A. Trial component placement. B. Carpal head attached to carpal plate. C. Reduction of trial components. (Courtesy of Biomet, Warsaw, IN.)
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Approach</th>
<th>Careful preservation of the wrist capsule and dorsal retinaculum ensures that adequate tissue will be available for closure.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius resection</td>
<td>Radius resection sets the tension on the implant. Close attention should be given to placing the radial guidewire into the absolute center of the medullary canal of the radius, as confirmed by radiographs. Guidewire placement is a key component of overall alignment.</td>
</tr>
<tr>
<td>Scaphoid excision</td>
<td>The distal pole of the scaphoid can be routinely removed as part of the carpal resection. Excision of the distal pole of the scaphoid and replacement with a radially augmented carpal plate significantly decreases the difficulty of the operative procedure in regard to insertion of the distal component.</td>
</tr>
<tr>
<td>Center of wrist motion</td>
<td>The center of motion is located at the head of the capitate. This may or may not coincide with the center of the third metacarpal, depending on individual patient anatomy. Attention should be focused on the capitate and not the capitate–third metacarpal relationship.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Early finger motion is begun as allowed by the bulky postoperative bandage. Any drains placed are removed within 24 hours.
- The splint is removed at the 1-week follow-up visit and a cast or splint is placed for an additional 1 to 3 weeks.
- Splint removal with gentle active motion several times daily is permitted at 2 weeks after surgery.
- If a distal ulna resection was performed, the forearm is splinted in neutral rotation for at least 3 weeks before starting forearm rotation exercises.
- More vigorous active and passive range of motion is begun at 4 weeks postoperatively.

OUTCOMES

- The results of a prospective study evaluating the use of the Universal 2 total wrist replacement in rheumatoid patients showed that this wrist provides good early outcomes in this cohort of patients if severe preoperative wrist laxity is not present.
- The authors reported significant improvement in range of motion and an improvement in the DASH score (Disabilities of the Arm, Shoulder and Hand) of 14 points at 1 year and 24 points at 2 years.
- Three prostheses were unstable and required further treatment.
Early results of the Maestro wrist replacement have been encouraging. A recent series of 14 patients with a minimum follow-up of 24 months (average 28 months) revealed that all patients had satisfactory pain relief postoperatively.

- Motion (FIG 4) improved from an average of 28 degrees flexion and 27 degrees extension before surgery to 41 and 43 degrees, respectively, postoperatively. Radial and ulnar deviation averaged 19 and 23 degrees, respectively.
- No significant complications were noted.15

### COMPLICATIONS

- Short-term complications include early postoperative wound concerns, superficial infections, and deep infections.
- The most significant long-term complication encountered is implant loosening. Loosening is not an immediate indication for revision but does necessitate close clinical and radiographic monitoring for progression.
- Implant instability may result from poor component placement, implant loosening, ligamentous instability, or component wear. Each case must be dealt with individually after determining the cause of such instability.
- Periprosthetic fracture is also an infrequently seen complication. Two options are available for salvage of loose or fractured prostheses: component revision or wrist arthrodesis.13,14

### REFERENCES

DEFINITION
- Dr. William Darrach described the distal ulna resection that bears his name in the early 1900s for the treatment of a post-traumatic volar distal radioulnar joint (DRUJ) dislocation. This operation continues to have a place for the treatment of a variety of afflictions of the DRUJ.
- In an effort to preserve some of the critical stabilizing soft tissue elements of the distal ulna, alternative treatments to complete ablation of the distal ulna have been developed.
  - Bowers\(^3\) published his results of the hemiresection-interposition technique (HIT). This procedure differs from the Darrach in that the weight-bearing seat and pole are resected, preserving the styloid and soft tissue elements of the triangular fibrocartilage (TFC).
  - Watson et al\(^{21,22}\) advocated the matched resection procedure.
  - The essential element is matching the profile of the resected distal ulna to the medial side of the radius.

ANATOMY
- The DRUJ is formed by the articulation between the sigmoid notch and the head of the ulna (FIG 1A, B). The sigmoid notch is the articular cartilage surface on the medial aspect of the distal radius. This concave surface matches the corresponding convex surface or “seat” of the distal ulna. The arc of curvature of the sigmoid notch ranges between 47 and 80 degrees, with an average radius of 12 to 18 mm.
- The articulation is constrained loosely, allowing both forearm rotation through a 150-degree arc and proximal and distal migration as well as dorsal and palmar translation of the ulna relative to the radius during forearm rotation. The articular cartilage-covered “cap” of the distal ulna can be divided into two functional regions. The seat of the ulna is the concave portion that articulates with the sigmoid notch. The arc of curvature ranges between 90 and 135 degrees, with an average radius of 8 to 13 mm. This region is covered by articular cartilage around 270 degrees of its surface. This is the region that supports the compressive loads of the distal radius during most activities of daily living and can be considered the fulcrum for load support.
- The pole is the distal portion of the ulna that lies deep to the cartilaginous TFC. This region supports the centrum of the TFC as compressive loads pass from the ulnar carpus to the bony elements of the forearm. The medial-distal portion of the ulna projects as the ulnar styloid. The base of the styloid contains the critical attachment of the deep layer of the TFC, the ligamentum subcruentum (FIG 1C).
- Distal to this, and in a more peripheral location, is the attachment of the superficial layer of the TFC. The dorsal and volar portions of the TFC are thickened, forming the limbi of the TFC, the volar and dorsal radioulnar ligaments. These ligaments play critical roles in stabilizing the DRUJ.

PATHOGENESIS
- Conditions that cause DRUJ degenerative change or altered DRUJ mechanics can lead to pain and DRUJ dysfunction. Most commonly, distal ulna resection is performed in patients with inflammatory arthropathy, usually rheumatoid arthritis. Frequently, treatment of the DRUJ is performed in conjunction with other bone or soft tissue reconstructions.
- DRUJ instability secondary to trauma or attritional changes of the supporting soft tissue elements can lead to degenerative change of this articulation.
- Malunions of the distal radius can negatively affect the sigmoid notch by alterations in angulation or length and can disrupt DRUJ kinematics.
- A less common cause of DRUJ arthritis is primary osteoarthritis, which may also lead to osteophytes and loose bodies.

FIG 1 • Diagrammatic representations of the bony anatomy (A) and relationship of the radius and ulna at the distal radioulnar joint (DRUJ) (B). C. Soft tissue elements of the DRUJ, including the deep (ligamentum subcruentum) and superficial peripheral attachments of the triangular fibrocartilage.
Developmental conditions, such as Madelung deformity, can alter DRUJ joint mechanics. Painful forearm rotation and degenerative changes as well as ulnar impaction can develop.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- **Patients with DRUJ problems present with pain and limited forearm rotation.**
  - In isolated DRUJ arthrosis, the patients usually localize their pain at the DRUJ articulation.
  - In patients with concomitant associated pathology of the soft tissue elements and DRUJ stabilizers, the ulnar-sided pain is more diffuse.

- Pain occurs with activities that require forearm rotation, such as turning doorknobs, turning keys in locks, starting a car, and opening jars. Lifting activities with the arm away from the body are difficult since the DRUJ is loaded in this position.
- Limited forearm motion may be secondary to an arthritic DRUJ; however, other conditions (eg, capsular contracture) must be considered.

- Prominence and deformity of the distal ulna is common in patients with inflammatory changes and in patients with distal radial fracture malunions.
- Inspection is usually unremarkable in patients with isolated DRUJ osteoarthritis. In contrast, DRUJ deformity and prominence is common in patients with rheumatoid arthritis. Fullness due to synovial proliferation may be visible and secondary attritional changes of surrounding soft tissue elements, such as extensor tendon rupture, can lead to abnormal hand posture.
- Radial malunions with shortening and angulation produce visible prominence of the distal ulna (FIG 2).

- Tenderness with pressure on the dorsal aspect of the DRUJ is frequently elicited. In patients with associated impaction or TFC pathology, tenderness may be more diffuse. Palpable crepitance with rotation is often present. Compressing the distal ulna into the sigmoid notch while rotating the forearm elicits painful crepitation and is suggestive of arthritis.
- Pain on the ulnocarpal stress test is indicative of TFC pathology.
- Pain on application of pressure in the interval between the ulnar styloid and flexor carpi ulnaris tendon is indicative of TFC or capsuloligamentous pathology (foveal sign).
- Piano key maneuver: Visible dorsal winging or instability of the distal ulna is noted. If the ulna is dorsally prominent, the examiner can manually reduce the ulna into the sigmoid notch. The ulna spontaneously dorsally subluxates when pressure is removed. Winging is associated with loss of structural support of the DRUJ.
- Grip strength is frequently limited secondary to painful compressive loading of the DRUJ.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs are usually sufficient to supplement physical examination findings. It is essential to obtain a neutral forearm rotation, posteroanterior (PA) lateral view (FIG 3A) to accurately assess ulnar variance, styloid morphology, inclination of the sigmoid notch, and position of the ulnar styloid. These factors are important in selecting the appropriate surgical management for disorders of the distal ulna.
- Thin-section CT scanning can provide useful additional information about DRUJ articular surfaces and subluxation.
- MRI evaluation is rarely necessary to diagnose arthritic disorders of the DRUJ but can be useful when detailed information about the radioulnar ligaments or surrounding bony ligaments of the TFC is necessary (FIG 3B).

**FIG 2** • Loss of the soft tissue support with or without associated degenerative change or malunion of the radius with resultant sigmoid notch incongruity leads to dorsal prominence and winging of the ulna relative to the radius. **A.** Dorsal prominence of the ulna relative to the radius is seen in a patient with a radial malunion. **B.** Radiograph of a wrist of a patient with rheumatoid arthritis shows the volar translation and secondary changes in the carpus that are associated with dorsal ulna prominence.

**FIG 3** • **A.** The zero-rotation view is taken with the patient’s shoulder abducted at 90 degrees, the elbow flexed 90 degrees, and the wrist pronated in the PA position. The ulnar styloid is seen in full profile in this view. This view is the standard radiographic view used to determine ulnar variance. **B.** While not part of the routine imaging evaluation for the triangular fibrocartilage, MRI can confirm the diagnosis for related conditions. This MRI in a patient with an ulnar-positive wrist shows a discrete intense lesion at the ulnar base of the lunate consistent with ulnar impaction.
DIFFERENTIAL DIAGNOSIS

- DRUJ arthritis
- Inflammatory
- Osteoarthritis
- Traumatic
  - Iatrogenic (e.g., altered joint mechanics after ulnar shortening)
- DRUJ instability
- TFC tears
- Ulnar impaction
- Lunotriquetral ligament tears or instability
- Extensor carpi ulnaris tendinitis
- Extensor carpi ulnaris instability
- Pisotriquetral disorders
- Nerve entrapment (canal of Guyon)
- Nerve injury (e.g., neuromas of dorsal ulnar sensory nerve)
- Madelung deformity with DRUJ dysfunction

NONOPERATIVE MANAGEMENT

- Patients with mild symptoms and minimal functional impairment may be managed with oral anti-inflammatories, intra-articular injections, or splinting.
- Splinting must include the elbow to eliminate forearm rotation.

SURGICAL MANAGEMENT

- Maintaining the distal ulna has gained recent popularity as resection can be associated with considerable postoperative complications and functional disability. Meticulous attention to preoperative, intraoperative, and postoperative detail is essential for a successful result.

Adjunctive Procedures

- After complete or partial resection of the distal ulna, convergence between the radius and ulna can develop. Loss of the weight-bearing fulcrum of the ulna seat can yield convergence with grip or loaded lifting with the arm extended and the forearm in neutral rotation (FIG 4).

- Adjunctive procedures incorporate some type of tendon transfer or interpositional material to stabilize the resected ulnar stump (FIG 5). The pronator quadratus, extensor carpi ulnaris, and flexor carpi ulnaris tendons have been used alone and in combination.
- In addition to tendon transfer, some authors have recommended suturing the ulnar capsule to the dorsal ulnar stump to help stabilize the remaining ulna. Kleinman and Greenberg advocated use of a dynamic pronator quadratus interosseous transfer in conjunction with an extensor carpi ulnaris distal tenodesis for failed distal ulna resections. More recently, allograft soft tissue interposition has been advocated, as well as distal ulna implant arthroplasty.
- Most adjunctive procedures have been described for treatment of a failed symptomatic Darrach procedure; however, they can be incorporated during the initial surgery. Symptomatic convergence tends to develop in a relatively younger, higher-demand patient. If distal ulna resection is necessary in this patient population, use of an adjunctive procedure is recommended.

Preoperative Planning

- The ideal candidate for a Darrach resection is a patient with a relatively low-demand upper extremity that does not require the load-bearing DRUJ.
- Coexisting pathology is frequently present in patients with distal ulna dysfunction, especially in patients with inflammatory arthropathy. Assessing for associated tenosynovitis and tendon ruptures is necessary.
- The status of the radiocarpal joint is critical. Patients with loss of radial-sided carpal support due to tenosynovitis often have ulnar translation. In advanced cases, the carpus may abut the distal ulna and isolated Darrach resection without carpal stabilization is contraindicated to avoid exacerbating ulnar translation.
- If a limited resection of the distal ulna is considered, one must evaluate the length of the ulna, ulna variance, and position of the styloid. If stylocarpal abutment exists, it will persist after limited resection. Therefore, consideration needs to be...
given to a joint leveling procedure or styloid recession in conjunction with limited resection.

- Alternatively, a complete distal ulna resection that addresses the ulna head as well as the styloid or a Sauvé-Kapandji DRUJ arthrodesis may be considered.

**Positioning**

- The patient is positioned supine. The operative arm is extended with the shoulder abducted at 90 degrees. The arm is supported on a standard table used for upper extremity surgery.
- A tourniquet is used.
- The motion of the elbow and shoulder should be noted before surgery. Limited passive motion can create awkward arm positioning.

**Approach**

- The incision used for distal ulna resection is based on whether the resection is performed alone or in conjunction with other procedures (FIG 6).
- The recommended approach for distal ulna resections is dorsal, deep to the fifth extensor compartment.
- A medial approach between the extensor carpi ulnaris and flexor carpi ulnaris tendons is not recommended. This approach has greater potential for disrupting the linea jugata, with resultant potential extensor carpi ulnaris destabilization.

**COMPLETE DISTAL ULNA RESECTION: THE DARRACH PROCEDURE**

**Incision and Dissection**

- Frequently, Darrach resection is performed in conjunction with other procedures, especially in patients with inflammatory arthropathies. In this situation, the surgical incision is usually dorsal midline longitudinal, which enables all aspects of the wrist reconstruction (wrist fusion, arthroplasty, tenosynovectomy, tendon transfer, etc.) to be completed via a single approach.
- If the Darrach procedure is to be performed independently, a single oblique or chevron dorsal approach is made (Fig 6) overlying the fifth dorsal compartment.
- During the dissection to the retinacular layer, take care to avoid injury to the transverse retinacular branch and dorsal sensory branch of the ulnar nerve that pass from the medial forearm to the dorsal hand between the ulnar styloid and pisiform (TECH FIG 1A).
- Keep the oblique incision or distal limb of the chevron approach parallel to this nerve to minimize this complication.
- Frequently, dorsal capsular reinforcement is necessary after distal ulna resection. This is especially true in patients with inflammatory arthropathies and multiple extensor tendon ruptures.
- When performed in conjunction with other procedures, raise opposing extensor retinacular flaps so that one of the flaps can be used to reinforce the dorsal capsule and create a stabilizing extensor carpi ulnaris sling during closure (TECH FIG 1B,C).
- When performed as an isolated procedure, raise a retinacular flap from the margin of the fourth dorsal compartment (TECH FIG 1D).

**Capsulotomy and Osteotomy**

- Perform a longitudinal capsulotomy deep to the fifth dorsal compartment (TECH FIG 2A). This capsular approach starts proximal to the dorsal radioulnar ligament and proceeds in a proximal direction.
- Extend the capsular release parallel and just proximal to the dorsal radioulnar ligament to facilitate exposure. Take care during the deep periosteal dissection.
to elevate and maintain as thick a periosteal sleeve as possible.

- Osteotomize the distal ulna using a power oscillating saw just proximal to the sigmoid notch (TECH FIG 2B). Enough ulna is sacrificed to completely decompress the DRUJ. Keep resection to 2 cm or less.

- Intraoperative fluoroscopic guidance is frequently helpful to assist with the location of the osteotomy.

- Once the distal pole and seat are resected, there is no advantage to preserving the ulnar styloid, and the entire styloid should be removed with the distal ulna.

TECH FIG 1 • (continued) B,C. Opposing retinacular flaps are raised to provide wide exposure and access to all extensor compartments. This approach is frequently necessary in patients with concomitant extensor tendon dysfunction. One of the flaps can then be used to reinforce the capsule deep to the extensors at the termination of the procedure. D. The fifth compartment is opened, exposing the extensor digiti quinti proprius tendon. An ulnarly based retinacular flap is raised, preserving the wall of the fourth dorsal compartment for later repair.

TECH FIG 2 • A. A longitudinal capsulotomy exposes the distal ulna (arrow) and allows access to the distal metaphysis, depending on the reconstruction being performed. B. The distal ulna has been osteotomized just proximal to the sigmoid notch. The resection should be less than 2 cm and should clear all abnormal bony elements that may affect rotation from within the sigmoid notch.
**Wound Closure**
- Meticulous attention to closure is imperative.
- Perform a secure multilayered closure. Perform separate closure of the periosteal and capsular layers with nonabsorbable sutures.
- Suture the retinacular flaps for capsular reinforcement.
- Transpose the EDQP tendon dorsal to the extensor retinaculum. This does not create any functional disability (**TECH FIG 3**).
- Routine skin closure follows.

**DISTAL ULNA HEMIRESECTION-INTERPOSITION TECHNIQUE**
- The surgical approach for the HIT procedure as developed by Bowers is identical to the Darrach resection. The difference lies in the treatment of the bone and soft tissue interposition after bone resection.
- Instead of resecting the distal ulna at the proximal margin of the sigmoid notch, the osteotomy removes the seat and pole of the ulnar head (**TECH FIG 4A,B**). The entire shaft and the styloid are left intact.
- After resection, the forearm is rotated through a full arc. This ensures that prominent osteophytes or bone that may interfere with forearm rotation have been removed.
- The resected shaft should be round in cross-section and should taper distally. The resection is lateral to the insertion of the deep portion of the TFC, so the integrity of both the deep and superficial components of the TFC is maintained. If the TFC is incompetent or cannot be made functionally competent by reconstruction, then there are no advantages over the Darrach complete distal ulna resection.
- Convergence of the radius and ulna develops after ulnar head resection. To mitigate this, the ulnarily based capsular flap raised during the approach is interposed between the radius and resected ulna. Interposition bulk may be increased by using a free tendon graft (**TECH FIG 4C**).
Modification

- In an effort to avoid an interpositional tendon graft, Adams Advocates a modification of the HIT procedure.
- In this technique, an ulnar-based retinacular flap is raised from the radial margin of the extensor carpi ulnaris sheath.
- Only 3 to 7 mm of bone is resected, and the ulna is tapered distally in a dowel shape. The fovea is not violated, thereby preserving all TFC attachments.
- The retinacular flap is then interposed and sutured to the volar DRUJ capsule. As in other procedures, attention is paid to avoid stylocarpal impingement.

MATCHED DISTAL ULNA RESECTION

- In this modification, developed by Watson, the distal ulna is resected in a long, sloping convex curve that matches the opposing concave radius (TECH FIG 5).
- The surgical approach is identical to the approaches listed for prior procedures. Although Watson advocated a transverse incision just proximal to the DRUJ, I prefer a more utilitarian longitudinal or chevron incision as previously described.
- The entire 270-degree arc of the ulna is addressed. Similar to the HIT procedure, great care is taken after bone resection to ensure full, unimpeded forearm rotation. Any osteophytes or prominent bone that may interfere with rotation must be removed.
- This technique differs from the HIT procedure since the ulna is reshaped over a longer distance and no interposition material is used. While this technique is advocated to preserve the ulnar sling, by necessity the resection sacrifices both the deep and superficial insertions of the TFC. Any resultant stability of the residual stump of the ulna is generated only by soft tissue scarring.

TECH FIG 4 (continued) C. After osteotomy and removal of the ulnar head, the space is filled with a free tendon graft that provides bulky tissue and mitigates impingement of the resected ulna against the medial wall of the distal radius.

TECH FIG 5 A B. The matched resection osteotomy is more proximal than the Bowers osteotomy (A) and is resected in a long, sloping curve matching the opposite concave surface of the radius through a complete 270-degree arc (B).
**PEARLS AND PITFALLS**

**Indications**
- Consider distal ulna resection as a final salvage procedure. Consider alternative procedures that will preserve the load-bearing fulcrum of the DRUJ. Distal ulna resections are tolerated in a relatively older, lower-demand patient.

**Associated conditions**
- Diagnose and treat associated bone and soft tissue pathology. Consider the effects of distal resection on the radiocarpal joint.

**Approach**
- Meticulous attention to soft tissue handling and avoiding injury to cutaneous nerves is essential. Raise retinacular and capsular flaps carefully so they can be used for stabilization or interposition if necessary. Avoid destabilizing the extensor carpi ulnaris. If the extensor carpi ulnaris sheath is violated and stability needs to be restored, reconstruct the sheath using retinacular flaps.

**Bone resection**
- Decompress the entire length of the sigmoid notch when performing a Darrach resection. Avoid removing the insertions of the TFC during the HIT procedure. Ensure that full forearm rotation is possible after bone resection. Similarly, after partial distal ulna resection, eliminate any remaining osteophytes or bony prominences to ensure full range of motion. Assess for postresection stylocarpal impingement, and correct length if impingement is present.

**Convergence and instability**
- Consider additional procedures that may stabilize or prevent symptomatic convergence and impingement, especially in the younger, more active, higher-demand patient.

**Aftercare**
- Maintain neutral forearm rotation with a long-arm or Munster-type splint for the first 3 postoperative weeks. Allow gentle forearm rotation until 6 weeks postoperatively. Full activity is allowed at 3 months postoperatively.

**POSTOPERATIVE CARE**
- Postoperatively, the extremity is maintained in a long-arm bulky dressing with the elbow at 90 degrees and the forearm supinated for 3 weeks. At 3 weeks postoperatively, long-arm splinting between exercises and at night begins and persists until 6 to 8 weeks postoperatively. Strengthening without splint immobilization can begin at that time.

**OUTCOMES**
- In general, distal ulna resections are associated with relief of pain and restoration of function. Elderly patients with lower demands on the upper extremities tend to have more favorable results than younger, active, higher-demand patients.
- Good results regarding relief of pain and recovery of function can be expected in 60% to 95% of patients with rheumatoid arthritis. Early clinical reports on the Darrach resection demonstrated marked improvement in pain and range of motion in greater than 80% of patients; however, other series do not present such optimistic clinical results.
- Leslie et al in 1990 and Melone and Taras in 1991 demonstrated 85% and 86% favorable results, respectively. Fraser et al’s 1999 study supported the use of the Darrach resection in patients with rheumatoid arthritis, finding 85% good to excellent results in 23 patients with rheumatoid arthritis versus only 36% satisfactory results in 27 patients with posttraumatic arthritis.
- George et al demonstrated satisfactory results in 21 patients treated with Darrach resections compared to a group who underwent Sauvé-Kapandji resection. They concluded that results were comparable and unpredictable. Despite reported complications, authors have advocated the use of the Darrach resection for patients with rheumatoid arthritis, emphasizing attention to correct technique as a critical factor in the procedure’s success.
- Compiled results using the HIT procedure for a variety of afflictions indicate that 76% of patients are pain-free and 24% report mild pain.
- Minami et al demonstrated better clinical outcomes using the HIT or Sauvé-Kapandji procedure than the Darrach procedure in 61 patients with osteoarthritis. This study supports the use of the Darrach procedure for the lower-demand, elderly patient. Van Schoonhoven and Lanz advocate use of partial resection of the ulnar head in cases of instability or radial malunion associated with arthrosis. These authors feel that maintaining the remaining contact of the TFC adds a biomechanical advantage to prevent secondary problems after resection.
- Two publications on the matched resection report good to excellent results in 24 of 32 patients with posttraumatic or mechanical disorders of the DRUJ and no or mild pain in 44 patients, most with rheumatoid arthritis. Weinzeig and Watson report excellent results in their entire series of 97 wrists over 21 years. Pain was improved in 14 of 15 patients with rheumatoid arthritis in Srikanth et al’s clinical study.

**COMPLICATIONS**
- Persistent pain
- Distal ulnar stump instability (coronal, sagittal)
- Radioulnar impingement
- Loss of forearm rotation
- Ulnar translation due to loss of ulnar support in rheumatoid arthritis
- Extensor tendon rupture
- Soft tissue irritation
- Cutaneous nerve injury
- Stylocarpal impingement
- Complex regional pain syndrome
- Extensor carpi ulnaris tendinitis or instability

**REFERENCES**


DEFINITION

- Disorders of the distal radioulnar joint (DRUJ) are a significant source of wrist pain for patients.
- The etiology of symptoms referable to this joint includes displaced fractures or malunions of the distal radius, which cause pain with forearm pronation–supination, and tears of the triangular fibrocartilage complex (TFC), which result in DRUJ instability, mechanical symptoms, and pain.
- Both Madelung deformity\(^2\)\(^3\) and rheumatoid arthritis (RA) can display secondary incongruity of the DRUJ, causing pain and loss of forearm rotation. Radial head fracture treated by resection and subsequent shortening of the radius (Essex-Lopresti lesion) also can result in painful incongruity or instability of the DRUJ.
- Management of DRUJ pain, incongruity, or instability alone is challenging, but the Sauvé-Kapandji procedure is one solution that treats all three disorders.\(^1\)\(^1\),\(^2\)\(^5\)

ANATOMY

- The DRUJ is a distal articulation in the biarticulate rotational arrangement of the forearm that allows one degree of motion: pronation and supination. The sigmoid notch of the radius is concave, with a 15-mm radius of curvature.
- The ulnar head is semicylindrical, with a radius of curvature of 10 mm, and has an articulate convexity of 220 degrees. It is surrounded by the ulnolunate and ulnotriquetral ligaments, which originate from the palmar radioulnar ligament near the ulnar styloid.
- The TFC is a fibrocartilaginous disc originating at the junction of the lunate fossa and the sigmoid notch inserting at the base of the ulnar styloid. Its central portion is cartilaginous and avascular and is designed for weight bearing.
- The peripheral margins, the dorsal and palmar radioulnar ligaments, are thick lamellar cartilage designed for tensile loading. They are well vascularized from the palmar and dorsal branches of the anterior interosseous artery and from the ulnar artery.
- The ulnar styloid acts as a strut on the end of the ulna to stabilize the ulnar soft tissues of the wrist. The sheath of the extensor carpi ulnaris (ECU), the ulnocarpal ligaments, and the TFC attach at the base of the ulnar styloid and together are known as the TFCS.
- The radius of curvature of the head of the ulna does not equal that of the sigmoid notch. In the extremes of pronation–supination, less than 10% of the ulnar head may be in contact with the notch. In pronation, the ulnar head translates 2.8 mm dorsally from a neutral position and in supination the ulnar head translates 5.4 mm volarily from a neutral position.
- The stability of the DRUJ comes from the joint surface morphology, the joint capsule, the dorsal and palmar radioulnar ligaments, the interosseous membrane, and the musculotendinous units that cross the joint, primarily the ECU and pronator quadratus (PQ). The PQ actively stabilizes the joint by coapting the ulnar head in the sigmoid notch in pronation and passively by viscoelastic forces in supination. The ECU is retained over the dorsal distal ulna by a separate fibro-osseous tunnel deep to and separate from the extensor retinaculum, allowing unrestricted rotation of the radius and ulna.\(^1\)\(^8\)

PATHOGENESIS

- Traumatic injury to the wrist can lead to derangement of the DRUJ, which can result in instability and eventually painful degenerative changes.
- Distal radial malunions with dorsal or volar subluxations or dislocations of the DRUJ produce secondary rupture, elongation, or functional shortening of the distal radioulnar ligaments.
- Arthritis of the DRUJ is a common complication of Colles fractures, particularly when fractures involve the sigmoid notch.
- Congenital disorders such as Madelung disease as well as traumatic epiphyseal closures of the distal radius can produce marked positive ulnar variance with dorsal dislocation of the DRUJ.
- In the rheumatoid wrist, progression of distal radioulnar synovitis typically results in the “caput ulnae syndrome” as described by Backdahl, which consists of the following:
  - Wrist weakness with pain on pronation and supination
  - Dorsal prominence of the ulnar head
  - Limitation of pronation and supination
  - Swelling of the distal radioulnar area
  - Secondary tendon changes with possible extensor tendon rupture and ECU subluxation\(^1\)
- If allowed to progress without intervention, the carpus will eventually fall in a more ulnarward and palmarward direction, with strength, mobility, and function all suffering.\(^2\)\(^1\)
- A chronically unstable DRUJ without degenerative changes can be treated with various soft tissue reconstructions, depending on the abnormalities and underlying pathology.
- As a group, many of these reconstructions fail to restore stability; even if stability is restored, limitation of forearm motion persists.

NATURAL HISTORY

- The natural history of DRUJ derangement is painful limitation of forearm rotation, often with additional functional deficits.
- When positive ulnar variance exceeds a few millimeters, additional limitations of wrist flexion–extension as well as radial–ulnar deviation movements can occur.
PATIENT HISTORY AND PHYSICAL FINDINGS

- Clinical evaluation begins with a detailed and accurate history.
- A history of fracture involving the forearm or wrist is clearly important. Patients may recall a specific injury involving damaging forces of torque with axial load applied to the involved wrist and forearm.
- The patient’s occupation or hobbies may give insight into the mechanism of injury as well as the most important functional deficits currently experienced by the patient.
- A complete medical history is important, including questions about inflammatory arthritis or osteoarthritis.
- DRUJ pathology most often causes ulnar-sided wrist pain, diminished grip strength, limited forearm pronation and supination, and limited wrist ulnar deviation.
- Pain is exacerbated with activity and increases with resisted rotation of the forearm.
- With large ulnar length discrepancy (positive ulnar variance), limited flexion-extension also can be seen.
- During the physical examination, the clinician should determine whether loss of forearm rotation is solely due to DRUJ pathology or if there is a concurrent problem at the proximal radioulnar joint or interosseous membrane. Other sources of wrist pain and dysfunction must be ruled out.
- The clinician should check for instability or chronic dislocation of the joint, comparing the injured with the uninjured wrist.
- The patient’s normal and affected wrist and forearm ranges of motion, both active and passive, should be measured. A rigid endpoint with loss of motion suggests bony pathology such as fracture malunion, whereas a soft end point with limited motion suggests soft tissue contractures.
- The clinician should carefully palpate, ballotte, and compress around the DRUJ and compare the findings to the opposite side. Grip strength measurements should be checked bilaterally.
- When evaluating patients with RA, the clinician should try to distinguish the pain and instability of the DRUJ from radiocarpal and midcarpal joint symptoms by careful palpation, ballottement, and compression of areas around the DRUJ, comparing the degree of symptoms elicited by forearm rotation versus wrist flexion-extension.
- Examinations to perform include:
  - Piano key test. The test, which isolates DRUJ disorders, is positive if it causes pain and/or crepitus.
  - Selective anesthetic injections. The test is positive when precise, selective injection of anesthetic into the area eliminates pain and improves function. Injections help to confirm pathologic changes and can be used to distinguish intra-articular from extra-articular lesions.
  - Lunocarpal compression test. A positive test reproduces the ulnar-sided wrist pain and grinding by translating force across the TFC. It also isolates pathologic changes in the TFC.
  - Lunotriquetral (Regan) shuck test. Pain, sometimes with increased joint mobility and grinding, represents a positive test. This test detects and assesses abnormalities or pathologic conditions associated with the lunotriquetral joint.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Standard neutral rotation posteroanterior (PA), lateral, and ulnar variance radiographs of the wrist should be obtained and compared with the normal side. The clinician should look for evidence of fractures, arthritic changes, bone lesions, and distal ulna position relative to the radius.
- Forearm and elbow radiographs are obtained if there is a history of an elbow injury (especially a radial head fracture) or forearm injury.
- If lunocarpal abutment is suspected, a PA radiograph is obtained with the forearm in pronation and the fist clenched. This will increase ulnar variance and potentially reveal ulna impaction.
- CT is best to evaluate subluxation and articular congruity of the distal radioulnar joint. To assess the distal radioulnar articular surfaces, simultaneous views are obtained of both extremities with the forearms in neutral rotation, full supination, and full pronation.
- MRI with single-injection gadolinium arthrography (MRA) is a good way to evaluate TFC lesions as well as the integrity of the scapholunate and lunotriquetral interosseous ligaments.

DIFFERENTIAL DIAGNOSIS

- Extensor carpi ulnaris tendinitis or subluxation
- Flexor carpi ulnaris tendinitis
- Pisotriquetral arthritis
- Lunotriquetral ligament tear
- TFC tear
- Acute DRUJ dislocation

NONOPERATIVE MANAGEMENT

- A trial of nonoperative management is helpful for some patients with DRUJ disorders.
- Minor strains of the DRUJ capsule or sprains of other ulnar-sided wrist ligaments may respond to rest, ice after activity, wrist splints, and oral anti-inflammatory medications.
- Easily reducible dislocations of the DRUJ can be treated by immobilization in a rigid splint or cast for 6 weeks.
- Inflammation of the ulnar-sided wrist tendons often accompanies DRUJ problems.
- Tendinitis should be treated first with stretching exercises, other physical therapy modalities, and sometimes a steroid injection before addressing the DRUJ surgically.

SURGICAL MANAGEMENT

- The Sauvé-Kapandji procedure is especially useful for patients with RA. Despite advanced radiographic findings of radiocarpal or midcarpal arthritis, complaints of wrist pain can be relieved in many RA patients by addressing the DRUJ pathology with a Sauvé-Kapandji procedure.
- Commonly, resection of the distal end of the ulna, the Darrach procedure, is recommended for patients with RA and ulnar-sided wrist pain. However, the inflammatory changes and deforming forces acting on the hand and wrist in RA tend to cause palmar and ulnar translocation of the wrist, resulting in decreased mobility, strength, and function. Removal of the distal ulna exacerbates and accelerates the problem.
With the Sauvé-Kapandji procedure, the retained distal ulna provides bony support for the ulnar corner of the wrist to help stabilize against the palmar-ulnar slide of the carpus (FIG 1). In addition, the important attachments of the ulnocarpal complex are preserved.\(^{21}\)

The Sauvé-Kapandji procedure is also beneficial in the treatment of DRUJ disorders resulting from trauma.

In cases of wrist trauma with ulnar-sided ligamentous injury and incompetence, retaining the ulnar head, as is performed with a Sauvé-Kapandji reconstruction, maintains the ulnocarpal buttress and the TFC to allow a more physiologic transmission of load from the hand to the forearm.

The osteotomy made in the ulna in the Sauvé-Kapandji procedure allows as much shortening as is needed to match the level of the radius while retaining supination and pronation.

Other surgical options include hemiresection and interposition arthroplasty, matched resection of the distal part of the ulna, Darrach resection, and more recently prosthetic replacement.\(^2\)

**Preoperative Planning**

The clinician should review preoperative radiographs and carefully assess whether fixation of the ulna head can be performed before any osteotomy or if an osteotomy and excision of the ulna segment needs to be done first to restore proper length and head position into the sigmoid fossa.

**Positioning**

- The patient is positioned supine with the upper extremity on a hand table.
- A pneumatic tourniquet is placed on the arm.
- An intraoperative fluoroscope is draped sterile and made available throughout the procedure.

---

**AUTHOR’S PREFERRED TECHNIQUE FOR THE SAUVÉ-KAPANDJI PROCEDURE**

**Incision and Dissection**

- Make a straight longitudinal incision, 6 to 8 cm long, along the ulnar border of the distal forearm.
- An alternative incision may be used if additional procedures are planned at the same sitting. For example, in patients with RA, often the Sauvé-Kapandji procedure needs to be combined with another soft tissue procedure such as a dorsal wrist synovectomy, tenosynovectomy, or tendon transfer to treat extensor tendon ruptures that result from the caput ulnae syndrome. If that is the case, start the incision more dorsally to facilitate exposure for the additional procedure, and then extend it proximally and obliquely to expose the distal ulna.

**TECH FIG 1** • Identification and mobilization of the dorsal sensory ulnar nerve, which is tagged with a rubber dam. Notice a dorsal branch under the probe.

- Identify the dorsal cutaneous branch of the ulnar nerve and protect it throughout the case (TECH FIG 1).
- Expose the distal 4 to 6 cm of the ulna extraperiosteally through the interval between the ECU and flexor carpi ulnaris (FCU).
**Osteotomy of the Ulnar Diaphysis**
- Select the appropriate level for an osteotomy of the ulnar diaphysis (TECH FIG 2A).
- Cut the bone just proximal to the flare of the ulnar head; this will leave enough of the distal ulna to accommodate two fixation screws.
- Confirm with fluoroscopy that the proposed osteotomy site is appropriate.
- Make a second cut proximal and parallel to the first (TECH FIG 2B), and remove a 10- to 14-mm segment of ulna (TECH FIG 2C). Resect the periosteum in the region of the gap and irrigate thoroughly to remove bone debris.
- If there is a positive ulnar variance, remove a correspondingly longer segment of the ulna so that when the ulnar head is recessed to neutral ulnar variance, the resulting gap will be adequate.
- Save the removed bone for subsequent grafting into the DRUJ arthrodesis site (TECH FIG 2D).

**Distal Radioulnar Joint Exposure and Preparation**
- Expose the DRUJ with a dorsoulnar capsulotomy just radial to the ECU tendon.
- Denude both the ulnar head and sigmoid fossa of the radius of all remaining cartilage to create flush surfaces of cancellous bone on each side of the arthrodesis site, and pack the harvested cancellous bone from the removed ulna segment (TECH FIG 3).
- In patients with severe bone loss, after decortication of the corresponding articular surfaces of the DRUJ, sculpt the resected segment of the ulna to fit into the space between the ulnar head and sigmoid notch as a corticocancellous bone graft.

**Fixation**
- Cannulated self-tapping screws are preferable to K-wires for fixation of the arthrodesis site.
- K-wires can irritate cutaneous nerves when buried or can cause wound problems when placed percutaneously.
- There is usually no need to remove hardware when screws are used, and rehabilitation can begin sooner because of secure fixation.
- Cannulated screws over guidewires allow accurate screw placement and facilitate the alignment of the cortices of the distal ulna and radius.
- Establish ulnar neutral variance by moving the ulnar head proximally or distally to bring its distal surface parallel with the distal radius surface; confirm correct placement fluoroscopically.
- Do this while holding the forearm in neutral rotation with the patient’s elbow resting on the operating table while supporting the forearm perpendicular to the table in neutral rotation.
- Temporarily fix the ulnar head to the sigmoid notch of the distal part of the radius with a single K-wire, and ensure proper position with fluoroscopy.
- While maintaining neutral forearm rotation, drill two guidewires across the DRUJ to stabilize the ulnar head in proper position.
- Place one wire a few millimeters proximal to the subchondral bone of the distal ulna, and position the second wire proximal enough to allow for seat-
BA TECH FIG 4 • A. Placement of the two K-wires to stabilize the ulna head. B. Drill over the K-wires, measure, and put in the screws.

- Confirm correct placement of the guidewires with fluoroscopy.
- Advance the distal wire into the far (radial) cortex of the radius and measure for screw length.
- The proximal screw provides rotational control and needs only tricortical fixation. It can be 5 mm shorter than the distal screw.
- After the screw lengths are measured, advance the wires through the skin to the radial side of the forearm with a mallet and grasp them with a clamp to avoid having the wire come out during drilling and screw placement.
- With a mallet, the chances of injuring a branch of the radial sensory nerve branch are less than those with a power driver.
- Drill over the guidewires with a cannulated drill bit (TECH FIG 4B).
- Pack additional cancellous bone harvested from the excised ulnar segment into the DRUJ space.
- Insert the selected screws over the guidewires while manually compressing the ulnar head against the radius.
- Tighten the distal screw first to avoid compressing the radial and ulnar shafts together and levering the ulnar head out of position.
- Do not use lag-screw technique on the proximal screw, and avoid tilting the head of the ulna; it must remain parallel to the long axis of the ulnar shaft.

TECH FIG 5 • Modification of the Sauvé-Kapandji procedure with ECU tenodesis as described by Minami et al. After the Sauvé-Kapandji procedure, a 3.5-mm hole was drilled from the dorsoulnar aspect of the ulnar shaft into the intramedullary cavity. The ECU tendon was then split in the central sulcus and the radial half released at the ulnocarpal level. It was then reflected proximally, leaving it attached at the musculotendinous junction. This proximally based strip was then passed into the medullary canal through the drill hole, retrieved at the distal stump of the ulna, and then sutured back on itself in an interlacing fashion.

- Split the ECU tendon in the central sulcus and release the radial half at the ulnocarpal level.
- Reflect this half of the ECU proximally, leaving it attached at the musculotendinous junction.
- Pass this proximally based strip, approximately 6 to 8 cm long, into the medullary canal through the drill hole, and retrieve it at the distal stump of the ulna, pulling it distally under moderate tension, and then suture it back onto itself in an interlacing fashion (TECH FIG 5).

Flexor Carpi Ulnaris Stabilization of the Proximal Ulna Stump

- Over a distance of 8 to 10 cm through the volar aspect of the incision, isolate a distally based slip of FCU tendon (measuring about half the width of the tendon) attached to the pisiform.
- Drill a 4- to 4.5-mm hole on the volar cortex, 1 cm proximal to the end of the osteotomized surface of the proximal ulnar segment.
- This is facilitated by inserting the drill bit obliquely through the medullary cavity in a dorsal to volar direction.
- Pass the slip of FCU tendon deep to the FCU muscle through the distal end of the ulnar stump, and loop it back on itself, securing it with nonabsorbable suture (TECH FIG 6).
- Suture the tendon under moderate tension, keeping the forearm in neutral rotation and the wrist in neutral flexion-extension and neutral radioulnar deviation.

Extensor Carpi Ulnaris Stabilization of the Proximal Ulna Stump

- After fixation of the DRUJ, drill a 3.5-mm hole from the dorsoulnar aspect of the ulnar shaft proximal stump into its intramedullary cavity.
Pull the pronator quadratus muscle into the gap in the ulna and suture it to the volar aspect of the tendon sheath of the ECU.

Reattach the sixth dorsal compartment within the groove on the ulnar head and close the wound.

**Wound Closure**

- Make sure that there is a gap of 10 to 12 mm between the proximal and distal ulnar segments.
- Suture the fascia of the underlying pronator quadratus into the gap to prevent reossification across the pseudarthrosis site and stabilize the stump of the ulnar shaft (TECH FIG 7A).
- Repair the retinacular compartments (TECH FIG 7B) and close the skin in routine fashion.

**TECH FIG 6** • Modification of the Sauvé-Kapandji procedure with FCU tenodesis as described by Lamey and Fernandez.12 Lateral aspect of the wrist, showing stabilization of the proximal ulnar segment with use of a distally based slip of the FCU tendon.

**TECH FIG 7** • A. Suturing the pronator quadratus into the gap. B. Closure of the retinaculum.

**TECHNIQUE FOR CASES CHARACTERIZED BY POOR BONE QUALITY (FUJITA TECHNIQUE8,9)**

- Make a 7-cm longitudinal skin incision on the dorsal aspect of the wrist centered on the ulna head (TECH FIG 8A).
- Open the fourth dorsal compartment. Divide the septum between the fourth and fifth compartments and reflect the retinaculum ulnarly to preserve a single common retinacular flap.
- Retract the extensor digitorum communis and extensor digiti minimi tendons radially and perform a neurectomy of the terminal branch of the posterior interosseous nerve.
- Incise the capsule of the DRUJ and dissect the distal part of the ulna subperiosteally.
- Perform an oblique osteotomy with an oscillating saw 30 mm proximal to the distal end of the ulna and excise the ulna head (TECH FIG 8B).
- Perform a synovectomy of the DRUJ and remove the periosteum of the resected portion of the ulna. Interpose the pronator quadratus muscle at the osteotomy site.
- Drill a hole 10 mm in diameter at the sigmoid notch of the radius while viewing the distal articular surface of the radius through the TFC, which is usually ruptured. Do not penetrate the subchondral bone (TECH FIG 8C).
- Remove all soft tissue from the resected portion of the ulna and then rotate it 90 degrees and insert the cut end of the ulnar graft into the hole in the radius, creating a shelf 12 to 15 mm long.
- Impact the ulnar graft into the subchondral and cancellous bone of the distal part of the radius without penetrating the radial cortex, and fix it in the drill hole with a cancellous bone screw (TECH FIG 8D). Do not overtighten the screw.
- Cover the graft with the joint capsule contiguous with a periosteal flap.
- Mobilize and relocate the ECU tendon by dissecting the septum between the fifth and sixth compartments.
- If subluxation of the ECU tendon is evident during rotation of the forearm, reflect the distal portion of the periosteal flap ulnarly beneath the ECU tendon to act as a sling, and suture it to the adjacent soft tissue to restrain the ECU in a dorsal and radial position over the graft.
- Close in the fashion previously outlined.
TECH FIG 8 • Modification of the Sauvé-Kapandji procedure with the distal ulna used as a bone peg as described by Fujita et al.\textsuperscript{9} \textbf{A.} Make a 7-cm longitudinal skin incision on the dorsal aspect of the wrist centered on the ulna head. \textbf{B.} Perform an oblique osteotomy with an oscillating saw 30 mm proximal to the distal end of the ulna and excise the ulna head. \textbf{C.} Drill a hole 10 mm in diameter at the sigmoid notch of the radius while viewing the distal articular surface of the radius through the TFC, which is usually ruptured. Do not penetrate the subchondral bone. \textbf{D.} Remove all soft tissue from the resected portion of the ulna and then rotate it 90 degrees and insert the cut end of the ulnar graft into the hole in the radius, creating a shelf 12 to 15 mm long. Impact the ulnar graft into the subchondral and cancellous bone of the distal part of the radius without penetrating the radial cortex, and fix it in the drill hole with a cancellous bone screw.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Technical details</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Ulnocarpal pain should be distinguished from DRUJ pain. This procedure should not be done for a pain-free, stable DRUJ.</td>
<td>▪ The dorsal sensory branch of the ulnar nerve should be identified and protected to avoid neuromas and stretch injuries.</td>
</tr>
<tr>
<td>▪ If the DRUJ is unstable and arthritic, use of either the FCU or ECU tenodesis of the proximal ulna stump should be strongly considered.</td>
<td>▪ Osteotomy of the ulna should be performed as distal as possible. To avoid stump instability, no more than 1 cm of ulna should be excised.</td>
</tr>
<tr>
<td>▪ In patients with rheumatoid arthritis, DRUJ symptoms should be distinguished clinically, not radiographically, from radiocarpal symptoms. Many patients can be treated with the Sauvé-Kapandji procedure successfully despite radiocarpal changes on radiographs.</td>
<td></td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

▪ Rehabilitation after the Sauvé-Kapandji procedure follows guidelines published by Skirven.\textsuperscript{16}

▪ Postoperatively, a bulky dressing with plaster splints extending above the elbow, maintaining the forearm in neutral position, is applied for 7 to 10 days.

▪ Sutures are then removed and the patient is given a removable, lightweight splint to support the wrist.

▪ Hand therapy is initiated with an emphasis on gentle active wrist, digit, and forearm rotation exercises.

▪ Except for exercise sessions and bathing, the splint is worn at all times.

▪ In the postoperative period, the goal is to allow adequate healing by supporting and protecting the arthrodesis site from stress, followed by gradual restoration of functional mobility without sacrificing the stability of the ulnar shaft or the arthrodesis.

▪ The arthrodesis is protected from loading forces for 4 to 6 weeks.

▪ When the arthrodesis appears healed radiographically, usually 8 weeks postoperatively, light strengthening exercises are initiated. Heavy lifting and forearm torque are avoided until 3 months postoperatively.

▪ For conservative management of postoperative instability of the ulnar shaft, Skirven has recommended a small, cuff-style splint to support the pseudarthrosis site and help stabilize the ulnar shaft.\textsuperscript{16}

▪ The splint, which is made of thermoplastic material, extends from the distal radius ulnarly to a few centimeters proximal to the pseudarthrosis site.

▪ An adjustable strap allows the patient to set the tension on the splint to provide comfort and the level of stability required for specific activities.
OUTCOMES

- There is a broad international experience with this operation on many patients.
- Zimmermann in Austria retrospectively reported on 43 patients’ clinical results and DASH questionnaires 8 years (range 5 to 12 years) after a Sauvé-Kapandji operation. Forearm rotation improved in all patients. Ulnar wrist pain was diminished in 97% of the patients, and 9% had mild pain at the proximal ulnar stump. Grip strength compared to the contralateral side improved from a preoperative mean of 38% to a postoperative mean of 55%. The mean DASH score was 28 points (range 0 to 53 points). In all cases the arthrodesis fused within 8 weeks.
- In Australia, Millroy reported on 81 procedures in 71 patients and found that “almost all patients were pain free during normal activity, although 7 experienced discomfort with overuse.”
- In Belgium, De Smet conducted a prospective survey on 84 patients treated for posttraumatic arthritis of the DRUJ with the procedure. According to the Mayo wrist score, there were 20 excellent, 34 good, 18 fair, and 12 poor results, with an overall satisfaction rate of 74%.
- In Denmark, Jacobsen found that 15 of 17 employed patients returned to work.
- In England, Carter found that 86% of his patients would have the operation again.
- In Germany, Daecke looked at the functional outcomes of 56 patients with the DASH and Mayo wrist scores as well as clinical results. Although only 50% of patients were free of symptoms during heavy labor, 95% had excellent results. The postoperative DASH score was 24.2 ± 22.5 and the Mayo wrist score was 76.1 ± 17.6.
- In Switzerland, Lamey reported on 18 patients who underwent the Sauvé-Kapandji procedure with the FCU tenodesis of the ulna stump. There were 6 excellent, 7 good, 4 fair, and 1 poor Mayo wrist scores. Eight of the patients who had performed heavy manual labor before the injury were able to return to work full-time without restrictions.
- Many other studies report similar outcomes, confirming the utility and broad appeal of this operation.

COMPLICATIONS

- The main source of complications from the Sauvé-Kapandji procedure is the distal stump of the ulna.
- Pain, ulnar impingement syndrome, and a feeling of instability of the ulnar shaft have been reported, but these symptoms are usually transient and resolve by 3 months postoperatively.
- Significant instability of the ulnar shaft is more commonly reported after the Darrach procedure, but it can also occur if too much bone is resected during the described procedure.
- To prevent instability, the surgeon should carefully stabilize the ulnar stump with pronator quadratus fascia advancement, should place the osteotomies as far distally as possible, and should not resect too much bone.
- The surgeon should also avoid excessive stripping of the interosseous membrane. A soft tissue tube should surround the pseudarthrosis site to connect and stabilize the proximal and distal ulnar segments.
- Despite these precautions, painful instability of the distal ulnar stump can occur. In this scenario, the stump can be stabilized by using a strip of the ECU or FCU tendon based on its distal attachment.
- Another complication from the Sauvé-Kapandji procedure is ossification of the pseudarthrosis site.
- The pronator quadratus should be interposed in the ulnar gap after the osteotomy is complete and the ulnar segment should be removed extraperiosteally to minimize the occurrence of this complication.
- If ossification does occur, the bone may be resected when mature. The patient should then immediately begin forearm rotation exercises.
- Injury of the dorsal cutaneous branch of the ulnar nerve is a potential problem and can be avoided with careful dissection.
- Wada and Ishii reported closed rupture of a finger extensor tendon after the Sauvé-Kapandji procedure. They postulated that this was due to the ulnar shaft stump’s being left distal to the edge of the extensor retinaculum, causing attritional rupture of the tendon trapped between the bone edge and the retinaculum.
- This could be avoided by contouring the ulnar shaft edge to a smooth edge and covering the stump with the interposed pronator quadratus.
- Painful neuromas of the dorsal sensory branch of the ulna nerve have also been reported.
- Lamey and Fernandez noted that this may be more common when harvesting a distally based slip of the FCU from one incision. They recommend this be done from a second incision.
- Some patients develop hardware pain from palpable screw heads. These screws can be removed.

REFERENCES

DEFINITION
- As with any synovial joint, the distal radioulnar joint (DRUJ) can degenerate due to osteoarthritis, inflammatory arthritis, chronic instability, infection, and trauma.
- Standard treatments such as partial (“matched resection”) or complete (Darrach procedure) distal ulnar resection have the potential to destabilize the forearm axis and cause painful forearm rotation.
  - The normal compressive muscle forces acting between the radius and ulna help stabilize the DRUJ.
  - When the distal ulna has been resected and the forearm is rotated under such a compressive load, a palpable grinding between the ulnar stump and the radius may develop; this is referred to as ulnar impingement. This may progress from minor irritation to painful erosion of the radius. These patients present with pain on stress loading of the upper extremity, weakness in grip strength, decreased forearm rotation, and difficulty with lifting.1
- Ulnar head implant arthroplasty is designed to maintain the DRUJ, thereby avoiding ulnar impingement. An adequate soft tissue envelope repaired over the implant provides stability.
  - The first prosthesis used was a silicone cap designed to provide a soft end to the ulnar stump. These prostheses understandably failed under loading.
  - Newer designs aim to restore the ulnar head using a metallic prosthesis to articulate with the sigmoid notch.

ANATOMY

PATHOGENESIS

NATURAL HISTORY

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients who have had an ulnar head resection complain of painful forearm rotation, often associated with instability of the forearm axis, decreased strength, and joint grinding.
- In addition to recording the range and fluidity of DRUJ motion, the examiner must determine the stability of the joint and the contribution of ulnar impingement to the patient’s pain.
- Radioulnar compression creates radioulnar impingement by external passive compression.
  - The examiner should encircle the patient’s distal forearm with his or her hands and apply firm compression.
  - A positive sign is reproduction of the patient’s pain.
  - Active radioulnar impingement is reproduced by active muscle contraction, specifically the brachialis.
- The patient has pain lifting a load of 2 lbs with the forearm in neutral position.
- Ulnar stump instability results from compromised soft tissue stabilizers of the distal stump, which tends to fall away from the radius as the forearm is rotated.
- The patient is asked to actively rotate the forearm. Dorsal and palmar subluxation of the ulnar stump is visible.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standard posteroanterior, lateral, and oblique radiographs of the wrist
  - These x-rays demonstrate scalloping of the ulnar cortex of the radial metaphysis and some corresponding pencilling of the distal ulnar stump.
- Posteroanterior stress-loaded radiographs
  - May demonstrate impingement between the radius and ulna
  - The patient stands with the involved forearm facing the x-ray tube. The wrist is stress-loaded by asking the patient to hold a 2.2-kg lead cylinder with the shoulder adducted, the elbow flexed to 90 degrees, and the forearm in the position of neutral rotation.
  - The forearm rests on the x-ray cassette and the radiograph is then taken with the beam aligned in the coronal plane, creating a posteroanterior view of the neutral forearm.
  - Radiographs are obtained before and after stress-loading.
- CT scanning
  - In patients with osteoarthritis of the DRUJ, axial scans are essential for evaluation of the extent of degenerative changes in the ulnar head and the need for total or partial replacement.
  - CT scanning is also essential for evaluation of the sigmoid notch for osteophytes and erosion in patients with painful ulnar head replacement.
  - CT scanning with forearm in pronation and supination is also useful in detecting radioulnar instability if clinical examination is equivocal.

DIFFERENTIAL DIAGNOSIS
- In addition to radioulnar impingement, a patient who has pain at the DRUJ after resection of the ulnar head may have pain due to the following conditions:
  - Ulnar neuropathy
  - Painful surgical scar due to sensory nerve injury or scarring
  - Radiocarpal or midcarpal arthritis

NONOPERATIVE MANAGEMENT
- Activity modification to minimize forearm rotatory movements will diminish pain.
- A Russe splint is partially helpful for patients with instability of the distal ulna stump but is of no help in preventing radioulnar impingement pain.
SURGICAL MANAGEMENT

- The most common indication for distal ulnar implant arthroplasty is to relieve impingement symptoms in patients who have undergone previous ulnar head resection.
- Other less common indications include:
  - Treatment of patients with primary degenerative arthritis of the DRUJ who have failed to respond to splinting and steroid injections
  - Reconstruction of the ulna after excision of a tumor involving the ulnar head
  - After unreconstructable fractures of the ulnar head as either a primary or delayed procedure
  - Relative indication: patients with well-controlled inflammatory arthritis but well-preserved bone stock
- The amount of the DRUJ that is replaced may vary for any given case.
  - Partial ulnar head replacement
  - Unconstrained replacement of the entire distal ulna with or without sigmoid notch resurfacing
  - Constrained total DRUJ replacement, including the sigmoid fossa of the distal radius
- Partial ulnar head replacement preserves the styloid process and the attachment of the triangular fibrocartilage.
  - This procedure is indicated when the disease process, typically arthritis, is limited to the distal ulnar articular surface.
  - Contraindications include instability of the distal ulna, excessive ulnar positive variance, and degeneration at the sigmoid notch.
  - Two types of implants are available: a one-piece stemmed metal prosthesis and a two-piece prosthesis with a titanium stem and an articulating pyrolytic carbon disc that replaces the head (FIG 1).
  - The long-term results of partial ulnar head replacement are not known. The articulating two-piece prosthesis has the theoretical advantage of less radius erosion from articulation with the pyrocarbon head.
  - Unconstrained complete ulnar head replacement is indicated for reconstruction of ulnar impingement after resection or replacement of an arthritic DRUJ associated with instability of the distal ulna. With mild instability, repair of the soft tissue envelope is adequate to restore stability. In cases with more obvious instability, an additional soft tissue procedure is indicated along with ulnar head replacement.
  - Ulnar head prostheses are generally spherical and made of metal or ceramic. An eccentric-shaped metallic head has been designed to more closely approximate the shape of the normal head. However, biomechanical studies have demonstrated normal tracking patterns of the distal ulna around the radius, closely simulating the normal joint, even with the use of spherical heads.
  - Ulnar head prostheses may articulate with a metal-backed polyethylene resurfacing of the sigmoid notch in an unconstrained manner (FIG 2).
  - An adequate soft tissue envelope is essential to prevent subluxation of a complete ulnar head replacement. The triangular fibrocartilage complex (TFCC) is no longer attached to the distal ulna, making the prosthesis prone to dislocation. Thus, an essential part of the surgical technique is reconstructing the capsuloligamentous envelope surrounding the ulnar prosthesis.
  - Other contraindications include previous open fracture, infection in or around the joint, skeletal immaturity, and known sensitivity to the implant materials.
  - In cases of marked instability, with lack of an adequate soft tissue stabilizing envelope and ablation of the DRUJ after trauma or tumor resection, a constrained total DRUJ replacement should be used (FIG 3).
  - The radial component consists of a plate with a polyethylene-lined metal sphere affixed to the interosseous surface of the radius.
  - The ulnar stem has a protruding peg that is captured and rotates within the polyethylene liner. The stem has limited
freedom of proximodistal and limited dorsopalmar motion, simulating normal DRUJ mechanics.

Preoperative Planning
- Preoperative radiographs of both sides are used for templating (FIG 4).
  - Normal anatomy and ulnar variance are reproduced to the extent possible.
  - The appropriate implant size is chosen.

Positioning
- Standard positioning and tourniquet application are used.

PARTIAL ULNAR HEAD REPLACEMENT ARTHROPLASTY
- Make a longitudinal incision in line with the fourth metacarpal.
- Divide the extensor retinaculum over the fourth compartment and reflect it ulnarly.
- Retract the two slips of the extensor digiti minimi tendon and elevate a large ulnar-based triquetral flap of capsule.
  - The flap includes the dorsal radiotriquetral ligament distally.
  - The TFCC should be repaired back to bone if foveal detachment is detected.
- Leave in place the ECU subsheath and ECU tendon.
- Resect the articular portion of the ulnar head using a customized jig specific to the implant system to be used.
- Ream the ulnar medullary canal and place a trial prosthesis of the appropriate size. Obtain intraoperative radiographs to confirm correct sizing of head and ulnar variance.
- Ascertain range of motion and stability and insert a definitive prosthesis. Restore the capsular flap and imbri cate it if necessary for stability (TECH FIG 1).

ULNAR HEAD HEMIARTHROPLASTY (WITHOUT SIGMOID NOTCH RESURFACING)
- Make a longitudinal skin incision on the ulnar border of the distal forearm (TECH FIG 2A).
- Incise the extensor retinaculum along the medial border of the distal ulna between the ECU and FCU.
- Identify and protect the dorsal cutaneous branch of the ulnar nerve as it crosses from volar to dorsal across the most distal part of the incision.
- Elevate the ECU tendon subsheath subperiosteally off the distal ulna along with the TFCC and ulnar collateral ligament distally.
- Determine the resection level of the distal ulna using a template and mark it with a pen or osteotome (TECH FIG 2B).
The aim is to create ulnar neutral variance after the implant is in place.

When the distal ulna has been previously excised, use the distal end of the sigmoid fossa of the distal radius as a landmark to determine the ulnar osteotomy level.

With soft tissue retractors in place, use an oscillating saw to osteotomize the distal ulna (TECH FIG 2C).

Take care to ensure that the cut is perpendicular to the long axis of the ulna.

Remove and size the ulnar head.

To allow for easy identification for soft tissue repair, place a tagging suture into the TFCC attachment in the fovea before releasing it from the ulna.

Inspect the sigmoid notch of the distal radius for incongruity. Remove osteophytes.

Define the intramedullary canal of the distal ulna using an awl or sharp broach. Gently enlarge the canal to the appropriate stem size using broaches of increasing diameter (TECH FIG 2D).

Gently impact the appropriate trial stem into the shaft of the distal ulna (TECH FIG 2E). The collar should seat firmly against the resected surface of the distal ulna.

In cases with previous excessive ulnar resection, a prosthesis with an extended collar may be indicated.

To ascertain the need for an extended collar, place a trial spacer on the neck of the trial stem before placing the trial head.

Place the trial head of the appropriate size onto the neck of the trial stem and reduce the DRUJ.

Supination and pronation should be full and smooth, with no instability at the articulation.

Obtain intraoperative radiographs to evaluate the size of the ulnar head and the ulnar variance.

If the prosthesis is too distal, resection of more distal ulna is necessary.

Remove the trial implant by gently applying anteriorly directed pressure on the distal ulna to dislodge the ulnar head from the sigmoid notch.

If a firm fit is obtained with the trial, a press-fit technique may be used with the final implant. In patients with osteopenia or previous wrist fusion, use cement to secure the ulnar stem.

Prepare the appropriately sized head for soft tissue stabilization before the stem is fully impacted. Pass two 3-0 nonabsorbable sutures with curved double needles through each row of holes in the prosthesis head. Pass the needles from the deeper suture through the TFCC at its previous foveal insertion, and insert the needles from the superficial suture into the ECU subsheath. Leave the sutures untied (TECH FIG 2F).

Insert and impact the final stem (with or without cement) using the stem impactor.

---

**TECH FIG 2**

A. A longitudinal incision is made between the flexor and extensor carpi ulnaris tendons on the ulnar border of the distal forearm and wrist. B. The cutting guide helps determine the level of resection of the ulnar head. The distal notches are for use with the three head sizes and standard stem, and the proximal notches are for use with a collared stem in cases of previous resection or resorption of the distal ulna. C. An oscillating saw is used to resect the ulnar head at the determined level. D. The ulnar medullary cavity is reamed using broaches. (continued)
Align the head of the prosthesis such that the two rows of suture holes are along the subcutaneous border of the ulna (TECH FIG 2G). Then place it onto the tapered neck of the stem and gently impact it.

Advance the soft tissues ulnarly over the head of the prosthesis as it is reduced into the sigmoid notch. With the forearm in midrotation, tie down the sutures placed in the head, closing the ECU subsheath over the top of the prosthesis.

Because the head does not freely rotate on the stem, it is essential to align the head before impaction onto the stem. The holes on the head are lined up with the subcutaneous border of the ulna. After the pull-through sutures of the prosthesis are tied down, the remaining soft tissue envelope deep to the extensor retinaculum is approximated with the forearm in neutral position. Preoperative radiographs of an unstable and incongruous ulnar head after comminuted fracture of the distal radius and ulna. Ulnar head replacement and soft tissue imbrication restored congruity and stability to the articulation.
CONSTRANDED DISTAL RADIOULNAR JOINT ARTHROPLASTY

- Make an 8-cm longitudinal incision in the shape of a hockey stick along the ulnar border of the distal forearm between the fifth and sixth dorsal extensor compartments (TECH FIG 3A).
- Create a rectangular ulnarily based fascia flap (TECH FIG 3B). Use the flap to create a barrier between the prosthesis and the ECU at closure.
  - The width of the flap should cover the head of the implant and may include the most proximal part of the extensor retinaculum.
- Expose the distal ulna through the floor of the fifth extensor compartment and mobilize the tendons of the extensor digiti minimi proximally for a distance of 8 cm.
- Divide the sensory branch of the posterior interosseous nerve to avoid avulsion of the nerve from the thumb extensors when placing an elevator between the extensor mass and the radius.
- Incise the ECU sheath to its insertion at the base of the fifth metacarpal.
  - This is to avoid pressure against the distal end of the implant.
- Excise the remaining head of the ulna at a level just proximal to the cartilage, or where the DRUJ would have been.
- Leave the radial attachment of the TFCC undisturbed to provide a barrier between the prosthesis and the carpal bones.
- Displace the ulnar shaft in a volar direction to expose the radius and sigmoid notch (TECH FIG 3C).
- Elevate the interosseous membrane along the distal 8 cm of the radius.

TECH FIG 3 • A. Intraoperative photograph of implantation with the Aptis system. The dorsoulnar skin incision is placed between the fifth and sixth extensor compartments. B. A large ulnar-based flap of retinaculum is raised for later interposition between the extensor carpi ulnaris tendon and the implant. C. The ulna is displaced volarly with retractors to expose the interosseous surface of the radius and the sigmoid notch. D. The radial plate template is positioned and temporarily fixed to the radius. The plate’s position is checked with radiographs (inset). E. Operative photograph demonstrating completion of fixation of the radial component. Radiographs confirm correct placement of implant and screw length (inset). F. A sizer with an attached ball is used to determine the level of ulnar resection. This ensures that the ulnar implant with seated polyethylene ball will be level with the radial socket. (continued)
Chapter 93  ULNAR HEAD IMPLANT ARTHROPLASTY 2855

TECHNIQUES

TECH FIG 3  (continued)  G. Medullary broaches are used to enlarge the medullary canal of the distal ulna.  H, I, J. Steps for final assembly of the system. After the ulnar stem is inserted, the polyethylene ball is placed over the peg. The ball is then aligned with the radial socket and the cap is placed over it and secured with two screws.  K. Final radiographs demonstrate correct placement of the implant.  L. The previously raised retinacular flap (marked by asterisks) is then placed over the prosthesis and beneath the extensor carpi ulnaris tendon.

- Place the radial trial plate over the interosseous crest of the radius with the volar border aligned with the volar surface of the radius (TECH FIG 3D).
  - The plate should lie at least 3 mm proximal to the distal end of the sigmoid notch of the radius to avoid impaction with the carpus.
- Use a burr to contour the distal radius as necessary to accommodate the plate. Position the plate and hold it temporarily with Kirschner wires passed through the plate.
- Use intraoperative imaging to check the position of the plate.
- After drilling the hole for the radial peg, remove the trial and gently impact the final radial component in place. Insert fixation screws into the radius to secure the implant and take radiographs (TECH FIG 3E). Remove the Kirschner wires.
- With the forearm fully pronated, seat a sizer with attached ball into the hemi-socket of the radius and align it with the ulna (TECH FIG 3F). Determine the level of ulnar resection.
- After resecting the distal ulna, insert a 1.6-mm guidewire into the medullary canal and use a cannulated drill to ream the canal.
- Insert a medullary broach of the appropriate size into the canal to bevel the distal ulna and plane its distal end (TECH FIG 3G).
- Irrigate the medullary canal and insert the stem of the ulnar component (TECH FIG 3H). Place the ultra-high-molecular-weight polyethylene ball over the distal peg and position the ulnar component within the hemi-socket of the radial component (TECH FIG 3I).
- Position the cover of the socket over the ball and secure it with two small screws (TECH FIG 3J).
- Obtain radiographs to confirm satisfactory positioning of the prosthesis (TECH FIG 3K).
- Position the fascia and retinacular flap between the prosthesis and the ECU tendon and suture them to the radius before doing a layered closure (TECH FIG 3L).
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Scar sensitivity or tenderness</th>
<th>■ Identify and protect the sensory branch of the ulnar nerve.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intraoperative fracture of the distal ulna</td>
<td>■ Broach the distal ulna with caution. In hard cortical bone, use a drill to enlarge the cavity before impacting a broach in the ulna.</td>
</tr>
<tr>
<td>Incorrect ulnar variance</td>
<td>■ Before making the ulnar osteotomy, identify the correct level of the DRUJ using radiographs or along the distal edge of the sigmoid notch.</td>
</tr>
<tr>
<td>Instability of the prosthesis</td>
<td>■ Raise a thick and large flap of soft tissue when exposing the distal ulna. This tissue can be imbricated to stabilize the prosthesis if needed. Alternatively, a distally based strip of the FCU can be wound around the prosthesis to provide volar stability.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- The forearm is immobilized in neutral rotation and held in a supportive long-arm or Muenster-type splint or cast for 3 weeks.
- Active range of motion of the wrist and forearm is initiated at 3 weeks.
  - A removable splint is required between therapy sessions for 3 weeks.
- Therapy is advanced as tolerated after 6 weeks, with strengthening starting only after functional wrist and forearm motion has been obtained.
- For a patient with rheumatoid arthritis, poor-quality soft tissue coverage, or mild instability intraoperatively, immobilization in supination for up to 6 weeks must be considered.
- Postoperative radiographs should be obtained at 6 weeks, 6 months, and then yearly.

OUTCOMES

- Outcomes vary with the indication and type of prosthesis used.
- The pain of radioulnar impingement is relieved in patients with previous excision arthroplasty and stability is restored.
- The range of motion of the forearm after prosthetic replacement remains largely unchanged, as it depends on previous scarring.
- Grip strength recovered depends on the underlying problem, but in patients with severe pain and weakness preoperatively, final grip averages about 60% of the opposite side.
- The long-term results and the incidence of prosthetic loosening, failure, and radius erosion are not known.

COMPLICATIONS

- Immediate or short-term complications
  - Fracture of the distal ulna during reaming or impaction of the prosthesis
  - Dislocation of the prosthesis from the DRUJ postoperatively
  - Long-term complications
    - Progressive degeneration of the sigmoid notch
    - Implant loosening
    - Tenosynovitis of the ECU tendon
    - Erosion of the radius sigmoid notch with pain
    - Ectopic bone formation around the distal ulna
    - Stress shielding and resorption of distal ulna
    - Prosthetic fracture
  - Infection and wound breakdown, especially in revision cases with poor soft tissue cover
  - Injury to the dorsal sensory branch of the ulnar nerve, leading to tender neuroma

REFERENCES

DEFINITION
- A tear of the triangular fibrocartilage complex (TFCC) is one of the most common causes of ulnar wrist pain. The treatment of TFCC tears and the associated synovitis is one of the primary indications for operative wrist arthroscopy.
- Ulnar-sided wrist pain associated with a TFCC tear in the presence of ulnar-neutral or ulnar-plus variance constitutes ulnar abutment syndrome. Successful treatment of an ulnar abutment syndrome requires not only the débridement of the TFCC tear but also shortening of the ulna.
- Patients with Palmer type IA* TFCC tears are prime candidates for TFCC débridement.
- Patients with Palmer type II (degenerative central tears) can also benefit from TFCC débridement. For the more advanced degenerative tears associated with lunatotriquetral ligament tears (Palmer type IID and E), other procedures such as an ulnar shortening osteotomy must be considered.

ANATOMY
- The triangular fibrocartilage is the primary stabilizer of the distal radioulnar joint. It attaches radially on the distal lip of the sigmoid notch (FIG 1). Ulnarly, the triangular fibrocartilage inserts at the base of the ulnar styloid via a continuation of the dorsal and palmar radioulnar ligaments and the fibers of the ligamentum subcruentum.4

PATHOGENESIS
- Tears of the triangular fibrocartilage are typically the result of a fall on the outstretched upper extremity. The ulna is driven distally and compresses the TFCC between itself and the lunate, producing a central or radial tear of the articular disc. This same mechanism can result in lunatotriquetral tears and peripheral TFCC tears (reviewed elsewhere).
- Forceful ulnar deviation, such as noted in racquet sports and golf, can lead to TFCC tears. Gymnastics, with its significant axial loading of the wrist, can also lead to a TFCC tear.
- The combination of ulnar axial load and torque noted during these sports can be sufficient to tear the triangular fibrocartilage.
- At least 50% of intra-articular distal radius fractures are associated with tears of the triangular fibrocartilage.1 Many of these tears remain asymptomatic and require no surgical treatment.
- An ulnar abutment (impaction) syndrome can develop as a result of shortening after a distal radius fracture (FIG 2). Radial collapse of the articular platform leads to a relative lengthening of the ulna.
- Palmer et al9 have demonstrated an increase in the ulnocarpal load with increasing ulnar variance.
- Repetitive axial loading of the wrist in a patient with an ulnar-zero or ulnar-plus variance can lead to an attritional tear of the triangular fibrocartilage and ulnar abutment syndrome.

NATURAL HISTORY
- The natural history of TFCC tears is not well established. Many asymptomatic TFCC tears are noted on routine wrist arthroscopy. If left untreated one could assume that a TFCC...
A tear could lead to chondromalacia of the lunate, triquetrum, and distal ulnar head. This in turn could lead to painful ulnocarpal synovitis.

- The increase in the force transmitted through the ulnocarpal joint noted in an ulnar abutment syndrome can lead to a degenerative tear of the triangular fibrocartilage, chondromalacia of the lunate, triquetrum, and distal ulna, and a triquetrolunate ligament tear.

**PATIENT HISTORY AND PHYSICAL EXAMINATION**

- Physical examination includes the following:
  - Ulnocarpal compression test: Pain at the ulnocarpal joint with or without popping and grinding is suggestive of a TFCC tear and possible ulnar abutment syndrome.
  - Lester press test: Pain at the ulnocarpal joint is suggestive of a TFCC tear and possible ulnar abutment syndrome.
  - Ulnocarpal palpation: Pain at the ulnocarpal joint suggests the presence of TFCC pathology as well as ulnocarpal synovitis.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- The radiographic evaluation of a patient with an ulnar abutment should include a standard wrist series and a Palmer 90°/90 neutral rotation view.
  - The Palmer 90°/90 view places the forearm in neutral rotation while the elbow is flexed to 90 degrees and the shoulder is abducted to 90 degrees. The ulnar variance is calculated from this view (Fig 3A). Ulnar abutment is suspected in a patient with an ulnar-zero or ulnar-plus variance.
  - The ulnar aspect of the lunate should be carefully examined for subchondral cysts.
  - An MRI should be considered when evaluating the patient for ulnar abutment syndrome. The MRI will demonstrate increased signal in the lunate on the T2 images (Fig 3B,C). This corresponds to either a cyst or intraosseous edema.
  - The triangular fibrocartilage can also be evaluated on the MR images. Whether an MR arthrogram is needed is a function of the MR resolution. The accuracy of lower-resolution MR is increased with the addition of an intra-articular gadolinium injection.

**DIFFERENTIAL DIAGNOSIS**

- TFCC tear
- Distal radioulnar ligament injury
- Distal radioulnar joint instability
- Ulnocarpal ligament injury
- Lunotriquetral joint instability
- Ulnocarpal synovitis
- Lunate chondromalacia
- Triquetral chondromalacia
- Distal ulnar chondromalacia
- Kienböck disease

**NONOPERATIVE TREATMENT**

- Immobilization of the involved wrist with either a Munster splint or long-arm cast for 4 weeks, combined with a course of nonsteroidal anti-inflammatory medications, activity modification, and therapy) can be helpful in patients who present acutely.
- A TFCC tear that is exacerbated by specific activities can occasionally respond to activity modification.

**SURGICAL MANAGEMENT**

- The failure of nonoperative treatment (splinting, rest, nonsteroidal anti-inflammatory medications, activity modification, and therapy) leads the surgeon to choose surgical débridement of a TFCC tear.
- Mechanical débridement of the triangular fibrocartilage has been successful. This can be challenging, particularly in regard to the débridement of the ulnar and dorsal aspects of the triangular fibrocartilage tear.
  - There are two potential problems with mechanical TFCC débridement:
    - Passage of the instruments across the radiocarpal joint places those joints at risk of scuffing.

---

**FIG 3**

- A. Ulnar-plus variance noted on 90°/90 neutral rotation view.
- B, C. T1- and T2-weighted MRIs of a wrist with an ulnar abutment demonstrating the change in signal at the ulnar proximal lunate.
The proximity of the scope to the operative site (TFCC) can distort the operator’s perception of the ulnocarpal joint.

Radiofrequency devices have become increasingly popular for TFCC débridement because of the small probe size and relatively low cost. Monopolar and bipolar radiofrequency devices are currently in use. The instrument settings vary with the device.

Arthroscopic ulnar shortening is indicated in patients with a TFCC tear who have longstanding or acute exacerbation of ulnar abutment syndrome and who do not respond to nonoperative treatment.

It is generally thought that an arthroscopically assisted ulnar shortening is indicated if the ulnar-plus variance is less than 4 mm.

The goal of the surgery is to create an ulnar-minus variance of 2 mm.

**Preoperative Planning**

- **TFCC débridement:** Preoperative evaluation should include wrist radiographs: a “wrist series” and a “90°/90°” view described by Palmer. An MRI with or without an arthrogram can also be helpful.
- **Arthroscopic ulnar shortening**
  - The patient must be informed that an arthroscopically assisted ulnar shortening may not be possible should there be laxity of the ulnocarpal ligaments, a peripheral TFCC tear, or lunatotriquetral laxity.
  - The amount of shortening should be calculated preoperatively.
  - The surgeon should verify that the operating room is equipped with a mini C-arm to permit intraoperative assessment of the amount of ulna resected.

**Positioning**

- The patient is placed in the supine position.
- A pneumatic tourniquet is placed on the proximal arm.
- The involved extremity is prepared and draped in the usual fashion.
- The wrist is distracted using a commercially available wrist traction device.

---

**MECHANICAL TFCC DÉBRIDEMENT**

**Portals and Arthroscopic Examination**

- The standard dorsal 3-4 and 4-5 or 6R wrist arthroscopy portals are used for TFCC débridement (TECH FIG 1). These portals should be wide enough to permit the easy passage of instruments.
- Before débriding the TFCC, perform a thorough and systematic arthroscopic examination of the radiocarpal, ulnocarpal, and midcarpal joints because associated intrinsic and extrinsic ligament injury and articular and synovial pathology could affect the treatment plan.
- Perform ulnocarpal synovectomy to ensure clear visualization of that joint.

**Radial and Palmar Débridement**

- The initial débridement of the radial and palmar and a portion of the dorsal aspects of the TFCC tear is accomplished with a scope in the 3-4 portal while the instruments enter through the 4-5 portal.
- Use small joint punches (straight and angled), graspers, mini-banana blades, and mini-hook knives to débride the TFCC. The suction punch is particularly useful.
- Take care not to injure the underlying ulnar head and overhanging lunate and triquetrum (TECH FIG 2).

**Ulnar Débridement**

- Once the radial and palmar aspects of the TFCC have been débrided, move the arthroscope to the 4-5 portal.

---

**TECH FIG 1** • Wrist arthroscopy portals.

**TECH FIG 2** • Mechanical débridement of the TFCC. The arthroscope is in the 3-4 portal looking ulnar, while the suction punch enters through the 4-5 portal to débride the palmar aspect of the TFCC.
Débride the ulnar aspect of the triangular fibrocartilage by passing the instruments through the 3-4 portal.

Keep three points in mind while débriding the ulnar aspect of the TFCC:

- Avoid injuring the attachment of the triangular fibrocartilage at its insertion at the base of the ulnar styloid.
- Avoid injuring the dorsal or palmar radioulnar ligaments. If the ulnar attachment of the TFCC is transected, or if the dorsal and palmar radioulnar ligaments are injured, distal radioulnar joint instability will result.
- Avoid scuffing the articular surfaces while passing the cutting and grasping instruments from the 3-4 portal across the radiocarpal joint into the ulnocarpal joint.

Dorsal Débridement

- The dorsal aspect of the TFCC tear can usually be débrided using the 3-4 and 4-5 portals. Occasionally, however, the instruments need to be passed through the 6U portal while the scope is placed in the 3-4 portal.
- Injury to the dorsal sensory branch of the ulnar nerve is avoided when establishing the 6U portal by using a longitudinal portal incision and blunt dissection to reach the ulnocarpal joint capsule.

Completion

- Once the TFCC has been débrided with the punches and knives, smooth the rough edges of the débrided TFCC using a full radius cutter.
- The 2.0-mm cutters are small but relatively ineffective, while the 2.9-mm cutters are effective but must be controlled so as to avoid collateral damage to the adjacent articular surfaces (TECH FIG 3A).
- The end point of the TFCC débridement is reached when the ulnar head is visible through the TFCC and a stable TFCC perimeter is created (TECH FIG 3B).
- Typically, a central defect measuring at least 1 cm in diameter is created.
- Before declaring the surgery complete, remove the instruments from the wrist, release the traction, and ulnarily deviate, axially load, and repeatedly supinate and pronate the wrist.
- The presence of popping or clicking is a sign that further débridement might be needed or that some other pathology is causing the popping and clicking.
- One source of such post-débridement popping is thickened synovium in the distal radioulnar joint just proximal to the TFCC.
- Close wounds using subcuticular sutures of 4-0 Prolene and apply a volar splint.

TECH FIG 3 • A. The arthroscope is in the 3-4 portal and the full radius cutter is passed through the 4-5 portal to smooth the edges of the débrided central TFCC tear. B. The débridement of the TFCC is complete. The ulnar head is clearly visible and ready for shortening.

LASER- OR RADIOFREQUENCY-ASSISTED TFCC DÉBRIDEMENT

- The technique of laser-assisted TFCC débridement is similar to that of mechanical débridement, with the exception that the arthroscope can be left in the 3-4 portal while the laser probe is kept in the 4-5 portal.
- The laser is set to 1.4 to 1.6 joules at a frequency of 15 pulses per second. With the help of a side-firing 70-degree laser tip, the triangular fibrocartilage can be rapidly and precisely débrided.
- The 70-degree laser tip permits ablation of not only the radial and palmar portions of the TFCC tear but also the ulnar and dorsal components.
- There is no need to bring the laser probe in through the 3-4 portal.
- During the débridement, take care not to injure the ulnar head. This is avoided by firing the laser tangentially to the head of the ulna or passing the probe beneath the triangular fibrocartilage and firing distally (TECH FIG 4).

TECH FIG 4 • Laser-assisted débridement of a TFCC tear. The laser probe is placed 1 mm from the TFCC.
The goal of the surgery is to create an ulnar-minus variance of 2 mm without any irregularities of the remaining distal ulna. Small irregularities, however, tend to flatten out with the passage of time.

Arthroscopic ulnar shortening is accomplished by placing the scope in the 3-4 portal and introducing the instruments through the 4-5 portal. Occasionally the 6U portal can be used, as can the distal distal radioulnar joint portal.

While the holmium:YAG laser is useful for ulnar shortening, the barrel abrader can also be used alone or in combination with the laser. If the holmium:YAG laser is used, it is introduced through the 4-5 portal and the cartilage and subchondral bone of the ulnar seat of the distal ulna are rapidly vaporized (TECH FIG 5A,B).

The laser becomes less efficient once the trabeculae of the distal ulna are visible (TECH FIG 5C). At that point, the 2.9-mm barrel abrader is brought in to finish the shortening (TECH FIG 5D).

It is important to avoid injury to the sigmoid notch, and frequent fluoroscopic monitoring of the amount of bone resected is mandatory.

Take care to fully supinate and pronate the wrist to adequately débride the ulnar head.

Remove all instruments at the end of the procedure, and ulnarily deviate, axially load, and supinate and pronate the wrist to be sure no clicking or popping is noted. If any clicking or popping is noted and it appears to be emanating from the area of the surgery, further ulnar leveling may be required.

Close wounds using subcuticular sutures of 4-0 Prolene and apply a volar splint.

**TECH FIG 5**  
A. The 70-degree side-firing laser probe easily vaporizes the hyaline cartilage and subchondral bone of the ulnar head.  
B. The laser has cleared the ulnar head of its cartilage and subchondral plate.  
C. The spacing of the bony trabeculae of the ulnar head decreases the laser’s efficiency. The final leveling of the ulnar head is achieved with the small joint burr.  
D. The small joint burr is brought in through the 4-5 or 6R portal to finish the ulnar shortening.
**POSTOPERATIVE CARE**

- Postoperative care includes early range of motion and suture removal at 2 weeks.
  - Early range of motion is critical as it leads to a more supple scar and a better range of motion.
  - Strengthening exercises are initiated at 6 weeks if needed.
  - Premature resumption of heavy lifting or repetitive activities will lead to ulnocarpal synovitis.
  - Some patients are pain-free after as little as 2 weeks, and the surgeon must temper the patient’s desire to return to full activity.
  - The patient is instructed to avoid heavy lifting for 3 months.
  - Typically patients are able to return to unrestricted activities in 12 weeks, although they may experience some discomfort for 6 to 12 months.
  - Patients who undergo a simple TFCC débridement will recover more rapidly than those who undergo an arthroscopic ulnar shortening.

**OUTCOMES**

- The results of arthroscopic débridement of traumatic triangular fibrocartilage tears have been very good.²,³
  - Minami et al¹ noted, however, that degenerative tears (Palmer type II) have a less favorable prognosis due to the associated ulnar wrist pathology noted in these patients.
  - Our results¹¹ and those reported by Osterman⁰ and Palmer⁸ suggest that arthroscopically assisted ulnar shortening in properly selected patients provides excellent and good results in over 80% of patients (FIG 4).

**COMPLICATIONS**

- TFCC débridement
  - Infection and injury to the dorsal branch of the ulnar nerve are rare.

- Excessive débridement of the TFCC (dorsal and palmar radioulnar ligaments, attachment in the ulnar fovea) can lead to instability.
- Formation of portal site cysts (very rare)
- Arthroscopic ulnar shortening
  - Inadequate bony resection can lead to a nonresolution of the patient’s symptoms.
  - Uneven resection of the distal ulna can lead to catching of any significant residual bony prominence on the overlying triangular fibrocartilage.
  - We have seen one patient reconstitute his triangular fibrocartilage and require repeat débridement. This phenomenon has been anecdotally reported by others.
  - The surgeon must remain vigilant and avoid injury to the sigmoid notch.
  - The surgeon must avoid excessive ulnar débridement, which could lead to the detachment of the triangular fibrocartilage from the fovea.

---

**PEARLS AND PITFALLS**

**TFCC débridement**

- The 4-5 and 6R portals should be placed just distal to the distal surface of the TFCC.
- Inappropriate distal placement of the portals can lead to scuffing of the lunate and triquetrum.

**Nerve injury**

- The dorsal branch of the ulnar nerve is at risk during the creation of all ulnar portals.
- All portals should be made by incising the skin with a no. 15 blade (avoid plunging a no. 11 blade into the joint). Once the skin is cut, a Hartmann hemostat should be used to bluntly dissect through the subcutaneous tissue and penetrate the wrist joint capsule.

**Débridement**

- Avoid injury to the peripheral attachments of the TFCC and the dorsal and palmar radioulnar ligaments.

**Incision orientation**

- Small transverse incisions in Langer lines closed with a subcuticular Prolene produce a superior cosmetic result.

**Scope**

- The 1.9-mm arthroscopes are less likely to scuff the wrist joint articular surfaces.

**Rehabilitation**

- Avoid early (before 4 weeks) heavy loading of the wrist.

**Arthroscopic ulnar shortening**

- Arthroscopically assisted ulnar shortening should not be combined with other procedures that require postoperative wrist immobilization.

**Excision of ulnar head**

- A systematic approach to the excision of the ulnar head is critical. The assistant must take the wrist from full supination to full pronation while the operator maintains the arthroscope in the 3-4 portal and the instruments in the ulnar portals. The ulnar head is débrided as it is presented to the surgeon by the assistant during the rotation of the distal radioulnar joint.

---

**FIG 4**

Six-month postoperative radiograph after arthroscopic ulnar shortening in patient in Techniques Figure 5.
REFERENCES

DEFINITION
- Ulnar impaction syndrome (ulnocarpal abutment) results from a chronic compressive overloading of the ulnocarpal articulation secondary to static or dynamic ulnar-positive variance.
- Ulnar variance defines the relationship of the length of the ulna to that of the radius.
- Ulnar-positive variance can be the result of a congenital anomaly; traumatic radial shortening from a distal radius, Essex-Lopresti, or Galeazzi fracture; injury to the distal radius physis; or a variant of normal anatomy.
- An ulnar shortening osteotomy is designed to decompress the ulnocarpal joint while simultaneously tightening the ulnocarpal and radioulnar marginal ligaments of the triangular fibrocartilage complex (TFCC).14

ANATOMY
- The distal radius has three articular surfaces: the scaphoid fossa, the lunate fossa, and the sigmoid notch.
- The radius articulates with and rotates around the ulnar head via the sigmoid notch. The sigmoid notch has well-defined dorsal, palmar, and distal margins, while the proximal margin is indistinct.
- The distal radioulnar joint (DRUJ) and ulnocarpal relationships are maintained by numerous ligamentous structures (FIG 1A).
- The interosseous membrane is a complex structure with a thickened central portion. It almost completely spans the radius and ulna, acting as a hinge for forearm rotation.
- The diaphysis of the distal half of the ulna is supplied by small segmental branches from the anterior and posterior interosseous arteries. These enter the ulna in 1- to 3-cm intervals from the direction of the interosseous membrane and must be protected during the surgical approach.22
- The dorsal capsule of the DRUJ contains two ligaments: the proximal metaphyseal arcuate ligament and the distal radioulnar ligament. The palmar capsule is composed of a single radioulnar ligament.1
- The TFCC spans the ulnocarpal joint and connects the distal radius to the distal ulna (FIG 1B). The TFCC functions to cover the distal ulna, to partially dampen and transmit a portion of the axial load of the wrist through the ulna, to stabilize the DRUJ, and to provide support for the ulnar side of the carpus.
- The TFCC contains a central avascular articular disc composed of types I and II collagen. It is of variable thickness

FIG 1 • A. The soft tissue structures encompassing the triangular fibrocartilage complex (TFC) of the wrist stabilizing the radioulnocarpal unit. The TFC proper originates from the radius medially and attaches to the base of the ulnar styloid. Fibers originating from the subsheath of the extensor carpi ulnaris dorsally cross path with fibers originating from the ulnocarpal ligaments volarly and blend with the TFC proper. B. Distal radioulnar joint (DRUJ) ligaments. (The disc component of the TFCC has been removed to show the deep limbs of the radioulnar ligaments.) The volar and dorsal radioulnar ligaments are the major soft tissue stabilizers of the DRUJ and insert onto the base of the ulnar styloid.
The articular disc is connected to the peripheral palmar and dorsal radioulnar (marginal) ligaments, which originate on the medial border of the distal radius and insert into the base of the ulnar styloid at the fovea. These ligaments are composed of linear type I collagen and are stabilizers of the DRUJ.

The ulnolunate and ulnotriquetral ligaments originate from the ulnar fovea and pass palmar to the palmar radioulnar ligament. They traverse the palmar surface of the TFCC to insert on their respective carpal bones. These ulnocarpal ligaments stabilize the ulnar side of the carpus relative to the ulna and resist carpal supination.

The periphery of the TFCC is supplied by dorsal and palmar branches of the anterior interosseous artery and the ulnar artery. Because of this vascular distribution, injuries to the periphery of the TFCC are capable of healing and are often amenable to repair. Injuries to the central avascular portion of the articular disc do not heal in a predictable manner and are often treated with debridement.

**PATHOGENESIS**

Normal ulnar variance ranges from neutral to plus or minus 2 mm. The average axial load transmitted across the TFCC and subsequently the ulna is 20% if ulnar variance is neutral. An ulnar-positive variance of 2.5 mm increases the load across the distal ulna 42.7%, while an ulnar variance of −2.5 mm decreases the ulnar load to 3.1% (Table 1).

Congenital or acquired ulnar-positive variance (FIG 2) can lead to degenerative wear of the TFCC and surrounding structures.

The Palmer classification divides TFCC lesions into traumatic (type I) or degenerative (type II). Type II lesions are associated with ulnocarpal impaction and are further subdivided based on the severity and the other structures involved. Type II TFCC tears are generally not amenable to direct repair.

- Type IIA: TFCC wear
- Type IIB: TFCC wear plus lunate or ulnar head chondromalacia
- Type IIC: TFCC perforation plus lunate or ulnar head chondromalacia
- Type IID: TFCC perforation plus lunate or ulnar head chondromalacia plus lunotriquetral ligament perforation
- Type IIE: TFCC perforation plus lunate or ulnar head chondromalacia plus lunotriquetral ligament perforation plus ulnocarpal arthritis

**NATURAL HISTORY**

Defining the natural history of ulnocarpal impaction syndrome is at best challenging.

The Palmer classification provides an accurate anatomic description of the degenerative changes seen in the ulnocarpal structures, but it does not dictate treatment, suggest prognosis, or indicate timing of progression.

Deterioration of the ulnocarpal structures is very common regardless of ulnar variance. Numerous cadaveric studies have found TFCC perforations and chondromalacia of the ulnar head, lunate, and triquetrum in up to 70% of “normal specimens.”

Ulnar-positive variance and persistent heavy demand across the ulnocarpal joint can hasten the development of the disease.

An individual’s ability to unload the ulnar side of the wrist with conservative measures and change of lifestyle may slow or even prevent progression.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

The patient history must be detailed and must include:

- Medical history
- Description of previous surgical procedures involving not only the wrist but also the elbow
- Analysis of whether the pain was caused by an acute injury or brought on by repetitive motion activities
  - A distal radius or radial head fracture can lead to ulnocarpal impaction, as can a chronic distal radius physeal injury (ie, the gymnast’s wrist).
- Characterization of the pain
  - Description of the location, duration, and radiation of the pain as well as any associated swelling, burning or tingling sensations, or sounds (clicks, etc.)
- Aggravating and alleviating factors
- The physical examination should always begin with inspection.

**Table 1**  

<table>
<thead>
<tr>
<th>Ulnar Length (mm)</th>
<th>Amount removed of the articular disk of the triangular fibrocartilage complex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
</tr>
<tr>
<td>Neutral</td>
<td>17.6%</td>
</tr>
<tr>
<td>−2.5</td>
<td>3.1%</td>
</tr>
<tr>
<td>+2.5</td>
<td>42.7%</td>
</tr>
</tbody>
</table>

*Removal of two thirds or more of the horizontal portion of the triangular fibrocartilage complex statistically decreased the percentage of force through the nine ulnas tested. (Adapted from Palmer AK, Werner FW. The triangular fibrocartilage complex of the wrist: anatomy and function. J Hand Surg Am 1981;6A:153–162.)
The wrist and elbow should be examined for surgical scars.

Prominence of the ulna either palmarly or dorsally may indicate instability of the DRUJ. A palmar sag and a supination posture of the wrist may indicate the capsuloligamentous instability that occurs in rheumatoid arthritis.

Swelling, bruising, perforations of the skin, or obvious dislocations may indicate trauma.

Intrinsic atrophy and clawing may indicate ulnar nerve pathology.

Splinter hemorrhages beneath the nails and decreased turgor in the volar digital pads suggests vascular insufficiency.

Single-finger palpation should proceed in a systematic fashion by isolating anatomic structures. The examination should be performed with the patient’s elbow resting on a table, the hand pointing toward the ceiling, and the forearm in a neutral position.

Tenderness over any anatomic structure suggests a specific clinical diagnosis.

Active and passive range-of-motion (ROM) maneuvers may illicit pain, suggesting pathology. Limitations of ROM may be the result of swelling or obstruction (blocking). The examiner should listen for sounds of pathology throughout ROM.

Specific provocative tests should be performed in an attempt to further define the injured structure(s).

Piano key test: A positive result is characterized by painful laxity in the affected wrist compared with the contralateral wrist, suggesting DRUJ synovitis.

Ulnar compression test: A positive test is exacerbation of pain, which suggests arthritis or instability; dorsal or palmar subluxation may be noted.

Lunotriquetral ballottement test: Used to elicit laxity associated with pain and crepitus in the presence of lunotriquetral instability.

Reagan shuck test: Positive if pain and clicking at the lunotriquetral joint is present, suggesting lunotriquetral ligament perforation or disruption.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

Plain radiographic views should include neutral rotation posteroanterior and lateral projections of both wrists. These are obtained with the patient seated and the elbow flexed at 90 degrees and the shoulder abducted at 90 degrees.

The contralateral wrist films may be used as a template for reconstruction.

Radiographic assessment of ulnar variance has used a neutral rotation radiographic view of the wrist that provides an image of the radioulnar length with the wrist unloaded. Such views may underestimate variance in wrists in which power grip and pronation result in significant proximal migration of the radius. Tomaino found that ulnar variance increased an average of 2.5 mm using the pronated grip view and ranged from an increase of 1 to 4 mm (FIG 3A).

Other plain views may be obtained based on clinical suspicion.

The carpal tunnel (FIG 3B) view visualizes the hook of the hamate and the pisotriquetral joint.

An oblique view in 30 degrees of pronation (FIG 3C) allows evaluation of the dorsal ulnar wrist.

The reverse oblique view (30 degrees of supination) (FIG 3D) allows evaluation of the palmar ulnar wrist with a profile of the pisotriquetral joint.

An ulnar deviation posteroanterior view (FIG 3E) may reveal lunotriquetral instability or evidence of ulnocarpal abutment. If ulnocarpal abutment is suspected, it is often useful to obtain a posteroanterior radiograph with the forearm in pronation and the fist clenched (Fig 3A), which increases ulnar variance.

Videofluoroscopy is useful for evaluating dynamic ligament instabilities. The wrist should be examined through an entire active and passive ROM as well as with provocative maneuvers in an attempt to demonstrate pathology while reproducing symptoms.

Arthrography may demonstrate a TFCC defect or interosseous ligament disruption if contrast material injected into one compartment leaks into an adjacent space.

MRI can aid in the detection of soft tissue and osseous lesions, including interosseous and extrinsic ligament tears, TFCC defects, tumors, avascular necrosis, and occult fractures (FIG 3F).

Sensitivity of the MRI increases if it is combined with arthrography. The ability to show marrow changes in the
ulnar portion of the lunate and simultaneous central TFCC pathology is very helpful in confirming a diagnosis of ulnocarpal impaction.

- Arthroscopy can confirm a diagnosis suggested by findings from other diagnostic modalities.
  - This is the most sensitive tool for diagnosis of chondral and ligamentous pathology.
  - It has therapeutic applications in the management of ulnar abutment, TFCC defects, interosseous ligament tears, chondral defects, loose bodies, synovitis, and degenerative arthritis.
- Bone scan, ultrasonography, and computed tomography serve a very limited role in the diagnosis of ulnar impaction syndrome.

Differential Diagnosis

- Extensor carpi ulnaris (ECU) subluxation or tenosynovitis
- DRUJ arthritis (degenerative or inflammatory), incongruity, intra-articular pathology, instability
- Ulnar styloid fracture nonunion
- Isolated TFCC tears
- Lunate and triquetrum lesions: chondromalacia, cyst, or interosseous ganglion (lunate/capitate), intraosseous pathology (enchondroma, osteoid osteoma)
- Kienböck disease
- Lunotriquetral instability (trauma or impaction)
- Midcarpal joint arthritis or chondromalacia
- Hamate hook, triquetral, or pisiform fractures
- Flexor carpi ulnaris tendinitis
- Pisotriquetral arthritis
- Guyon canal pathology: ganglion, tunnel syndrome, ulnar artery thrombosis
- Ulnar neuritis

Nonoperative Management

- Rest and avoidance of any aggravating maneuvers are the mainstay of nonoperative management for ulnar impaction syndrome.
- The success of this treatment lies with the patient’s ability to change the way he or she does any number of routine tasks and may involve a change of employment.
- Ice and elevation may help to reduce any swelling associated with overuse or aggravation of a previous injury.
- Nonsteroidal anti-inflammatory medications will also reduce swelling and provide some analgesia.
- Neutral splinting provides support for the wrist and may help to prevent aggravating maneuvers.
- Injection of a steroid and local anesthetic mixture into the wrist may provide some temporary relief of symptoms and decrease swelling.
- An intra-articular injection may also help differentiate intra- and extra-articular disorders.
- A combination of hand therapy modalities (ie, ultrasound, iontophoresis) and patient education may alleviate some symptoms.

Surgical Management

- Surgical treatment of ulnar impaction syndrome is indicated for patients who fail to respond to conservative modalities or those who cannot avoid aggravating maneuvers.
- Patients undergoing ulnar shortening osteotomy must be good surgical candidates, with a high likelihood of healing the osteotomy site.
- Otherwise, an alternative surgical procedure, such as a wafer resection osteotomy, should be considered.
- Wrist arthroscopy is frequently used to document physical findings consistent with ulna impaction syndrome before performing a shortening osteotomy, especially in cases of diagnostic uncertainty even after nonoperative management and injections discussed above.

Commercial Devices for Ulnar Shortening Osteotomy

- Plates and jigs to assist with ulnar osteotomy are commercially available. These offer features such as low-profile plate design, locking screws, simplicity of use, decreased surgical time, and improved accuracy of the osteotomy cuts.
The surgeon must consider whether the potential advantages of these systems justify the additional expense.\textsuperscript{18}

**Preoperative Planning**

- Neutral rotation posteroanterior and lateral radiographs of both wrists demonstrate ulnar variance and the morphology of the DRUJ, helping to determine the degree of shortening required to unload the joint and still provide a congruent articulation.
- In principle, a long ulna should be shortened to neutral or 1 mm of negative variance. If there is ulnar-neutral variance as a baseline, 2 mm of bone should be removed.\textsuperscript{7}
- Care must be taken to prevent excessive shortening of the ulna, as this has the potential to increase pressures across the DRUJ articular surface\textsuperscript{11} and can lead to limitation of forearm rotation.
- The absolute amount of shortening possible is limited by the marginal ligaments of an intact TFCC.
- This is reportedly 15 mm in the setting of posttraumatic ulna impaction syndrome.\textsuperscript{8}
- DRUJ anomalies, congenital disorders, or arthritis should be ruled out.
- DRUJ stability is best assessed with examination under anesthesia.

**Positioning**

- Preoperative antibiotics with a coverage spectrum for skin flora are given intravenously about 30 minutes before the skin incision.
- The patient is positioned supine on the operating table with the upper extremity on an armboard.

### AUTHORS’ PREFERRED TECHNIQUE FOR ULNAR SHORTENING OSTEOTOMY

**Exposure**

- Make an 8- to 10-cm incision over the subcutaneous border of the ulna as previously described (TECH FIG 1A).
- Elevate the ECU muscle–tendon from the distal, dorsal aspect of the ulna to allow sufficient room for a six- or seven-hole AO dynamic compression plate (Synthes LC-DCP, Synthes USA, Paoli, PA) (TECH FIG 1B).
- Take care to avoid disrupting the ECU subsheath distally.

**Osteotomy**

- Position the LC-DCP plate along the distal dorsal ulnar shaft to ensure fit, and prebend it into a very slightly concave configuration to ensure compression of the volar cortex with plate application.
- A 3.5-mm plate is appropriate for most individuals, although a 2.7-mm plate may be used for smaller patients.
- Draw the proposed oblique osteotomy site beneath the third (for a six-hole plate) or fourth (for a seven-hole plate) hole in the plate.
Chapter 95  Ulnar Shortening Osteotomy

The osteotomy is made obliquely in a dorsal to palmar direction so that the osteotomy site can later be secured with an interfragmentary screw applied through the dorsal plate.

The oblique osteotomy angle is about 45 to 60 degrees, and it is typically 5 to 6 cm proximal to the ulnar styloid (TECH FIG 2A).

The orientation of the osteotomy (either distal dorsal to proximal palmar or vice versa) is designed such that the acute angle (point) of the cut bone is adjacent to the plate on the side of the fragment to be compressed. This technique compresses the bone to the plate, avoiding displacement of the osteotomy.

Secure the Synthes small distractor–compressor apparatus over the proposed osteotomy site (along the ulnar border) with four 2.5-mm threaded Kirschner wires (TECH FIG 2B).

Place the pins into the ulna in a region that will later be spanned by the plate to avoid creating unprotected stress risers after removal.

Avoid interfering with the osteotomy when placing the pins by referring to the line drawn at the proposed osteotomy site.

Place the pins palmar enough to allow the plate to be securely seated over the dorsal surface of the ulna.

Kerf thickness varies based on the specific blade used and can be obtained from the manufacturer.8

Make the second parallel osteotomy cut proximal to the first, using a freehand technique, and remove the wafer of bone.

Distract the osteotomy site and inspect it to ensure that there are no bony excrescences or residual uncut bone margins, which could interfere with apposition of the fragments.

**Alternative Osteotomy Technique**

Perform a single osteotomy cut using stacked saw blades. This theoretically removes some of the “human element” and provides a more precise cut with improved apposition of the fragments.

Using a single cut technique, reproducible ulnar shortening with precision within 0.2 mm of the exact desired ulnar variance has been reported.

A relatively steep angled cut (60 degrees) using stacked blades with a kerf thickness of 4.45 mm can allow for up to 9 mm of shortening with a single cut.

Cuts may be made at lesser angles and with lesser kerf thicknesses to allow for lesser degrees of shortening.8

**Ulna Osteotomy**

Remove the plate from the operative field and complete the first osteotomy cut using a precise oscillating blade (TECH FIG 3).

It may be helpful to complete the distal cut first to avoid removing too much distal bone, forcing distal placement of the plate and poor fixation.

Take care to continuously irrigate the bone edges while sawing to avoid thermal necrosis of the bone and periosteum.

The kerf (amount of bone resected by the saw blade itself) must be taken into account when planning the site of the second osteotomy cut to determine accurately the total amount of bone removed.
Reduction and Stabilization

- Dial down the small distractor apparatus to achieve compression at the osteotomy site and bone-to-bone abutment (TECH FIG 4A).
  - A reduction clamp is valuable in guiding and then securing the fragments as compression is applied.
- Examine the radioulnar relationship under fluoroscopy to ensure adequate correction of ulnar variance and DRUJ congruence.
  - Additional bone resection followed by repeat reduction and compression can be easily achieved if necessary.
- Again place the Synthes nonlocking LC-DCP plate on the dorsum of the ulna, and drill screw holes using a compression or neutral drill guide.
  - With the exception of the interfragmentary lag screw hole, directly over the osteotomy site, all screw holes in the plate are drilled using a 2.5-mm drill followed by a 3.5-mm tap (unless self-tapping screws are used).
- First secure the plate with static screws to the fragment with the acute angle (point) on the side away from the plate (palmar in this case, using a dorsal plate).
- Reduce and secure the osteotomy, and then place compression screws in the other fragment, the one with the acute angle (point) adjacent to the plate.
  - Place the first compression screw in the second hole away from the osteotomy.
  - Fill the remaining more proximal holes with either compression or static screws.
- As a final step, insert an interfragmentary lag screw through the osteotomy via the hole in the plate directly over the osteotomy (TECH FIG 4B).
  - Pass a 3.5-mm drill only through the near cortex, followed by a 2.5-mm drill through the far cortex. Tap this hole and fill it with a 3.5-mm bone screw.
  - Once proximal and distal stabilization has been achieved, it may be necessary to remove the 2.5-mm pins to fill the remaining screw holes.

Completion

- Again examine the bone under fluoroscopy to ensure good plate-to-bone and osteotomy site apposition and to assess screw lengths. Make a final assessment of the radioulnar relationship using standard posteroanterior and lateral neutral rotation views (TECH FIG 5).
- Irrigate the wound with normal saline. Close the deep subcutaneous layer with 3-0 Vicryl and approximate the skin edges with interrupted horizontal mattress 4-0 nylon.
- Apply a palmar, forearm-based plaster wrist splint after the tourniquet is deflated and sterile dressings have been applied.
  - The arm is protected in a cast or splint until bony union has occurred.
ULNAR SHORTENING OSTEOTOMY USING AN AO COMPRESSION DEVICE

- Expose the ulna in the manner previously described and plan the osteotomy about 5 to 6 cm proximal to the ulnar styloid.
- Place a five- or six-hole 3.5-mm LC-DCP plate on the flat surface of the distal ulna, centered about the planned osteotomy site, with two or three holes distal, one hole across, and two or three holes proximal to the osteotomy.
- Although the plate may be placed dorsal or volar, palmar positioning of the plate may be preferable to avoid subcutaneous prominences of the hardware after surgery.
- Contour the plate in the manner described above.
- Fix the plate distally with two or three 3.5-mm cortical screws placed in a static mode.
- For a dorsal plate, draw the planned osteotomy on the bone with a marking pen at an angle of about 45 degrees distal dorsal to proximal palmar so that the proximal fragment will compress into the plate (TECH FIG 6).
- Fix the standard AO compression device to the ulna proximally with one unicortical screw and engage the mobile arm in the most proximal plate hole.
- Place the unicortical screw far enough proximal that adequate compression can be obtained. This distance will vary based on the amount of bone to be removed.
- Once shortening is complete and the compression device removed, the empty screw hole must not be too close to the proximal margin of the plate in order to avoid a stress riser.
- Remove the compression device and one distal screw, and loosen the most distal screw slightly, allowing the plate to be rotated away.
- Using a water-cooled oscillating saw, make the distal cut first using the freehand technique.
- Interrupt the osteotomy cut after it is two thirds complete.
- The saw blade may be left in this initial cut to act as a planar guide for the second parallel and proximal osteotomy cut.
- Place a new blade into the saw and make the proximal cut two thirds of the way through the bone.
- Complete the initial distal cut, followed by the proximal cut, and remove the perfectly round wafer of bone.
- Replace the previously removed distal screw and tighten both screws.
- Reapply the compression device and compress the osteotomy.
- Place the screw just proximal to the interfragmentary compression hole in a compression mode using the compression guide.
- Place the interfragmentary compression screw by first drilling a gliding hole through the near cortex with a 3.5-mm drill bit.
- Then, using a drill guide (“top hat”), drill the far cortex with a 2.5-mm drill bit. Measure the hole, tap the far cortex with a 3.5-mm tap, and place the interfragmentary compression screw.
- Remove the compression device and fill the remaining proximal screw hole(s) using the static drill guide.
- Irrigate and close the wound and apply a splint as previously described.

OSTEOCHONDRAL SHORTENING OSTEOTOMY

- Wrist arthroscopy is performed to both stage and treat any ulnocarpal arthritis or TFCC tear that may require débridement or repair.
- After arthroscopy, make a longitudinal incision over the fifth dorsal compartment.
  - Take care to identify and protect the dorsal sensory branch of the ulnar nerve.
  - Incise the fifth extensor compartment, retract the extensor digiti quinti tendon, and create a capsulotomy through the floor of this fifth compartment.
  - Complete the capsulotomy in an L-shaped fashion by extending the incision transversely just proximal to the dorsal radioulnar ligament of the TFCC, thus preserving its stabilizing function for the DRUJ.
- Based on preoperative determinations, resect a 3- to 5-mm wafer of bone using a microsagittal saw at the level of the proximal margin of the DRUJ.
- Leave the distal ulna articular surface and the TFCC foveal attachments intact (TECH FIG 7A–C).
- Reduce and compress the osteotomy with a hemostat and a Kirschner wire placed for temporary stabilization.
- Intraoperative fluoroscopy is used to confirm the adequacy of resection and osteotomy reduction.
- More bone can be removed if necessary, up to 5 mm total.
- Excessive bony resection could lead to DRUJ instability or impingement.
Thread a cannulated headless compression screw over the previously inserted Kirschner wire while manual compression is maintained (TECH FIG 7D,E).
- Remove the Kirschner wire and irrigate the wounds.
- Repair the dorsal capsule with interrupted nonabsorbable sutures.
- Transpose the extensor digiti quinti tendon out of the fifth compartment as the capsule is repaired.
- Close the skin incision with a nonabsorbable monofilament suture, and inject all incisions, as well as the wrist, with a local anesthetic.
- Place the wrist in a bulky dressing with a volar splint.

PEARLS AND PITFALLS
- In very osteopenic bone, the surgeon should consider using a longer plate or locking hardware to achieve better bony purchase (FIG 4).
- Smokers, malnourished patients, and patients with poorly controlled diabetes or vascular compromise have a higher risk of osteotomy nonunion. The surgeon should consider a procedure that does not require bone healing (Darrach or wafer osteotomy).
Ulnar shortening osteotomy should be avoided in patients with DRUJ arthritis. The surgeon should consider unloading the ulnocarpal axis with a Sauvé-Kapandji or Darrach procedure.

The dorsal sensory branch of the ulnar nerve should be protected during the surgical exposure. It runs medial to the ulnar head with the forearm supinated and more palmar with the forearm pronated.\(^2\)

The surgeon should avoid circumferential exposure of the ulna to avoid injury to the segmental blood supply to the ulnar diaphysis, which typically enters the bone from the region of the interosseous membrane.\(^22\)

The ECU subsheath should not be disrupted during the surgical approach.

In smaller patients, the surgeon should consider using a 2.7-mm AO dynamic compression plate.

The Kirschner wires used in the Synthes distractor apparatus should be inserted far enough away from the osteotomy site such that they will not interfere with the osteotomy cuts. They should be biased palmarly in the ulna if dorsal plating is planned. The four pins should be inserted in the region that will be spanned by the plate to prevent creation of an unprotected stress riser. The surgeon should avoid passing the distal pins through the ulna into the radius, as this will prevent shortening of the ulna.

Making the distal cut first may help to avoid placing the plate too distally on the ulna.

The osteotomy site should be continuously irrigated while the bone is being cut to avoid thermal necrosis of the bone and periosteum.

The surgeon should avoid overshortening the ulna, as this can lead to DRUJ instability, loss of forearm rotation, and increased DRUJ contact pressures. Failure to consider the kerf thickness when planning the osteotomy can lead to excessive shortening.

After the cuts are made, the surgeon should distract the osteotomy and inspect for bony excrescences or residual uncut bone margins, which can interfere with apposition of the proximal and distal fragments.

Although the plate may be placed on the dorsal or palmar surface of the ulna, palmar positioning of the plate may be preferable to avoid a subcutaneous prominence of the hardware after surgery in thin or smaller patients.

### POSTOPERATIVE CARE

- Short-arm below-elbow splint immediately postoperatively
- Ice and elevation to assist with swelling control
- Elbow and finger range of motion is encouraged immediately.
- Sutures are removed at 10 to 14 days.
- A removable splint is applied and protected range of motion is started at 6 to 8 weeks, depending on the radiographic appearance of healing.
- More aggressive range-of-motion exercises are started with hand therapy after 8 to 10 weeks if necessary.

### OUTCOMES

Chun and Palmer\(^6\) reviewed their series of 30 wrists in 27 patients with an average follow-up of 51 months. Wrist s were graded preoperatively and postoperatively according to the Gartland and Werley wrist system. Preoperative wrists graded as poor (28) and fair (2) improved to excellent (24), good (4), fair (1), and poor (1) after ulnar shortening osteotomy. They reported no ulnar nonunions, and complications were rare.

Loh et al\(^10\) evaluated 23 wrists at a mean follow-up of 33 months. A statistically significant reduction in pain intensity by visual analogue scale assessment was seen in 77% of patients. Preoperative versus postoperative change in range of motion was not statistically significant, and postoperative wrist function and grip strength also failed to show a statistically significant improvement. Sixty-eight percent of patients complained of local irritation secondary to prominent hardware and 32% eventually had the implant removed.

We do not think that the use of specialized equipment is necessary to achieve accurate cuts and stable fixation for an ulnar shortening osteotomy.

Sunil et al\(^20\) reported no significant differences in duration of surgery, relief of pain, return to work, postoperative complications, time elapsed between surgery and return to work, or osteotomy union in patients undergoing ulnar shortening osteotomy using the Rayhack device versus those undergoing freehand osteotomies.

Braun\(^3\) reported a $650 increase in cost with use of the Rayhack device compared to performing the technique freehand.

Our preferred technique is simple, it does not require specialized equipment (Synthes Small External Fixation and Small Fragment Bone Fixation Systems), it provides for rotational control of the distal segment, it provides compression of the osteotomy site, and it uses only one size of drill bit, tap, and screw except for the single interfragmentary hole at the osteotomy site.

### COMPLICATIONS

- Wound infection and osteomyelitis (rare)
- Hardware fracture (rare with 3.5-mm plate)
- Hardware failure with very osteopenic bone
- Delayed union rates in smokers (7.1 months for smokers versus 4.1 months for nonsmokers)\(^4\)
- Painful, prominent hardware: It is generally not necessary to remove hardware, but 3.5-mm compression plates seem to be removable at 6 to 9 months in symptomatic patients with a low risk for refracture when sequential sets of radiographs confirm healing of the osteotomy site.\(^17\)

### REFERENCES

DEFINITION

- Acute compartment syndrome is a condition in which increased tissue pressure compromises the circulation within the enclosed space of fascial compartments. As a result of this elevated interstitial pressure, the blood supply to the soft tissues is impaired. If left untreated, elevated pressures can cause irreversible muscle and nerve damage resulting in fibrosis and contracture.

ANATOMY

- Compartment syndrome is most common in the forearm and hand but can occur in the arm and in the finger.
- The arm is divided into two fascial compartments, the forearm into three compartments, the hand into ten compartments, and the finger into two compartments.
- The two arm compartments are the anterior and posterior, separated by the medial and lateral intermuscular septa (FIG 1A).

- The anterior arm compartment contains the biceps brachii, brachialis, and coracobrachialis.
- The posterior arm compartment contains the triceps brachii.
- The forearm consists of three compartments: the volar, the dorsal, and the mobile wad of three (FIG 1B).
- The contents of the volar compartment include the flexor muscles and can be subdivided into superficial and deep components. The superficial muscles are the flexor carpi ulnaris, palmaris longus, pronator teres, and flexor carpi radialis. The deep muscles are the flexor digitorum superficialis and profundus, and the flexor pollicis longus.
- The dorsal compartment of the forearm contains the extensor muscles. The superficial extensors include the extensor digitorum communis, extensor digiti minimi, and extensor carpi ulnaris. The deep layer includes the supinator, abductor pollicis longus, extensor pollicis longus, extensor pollicis brevis, and extensor indicis.

FIG 1 • A. Compartments of the arm. (continued)
The mobile wad of three is a distinct muscle compartment that contains the brachioradialis, extensor carpi radialis longus, and extensor carpi radialis brevis.

The wrist has one significant closed space, the carpal tunnel. Although not a compartment in the strictest sense, increased pressure in this tunnel can be detrimental to the median nerve.

The hand contains ten distinct compartments (FIG 1C).

- There are seven compartments for the interossei. Each of the four dorsal and three palmar interossei has a separate compartment.
- The adductor compartment contains the adductor pollicis.
- The thenar compartment contains the abductor pollicis brevis, the opponens pollicis, and the flexor pollicis brevis.
- The hypothenar compartment contains the abductor digiti minimi, flexor digiti minimi, and opponens digiti minimi.
- Compartment syndrome can also occur in the finger due to the limited skin compliance from the multiple fascial attachments.

PATHOGENESIS

- Increased pressure within a compartment decreases the blood supply to the soft tissues and can result in tissue ischemia and ultimately necrosis. The blood flow to a compartment is determined by several factors, including venous pressure, arterial pressure, and local interstitial pressure. Increased capillary permeability results from muscle ischemia. This increased permeability leads to intramuscular edema, increases the tissue pressure, decreases blood flow and oxygen transport, and leads to more tissue damage. It is easy to appreciate the vicious cycle that escalates the pathophysiology of the compartment syndrome.

- Many conditions are associated with compartment syndrome. These can be divided into two major categories:
  - Conditions that decrease compartment volume (tight casts or dressings, burn eschar, limb lengthening or application of traction, increased external pressure on limb from prolonged weight [lying on limb or entrapment under a weight])
  - Conditions that increase compartment contents (bleeding—arterial or venous injury, anticoagulation, trauma, reperfusion injury, edema, infiltrated infusion, snakebite, infection, high-pressure injection)

NATURAL HISTORY

- Compartment syndrome results in hypoxic cell damage and ultimately anoxic cell death. Functional changes occur in muscle after 2 to 4 hours of total ischemia. Hypoxia to nerves causes paresthesia and hypoesthesia within 30 minutes of ischemia, but irreversible nerve damage may not occur until 12 hours or more of total ischemia.
An untreated compartment syndrome can result in permanent neural deficit, tissue necrosis, growth arrest, Volkmann contracture, and even wet gangrene.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- It is important to elicit a detailed history and evaluate the possible causes of compartment syndrome (discussed above).
- Pain out of proportion to physical findings is the most important finding. For patients with this finding, one must have a high clinical suspicion regardless of the presumed severity of the inciting event.
- Most commonly, patients will present with a history of trauma or a crushing injury; however, other causes must not be overlooked.
- Compartment syndrome may involve single or multiple compartments in the extremity.
- Physical examination findings include:
  - A tense, swollen, and tender compartment (FIG 2)
  - Pain with passive stretch of the muscles within the compartment
  - Paresthesias or sensory disturbances in the nerve distribution of the compressed nerve are intermediate findings. This can be accompanied by motor weakness. Motor paralysis is a later finding.
  - Pallor and pulselessness are late findings.
- The findings of pain out of proportion to physical examination, a tense compartment, and pain with passive stretch are sufficient to warrant intracompartmental pressure measurements. One should not delay definitive diagnosis and treatment until later findings are present.

In obtunded or sedated patients, a tense, swollen compartment is sufficient to warrant intracompartmental pressure measurements.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Clinical examination is the cornerstone of the diagnosis, and it is important to have a high degree of suspicion for compartment syndrome.
- Immediate fasciotomy is indicated in patients with unequivocal symptoms and signs of compartment syndrome. Direct measurement of compartment pressures is indicated in all cases when the patient’s symptoms and physical examination signs are indicative of compartment syndrome, and it is especially important in patients who are obtunded or sedated.
- Diagnosis of compartment syndrome of the finger is made clinically and not through the use of pressure measurement.
- Pressure measurement in the arm is made in both anterior and posterior compartments. Anteriorly, the pressure is measured over the biceps muscle, and posteriorly over the triceps muscle.
  - The physician must be careful not to injure the radial nerve when measuring the arm compartment pressure. The nerve courses deep to the triceps in the spiral groove of the humerus. Ten centimeters proximal to the lateral epicondyle, it passes through the lateral intermuscular septum to the anterior compartment.
- In the forearm, the pressure is measured over the palmar, mobile wad, and dorsal compartments.
  - The median and ulnar nerves are at risk during measurement of the palmar compartment. The ulnar nerve courses deep to the flexor carpi ulnaris in the ulnar forearm; the median nerve is between the flexor digitorum superficialis and profundus muscles.
  - When measuring the mobile wad, the superficial branch of the radial nerve is deep to the brachioradialis in the forearm but emerges between the brachioradialis and extensor carpi radialis longus tendons about 8 cm proximal to the radial styloid.
  - The posterior interosseous nerve courses around the radial neck in the proximal radial forearm and should be avoided when measuring the mobile wad and dorsal compartments.
- In the hand, pressure measurements should be made in the affected compartments; measurements are generally made in the area of the planned incisions.
  - There is not an absolute increased compartment pressure that warrants fasciotomy. When the pressure approaches 30 to 45 mm Hg, or 30 mm Hg less than the diastolic pressure, with concordant physical examination findings, decompressive fasciotomy should be performed. In the hand, lower pressures (15 to 20 mm Hg) may indicate compartment syndrome.
  - Plain radiographs should be performed to evaluate any underlying bony abnormality. Fractures and dislocations should be reduced as anatomically as possible.
  - Arterial injury can lead to ischemia and can present similarly. Arteriography is indicated if the history may be significant for arterial injury (fracture, avulsion, or laceration).

**DIFFERENTIAL DIAGNOSIS**

- Arterial injury
- Nerve injury

---

**FIG 2** Diffuse, tense swelling of the hand. A. Palmar view with loss of palmar concavity. B. Radial view.
NONOPERATIVE MANAGEMENT

- There is no role for nonoperative management of an acute compartment syndrome. In acute cases of compartment syndrome with elevated compartment pressure, prompt decompressive fasciotomies are required to relieve tissue ischemia.
- In patients with early symptoms and signs of compartment syndrome, but without elevated compartment pressures, removal of all compressive dressings and casts, and elevation of the affected extremity to the level of the heart is indicated.
- Frequent close monitoring by physical examination and repeated pressure measurements as necessary are critical.
- In patients presenting late with aseptic muscle necrosis, acute fasciotomy and débridement may not be indicated.

SURGICAL MANAGEMENT

Preoperative Planning

- The surgeon should review radiographs and plan for surgical stabilization as necessary.

Positioning

- The patient is positioned supine on the operating table with the upper extremity on an armboard.

SURGICAL MANAGEMENT

Preoperative Planning

- The surgeon should review radiographs and plan for surgical stabilization as necessary.

Positioning

- The patient is positioned supine on the operating table with the upper extremity on an armboard.

Tourniquets are not routinely used during decompressive fasciotomy.
- If the arm is affected, the shoulder and axilla are included in the sterile field to allow exposure to the entire extremity.

Approach

- Skin is considered a significant compressive structure, and it is important to create a skin incision of sufficient length to allow complete decompression. Cosmesis is not a concern.
- Incisions are planned to afford complete and rapid decompression of the compartments while maintaining coverage of vital structures and avoiding joint contractures due to scarring.
- The viability of muscles is determined by muscle tone and color, contractility, and bleeding.
- If the viability is still unclear, the muscle should be left alone and re-inspected in 24 to 48 hours.
- The skin is left open and the wounds are copiously irrigated and covered with wet saline dressings. Occasionally, a wound vacuum dressing can be applied to facilitate care and reduce edema and pain associated with frequent dressing changes.
- Once the wound is considered to be stable and clean, the skin can be closed if under no tension. If tension is present, split-thickness skin grafts are usually applied.

DECOMPRESSION OF THE ARM

- Compartment syndrome of the arm is rare. It can be approached from the lateral, posterior, or anteromedial approach.
- The choice of incision may be based on the need for fracture fixation.\(^1,2\)
- The lateral approach begins at the deltoid insertion and extends to the lateral epicondyle. The fascia overlying the biceps anteriorly and triceps posteriorly is split through the incision (TECH FIG 1A).
- The anteromedial approach extends from the medial epicondyle toward the axilla, and the fascia overlying the biceps and triceps is split (TECH FIG 1B). This incision can be continued from the forearm skin incisions.
- The ulnar nerve must be protected in this approach.
- For isolated posterior compartment syndrome, a posterior incision can be made from 8 cm distal to the acromion to the olecranon\(^5\) (TECH FIG 1C). The triceps fascia is directly exposed and incised.
- The radial nerve runs between the long and lateral heads of the triceps and is at risk during muscle débridement.

TECH FIG 1 • A. Lateral approach to the arm. B. Anteromedial approach to the arm. C. Posterior approach to the arm.
DECOMPRESSION OF THE Volar Forearm

- Design a curvilinear incision from the carpal tunnel to the antecubital fossa. A complete carpal tunnel release is indicated if symptoms of median nerve compression are present (TECH FIG 2).
- Start the incision distally between the thenar and hypothenar eminences in line with the radial border of the ring finger. Release the skin, palmar fascia, and transverse carpal ligament.
- Continue the incision proximally to the distal wrist crease, then curve it ulnarly to the pisiform and extend it proximally along the ulnar side of the distal forearm.
  - This prevents exposure of the flexor tendons and median nerve and protects the palmar cutaneous branch of the median nerve.
- Curve the incision radially in the mid-forearm and then just anterior to the medial epicondyle at the elbow.
  - Creation of this flap provides coverage of the median nerve.
- At the antecubital fossa, curve the incision slightly anteriorly to meet the incision of the arm, if necessary.
  - This prevents a linear incision at the level of the elbow and provides coverage for the brachial artery.
- Release the fascia covering the superficial and deep compartment of the forearm, as well as the mobile wad, through this incision. Release the lacertus fibrosis at the elbow. Release individual muscle fascia if release of the compartment fascia does not relieve the pressure within each muscle.
- Loosely close the wound over the carpal tunnel; it is generally left open over the forearm.
  - If the swelling is mild, the fascia may be left open and the skin closed, or the skin edges may be approximated with a vessel loop-stapling technique.
  - If the wound is left open, it is covered with a sterile nonocclusive dressing. Alternatively, a VAC dressing may be applied.
- An alternative incision uses the Henry approach between the brachioradialis and the flexor carpi radialis, connecting to the carpal tunnel distally and proximally crossing the antecubital fossa obliquely from radial to ulnar.
  - If this approach is used, take care not to injure the palmar cutaneous branch of the median nerve at the wrist.

TECH FIG 2 • Incision for decompression of the palmar forearm. Note the incision in the hand used here for release of the thenar compartment.

DECOMPRESSION OF THE DORSAL FOREARM

- In the forearm, release of the volar compartment and mobile wad may decrease the pressure in the dorsal compartment. Once the palmar fasciotomy has been performed, the dorsal compartment should be re-evaluated for the need for fasciotomy.
- Make a longitudinal dorsal incision just ulnar to the tubercle of Lister and extending proximally toward the lateral epicondyle. Release the fascia over the dorsal compartment (TECH FIG 3).
- Release individual muscle fascia if necessary.
- If posterior interosseous nerve involvement is suspected, separate the extensor carpi ulnaris and extensor digitorum communis muscles to expose and release the fascia overlying the supinator.
- The wound is managed in a similar way to that described for the volar forearm fasciotomy.

TECH FIG 3 • Incision for approach to the dorsal forearm.

DECOMPRESSION OF THE HAND COMPARTMENTS

- To release the four dorsal and three palmar interosseous compartments and the adductor compartment, make two dorsal longitudinal incisions over the second and fourth metacarpals (TECH FIG 4A).
- Take the incisions to the level of the extensor tendons. Avoid the sensory branches of the radial and ulnar nerves, and preserve dorsal veins to minimize postoperative edema.
Retract the extensor tendons and the dorsal surface of the metacarpal. Release the dorsal compartments on each side of the metacarpal (the first and second dorsal compartments are reached on either side of the second metacarpal, and the third and fourth dorsal compartments are found on either side of the fourth metacarpal). Continue blunt dissection palmarly through the dorsal interosseous to release the three palmar interosseous compartments.

Release the adductor compartment through the incision over the second metacarpal.

Release the thenar compartment through a longitudinal incision along the radial border of the thumb metacarpal, and release the hypothenar compartment through an incision along the ulnar border of the fifth metacarpal (TECH FIG 4B). Split the underlying fascia longitudinally.

The wounds are left open (TECH FIG 4C) and the hand is placed in a bulky splint in intrinsic-plus position (metacarpophalangeal joints flexed 70 degrees and interphalangeal joints extended).

DECOMPRESSION OF THE FINGER

Make longitudinal midaxial incisions along the finger. These incisions are made by connecting the most dorsal portions of the joint flexion creases (TECH FIG 5A). These are more easily seen with the finger in flexion.

Avoid making a more palmar, midlateral incision to prevent postoperative flexion contracture.

Carefully divide the transverse retinacular ligament and Cleland’s ligament to release the neurovascular bundles on both radial and ulnar sides (TECH FIG 5B).

If possible, loosely approximate the skin.

TECH FIG 5 • A. Incision for the release of the finger. Dots are placed at the apex of each flexion crease, and connecting the dots provides the midaxial line. B. Division of the transverse retinacular ligament and Cleland’s ligament.
POSTOPERATIVE CARE

A second look is planned 48 to 72 hours after the index procedure.
- Additional débridement of devitalized tissue is performed. Serial débridements are performed until no devitalized tissue remains.
- Delayed primary closure of the skin (not fascia) may be possible. More frequently, split-thickness skin grafting is performed to cover the wounds (FIG 3). If significant soft tissue has been lost with exposed tendon, nerve, or bone, flap coverage is planned.
- Wound coverage should be performed as soon as possible to minimize complications such as infection, desiccation, and amputation.
- The upper extremity should be elevated and splinted in an intrinsic-plus position. Gentle active and active assisted range of motion of the hand, wrist, and elbow should be initiated as soon as swelling begins to subside, generally within 2 to 3 days after wound closure. Placement of a flap or skin graft may preclude motion at certain joints, but unaffected joints should be ranged.

OUTCOMES

- The outcome after compartment release depends both on the severity of the initial injury and the time elapsed before release.
- Patients with prompt diagnosis and treatment and limited devitalized tissues generally have favorable outcomes.
- Patients with severe initial injuries, delayed treatment, or extensive tissue necrosis have a more guarded prognosis for functional recovery of the upper extremity.

COMPLICATIONS

- Volkmann ischemic contracture is the result of untreated acute compartment syndrome.
- Necrosis and fibrosis of the muscle occur, with a resultant claw hand deformity. This deformity is due to extrinsic flexor and extensor contracture with concomitant intrinsic muscle dysfunction.
- Nerve dysfunction results either from the initial ischemic injury or from subsequent compressive neuropathy due to the dense scarring of the tissues surrounding the nerves.
- The deeper compartments are more severely compromised, with the flexor digitorum profundus alone affected in milder cases, and fibrosis of all muscles in the most severe.

REFERENCES

DEFINITION
- Since the beginning of the Industrial Revolution and the advent of industrial machinery, high-pressure injuries have been reported in the literature.
- The force needed to break the skin is 100 pounds per square inch (psi). In general, high-pressure injuries are forced into the tissues at a pressure of 141 to 703 kg/cm² (2000 to 12,000 psi)\(^8\) (FIG 1).
- The substances typically injected include grease, paint, paint thinners, diesel fuel, oil, water, and cement. Cases involving molten metal,\(^4\) dry cleaning solvents,\(^10\) and veterinary vaccines\(^6\) also have been documented.

ANATOMY
- The site of injection and pressure helps to determine the extent of injury.
  - Kaufman\(^{14,15}\) found that fingers that were injected with wax experienced tissue injury until a point of resistance was encountered. In the digits, the limiting factors to the extent of injury are the pulleys. He noted that the cruciate pulleys are pliable and thin, whereas the annular pulleys are rigid.
  - If the injection occurs at the level of the proximal or distal interphalangeal joints (PIP or DIP joints), the substance injected will dissect through the tendon sheath.\(^{14}\)
  - The synovial sheaths of the index, long, and ring fingers extend to the metacarpophalangeal joint; the synovial sheaths of the thumb and little finger extend into the proximal palm at the radial and ulnar bursae.\(^9\)
  - Any injections that occur over the middle segments of the fingers, away from the joints, will be diverted around the digit and spread laterally in the superficial tissues.\(^{14}\)
  - Based on this information, the proximal spread of material can be predicted.
  - Injections into the palm, thenar, and hypothenar eminences are generally contained in those myofascial spaces and lead to less permanent impairment.\(^{18}\)
  - The morbidity is determined by the volume, pressure, viscosity, resistance of the tissues, location of injection, anatomy of the compartment, and toxicity of the material injected.

PATHOGENESIS
- High-pressure injuries are divided into three stages.
  - The acute stage occurs immediately.
    - The injection causes compression and spasm of the vessels, leading to compromised blood flow. This is manifested by white, mottled tissue; numbness; severe pain; or a combination of these findings.
    - Any initial paresthesias that occur are due to local compression or chemical irritation of the digital nerves.
    - During this stage, the site of injection is key in determining where the material has spread. Very high pressures can overcome tissue resistance.
    - The volume of material injected also determines the degree of tissue distention and impairment in blood flow.
    - In several studies by Gelberman,\(^8\) Schoo,\(^{25}\) and Hayes,\(^{12}\) patients with hands that had higher-volume injections and longer time to decompression had higher morbidity rates.
  - During the intermediate stage, a foreign body reaction induces oleogranuloma formation and fibrosis.
    - The inflammation that occurs is determined by the volume and type of substance.
    - The injection of paint solvent has a significantly higher morbidity due to its low viscosity, allowing diffusion through the soft tissues. Its corrosive effects cause severe tissue necrosis.\(^9\)
    - Patients with grease injections have more chronic inflammatory reactions, leading to prolonged sequelae (foreign body granulomas).\(^{12,26}\)
    - Schoo\(^{25}\) reported that amputation rates associated with various injection injuries were as follows: paint thinner, 80%; paint (soya alkyl base), 58%; automotive grease, 23%; and hydraulic fluid, 14%.
  - The late stage of injury occurs when the granulomas break open, resulting in draining sinuses and cutaneous lesions.
    - Chronic sinuses may degenerate into malignancies (squamous epithelioma).\(^{7,25}\)
    - Secondary infections may occur in this stage; these may be due to Staphylococcus aureus, Streptococcus epidermidis, Pseudomonas spp., or a variety of polymicrobial flora.\(^{23,24}\)

FIG 1 • An innocuous-appearing puncture of the volar radial surface of the right small finger. This may be the only visible point of injury in a high-pressure injection injury.
NATURAL HISTORY
- Most patients with high-pressure injection injuries are young men. These injuries occur more commonly among manual laborers (FIG 2).
- Previously it was thought that most of these injuries occurred to people who had been on the job for less than 6 months, but more recent studies show that the mean time on the job was 11 years.\(^1\)\(^1\),\(^3\)\(^1\)
- The nondominant hand (58%–76%)\(^7\),\(^1\)\(^1\) is injured more often than the dominant hand.
- The index finger, thumb, palm, and small finger are affected in descending order.
- Controversy continues as to what induces the inflammatory response in these injuries.
- Some authors have suggested that the injury overwhelms the patient, leading to morbidity, whereas others believe that the injury induces a significant inflammatory response.
- Most agree that surgery should be done within the first 3 hours after injury to decrease the morbidity.\(^2\)\(^7\),\(^2\)\(^8\)

PATIENT HISTORY AND PHYSICAL FINDINGS
- Important factors to discover include the patient’s hand dominance and occupation; the sequence of events post-injury; and the type of injector and pressure, as well as the substance injected.
- Comorbidities, including vascular disease, diabetes, and smoking history, are relevant risk factors that influence healing and post-treatment function.\(^1\)\(^8\)
- If possible, the material safety data sheet (MSDS) for the substance injected should be obtained from the company.
- Physical examination should include:
  - Determining the location of the puncture site to determine the spread of the injectate. It is not uncommon for the site of injury to be small and difficult to find.
  - Observing range of motion when the patient attempts to form a fist
  - Palpation of the digit, hand, and arm to help determine the extent of débridement that will be required

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographs of the hand and forearm are helpful in evaluating the extent of injury.
- Although not all injected substances are radiopaque, air may be present in the compartments of the hand and forearm, which may help in determining how far the substance has traveled.\(^2\)\(^0\),\(^2\)\(^3\),\(^3\)\(^0\)
- It may be necessary to obtain radiographs of the arm and chest. Extension into the arm, chest wall, and mediastinum from injuries to the hand has been reported.\(^2\)\(^9\)
- Imaging studies also document pre-existing pathology.

DIFFERENTIAL DIAGNOSIS
- Snake bite
- Spider bite
- Crush injury
- Suppurative tenosynovitis
- Black thorn tenosynovitis
- Mycobacterium marina infection (chronic)

NONOPERATIVE MANAGEMENT
- Most injuries require surgical débridement, and there are only few case reports of nonoperative management for such injuries.
- Cases that are managed without surgery include air injection into the hand, which leads to subcutaneous emphysema that resolves within hours to days\(^1\)\(^7\) or, occasionally, water injection that is managed conservatively.\(^1\)\(^6\)

SURGICAL MANAGEMENT
- Early and aggressive decompression and débridement of all tissues is the cornerstone of treatment.
- The time from injury to surgery is the major determinant of morbidity and prognosis in high-pressure injection injuries.\(^2\)\(^7\),\(^2\)\(^8\)

Preoperative Planning
- Radiographic studies should be reviewed.
- Attention should be paid to radiopaque areas of the hand and forearm.
- Air in the soft tissue should be evaluated.
- The bones should be evaluated for any possible fractures or pre-existing lesions.
- Any intravenous lines should be placed in the patient’s non-injured extremity, and manipulation of the injured extremity should be limited.

Positioning
- The patient should be placed supine with the arm abducted.
- The arm should not be exsanguinated with an Esmarch bandage, to avoid proximal spread of the injected material and further trauma to the tissues.
- Regional anesthesia can be used to avoid general anesthesia, if necessary, but local blocks and injections should not be performed.
- If the IV regional (Bier) block is selected, gravity exsanguination is performed without a compression wrap but with 4 minutes of elevation.

Approach
- Two basic techniques are used to approach high-pressure injection injuries. Both are based on the idea of wide débridement, limited by scar formation over joint areas.
BRUNER’S INCISIONS

- The hand is prepped and exsanguinated by elevation.
- For longitudinal exposure of the digits, it is important to avoid crossing the joint creases in a straight line. This is accomplished by creating Bruner zigzag incisions at the joint creases.
  - The digit is incised to avoid crossing the flexion creases so that no longitudinal incisions are made through the crease itself (TECH FIG 1A).
  - The injectate is removed, avoiding the neurovascular bundles located on the volar radial and volar ulnar surfaces of the digits.
  - The incision is extended to the palm, if necessary. The palmar incisions also are placed in such a manner as to avoid postoperative contracture of the crease (TECH FIG 1B).
  - If extension is necessary proximal to the wrist crease, the incision should be angled with the point toward the ulnar surface to avoid injury of the palmar sensory branch of the median nerve (TECH FIG 1C).
  - Extension onto the forearm may be longitudinal or in an S curve, if compartment decompression is necessary\(^1\) (TECH FIG 1D).

### TECH FIG 1

- Bruner’s incision of the right index finger. A. The incision was made for adequate exposure to remove grease debris in the finger while avoiding crossing the joint creases. B. The incision is extended to the palm to allow for visualization of affected tissues and further débridement. C. Incision across the wrist crease. Crossing the crease is avoided by creating a Bruner’s incision or a curvilinear incision at the wrist crease. D. Longitudinal extension of the incision into the forearm. High-pressure injectate was pushed into the forearm tissues.

MIDAXIAL INCISIONS

- Longitudinal midaxial incisions are made on the digit, radially and ulnarily.
  - These incisions are made dorsal to the neurovascular bundles (TECH FIG. 2).

### TECH FIG 2

- Midaxial incision of the finger. This will sacrifice the dorsal branches of the neurovascular bundle, but the digital nerve and artery are protected in the volar tissues.

- The incision is continued across the palm, if necessary. If extension onto the palm is necessary, then it may be necessary to cross the web space, including the neurovascular bundles, but it must not be divided.
- Incision across the palm continues as described for Bruner’s incision.\(^3\)
MODIFIED BRUNER’S INCISION

- The digit is incised with a Bruner’s incision distal to the flexion crease, extending to the lateral aspect of the skin on the volar digital skin (TECH FIG 3A).
- At the flexion crease, a transverse incision is made through the flexion crease, and the next interphalangeal incision is another oblique Bruner’s incision (TECH FIG 3B).
- This is continued along the length of the digit onto the palm.

TECH FIG 3 • **A.** Modified Bruner’s incision with transverse extensions at the interphalangeal flexion creases allows for a widened visual field and more complete débridement. **B.** Modified Bruner’s incision at the metacarpophalangeal joint crease allows for visualization of the A1 pulley system, the neurovascular bundles, and the surrounding soft tissues.

PEARLS AND PITFALLS

- Understand that the underlying pathology usually will be worse than the external wound.
- Comorbidities are critically important in management of patients with injection injuries.
- Obtain the Material Safety Data Sheet (MSDS) to understand the toxic effects of the injected material.
- Exploration should extend to clearly healthy tissue. Avoid “minimally invasive” treatment.
- Leave the wound open or very loosely closed.

POSTOPERATIVE CARE

- The wound should be left open and packed, or very loosely closed. The hand should then be splinted in the “safe” position (FIG 3A,B).
- Any additional débridement should be performed at 48-hour intervals, as necessary, until the wound can be primarily closed or covered (FIG 3C).
  - Less involved injuries often are allowed to heal by secondary intention, especially if critical structures are covered.
  - Occasionally, free tissue transfer may be necessary for coverage.5,22
- Parenteral corticosteroids have been advocated to decrease the inflammatory response postoperatively.
- The possibility of increasing the infection rate with corticosteroids does exist, although neither animal data nor human clinical findings show such an increase.
- Animal studies have suggested that corticosteroids may be beneficial for patients sustaining injections of organic solvents.
- No convincing human data have been published that show that corticosteroids are effective in limiting tissue loss, and they should be used cautiously.13,21

OUTCOMES

- Outcomes of high-pressure injection injuries are based on the volume, pressure, viscosity, resistance of the tissues, location of injection, anatomy of the compartment, and toxicity of the material.
- Morbidity includes cold intolerance, hypersensitivity, paresthesias, constant pain, impairment of the activities of daily living, infection, oleoma formation (FIG 4A), squamous degeneration,25 and amputation.
- Amputation rates ranging from 14% to 88% have been reported in the literature.12,19,25
- The highest amputation rates are associated with organic solvent injection into the fingers.13
- In this subset of patients, the time to débridement also had a significant impact on the amputation rate.
  - If surgery occurs within 6 hours of injury, the amputation rate is 40%.
  - If the surgery is delayed for more than 6 hours, the amputation rate increases to 57%.
  - If débridement is delayed to more than 1 week after injury the amputation rate is 88%.13
- Metacarpophalangeal range of motion decreases an average of 8.1%, proximal interphalangeal range of motion decreases...
23.9%, and distal interphalangeal range of motion decreases by 29.7%.
- Maximum grip strength diminishes by 12%, and pinch strength decreases by 35%.
- Two-point discrimination increases by 49%31 (FIG 4B,C).
- Permanent partial impairment of the injured hand depends on the mechanism of injury and the time to treatment.

- The average impairment for injuries caused by spray guns is 15%, by pneumatic hoses less than 2%, and by hydraulic fluid 6%.30
- If treatment is delayed more than 6 hours after injury, then the permanent impairment rate is approximately 17%; however, if treatment is obtained in under 6 hours, that rate is only 4%.30
- Loss of work related to these injuries also varies, from 6 to 26 weeks, with about 92% of patients returning to their previous jobs.12
COMPLICATIONS

- Infection
- Cold intolerance
- Hypersensitivity
- Oleoma formation
- Malignant degeneration
- Decreased range of motion and function
- Paresthesias
- Diminished two-point discrimination
- Amputation

REFERENCES

Replantation is the reattachment of a completely amputated body part.
Revascularization is the restoration of circulation and repair of all injured structures in an incompletely amputated, dysvascular body part. Revascularization always includes repair of the arteries to re-establish blood flow to the part.
Revision amputation is the procedure performed at the site of amputation to gain soft tissue coverage and to address concomitant injuries to the digit.
The decision of whether to perform replantation or revascularization and revision amputation of a digit is multifactorial. The relative indications and contraindications for each are discussed later in the chapter.

ANATOMY
An understanding of the anatomy over the complete length of the digit is essential for successful replantation. The anatomy of the thumb is different from that of the four fingers.
Palmar and dorsal cutaneous ligaments maintain the position of the neurovascular bundle during range of motion of the digit.
Grayson’s ligament is palmar to the neurovascular bundle, originates from the flexor tendon sheath, and inserts on the skin.
Cleland’s ligament travels dorsal to the neurovascular bundle from the phalanx to the overlying skin.
A radial and ulnar proper digital artery supplies each digit. Each vessel travels with a respective radial and ulnar proper digital nerve. At the level of the digit, the artery lies dorsal to the nerve.
The ulnar digital artery is typically larger in the thumb and index finger. The radial digital artery usually is larger in the small finger.
Three major palmar arches arise from the digital arteries. The proximal, middle, and distal arches are consistently located at the level of the C1 pulley, C3 pulley, and just distal to the flexor digitorum profundus (FDP) insertion, respectively.
Four palmar and four dorsal branches usually extend from each digital artery.
Injection studies have demonstrated that the venous system of the digit consists of a series of arcades on the dorsal and palmar surfaces, with connecting oblique and transverse anastomotic veins. The dorsal veins have a larger caliber than the palmar veins, which do not consistently travel with the digital artery and nerve.
A radial and ulnar proper digital nerve travels with each proper digital artery. The digital nerve is sensory only and typically contains one to three fascicles. It trifurcates at the level of the distal interphalangeal (DIP) joint.
Each finger has two flexor tendons within the flexor tendon sheath.
The FDP tendon inserts at the proximal base of the distal phalanx.
The flexor digitorum superficialis (FDS) tendon inserts as two slips into the midportion of the middle phalanx. The FDS tendon splits into two slips, and its relative position to the FDP tendon switches from palmar to dorsal at Camper’s chiasm. This allows the deeper FDP tendon to continue to its more distal insertion.
There are a series of five annular and three cruciform pulleys, which are discrete thickenings of the fibro-osseous sheath. The annular pulleys prevent bowstringing of the flexor tendons during flexion, whereas the cruciate pulleys are collapsible, accommodating flexion.
The odd-numbered annular pulleys are located over the joints of the finger, and the even-numbered annular pulleys are over the proximal and middle phalanx, respectively.
The A2 and A4 pulleys are most important in preventing bowstringing and should be preserved if possible.
Each lesser digit receives a tendon from the extensor digitorum communis (EDC). The index and small fingers each have a second extensor tendon, the extensor indicis proprius (EIP) and extensor digiti minimi (EDM), respectively. Both of these tendons are ulnar to the EDC tendons.

PATHOGENESIS
The mechanism of injury has a considerable effect on the potential for replantation.
Sharp amputations are ideal for replantation because of the narrow zone of injury.
The degree of tissue injury increases substantially with crush and avulsion mechanisms and may prohibit successful replantation (FIG 1).
Most digit amputations occur as an isolated injury. When amputations occur in the multiply injured patient, consideration of other systemic injuries and adherence to ATLS (Advanced Trauma Life Support) protocols may prevent replantation.

NATURAL HISTORY
Replantation of an amputated digit results in longer hospital stays and more prolonged rehabilitation than revision amputation. Patient satisfaction, however, usually is higher with replantation than with revision amputation or a prosthesis.
Functionally, the expected range of motion in a replanted digit is 50% of normal.
Secondary procedures, such as tenolysis, are common.
The literature reports rates of reoperation ranging from 3% to 93%. In a series of more than 1000 replants and revascularizations, 35% of patients required at least one secondary surgery. The incidence is higher for replantations than for revascularizations.
Expected survival rates of replanted digits are 80% or higher, with even higher survival rates in revascularized digits.
PATIENT HISTORY AND PHYSICAL FINDINGS

- The surgeon must evaluate the patient in the emergency room immediately on arrival. A complete history and physical examination are performed.
- The history should include specific details regarding the mechanism and timing of the injury. Identification of the specific machinery involved often reveals valuable information about potential contamination and the pattern of injury sustained by the amputated part.
- A history of mental instability is relevant, because rehabilitation protocols require significant patient compliance to maximize functional outcomes. Furthermore, self-inflicted amputations are unlikely to yield the same functional results after replantation as accidental amputations.
- A history of medical comorbidities should be thoroughly evaluated. Conditions such as diabetes, peripheral vascular disease, hypercoaguability, and tobacco use are not absolute contraindications to replantation but must be considered.
- Similarly, the surgeon must evaluate for medical conditions that prevent the patient from tolerating the blood volume changes associated with major limb replantation. Revision amputation may be the best choice if the patient has a history of previous trauma or arthritis in the amputated part.
- Ischemia time and method of transport should be evaluated for appropriateness. In the digits, a warm ischemia time of less than 6 hours is desired. In more proximal amputations containing muscle, ischemia time is more critical.
  - Cooling the amputated part reduces metabolic acidosis, bacterial growth, and muscle necrosis. Cold ischemia times of up to 12 hours are tolerated for replantation of digits. There are reports of successful replantation of digits with warm ischemia times of 42 hours and cold ischemia times of 96 hours.\(^1\,2\,4\)
  - Proper transportation of the amputated part is essential. Never place the part directly on ice. The part should be wrapped in a sterile gauze moistened with Ringer’s lactate or normal saline. The gauze is then placed in a leak-proof plastic bag and the bag is placed on ice (FIG 2). The goal temperature is 4°C.
  - Alternatively, the part may be immersed in Ringer’s lactate or normal saline in a plastic bag with the bag then placed on ice.
  - The surgeon examines the part and the injured extremity to evaluate suitability for replantation. The number of digits, level of injury, and type of injury are assessed.
  - Specifically, the surgeon evaluates the injured parts for the red-line sign and the ribbon sign.
    - The red-line sign refers to a red streak of ecchymosis along the lateral border of the digit, which is the result of hemorrhage from avulsed branches of the digital artery after a traction injury (FIG 3).
    - The ribbon sign also represents an avulsion injury. Coiling of the artery at the amputation site results from
disruption of the vessel wall layers from traction. If re-plantation is attempted, vein grafting is required.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- When the patient arrives in the emergency department, standard radiographs of the amputated parts and the injured limb are obtained (FIG 4).
- Laboratory evaluations should include a complete blood count, basic metabolic panel, coagulation panel, drug screen, and blood type and crossmatch. Other preoperative tests are ordered as indicated by the patient’s age and comorbidities.

NONOPERATIVE MANAGEMENT

- There is no role for nonoperative management of these injuries.
- Some surgeons advocate performing revision amputations in the emergency department under local anesthesia. It has been our experience that these procedures are best performed in the operating room with appropriate anesthesia, hemostasis, sterile conditions, lighting, and equipment.

SURGICAL MANAGEMENT

- The decision to replant a digit is predicated on the determination that the anticipated function after replantation will be better than that of a revision amputation. This determination is made after careful consideration of the factors influencing the predicted survival of the replanted digit, morbidity to the patient, and functional outcome.
- Specific factors related to the status of the amputated part and the status of the patient include:
  - Mechanism of injury (eg, sharp, crush, avulsion)
  - Level of amputation
  - Ischemia time (warm or cold)
  - Health of patient
  - Age of patient
  - Presence of segmental injury
  - Predicted rehabilitation
  - Vocation and hobbies
- Informed consent for replantation versus revision amputation must reference the postoperative care differences.
  - Patients undergoing revision amputation typically are discharged from the hospital much quicker and have much shorter, less intensive rehabilitation protocols.
  - Patients treated by replantation typically require a 5- to 7-day hospital course, avoidance of smoking and caffeine, possible blood transfusions, and prolonged rehabilitation. Furthermore, these patients must be advised about the likelihood of cold intolerance.
- The techniques we use for replantation of amputated digits are described in detail in the following sections. The same techniques and sequence of repair are followed for the revascularization of partially amputated parts.
  - In partial amputations, not all structures will be injured, so it may be that only some structures require repair. For example, if the dorsal skin and its veins remain intact, the procedure does not require venous anastomosis for outflow.
  - Each case should be examined individually, and all structures should be carefully evaluated for injury.

Preoperative Planning

- Broad-spectrum antibiotics and tetanus prophylaxis are administered on presentation in the emergency department.
- The patient, hand, and amputated parts are examined to confirm suitability for possible replantation.
- A urethral catheter should be placed for long procedures.
- Regional anesthesia is preferred due to the autonomic block, which yields increased peripheral vasodilation. Ideally, an indwelling catheter is placed to allow for continuous postoperative pain relief and sympathetic block. General anesthesia is required for children.
- If an attempt at replantation is determined to be appropriate and desired, the parts are brought to the operating room as soon as possible. Initial preparation of the parts can begin while the anesthesia team evaluates the patient.
- The operating room and patient must be kept warm to prevent peripheral vasoconstriction.
- The sequence of repair is as follows:
  1. Débridement and identification of structures
  2. Bone shortening and fixation

FIG 3 • The red-line sign, which represents an avulsion injury, is seen clinically as a red streak of ecchymosis along the lateral border of the digit. This ecchymosis is the result of hemorrhage from avulsed branches of the digital artery after a traction injury. The ribbon sign, which also represents an avulsion injury, refers to the corkscrew appearance of the digital artery resulting from disruption of the vessel wall layers. When these clinical signs are present, the zone of injury must be bypassed with vein grafts if replantation is attempted.

FIG 4 • A. Standard PA radiograph of the injured hand. B. A radiograph of the amputated parts is also obtained by placing the bag containing the parts directly on the x-ray cassette.
3. Extensor tendon repair
4. Flexor tendon repair
5. Arterial repair
6. Nerve repair
7. Vein repair
8. Skin closure/coverage

**Positioning**
- The patient is positioned supine on a standard operating room table with a hand table attachment. The table is rotated 90 degrees to allow access for the operating microscope and fluoroscopy.

**Approach**
- Slightly dorsal midaxial incisions are made on both the radial and ulnar sides of the digits. These incisions allow for rapid identification of both the neurovascular bundles and the dorsal veins. Both the palmar and dorsal flaps can be reflected as needed (**FIG 5**).

**PREPARATION OF THE AMPUTATED PART**
- A two-team approach is used. One team prepares the amputated part while the other team prepares the patient.
- The parts should continue to be kept cool until they are reattached. A sterile prep table and a sterile covered ice-filled basin are required for preparation of the parts (**TECH FIG 1**).
  - A sterile metal irrigation basin is filled with ice and covered with a sterile adhesive drape.
  - A moist sterile towel is placed over the drape as a working surface.
  - The basin should be filled such that the ice forms a mound above its rim.
  - The parts are brought to the operating room and cleaned on the sterile prep table with Hibiclens and sterile Ringer’s lactate.

**TECH FIG 1 • A,B.** The amputated parts are removed from the bag, and a sterile prep is performed on a separate table. 
**C.** A sterile metal irrigation basin is filled with ice and covered with a sterile adhesive drape. Use as much ice as can be placed without disruption of the sterile environment to maximize contact with the amputated parts. 
**D.** A sterile surgical towel is then placed over the drape and used as a working surface. 
**E.** Nylon sutures placed through the amputated parts are secured to the surgical towel. The amputated parts are now ready for débridement and preparation.
TECHNIQUES

PREPARATION OF THE STUMP

- A nylon suture is passed through the tip of each amputated part and secured to the towel with a small hemostat.
- Under loupe magnification, the contaminated skin edges and subcutaneous tissues are débrided.
- Slightly dorsal midlateral incisions are made on the radial and ulnar sides of the digit. Arteries, nerves, and veins are identified and tagged for later with small hemoclips. The hemoclips should be placed as close to the vessel and nerve ends as possible to avoid damaging the structures.
- The nerves and vessels are exposed for a length of 1.5 to 2 cm. The veins lie in the subdermal plane and can be identified by elevating the dorsal skin flap. If the veins are difficult to isolate, the surgeon may defer their identification until after the anastomosis of one artery when engorgement makes them more prominent.
- The flexor tendons are identified, and a 4-0 nonabsorbable braided suture is placed in each tendon in a Tajima fashion. The crossing limb of the Tajima suture should be placed 1.0 to 1.2 cm from the free end of the tendon.
- The bone is then shortened appropriately. Consideration of the level and geometry of amputation is required. It is necessary to reference the recipient site to match the orientation of the bone ends.
- In general, 4 to 10 mm of total digit shortening allows for appropriate débridement of nerves and vessels to healthy tissue and subsequent primary repair without tension. Shortening also eases skin coverage of the repair site. The amount of shortening depends partly on the mechanism of injury. Crush injuries typically require more resection than sharp injuries.
- Two 0.045-inch K-wires are placed longitudinally down the long axis of the bone in a retrograde fashion. The K-wires should exit through the tip of the digit just palmar to the nail. The K-wires are advanced until the tips are showing through the bone so that the amputated digit is now ready for immediate attachment.
- The parts should continue to be kept cool under ice packs until they are reattached.

Once a vein is located, continue the dissection in the same subdermal plane to identify others. If possible, two veins are repaired for each artery.

- Flexor tendons are identified, and a Tajima suture is placed in each (TECH FIG 2). If the tendons have retracted proximally, atraumatic retrieval is necessary to avoid inducing spasm or damaging the proximal vessels. If required, a separate proximal incision is made to retrieve the tendons safely.

**TECH FIG 2** • A. A Tajima-type suture repair is used so that the flexor tendons can be opposed and secured at the ideal time. B,C. The suture is placed in the proximal and distal ends of the tendon. D. The sutures are then tied in the repair site at the appropriate time.
Bone shortening has already been performed at the time of débridement. If shortening was limited by the proximity of joints, the use of vein grafts should be entertained at the time of vessel anastomosis. When shortening the bone in a thumb amputation, the resection should be maximized on the amputated part so that if the replant fails, thumb length is maintained.

Numerous methods of bone fixation are available, including longitudinal K-wires, crossed K-wires, intraosseous wiring, tension band, intramedullary screw, and plate and screws.

- Parallel longitudinal K-wires are quick, easy, and have low nonunion and complication rates. When possible, this is my preferred technique (TECH FIG 3A–D).
- Crossed K-wires are also relatively quick and easy to use. The drawback to crossed K-wires is potential risk to the neurovascular bundles, either directly or by tethering (TECH FIG 3E–H).
- Intraosseous wiring takes more time and exposure to perform, but allows for early range of motion. Drill holes accepting of a 24-gauge wire are placed in a dorsal-to-palmar and radial-to-ulnar orientation at each bone end. Two loops of 24-gauge wire are then passed perpendicular to each other through the analogous drill holes at each bone end and tightened in standard cerclage fashion.
- The tension band technique is a useful option for arthrodesis, because it allows the surgeon to set the desired amount of flexion. Two parallel 0.045-inch K-wires are placed across the fusion site, and a figure-8 loop of 24-gauge wire is used over the dorsum of the finger to complete the construct.

Any amputated parts that are not being replanted should not be discarded, because these are an excellent source for donor grafts.

**BONE FIXATION**

- Bone shortening has already been performed at the time of débridement. If shortening was limited by the proximity of joints, the use of vein grafts should be entertained at the time of vessel anastomosis. When shortening the bone in a thumb amputation, the resection should be maximized on the amputated part so that if the replant fails, thumb length is maintained.
- Numerous methods of bone fixation are available, including longitudinal K-wires, crossed K-wires, intraosseous wiring, tension band, intramedullary screw, and plate and screws.
  - Parallel longitudinal K-wires are quick, easy, and have low nonunion and complication rates. When possible, this is my preferred technique (TECH FIG 3A–D).
  - Crossed K-wires are also relatively quick and easy to use. The drawback to crossed K-wires is potential risk to the neurovascular bundles, either directly or by tethering (TECH FIG 3E–H).
  - Intraosseous wiring takes more time and exposure to perform, but allows for early range of motion. Drill holes accepting of a 24-gauge wire are placed in a dorsal-to-palmar and radial-to-ulnar orientation at each bone end. Two loops of 24-gauge wire are then passed perpendicular to each other through the analogous drill holes at each bone end and tightened in standard cerclage fashion.
  - The tension band technique is a useful option for arthrodesis, because it allows the surgeon to set the desired amount of flexion. Two parallel 0.045-inch K-wires are placed across the fusion site, and a figure-8 loop of 24-gauge wire is used over the dorsum of the finger to complete the construct.

Any amputated parts that are not being replanted should not be discarded, because these are an excellent source for donor grafts.
The intramedullary screw is most useful in thumb amputations at the metacarpal level. Removal of this hardware is difficult, so its use should be avoided in highly contaminated wounds where the risk of infection is high.

Lag screw fixation is appropriate to treat long oblique fractures. However, because most amputations do not result in this fracture pattern, this technique is seldom used in replantation surgery.

After bone stabilization, the extensor mechanism is repaired.

In the digit, the tendon is repaired with two horizontal mattress sutures using a 4-0 nonabsorbable suture. It is imperative to repair the entire extensor mechanism. If the amputation is through the proximal phalanx, repair of the lateral bands will optimize functional outcomes.

EXTENSOR TENDON REPAIR

- After bone stabilization, the extensor mechanism is repaired.
- In the digit, the tendon is repaired with two horizontal mattress sutures using a 4-0 nonabsorbable suture.

FLEXOR TENDON REPAIR

- Because the Tajima sutures have already been placed, they are now ready to be tied in the repair site. The two strands of the repair should be tied simultaneously to achieve a symmetric repair.
- In certain circumstances, the surgeon may choose to delay tying the sutures until after the microsurgical portion of the case. Specifically, in very proximal amputations, the ability to position the digit in slight hyperextension may facilitate the vessel and nerve repair.
- Both the FDS and FDP are repaired when feasible. If the amputation is in zone 2 and the tendons are not cleanly cut, repair of only the FDP tendon is reasonable.
- If the amputation level is distal to the FDS insertion, but proximal to the DIP joint, we typically do not repair the FDP or extensor tendon. We favor arthrodesis of the DIP joint with K-wires and direct rehabilitation toward early active and passive range of motion of the proximal interphalangeal (PIP) joint.

ARTERIAL REPAIR

- We have found that both digital arteries should be repaired, when feasible, to maximize survival rates.
- The operating microscope and microsurgical instrument set are used.
- The most important factor affecting survival is achieving a tension-free anastomosis of normal intima to normal intima (TECH FIG 4A–C).
- Débridement of damaged arteries is performed under the operating microscope. The surgeon must resect until normal intima is identified. The liberal use of vein grafts is advocated for resulting defects.
- The tourniquet is released to ensure good blood flow from the proximal stumps.

- Plate-and-screw fixation is generally not required in digit replantation because nonunion is rare. While it provides rigid fixation, the hardware is bulky, increases tendon adhesions, and requires more time and exposure.
- Regardless of the method of fixation, the surgeon must constantly evaluate alignment and rotation of the digit in both flexion and extension. The flexed fingertips should point toward the distal pole of the scaphoid.
Sharply trim the proximal stump with angled Potts scissors and dilate the lumen with jeweler’s forceps or a lacrimal duct dilator.

If adequate blood flow is not obtained, evaluate for all reversible causes of vasospasm, including hypotension, hypovolemia, acidosis, pain, or cold. Double check that the tourniquet was deflated.

Evaluate the proximal vessel for mechanical constriction.

Thoroughly irrigate the lumen with warm heparinized Ringer’s lactate through a 30-gauge blunt-tipped needle on a 10-ml syringe.

If vasospasm persists, irrigate the proximal vessel with papaverine solution (diluted 1:20 with sterile normal saline).

After appropriate blood flow is established, the proximal and distal stumps are placed within the vascular approximators. Several types of approximating devices are available. We favor two clamps on a sliding bar. The clamps should have less than 30 g of closing pressure and should be limited to no more than 30 minutes of application time due to the potential for vessel damage (TECH FIG 4D).

Place a microsurgical background deep to the repair site.

A bolus of 3000 to 5000 U of intravenous heparin is given just before the anastomosis. After the bolus, we typically initiate a heparin drip at 1000 U/hr.

Repeat inspection of the intima is performed proximally and distally to confirm its integrity. Verify that the anastomosis is tension-free and that no adventitia overhangs the lumen.

Appropriately sized monofilament nylon sutures (Table 1) are used, and initial sutures are placed 180 degrees apart.

The size of each “bite” should be about one to two times the thickness of the arterial wall.

Care must be taken to avoid damaging the intima of the vessel.

One limb each of the initial sutures should be cut long for use in manipulating the vessel without directly handling it.

Suture the front wall of the artery sequentially between stay sutures.

Irrigate the lumen after each suture is tied, and inspect the repair site to confirm that the back wall was not captured.

Flip the approximating clamp to expose the back wall and complete the anastomosis.

Remove the vessel from the approximating clips and repeat the procedure on the other digital artery.

### Table 1

<table>
<thead>
<tr>
<th>Site of Repair</th>
<th>Suture Size</th>
<th>Needle Size (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palm</td>
<td>9-0</td>
<td>100</td>
</tr>
<tr>
<td>Proximal digit</td>
<td>10-0</td>
<td>75</td>
</tr>
<tr>
<td>Distal digit</td>
<td>11-0</td>
<td>50</td>
</tr>
</tbody>
</table>

If a tension-free repair is not possible, primary nerve grafting is performed. The medial antebrachial cutaneous nerve is the ideal caliber for digital nerves and can be obtained from the ipsilateral extremity. Similarly, any amputated digits that are not candidates for replantation provide an excellent source for grafts.
VEIN REPAIR

- Ideally, a minimum of two veins are repaired for each artery. The largest veins identified should be repaired.
- When performing the anastomosis, each “bite” should be about two to three times the thickness of the vein wall.
- Constant irrigation with heparinized Ringer’s lactate helps to “float” the lumen of the vein open.
- Due to the low pressure flow, the venous anastomosis can be performed with fewer sutures than are required for the arterial anastomosis (TECH FIG 6).
- Familiarity with alternatives to venous anastomosis is necessary in the event suitable veins cannot be located.

- Continuous venous oozing can be encouraged by removal of the nail with subsequent scraping of the matrix. This scraping is performed every 2 hours with a cotton-tipped applicator and is followed by the application of heparin-soaked pledgets.
- If proximal veins are present but distal veins are not, creation of either an arteriovenous or venous-cutaneous fistula may facilitate outflow to reduce congestion. This scenario is most common in very distal amputations just proximal to the nail. An arteriovenous fistula may be created possibly if one artery has been successfully repaired and back-bleeding is present from the other distal artery. This artery can be anastomosed to the proximal vein. Alternatively, a vein graft can be used to create a temporary shunt from the skin of the pulp to the proximal vein.
- Medicinal leeches (Hirudo medicinalis) can be placed on the engorged part if venous congestion occurs. They should be changed every few hours and should be used for a minimum of 7 days to allow for the establishment of collateral circulation. Although the leeches may fall off after engorgement, they secrete hirudin, a local anticoagulant that keeps the digit bleeding for 8 to 12 hours. While using leech therapy, the patient should be treated with a third-generation cephalosporin as prophylaxis against Aeromonas hydrophilia infection, a symbiotic gram-negative rod in the leech gut.

SKIN COVERAGE AND WOUND CLOSURE

- Before the wound is closed, meticulous hemostasis must be achieved. Even small postoperative hematomas can compress the vascular repairs and result in failure of the replant.
- Interrupted nylon sutures are used to close the wounds, avoiding constriction of underlying structures. The midlateral incisions can be left open without concern for healing difficulties. If the repaired dorsal veins lack local coverage, a split- or full-thickness graft should be applied.

- No part of the postoperative dressing should be circumferential. Small strips of petroleum-impregnated gauze are applied to the incisions. A bulky dressing is constructed with a plaster splint extending above the elbow. The tips of all digits must remain exposed, and a temperature probe is taped to the pulp of the replanted digit for monitoring.
- The limb is elevated in a foam pillow.
## POSTOPERATIVE CARE

- Usually, the hand is elevated, with the level of elevation adjusted for changes in vascular status. If arterial inflow becomes problematic, the hand is lowered. If venous congestion is present, the hand is raised.
- Color, warmth, turgor, and capillary refill are monitored by the surgeon. 
- The patient’s room should be kept warm, preferably above 22°C (72°F). The temperature probe is monitored by the nursing staff, and the surgeon is notified if the digital temperature is less than 30°C or if the temperature drops 2°C over 1 hour.
- The patient is maintained on bed rest for the first 2 or 3 days, and the room is kept dark with minimal stimulation. Visitors are limited to two at a time.
- The patient is restricted from nicotine and caffeine products.
- The intravenous heparin drip is continued at 1000 U/hr. The rate is adjusted for a goal activated partial thromboplastin time (aPTT) of 1.5 times normal. It is maintained for 5 days, then weaned by 100 U/hr until off.
- Dextran 40 is given as a 50-mL bolus and then maintained at a rate of 20 mL/hr while the patient is in the hospital.
- Enteric-coated aspirin (325 mg daily) and dipyridamole (50 mg tid) are initiated and maintained for 6 weeks postoperatively.
- Chlorpromazine (25 mg orally q 8 h) is useful as both an anxiolytic and a peripheral vasodilator. We generally use it for the duration of the patient’s hospital stay.
- Appropriate antibiotics are maintained for 7 days.
- We prefer to leave the operative dressing in place for 7 days to avoid causing vasospasm. Excessive bleeding with formation of a blood cast that would restrict venous outflow should prompt an earlier dressing change.
- Gentle active motion is started on postoperative day 3 within the confines of the splint. Formal hand therapy is initiated after the splint is removed.

### OUTCOMES

- A survival rate greater than 80% is expected for replantation surgery.
- Functional outcomes are greatest for replantation of the thumb, proximal hand, and single digit distal to the FDS insertion (Fig 6A–D).  
- Recovery of sensation is correlated with function. As in other peripheral nerve injuries, age is the most important factor influencing recovery.

### PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Amputated parts</th>
<th>Take the amputated parts to the operating room to begin débridement and identification of structures as soon as the room is ready.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heterotopic replantation</td>
<td>Prioritize the functional goals for replantation. If multiple digits are amputated, but not all parts are suitable for replantation, put the salvageable digits in the most functional position (eg, replant a finger in the thumb position if the thumb cannot be saved).</td>
</tr>
<tr>
<td>Vein grafts</td>
<td>If there is concern for intimal damage, resection and the liberal use of vein grafts saves time and frustration. Always reverse the vein graft in case valves are present in the segment. The volar aspect of the wrist contains numerous veins 1 to 2 mm in diameter.</td>
</tr>
<tr>
<td>Spare-parts surgery</td>
<td>Never discard any amputated parts until the conclusion of the case. Amputated parts that are not suitable for replantation are an ideal source of autologous grafts.</td>
</tr>
<tr>
<td>Vascular anastomosis</td>
<td>Never perform an anastomosis under tension. Either additional bone shortening or vein grafting should be performed.</td>
</tr>
<tr>
<td>Multiple digit replantations</td>
<td>The overall duration of surgery is decreased by performing a structure-by-structure repair instead of a digit-by-digit repair (ie, repair the same anatomic structure in all digits before repairing the next structure).</td>
</tr>
</tbody>
</table>

*FIG 6 • A–D. This patient sustained an amputated thumb, which was successfully replanted with good cosmetic and functional results. (continued)*
factor for recovery, with better results in younger patients. The average two-point discrimination in replanted thumbs is 11 mm and in fingers is 8 mm.7 These values represent the average recovery for sharp amputation. Crush and avulsion mechanisms result in poorer two-point discrimination.

- Range of motion is related to level of amputation. Active PIP joint motion in replantations proximal to the FDS insertion average 35 degrees, whereas replantations distal to the FDS insertion result in 82 degrees of PIP joint motion (FIG 6E–G).10

COMPLICATIONS

Immediate Complications
- Immediate complications affect the survival of the replanted digit and typically relate to the vascular status.
- Arterial insufficiency may result from unrecognized vessel injury away from the anastomosis, which causes thrombosis or vasospasm.
  - A check for reversible causes is initiated to ensure that the patient is warm, comfortable, hydrated, and calm.
  - Check the dressings to confirm that there is no mechanical constriction.
  - Confirm that the patient’s hematocrit is near normal and that all ordered medications are being given appropriately.
  - The hand should be lowered to increase inflow, and an intravenous bolus of heparin (3000–5000 U) is given. If the patient has not been anticoagulated or has not achieved therapeutic levels, a regional sympathetic block will aid peripheral vasodilation.
  - Vigilant re-examination of color, warmth, turgor, and capillary refill is necessary to decide whether exploration in the operating room is indicated. Revisions after 4 to 6 hours of reduced perfusion seldom result in digit salvage.10
  - If venous engorgement occurs postoperatively, elevate the hand and remove constrictive dressings (including sutures that are too tight).
  - Consideration for return to the operating room is based on intraoperative findings affecting the possibility of revising the venous anastomosis.
  - If this is not possible, leeches or nail removal are used to alleviate venous congestion. These methods typically are used to bridge the first 4 to 6 days until adequate outflow is established.

Long-term Complications
- Long-term complications include pin tract infections, cold intolerance, stiffness, malunion, and nonunion.
- Pin tract infections usually occur more than 4 weeks after surgery. They are easily treated by pin removal and a course of oral antibiotics.
- Cold intolerance is almost universal. (This also is a problem in revision amputations.) Cold intolerance is expected to improve over the first 2 years but it remains debatable whether it completely resolves.3,18
- Digital stiffness is common, because both the flexor and extensor tendons are repaired. Tenolysis should be delayed for at least 3 months post-replantation but has demonstrated good results.12
- Malunion usually results from malalignment at the time of bone fixation. Intraoperatively, rotational alignment is the most difficult to assess. Malunion is more common in proximal amputations, because even slight malalignment at the amputation level is greatly accentuated at the fingertip.
- Nonunion is not common after replantation of the digit. It has been reported in fewer than 10% of digit replantations and rarely requires reoperation.19,20

REFERENCES
DEFINITION
- Vasospastic and vaso-occlusive diseases of the hands include a wide range of disorders that cause decreased or limited blood flow to the digits, resulting in chronic ulcerations and even loss of digits.
- Vasospastic disorders result from constriction of the microvasculature, resulting in decreased blood flow.
  - The most common vasospastic disorder is Raynaud syndrome.
  - Raynaud syndrome may also have an obstructive component.
- Vaso-occlusive disorders produce disruption of blood flow due to a reduction in cross-sectional area of the vessel lumen.

ANATOMY
- The right common carotid artery and right subclavian artery originate from the brachiocephalic trunk, whereas the left subclavian artery branches directly from the aorta.
- The subclavian artery becomes the axillary artery at the distal edge of the first rib and ends at the distal edge of the teres major tendon.
- The brachial artery is a continuation of the axillary artery, beginning at the distal margin of the teres major.
- The hand is supplied by the radial and ulnar arteries, which originate from the brachial artery at the level of the antecubital fossa.
- The radial artery becomes the deep palmar arch; the ulnar artery becomes the superficial palmar arch (FIG 1).
  - The superficial palmar arch is the major arterial inflow to the fingers on the ulnar aspect of the hand, whereas the deep palmar arch supplies blood to the digits on the radial aspect of the hand.
  - The superficial palmar arch lies more distal in the palm than the deep palmar arch.
  - In about 80% of patients, the deep and superficial palmar arches are in continuity, a configuration described as a complete palmar arch.\(^3\)
  - In a small subset of patients, a persistent median artery also can contribute blood supply to the hand.
  - Sympathetic nerves exit the spinal cord along with the ventral roots of the second and third thoracic nerves, passing via the brachial plexus into the forearm and hand.
  - The sympathetic nerve fibers innervate the blood vessel walls, controlling the tone of the vascular smooth muscle.

PATHOGENESIS
- Raynaud’s syndrome, a vasospastic disorder, is characterized by significant structural narrowing of the arterial lumen due to intimal hyperplasia. Vasospasm can occur from increased sympathetic tone in response to temperature, vibratory stimuli, and sometimes emotional stress, causing further ischemia and the clinical manifestation of color changes.
- Vaso-occlusive disorders result in ischemia distal to the site of occlusion.

NATURAL HISTORY
- Clinical manifestations of vasospastic disorders range from episodic digital vasospasm and pain, to severe hand and digit ischemia, progressing to gangrene.
- The classic triphasic attack in Raynaud’s syndrome consists of sudden onset of digital pallor or blanching after cold exposure.
or emotional stress, followed by a period of cyanosis and then redness with rewarming, resulting in the classic white-blue-red sequence of color changes.1
  - The typical Raynaud’s attack lasts for 15 to 45 minutes.
  - Vaso-occlusive disorders follow a more predictable clinical course in that they usually result from fixed lesions that are progressive.
  - Cold intolerance and vasomotor color changes in the hand develop, forcing patients to seek treatment.

PATIENT HISTORY AND PHYSICAL FINDINGS
  - A complete history and physical examination must be done on each patient, focusing on evidence of connective tissue or cardiovascular disease.
  - Does the patient describe paresthesias, pallor, cold intolerance, pain, digit ulceration?
  - The entire upper extremity is examined for range of motion, skin color and turgor, capillary refill, radial and ulnar pulses, temperature, and presence of ulcerations.
  - The distal fingertips and nails of each finger are examined closely.
  - The radial and ulnar pulses are palpated and examined by Doppler probe if necessary.
  - The palmar arch is assessed with the Doppler probe as well as the radial and ulnar digital arteries to each finger.
  - Allen’s test is performed.
    - The radial and ulnar arteries are occluded at the level of the wrist.
    - The arterial flow is then re-established to the hand sequentially by releasing the radial and ulnar arteries, and capillary refill is assessed.
    - This test evaluates the patency of arterial inflow to the hand through the radial and ulnar arteries.
  - Any pulsatile masses are noted and evaluated.

IMAGING AND OTHER DIAGNOSTIC STUDIES
  - Posteroanterior (PA), lateral, and oblique radiographs to evaluate bone architecture and the presence of any calcification in the radial and ulnar arteries, palmar arches, or digital arteries
  - Doppler examination
  - Echocardiogram to evaluate potential sources of emboli
  - Digital photoplethysmography, which measures digital volume changes over time, can be used to differentiate vasospastic from vaso-occlusive disease.
  - Segmental arterial pressure measurements
  - Nielsen digital hypothermic challenge test
  - Ultrasonography
  - Angiography: remains the gold standard to evaluate blood flow to the hand
  - MR angiography
  - Laboratory tests: complete blood cell count (CBC) with platelet count, coagulation studies, markers for collagen vascular diseases

DIFFERENTIAL DIAGNOSIS
  - Raynaud’s disease
  - Hypothenar hammer syndrome
  - Malignancy
  - Trauma
  - Buerger disease (thromboangiitis obliterans): an inflammatory occlusive disease of the small and medium-sized vessels of the limbs
  - Arteritis: a group of disorders characterized by acute or chronic inflammation in the walls of small, medium, and large arteries. Patients with these conditions often present with concurrent fever, malaise, weight loss, cutaneous lesions, and arthralgias.
  - Diabetes
  - Peripheral vascular disease, atherosclerosis
  - Thoracic outlet syndrome
  - Connective tissue disorders (eg, scleroderma, systemic lupus erythematosus, rheumatoid arthritis)
  - Illicit drug use
  - Vascular tumors
  - Pseudoaneurysm
  - Iatrogenic injury

NONOPERATIVE MANAGEMENT
  - Pharmacologic therapy is the mainstay of treatment of vasospastic disorders of the hand.
  - Avoidance of smoking and exposure to cold temperatures may control vasospastic episodes.
  - Biofeedback
    - Patients are trained to control certain bodily processes that occur involuntarily.
    - Electrodes are attached to the skin of the patient and physiologic responses monitored.
    - The biofeedback therapist then leads the patient through exercises that bring about desired physical changes.
    - Occlusive dressings may be helpful both to protect areas from recurrent trauma and to promote healing of lesions.
    - Calcium channel blockers, eg, nifedipine
    - Pentoxifylline decreases blood viscosity and may result in relaxing vascular smooth muscle.
    - Prostacyclins
  - Nitrates
  - Local anesthetic blockade
  - Botulinum toxin A
  - Thrombolytic therapy

SURGICAL MANAGEMENT
  - The surgical management of vasospastic and vaso-occlusive diseases should proceed in a systematic fashion.
  - Indications for operative management are progressive symptoms (eg, Raynaud’s syndrome, ulcers, pain, cold intolerance) despite optimal medical management and with angiographically defined occlusion of one or both inflow arteries (ie, radial, ulnar).
  - Indications for a digital sympathectomy are progressive symptoms of Raynaud syndrome or ulcerations refractory to medical management with no evidence of major occlusion of the radial or ulnar arteries and with good visualization of three common digital arteries in the palm.
  - Cold challenges are very painful for patients with scleroderma and systemic lupus erythematosus and are used on a case-by-case basis.
  - The patient should be educated on the outcomes of the various procedures and realize the limitations of each one.

Preoperative Planning
  - The preoperative history and physical examination are reviewed.
The site of operative intervention is determined primarily by the preoperative imaging studies (eg, angiogram).

If vascular grafting is indicated, the donor vessels are identified and marked.

**Positioning**

- The patient is placed in the supine position on the operating room table with the extremity on an appropriately padded hand table.
- An upper arm tourniquet is placed, because a bloodless field is essential.
- If a vein graft is anticipated, another extremity (usually a leg) is prepped and a proximal tourniquet applied.

**Approach**

- Usually, the hand surgeon must access proximal arterial inflow vessels when treating either vasospastic or vaso-occlusive disorders of the hand.
- The brachial artery in the upper arm is approached via an incision on the medial aspect of the arm.
- The distal brachial artery and proximal radial and ulnar arteries are approached through a lazy S incision in the antecubital fossa.
- Care is taken to avoid making a straight line incision across the antecubital fossa.
- The radial and ulnar arteries in the forearm are approached through a longitudinal incision over the specific vessel.
- The palmar arches are accessed via Bruner incisions extending proximally from the proximal phalanges, using natural creases in the palm where possible, or through an inverted J-shaped incision in the palm.
- The digital arteries are approached through Bruner incisions on the palmar aspect of the finger or through a midlateral incision on the digit.

**FLATT DIGITAL SYMPATHECTOMY**

- Flatt digital sympathectomy is used for patients with vasospastic disorders such as Raynaud phenomenon.
- Proximal or cervical sympathectomy has largely fallen out of favor due to the high recurrence rates.
- Peripheral sympathectomy has gained popularity since Pick identified sympathetic nerve fibers innervating the arteries from the wrist to the fingers.
- Sympathectomy is performed at the level of the digital arteries.
- Make Bruner incisions in the distal palm and expose the digital arteries.
- Disrupt all connections between the digital nerves and digital arteries.
- Strip the adventitia from the digital arteries over a distance of 0.5 to 2.0 cm using the operating microscope (TECH FIG 1A,B).
- This must be performed very carefully to avoid damaging the digital arteries themselves.
- In cases of more widespread vasospasm, when more radical digital sympathectomy is required, strip the adventitia from the distal radial and ulnar arteries, the superficial palmar arch, and the common digital arteries in the palm (TECH FIG 1C,D).
**LERICHE SYMPATHECTOMY**

- If adequate collateral flow is present, consider excision of a segment of thrombosed or occluded artery.
- This is thought to reduce the sympathetic discharge from the diseased artery that is producing vasospasm in the more distal vessels.
- It also occasionally is used to treat a thrombosed or occluded ulnar artery in hypothenar hammer syndrome.

**MICROSURGICAL REVASCULARIZATION**

- Reconstruction of a thrombosed or occluded artery is considered if:
  - A discrete segment of artery can be resected and bypassed.
  - Adequate arterial inflow and patent distal arteries with adequate distal “run-off” are present.
- Resect the arterial segment and measure the defect.
- Reverse vein grafts (e.g., cephalic, saphenous) or arterial grafts (e.g., deep inferior epigastric artery, lateral circumflex artery, thoracodorsal artery) are harvested in the standard fashion.
- Draw an axial line down the length of the vessel to be harvested while it is still in situ.
- This helps prevent inadvertent “twisting” of the graft during the anastomoses.
- Perform standard microsurgical anastomoses using 9-0 or 10-0 nylon sutures and the operating microscope between the distal radial or ulnar arteries and the deep or superficial palmar arches respectively, or directly to one or more common digital arteries (TECH FIG 2).
- An end-to-side anastomosis of the graft to the inflow artery is preferable to maximize any remaining circulation to the hand, but end-to-end anastomoses are technically easier.
- The distal anastomosis usually is end-to-end to the superficial or deep palmar arches or end-to-side to the common digital arteries.
- After the anastomoses have been completed, the tourniquet is deflated, and vascular inflow through the other artery is occluded by manual compression for a few minutes to maximize flow across the anastomoses.
- Restoration of arterial flow into the hand is assessed either by using a pencil Doppler probe or by performing an Acland “adventitial strip test” distal to the distal anastomosis.

**TECH FIG 2**

- A. Microsurgical revascularization for thrombosis or occlusive disease of the distal ulnar artery and superficial palmar arch, using an interposition vein graft from the ulnar artery to the common digital arteries.
- B. Microvascular revascularization for thrombosis or occlusive disease of the distal radial artery and deep palmar arch, using an interposition vein graft from the radial artery to the princeps pollicis artery.
EMBOLECTOMY
- An acute embolus is treated by immediate heparinization to prevent propagation of the embolus more distally into the digits.
- Small Fogarty embolectomy catheters may be used selectively at the arm, elbow, forearm, and wrist levels, but use of embolectomy catheters in the hand and digits is difficult and can itself lead to vascular injury.
- After identification of the segment involved by the embolus, control the affected artery both proximal and distal to the embolus.
- Make a longitudinal arteriotomy proximally to access the vessel lumen.
  - A side branch may be chosen if available.
- Insert the Fogarty catheter into the artery, and pass it down the lumen beyond the area of occlusion; then inflate the balloon.
- Gently withdraw the catheter to retrieve any thrombus.
- This is repeated until the lumen is completely cleared of the embolus, as demonstrated by improved back-bleeding from the distal vessel.
- Suture the arteriotomy and release arterial inflow.
- Assess the restoration of arterial flow into the hand either by using a pencil Doppler probe on the artery more distally or by performing an Acland “adventitial strip test” distal to the site of embolism.

ARTERIALIZATION OF THE VENOUS SYSTEM
- Choose a suitable vein on the dorsum of the hand, that is, one that will lie in a straight line following anastomosis to the radial or ulnar artery near the palmar wrist.\(^ {16}\)
- Mobilize the vein and ligate the multiple side branches of the vein with small hemoclips to maximize flow to the fingers.
- Perform valvulotomies in the vein to prevent valvular obstruction.
- Ligate the vein proximally and perform an end-to-side microsurgical anastomosis between the vein and the radial or ulnar artery at the wrist.
- After the anastomosis has been performed, assess arterial flow through the distal vein.
- Any remaining obstruction due to a valve should be relieved by an open valvulotomy and excision of the valve leaflets, followed by microsurgical closure of the vein.
- Postoperative monitoring is performed using a pencil Doppler probe over the distal arterialized vein to the fingers.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Embolectomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>- A thorough history and physical examination must be performed.</td>
<td>- Identification of an embolus must be treated with heparinization immediately to prevent propagation of the clot.</td>
</tr>
<tr>
<td>- Preoperative studies must be reviewed before surgical intervention.</td>
<td>- The use of embolectomy catheters in the hand and digits should be done selectively and with caution.</td>
</tr>
</tbody>
</table>

Sympathectomy
- The adventitia of the artery must be stripped over a distance of 0.5 to 2.0 cm.

Microsurgical revascularization
- A discrete segment of thrombosed or occluded artery must be identified for this to be effective.
- Adequate arterial inflow and distal runoff is essential.

Embolectomy
- Generally used for unreconstructable vascular lesions
- Valvulotomies must be performed to prevent vascular obstruction when flow is established.
- All venous side branches should be ligated to maximize flow distally.

POSTOPERATIVE CARE
- The hand is immobilized in a lightweight splint to protect the operative site, with care taken to avoid any pressure on the underlying anastomoses or vulnerable mobilized arteries.
- The fingertips are observed for color and capillary refill, temperature using small temperature probes or oxygen saturation using a pulse oximeter.
- Microvascular reconstruction with interposition grafts can be monitored using a pencil Doppler probe.
- Relative anticoagulation can be achieved using a continuous infusion of dextran 40 or low-dose aspirin.

OUTCOMES
- Calcium channel blockers have been shown to be moderately effective in patients with Raynaud’s phenomenon, with 35% reporting improvement in severity of their symptoms.\(^ {19}\)
- The results of sympathectomy remain variable, although surgeons have reported improvements in pain, ulcer healing, cold intolerance, and quality of life.\(^ {8,11,18,20}\)
- Long-term patency rates for vascular bypass grafting secondary to occlusive disease have been reported to range between 53% and 94%.\(^ {2,8,10,13}\)
Combining sympathectomy with arterial reconstruction may offer improved outcomes versus sympathectomy alone.  

COMPLICATIONS
- Bleeding and hematoma
- Infection
- Thrombosis of the interposition graft
- Progression of the underlying systemic disease

REFERENCES
DEFINITION
- An *acute paronychia* is an infection of the soft tissue fold around the fingernail.
  - It is the most common soft tissue infection of the hand.
  - The most common infecting organism is *Staphylococcus aureus*, although these infections are commonly mixed infections.
- A *chronic paronychia* is characterized by repeated infection and inflammation of the eponychium.
  - The eponychium becomes thickened and rounded.
  - This problem often occurs in the setting of repeated and prolonged exposure to water.
  - The most commonly isolated organisms are *Candida albicans*, gram-positive cocci, gram-negative rods, and *Mycobacterium* spp.
- Herpetic whitlow is caused by an outbreak of herpes simplex virus in the skin of the finger and can be confused with acute paronychia or felon.
  - Herpetic whitlow is common in children and medical personnel who come into contact with oral secretions.
- A *felon* is a tense abscess of the distal pulp of the finger or thumb that involves multiple septal compartments (FIG 1).

ANATOMY
- The nail complex consists of the nail bed, nail plate, and perionychium (FIG 2).
  - The nail plate sits below the proximal nail fold.
  - The perionychium is the border tissue which surrounds the nail.
  - The eponychium is the tissue that attaches closely to the nail plate proximally, commonly referred to as the cuticle.
  - The nail folds consist of skin, which continues underneath the visible edges to form a protective barrier.
  - The pulp of each digit consists of multiple compartments separated by fibrous septa.
  - These vertical septa extend from the periosteum of the distal phalanx to the epidermis, lending structural support to the fingertip.

PATHOGENESIS
- Acute paronychia results from the introduction of bacteria into the space between the nail fold and the nail plate, either proximally or laterally.
  - This commonly occurs as a result of a hangnail, nail biting, or an overzealous manicure.
- Chronic paronychia results from colonization and infection by organisms that enter the space between the nail plate and the cuticle, eponychium, and nail fold.
  - This chronic infection and inflammation lead to fibrosis of the eponychium, which, in turn, leads to decreased vascularity of the dorsal nail fold.
  - This decreased vascularity predisposes to repeated bacterial insults, resulting in the characteristic clinical exacerbations.
- Felons often result from penetrating trauma, or from bacterial inoculation through the exocrine sweat glands contained within the pulp.
  - Cellulitis and local inflammation lead to local ischemia, which, in the setting of the closed spaces defined by septa, leads to increased pressure.
  - Fat necrosis and abscess formation result from the increased pressure, which, in turn, causes a further increase in pressure, and, in effect, a compartment syndrome.

NATURAL HISTORY
- If acute paronychia is left untreated, an early infection will turn into an abscess along the nail fold.
  - The abscess may then extend into the pulp space or into the eponychium and then to the opposite side of the nail.
  - Purulence at the base of the nail may cause ischemia of the germinal matrix, which then may lead to temporary or permanent nail growth arrest.
- Herpetic whitlow improves without any intervention in approximately 3 weeks.
  - Many cases of herpetic whitlow are misdiagnosed as acute paronychia or felon.
Subsequent incision and drainage may lead to secondary bacterial infection.

Chronic paronychia are characterized by induration of the eponychium punctuated by episodes of swelling and drainage.

A felon, if left untreated, may lead to osteomyelitis or septic flexor tenosynovitis.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- In acute paronychia, the patient will complain of swelling and pain immediately adjacent to the nail.
  - If an abscess has formed, there may be purulent drainage.
- In chronic paronychia, the patient will present with a chronically indurated and rounded eponychium characterized by repeated episodes of inflammation and drainage.
- Herpetic whitlow is characterized by pain and swelling followed by the appearance of multiple vesicular lesions.
  - The pain typically is out of proportion to the physical findings, and the fingertip is not tense (in contrast to a felon).
- A patient with a felon will present with severe throbbing pain, swelling, and a tense fingertip pad.
  - A felon will not extend proximal to the distal interphalangeal (DIP) joint flexion crease unless it is associated with septic flexor tenosynovitis.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Radiographs are indicated to rule out osteomyelitis or if a foreign body is suspected.
- The diagnosis of herpetic whitlow is confirmed by Tzanck smear, which will show multinucleated giant cells.
- Patients suspected of having a systemic illness should have the appropriate laboratory workup.

**DIFFERENTIAL DIAGNOSIS**

- Acute paronychia
- Chronic paronychia
- Herpetic whitlow
- Felon
- Osteomyelitis
- Septic arthritis of the DIP joint

**NONOPERATIVE MANAGEMENT**

- Acute paronychia may be treated with warm soaks and oral antibiotics if infection is caught early and if no significant abscess is present.
- Herpetic whitlow is managed by keeping the hands clean to prevent bacterial superinfections; these lesions will resolve on their own.
  - Some recommend treatment with oral acyclovir, but multiple clinical trials have failed to show any definite benefit.
- Nonoperative treatment has no role in the treatment of chronic paronychia unless there is a concomitant fungal infection that may benefit from medical therapy.
- Given the rapid clinical progression of a felon, nonoperative treatment with antibiotics rarely will be successful, except in very early cases.

**SURGICAL MANAGEMENT**

- If the abscess is superficial, drainage may sometimes be performed without anesthesia.
- If the infection is more extensive or involves both sides of the nail, incision and drainage should be performed under digital nerve block.
  - Use lidocaine or a mixture of lidocaine and bupivacaine without epinephrine.
  - Instillation of the medication at the level of the distal metacarpal from dorsal to volar is the safest and best tolerated technique.
- Chronic paronychia usually are treated with eponychial marsupialization.
  - Chronic paronychia associated with underlying fungal infections may be amenable to more standard surgical treatments as performed for acute paronychia after the fungal infection has been successfully treated medically.
- Herpetic whitlow is treated with incision and drainage only if a bacterial superinfection has occurred.
Positioning
- The patient is placed in the supine position with a standard hand table and either digital or forearm tourniquet.

Approach
- The surgical approach is dictated by the location of the infection.
- Infection under the nail plate will require elevation of part of the nail.
- Infection under the eponychial fold will require elevation of the eponychium.
- Infection into the pulp will require incision deep into the pulp space.

**INCISION AND DRAINAGE OF AN ACUTE PARONYCHIA**

**Single Incision**
- Use a no. 15 scalpel to incise into the paronychial sulcus, keeping the blade directed away from the nail bed (TECH FIG 1A).
- If the abscess extends below the nail plate, then that portion of the nail is freed from the underlying bed, a longitudinal incision is made in the nail, and that section of the nail is removed in an atraumatic manner (TECH FIG 1B,C).
- Alternatively, if the purulence extends into the pulp space, the perionychium may be incised peripheral and parallel to the nail sulcus (TECH FIG 1D,E).
- If the abscess extends to the eponychium, the incision may be carried as far proximally as necessary; a portion of nail may then be removed if necessary.

**Parallel Incisions**
- If the abscess involves the eponychium and is not completely decompressed with a single incision, a parallel incision may be made on the opposite paronychial sulcus. The entire eponychial fold is elevated, and the proximal third of the nail is excised (TECH FIG 2).
- This is then irrigated and packed with gauze to prevent premature closure.
Chapter 100  SURGICAL TREATMENT OF ACUTE AND CHRONIC PARONYCHIA AND FELONS 2909

- Make a crescent-shaped incision 1 to 3 mm proximal to the eponychial fold, extending 3 to 5 mm proximally and extending to the edge of each nail fold (TECH FIG 3A,B).

- Excise this tissue, taking care not to damage the underlying germinal matrix (TECH FIG 3C).

- Irrigate and dress the wound appropriately.

- Allow the wound to heal by secondary intention.

EPONYCHIAL MARSUPIALIZATION FOR A CHRONIC PARONYCHIA

- Base the incision over the point of maximal tenderness. Be aware that an incision on the pulp can result in a tender scar.

- For a volarly oriented abscess, make an incision precisely in the midline distal to the DIP joint flexion crease (TECH FIG 4A,B).

- When the point of maximal tenderness is on the side of the finger pulp, make the incision longitudinally, dorsal to the tactile surface of the finger, not more than 3 mm from the edge of the nail. A more volar incision risks damage to the digital nerve branches (TECH FIG 4C).
PEARLS AND PITFALLS

**Misdiagnosis**
- Avoid misdiagnosis of herpetic whitlow as an acute paronychia with concomitant overtreatment of this problem resulting in a secondary bacterial infection and no improvement in the herpetic whitlow.
- Recognize underlying osteomyelitis in longstanding cases.
- Recognize any systemic illness that may hinder resolution of the infection.
- Chronic paronychia: avoid missing a cyst, tumor, or associated fungal infection.

**Technique**
- **Acute paronychia:** Determine whether purulence is present under the nail plate or extending into the pulp. Avoid incising into the sterile matrix by keeping the blade turned away from the nail bed.
- **Chronic paronychia:** Excise tissue superficial to the germinal matrix; avoid damaging the germinal matrix.
- **Felon:** Base the incision on the location of maximal tenderness. With a lateral incision, avoid damaging the digital nerve branches by remaining within 3 mm of the lateral edge of the nail. With a volar incision, do not cross the DIP joint flexion crease and avoid incising the flexor tendon sheath. Such incisions may lead to septic tenosynovitis.

**Postoperative care**
- **Acute paronychia and felon:** Treat with 10 days of oral antibiotics. Use of a removable splint over the distal digit is valuable early in recovery for patient comfort. Encourage early digital range of motion exercises during daily soaks.
- **Chronic paronychia:** Failure to modify environmental factors and treat systemic disease may lead to recurrence.

**POSTOPERATIVE CARE**
- Acute paronychia and felons
  - Oral antibiotics should be started postoperatively.
  - Soaks in a dilute solution of either chlorhexidine or povidone-iodine may be started on postoperative day 2 and continued until wound healing is completed. The packing is removed when the soaks begin.
  - Begin early range-of-motion exercises to avoid stiffness.
- Chronic paronychia
  - Oral antibiotics usually are not necessary.
  - Soaks in a dilute solution of either chlorhexidine or povidone-iodine may be started on postoperative day 2 and continued until wound healing is completed.

- Correction of environmental factors or systemic illness is critical.
- Begin early range-of-motion exercises to avoid stiffness.

**COMPLICATIONS**
- Recurrent infection (systemic spread of the infection)
- Incisional tenderness (pulp)
- Digital nerve injury
- Decreased sensation
- Neuroma
- Osteomyelitis
- Nail plate deformity
REFERENCES

DEFINITION

- Deep space infections occur in one of three anatomically defined potential spaces within the hand—the thenar, midpalmar, and hypothenar spaces—or in one forearm potential space, Parona’s space.
- Thenar space infections are the most common deep space infections. Midpalmar and hypothenar space infections are much more rare.
- Deep space infections usually result from direct penetrating trauma or spread from an adjacent infection such as a superficial abscess or a flexor tenosynovitis (in the case of thenar and midpalmar space infections).
- The single most common infecting organism is *Staphylococcus aureus*, although most of these infections are mixed.

ANATOMY

- The thenar space (FIG 1) is defined by the fascia of the adductor pollicis muscle dorsally and the tendon sheath of the index finger and palmar fascia volarly.
  - The radial border is defined by the insertion of the adductor pollicis tendon and fascia on the thumb proximal phalanx.
  - The ulnar border is the midpalmar (oblique) septum, which extends from the third metacarpal to the palmar fascia.
- The midpalmar space (see FIG 1) is bordered radially by the midpalmar septum and bordered ulnarly by the hypothenar septum, which extends from the fifth metacarpal to the palmar fascia.
  - The dorsal border of the midpalmar space is the fascia of the second and third palmar interosseous muscles, and the volar border is the flexor sheaths of the long, ring, and small fingers and the palmar fascia.
- The hypothenar space (FIG 1) is bordered radially by the hypothenar septum and dorsally by the periosteum of the fifth metacarpal. The fascia of the hypothenar muscles forms the ulnar and palmar borders.
- Parona’s space is a deep potential space in the distal forearm superficial to pronator quadratus and deep to the flexor digitorum profundus tendons. It is continuous with the midpalmar space.

PATHOGENESIS

- Thenar space infections may result from penetrating injury or local spread from adjacent flexor tenosynovitis or a subcutaneous abscess.
  - If not treated early, the infection may spread to the dorsal side of the hand after destroying the fascia of the adductor pollicis muscles and traveling between the transverse and oblique heads.
  - Midpalmar space infections usually result from direct penetrating trauma, but may also result from spread of an adjacent flexor tenosynovitis or superficial abscess.
  - Hypothenar space infections usually result from direct penetrating trauma, but may also result from spread of a superficial abscess.
  - Parona’s space infection may result from direct penetrating trauma, in which case the infection may be isolated to Parona’s space.
  - Infection involving Parona’s space may also result from contiguous spread from a ruptured radial or ulnar bursae (FIG 2). The end result will be involvement of the midpalmar space and a horseshoe abscess (FIG 3).
PATIENT HISTORY AND PHYSICAL FINDINGS
- The patient may recall a history of a penetrating injury in the vicinity of the involved deep space.
- In the case of a thenar space infection, the patient will present with swelling and tenderness in the thenar region.
  - The patient will hold the thumb in an abducted position to minimize the pressure for comfort.
  - If the infection has been present for some time, it may have spread dorsally, in which case swelling and tenderness will be found dorsally in the first web space.
- In the case of a midpalmar space infection there will be tenderness and swelling in the midpalm, although dorsal swelling may be more impressive due to the strength of the palmar aponeurosis.
  - The fingers will be held in a semiflexed posture.
  - This condition is distinguished from flexor tenosynovitis by relative lack of pain with passive motion of the fingers and with direct palpation of the flexor sheath along the digit.
  - Infection of Parona’s space is characterized by swelling in the distal volar forearm and pain with digital flexion.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographs should be obtained in all cases to rule out the presence of foreign bodies.
- Radiographs also may reveal underlying osteomyelitis in the setting of more chronic infections.
- Patients suspected to have systemic illness should have an appropriate laboratory workup.

DIFFERENTIAL DIAGNOSIS
- Thenar space infection
- Midpalmar space infection
- Hypothenar space infection
- Flexor tenosynovitis
- Superficial abscess
- Osteomyelitis

NONOPERATIVE MANAGEMENT
- There is no role for nonoperative treatment in the setting of deep space infections.
- Antibiotics should be avoided until adequate cultures can be obtained, unless the patient is systemically ill and there will be a forced delay in operative treatment.

SURGICAL MANAGEMENT
- Drainage of deep space infections should be carried out in the operating room under general anesthesia.
- Gram stain and cultures for aerobes, anaerobes, mycobacteria, and fungi should be obtained intraoperatively just before IV antibiotics are administered.
- Thorough irrigation with 6 to 9 L of normal saline should be performed.
- All nonviable tissue must be débrided sharply.
- Surgical wounds may be closed very loosely over a drain if all necrotic tissue has been thoroughly débrided.
- If there is any doubt, the wound should be left open to heal by secondary intention using wet-to-dry dressing changes and soaks.
- In very severe cases, a second irrigation 48 to 72 hours later may be required.

Positioning
- The patient is positioned supine with a standard hand table and nonsterile tourniquet.

Approach
- Drainage of thenar space infections can be performed through a volar incision or a dorsal longitudinal incision (or, sometimes, both).
  - A volar incision involves risk to the recurrent motor branch of the median nerve, the digital nerves to the thumb and index finger, the princeps pollicis artery, and the proper digital arteries.
  - A volar incision also allows concomitant treatment of a thumb septic flexor tenosynovitis.
  - A dorsal longitudinal incision avoids the painful scar associated with a volar incision.
- Drainage of midpalmar space infections may be performed through a transverse skin incision in, or parallel to, the distal palmar crease over the third and fourth metacarpals.
  - Alternatively, a curved longitudinal incision may be used.
- Hypothenar space infections are approached through an incision in line with the ulnar border of the ring finger extending from 3 cm distal to the wrist crease to just proximal to the midpalmar crease.
- Parona’s space may be approached through a longitudinal incision just ulnar to the palmaris longus.
  - Alternatively, a trans–flexor carpi radialis approach may be used.
INCISION AND DRAINAGE OF THENAR SPACE INFECTIONS

- In the case of a volar approach, make an incision just adjacent and parallel to the thenar crease, beginning 1 cm proximal to the web space and extending 3 to 4 cm proximally (TECH FIG 1A).
- After blunt dissection through the palmar fascia, the digital nerves to the thumb and index finger, the princeps pollicis artery, the proper digital arteries, and the recurrent motor branch of the median nerve are encountered (TECH FIG 1B,C).
- The abscess will lie superficial to the adductor pollicis muscle.
- Dissection should then continue dorsally over the distal edge of the adductor muscle to decompress any dorsal extension of the abscess.
- Alternatively, a thenar space infection may be approached dorsally through a longitudinal incision (TECH FIG 1D).
- The dorsal incision may be straight or slightly curved and should bisect the space between the first and second metacarpals.
- Dissection should be carried down to the interval between the first dorsal interosseous muscle and adductor pollicis muscle, where the purulence will be encountered.
- Thoroughly débride all necrotic tissue, and irrigate copiously with sterile saline.
- Place a strip of packing strip gauze into the open wound to allow for drainage, and dress the wound appropriately.

INCISION AND DRAINAGE OF MIDPALMAR SPACE INFECTIONS

- Make a transverse incision parallel to or in the distal palmar crease over the third and fourth metacarpals (TECH FIG 2A).
- Alternatively, a curved longitudinal incision may be used (TECH FIG 2B).
- Bluntly dissect to either side of the flexor tendons to the ring or middle finger, where the abscess will be encountered.
- Protect the neurovascular bundles, which lie on either side of the tendons (TECH FIG 2C).
- Thoroughly débride all necrotic tissue, and irrigate copiously with sterile saline.
- Place a strip of packing strip gauze into the open wound to allow for drainage, and dress the wound appropriately.
INCISION AND DRAINAGE OF HYPOTHENAR SPACE INFECTIONS

- Make an incision in line with the ulnar border of the ring finger extending from just proximal to the midpalmar crease to 3 cm distal to the wrist crease (TECH FIG 3A).
- Incise the hypothenar fascia in line with the skin incision, and the purulence will be encountered (TECH FIG 3B).
- Thoroughly débride all necrotic tissue, and irrigate copiously with sterile saline.
- Place a strip of packing strip gauze into the open wound to allow for drainage, and dress the wound appropriately.

INCISION AND DRAINAGE OF PARONA’S SPACE INFECTIONS

- Approach Parona’s space with a longitudinal incision in the distal forearm just ulnar to the palmaris longus.
- If the infection is isolated to Parona’s space, keep the incision proximal to the wrist flexion crease.
- If the infection is contiguous with a midpalmar space abscess, the incision is carried across the wrist in Brunner fashion.
## PEARLS AND PITFALLS

| Misdiagnosis | • Recognize underlying osteomyelitis in longstanding cases.  
• Recognize any systemic illness that may hinder resolution of the infection. |
| Presurgical planning | • Always obtain radiographs to evaluate for osteomyelitis or a foreign body. |
| Technique | • When approaching the thenar space, protect the digital nerves to the thumb and index finger, the princeps pollicis artery, the proper digital arteries, and the recurrent motor branch of the median nerve.  
• In the midpalmar space, protect the superficial palmar arch and the digital nerves and arteries.  
• In the hypothenar space, protect the ulnar nerve and its branches, together with the ulnar artery.  
• Obtain Gram stain and cultures for anaerobes, aerobes, mycobacteria, and fungi.  
• Administer IV antibiotics intraoperatively once cultures have been obtained.  
• May close over Penrose drain if débridement is adequate.  
• If there is the possibility of remaining necrotic tissue, the wound should be left open to close by secondary intention. |
| Postoperative care | • Allow open wounds to heal by secondary intention with wet-to-dry dressing changes.  
• IV oral antibiotics for 7 to 14 days.  
• Infectious disease consultation, if necessary.  
• Maintain elevation.  
• Use of a removable splint will rest soft tissues and improve patient comfort.  
• Perform soaks in warm water three times per day.  
• Begin early digital range-of-motion exercises.  
• Be prepared to repeat irrigation and débridement if there is no clinical improvement after 48 hours. |

### POSTOPERATIVE CARE
- Intravenous antibiotics, initially given intraoperatively, are continued postoperatively.  
- The patient may be switched to oral antibiotics once cultures and sensitivities return from the microbiology laboratory and if he or she is responding to IV antibiotic therapy.  
- Let open wounds heal by secondary intention using wet-to-dry dressing changes and soaks or whirlpools.  
- Remove drains after 24 to 48 hours, depending on the condition of the wound and particulars associated with surgery.  
- Begin early range-of-motion exercises during soaks or whirlpool treatments to minimize digital stiffness.  
- Treatment of systemic illness is critical.

### COMPLICATIONS
- Persistent abscess formation if irrigation and débridement is inadequate or the wound is closed tightly and not allowed to drain.  
- Systemic spread of the infection if appropriate treatment is delayed.

### SUGGESTED READING
DEFINITION
- Septic arthritis is defined as an infection within the closed space of a joint.
- It is usually acute and purulent secondary to a pyogenic bacterial infection.
- It causes irreversible damage to articular cartilage and therefore warrants prompt treatment with adequate drainage and an appropriate antibiotic regimen.
- Delay in making the diagnosis and initiating treatment has serious implications for prognosis.

ANATOMY
- The interphalangeal (IP) and metacarpophalangeal (MP) joints of the hand are hinge joints (FIG 1).
- The IP joint space is maximized in slight flexion and the MP joint in extension.
- The wrist joint includes the radiocarpal, midcarpal, and radioulnar joints. Septic arthritis may be present in all of these wrist joint spaces, concomitantly or separately, if there are no intersseous ligament perforations, as is the case in younger patients (see FIG 1).

PATHOGENESIS
- Septic arthritis may affect any joint of the hand or wrist.
- Septic arthritis does not have a gender or race predilection, but it is more common in adults than in children.
- The inoculation of the joint is most likely due to a penetrating injury (ie, lacerations, puncture wounds, and bites). Other causes include hematogenous seeding or contiguous spread.¹⁰
- At the distal IP joint, septic arthritis is common from penetrating trauma as well as contiguous infection from a mucous cyst, felon, paronychia, or suppurative flexor tenosynovitis.
- At the proximal IP joint, contiguous infection is most commonly related to a suppurative flexor tenosynovitis.
- At the MP joint, septic arthritis is most common after direct inoculation from a clenched fist injury or fight bite.
- Hematogenous spread can result from any concomitant or preceding infection of the body, including oral, upper respiratory, gastrointestinal, and genitourinary infections.
- The synovium is highly vascular and contains no limiting basement membrane, promoting easy access of blood contents to the synovial space.³
- The presence of bacteria within the joint induces a cellular and immunologic response that is detrimental to the joint. Bacteria rapidly replicate, producing toxins. The presence of bacteria stimulates an immunogenic response, resulting in the arrival of leukocytes, which produce proteolytic enzymes. Both the bacterial toxins and leukocytic enzymes destroy the articular cartilage of the joint by degrading proteoglycans and eventually injuring the underlying chondrocytes.
- Multiple risk factors can predispose a patient to septic arthritis (Table 1).
- Any disorder that results in an immunocompromised state can predispose to septic arthritis.
- Rheumatoid arthritis, in particular, poses a high risk. This risk is related to a variety of factors including general debilitation, immunosuppressive medication, tumor necrosis factor blockers (eg, infliximab or etanercept) and chronic joint injury.

<table>
<thead>
<tr>
<th>Local Factors</th>
<th>Systemic Disorders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetrating joint trauma</td>
<td>Rheumatoid arthritis</td>
</tr>
<tr>
<td>Recent joint surgery</td>
<td>Diabetes mellitus</td>
</tr>
<tr>
<td>Open reduction of intra-articular fractures</td>
<td>Liver diseases, alcoholism</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>Chronic renal failure, hemodialysis</td>
</tr>
<tr>
<td>Prosthetic joints</td>
<td>Malignancies</td>
</tr>
<tr>
<td>Social Factors</td>
<td>Acquired immunodeficiency syndrome</td>
</tr>
<tr>
<td>Newborns</td>
<td>Immunosuppressive medication</td>
</tr>
<tr>
<td>Elderly</td>
<td>IV drug abusers</td>
</tr>
<tr>
<td>Occupational exposure to animals</td>
<td>Low socioeconomic status</td>
</tr>
</tbody>
</table>

Table 1: Common Risk Factors Predisposing to Septic Arthritis

FIG 1 • Anatomy of the interphalangeal, metacarpophalangeal, and wrist joints.
In patients with rheumatoid arthritis, a diagnosis of septic arthritis may be delayed because of misinterpretation of a rheumatoid flare. A high index of suspicion must be maintained when evaluating for septic arthritis in patients with rheumatoid arthritis.5

Virtually any microbial pathogen is capable of causing pyogenic septic arthritis (Table 2).

- *Staphylococcus aureus* and *Streptococcus* spp. are the most common offending organisms.
- Gram-negative, anaerobic, and polymicrobial infections also are possible, especially in IV drug abusers and immunocompromised patients.
- Specific bacterial pathogens are related to certain circumstances, e.g., *Eikenella corrodens* in human bite wounds, *Pasteurella multocida* after domestic animal bites, *Neisseria gonorrhoeae* infections in sexually active young patients, and fungal and mycobacterial infections in immunocompromised patients.

**NATURAL HISTORY**

- The combination of the growing bacterial load and the ensuing inflammatory response results in a growing effusion that causes synovial ischemia, pressure necrosis of the cartilage, and infiltration of the bacteria into both the subchondral bone and overlying skin.
- Bacterial infiltration out of the joint can result in secondary osteomyelitis, suppurative flexor tenosynovitis, and skin breakdown with spontaneous drainage.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Patients will complain of pain and swelling.
- Systemic signs of joint infection may include fevers, chills, malaise, and tachycardia.
- The patient should be asked about a history of penetrating trauma; human, animal, or insect bites; recent joint aspirations; recent infections elsewhere; and the presence of an immunocompromising condition.
- On examination, patients will manifest a painful swollen joint, with overlying erythema and warmth.
- The most important physical examination finding is exquisite pain with motion, in contrast to a noninfectious effusion or overlying cellulitis.
- Medical professionals at the triage level may attempt to perform a regional block for pain relief. This must be prevented, because it will mask the condition.

- Attempted active digital motion will result in significant guarding, and passive flexion and extension should induce exquisite tenderness.
- Physical examination of the wrist often is less dramatic than that of the digits. The joint typically is held in a neutral position.
- Active wrist motion also will induce guarding and passive flexion, and extension should induce exquisite tenderness.
- Passive pronation and supination may help evaluate involvement of the distal radioulnar joint.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Laboratory studies should include white blood cell count (WBC), erythrocyte sedimentation rate, C-reactive protein, and blood cultures.
- The WBC usually is not elevated, but the erythrocyte sedimentation rate and C-reactive protein levels are consistently elevated (unless the patient is immunocompromised).
- Diagnosis of a septic arthritis is best accomplished by joint aspiration and analysis.
- If infection is present, increased fluid will be present in the joint.
- Joint aspirates should be sent for a cell count with differentiation, Gram stain, crystal analysis, glucose, and cultures (aerobic, anaerobic, fungal, and mycobacterial; Table 3).
- Diagnosis can be made most reliably with a joint fluid WBC count greater than 50,000 (and a differential of 75% or more segmented neutrophils); a Gram stain confirming the presence of bacteria; or positive cultures.3
- A low WBC count with a high percentage of neutrophils (>90%) may indicate an early septic arthritis.11
- A joint glucose of 40 mg/dL or less compared with the fasting blood glucose level also suggests a septic process.7
- Crystal analysis is necessary to rule out the presence of gout or pseudogout, because they also can present similarly, including an elevated WBC count in the aspirate.
- The role of imaging studies early in the course of the septic process is limited. Radiographs may reveal joint distension, presence of foreign bodies, osteomyelitis, air in the soft tissues, and chondrocalcinosis—characteristic of both gout and pseudogout (FIG 2A). Later radiographs will reveal joint destruction.
- MRI is effective in diagnosing early septic arthritis and in differentiating it from osteomyelitis or overlying tenosynovitis (FIG 2B).
Differential Diagnosis
- Rheumatoid arthritis
- Crystalline arthropathies: gout, pseudogout
- Seronegative arthropathies: systemic lupus erythematosus, psoriatic arthritis, Reiter syndrome, ankylosing spondylitis, rheumatic fever
- Lyme disease
- Cellulitis
- Osteomyelitis
- Suppurative flexor tenosynovitis

Nonoperative Management
- If septic arthritis is detected or suspected early enough, antibiotics alone have been suggested in the medical literature to be sufficient to eradicate the infection.\(^3\)
- In cases where comorbid conditions contraindicate surgery, serial aspiration of the involved joint can be done to decrease the bacterial load, decompress the joint, and allow medical management with antibiotics to treat the infection.
  - This technique has been shown to be less effective than open surgical drainage in large joints and, therefore, would be even less reliable in small joints.\(^4\)

Surgical Management
- Septic arthritis usually is considered a surgical pathology that warrants prompt treatment.
- Open and arthroscopic techniques are available for surgical drainage of the wrist.

Preoperative Planning
- Arrangements for instruments, irrigation fluid, drains, sutures, and assistants should be made in advance of surgery.

Positioning
- Approaches to the hand and wrist can be accomplished with the patient supine and the operative extremity extended on a hand table with the surgeon and assistants seated.
  - The hand table should be stable and well-secured, and should allow adequate space for both the operative limb and the surgeon’s elbow and forearm, to minimize surgeon fatigue and enhance stability.
  - Tourniquet use is advised to obtain a bloodless field and clear visualization of anatomic structures.
  - The limb usually is exsanguinated via gravity with elevation before inflating the tourniquet to avoid proximal spread of the bacteria.
  - A small-joint wrist arthroscopy tower should be used. This will provide positioning and application of traction during arthroscopy and also facilitate conversion to an open procedure if necessary. Additionally, small-joint arthroscopy equipment, including a 30-degree 2.7-mm camera, should be used.

Approach
- Multiple approaches to a joint are available. The choice of which approach to use should be based on ease of the approach while still allowing adequate joint exposure for débridement and minimizing contiguous spread of infection.
  - All surgical approaches of the hand and wrist warrant a sound understanding of surface anatomy, surgical anatomy, internervous planes, and surgical technique.

Aspiration of Interphalangeal or Metacarpophalangeal Joints
- Prepare the skin with an antiseptic wash, but avoid placing local anesthesia before the aspiration, because it may mask the location of the joint space.
- As large a needle as possible should be used, preferably 18- or 20-gauge.
- A syringe no larger than 3 or 5 mL should be used, because larger syringes cause too great a vacuum aspiration and collapse the joint, making them, therefore, less effective for aspiration.
  - The joint space can be identified just radial or ulnar to the extensor mechanism on the dorsal surface.
  - The needle should be inserted in a dorsal-to-volar direction with a 30- to 45-degree angle toward the midline.
  - A palpable “pop” or sensation of entering the joint should be felt, and the joint should be aspirated.
  - Distraction of the joint can sometimes aid entry.
  - If there is resistance to aspiration, the needle should be redirected while maintaining suction on the syringe.
SURGICAL DRAINAGE OF INTERPHALANGEAL OR METACARPOPHALANGEAL JOINTS

- For the MP joint, a dorsal longitudinal incision is made (TECH FIG 1A). The extensor mechanism is exposed and also incised longitudinally to expose the capsule.
- Alternatively, the capsule can be exposed by incising the ulnar sagittal band.
- The joint is exposed by incising the capsule dorsal to the collateral ligaments.
- For the proximal IP joint, a midaxial incision is preferred to avoid injury to the central slip and creation of a septic boutonniere deformity (TECH FIG 1B).
- The neurovascular bundle may be identified and retracted volarly. The dorsal sensory branches are at risk and should be retracted with the dorsal flap.
- The extensor mechanism, including the lateral bands, is identified and retracted dorsally, thereby exposing the capsule laterally. The accessory collaterals (volar to the proper collaterals) are released to allow entry into the joint.
- The distal IP joint can be approached through a midaxial incision or through a dorsal “H” incision and the terminal tendon retracted laterally, exposing the joint dorsal to the collateral ligaments.
- Injury to the terminal tendon can result in a mallet finger and possible late swan-neck deformity.
- Obtain cultures and thoroughly irrigate and débride the joint with gravity cystoscopy tubing or a bulb syringe.
- In-line traction on the digit will help expose the joint space.
- Inspect the joint surfaces for articular damage.
- Leave a small wick in the joint to prevent premature closure of the joint capsule, and reapproximate the extensor mechanism using a monofilament suture. Avoid using deep braided sutures in the face of an infection.
- Loosely close the skin around the wick with one or two 4-0 nylon sutures.
- Place the hand in a volar splint for comfort and emphasize that the patient should keep it elevated.

ASPIRATION OF THE WRIST

- Prepare the skin with an antiseptic wash but avoid placing local anesthesia pre-aspiration, because it may mask the location of the joint space.
- As large a needle as possible should be used, preferably 18-gauge.
- A syringe no larger than 5 or 10 mL should be used.
- Larger syringes cause too great a vacuum on aspiration and collapse the joint, and are, therefore, less effective for aspiration.
- The joint space can be identified just distal to Lister’s tubercle on the dorsum of the wrist. The needle should be angled approximately 10 degrees volar to accommodate for the normal volar tilt of the radius.
- Alternatively, the joint may be easily entered through the dorsal ulnocarpal space, just distal to the triangular fibrocartilage complex.
- A palpable pop or sensation of entering the joint should be felt and the joint should be aspirated. If there is resistance to aspiration then the needle should be redirected while maintaining suction on the syringe.
ARTHROSCOPIC DÉBRIDEMENT OF THE WRIST

- Secure the hand and wrist in a sterile small-joint arthroscopy tower. Apply 5 to 10 pounds of traction.
- Identify and mark the dorsal surface anatomy of the wrist. Specifically, palpate the dorsal and distal surface of the radius, ulna, distal radioulnar joint, and Lister’s tubercle. These landmarks will guide safe establishment of portals and maximize visualization (TECH FIG 2).
- The 3–4 portal is the main “viewing” portal and should be established first to visualize the radiocarpal joint. Begin by identifying the soft spot just distal to Lister’s tubercle. The portal is bordered by the third and fourth dorsal compartments.
  - An 18-gauge needle is directed just distal to Lister’s tubercle and should be angled about 10 degrees volar to accommodate for the normal volar tilt of the radius. The joint is then insufflated with 5 to 10 mL of normal saline.
- Create the portal with a 3-mm longitudinal skin incision using a no. 11 blade directed superiorly. Spread the soft tissue bluntly with a curved hemostat down to the joint, avoiding inadvertent penetration of the capsule.
- Direct a blunt-tipped cannula and trocar into the joint, again angling about 10 degrees volar just distal to Lister’s tubercle. Avoid plunging the cannula uncontrollably into the joint, because this may cause iatrogenic articular cartilage injury.
- Replace the trocar with the camera.
- Cultures can be taken through the cannula.
- Systematically explore the radioscapoid, radiolunate, and ulnocarpal joints for turbid fluid.
- In addition, evaluate the scapholunate ligament and triangular fibrocartilage complex for tears that may allow the infection to communicate with the midcarpal and distal radioulnar joints, respectively.
- Establish a second “working” portal. Arthroscopic equipment such as the shaver and probe will be used through this portal. A 25-gauge needle is directed into the proposed site under direct arthroscopic visualization before making the skin incision.
- The 4–5 portal is identified just ulnar to the fourth dorsal compartment and just distal to the distal radioulnar joint (see Tech Fig 2).
- Alternatively, a 6-R or 6-U portal can be used and can be identified just radial or ulnar, respectively, to the sixth dorsal compartment. Diligent blunt dissection with a curved hemostat must be performed before inserting the blunt cannula and trocar to avoid inadvertent injury to the dorsal ulnar sensory nerve.
- The joint can be both visualized and washed through the camera cannula in the viewing portal and drained through the working portal with a cannula. Drainage can be applied to gravity or suction.
- The joint can be further débrided with the aid of a shaver with suction placed through the working cannula.
- Devitalized tissues and synovial shavings can be taken through the shaver.
- Thorough arthroscopic débridement of the wrist should include visualization and irrigation of the midcarpal joint as well.
  - Palpate a soft spot about 1 cm distal to the 3–4 portal.
  - Place a 25-gauge needle first, and insufflate the joint with 5 mL of normal saline.
  - Direct a blunt cannula and trocar into the midcarpal joint just radial to the base of the capitate.
- After thorough visualization, irrigation, and débridement of the wrist, insert a small Hemovac drain through the working portal cannula.
- Remove the arthroscopic equipment. Close the portals with 4-0 nylon stitches.
- Place the wrist in a volar splint for comfort, and encourage limb elevation and active finger motion.

OPEN SURGICAL DRAINAGE OF THE WRIST

- A dorsal longitudinal incision should be placed just ulnar to Lister’s tubercle (TECH FIG 3A). The incision should be approximately 4 cm in length, with about two thirds distal to the tubercle.
- Alternatively, a transverse incision may be used. Although more cosmetic, it may not provide adequate exposure.
Once the extensor retinaculum is exposed with blunt dissection, the distal third is released perpendicular to the fibers and ulnar to the third dorsal compartment.

The interval between the third and fourth extensor compartments is bluntly dissected, and the joint capsule is exposed (TECH FIG 3B).

The joint capsule is incised longitudinally, and limited flaps are raised subperiosteally off the dorsal distal radius, like an inverted T (TECH FIG 3C).

Cultures are taken, and synovial tissue should be sent for culture and histology.

The joint should be thoroughly débrided and irrigated with gravity cystoscopy tubing or a bulb syringe.

Pulse lavage should be avoided due to its potential to cause additional soft tissue injury.

The joint should be ranged during irrigation to maximize the effect of the lavage.

The joint surfaces are inspected for articular damage.

Leave a small wick or drain in the joint and loosely close the skin around the wick.

Primary closure of the joint risks reaccumulation of pus.

Typically, two to three loosely placed 4-0 nylon sutures will be sufficient.

Place the wrist in a volar splint for comfort and encourage limb elevation.

Diagnosis
- Diagnosis is best accomplished by joint aspiration and analysis.

Antibiotics
- Obtain cultures before beginning antibiotics.
- Empiric antibiotics should be tailored to the most likely organism based on mechanism of injury and patient factors.

Aspiration
- Avoid using larger syringes, because the vacuum created can collapse the joint and may be less effective for aspiration.

Arthroscopic drainage
- Identify the surface landmarks of the joint and avoid inadvertent injury to the dorsal tendons and cutaneous nerve.
- Be prepared to convert to an open procedure if adequate exposure and débridement are not possible.

Open surgical drainage
- Be prepared to perform a second open surgical débridement if symptoms do not improve.

POSTOPERATIVE CARE
- Empiric IV antibiotics are initiated immediately after obtaining cultures and then later tailored to the results of laboratory cultures and sensitivities.
- IV antibiotics should be continued for 2 weeks or at least through symptom resolution, followed by oral antibiotics.\(^8\)
- The duration of antibiotics is the subject of some controversy. This should be determined on a case-by-case basis, with consideration of surgical findings, virulence of the offending bacterial pathogen, and the response to treatment.
- Early range of motion (active and active-assisted) in diluted povidone-iodine soaks is initiated three times daily to provide mechanical lavage of the joint and to prevent premature wound closure.
- The wick or drain is removed 1 or 2 days postoperatively.
As symptoms resolve, the soaks are discontinued to allow the wound to heal, and progressive range of motion exercises are initiated.

If symptoms do not improve within 2 days, then a repeat surgical drainage should be considered.

OUTCOMES

The results of surgical treatment of septic arthritis are not well-documented in the literature, and it is difficult to predict the outcome even during the course of treatment.

Functional outcome is most closely correlated to the duration of symptoms before treatment is initiated.10

Some loss of motion and joint stiffness are expected, even in cases treated with early surgical drainage and rehabilitation.1,10,12–14

Some joint space narrowing usually is seen following treatment, and significant arthrosis and ankylosis may occur in severe cases or when treatment has been delayed.

COMPLICATIONS

Joint stiffness, arthrosis, osteomyelitis, and secondary tendon adhesions

Salvage options for postseptic arthritis include arthrodesis, resection arthroplasty, or amputation.

Implant arthroplasty is controversial and is not generally recommended for a previously infected joint.

REFERENCES

DEFINITION
- Injury to the nail usually occurs in the traumatic setting. Because of its location at the distal end of the digits, the peri-onychium is the most frequently injured part of the hand.\(^9\)
  - Restoration of normal nail appearance is best achieved by acute treatment of the nail matrix.
  - Reconstructive techniques may be used to provide a more normal-appearing nail.
  - Excision of benign and malignant tumors involving the nail bed matrix may require techniques of nail bed repair and reconstruction also used in the traumatic setting.
  - Optimal treatment depends on thorough understanding of the components of the perionychium—skin, sterile matrix, germinal matrix, eponychial fold, and distal phalanx—and their anatomic relationship with each other.

ANATOMY
- The nail serves multiple functions: protecting the fingertip, regulating peripheral circulation, and contributing to sensory feedback of the fingertip.\(^9\)
- The perionychium includes the nail plate, nail bed, hyponychium, eponychium and fold, and paronychium (FIG 1).
- The proximal portion of the nail matrix is the germinal matrix, and the distal portion is the sterile matrix. The germinal matrix produces about 90% of the nail, while the sterile matrix produces the remaining 10% of the nail and produces the cells on the undersurface of the nail responsible for nail adherence.
- The hyponychium is the skin distal to the nail bed, the paronychium is the skin on each side of the nail, and the eponychium is the skin over the nail fold.
- The nail bed is adherent to the distal phalanx.

PATHOGENESIS
- The main causes of nail deformity are trauma and tumor.\(^13\)
- The middle finger is the most commonly injured finger.\(^1\)
- Inadequate treatment in the acute setting often leads to a nail deformity.
- There is an associated distal phalanx fracture in 50% of nail bed injuries. This type of injury should be considered an open fracture and treated as such, with irrigation and débridement, reduction of the fracture and fixation if necessary, and repair of the nail bed (FIG 2).\(^1,4\)
- Scarring can lead to a split nail deformity.
- Absence of nail matrix can lead to detachment of the nail.
- Lack of support from the distal phalanx leads to the hook nail deformity.
- Benign tumors (glomus tumor, distal interphalangeal joint ganglion), and malignant tumors (squamous cell carcinoma, melanoma) can affect nail appearance.

NATURAL HISTORY
- Repair in the acute period provides the best chance for normal appearance of the nail.
- The nail plate grows at about 0.1 mm per day or 2 to 3 mm per month. When the nail plate is removed for nail bed repair, new nail growth is delayed for 3 to 4 weeks.\(^9\)
- If placed back on after repair, the old nail will remain adherent for 1 to 3 months and then fall off as a new nail pushes out the old nail.\(^12\)
- After nail repair, it will take about 12 months for the nail to achieve its final appearance. Thickening of the nail proximal to the level of injury is seen for about 50 days (FIG 3).\(^9,12,13\)

PATIENT HISTORY AND PHYSICAL FINDINGS
- Traumatic injury to the perionychium is usually caused by a crush injury.\(^1,4\)
- In the acute setting, the status of the entire fingertip must be assessed: quality of the skin, presence of a subungual hematoma, quality of the nail matrix, capillary refill, sensory...
function, flexion and extension at the distal interphalangeal joint, presence of a distal phalanx fracture.

■ Features of acute nail bed injury
  ■ Subungual hematoma (FIG 4A,B): bleeding beneath the nail from laceration of the nail bed
  ■ Pain secondary to pressure in the space between the nail plate and the nail bed
  ■ Treated with evacuation of hematoma by trephination
  ■ Laceration of nail bed (FIG 4C,D)
    ■ Mechanism of injury usually is crush.
    ■ Concomitant injury to fingertip skin or distal phalanx fracture may be present.
    ■ Nail lacerations can be described in one of four ways: simple laceration, stellate laceration, severe crush, and avulsion.
    ■ Repair of nail bed laceration and Kirschner wire fixation of distal phalanx fracture if unstable
  ■ Nail bed avulsion (FIG 4E)
    ■ Quality of avulsed nail matrix and size of defect will determine treatment.
    ■ Treatment options include returning avulsed piece back on defect or harvesting a split nail graft from the adjacent matrix or from the great toe.
  ■ Posttraumatic nail deformities
    ■ Nail nonadherence or split nail (FIG 4F)
      ■ Usually due to injury to the sterile matrix, which produces the cells responsible for adherence

■ Excision of scar and primary closure or nail matrix reconstruction with a split graft from the great toe
■ Hook nail deformity (FIG 4G)
  ■ Due to excessive tension at junction of nail bed and hyponychial skin and loss of support of distal phalanx
  ■ Revision amputation or reconstruction of nail bed and bone graft to the distal tip of the distal phalanx
■ Nail remnant (FIG 4H)
  ■ Due to presence of residual germinal matrix not completely ablated at the time of initial repair or revision amputation
  ■ Complete nail matrix ablation or revision amputation
■ Pincer nail deformity (FIG 4I): characterized by excessive transverse curvature of the nail and progressive pinching off of the distal fingertip, causing pain and abnormal appearance
  ■ Partial or complete nail ablation
  ■ Reconstruction of nail bed with elevation of the lateral nail bed using dermal graft or AlloDerm

IMAGING AND OTHER DIAGNOSTIC STUDIES
■ AP and lateral radiographs of the distal phalanx are recommended to rule out a fracture.
  ■ Depending on the level of injury, the following fractures are seen: distal tuft fracture, comminuted fracture, and a transverse or oblique fracture of the midshaft.
  ■ Intra-articular fractures at the distal interphalangeal joint are rare with an associated nail bed injury.

DIFFERENTIAL DIAGNOSIS
■ Trauma
■ Benign tumor
  ■ Glomus tumor
  ■ Distal interphalangeal joint ganglion cyst
■ Malignant tumor
  ■ Squamous cell carcinoma
  ■ Melanoma

NONOPERATIVE MANAGEMENT
■ Left untreated, traumatic injury to the nail matrix may result in an abnormal appearance of the nail.
SURGICAL MANAGEMENT

- Repair in the acute period increases the chance of a normally appearing nail.
- Both surgeon and patient should be aware of the stages of nail growth and characteristic appearance at different points in the healing process as the nail grows out.
- Reconstruction of the nail matrix in a chronic injury should be approached with realistic expectations.
- Reconstruction of the nail matrix after tumor excision will depend on the amount of nail bed excised and the amount remaining.2,6–8

Preoperative Planning

- Management of malignant tumors involving the nail bed requires an understanding of the safe level of amputation (usually to the level of the more proximal joint) and the need for sentinel node biopsy.

Positioning

- To provide a bloodless field, use of a Penrose drain tourniquet at the base of the digit secured with a clamp is recommended (FIG 5).
- Use of a portion of a surgical glove as a tourniquet is discouraged because of the risk of leaving the tourniquet at the base of the digit after repair and placement of the dressing.

The dressing may then hide the tourniquet, and vascular compromise and subsequent necrosis of the finger is possible in the postoperative period.

Approach

- Sterile preparation and draping is done.
- A digital block with 1% plain lidocaine (maximum dose 7 mg/kg) is administered.
- Use of surgical loupes (2.5X magnification is sufficient) is recommended for the most accurate repair.
- A Kleinert elevator is used to separate the nail plate from the nail matrix.


FIG 5 • Use of Penrose drain tourniquet at base of digit.
The nail plate is cleaned and soaked in povidone-iodine (Betadine) as nail bed repair is done. If the nail plate is not available, a silicone sheet or nonadherent gauze can be used to maintain the eponychial fold after repair.

- Minimal débridement of the nail matrix is performed to preserve as much of the nail bed as possible.
- Incisions perpendicular to the eponychial fold may be necessary for adequate exposure of the germinal matrix (FIG 6).

**FIG 6** • Incisions made perpendicular to eponychial fold for exposure of the germinal matrix.

**DRAINAGE OF SUBUNGUAL HEMATOMA**

- A standard surgical preparation is performed to prevent introducing bacteria into the subungual space.
- Trephination of the nail can be accomplished using a heated paper clip, needle, or handheld battery-powered cautery (TECH FIG 1).
- Nail removal and repair is recommended if more than 50% of the nail is lifted up by the underlying hematoma or if the nail edges are not intact.

**TECH FIG 1** • Trephination of the nail to drain a subungual hematoma using a heated paper clip (A) or battery-powered cautery (B).

**REPAIR OF NAIL BED LACERATION**

- Use a digital block, standard surgical preparation, and a Penrose drain at the base of the digit to serve as tourniquet.
- Use the Kleinert elevator to separate the nail plate from the nail bed for adequate exposure (TECH FIG 2A).
- Repair the laceration under loupe magnification using simple sutures of 7-0 chromic (TECH FIG 2B).
- Avoid aggressive débridement of the nail bed.
- Clean the nail plate, soak it in Betadine, and rinse it with normal saline; then place it back into the proximal fold.

**TECH FIG 2** • Repair of nail bed laceration. A. Laceration with nail plate present. The nail plate is cleaned and will be used later as a splint to maintain the eponychial fold. B. Repair of nail bed and surrounding skin after débridement. (continued)
to maintain this space and to serve as a splint for a distal phalanx fracture (TECH FIG 2C).
- A figure 8 suture of 5-0 nylon or a simple stitch from nail to hyponychium can be used to hold the nail in place if desired (TECH FIG 2D).
- A silicone sheet may be used if the nail plate is not available.

- Repair of a nail bed avulsion and resultant proximal germinal matrix disruption may require incisions perpendicular to the curved portion of the eponychial fold for exposure.

### TREATMENT OF NAIL BED DEFECTS

- A defect amenable to reconstruction may be present after excision of scar (causing nonadherence or a split nail deformity) from prior injury to the nail bed (TECH FIG 3A).
- Small areas (less than 5 mm) can be left to heal by secondary intention but may result in recurrent scarring and nail deformity.
- Defects larger than 5 mm can be treated with split-thickness nail bed grafts from the adjacent noninjured nail bed, the nail bed from another digit, or the nail bed from a toe (TECH FIG 3B).²,⁶,⁹,¹³
- Prepare and drape the recipient and donor sites in standard surgical fashion and perform a digital block.
- Exsanguinate the digit and place a Penrose drain tourniquet at its base.
- Expose both nail beds and measure the defect.

- Harvest split-thickness nail bed graft from the sterile matrix of the donor digit using a no. 15 scalpel (TECH FIG 3C,D).
- To reduce the risk of donor-site nail deformity, the germinal matrix should not be used as a graft for a defect of the sterile matrix.
- Graft is carefully harvested by placing the blade parallel to the nail bed and taking it thin enough so that the blade can be seen through the graft.
- Suture the split-thickness nail bed graft in place using 7-0 chromic, as is done in a laceration repair (TECH FIG 3E).
- Reconstruction of the germinal matrix with subsequent nail growth on the recipient digit requires harvest of a full-thickness germinal matrix graft from a toe (preferably the second toe) (TECH FIG 3F).¹⁰

---

**TECH FIG 2 • (continued)**
C. Nail plate being placed back into fold.
D. Completed nail bed laceration repair.
Chapter 103  NAIL MATRIX REPAIR, RECONSTRUCTION, AND ABLATION

NAIL MATRIX REPAIR, RECONSTRUCTION, AND ABLATION

A nail remnant may grow at the site of a previous nail ablation (TECH FIG 4A). It may grow in a dorsal direction, catching on clothes and requiring frequent clipping. This remnant may be a source of persistent pain, irritation, or infection.

- A cyst may form from a nail remnant after a revision amputation and become a source for a subcutaneous abscess (TECH FIG 4B).
- Complete excision of the residual germinal matrix is the goal of treatment.
- It is important to tell the patient that a nail will no longer grow at the fingertip.
- Re-enter the old incision, preserving skin to allow adequate primary closure.

Dissect to the proximal portion of the distal phalanx at the expected location of germinal matrix.

- The distal interphalangeal joint is used as a landmark to guide dissection to the level of the germinal matrix. It may be difficult to distinguish scar from residual germinal matrix after traumatic injury.
- Use a scalpel, curette, or rongeur (or some combination) to ablate the residual nail bed germinal matrix (TECH FIG 4C,D).
- To preserve length yet fully ablate the nail, a full-thickness skin graft can be used to cover the distal phalanx.
- The distal phalanx is a unique area where a skin graft may survive even after being placed directly on bone without the presence of periosteum.

Additional soft tissue bulk to the volar pad may be required to support the reconstructed nail.

- A thenar flap is available for reconstruction of the index or middle fingertips.
- Bone graft can be used for support, but there is a high rate of resorption.
- A favorable cosmetic result is often difficult to achieve.

TREATMENT OF PINCER NAIL DEFORMITY

- The goal of treatment is to flatten out the excessive curvature of the nail and correct the “pinched-in” appearance of the nail (TECH FIG 5A).
- Elevate the lateral margins of the nail bed from the distal phalanx using a Kleinert-Kutz elevator (TECH FIG 5B).
- Avoid injuring the paronychium as the nail bed is elevated.

Hook nail deformity can be caused by overaggressive débridement of the distal phalanx, resulting in lack of support, or by too much tension on the closure at the tip, creating an unnatural, curved appearance of the nail.

- If the germinal matrix is still present, the nail will continue to grow but will hook without adequate bony support.
- Three treatment options exist: doing nothing, reconstruction of the nail to produce a flatter nail with or without bone graft, and revision amputation.

Additional soft tissue bulk to the volar pad may be required to support the reconstructed nail.

- A thenar flap is available for reconstruction of the index or middle fingertips.
- Bone graft can be used for support, but there is a high rate of resorption.
- A favorable cosmetic result is often difficult to achieve.

TREATMENT OF PINCER NAIL DEFORMITY

Hook nail deformity can be caused by overaggressive débridement of the distal phalanx, resulting in lack of support, or by too much tension on the closure at the tip, creating an unnatural, curved appearance of the nail.

- If the germinal matrix is still present, the nail will continue to grow but will hook without adequate bony support.
- Three treatment options exist: doing nothing, reconstruction of the nail to produce a flatter nail with or without bone graft, and revision amputation.

Additional soft tissue bulk to the volar pad may be required to support the reconstructed nail.

- A thenar flap is available for reconstruction of the index or middle fingertips.
- Bone graft can be used for support, but there is a high rate of resorption.
- A favorable cosmetic result is often difficult to achieve.
- Make stab incisions on the ulnar and radial fingertip.
- Through these stab incisions, create subcutaneous tunnels to the radial and ulnar eponychium using the elevato. Make a second set of stab incisions at that proximal location (**TECH FIG 5C**).
- Cut dermal graft or AlloDerm to the appropriate length and place it through each tunnel.
- Pull the graft through the tunnel, distal to proximal, with the aid of a suture. This positions the graft in the desired location (**TECH FIG 5D**).
- Close the stab incisions with 6-0 nylon and replace the nail (**TECH FIG 5E,F**).

**PEARLS AND PITFALLS**

**Traumatic injury**
- With prompt treatment of nail bed injury, subacute and chronic problems can be avoided and a more complex reconstruction may be avoided.
- Failure to treat a nail bed laceration and concomitant distal phalanx fracture as an open fracture may result in osteomyelitis.
- Too much tension at the site of nail bed repair or a lack of support from the distal phalanx may result in a hook nail deformity.

**Nail growth**
- An accurate repair of the nail matrix allows the nail plate to grow out with a smooth, flat appearance.
- The germinal matrix produces about 90% of the nail.
- The sterile matrix contributes cells that are responsible for nail adherence to the underlying nail bed.
- The nail grows at 0.1 mm a day.
- New nail growth is completed by 6 to 9 months.

**Nail bed reconstruction**
- The goal of reconstruction is to restore the nail bed after loss due to trauma, scarring, or excision to allow more normal growth.
- Reconstruction of the sterile matrix can be accomplished with a split nail bed graft from the adjacent nail bed, an adjacent digit, or a toe.
- Reconstruction of the germinal matrix and sterile matrix can be accomplished with a germinal matrix and sterile matrix graft from the second toe.
POSTOPERATIVE CARE

- The postoperative dressing is left on for 5 to 7 days and may need to be soaked in a mixture of hydrogen peroxide and water for removal. The repaired nail is checked for signs of infection, seroma, and hematoma.
- Nonadherent gauze placed to maintain the eponychial fold should be removed. Any suture used to hold the nail or silicone sheet within the fold should also be removed at 5 to 7 days postoperatively.
- Sutures placed in the skin of the hyponychium or paronychium should be removed at 10 to 14 days after repair.
- Early motion of the proximal interphalangeal joint should be encouraged. The fingertip splint provides protection of the tip and will allow earlier motion of the injured digit.
- Hypersensitivity of the tip may be present for 1 to 3 months after injury, and desensitization exercises may be necessary to promote use of the affected digit.

OUTCOMES

- While repair in the acute period provides the best chance for a normal-appearing nail (FIG 7), scarring at the site of injury may produce a nail deformity, and patients should be reminded of this possibility at the time of repair. 10,13,14
- Results of nail bed repair are adversely affected by avulsion or crush injury of the fingertip, presence of a distal phalanx fracture, three or more sites injured, and the need to use a silicone sheet for replacement of the nail. 1,4,13
- Late reconstruction of the nail bed is often not as successful as surgeon or patient would desire. 9
- Management plans must be individualized and realistic expectations must be discussed when treating patients with nail bed injuries.

COMPLICATIONS

- Complications in the acute or subacute setting include soft tissue infection, osteomyelitis of the distal phalanx, nonunion of the distal phalanx fracture, and posttraumatic stiffness and loss of motion at the distal interphalangeal joint.
- Complications or unfavorable outcomes in the chronic setting include scarring in the sterile matrix, leading to a split nail or nonadherent nail; scarring at the eponychial fold, which may interfere with nail plate growth; and persistent nail growth after an unsuccessful attempt at nail ablation.

REFERENCES


FIG 7 • Appearance of the nail in Techniques Figure 3, 1 year after nail matrix reconstruction with a split graft from the toe.
Chapter 104

Soft Tissue Coverage of Fingertip Amputations

Christian Ford and Jeffrey Yao

DEFINITION
- A fingertip injury or amputation involves trauma to the finger distal to the distal interphalangeal (DIP) crease.
- The fingertip is the most sensitive area of the hand.
- Fingertip injuries are common, accounting for 45% of emergency room hand injuries.

ANATOMY
- **FIGURE 1** depicts the anatomy of the fingertip.
- Eponychium: the cuticle or the thin membrane over the dorsum of the nail at the nail fold
- Perionychium: the skin at the lateral nail margin
- Hyponychium: the skin below the distal aspect of the nail plate, consisting of a mass of keratin with a high concentration of lymphocytes and polymorphonuclear cells; serves as a barrier to infection
- Nail root: portion of the nail plate proximal to the eponychial fold
- Lunula: the curved white opacity representing the distal, visible portion of the germinal matrix
- Germinal matrix: produces 90% of the nail plate volume
- Sterile matrix: contributes to nail plate adherence
- Nail plate: consists of flattened sheets of anuclear keratinized epithelium
- Nail bed: the floor of the nail plate, comprising proximal germinal matrix and distal sterile matrix
- Distal phalanx: lies deep to the nail bed
- Pulp: composed of fibrous septa

PATHOGENESIS
- Various mechanisms of trauma
  - Avulsion
  - Crush
  - Compression
  - Sharp
  - Dull

NATURAL HISTORY
- Fingertip injuries with no bone exposed will ultimately heal by secondary intention.
- In the setting of wounds less than 1 cm², secondary-intention healing aided by daily dressing changes actually allows for increased recovery of sensation.
- The use of secondary-intention healing for larger injuries involves a prolonged period of dressing changes with associated risk of infection and unfavorable scarring.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Full history and physical examination
- Mechanism of injury
- Age
- Handedness
- Occupation
- Level of cooperation and understanding
- Injury assessment
  - Digit or digits involved: thumb versus finger
  - Transverse versus dorsal oblique–volar oblique versus radial–ulnar
  - Damage to nail or nail bed
  - Exposure of bone
  - Static and moving two-point discrimination: There is decreased density of innervation with increased two-point discrimination.
  - Terminal flexion and extension: Injury to tendons will require more significant flap coverage.
  - Vascularity: Prolonged capillary refill is suggestive of arterial injury.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs in orthogonal planes (posteroanterior, lateral)

NONOPERATIVE MANAGEMENT
- Most fingertip amputations can be treated at the bedside using sterile technique and employing a metacarpal block, finger tourniquet, and loupe magnification.
There should be a low threshold for operative management.
- If no bone is exposed, options include healing by secondary intention, primary closure, or skin grafting.
- Secondary-intention healing aided by daily dressing changes provides the best recovery of sensation and is appropriate for wounds less than 1 cm².
- Primary closure is an option only if there is minimal skin loss.
  - Tight closures should be avoided. This can minimize function by causing joint contracture and distal tip tenderness due to poor soft tissue coverage of the bony prominences.
  - Sewing the volar skin tightly to the distal nail can result in a cosmetically displeasing “hook nail.”
- If a nail bed laceration is suspected, the nail plate should be removed with a Freer elevator, allowing repair of the nail bed with either 6-0 or 7-0 simple interrupted absorbable sutures (chromic gut). Loupe magnification is extremely helpful.
- The eponychial fold should be stented open with either trimmed and carefully cleansed nail or other material (e.g., foil from a suture pack) to prevent abnormal growth of the future nail.
- With amputations through the germinal matrix, any remaining unrepairable matrix should be removed to prevent formation of a painful nail remnant.

**SURGICAL MANAGEMENT**
- The decision to take a patient with a fingertip injury to the operating room depends on the size of the defect, presence of exposed bone, angle of amputation, willingness of the patient to do dressing changes, and surgeon experience.
- The goals are to preserve function and sensation and allow early return to activity.
- In terms of functional outcome, healing by secondary intention provides equal or better results for defects less than 1 cm in diameter.
- Full-thickness grafts are preferable to split-thickness grafts.
  - Split-thickness grafts should be used only on the ulnar side of the index, middle, and ring fingers.
  - Donor site options include the volar wrist skin (should be avoided as it can mimic a suicide attempt laceration), antecubital skin, medial upper arm skin, and hypothenar skin.
  - These donor sites can be closed primarily.
- If salvageable, the original skin from the amputated segment can be defatted and applied as a graft–biologic dressing.
- If bone is exposed, options include bone shortening and primary closure and bone shortening and healing by secondary intention or fingertip flaps.

**Preoperative Planning**
- Preliminary irrigation and débridement, exploration
- Antibiotics
- Patient comorbidities
  - Is the patient a diabetic? Smoker? Recreational drug user?
  - Is the tetanus status up to date?
- Anesthesia assessment

**Positioning**
- Supine with standard hand table. An arm, forearm, or digital tourniquet is used. The arm is placed in the center of the hand table for equal access by the surgeon and assistant.

**Approach**
- Once the decision to perform a flap has been made, the angle of amputation, patient age, and patient gender determines whether an advancement or regional flap is appropriate.

**SKIN GRAFTING**
- Measure the size of the defect carefully and create a template.
  - This template is used to draw a corresponding defect on the donor site (TECH FIG 1A).
- Harvest the full-thickness graft with a no. 15 blade. Take great care to defat the graft down to dermis (TECH FIG 1B,C).
- Sew the graft into place and secure it using absorbable suture (TECH FIG 1D).
  - At four corners the suture is left long so that later it may be tied over a bolster.
- Cover the skin graft with Xeroform dressing and mineral oil-soaked sterile cotton balls.
- Tie down the four long sutures over the cotton balls to create a bolster, placing gentle pressure on the graft to minimize shear.
- The finger is padded with gauze and protected with a finger splint, leaving the proximal interphalangeal (PIP) joint free for 5 to 7 days.
- After 5 to 7 days, the splint and dressing should be carefully removed, the graft inspected, and daily Xeroform dressing changes instituted until the graft is fully healed.
**TECH FIG 1 • (continued)** B. The hypothenar full-thickness skin graft is harvested, taking great care to defat the graft; only the dermis and epidermis are harvested. C. The hypothenar full-thickness skin graft ex vivo. Note a paucity of fat. D. The skin graft is inset using absorbable sutures. Four bolster sutures are then tied over a mineral oil-soaked cotton ball placed on top of the graft (not pictured). A dry dressing is applied. The bolster is left in place for 5 to 7 days.

**MOBERG ADVANCEMENT FLAP**

- Indication: thumb tip amputation less than 1.5 cm; preserves sensation and length (TECH FIG 2A,B)
- Make a longitudinal incision just dorsal to the neurovascular bundles, based at the metacarpophalangeal joint flexion crease (TECH FIG 2C).
- Elevate a flap elevated from the flexor sheath (TECH FIG 2D).
- If the flap is difficult to advance, consider the following (TECH FIG 2E):
  - Flexing the interphalangeal joint
  - Extending the lateral incisions toward the palm with excision of skin at base to create an island flap; skin grafting of the secondary defect
  - Excise a triangle of skin at the bilateral flap base (ie, triangle of Burow).
  - Carefully preserve bridging vessels.
  - Close with permanent suture under minimal tension (TECH FIG 2F).

**TECH FIG 2 • A.** Distal thumb defect with exposed proximal phalanx. B. Nonreplantable distal phalanx. C. Intraoperative photograph indicating planned Moberg flap with longitudinal incisions just dorsal to neurovascular bundles and based at metacarpophalangeal joint flexion crease. D. Moberg flap elevation from flexor sheath. E. Advancement of Moberg flap was possible without creation of an island flap or use of a triangle of Burow. F. Closure of the defect after advancement of Moberg flap. (Courtesy of James Chang, MD.)
LATERAL V–Y ADVANCEMENT FLAPS (KUTLER)

- Indication: transverse fingertip amputation with exposed bone
- The apex of the V is located at the lateral distal digital crease (TECH FIG 3).
- Adequately mobilize the flap: only nerves and vessels need to be kept intact.
- Bilateral triangles are advanced and sutured together distal to the nail bed.

VOLAR V–Y ADVANCEMENT FLAP (ATASOY-KLEINERT)

- Indication: dorsal oblique fingertip amputation (ie, more dorsal than palmar skin loss) with exposed bone
- The apex of the V is at the volar midpoint of the distal digital crease (TECH FIG 4).
- The base of the triangle should be as wide as the nail bed.
- Adequately mobilize the flap.

CROSS-FINGER FLAP

- Indication: volar fingertip defects up to $1.5 \times 2.5$ cm with an uninjured adjacent digit present (TECH FIG 5A–C)
- The donor area is the dorsal aspect of the middle phalanx skin of the adjacent finger.
  - The middle finger is used for an index finger tip amputation; otherwise the donor skin is derived from the radial digit.
  - Make two transverse midaxial to midaxial incisions on the donor area at roughly the DIP and PIP extension creases. Make one longitudinal midaxial incision on the side of the donor digit away from the injured digit to connect these two transverse incisions.
  - Dissection is carried out in the loose areolar plane above the extensor paratenon.
  - The graft is mobilized to the midaxial line adjacent to the injured digit (TECH FIG 5D).
  - Apply a full-thickness skin graft to the secondary defect.
- The full-thickness graft should be first sewn to the hinge margin of the primary defect.
- The flap and full-thickness graft are then each rotated 180 degrees, allowing the flap to cover the primary defect and the full-thickness graft to cover the secondary defect (TECH FIG 5E).
- The flap is divided 2 to 3 weeks after the index procedure (TECH FIG 5F,G).

TECH FIG 5 • A. Intraoperative photograph depicting ring finger volar fingertip avulsion with exposed flexor tendon and small finger amputation at middle phalanx level. B,C. Two weeks after successful replantation of small finger with continued problem of ring finger wound, which had been treated with daily dressing changes. D. Intraoperative photograph after elevation of cross-finger flap from dorsal aspect of middle phalanx skin of adjacent finger. E. Intraoperative photograph after cross-finger flap from middle finger for coverage of volar ring finger defect. Donor site was covered with a full-thickness skin graft. Blue background indicates preservation of sensory branch. F,G. Intraoperative photographs after cross-finger flap division at 3 weeks.

REVERSE CROSS-FINGER FLAP

- Indication: dorsal fingertip injury
- Raise a de-epithelialized full-thickness flap from the dorsal middle phalanx skin (TECH FIG 6A,B).
- Elevate the subcutaneous tissues underlying the raised graft (TECH FIG 6C,D).
- Cover the primary defect with the elevated deep tissue and then with a full-thickness graft (TECH FIG 6E).
- Cover the secondary defect with the previously described native full-thickness flap (TECH FIG 6F).
- The subcutaneous flap is divided in 2 to 3 weeks (TECH FIG 6G).
The designed H-flap should be 50% wider than the defect to fully cover the pulp’s semicircular contour. Raise the flap at the level of the thenar muscles with as much subcutaneous tissue as possible (TECH FIG 7C). Take care to avoid injury to the digital nerves to the thumb. The H-flaps may either be “tubed” around the defect or one flap may be advanced to fill the defect of the other flap that is sewn to the amputation site (TECH FIG 7D). The flaps are divided at 3 weeks. One or both H-flaps can be used to close the donor defect primarily.

**TECH FIG 6** • **A.** Dorsal defect of the right index finger with the flap drawn out on the adjacent long finger. **B.** Ulnarly based skin flap raised from the long finger. **C, D.** The subcutaneous tissue is elevated off the paratenon of the long finger. **E.** The flap is inset onto the index finger defect. **F.** Split-thickness skin graft placed on the recipient site. The native ulnarly based skin flap is restored onto the long finger. **G.** Three months postoperatively. (Courtesy of Phani Dantuluri, MD.)

**THENAR FLAP**

- **Indication:** index or middle fingertip injury with exposed bone and more palmar than dorsal skin loss (defects roughly 1 × 1.5 cm in size) in patients younger than 35 years of age who are less likely to develop PIP joint contractures.
  - Women are better candidates for this flap than men.
  - Press the amputated tip against the thenar eminence with the digit in the position of least PIP flexion (TECH FIG 7A).
  - The position of the H-flap is indicated by the bloody imprint from the amputation site (TECH FIG 7B).
**NEUROVASCULAR ISLAND PEDICLE FLAP (LITTLER)**

- **Indication:** Volar distal thumb defect as well as volar radial index or volar ulnar small finger defects sufficient to produce a scarred pulp and an anesthetic tip (TECH FIG 8A,B).
- **Use Doppler to ensure that flow is present in the ulnar digital artery of the ring finger and the radial digital artery of the middle finger.**
- **Create a template of the defect on the ulnar aspect of the donor digit.**

- Apply the pattern to the distal ulnar aspect of the middle finger with small V-shaped indentations at the DIP joint creases.
- The flap may be continued posteriorly, beyond the midaxial line.
- Make a Bruner incision to the distal flexor retinaculum.
- Dissection is commenced in the palm to ensure normal anatomy.
- Isolate and ligate the radial digital artery to the ring finger.
POSTOPERATIVE CARE

- Mobilize the vessel to the level of the superficial palmar arch to allow maximum pedicle length (TECH FIG 8C).
- Pass the entire pedicle beneath the digital nerve if it causes tension.
- Create a subcutaneous tunnel to the thumb using blunt scissor dissection.
- The tourniquet is released and flap viability assessed.
- The flap is then gently placed into a Penrose drain and secured in place with a 4-0 nylon suture to the tip of the flap skin.
- The Penrose drain is used to avoid kinking and twisting of the pedicle as the flap is passed through the subcutaneous tunnel to the recipient site.
- The flap is sutured in place under minimal tension and the donor site is closed primarily or with a full-thickness graft (TECH FIG 8D).

PEARLS AND PITFALLS

- Fingertip injuries less than 1 cm² can generally be treated with dressing changes with equal or better results than flap closure.
- The bridging vessels should be carefully preserved when performing a Moberg flap to prevent skin necrosis.
- V–Y advancement flaps may lead to scarring and hypersensitivity at the fingertip.
- The radial digital nerve should be carefully preserved and protected when performing a thenar flap.
- Cross-finger flaps (nonglabrous skin) may lead to hair growth on the fingertip and deficiency of pulp.
- Thenar flaps (glabrous skin) allow good sensibility in the flap but may be complicated by development of PIP joint contractures, especially in older male patients.
- Poor sensory outcome in neurovascular island flaps can be minimized by use of the most distal portion of donor skin, preservation of as much subcutaneous skin on the pedicle as possible, and avoidance of tension and kinking in the pedicle.

POSTOPERATIVE CARE

- When possible, the patient should meet the hand therapist preoperatively.
- Active and passive range of motion
- Sensory re-education
- Scar massage
- Moberg advancement flap: thumb spica splint for 10 days to 2 weeks followed by range-of-motion exercises
- Lateral V–Y advancement and volar V–Y advancement flaps: finger splintage of only the involved joint for 10 days to 2 weeks, followed by range-of-motion exercises
- Cross-finger flap and reverse-cross finger flap: A nonadherent bolster dressing is applied to the skin graft site and a splint is applied. PIP joints and the DIP joint of the donor finger can be gently ranged 2 weeks after flap inset, taking care to avoid tension on the flap. After flap division at 3 weeks, range-of-motion exercises are directed toward extending the PIP joints. Severe contractures may be treated with static progressive splinting.
- Thenar flap: A splint is applied postoperatively. Gentle range of motion of unaffected digits is started 2 weeks after flap inset, with care taken to avoid tension on the flap. Full range-of-motion exercises are started after flap division at 3 weeks. Severe contractures may be treated with static progressive splinting.
- Neurovascular island flap: The splint is changed 10 days after surgery, when sutures can be removed; gentle active range of motion is started, with full range of motion delayed until 3 weeks after surgery. Sensory re-education is necessary to help differentiate thumb from middle finger sensation.
OUTCOMES

- Moberg flaps consistently provide return of normal two-point discrimination or within 2 mm of the contralateral digit and may result in a decrease in the hyperextensibility of the interphalangeal joint with no functional impairment.3
- V-Y advancement flaps result in return of sensation to within 2.75 mm of the contralateral digit but may also result in paresthesia, hypersensitivity, and cold intolerance (50%).3
- Patients who undergo a cross-finger flap have a return of protective sensation (8 mm of two-point discrimination), most predictably in younger patients, but the sensation remains less than the normal pulp.3
- Hematoma or seroma significantly impairs the return of sensation.8
- Thenar flaps provide superior return of sensation compared to cross-finger flaps, but still less than normal.3
- Neurovascular island flaps may result in hyperesthesia (23%) and cold intolerance (32%), which can be minimized by proper attention to detail and technique.3

COMPLICATIONS

- Moberg flap: interphalangeal joint flexion contracture and skin necrosis19
- Lateral V–Y advancement flaps (Kutler): scarring at the fingertip, which may be insensate or painful5
- Volar V–Y advancement flap (Atasoy-Kleinert): hook nail or hypersensitivity3
- Cross-finger flap: deficiency of fingertip pulp and hair growth on the fingertip8
- Thenar flap: PIP joint flexion contracture of recipient finger8
- Hematoma8
- Seroma8
- Infection8
- Skin necrosis8
- Dysesthesia or altered sensation8
- Flexion contractures8
- Loss of flap8
- Epidermal inclusion cysts8
- Nail deformities8
- Symptomatic neuromas8

REFERENCES

DEFINITION

- Upper extremity wounds that are candidates for skin grafting very closely parallel wounds suitable for skin grafting in other areas of the body. Certain wound conditions must be adhered to, and the principles of grafting remain constant, no matter the location of a wound.

Terminology

- **Autograft** refers to skin that is harvested from the same individual to whom it will be applied at a different location.
- **Isograft** refers to skin harvested from an identical twin of the recipient individual. Isograft behaves like autograft.
- **Allograft** refers to skin harvested from an individual of the same species as the recipient individual. Due to histocompatibility mismatch, these grafts eventually separate from the wound, except in immunosuppressed patients, and so provide only temporary coverage.
- **Xenograft** refers to the use of skin grafts from a species different from the recipient individual. Due to histocompatibility mismatch, these eventually separate from the wound, except in the immunosuppressed patient, and so provide only temporary coverage. Xenograft use is associated with an elevated rate of wound bed infection.
- **Split-thickness skin grafts** contain epidermis, along with a varying thickness of dermis that represents less than the full thickness of the dermis.
- **Full-thickness skin grafts** incorporate the full thickness of dermis and epidermis.
- **Donor site** refers to an area from which either a split- or full-thickness skin graft is harvested. Depending on the thickness of the graft, donor site treatment varies, from topical dressings, which typically are used for split-thickness skin graft donor sites, to direct closure, which is the usual method for addressing full-thickness skin donor defects.
- **Skin substitutes** are semisynthetic or purely synthetic constructs designed to act as replacements for lost skin structures. Ideally, they will be incorporated into the host to act as durable long-term replacements for lost tissue. In 1984, Pruitt and Levine described the characteristics of ideal biologic dressings and skin substitutes. Their list of qualities considered to be ideal for skin substitutes still holds true more than 20 years later:
  - Little or no antigenicity
  - Tissue compatibility
  - Lack of toxicity
  - Permeability to water vapor, as would be seen in normal skin
  - Impenetrability to microorganisms
  - Rapid and long-term adherence to the wound bed
  - Capacity for ingrowth of fibrovascular tissue from the wound bed
  - Malleability, which would allow the construct to conform to the wound bed
  - Inherent elasticity that would not impede motion
  - Structural stability against linear and shear forces
  - Smooth surface to hinder bacterial proliferation
  - Good to tensile strength that would allow it resist fragmentation
  - Biodegradability
  - Low cost
  - Ease of storage
  - An indefinite shelf life

Wound Bed

- Before making a decision about using skin grafts or a substitute, it is important to be familiar with the characteristics of a wound bed that make it suitable for grafting.
- **Graft beds** should be properly débrided so that they are free of dead tissue and made as clean as possible to help minimize the risk of graft loss from infection.
- Beds that are being considered for grafting must have an appropriate substrate from which the graft can derive its blood supply. In the context of upper extremity wounds, the bed specifically should contain no areas of denuded tendon or bone, as these denuded areas will not support inosculation (ie, neovascularization of the graft).
- A further requirement, once débridement is complete, is the reduction of bacteria in the wound, which usually is effected through the use of a pulse lavage system. Enhanced skin graft survival by means of reducing bacterial counts is supported by studies published by Perry in 1989.
- A useful tool in maturing a wound bed for grafting is the vacuum-assisted closure device (VAC). This device provides microdébridement of the wound bed and can help to promote the development of healthy granulation tissue, an ideal substrate for the support of skin graft adherence. Moreover, the vacuum-assisted closure device can be used over the top of a skin graft applied to a wound and, through its negative pressure effect, limit fluid collection beneath the graft, also helping to ensure contact between graft and bed through an even distribution of pressure across the interface.
- Elements key to the development of an adequate graft bed are:
  - Débridement of all nonviable tissue
  - Minimization of bacterial colonization within the wound bed
  - Ensuring that there exists an appropriate substrate for adherence of graft
  - Microdébridement and maturation of the graft bed using appropriate dressings, which may include myriad measures ranging from the use of wet-to-moist saline gauze dressings to use of the VAC device.
ANATOMY

- The decision-making process in choosing split- versus full-thickness graft in the distal upper extremity involves both gross and microanatomic considerations.
- The lack of secondary contraction seen in full-thickness skin grafts supports their use on surfaces that overlie or are juxtaposed to joints. This lack of secondary contraction helps minimize the risk of unwanted joint contracture as the grafts mature.
- Over broad flat surfaces, such as the dorsal or volar aspect of the forearm, split-thickness skin grafts perform well.
- Wounds that involve the glabrous surface of the hand ideally are replaced with skin that possesses the same characteristics as the adjacent skin.
- Harvest of glabrous skin from the sole of the foot or from the contralateral uninjured hand should be considered for such use.
- In some cases, the wound may be so large that it is not possible to harvest sufficient donor skin while still permitting primary closure of the donor site. When this is the case, the arch within the sole of the foot may yield a full-thickness glabrous skin graft sufficient to cover the area of the original wound; however, the donor site then may require a skin graft itself. The donor site from the arch of the foot can be grafted with nonglabrous, meshed split-thickness graft with minimal morbidity due to its minimal weight-bearing requirement.

Microanatomy

- As suggested earlier, the surgeon must be concerned with the microanatomic conditions of the wound bed.
- An appropriately vascular substrate is required to ensure proper graft take. Healthy fat, muscle, paratenon, or periosteum must be present within the base of the wound to ensure success.
- Additional considerations include proper débridement of nonviable tissues from the wound bed as well as the minimization of bacterial contamination.

Donor Sites

- Glabrous skin
  - The sole of foot within the arch, beginning at the junction of glabrous and nonglabrous skin along the medial aspect of the arch
  - The ulnar aspect of the hand, beginning at the junction of the glabrous and the nonglabrous skin along the ulnar aspect of the palm
- Full-thickness skin
- Redundant areas of full-thickness skin available for harvest that maintain ease of primary closure of the donor defect include the lower abdomen, running from the anterior superior iliac spine in a gentle arc around the lower portion of the abdomen to the contralateral anterior superior iliac spine.
- Skin harvested from this area may be hair-bearing. Depending on requirements of the recipient site, selection of full-thickness skin graft can range from the relatively hairless portions found laterally to the hirsute areas found centrally.
- Smaller areas of satisfactory full-thickness skin can be harvested from the upper inner arm. This skin, located at the junction of the medial biceps and triceps muscle groups, is thin and usually hairless.
- Split-thickness skin graft
- Traditionally preferred sites have included the anterior thighs due to the ease of harvest and postoperative care of these areas.
- Another site that has favorable characteristics in terms of quality of graft donor, as well as healing of donor site, includes the scalp.
- Harvest of split-thickness skin graft from the scalp requires shaving of the head and the injection of epinephrine-containing wetting solution, eg, Pitkin's solution or Klein's solution, which is directed via puncture into a subgaleal plane to help minimize blood loss from the harvest.
- The very rich vascular supply to the scalp makes split-thickness skin grafts from this site quite robust.
- If the harvest is kept within the hair-bearing portions of the scalp, little to no donor defect can be detected once hair has grown back. Moreover, because of the high density of epidermal appendages in the scalp, re-epithelialization of this area is more rapid than at other sites on the body. This rapid re-epithelialization helps to minimize the potential for donor deformity (ie, scarring and dyspigmentation).

Harvest

- Skin harvest is greatly facilitated by proper preparation of the chosen site.
- First, a template of the bed to be grafted should be transferred to the donor site to ensure an adequate harvest. This is easily done with gentian violet and a sterile glove wrapper.
- Limiting blood loss from the harvest site is desirable and is easily achieved by pre-injecting the hypodermis of the planned harvest area with an epinephrine-containing local anesthetic.
- If a long-acting local anesthetic such as Marcaine with epinephrine is used, the patient will have the additional benefit of prolonged donor site anesthesia postoperatively.
- As split-thickness donor sites are typically quite painful, this is a real benefit and is appreciated by the patient.
- When a large area is planned for harvest, attention must be paid to the appropriate maximum dosage for the local anesthetic selected. Dilute solutions in these cases can provide the benefits sought for these larger surface areas while still respecting the maximum allowed dosages.

PATHOGENESIS

- Wounds in the distal upper extremity requiring coverage arise from a host of different mechanisms. Among the most common are traumatic injuries, which commonly result in avulsive loss of skin. Other causes include burn injury to the upper extremity, as well as defects created by tumor removal.
- Any one of these mechanisms may result in a wide range of injuries, from simple skin loss to injuries of deeper structures, including loss of paratenon or periosteum.

NATURAL HISTORY

- Skin graft healing varies from site to site on the body, and each location will vary from person to person.
- Skin in young adults is thick and healthy; however, in about the fourth decade the skin begins to thin.
- Despite differences in skin thickness at differing anatomic locations, the overall dermal-to-epidermal ratio remains relatively constant: about 95% dermis to 5% epidermis.
- Blood vessels form arborizations into the dermis of the skin through access portals in the dermal papillae.
How Do Grafts Work?

- After application to an appropriately prepared wound bed, both split- and full-thickness grafts undergo a process that has been commonly termed “take.”
- The process involved in adherence of skin graft to wound bed is complex and involves an initial hypermetabolic condition within the graft, supported by plasmatic imbibition. Plasmatic imbibition is the process whereby nutrients and oxygen are drawn into the graft by absorption and capillary action. During this time, the graft remains adherent by a thin and friable film of fibrin between wound bed and graft.
- This early phase of graft support is followed by inosculation and capillary ingrowth. Before inosculation, there is a period during which ischemia and, therefore, hypoxia within the graft, with attendant histologic findings, are present.
- Once capillary ingrowth occurs and makes contact with the vascular network inherently present within the graft, blood flow is re-established, and the skin graft takes on a pinkish hue. This process likely involves both the use of the inherent network of vessels within the graft and new vascular proliferation.
- Secondary adherence is mediated through fibrovascular ingrowth. The new vascular connections between graft and bed, as well as the new fibrous connections, solidify graft adherence.

Properties of Skin Grafts

- Skin grafts have been used to provide both temporary and permanent coverage, offering the inherent benefit of protection of the host bed from additional trauma while also providing an important barrier to infection.
- Split-thickness grafts tend to adhere to wound beds more easily and under adverse conditions that would not typically support full-thickness graft viability. This characteristic of split-thickness skin grafts provides a considerable advantage in managing difficult wounds; however, certain disadvantages can arise from their use. Once healed, split-thickness skin grafts undergo secondary contraction which, under uncontrolled conditions, can lead to pathologic contracture.
  - Contracture refers to a disability in function that arises from secondary contraction.
  - Additional disadvantages arising from the use of split-thickness skin grafts include dyschromia, poor elasticity, and reduced durability when referenced against their full-thickness counterparts.
- Full-thickness skin grafts include the full thickness of the dermis, along with the epidermis. In the initial phases, full-thickness skin grafts tend not to show the hardy “take” often seen with split-thickness skin grafts. To ensure full-thickness graft success, their use should be limited to well-vascularized recipient beds only.
  - Once established, full-thickness grafts offer distinct advantages; specifically, secondary contraction is far less problematic. Their thickness offers more resistance to external trauma and tends to be less likely to experience the dyspigmentation often associated with split-thickness grafts. They have much better inherent elasticity than split-thickness grafts, and for this reason they are the graft of choice for use over and around joints.

Contraction

- As mentioned earlier, split-thickness skin can undergo a process of secondary contraction that ultimately may lead to pathologic contracture. Immediately on harvest, full- and split-thickness skin grafts behave differently.
  - The phenomenon of primary contraction refers to the tendency of a graft to shrink on elevation from the donor site. Substantial primary contraction is more often associated with full-thickness skin grafts than with split-thickness skin grafts.
  - It is clinically important to remember that the immediate and long-term elasticity of full-thickness skin grafts is much greater that in split grafts. It is this elastic property that makes full-thickness skin grafts an ideal choice for use around joints.
- Once skin grafts have healed in place, the secondary process of contraction occurs more than in split-thickness grafts.
  - Full-thickness grafts tend to remain about the same size and, for practical purposes, show little to no secondary contraction. Full-thickness skin grafts have the capacity to increase their surface area with limb growth over time, whereas split-thickness grafts tend to decrease in size by a process of contraction, or, alternatively, their size remains static.

Reinnervation

- The restoration of sensation in skin grafts is mediated through both peripheral ingrowth and direct growth into the graft from the bed.
  - Factors affecting reinnervation of skin grafts include the location and quality of the recipient bed, as well as the choice of full- versus split-thickness skin graft.
  - Timing of recovery is variable, with some sensory recovery at between 4 and 6 weeks post-grafting. The return of normal sensation occurs between 12 and 24 months.
  - The speed with which sensory recovery is realized depends on the accessibility of graft neural sheaths to wound bed nerve fibers. Accessibility of neural sheaths is improved in full-thickness grafts over their split-thickness counterparts, and, therefore, sensory recovery in full-thickness grafts is both more rapid and more complete.

Dyspigmentation

- The harvest of a graft disrupts its normal circulation, causing a loss of melanoblast content. This reduction results in a significant decrease in the number of pigment-producing cells within the graft.
- After graft revascularization, the initial hypoxia is corrected, and the melanocyte population recovers to a normal level.

Skin Substitutes

- The use of skin substitutes for wound coverage in the distal upper extremity typically is considered when the surface area involved is greater than that which could be reasonably covered with a full-thickness skin graft, but for which a split-thickness skin graft is suboptimal, for cosmetic or functional reasons.
- Of the several skin substitutes on the market, the most clinically relevant are AlloDerm (LifeCell Corporation, Branchburg, NJ) and Integra Dermal Regeneration Template (Integra LifeSciences Corporation, Plainsboro, NJ). AlloDerm is a de-antigenized human cadaveric acellular dermal construct. Integra consists of a bovine collagen dermal matrix sheathed with a silicone top membrane creating a bilaminar structure.
Wounds with a bacterial content greater than $10^5$ colony-forming units (CFUs) have significantly reduced successful graft take. A quantitative culture can be performed to assess this variable before skin grafting. A punch biopsy is used to obtain a portion of vascularized wound bed, and this tissue sample is sent to the laboratory, where it is homogenized and then plated. CFUs on the culture plate are counted and then referenced against the initial sample weight. A concentration of more than $10^5$ CFUs per gram of sample tissue is a negative predictor of successful graft adherence.

The area of tissue biopsied must be delivered from the viable portions of the tissue bed and not from devitalized tissues, which will show very high colony counts and are not representative of the grafted bed.

**DIFFERENTIAL DIAGNOSIS**
- Superficial or partial thickness skin loss
- Full-thickness skin loss
- Full-thickness skin loss concomitant with deep tissue injury
- Loss of paratenon or periosteum
- Wound over or adjacent to joints
- Wound over broad, flat surface that does not overlie a joint

**NONOPERATIVE MANAGEMENT**
- Superficial abrasions or burns over broad surfaces with maintained viability of the dermal and hypodermal structures can be treated by local wound care without the use of grafting. Areas of skin with abundant epidermal appendages (sebaceous glands, sweat glands, and hair follicles) have inherent source tissue for re-epithelialization of these superficial wounds.
- Conservative management ideally includes a moist wound-healing environment that limits bacterial growth and does not inhibit the process of neoeapithelialization, such as the petrolatum-based antimicrobial ointments (eg, Neosporin [Johnson & Johnson, New Brunswick, NJ] and Xeroform gauze [Covidien, Mansfield, MA]).
- When conservative wound management is being employed, serial observation is advised to ensure that the process of neoepithelialization is underway and is not hindered by the development of local infection or other unforeseen factors.
- If the process of re-epithelialization is complete by the end of 2 weeks after the event of the initial injury, scarring at the site of injury will be minimized.
- Smaller wounds that are deeper and penetrate through dermis into the hypodermis may be treated conservatively as well.
- Local wound care, with serial wet-to-moist changes or by use of the Vacuum-Assisted Closure (VAC) Device (KCI, Inc., San Antonio, TX) can help facilitate healing by secondary intention.
- Larger areas of skin loss allowed to heal by secondary intention can result in a substantial delay in wound healing. In addition, functionally limiting contractures can develop as a byproduct of secondary intention healing.
- Larger, superficial dermal wounds such as second-degree burns can be managed nonoperatively by use of synthetic membrane dressings such as Biobrane (Smith & Nephew, Hull, UK, FIG 1) or TransCyte (Smith & Nephew). These dressings are applied immediately after debridement of nonviable skin.
- This class of dressing is effective for superficial wounds that penetrate only to middermal levels. They depend on retained epidermal appendages (ie, hair follicles, sebaceous and sweat glands) to accomplish the task of re-epithelialization.
- Deeper, full-dermal thickness areas of wounding require deeper débridements that typically are followed by skin grafting or skin graft substitutes.

**SURGICAL MANAGEMENT**

**Preoperative Planning**
- Once appropriate débridement has been performed, and the wound is deemed clean and the wound bed is appropriately vascularized, the surgeon can proceed with skin grafting.
- Before beginning in the operating room, the surgeon should have discussed the proposed donor site with the patient and also should have decided whether a full- or split-thickness graft is most appropriate.
Positioning
- The volar and dorsal aspects of the distal upper extremity can be accessed easily with the patient in a supine position with the arm placed on an arm table.
- Occasionally, patients who have limited range of motion in their joints at the shoulder or elbow must be placed prone to facilitate access to certain areas.

Approach
- Wounds that are being considered for placement of skin graft or skin graft substitutes are, by definition, vascularized wound beds with direct superficial access.
- Logical preoperative planning determines the approach.
- Decisions about positioning should be made well in advance of initiation of the procedure.

SPLIT-THICKNESS SKIN GRAFT

Determining Wound Size and Making a Template
- To begin the procedure, a sterile ruler is used to measure the size of the wound to be addressed with skin grafting.
- A simple and effective way to determine the shape of a wound bed is to place a sheet of sterile glove paper within the wound. The mark left on the paper by the wound is a close match of the wound bed. (This technique is not as accurate for wounds with markedly irregular contours.)
- Once the wound has transferred moisture onto the glove paper, the paper can be trimmed with scissors to provide a template of the wound bed. This template then can be transferred to the area of planned skin harvest.
- The shape of the template is marked with a dashed line, using a gentian violet marker, on the skin that is to be harvested.

Harvesting the Graft
- Most modern dermatomes are designed to harvest skin in a quadrangular pattern.
- To ensure that the harvested graft is capable of proper wound coverage, it should be larger than the gentian violet marks on all sides, both to offset shrinkage from primary graft contraction and to compensate for the difficulties in harvesting amorphous shapes with an instrument designed to cut quadrangular patterns.
- The degree of primary contraction is a function of the depth of dermis harvested. For very thin split-thickness grafts, primary contraction is virtually absent.
- Grafts usually are harvested with either nitrogen- or electric-powered dermatomes (TECH FIG 1), which can be adjusted for depth of harvest as well as the desired harvest width.
The usual appropriate depth for harvesting skin to be applied to a wound bed in the distal upper extremity is between 0.012 and 0.014 inch.

Unmeshed versus Meshed Grafts
- Once a graft of appropriate size has been harvested, it must be decided whether to use the graft as a sheet graft (unmeshed) versus an expanded graft (meshed) (TECH FIG 2).
- Sheet grafts, because of their contiguous nature, have a greater tendency to develop subgraft seromas and hematomas.
  - This complication can lead to graft loss; for this reason, it is worth considering the use of meshed grafts.
- Under ideal circumstances, a meshed graft can be used in its nonexpanded state.
  - To do this, simply mesh the graft using the appropriate device, and after placing it in the wound bed, close the small fenestrations made by meshing.
  - This closure will give a final healed appearance very close to that of a sheet graft but without the complication of accumulated fluid beneath the graft, which can lead to graft loss.

Placing the Graft
- Once the graft has been placed in the wound with the dermis side down, the graft can be secured in place using either staples or sutures around the periphery.
  - As this is done, excess peripheral graft may develop. This is the byproduct of the quadrangular shape of the harvest versus the amorphous shape of the typical wound.
  - Excesses are easily trimmed by holding the graft in place and using thin, sharp scissors to skirt just outside the periphery of the wound.
  - Once excess has been removed and the entire peripheral edge of the skin graft has been secured, any surface irregularity leading to noncontact with the undersurface of the graft can be addressed by placement of quilting sutures.
    - These sutures are placed through the surface of the graft into the depth of the contour irregularity and then back out of the graft.
    - When tied, the sutures draw the deep surface of the graft into contact with the wound bed.
    - A suitable suture for this purpose is 4-0 chromic.
- A nonadherent interface (eg, Xeroform [Kendall, Mansfield, MA] or Aquaphor [Beiersdorf AG, Hamburg, Germany] gauze) should be placed over the graft to prevent the graft from adhering to the bolster that will further secure the graft in position.
  - If Aquaphor gauze is used and the patient is not allergic to bacitracin ointment, a triple antibiotic ointment doping of the Aquaphor further inures the graft from injury when the overlying bolster is removed.
  - In the upper extremity, lightly applied circumferential dressings work well as bolsters.
  - Tie-over bolsters typically are not required, but they can be used if preferred. Reston foam (3M, St. Paul, MN) or saline- and mineral oil–doped cotton batting secured in place with light gauze and an elastic overwrap from the tips of the fingers to a point several centimeters beyond the most proximal aspect of the grafted site is sufficient.
  - A sugar-tong splint should then be applied to help prevent the shear stress created between the wound bed and the undersurface of the graft, which occurs as a byproduct of pronation and supination, as well as wrist and finger flexion and extension.
  - The patient’s arm should be elevated to help minimize accumulation of edema at the graft site.

Postoperative Care
- On postoperative day 5, dressings should be removed and the graft examined. Typically, at this time, the graft will have acquired a pink coloration, and although most of the fenestrated areas may not have fully epithelialized, it should be clear that graft take is underway. If this is not the case, the wound should be inspected to determine why the graft is not taking.
  - For fenestrated grafts, it is unusual for either hematoma or seroma to be a cause of graft failure. The more common cause for graft failure with fenestrated split-thickness grafts is wound infection.
  - Quantitative cultures obtained preoperatively will help guide the surgeon in appropriate antibiotic treatment for these patients pre-, intra-, and postoperatively.
  - Once early graft healing has occurred, wound infection is unlikely, and the application of a hypoallergenic emollient cream helps keep the graft supple and moisturized while at the same time promoting slough of scaling stratum corneum and eschar.

FULL-THICKNESS SKIN GRAFT

Donor Site
- If the area of the wound is over or in proximity to a joint, it may be decided to use a full-thickness graft. Again, a template can be made using sterile glove paper, with this glove-paper template then transferred to the area desired for harvest of the full-thickness graft.
There are limitations on the surface area that can be obtained from full-thickness skin graft donor sites, and, therefore, consideration should be given to the recipient bed surface area when deciding on the type of graft. Typical donor sites include the lower abdomen and the inner aspect of the upper arm.

**Graft Harvest**

- Once the template has been transferred to the skin, harvest can be facilitated by injection of 1% lidocaine with epinephrine into the subcutaneous fat directly beneath the area planned for harvest.
  - Allow approximately 7 minutes for the epinephrine to take effect and help minimize bleeding during harvest.
- A no.15 scalpel blade can be used to accurately incise the periphery of the planned graft harvest, followed by elevation of the full-thickness graft in the plane directly beneath the undersurface of the full thickness of dermis, directly above the subdermal fat and below dermal papillae.
- In most cases, some fat is adherent to the underlying dermis after elevation.
  - The full-thickness skin graft can be stretched over the finger and curved scissors used to directly excise fat from the undersurface of the full-thickness graft.
  - The removal of unwanted fat maximizes the surface area of deep dermis in direct contact with the wound bed, which helps to facilitate the ingrowth and revascularization process.
- Full-thickness grafts have a greater degree of primary contraction than do split-thickness grafts; therefore, upon immediate harvest the graft will appear much smaller than it did when in situ. Once sewn in place around the periphery, however, the graft will return to the actual size of the template with little effort.
  - This ability to return to the template size, and even extend beyond it, means that when harvesting full-thickness graft, the harvest should not be extended much beyond the periphery of the template, as is done with split-thickness grafts.

**Graft Preparation**

- To minimize the accumulation of hematoma or seroma beneath the graft, a well-prepared bed is required.

**SKIN SUBSTITUTES**

- The goal with skin substitutes is to place within the wound bed a biosynthetic dermal construct that will offer the advantages of a full-thickness skin graft, but without the physical cost of obtaining such a large full-thickness skin graft harvest from the patient.
- The dermal constructs are placed within the wound in much the same manner as a full-thickness graft. They become fibrovascularly integrated into the wound bed as a synthetic neodermis. After maturity, application of a thin split-thickness skin graft (0.008 to 0.010 inch) converts these nonepithelialized constructs to closed wounds.
- One measure to help prevent subgraft fluid accumulation is “pie-crusting,” a technique in which the surgeon simply makes random perforations through the full thickness of the graft using a no.11 scalpel blade.
- These perforations provide avenues of egress for accumulated subgraft fluid in much the same way that meshing does for split-thickness grafts.

**Graft Placement**

- To improve the precision of dermal edge contact of the graft in the wound, suture fixation is preferred over staple fixation. Again, an ideal suture for this purpose is 4-0 chromic.
- The process for dressing this graft is the same as that for a split-thickness graft: the use of either Aquaphor or Xeroform gauze dressings with an overlying bolster of Reston foam or cotton batting secured with gauze and an elastic wrap, followed by appropriate immobilization of the area.
- The VAC is not recommended for unmeshed grafts and so should not be used for full-thickness skin grafts even if pie-crusted (TECH FIG 3).

**SKIN SUBSTITUTES**

- The technical application of AlloDerm and Integra is the same as placement of a full-thickness skin graft.
- AlloDerm and Integra usually are secured in place around the periphery with either 4-0 chronic or staples (TECH FIG 4A).
- Once a split-thickness skin graft is applied to a site treated with either AlloDerm or Integra, these split-thickness grafts should be treated in just the same manner as split-thickness skin grafts on any wound bed, observing the postoperative technical requirements of such grafts (TECH FIG 4B).
AlloDerm
- When using AlloDerm, bolstering dressings are applied over a petrolatum-doped nonadherent gauze interface, and the dermal construct is observed periodically at twice-weekly intervals.
- AlloDerm will demonstrate granulation tissue issuing through the pores of the dermal construct, typically at about 2 to 3 weeks after graft placement.
- Once this has occurred, the AlloDerm is ready for split-thickness skin grafting.

Integra
- On initial placement, Integra appears white, with a transition over the succeeding 2 to 3 weeks to a rosy color, the byproduct of neovascularization. At this point the Silastic layer of the Integra can be separated and the vascularized dermal construct grafted with a thin split-thickness skin graft.
- If desired, Integra can be meshed 1:1 with a specialized mesher designed not to crush the construct (eg, Brennen Medical Skin Graft Mesher, Brennen Medical, LLC, St. Paul, MN).
  - Meshing may help the construct conform to the wound bed and also help limit subgraft fluid accumulations.
  - The meshed construct should not be expanded on the wound bed, since its purpose is to replace absent dermis. Its expansion thins the Integra construct and diminishes its benefits.
  - Fenestrations in Integra are made only for the purpose of creating an avenue for fluid escape. Integra has a Silastic membrane that acts as an external barrier.
  - Integra’s Silastic membrane obviates the need for petrolatum-doped dressing and is transparent, which allows direct observation of the process of maturation of the dermal construct beneath.

Biobrane
- Biobrane is appropriate for use only in wounds that have some retained dermis and, because of this distinction, acts as an advanced wound dressing rather than a skin substitute. For wounds with full-thickness loss of skin, Biobrane is not an appropriate choice, because epidermal appendages, which are required to act as the source of cells needed for re-epithelialization, must be present.
- Biobrane acts as a protective barrier and a scaffold for the healing process. It notably decreases pain; allows for the retention of moisture within the wound, improving the healing environment; acts as a barrier to infection; and promotes more rapid healing.
- Its clinical use is most evident in treatment of burn injuries, but it also may be used to treat split-thickness skin graft donor sites to minimize morbidity in these areas.
- The application of Biobrane includes tangential excision of nonviable tissues or rough débridement with an antibiotic solution–doped lap sponge, followed by drying and then application of the Biobrane to the wound surface.
  - It is secured in place around the periphery using staples.
  - This is followed by application of a nonadherent gauze dressing with placement of an absorbent dressing, such as a sterile absorbent gauze pad held in place with gauze and an elastic wrap.
  - The site is immobilized for 24 hours, after which all dressings are removed, leaving Biobrane in place.
  - At this stage, the Biobrane should be adherent to the wound bed.
  - Biobrane is observed over time and allowed to separate from the wound without disturbance.
  - Small abscesses below the Silastic layer, if they develop, can be treated by simple incision and drainage. As edges release they are trimmed.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Category</th>
<th>Advice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary contraction</td>
<td>Full-thickness grafts tend to shrink immediately on harvest. This primary contraction is easily overcome by application of peripheral sutures to draw the elastic full-thickness graft back out to its original surface area when applied to the wound.</td>
</tr>
<tr>
<td>Secondary contraction</td>
<td>Split-thickness grafts tend to shrink over time as a function of harvesting less than the full thickness of dermis. This problem is exacerbated by meshed graft expansion. Secondary contraction can lead to functional contracture, especially when grafts are used over or near joints.</td>
</tr>
</tbody>
</table>
Proper immobilization to prevent shear stress across the wound-graft interface cannot be overemphasized. Preparation requires débridement of nonviable tissue and bacteria. Quantitative culture can assist the surgeon in defining the species and number of bacterial colonies within the wound. More than 10^5 colony-forming units per gram of harvested tissue increases the likelihood of graft loss secondary to infection.

Enhancing graft adherence
Proper immobilization to prevent shear stress across the wound-graft interface cannot be overemphasized.

Vacuum-assisted closure device
The VAC device may be used as a skin graft bolster over fenestrated grafts. Its negative pressure serves to effectively immobilize graft on the wound bed, as well as draw interstitial fluid from the wound, preventing its accumulation beneath the graft.

POSTOPERATIVE CARE
- On admission to the postanesthesia care unit, the patient’s operated extremity should be placed in elevation and kept relatively immobile until time to take down dressings and evaluate the graft.
- Examination of the graft can be done as early as 3 days postoperatively; however, the graft at this point is very sensitive to manipulation.
- If takedown of the dressings is done on postoperative day 5 or 6, allowing time for additional graft maturation, the risk of disturbing the graft is reduced.
- Once maturation of the graft has been noted to be underway, application of a nonadherent dressing such as Xeroform or Aquaphor gauze should be continued, with light overpressure provided by an absorbable gauze dressing held in place by gauze and a light elastic wrap and splinting.
- After the graft has more fully matured, with all interstices fully epithelialized, at between 2 and 3 weeks postoperatively, the graft will require no further application of nonadherent dressings. Instead, light application of a hypoallergenic emollient cream such as Eucerin (Beiersdorf North America Inc., Wilton, CT) is preferred. This helps to keep the graft hydrated while maturation continues without the restrictions of constant compression and splinting.
- An occupational therapist should be consulted to help develop a program of appropriate splinting in tandem with an exercise regimen that will provide the foundation for maximizing the patient’s final functional range of motion.

OUTCOMES
- Because of the disparate nature of wounds and the significant variation that exists in patient physiology, it is impossible to provide standardized outcome measures for skin grafting.
- The goal of the general principles defined in this chapter is to assist the surgeon in optimizing outcomes for all cases. Collectively, they will work to help limit complications while maximizing functional outcomes.

COMPLICATIONS
- Wound or graft infection with loss
- Subgraft seroma or hematoma
- Hypertrophic or keloid scarring
- Contractures
- Loss of functional range of motion
- Tendon adherence to graft
- Poor durability
- Hyperpigmentation

REFERENCES
DEFINITION

- A flap is a composite collection of tissue (i.e., skin, fascia, muscle, bone) that is moved from its original location to another location in or on the body.\(^5\)
- Several different types of flaps exist, defined by their blood supply.
  - Random flaps (e.g., Z-plasty, V-Y, cross-finger) depend on preserving enough of the subcutaneous and subdermal vascular plexus for flap survival (FIG 1A).
  - Axial flaps depend on the blood supply from a single consistent (usually named) blood vessel; this includes radial forearm and dorsal metacarpal artery flaps (FIG 1B).
  - Free flaps depend on the division and microscopic reanastomosis of the artery and vein to re-establish blood flow to the flap.
  - Flaps also can be defined by how the tissue is moved.
    - Advancement flaps are elevated and advanced in a linear direction away from the base of the pedicle (FIG 1C).
    - Rotational flaps are elevated adjacent to the defect and re-inset within the same bed\(^10\) (FIG 1D).
    - Transpositional flaps are elevated and moved across normal tissue to a new defect site (FIG 1E).
    - Island flaps are elevated, then moved within a subcutaneous tunnel to the defect site.

---

FIG 1 • A. Random flap. The distal skin flap is not supplied directly by the underlying vessels, but relies on circulation from the dermal and subdermal plexus for nutrition.
B. Axial flap. The entire flap is carried over an underlying vascular pedicle. C. Advancement flap. This is a direct tissue advancement. This figure also shows Burow’s triangles, which will decrease the dog-ears at the corners.
D. Rotational flap. The flap rotates into the adjacent defect. The radius of the flap decreases with the rotation. A backcut can be used to extend the arc of coverage.
E. Transposition flap. This flap is similar to a rotational flap, but the flap is moved across normal tissue to fill the defect.
Grafts are differentiated from flaps in that there is no native blood supply to the tissue. A skin graft survives initially by osmosis (imbibition) before it obtains vascular ingrowth into the graft. This process works only for fairly thin tissue grafts.\(^3,4\)

**ANATOMY**
- A thorough understanding of the anatomy of the area injured and the donor area of the flap is necessary for safe elevation and inseting of these flaps.
- A full description of the anatomy of the forearm and hand is beyond the scope of this chapter, but the key points of the relevant anatomy will be addressed in the separate sections.
- The skin and soft tissue covering the forearm and hand vary by location, and this variation must be accounted for when considering coverage.
- The palm (volar surface) of the hand consists of very thick dermis and epidermis that is structurally anchored to the underlying tissues by numerous vertical fascial connections.
- The glabrous skin of the palm should be used to cover palmar defects, if possible.
- The dorsum of the hand has thin dermis and subcutaneous fat covering gliding extensor tendons.
- Coverage here should be as thin as possible, to match the lost tissue.
- Fingertip sensation and durability should be of high consideration when deciding on type of coverage.
- The forearm has thin soft-tissue coverage.
  - Proximally there is muscle, which often can be covered with a skin graft.
  - Distally there is tendon on the palmar and dorsal surfaces. Trauma to the soft tissue often disrupts the paratenon and will require flap coverage.

**PATHOGENESIS**
- The mechanism of injury has a considerable effect on the need for flap coverage.
  - Sharp injuries can usually be closed primarily, without the need for flap coverage.
  - Abrasive injuries commonly occur as a result of motor vehicle accidents. These usually involve one surface of the hand, and the extent of injury is usually relatively apparent. However, the level of contamination often is high, and extensive débridement of contaminated and devitalized tissue is necessary.
  - Crush injuries can lead to necrosis of skin, tendon, bone, and muscle. The zone of injury often is large and can be underestimated on initial inspection.
  - Other systemic injuries may delay treatment of extremity injuries. However, treatment for compartment syndrome and gross contamination must not be delayed any longer than necessary.

**NATURAL HISTORY**
- The natural history of a wound depends greatly on the type of injury. The degree of original injury is the primary factor contributing to the prognosis for function of the hand.
  - A large wound involving the bones, tendons, or joints often has a profound negative affect on future function of the hand.
  - Early coverage can decrease total inflammation of the injured area and can limit the detrimental effect of the injury on the return to function.
- Many wounds will heal secondarily without coverage. Secondary healing can lead to acceptable results in some locations, but also may lead to very poor results in others. These factors must be taken into account when deciding type of coverage.
  - Small wounds (<1 cm) on the fingertips, without exposed bone or tendon, will likely heal well on their own. This secondary healing often gives the strongest soft tissue coverage with the best sensibility and is the preferred treatment for most wounds of this type.
  - If dorsal hand wounds secondarily heal or “granulate” over tendons, the tendons tend to scar, which limits gliding and impairs finger motion.
  - Exposed bones, tendons, nerves, or vessels usually should be covered with a flap. Secondary healing or skin grafts will result in more scarring or unstable coverage.
  - Skin grafts are best for wounds that have no exposure of tendons, nerves, or vessels. However, in dire circumstances, a skin graft can provide temporary coverage over most viable tissue. Skin grafts will not survive on bone or tendon when the periosteum or paratenon is not viable.
  - A well-performed flap will provide stable, durable coverage over any viable wound bed. This will allow earlier therapy and motion.

**PATIENT HISTORY AND PHYSICAL FINDINGS**
- After a traumatic injury, a complete history and physical examination are performed.
- The mechanism of the injury is important. Contaminated or crush injuries often require more than one procedure for adequate irrigation and débridement.
- Any past medical history of diabetes, smoking, heart disease, peripheral vascular disease, or hypercoagulability will impact the healing of any flap, but none of these is an absolute contraindication.
- Examination of the wound and extremity should be comprehensive:
  - Assessment of vascular status
  - Imaging for fracture
  - Motor and sensory examination to evaluate for nerve, tendon, or muscle injury
  - Examination for compartment syndrome in severe injuries

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Radiographs of the hand should be obtained to evaluate for bony injury.
- Advanced imaging, such as CT scan or MRI, may be warranted for fracture pattern delineation, but these studies rarely are needed to assess the indications for flap coverage.
- Questionable blood flow or limb perfusion warrants further evaluation, such as angiography.
- Adequate blood flow to the extremity must be restored before considering flap coverage.

**TYPES OF FLAPS**

**Radial Forearm Flap**
- Workhorse flap to cover upper extremity wounds. This flap can be a pedicle or free flap and provides excellent thin soft tissue coverage.\(^9\)
The donor site is the major area of morbidity.
- The volar forearm donor site is relatively conspicuous.
- If a skin graft is needed to close the donor site, the appearance is poor.
- The radial artery is divided during movement of the flap. Therefore, ulnar artery patency is critical. This must be confirmed with an Allen’s test, or with direct Doppler evaluation of the hand with the radial artery occluded with manual pressure.
- The flap can be elevated with a proximal (anterograde) or distal (retrograde or reversed) pedicle.
- The anterograde flap is useful for coverage of the elbow, as either a pedicled flap or a free flap.
- The reversed radial forearm flap can cover the volar and dorsal hand to near the tips of the fingers.
- The reversed radial forearm flap has arterial flow through the ulnar artery and palmar arches and back through the radial artery. The venous return is compromised due to valves in the vein, but occurs through interconnections in the vena comitans that bypass the valves.

**Advantages**
- Thin pliable tissue
- Reliable anatomy
- Fair color match
- Can be elevated under tourniquet control

**Disadvantages**
- Poor donor site
- Requires patent ulnar artery
- Reversed flap can often appear congested (but loss of flap is rare)

**Relevant anatomy**
- The brachial artery divides in the proximal forearm to form the radial and ulnar arteries. The ulnar artery is the dominant arterial blood supply to the hand in most people.
- The radial artery courses distally just deep to the interval between the brachioradialis (BR) and the flexor carpi radialis (FCR) muscles. In the proximal forearm, the superficial branch of the radial nerve is adjacent to the radial artery.
- The radial artery has paired venae comitantes that are important for venous egress from the flap once it is elevated.
- There is a loose tissue septum between the FCR and BR. Within this septum, there are perforating branches of the radial artery to the skin that provide blood supply to the overlying skin. These are meticulously preserved to perfuse the flap (**FIG 2**).

**Groin Flap**
- The groin flap is another workhorse pedicled flap for coverage of larger soft tissue avulsions of the hand.
- This fasciocutaneous flap is based on the superficial circumflex iliac artery (SCIA) and is located on the anterior thigh, just below the inguinal ligament.  
- It can be taken as a free flap, but more commonly is used as a pedicled flap and a two-stage operation.
- In the first stage, the flap is elevated laterally and inset onto the injured area. It is still attached medially to its pedicle coming off the femoral vessels.
- In the second stage (2 to 3 weeks later), the pedicle is divided, freeing the arm from its connection to the groin.

**Advantages**
- The flap is thin.
- It is nearly hairless, which may or may not be an advantage, depending on the recipient site.
- It is very reliable.
- Flap elevation is relatively quick.
- The donor site can be closed primarily with widths up to about 10 cm.

**Disadvantages**
- Mandatory two-stage operation
- The injured hand is connected to the patient’s groin for 2 to 3 weeks while waiting for vascular ingrowth.
- Poor color match
- Postoperative numbness in the lateral femoral cutaneous nerve is common.

**Relevant anatomy**
- The SCIA arises off the femoral artery about 3 cm inferior to the inguinal ligament and deep to the deep fascia of the thigh (**FIG 3**).
- SCIA travels superolaterally beneath the deep fascia.

**FIG 2** Cross-section showing the relevant forearm anatomy for a radial forearm flap. The septum lies between the brachioradialis and the flexor carpi radialis. The skin and subcutaneous tissue and fascia above the volar forearm musculature are elevated as a unit with the radial artery and septum with perforating vessels.

**FIG 3** Relevant groin flap anatomy. The superficial circumflex iliac artery (SCIA) arises from the femoral artery 3 cm distal to the inguinal ligament. It then travels laterally, anterior to the thigh musculature, parallel and inferior to the inguinal ligament.
As the SCIA crosses the sartorius, it supplies branches to the muscle.
About 6 cm from the femoral artery, the SCIA travels superficial to Scarpa’s fascia.

Kite Flap
- The kite flap, or first dorsal metacarpal artery flap, is a reliable flap taken from the dorsum of the index finger over the proximal phalanx.
- Its most common use is for reconstruction of palmar thumb defects. Both soft tissue coverage and sensibility can be provided if the dorsal branches of the radial nerve are moved with the flap.1
- It also can be used for web space reconstruction or covering smaller defects on the dorsum of the hand or wrist.
- The flap can be 2 x 4 cm in size.

Relevant anatomy
- The radial artery travels through the anatomic “snuff-box,” then onto the dorsum of the thumb, before diving between the two heads of the first dorsal interosseous muscle. This artery has three main branches:
  - The dorsal carpal arch
  - The princeps pollicis artery to the thumb
  - The first dorsal metacarpal artery

The first dorsal metacarpal artery extends dorsally out along the surface of the first dorsal interosseous muscle to the dorsum on the index finger (FIG 4).
- The venous drainage of the flap is from the dorsal venous system of the finger.
- The radial nerve provides sensation to the dorsum of the radial hand and fingers distally. These small branches can be preserved and brought with the flap, if desired.

Posterior Interosseous Flap
- The posterior interosseous flap, a fasciocutaneous flap, is a less-used flap on the dorsum of the forearm. This flap can be based proximally to cover the elbow or distally to cover the dorsum of the hand, or can be harvested as a free flap.
- The reversed flap, as used to cover the hand or wrist, relies on retrograde venous and arterial flow. The valves within the veins are bypassed by interconnections between the paired venae comitantes.
- The donor site on the dorsal forearm is more visible and subsequently less desirable than even the radial forearm flap.
- The flap is based on the perforating arteries coming from the posterior interosseous artery.
- The posterior interosseous artery travels on the posterior side of the interosseous membrane and arises from either a common interosseous artery or the ulnar artery.
- Septocutaneous perforators travel in the septum between the extensor digiti quinti (EDQ) and extensor carpi ulnaris (ECU) to the skin.
- The posterior interosseous artery connects with the anterior interosseous artery near the distal radioulnar joint (DRUJ), and also will get retrograde flow through the dorsal carpal arch. This site is the location of the distal pivot point of the flap.
- Proximally, the posterior interosseous artery enters the posterior compartment of the forearm at the junction of the proximal and middle thirds of the forearm (FIG 5).

Advantages
- Thin pliable tissue with good match to dorsal hand tissue
- Preservation of both the ulnar and radial arteries
- Can be closed primarily if flap width is less than 5 cm

FIG 4 • Anatomy of the dorsal metacarpal artery.

FIG 5 • The posterior interosseous flap is elevated with the posterior interosseous artery in a retrograde fashion. Perforating vessels are present within a septum that lies between the extensor digitorum quinti (EDQ) and extensor carpi ulnaris (ECU). The skin, subcutaneous tissue, fascia, and septum are all elevated with the artery.
- Disadvantages
  - Technically difficult dissection due to the proximity of the posterior interosseous nerve
  - The anatomy does not always allow safe dissection of the flap, and the surgeon should have a plan for an alternate flap if necessary.
  - Flap repair is contraindicated with wrist trauma due to disruption of the dorsal wrist vascular arcade.

**Z-Plasty**
- Although Z-plasty is not often used during immediate reconstruction, it is a useful adjunct for secondary reconstruction due to scar contracture.
- This method lengthens or redirects a scar by transposing two triangular flaps to bring normal tissue within a scarred area.
- A prerequisite is good tissue on either side of the area to be lengthened, because this tissue is interposed in the place of the original scar.

**NONOPERATIVE MANAGEMENT**
- As with all reconstructive procedures, if nonoperative management is possible, it should be considered and may be preferred.
- Small wounds often will heal secondarily with good results.
- Fingertip injuries that do not expose bone or tendon usually heal with good results and with good sensibility. These wounds should be débrided and cleaned, then dressed appropriately and allowed to heal over 2 to 3 weeks.
- Wounds on the distal forearm and hand often have exposure of tendon, bone, nerve, or vessel. Except in rare circumstances, these should all be covered with good tissue.
- Primary closure is the ideal, but with tissue loss this may not be possible.
- Skin grafts provide good coverage for muscle or clean wounds of the hand, but often do not offer the best coverage for future function of the hand.
- A skin graft will heal on bone or tendon if the periosseous paratenon is intact, but this may create a thin, unstable wound. Skin grafting over tendons is prone to scarring and may decrease tendon excursion.
- Skin grafts will heal over nerves or vessels, but can result in hypersensitivity with nerves or thin coverage over vessels increasing the chance of bleeding.
- In many cases, early flap closure with a good gliding surface (for tendon movement) may be better than delayed healing with increased scar tissue.

**SURGICAL MANAGEMENT**
- The wound should be débrided back to viable tissue before it is covered.
- If there is gross contamination, débridement often can be done in several stages to obtain a clean wound.
- The wound depth and size must be taken into consideration.

**Preoperative Planning**
- If there is tendon or bone involvement of the injury site, the selected reconstruction should consider these factors.
- The affected area should be well perfused when the patient is brought to the operating room for flap coverage.
- Only rarely should flaps be performed on an emergent basis in an unhealthy patient.
- Flap coverage should be performed over a stable skeleton, and devitalized or contaminated tissue should not be covered.

**Positioning**
- The arm usually is placed on an armboard at a 90-degree angle. The operating table is positioned to allow the surgeon and the assistant to sit on either side of the arm.
- This positioning gives excellent access to the palmar and dorsal forearm, arm, and hand.
- If a skin graft is considered, the ipsilateral groin or thigh is prepaped to allow for full- or split-thickness grafting, respectively.
- Small full-thickness grafts can be obtained from the antecubital fossa, the ulnar forearm, or the ulnar side of the palm (for thick glabrous skin).

**Approach**
- For all procedures, a padded tourniquet is used on the patient’s arm and inflated for the duration of the débridement of the wound and for flap elevation.
- At the end of the flap elevation, the tourniquet is released and bleeding controlled with bipolar electrocautery.
- Easily visible vessels are divided with clips or ties while the tourniquet is inflated.
- The wound site is always well débrided back to good tissue. Any foreign material is removed, and the wound irrigated with saline. Pulse lavage irrigation is used for heavily contaminated wounds.
- Careful handling of the tissue is imperative. Avoid handling the skin edges with pickups because the corners of flaps are particularly susceptible to trauma. Use retention sutures and skin hooks as much as possible.

**RADIAL FOREARM FLAP**
- A template of the defect is made (TECH FIG 1A).
- The position of the radial artery is established using Doppler ultrasound and marked on the forearm (TECH FIG 1B).
- The template is placed over the radial artery on the volar forearm and marked in place.
  - If a reversed flap is to be used for hand coverage, it usually is obtained from the proximal forearm.
  - If antegrade flap is to be used, it is obtained from the distal forearm.
  - The proximally based flap can pivot at the bifurcation of the radial and ulnar arteries. The distally based flap will pivot at the level of the radial styloid.

- An incision is made distal to the flap to identify the radial artery.
- Then, starting on the ulnar aspect, the skin and subsequently the forearm fascia are incised.
- The flap is elevated deep to the forearm fascia.
- Care must be taken when approaching the radial artery not to cross and divide the septum between the FCR and BR (see Fig 2).
- The perforating vessels that perfuse the skin paddle lie within this septum.
- Once the radial artery is identified along the course of the flap on the ulnar aspect, the radial aspect of the flap is elevated in a similar fashion.
The radial artery exposure is facilitated by lateral opposing traction on FCR and BR, which can be provided by a self-retaining retractor. The radial artery is then divided proximally (or distally) and the flap elevated (TECH FIG 1C). It is imperative that the venae comitantes be preserved with the flap during the dissection and elevation of the radial artery. These will provide venous outflow for the flap. Once flap elevation is complete, the flap is inset in the defect, and the donor defect covered with a skin graft (TECH FIG 1D).

A template of the defect is made (TECH FIG 2A). The inguinal ligament is marked from the anterior superior iliac spine to the pubic tubercle (see Fig 3). The origin of the SCIA is about 3 cm below the inguinal ligament, and off the femoral artery. A second line is drawn parallel to the first, 3 cm inferior to it, indicating the SCIA. The flap can be as large as needed up to the following guidelines—any larger and the donor site may not close primarily. The flap margins are marked as follows:

As the flap is elevated over the tendons of the FCR and palmaris longus, the paratenon must be preserved, because this will provide the vascular bed for the skin graft that will cover the donor site.

A second line is drawn parallel to the first, 3 cm inferior to it, indicating the SCIA. The flap can be as large as needed up to the following guidelines—any larger and the donor site may not close primarily. The flap margins are marked as follows:

GROIN FLAP

- A template of the defect is made (TECH FIG 2A).
- The inguinal ligament is marked from the anterior superior iliac spine to the pubic tubercle (see Fig 3).
- The origin of the SCIA is about 3 cm below the inguinal ligament, and off the femoral artery.

TECH FIG 2 • A. This patient had a traumatic amputation of his thumb, leaving reasonable bony length, but no soft tissue coverage. B. The groin flap is elevated from lateral to medial. Lateral to the sartorius, the superficial fascia is elevated with the flap. At the lateral border of the sartorius, the deep fascia is elevated, and the perforating branches are ligated. Elevation stops at the medial border. (continued)
TECH FIG 2 • (continued) C. After elevation and inset of the flap, the thumb is well covered. D. After 3 weeks, the flap had matured well in place. The pedicle is divided in the operating room. E. Three months after pedicle division, the flap is doing well. The preserved length of the thumb allows for a good post for opposition. The bulk of the flap can be reduced operatively over time.

- Superior margin: 2 to 3 cm above the inguinal ligament
- Inferior margin: 7 to 8 cm below the inguinal ligament
- Lateral margin: 8 to 10 cm lateral to the anterior superior iliac spine
  - The flap is then elevated from lateral to medial (TECH FIG 2B).
  - The skin is incised laterally, and the flap elevated at the level below the superficial fascia (Scarpa’s fascia).
  - When the lateral border of the sartorius is encountered, the dissection proceeds beneath the deep fascia, just on top of the muscle fascia.
  - The penetrating branches to the sartorius are ligated and divided.
- When the medial border of the sartorius is encountered, the dissection stops (for the pedicled flap).
- The donor site is then closed over a drain. Near the origin of the flap, care is taken not to strangulate the flap with the closure.
- The proximal portion of the flap is then tubed if possible; however, there cannot be any tension on the tube.
- The flap is then inset on the hand, usually over a Penrose drain (TECH FIG 2C).
- The flap may then be divided 2 to 3 weeks later (TECH FIG 2D,E). Perfusion of the flap can be tested before division by temporarily occluding the pedicle with a circumferential Penrose drain and assessing flap perfusion.

KITE FLAP: FIRST DORSAL METACARPAL ARTERY FLAP\(^1,11\)

- A template of the defect is made (TECH FIG 3A).
- The template is transferred to the dorsum of the index finger overlying the proximal phalanx, on the radial aspect.
- The flap is marked, then a proximal incision is marked in a zigzag or curvilinear fashion to extend to the takeoff of the first dorsal metacarpal artery (TECH FIG 3B).
- The flap is incised along the sides and distally down to the level of the extensor apparatus. Care is taken to preserve the paratenon of the extensors.
- The first dorsal interosseous artery will be elevated, with the subcutaneous tissue lying above it. The skin above the artery is left in its original location.

TECH FIG 3 • A. This wound of the volar thumb has exposed tendon and will not heal without a vascularized skin flap. B. The flap is planned on the dorsoradial aspect of the index finger. The proximal incision is for pedicle dissection. (continued)
The skin incision is made proximal to the flap. The incision around the proximal border of the flap needs to remain shallow, at the subdermal level as the venous drainage is through the small veins in the subcutaneous tissue.

The skin proximal to the flap is elevated on the radial and ulnar side of the artery. The skin is elevated off the fat at the subdermal level.

The pedicle should be elevated, with a total width of about 1 cm. On the ulnar side the pedicle border is the middle of the metacarpal. On the radial side, the pedicle border is 5 to 10 mm radial to the artery.

The artery lies on top of the fascia of the first dorsal interosseous muscle. To help preserve the artery and subcutaneous tissue, the muscle fascia is elevated with the pedicle.

Once the dissection of the pedicle has reached the radial artery proper, as it dives palmar to the deep palmar arch, the elevation typically ends.

This should allow enough pedicle length for coverage of many volar thumb defects and some dorsal hand defects.

The operation is performed under tourniquet control, but without Esmarch exsanguination, to maintain visibility of the small vessels.

The wound is débrided and irrigated, and then a template is made. A line is drawn from the lateral epicondyle to the DRUJ. The line approximates the position of the posterior interosseous artery (TECH FIG 4B, C).

The template is placed over the line marking the pedicle. It can be placed proximally as close as 6 cm from the lateral epicondyle of the humerus.

An incision is made along the flap outline proximal to the pivot point. Dissection is carried between the EDQ and ECU to look for the posterior interosseous artery (see Fig 4).

If the artery is found at this location, it is generally consistent with favorable anatomy. If the artery is not satisfactory, the operation is aborted.

Once the artery has been determined to be acceptable, the radial incision is made. The skin flap is elevated below the level of the muscular fascia. The EDC, extensor indicis proprius, and EDQ muscles are all retracted radially to facilitate exposure of the septum.

The muscular branches of the posterior interosseous artery (PIA) are carefully divided, exposing the PIA along the septum.

Once one good septocutaneous perforator is located, the PIA is divided proximal to this branch. Further dissection to obtain more perforators is discouraged because of the proximity to the posterior interosseous nerve and potential damage to this nerve.

After locating the major perforator and dividing the PIA proximally, the ulnar incision around the flap is made. This side is also elevated at a subfascial level.

The flap is then elevated from proximal to distal. This dissection is facilitated with ulnar retraction of the ECU. A generous cuff of surrounding tissue is taken with the PIA to help preserve its vena comitans.

A superficial vein may be preserved in the elevation for distal reanastomosis to help with venous drainage.
SOFT TISSUE LOSS, THERMAL INJURIES, AND CONTRACTURES

Z-PLASTY

- The angle of the flaps in Z-plasty is most commonly 60 degrees (TECH FIG 5A), but it can be varied to give more or less lengthening, depending on the quality of the adjacent tissue. Theoretically, 60-degree flaps will provide a lengthening of 75%.
- The central incision is designed along the tight scar. This scar often is excised during this part of the procedure (TECH FIG 5B).
- The two limbs are designed at opposing ends of the scar on opposite sides of the central member. These limbs are placed at about 60 degrees from the central incision (TECH FIG 5C).
- The flaps created are then elevated at a subcutaneous level. Then the two triangular flaps are transposed and sutured into place.
- Once the two flaps are elevated, they often “fall” into the correct position and are easily sutured in place.
- This usually gives an obvious and considerable lengthening immediately after flap transposition and insetting (TECH FIG 5D).

(continued)

TECH FIG 4 • A. This traumatic wound has exposure of the extensor tendons. B,C. The posterior interosseous flap is located proximally over the posterior interosseous artery. The flap is centered over a line from the lateral epicondyle to the distal radioulnar joint (DRUJ). D. After elevation, the flap is inset on the wound. E. The wound is well healed.
PEARLS AND PITFALLS

**Indications**
- A thorough physical examination must be completed before reconstruction of any defect.
- The choice of reconstruction is guided by the reconstructive ladder. Less invasive operations should be considered before more invasive procedures, but, ultimately, the expected outcome of the type of operation will direct the choice.
- Before any wound is covered, it must be clean, with no foreign material or dead tissue. Delaying reconstruction a few days until these goals are met is worthwhile.

**Flap elevation**
- Flap elevation must be done with care and precision, with attention to preservation of the feeding blood vessels. The small vessels perfusing the flaps are vital to flap survival.
- Frequent use of Doppler ultrasound facilitates vessel identification.

**Radial forearm flap**
- The dissection is safest when the fascia is elevated first from the ulnar side. The septum rises obliquely under the BR.
- Preservation of the paired venae comitantes and the septal perforators is critical to survival of the flap.
- The reversed flap needs a patent palmar vascular arch.

**Groin flap**
- The patient must be prepared to have the hand connected to the groin and must understand that a second operation is mandatory.
- This flap and the radial forearm flap are the workhorse flaps for large soft tissue flaps of the hand.

**First dorsal metacarpal artery flap**
- Reliable coverage for volar thumb or small dorsal hand defects
- Sensation can also be preserved with this flap through branches of the superficial radial nerve.
- The dissection is somewhat complex due to the small caliber of the vessels.

**Posterior interosseous flap**
- This flap is not typically a first choice.
- It is used when there is not a patent palmar arch (i.e., when a radial forearm flap is contraindicated) and when there is a reason not to use a groin flap.

POSTOPERATIVE CARE
- The postoperative care largely depends on the flap that has been used.
- For all of the operations, some of the same principles are followed.
  - Postoperative antibiotics often are indicated, because the wounds have been open for some time, have been contaminated, or have associated open fractures. The choice of antibiotic is individualized for each patient.
  - The operative site usually is splinted to allow for healing of the flap without movement. If there is no bony injury, this is usually for 7 to 10 days, but the length of time may vary.
  - The arm should be elevated above the level of the heart as much as possible. This will help decrease both edema within the flap and patient discomfort.
  - The radial forearm flap should be monitored in the hospital for 2 or 3 days.
  - When distally based, this flap may be susceptible to venous congestion.
  - Care should be taken during the operation to meticulously preserve the vena comitans.
  - If the cephalic vein has been preserved with the flap, it can be anastomosed to a vein in the field of the flap, but this is rarely necessary with the reversed flap.
  - Care should be taken not to make the splint or dressing too tight.
  - If a skin graft is placed during the operation, the bolster dressing is removed at 5 to 7 days, and the skin graft is dressed daily with petrolatum-infused gauze or a nonadhering dressing until fully healed.
  - Sutures around the flap are removed at 10 to 14 days.
  - Early active motion of the fingers is encouraged to promote tendon gliding and lessen edema, unless contraindicated after coverage.
  - Hand therapy is initiated in most patients at 1 to 2 weeks following surgery.
COMPLICATIONS

- Short-term complications include those related to flap survival and healing of the wound.
- Long-term complications result from undesirable scarring relating to both the primary injury and the method of closure.
- Complete flap loss due to flap ischemia is uncommon. More often, a small area of the flap margin may not heal to the native skin margin, due to inadequate débridement of the skin edges or rough handling of the flap skin.
- As the flaps heal, the function of the hand depends on subsequent scarring, which, if it occurs, leads to poor tendon gliding. Persistent tendon scarring requires later tenolysis. After 3 months, loss of the flap by inadvertent pedicle division is rare, but late flap loss has been reported.
- If scarring from the flap margin creates a contracture across a joint, a Z-plasty may be necessary.
- Overall, the complications related to flap closure are less than complications related to secondary healing. The long-term outcome will be better with flap coverage compared to secondary healing, because secondary intention creates an abundance of scar tissue, which can impair function of the hand.

REFERENCES

DEFINITION
- Burns and electrical injuries of the hand and forearm can present as both acute and long-term surgical problems.
- High-voltage electrical injury is defined as involving a power source with a voltage greater than 600 volts.
- Electrical burns constitute a unique type of injury, because “hidden” local and regional deep tissue damage exists beyond the confines of the cutaneous burn.
- Acutely, circumferential or near-circumferential full-thickness burns of the extremity may require escharotomy, in which the unyielding burned tissue is released to reduce soft tissue tension.
- Compartment syndrome is a serious sequela that warrants immediate surgical attention.
- Contractures are common in burn patients, resulting from loss of normal skin pliability when the skin is replaced by scar tissue after second- and third-degree burns.
- Despite aggressive acute care, splinting, and therapy, long-term hand and wrist deformities are common.6

ANATOMY
- Compartments are anatomic spaces enveloped by fascia, bones, and interosseous membrane.
- The forearm is divided into three compartments: volar, dorsal, and the mobile wad (FIG 1A).
- The hand has compartments housing four dorsal interosseous muscles, three volar interosseous muscles, thenar muscle, and hypothenar muscle (FIG 1B).
- Postburn scarring and contracture tend to produce the “classic” clawing deformity with flexed wrist and proximal interphalangeal (PIP) joints, extended distal interphalangeal (DIP) and metacarpophalangeal (MCP) joints, and adducted web spaces1 (FIG 1C,D).

PATHOGENESIS

Electrical Burns
- Electrical shock produces a complex pattern of injury in which the severity of injury depends on the intensity of the current and the duration of contact.
- Tissue damage occurs predominantly by two mechanisms: thermal injury and electroporation.7
- As an electrical current travels, heat is generated along its path, leading to thermal damage.
- Tissues with high electrical resistance, such as the skin and bone, generate more heat, causing more damage to both themselves and the surrounding tissues.
- Electroporation is cellular damage induced by the electric field. The severity of injury is determined by the cell’s size and its transmembrane potential.
- Cells with larger surface area, such as myocytes, are more prone to electroporation injury.
- In addition, it has been suggested that due to the architecture and orientation, myocytes near a bone may experience increased transmembrane potential compared to those further from the bone.
- Secondary to these mechanisms, patients with high-voltage electric burns often sustain extensive deep tissue and muscle injuries that predispose the patient to developing acute compartment syndrome.
Compartment Syndrome
- Arteriovenous gradient theory is commonly accepted as describing the relation between increasing soft tissue pressure and decreasing arterial inflow.
- In burns, vascular permeability leads to swelling of the soft tissues and, in particular, the muscles.
- The inelastic fascia housing each compartment does not allow the edematous muscles to expand. The increased pressure within the compartments eventually interrupts arterial inflow to the muscles.
- Although compartment syndrome most often is discussed in relation to fascial compartments, it can occur in full- or near–full-thickness burns because the inelastic skin limits the ability of underlying soft tissue to expand.
- The inelastic skin in a circumferential burn acts as a tourniquet, compromising venous return and capillary perfusion, and leading to tissue ischemia distal to the burns.8

Burn Contractures
- Increased and disorganized deposition of collagen fibers has been observed in burn wounds, forming compact and shortened scars.6
- The amount and severity of hypertrophic scarring and contracture is directly related to the depth of the burn and the time required for wound healing.
- Inflammation, pain, and edema from burn injuries promote immobility (in the position of comfort) and cause wound contracture.1
- Immobility and abnormal scarring lead to rapid formation of contractures in the pattern described under Anatomy.

NATURAL HISTORY
Evolution of Compartment Syndrome
- Acute burn management for large body surface area burns requires aggressive fluid resuscitation. Massive edema is seen within 36 hours of injury.
- Intracompartmental pressure can, in turn, elevate rapidly in the early postburn period.
- Classic studies have shown that myonecrosis occurs after 6 hours of ischemia. Once tissue is ischemic for longer than 8 to 12 hours, irreversible functional damage occurs.5,8
- Prompt fasciotomy minimizes functional loss and promotes recovery.
- If compartment syndrome is left untreated, the result is Volkmann’s ischemic contracture, a late sequela in which muscles and nerves die and are replaced by fibrous tissue.12

Natural Progression of Burn Injury
- Proper management of burn injuries includes early excision and grafting, followed by appropriate therapy programs.
- Even with splinting, range-of-motion exercises, compression, and positioning, 80% of patients will have decreased joint motion, and up to 10% will have difficulties with activities of daily living.3

PATIENT HISTORY AND PHYSICAL EXAMINATION
Acute Burn Injuries
- In addition to routine medical history, it is imperative to obtain the mechanism of the burn injury.
- High-voltage electrical burns, burns that occurred in an enclosed space, or burns associated with explosions require trauma and critical care consultation to evaluate for other life-threatening injuries.
- Thermal and electrical burns are evaluated for depth.
- First-degree burns involve only the epidermis and appear as a painful, erythematous plaque that blanches with pressure.
- Second-degree burns involve the epidermis as well as partial thickness of the dermis. Second-degree burns invariably are associated with blistering of the skin that evolve into moist, weepy, and painful wounds after sloughing of the epidermis.
Third-degree burns involve the entire thickness of the skin and are characterized by charred, painless, leathery skin with visible coagulated vessels.

**Acute Compartment Syndrome**
- Clinically, elevated soft tissue pressure presents with severe edema and tightness of the hand, wrist, and forearm distal to the burn.
- Treatment for fascial compartment syndrome of the forearm and hand should be initiated based on clinical suspicion.
- Compartment syndrome can present with a constellation of symptoms:
  - Pain with passive muscle stretch
  - Progressive pain despite immobilization
  - Nerve ischemia symptoms such as diminished sensation and muscle weakness
  - Compartments tender and firm to palpation
- Compartment and soft tissue pressures can be measured using a pressure transducer (FIG 2).
  - A simple device for measuring pressure can be made with an 18- or 20-gauge needle attached to a syringe containing saline and a pressure transducer, all connected via a three-way stopcock.
  - The transducer is set to zero at the level of the soft tissue or compartment to be measured.
  - After the needle is inserted into the subcutaneous tissue, a small amount (0.2–0.5 mL) of saline is injected to establish a water column.
  - The transducer is then opened to the needle for pressure monitoring.
- Compartment and soft tissue pressures can also be measured using a commercially available device.
- The recommended threshold for performing fasciotomy is pressure higher than 30 mm Hg for normotensive patients.
  - In patients with hypotension, when the compartment pressure rises to within 20 mm Hg of the diastolic pressure, fasciotomy is indicated.9

**Secondary Burn Reconstruction and Contracture Release**
- Preoperative examination for patients undergoing secondary burn reconstruction should include a complete hand examination, focusing on range of motion of the affected joints.
- Substantial limitation of active and passive joint motion in the PIP and MCP indicates contracture of underlying joint tissues.3,11
- Examination should also focus on the scar and skin quality, because immature scars may still be amenable to nonoperative management.
- Poor or unstable skin coverage may limit local tissue rearrangement options and necessitate coverage with a distant flap.

**Physical Examination**
- Vascular examination includes checking pulse and capillary refill.
  - Pulse is graded as normal, diminished, or absent compared to the contralateral side.
  - Capillary refill is graded as delayed, normal (2–3 second), or quickened.
    - Absent or diminished pulse is a late finding in compartment syndrome.
    - Quickened capillary refill is suggestive of venous congestion.
    - Delayed capillary refill may suggest increased soft tissue or compartment pressure.
- The neurologic examination includes light touch, two-point discrimination, and motor function testing.
  - Sensibility to light touch is graded as normal, diminished, significantly diminished, and absent.
  - Two-point discrimination is graded as normal (< 6 mm static, < 3 mm moving), and abnormal.
  - Motor examination is graded from 0 to 5, with 0 being absent, and 5 normal.
  - Altered neurologic finding compared to the contralateral limb is an indication of increased compartment pressure.
- A passive stretch test should be performed.
  - Pain with passive stretch is an abnormal finding.
  - A positive passive stretch test is indicative of muscle ischemia and injury.
- Measure subeschar and compartment pressure. Elevated pressure is confirmed if the measured pressure is greater than 30 mm Hg or within 20 mm Hg of the diastolic pressure. Persistently or worsening elevated pressure is an indication for escharotomy or fasciotomy.
- Examine MCP range of motion:
  - Type I: mild limitation in MCP flexion with wrist flexion, more than 30 degrees of flexion with wrist in extension
  - Type II: severe limitation in MCP flexion with wrist in flexion, less than 30 degrees of flexion with wrist in extension
  - Type III: severe limitation in MCP flexion with wrist in extension
  - Type II and III contractures signify underlying joint and ligamentous pathology that cannot be corrected with soft tissue release alone.
- Examine PIP range of motion:
  - Type I: near-normal PIP extension with MCP in flexion
  - Type II: moderately limited PIP extension with MCP in flexion
  - Type III: fixed PIP flexion regardless of MCP position
  - Type II and III contractures signify underlying joint and ligamentous pathology that cannot be corrected with soft tissue release.

**FIG 2** Pressure transducer adapted for measurement of compartment pressure.
IMAGING AND OTHER DIAGNOSTIC STUDIES
- Currently, no available imaging modality can detect acute increases in compartment pressure.
- For secondary reconstruction of the contracted hand and fingers, plain radiographs should be obtained to evaluate the condition of the joint and determine whether heterotrophic ossification is present, because that requires alternative treatment options.

DIFFERENTIAL DIAGNOSIS
- The differential diagnosis for compartment syndrome includes:
  - Nerve injury
  - Arterial insufficiency or injury
  - Venous thrombosis
- Burn contractures should be differentiated from:
  - Intrinsic joint disease
  - Other scarring or contracture phenomena (eg, Dupuytren disease)

NONOPERATIVE MANAGEMENT
- Early in the healing process (usually within 6 months of injury), immature scars are hyperemic in appearance and amenable to conservative measures.
- Conservative management includes the use of pressure garments, silicone dressing, and physical therapy.
- Pressure garments and silicone have been shown to control hypertrophic scars and must be worn for several months. \(^6\)
- Therapy should focus on aggressive range-of-motion exercises and splinting in an antideforming posture (FIG 3).

SURGICAL MANAGEMENT
- Burn débridement, escharotomy, fasciotomy, local tissue rearrangement for linear and web space contracture, and pedicled groin flap coverage for soft tissue defects are discussed in the Techniques section.

Indications for Surgical Management of Acute Burns and Acute Compartment Syndrome
- High-voltage injury is an indication for immediate fasciotomy and burn débridement because it is difficult to assess the extent of deep thermal damage.
- Patients with thermal burns and low-voltage electric injury require closed monitoring by experienced personnel to assess potential increased soft tissue or compartment pressure, but may otherwise be débrided in 48 to 72 hours to allow for demarcation of burned areas.
- Elevated soft tissue pressure and fascial compartment pressure are indications for emergent surgical intervention.
- Despite the potential utility of pressure monitors, diagnosis of the pathology still relies on clinical judgment.
- If there is any doubt regarding the diagnosis, escharotomy and fasciotomy should be undertaken expeditiously.
- Fascial compartment syndrome may be masked by elevated pressure of the overlying soft tissue, and it is of the utmost importance to check muscle compartment pressures after an escharotomy.
- If elevated compartment pressure is not relieved by escharotomy of the overlying burned tissue, a full fasciotomy is necessary.
- After escharotomy or fasciotomy, patients must be observed closely for signs and symptoms of inadequate release, which will require urgent reoperation.

Considerations in Contracture Release and Secondary Burn Reconstruction
- Burn injuries cause soft tissue contracture and result in tissue deficiency. The secondary effects of soft tissue contracture are joint and tendon changes that also require release.
- Mild volar and dorsal linear scar bands, as well as web space contractures, can be corrected with scar release and local tissue rearrangement.
- Basic Z-plasty is a technique of local tissue rearrangement in which two equal triangular skin flaps are transposed (FIG 4A). Z-plasty is ideally suited for linear scar release because it lengthens and interrupts a scar, and also redirects the line of tension.
- The theoretical gain in length is proportional to the angle of the Z-plasty. A larger angle provides more lengthening but is more difficult to transpose (Table 1).
- However, an adequately sized Z-plasty flap often is difficult to fit into a contracted web space.
- For web space contracture release we prefer a five-flap “jumping man” Z-plasty, which is a combination of two Z-plasty flaps with a Y-to-V advancement flap (FIG 4B).

![FIG 3](image-url) Immature burn scars that are amenable to conservative treatment. A volar intrinsic-plus splint with the thumb in palmar abduction to prevent debilitating postburn contractures.

![FIG 4](image-url) A. Basic Z-plasty flaps and their theoretical gain in length. B. Five-flap jumping man Z-plasty, which is made up of two opposing Z-plasty flaps and a Y-to-V flap.
Compared to a basic Z-plasty, the additional flaps maximize gain in length. In addition, the Y-to-V flap introduces unscarred skin into the reconstruction, providing more pliability and elasticity to the reconstructed web space.

Even without scar resection, surgical release of burn scars often result in a large soft tissue defect due to tissue deficiency.

Thick split- or full-thickness skin grafts can be used to resurface the soft tissue defect.

Flap coverage may be necessary if contracture release or scar excision leads to exposure of joint structures, tendons, or neurovascular bundles.

### Z-plasty Angles and Corresponding Theoretical Gains in Length

<table>
<thead>
<tr>
<th>Z-plasty angle (degrees)</th>
<th>Theoretical gain in length (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>75</td>
</tr>
<tr>
<td>75</td>
<td>100</td>
</tr>
</tbody>
</table>

Preoperative Planning

- If hand and forearm burns are part of a larger insult, the ABCs (airway, breathing, and circulation) of trauma resuscitation and patient stabilization cannot be overlooked.
- Burn débridements may incur a significant amount of blood loss, and blood products should be made available intra- and perioperatively.
- For secondary burn reconstruction, one must appreciate the structure involved in the deformity.
- If tightness of the deep tissue is present, capsulotomy and ligamentous release should be addressed simultaneously.

### Positioning

- Supine positioning with the affected arm extended on an arm table is adequate for most described procedures.
- For secondary reconstruction, an upper arm tourniquet is used.
- The ipsilateral upper thigh and lower abdominal quadrant is prepped and draped if a groin flap is planned for soft tissue coverage.

**ESCHAROTOMY FOR FULL OR DEEP PARTIAL-THICKNESS BURNS**

- Escharotomy can be performed at the bedside using electrocautery with the patient under sedation.
- A full-thickness skin incision is made the length of the full-thickness burn on the radial aspect of the forearm, along the line connecting the lateral end of the antecubital flexion crease and radial styloid (TECH FIG 1).
- The incision is deepened until viable tissue is encountered. The length of the incision spans the entire burn, from normal skin to normal skin.
- If the hand and the forearm are still tight after a radial release, a second escharotomy incision can be made along a line just volar to the ulna, spanning the entire burn (see Tech Fig 1).
- To perform escharotomy of the hand, one can extend the radial incision onto the hand with the radial incision at the midaxial line over the thenar eminence. The radial sensory nerve will lie along this incision and must be protected.
- The ulnar incision can be carried onto the hypothenar eminence as needed.

- Circumferential finger burns are treated with a digital escharotomy. A midlateral incision down into subcutaneous fat is made along one side of the finger, from the MCP joint to the fingertip.
- If the compartment pressure is still high after escharotomy, fasciotomy should be carried out as described in the following section.
- Escharotomy wounds are dressed with a moist dressing.

**Intrinsic Compartment Release**

- Two dorsal incisions centered over the index and ring metacarpals are used to release the interosseous muscle and the thumb adductor muscle compartments (TECH FIG 2A).
- Incisions are carried down ulnar and radial to the index and ring extensors. Dissection is continued until the fascia of the dorsal interosseous muscles is encountered. The fascia is opened sharply.

- Blunt dissection is performed along the ulnar and radial side of the index finger metacarpal to open the first volar interosseous and adductor pollicis muscles.
- The second volar interosseous muscle is opened with deep blunt dissection along the radial border of the ring finger metacarpal.
- Finally, through the ring finger metacarpal incision, deep blunt dissection along the radial border of the small finger metacarpal releases the third volar interosseous muscle.
Thenar muscles are released through an incision on the radial border of the thumb metacarpal between the volar glabrous and dorsal pliable skin. The dissection is volar to the metacarpal to expose the fascia of the thenar muscles, which is sharply opened.

The hypothenar muscles are released similarly with an incision on the ulnar aspect of the small finger metacarpal (TECH FIG 2B).

Carpal Tunnel Release
- The carpal tunnel is released through a standard incision over the palm, along the ring metacarpal.
- Incision begins at the Kaplan’s cardinal line (the line connecting the apex of the first web space to the hook of the hamate), and extends 2 to 3 cm proximally (TECH FIG 3).
- We prefer to avoid an incision across the wrist joint, to protect the median nerve from exposure.
- The palmar fascia is divided sharply to expose the transverse carpal ligament.
- The transverse carpal ligament is divided under direct visualization.

Forearm Fasciotomy
- We prefer to perform fasciotomy of all three forearm compartments at the same time to avoid lingering doubts regarding inadequate release. Two incisions are used (TECH FIG 4A).

A straight-line incision is made over the first third of the ulnar aspect of the volar forearm, beginning just proximal to the wrist crease and extending to just distal to the ulnar aspect of the elbow flexion crease (TECH FIG 4B).
- The incision is carried down through the fascia, into the volar compartment. The fascia is opened along the length of the compartment.
- The superficial and deep muscles are examined.
The mobile wad and dorsal compartment release is accomplished by placing a middorsal straight line incision beginning 3 to 4 cm proximal to the wrist crease and extending to the radial aspect of the flexion crease at the elbow (TECH FIG 4C).

The compartmental fascia for both compartments are incised over their entire length and the muscles are examined.

After release, the muscles should bulge out over the incision.

The muscles are not débrided until a second-look procedure at 48 hours, because some muscles with questionable viability may recover after fascial release.

The open wounds are packed with moist dressing until the second-look procedure.

**Burn Débridement**

Burn débridement is performed without a tourniquet and can be carried out with escharotomy or fasciotomy.

Sharp débridement is used to removed partial- and full-thickness burns.

- For small areas or areas with irregular contour, a no. 15 or no. 10 blade is used to remove burnt tissue, layer by layer, until bleeding tissue is encountered.
- For larger areas, a Weck blade with a no. 8 or no. 10 guard is used to tangentially remove burn tissue until punctate bleeding is encountered.

- For uncomplicated thermal burns, immediate coverage can be accomplished.
- For uncomplicated wounds, a .012-inch split-thickness skin graft can be placed. We typically use unmeshed graft for the hand and over the wrist joint. Forearm burns can be covered with a graft meshed 1 to 1½ expansion.
- For deeper wounds with small areas of exposed deep structures (eg, tendons or joints), a dermal substitute such as Integra is used to provide a revascularized dermal foundation. Delayed split-thickness skin grafting is done in 2 weeks.
- Large burn wounds with exposed deep structures or exposed neurovascular bundles are temporarily covered with moist dressing changes, and will require local flap, distant flap, or free tissue coverage within 48 to 72 hours.
- Electrical burns often have injuries to subcutaneous tissues and muscles in addition to cutaneous burns. After débridement of the cutaneous portion of the burns, as described in Burn Débridement, the subcutaneous tissue and muscles are sharply débrided with a no. 10 blade in a layered manner until bleeding tissue is encountered.
- Patients with electrical burns are managed with moist dressing changes and taken back to the operating room for a second look procedure in 48 hours.

**SECOND-LOOK PROCEDURE**

- The second-look procedure is performed without the use of a tourniquet.
- Necrotic tissues are aggressively débrided with a no. 10 blade in a tangential manner until bleeding tissue is encountered.
- Electrical burns may require multiple débridements every 48 hours until the area of injury is demarcated and all necrotic tissues are removed.
- Large wounds with exposed deep structures or exposed neurovascular structures are temporarily covered with...
moist dressing changes and will require local flap, distant flap, or free tissue transfer coverage within 48 to 72 hours.

- For uncomplicated fasciotomy wounds, once adequate débridement has been achieved, moist dressing changes are performed for 7 to 14 days in preparation for primary closure or skin grafting.

- With increasing frequency, a negative-pressure dressing is being used for fasciotomy defects as an alternative to traditional wound care.
- Edema often subsides and allows for primary wound closure (TECH FIG 5).
- Open defects are covered with a .012-inch split-thickness skin graft.

**Basic Z-Plasty**

- One or multiple Z-plasty flaps are used to break up mild to moderate linear contractures.
- The central limb of the Z is planned along the axis of the scar band, and the angle of the Z-plasty can be varied, with a larger angle providing more release. We prefer 45-degree flaps (TECH FIG 6A).
- The Z-plasty flaps are elevated just below the dermis, preserving a small cuff of subcutaneous fat on the underside of the flaps.
- Foreshortened fibrous bands that require release with scissors or a knife often are present in the underlying soft tissue.
- Care is taken to protect the neurovascular bundle.
- After release of underlying tissue and extension of the joint, the Z-plasty flaps should fall naturally into a transposed position.
- The flaps are sutured in place with nonabsorbable sutures (TECH FIG 6B).

**LOCAL TISSUE REARRANGEMENT FOR RELEASE OF CONTRACTURE BANDS**

**Five-Flap Z-Plasty for Release of Web Space Contractures**

- Xeroform (Covidien, Mansfield, MA) strips and bacitracin are applied to the incision, followed by a gauze dressing. A gentle elastic bandage is applied.
- The bandage is removed in 2 days, and patients are allowed progressive gentle range of motion. Stretching and scar massage are encouraged to begin 2 to 3 weeks postoperatively.

- The central limb of the five-flap Z-plasty is designed to lie on the axis of the web space contracture.
- The Z-plasty is oriented with the Y-to-V flap occupying normal skin, to maximize advancement of unburned skin into scar tissue (TECH FIG 7).
- Skin incisions are made in the central limb as well as the Y-to-V flap. The lateral limbs of the Z-plasty flaps are not incised initially.
- The Y-to-V flaps and the skin around the central limb are elevated just below the dermal fat junction.
Chapter 107  SURGICAL TREATMENT OF THERMAL AND ELECTRICAL INJURY, AND CONTRACTURE

The underlying fibrous tissues are released using a combination of blunt and sharp dissection.

At this point, the Y-to-V flap is advanced into place.

More advancement can be achieved by lengthening the Y-to-V limbs and enlarging the flap. The central limb is lengthened accordingly. Flap size is limited by the size of the web space.

The lateral limbs of the Z-plasty flaps are now incised corresponding to the length of the enlarged Y-to-V flap (now a V-flap).

The flaps are then secured in their transposed position with nonabsorbable sutures.

Xeroform and bacitracin are applied, followed by gauze dressing and a gentle elastic bandage.

The bandage is removed in 2 days, and the patient is allowed progressive gentle range of motion. Stretching and scar massage are encouraged to begin 2 to 3 weeks postoperatively.

Groin Flap for Extensive Burn Contracture

Scar Excision

An incision is made around the contracted scar into the subcutaneous fat and underlying structures. Often, the scar is adherent to underlying fascia, tendons, and joints.

Traction is applied to assist in identifying the areolar plane between scar and normal tissue.

The scar is lifted in its entirety. Tight underlying fibrous bands are broken up with blunt and sharp dissection.

After complete excision of the scar, the affected joints are put under stretched to evaluate the need for capsulotomy or ligamentous release.

Flap Harvest

Attention is then paid to harvest of the ipsilateral groin flap.

Doppler ultrasound is used to identify the superficial circumflex iliac artery.

At the ipsilateral groin, a line between the anterior superior iliac spine (ASIS) and pubic tubercle is drawn, identifying the inguinal ligament. A second parallel line is drawn 2 to 3 cm below as the midaxis of the flap, which should correspond to the course of the superficial circumflex iliac artery.

Using a pattern of the defect, a flap is designed inferior to the ASIS to lie along the previously marked midaxis. If necessary, the flap can be extended lateral to the ASIS for additional length (TECH FIG 8A).

A flap up to 20 × 10 cm can be closed primarily and is sufficient for most hand and wrist defects.

It is important to keep in mind that a small portion of the flap will be tubularized near the pedicle and will have to be included in the design.

The flap is oriented to minimize kinking and twisting of the pedicle after inset.

The flap is incised down to the underlying fascia. Inferiorly, the fascia lata and sartorius muscle fascia are identified.

The flap is elevated tangentially off the fascia in a lateral-to-medial fashion until the lateral aspect of the sartorius fascia is encountered (TECH FIG 8B).

The sartorius fascia is incised at its lateral margin and elevated from the underlying muscle, with care taken to avoid injuring the lateral femoral cutaneous nerve.

At this point, scissor dissection is used to identify the vascular pedicle as it traverses out of the femoral triangle and through the sartorius fascia.

A cuff of sartorius fascia is incised superior and inferior to the pedicle to untether the pedicle from the muscle (see Tech Fig 8B).

The proximal portion of the flap is tubularized around the pedicle.

The donor defect is closed primarily. The standing cutaneous deformity at the lateral aspect is excised. A small open area may be left at the base of the flap.

Completion of the Groin Flap

The flap is gently thinned along the margins.

The defect is then brought into the field, and the flap is inset using nonabsorbable sutures (TECH FIG 8C).

The forearm is then secured to the abdominal skin with several large nonabsorbable sutures.

Xeroform and bacitracin are applied, followed by fluffed gauze dressing.

An elastic bandage is wrapped around the hip to further stabilize the reconstruction.

Members of the surgical team must be present at the time of recovery from anesthesia to mitigate the chance of accidental flap avulsion.
**TECH FIG 8** • **A.** Design of a groin flap for a large dorsal hand wound after scar excision. The defect has been traced onto a template and transposed to the groin area. **B.** Elevation of the groin flap. A cuff of the sartorius fascia has been incised (indicated by the periosteal elevator) and elevated with the flap to improve mobility of the pedicle (superficial circumflex iliac artery; white arrow). The lateral femoral cutaneous nerve (black arrow) is visible just medial to the incised sartorius fascia. **C.** The groin flap is inset onto the dorsal hand wound. This patient also has soft tissue defects of the ring and small fingers that are buried in subcutaneous pockets for future skin grafting.

**PEARLS AND PITFALLS**

**Fasciotomy and escharotomy**
- Blood products should be made available before escharotomy, because significant bleeding can occur.
- Early recognition and intervention for compartment syndrome are key to prevent irreversible damage, and the threshold for pressure measurement should be low.
- The patient must be monitored closely after the procedure for evidence of inadequate release, especially with ongoing resuscitation.

**Web space release**
- The Y-to-V advancement of the five-flap Z-plasty provides most of the elongation.
- The five-flap Z-plasty should be designed to maximize the amount of unburned tissue in the Y-to-V flap.

**Groin flap**
- Flap orientation must be carefully designed.
- A template of the upper extremity defect can be made with an extension to simulate the pedicle to test various flap configurations and orientations.
- Postoperative congestion or ischemia is likely, secondary to kinking of the pedicle, and should resolve with proper positioning of the arm.

**POSTOPERATIVE CARE**
- After acute burn and wound management, the affected upper extremity will require appropriate splinting (intrinsic-plus with thumb in palmar abduction), elevation, and early range of motion to prevent secondary complications.
- A soft dressing consisting of gauze and an elastic bandage is applied after scar release and local tissue rearrangement. Sutures are removed in 2 weeks.
- Early mobilization and therapy are initiated about 2 weeks postoperatively to maintain release.
- Abduction or extension splints may be used at night to maintain posture.
- Upon completion of the groin flap, elastic bandages are used to strap the arm to the torso for 3 to 4 days. Care is taken to avoid kinking of the pedicle.
- During the immediate postoperative period, the flap is monitored for arterial insufficiency or congestion. A kinked pedi-
cle necessitates repositioning of hand or patient. Suture release near the pedicle may be needed for congestion.

- If present, the small open area at the base of the flap is cared for with daily Xeroform dressing changes.
- Range-of-motion exercises for the nonaffected joint can start immediately postoperatively. Exercises for the affected joints can resume 2 weeks postoperatively.
- Before flap division, the pedicle is gently occluded to check for viability.
- The flap is divided, thinned, and inset 3 to 4 weeks after the index procedure.

OUTCOMES

- When adequately done, the outcome after fasciotomy, in any location, is closely related to its timing. In fasciotomy performed within 12 hours of onset of compartment syndrome, normal function has been reported in 68% of patients. The number decreases sharply, to 8%, if fasciotomy is delayed beyond 12 hours.\(^\text{10}\)
- Approximately 30% of fasciotomy wounds can be closed primarily. The rest require skin grafting.\(^\text{2}\)
- Several articles describing various local tissue rearrangement procedures for contracture release document low complication rates and good results.
- Our experience agrees with published series that pedicled groin flaps provide stable soft tissue coverage of upper extremity defects with low complication rates.

COMPLICATIONS

- Complications for escharotomy and fasciotomy include:
  - Bleeding
  - Inadequate release
- Complications for local tissue rearrangement for contracture release include:
  - Partial skin necrosis
  - Dehiscence
- Recurrence
- Injury to neurovascular bundle
- Complications for groin flap include:
  - Flap necrosis
  - Avulsion
  - Excessive bulk requiring revisions

REFERENCES

DEFINITION

- Post-traumatic metacarpophalangeal (MCP) joint and proximal interphalangeal (PIP) contractures may develop directly as a result of injury to the joints and adjacent tissues or indirectly as a result of excessive immobilization or poor splinting of the hand.
- The circumstances precipitating the contracture determine the structures most involved:
  - Joint capsule and collateral ligament contracture
  - Flexor tendon adhesions
  - Intrinsic musculature contracture
  - Extensor tendon adhesions
  - Skin and subcutaneous tissue scarring
  - The MCP joint generally becomes stiff in the extended position. Flexion contractures are uncommon and, when present, generally do not cause significant disability.
  - The PIP joint often becomes contracted in the flexed position, although extension and combined contractures are not uncommon.
  - The key to successfully mobilizing a stiff MCP or PIP joint is anticipating the pathologic causes before surgery.

ANATOMY

- MCP joint osteology allows biaxial motion, including circumduction. The articular surface of the metacarpal head is asymmetrical, with a relatively flat mediolateral convex arc (abduction-adduction) and a large anteroposterior convex arc (flexion-extension) that extends more volarly (FIG 1A).
- The MCP joint is enveloped by a relatively loose capsule inserting onto ridges surrounding the articular cartilage.
- Proper collateral ligaments originate from a dorsolateral tubercle on the metacarpal head and insert on the lateropalmar edge of the phalangeal base (FIG 1B).
- The volar plate of the MCP joint is an extension of the phalangeal articular surface. Unlike the volar plate of the PIP joint, the volar plate of the MCP joint is collapsible and there is little tendency to produce check reins.
  - This is one reason why MCP joint flexion contractures are much less common than those in the PIP joint.
  - The flexor and extensor mechanisms surround the MCP joint.
  - Volarly, the flexor sheath lies directly on the palmar plate and is thick, forming the first annular pulley.
  - Dorsally, the extensor tendon gives rise to fibroaponeurotic sagittal bands that wrap around to insert on the palmar plate. The tendons of the lumbricals and interossei join the dorsal expansion of the extensor. A slip of the dorsal interossei inserts on the dorsolateral aspect of the phalangeal base.
  - The PIP joint is stabilized by a boxlike arrangement of structures consisting of the proper and accessory collateral ligaments, the volar plate, and the dorsal capsule (FIG 1C,D).

PATHOGENESIS

- The irregular contour of the MCP joint functions as a cam, transforming joint flexion into translation (or elongation) of the collateral ligaments. When flexed, the MCP joint has minimal capsular volume and is maximally constrained. Conversely, extension allows maximal capsular volume and joint laxity.
- Direct trauma to the MCP joint causes joint effusions and hemorrhosis. Hand trauma elsewhere results in edema, which also collects within the MCP joints. In both cases, as the capsule fills with fluid the MCP joint is hydraulically pushed into a nearly fully extended position.
- With time the dorsal capsule becomes thick and noncompliant, leading to an extension contracture. The overlying extensor mechanism may become adherent to the capsule. The underlying collateral ligaments shorten and scar laterally to the metacarpal head. The volar recess may fill with adhesions between the volar plate and condyles.
- The extended MCP joint increases flexor tone and relaxes the extensor mechanism, leading to interphalangeal joint flexion, and may indirectly result in a fixed flexion contracture of the PIP joint.
- The combination of extended MCP joints and flexed interphalangeal joints defines the intrinsic-minus hand.
- Injury, infection, excess immobilization, and inappropriate splinting may directly result in fixed flexion or extension contracture of the PIP joint.
- An accumulation of fluid or blood within the capsule leads to stiffness, as does articular damage.
- Curtis3,4 has reported that a contracture of the PIP joint can be due to:
  - Contracture of the volar plate or the capsular structures
  - Collateral ligament contracture
  - Scar contracture over the joint
  - Volar skin contracture
  - Flexor sheath contracture
  - Extensor tendon contracture or adhesions
  - Interosseous contracture or adhesions
  - A bony block or exostosis
- Additional causes not pertinent to this chapter include fascia contracture, as in Dupuytren disease.
- Watson et al11 reported that a flexion contracture of the PIP joint is due to contracture of the check reins on the proximal surface of the volar plate.

NATURAL HISTORY

- Longstanding scarring and contracture of the MCP or PIP joint capsule almost invariably leads to adhesions to the adjacent extensor mechanism.
- Residual joint kinetics is often altered with joint motion occurring through incongruous articular motions such as pivoting.
Cartilage gradually atrophies and softens with disuse. Surface irregularities may develop.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The history should identify:
  - The inciting cause of the joint contracture
  - The time of the insult
  - Efforts made to mobilize the digit
- The hand is evaluated for edema and the return of normal skin creases.
- Ongoing swelling and inflammation (FIG 2A) must subside before surgery.
- The dorsal soft tissues are assessed for mobility and compliance.
  - Capsulectomy after burns and crush injuries may fail due to inadequate dorsal coverage.
  - Skin contracture can also be an original inciting cause for digital stiffness.
- The MCP and interphalangeal joints are assessed for differences in active and passive motion. Passive motion is always greater than active; however, a large difference suggests extrinsic tendon adhesions.
- Bunnell intrinsic tightness test: Intrinsic release may be necessary to mobilize a PIP joint with extension contracture.
- Finger threshold sensitivity is checked, along with overall sensitivity to percussion and cold. Vascularity is assessed by checking capillary refill. The painful and insensitive stiff finger may be a better candidate for amputation than capsulectomy. Poor vascularity is a relative contraindication to capsulectomy.
- Concomitant PIP flexion and distal interphalangeal hyperextension mark a boutonnière deformity (FIG 2B), whereas hyperextension at the PIP joint is a sign of a swan-neck deformity (FIG 2C).

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs of the hand are made to evaluate for extrinsic and intrinsic causes of joint stiffness.
  - Extrinsic
    - Metacarpal neck or shaft fracture: Extensor tendon adhesions at the fracture site may restrict MCP joint flexion (passive and active).
    - Proximal phalangeal fracture: Flexor and extensor tendon adhesions at the fracture site may limit active PIP (and sometime MCP) joint motion; passive motion may be maintained.
  - Intrinsic
    - Intra-articular fracture: Articular incongruity may serve as a bony restraint to joint motion.

---

**FIG 1**

- **A.** The articular surface of the metacarpal head protrudes volarly, making the capsule (and proper collateral ligaments) taut with flexion. **B.** Metacarpophalangeal joint anatomy can be considered in two layers: the capsule and collateral ligaments, which lie immediately adjacent to the articular surfaces, and the flexor and extensor mechanisms, which envelop the joint. **C.** Normal anatomy of the proximal interphalangeal joint showing the arrangement of the collateral ligaments and the volar plate. **D.** Normal proximal interphalangeal anatomy showing the arrangement of the proper and accessory collateral ligaments.
Arthritic changes: Cartilage softening and erosion often result in some degree of radiographically apparent arthritis.

A “true” lateral radiograph of the involved joint must be closely examined for significant arthritic changes or any subluxation.

There is little role for CT scanning or MRI of the digits.

DIFFERENTIAL DIAGNOSIS

- MCP extension contracture from extrinsic extensor muscle spasticity or intrinsic muscle paralysis or denervation
- PIP contracture from tendon imbalances, including boutonnière deformity and swan-neck deformity
- Skin contracture
- Dupuytren disease

NONOPERATIVE MANAGEMENT

- Nonoperative efforts to improve joint motion must be tried until motion has plateaued and the soft tissues are absolutely quiescent.
- As a general rule, inflammation and edema will subside and range of motion will improve for a minimum of 3 to 4 months after a traumatic or surgical insult to the hand.
- During this time a supervised hand therapy program is essential.
- Most MCP contractures occur in extension. In addition to regular exercises, dynamic flexion splints (daytime) and static extension splints (nighttime) are useful.
- Most PIP contractures occur in flexion. Treatment begins with application of a nonelastic extension force across the PIP joint for an extended time. This can be done with serial finger casts or commercially available splints such as the Joint-Jack (Joint-Jack Company, Wetherfield, CT) or wire-foam splints. Once the contracture is corrected, elastic splints such as the Joint-Spring or clock-spring splints can be used.
- Prosser\(^8\) presented one of the few studies to follow patients treated conservatively. Using a Capener splint to be worn for 8 to 12 hours per day over an 8-week period, there was an average improvement in the flexion contracture from 39 to 21 degrees. There was no association between time in the splint with final extension or with final stiffness.

SURGICAL MANAGEMENT

- A capsulectomy is indicated only for a contracture not associated with articular incongruity or persistent subluxation of the joint.
- A stiff MCP or PIP joint in the face of articular incongruity or subluxation is best treated as an arthritic joint with a salvage type of surgery such as arthroplasty or arthrodesis.
- Mild to moderate joint wear is not a contraindication to capsulectomy, particularly in younger patients. Focal areas of articular cartilage irregularity and dorsal osteophytes may be débrided at the time of surgery.
- The literature does not give any specifics as to when to recommend surgery. We usually make this decision when a “functional arc of motion” has not been achieved after 3 months of therapy.
- There is no absolute functional arc of motion for the MCP joint. In the absence of interphalangeal contractures, we have found that index, middle, ring, and small finger MCP flexion of 30, 35, 40, and 45 degrees, respectively, is generally satisfactory. When the interphalangeal joints have limited flexion, greater degrees of MCP flexion may be useful.
- Similarly, 45 degrees or more of total PIP motion is usually satisfactory. Flexion contractures greater than 45 degrees are poorly tolerated and may benefit from surgical release.
- Extreme flexion contractures (more than 60 or 70 degrees) may be best managed with arthrodesis.
- Extension contractures are better tolerated, especially if there is flexion to at least 75 degrees.
- When a patient has exhausted nonoperative management options and joint stiffness exceeds the preceding guidelines, surgery for contracture release is considered.

Preoperative Planning

- The patient is required to demonstrate a commitment to therapy before surgery is undertaken. A preoperative meeting between the patient and the therapist is arranged to plan...
the first postoperative visit and to fabricate a dynamic flexion splint.

- If possible, surgery is planned under a form of anesthesia that will allow patient cooperation and active motion during the procedure.
  - A wrist block with sedation is optimal; however, a Bier block may be used and reversed with deflation of the tourniquet.
  - In severely scarred hands (e.g., massive crush injuries and burn patients), the surgeon must anticipate inadequate dorsal soft tissue and extensor tendon excursion. A transverse incision and extensor tenotomy is indicated and coverage of the residual soft tissue defect is planned and discussed with the patient. Kirschner wire fixation of the MCP joints in flexion may be necessary to maintain a flexed joint and protect the dorsal soft tissue reconstruction.

**Positioning**

- Patients are positioned supine with the affected extremity on a hand table. A brachial tourniquet is applied that allows access to the forearm should a full-thickness skin graft be necessary.

**Approach**

- The approach for MCP contracture depends on three factors:
  - The number of involved MCP joints
  - The need to operate on the PIP joint
  - The quality of the dorsal soft tissues

- A single MCP joint is approached with a dorsal longitudinal incision. If the PIP joint has an extension contracture, the incision is carried over the PIP in the midline. If the PIP has a flexion contracture, the incision may be extended distally in the midaxial line (FIG 3A).

- Multiple MCP joint extension contractures are approached using separate dorsal longitudinal incisions.
  - This is the most extensile method and facilitates management of associated extensor tendon adhesions and PIP contractures (FIG 3B).

- Two adjacent MCP joints may also be approached by making a dorsal longitudinal incision centered in the web between affected rays.
  - If necessary, it is safe to extend this incision as a Y onto each digit to complete a tenolysis or operate on the PIP joints.

- Multiple MCP joints may be also approached by making a single transverse incision lying just proximal to the metacarpal heads.
  - This approach is preferred only when the dorsal soft tissues are fibrotic and noncompliant. In this situation, the surgeon should plan for skin graft or flap coverage of the anticipated defect.

- The surgical approach for isolated PIP joint contractures varies with the procedure used.
  - A capsulectomy for a flexion contracture is performed through a lateral approach, a check-rein release through a volar approach, and percutaneous release laterally.
  - A dorsal skin incision could be used with a capsulectomy for an extension contracture or when there is a previous dorsal incision or specific hardware to remove.

**MCP JOINT CONTRACTURES**

**Dorsal Capsulectomy of the Joint**

- Make the skin incision based on the aforementioned considerations (TECH FIG 1A).

- Carry dissection down sharply to the extensor mechanism, preserving small dorsal nerves.
  - If the soft tissues about the MCP joint are excessively scarred, identify the extensor mechanism proximally and distally with careful development of soft tissue planes in between.

- Raise full-thickness soft tissue flaps over the length of the extensor mechanism (TECH FIG 1B).

- Use a Freer elevator to lyse adhesions beneath the extensor mechanism, especially over the metacarpal proximally (TECH FIG 1C).

- As described by Curtis and later Tsuge, the extensor tendon is bisected sharply over the MCP joint (TECH FIG 1D); the sagittal fibers are preserved. Do not carry the extensor split into the transverse fibers of the extensor hood.

- In the index or small finger, the split is made between the extensor communis and the extensor proprius tendons.
Retract each half of the extensor tendon and attached sagittal band to expose the joint capsule.

At times it may be painstakingly difficult to develop the interval between the extensor mechanism and capsule, and a combination of both sharp and blunt dissection is necessary.

The capsule is usually quite thick and generally should be excised rather than released (TECH FIG 1E).

Attempt passive finger flexion; it usually is limited, necessitating release or excision of the collateral ligaments (TECH FIG 1F).

Start dorsally and release the proper collateral ligaments from the collateral recess and from any adhesions to the metacarpal head. Often, the collateral origin may be gently pried away from the metacarpal head with a Freer elevator.

Dense adhesions and excessively thick collateral ligament tissue may need to be incised at the metacarpal origin and removed.

Reassess passive MCP flexion (TECH FIG 1G). If flexion remains inadequate or the joint “jumps” or “snaps” when reaching full extension, then the accessory collaterals may need to be released as well.

The goal is an incremental collateral ligament release—enough to restore joint motion but not compromise stability, especially on the radial (pinch) side.

Assess the volar recess and release any adhesions between the volar plate and condyle with a Freer elevator.

Failure to release the volar adhesion can result in joint “hinging” with dorsal gapping of the joint during flexion.

The joint should now have a smooth arc of passive motion without any hinging during flexion or snapping into extension. Ninety degrees of flexion can usually be achieved.

If the patient is under a wrist or Bier block anesthesia, check active flexion.

Alternatively, a short incision may be made on the volar ulnar aspect of the forearm and traction applied to the appropriate extrinsic flexor tendons.
If active flexion is limited, consider performing a flexor tenolysis.
- We prefer to release the flexor at the same sitting, although the tenolysis may be staged, emphasizing passive motion between surgeries.
- Release the tourniquet and achieve hemostasis with bipolar electrocautery.
- While keeping the MCP joint flexed, close the extensor mechanism with 4-0 interrupted inverted nonabsorbable braided suture and close the skin with nonabsorbable interrupted sutures.
- If bleeding from scar is excessive, then use a small rubber vascular loop or a quarter-inch Penrose drain to stent open the wound to allow drainage for the first 24 hours.
- A dorsal splint is applied to maintain the MCP joints in 70 degrees of flexion.

**Limited Dorsal Capsulotomy of the MCP Joint**
- In mild contractures, a dorsal capsulectomy may not be necessary. Bode and Gottlieb\(^1\) have described a limited capsulotomy.
- Expose the extensor mechanism as described earlier (Tech Fig 1).
- Use a Freer elevator to release the extensor mechanism and sagittal bands from the dorsal capsule (TECH FIG 2A).

Retract the dorsal capsule distally.
- Incise the capsule transversely at the distal dorsal aspect of the metacarpal head (TECH FIG 2B).
- The incision extends from one collateral recess to the other.
- Using a Beaver blade or Freer elevator directed to the periphery of the capsulotomy, perform a stepwise release of the collateral ligaments off the metacarpal head (TECH FIG 2C).

**Extensor Tenotomy of the MCP Joint**
- In longstanding densely scarred multidigit MCP contractures, the extensor communis tendon may need to be tenotomized to achieve flexion (TECH FIG 3A).
- Make a tenotomy at the distal margin of the sagittal bands.
- Capsulectomy and collateral ligament release follow as described earlier.
- At closure, sew the proximal tendon to the sagittal bands; close the extensor hood upon itself in the midline dorsally.
- Given the chronicity of these contractures, consider temporary Kirschner wire fixation of the MCP joints in flexion (TECH FIG 3B).
- Kirschner wire fixation is especially useful for protection of skin grafts or flaps when the dorsal soft tissues are deficient (TECH FIG 3C).
TECH FIG 3 • (continued) B. The metacarpophalangeal joints are maintained in flexion with Kirschner wires. C. The dorsal soft tissue defect is covered with a pedicled tensor fascia lata flap.

**PIP JOINT CONTRACTURE**

**Capsulectomy for PIP Joint Flexion Contracture**

- If there is an adequate skin envelope, the finger is approached through a midaxial incision (TECH FIG 4A).
- Make a radial incision centered over the PIP joint; it is usually 4 cm long.
- Retract the neurovascular structures volarly and protect them. Take care to preserve the dorsal branch of the digital nerve, which typically crosses the proximal aspect of the incision.
- Open the flexor sheath just distal to the A2 pulley.
  - Excise a segment of pulley if it is contracted.
  - Perform a formal flexor tenolysis as necessary.
- If a more extensive tenolysis is required, the incision can be extended volarly over the flexor sheath. Take care to avoid injury to the digital nerve and artery that cross the operative field at the level of the web space.
- Excise a volar segment of collateral ligament (including the underlying capsule) using a no. 69 Beaver blade while carefully protecting the transverse retinacular fibers (TECH FIG 4B). Excise the entire accessory collateral ligament as necessary.
- Isolate and preserve the transverse retinacular fibers by bluntly dissecting perpendicular to the fibers (TECH FIG 4C).
- Do not excise the volar plate (joint capsule), but expand the volar pouch by lifting the volar plate from the phalanges with a Freer elevator. Lengthen the interossei as needed.

**TECH FIG 4 • A.** Skin incision. **B.** The transverse retinacular ligament is protected and the collateral ligament is exposed for excision. **C.** The collateral ligaments are excised. (continued)
If there is still stiffness after completing the dissection on the radial side of the finger, then make a similar incision on the ulnar side of the digit.

The ulnar incision is usually only 3 cm long, as the flexor and extensor tendon disorders have already been addressed. If there is concern that extensor tendon adhesions may limit active extension after release of the flexion contracture, then an extensor tenolysis is performed by elevating the dorsal skin. During the extensor tenolysis, protect the central slip insertion (TECH FIG 4D).

A skin graft or local flap may be required if there is inadequate soft tissue coverage after joint mobilization.

If there is insufficient volar skin or unstable volar skin, then raise a cross-finger flap from the adjacent finger. When a cross-finger flap is used, make a transverse incision over the volar aspect of the PIP joint and extend it with a radial midaxial incision.

Curtis3,4 originally described pinning the joint in extension for 1 week, but most surgeons do not follow this recommendation.

Check-Rein Ligament Release for PIP Flexion Contracture

According to Watson et al,11 the volar plate does not flex but rather slides proximally and distally with flexion and extension. PIP joint adhesions causing contracture occur proximal to the volar plate and involve the check-rein ligaments.

Excision of the volar plate or division of the collateral ligaments is rarely required to achieve full extension.

The joint is approached volarly, often with a V–Y incision to address palmar skin contracture.

Open the theca between the A2 and A4 pulleys and retract the flexor tendons (TECH FIG 5A).

Release the check-rein ligaments, preserving the nutrient vessel (TECH FIG 5B).

If there is still a contracture after release of the check reins, release the dorsal portion of the collaterals or the oblique retinacular ligament of Landsmeer.

This technique is helpful if a palmar exposure is required for excision of Dupuytren disease or during flexor tendon reconstruction.
Percutaneous Collateral Ligament Release for PIP Flexion Contracture

- Stanley et al\(^9\) described a percutaneous release of the collateral ligaments for persistent PIP flexion contractures.
- Place a no. 69 Beaver blade percutaneously adjacent to the proximal phalangeal head (TECH FIG 6A).
- Disinsert the proper collateral ligaments with a sweeping-type motion (TECH FIG 6B).
- Gently manipulate the finger into extension.

Use of an External Fixator for PIP Flexion Contracture

- Two types of distractors have been used.
- Kasabian et al\(^7\) described the use of a multiplanar distractor used for mandible reconstruction.
- The use of a Digit Widget (Hand Biomechanics Lab, Inc., Sacramento, CA) has become popular (TECH FIG 7).
- An external frame is applied without any soft tissue release.
- The frame is left in place for about 6 weeks.
- There are no outcomes reported in the literature. In several of our patients we have noted initial favorable results followed by contracture recurrence.

Capsulectomy for PIP Joint Extension Contracture

- Make a dorsal curvilinear incision.
- Preserve the transverse retinacular ligament by blunt dissection and excise the proper collateral ligaments with a no. 69 Beaver blade as described earlier (TECH FIG 8).
- Perform a dorsal capsulectomy and an extensor tenolysis. If there is intrinsic tightness, perform a lengthening or release.

TECH FIG 6 • A. Cross-section shows placement of the no. 69 Beaver blade parallel to the proximal phalanx and adjacent to the proximal interphalangeal collateral ligament origin. B. Sagittal view demonstrates the technique of “sweeping” the Beaver blade and detaching the collateral ligament from its origin.

TECH FIG 7 • Application of the Digit Widget for proximal interphalangeal flexion contractures.

TECH FIG 8 • Through a dorsal incision, the transverse retinacular ligament is protected and the collateral ligament is excised. The dorsal capsule is also released.
POSTOPERATIVE CARE

- Patients are instructed in strict elevation until the first postoperative visit.
- The wounds are assessed 48 to 72 hours after surgery and, if stable, immediate active-assisted range of motion is begun.
- Wound care and edema control measures are also instituted. A nonadherent gauze should be applied until the wound is watertight. A Coban wrap and gauze finger sleeve limit swelling. Once the wound is healed, compression gloves or elastic finger sleeves further decrease swelling.
- Therapy may quickly advance to include active and passive range of motion as the status of the extensor mechanism allows.
- For MCP extension contractures:
  - Patients are maintained in a static splint full time to keep the MCP joints in 70 degrees of flexion. A daytime dynamic flexion splint is applied at about 1 week once the initial postoperative swelling has subsided (FIG 4).
  - If Kirschner wire fixation was performed, then only interphalangeal joint motion is begun immediately and MCP therapy is delayed until wire removal at 7 to 10 days.
  - Patients are reassessed 2 to 3 weeks after surgery. If there is a significant extensor lag (as may follow an extensive extensor tenolysis), a dynamic extension splint can be alternated with the dynamic flexion splint during the day.
  - Nighttime static splinting is continued for a minimum of 6 to 8 weeks.
  - Therapy is usually continued for about 3 months.
- PIP release often benefits from early dynamic splinting during the day and passive splinting at night.

OUTCOMES

- Final motion is often much less than that obtained at surgery but often makes a substantial difference in hand function.
- Motion plateaus 3 to 6 months after surgery.
Results are best when the joint can be mobilized with capsulectomy alone. Each additional procedure, such as tenolysis, increases postoperative swelling and scar formation, limiting long-term gains.\(^4\)

In some cases, an improvement in MCP or PIP joint motion of 30 to 45 degrees is a reasonable expectation.\(^2,13\)

According to Gould and Nicholson,\(^6\) improvement in MCP and PIP motion depends on the cause of the contracture. In a study of 105 MCP capsulectomies and 112 PIP capsulectomies, patients with direct joint trauma (fractures or crush injuries) gained an average of about 20 degrees of active motion, slightly more for the MCP and less for the PIP. Patients with indirect causes of capsular contracture (nerve injury, stroke, or skin burns) did better.

Ghidella et al\(^5\) reported on the results of 68 PIP capsulectomies. The average overall improvement was a disappointing 7 degrees. The best results occurred in young patients without a history of crush injury, pain syndrome, or revascularization. The average improvement measured 17 degrees in this group compared with 0 degrees when there was a “complex diagnosis.”

Comlications

- Wound dehiscence and infection
- Persistent or recurrent contracture
- Extensor rupture
- Ulnar deviation of the finger at the MCP joint
- Postoperative subluxation or dislocation
- Injury to the dorsal branch of the digital nerve

References

DEFINITION
- Dupuytren disease (DD) is a fibroproliferative disorder that affects primarily the palmar fascial complex of the hand, with occasional secondary involvement of other areas of the hand as well as remote tissues.
- It is an unparalleled condition that clinically and pathophysiologically resembles no other known ailment.
- Although physiologically DD bears a resemblance to the processes associated with normal wound healing, the perpetual and progressive proliferation and abnormal collagen deposition with resultant tissue contracture is astonishing.
- There have been attempts to classify DD under other headings such as inflammatory and neoplastic disorders; however, its uniqueness places it in a class of its own.

ANATOMY
- The radial, ulnar, and central aponeuroses, palmodigital fascia, and digital fascia are elements of the palmar fascial complex.\(^{14}\)
- The radial aponeurosis has four components:
  - The thenar fascia, which is an extension of the central aponeuroses
  - The thumb pretendinous band, which is small or absent
  - The distal and the proximal commissural ligaments
- The ulnar aponeurosis has three components:
  - The hypothenar muscle fascia, which is an extension of the central aponeurosis
  - The pretendinous band to the small finger, which is consistent and substantial
  - The abductor digiti minimi confluence
- The central aponeurosis is the core of DD activity and has a triangular shape with a proximal apex (FIG 1A).

- Its fibers are oriented longitudinal, transverse, and vertical.
- The longitudinal fibers fan out as the pretendinous bands to the three central digits. Each pretendinous band bifurcates distally and each bifurcation has three layers. The superficial layer inserts into the dermis, the middle layer continues to the digit as the spiral band, and the deep layer passes almost vertically dorsally toward the flexor tendon and its digital sheath.
- The transverse fibers make up the natatory ligament (NL) located in the distal palm and the transverse ligament of the palmar aponeurosis (TLPA). The TLPA is proximal and parallel to the NL (FIG 1B) and lies deep to the pretendinous bands. Its distal, radial extent is the proximal commissural ligament. The TLPA gives origin to the septa of Legueu and Juvara, which protect the neurovascular structures and provide an additional proximal pulley to the flexor tendons.
- The vertical fibers of the central aponeurosis are the minute but strong vertical bands of Grapow and the septa of Legueu and Juvara (FIG 1C,D), which lie deep to the palmar fascia. There are eight septa that form seven fibro-osseous compartments\(^{3}\) of two types: four flexor septal canals that contain the flexor tendons and three web space canals that contain common digital nerves and arteries, and lumbrical muscles. These septa are inserted in a soft tissue confluence that consists of five structures: A1 pulley, palmar plate, sagittal band, inter-palmar plate ligament (IPPL; FIG 1D,E), and septum of Legueu and Juvara.
- The palmodigital fascia encompasses a number of fascial structures, including the terminal fibers of the pretendinous bands, the spiral bands, the beginning of the lateral digital sheet, and the NL. The middle layer of the bifurcated pretendinous band spirals about 90 degrees and the peripheral fibers run vertically adjacent to the metacarpophalangeal (MCP) joint.

FIG 1 • A. The central aponeurosis is the core of Dupuytren disease activity and has a triangular shape with a proximal apex. B. The transverse fibers make up the natatory ligament (NL) located in the distal palm and the transverse ligament of the palmar aponeurosis (TLPA). C. There are eight septa of Legueu and Juvara that form seven fibro-osseous compartments of two types: four flexor septal canals that contain the flexor tendons and three web space canals that contain common digital nerves and arteries, and lumbrical muscles. (continued)
They continue distally deep to the neurovascular bundle and NL and emerge distal to this ligament and contribute to the formation of the lateral digital sheet. The proximal fibers of the NL run in a transverse plane, but the distal fibers form a U that continues longitudinally along both sides of the digit, forming the lateral digital sheet. The lateral digital sheet therefore has deep and superficial contributions from the spiral band and NL.

- The digital fascia surrounds the neurovascular bundle in the digit, and this includes the Grayson ligament (palmar), the Cleland ligaments (dorsal), the Gosset lateral digital sheet laterally, and possibly fibers from the check-rein ligaments medially and dorsally that were described previously as Thomaine retrovascular fascia.

**PATHOGENESIS**

- In DD normal bands become diseased cords,¹¹ and Dupuytren nodules and cords are pathognomonic of the disease.¹²
- A nodule usually appears first, followed by the cord.
- The cords involve the palmar, palmodigital, or digital regions and progressively shorten, leading to joint and soft tissue contracture.
- The Grapow vertical bands become microcords, leading to thickening of the skin, which is one of the earliest manifestations of DD.
- Skin pits develop from the first layer of the split pretendinous band.
- The pretendinous cord develops from the pretendinous band and is the most common cord in DD. It leads to MCP joint flexion deformity and often extends distally, contributing to the digital cords. The pretendinous cord may bifurcate distally with each branch extending into a different digit, forming a commissural Y cord (FIG 2).
- The vertical cords, or diseased septa of Legueu and Juvara,² are short and thick. They are connected to the pretendinous cord and extend deeply in between the neurovascular bundle and flexor tendon fibrous sheath.
- Extensive palmar fascial disease is encountered in severe conditions and affects larger areas of the palm, leading to diffuse thickening of many components of the palmar fascial complex.
- The spiral cord has four components: the pretendinous band, the spiral band, the lateral digital sheet, and the Grayson ligament. It is encountered most often in the small finger.
- In the palm, this cord is located superficial to the neurovascular bundle. Distal to the MCP joint, it passes deep to the neurovascular bundle and in the digit it runs lateral to the neurovascular bundle as it involves the lateral digital sheet and again becomes superficial to the neurovascular bundle as it involves the Grayson ligament.
- Initially the cord spirals around the neurovascular bundle, but as it contracts, the cord straightens and the neurovascular bundle spirals around the cord.
- The distorted anatomy of the neurovascular bundle, which is displaced medially and centrally, becomes at risk of injury during surgery.¹⁹
- The natatory cord develops from the NL, converting the U-shaped web space fibers into a V shape, resulting in contracture of the second, third, and fourth web spaces.
- This cord extends along the dorsal lateral aspect of the adjacent digits and is best detected by passively abducting the digits and at the same time flexing one digit and extending the other at the MCP joints.
- The most commonly encountered digital cord is the lateral cord, followed by the central and spiral cords. These are responsible for proximal interphalangeal (PIP) joint flexion deformity.
- The central cord is an extension of the pretendinous cord in the palm.
- The lateral cord originates from the lateral digital sheet and attaches to the skin or to the flexor tendon sheath near the Grayson ligament. The lateral cord leads to contracture of the PIP joint but can also cause a distal interphalangeal joint contracture.
The abductor digiti minimi cord, also known as the isolated digital cord, takes origin from the abductor digiti minimi tendon, but may also arise from adjacent muscle fascia at the base of the proximal phalanx.

- It courses superficial to the neurovascular bundle, and infrequently entraps and displaces the bundle toward the midline.
- It inserts on the ulnar side of the base of the middle phalanx but may attach on the radial side or have an additional insertion in the base of the distal phalanx, causing a distal interphalangeal joint contracture.
- The distal commissural cord develops from the diseased digital commissural ligament, which is the radial extension of the NL. The proximal commissural cord originates from the proximal commissural ligament, which is the radial extension of the TLPA.
- Both of these cords cause first web space contracture.
- The thumb pretendinous cord originates from the thumb pretendinous band and causes thumb MCP joint flexion deformity, which is uncommon.

**NATURAL HISTORY**

- DD has three clinical phases: early, intermediate, and late.\(^\text{13}\)
  - Skin changes with loss of normal architecture and skin pitting characterize the early phase.
  - Nodules and cords form during the intermediate phase.
  - Contractures mark the late phase, with the MCP joint most frequently affected, followed by thePIP joint.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The classic DD patient is a Caucasian man with a positive family history. The condition is bilateral and progressive and may extend to the digits, leading to their contracture.
- Palmar involvement usually precedes disease extension into the digits, but the disease may begin and remain in the digits.
- The ring finger is the most commonly involved digit, followed in order of frequency by the small, middle, and index finger and last by the thumb.
- DD may affect areas outside the palmar surface of the hand.
- Ectopic disease can be either regional in the upper extremity or distant in other parts of the body.
- Garrod nodes are different from knuckle pads, occur on the dorsum of the hand, and are almost always limited to the finger (FIG 3).
Distant ectopic DD affects the plantar fascia and male genitals.

Patients said to express a Dupuytren diathesis or genetic predisposition typically have faster and more severe development of the condition.

- Positive family history
- Young age of onset
- Ectopic sites of fibromatosis such as the dorsal digital area (Garrod nodes), plantar fascia (Ledderhose disease), and male genitals (Peyronie disease)

DIFFERENTIAL DIAGNOSIS

- Non-Dupuytren disease
  - Occurs in a diverse ethnic group, is unilateral and non-progressive, usually involves a single digit, and frequently follows trauma or surgery
  - Patients with this disease rarely require surgical treatment. Confusing this with DD will produce contrasting epidemiologic data.
  - Epithelioid sarcoma
  - Occupational thickening and callus formation that mimic Dupuytren nodules
  - Palmar subcutaneous soft tissue lesions, such as localized pigmented villonodular synovitis, palmar ganglions, and inclusion cysts
  - Stenosing tenosynovitis without triggering can be associated with thickening and adherence of the skin to the underlying flexor tendon sheath.
  - Prominent flexor tendons can be confused with pretendinous cords because of attenuation of annular pulleys, as seen in rheumatoid arthritis.

NONOPERATIVE MANAGEMENT

- No treatment is necessary for non-Dupuytren disease.
- Observation is appropriate for non-progressive DD with minimal contracture and without compromise of function.
- Surgical treatment for minor disease or pitting can result in a disease flare and must be avoided.
- Basic science research has shown the potential of certain local agents in the treatment of DD. These include calcium channel blockers, nifedipine, and verapamil for early stages and collagenase for advanced stages of the disease.
- Steroid injection of nodules has been used to suppress the disease.

SURGICAL MANAGEMENT

- Surgery is the most widely used treatment method for symptomatic and severe DD.
- Outpatient surgery offers substantial savings and should be used in an otherwise healthy patient with moderate hand involvement.
- Local, regional, or general anesthesia can be used depending on the procedure performed.
- Flexion contractures of the MCP joint of greater than 30 degrees and PIP flexion contractures of 15 degrees interfere with function and, in the presence of a well-developed cord, are indications for surgical treatment.
- The outcome after surgery for MCP joint contracture is more successful than that for PIP joint contracture.
- PIP joint check-rein release is indicated if 40 degrees of residual flexion is present after conventional fasciectomy.

Procedures

Percutaneous Fasciotomy

- Percutaneous fasciotomy is indicated for palmar cords in elderly unhealthy patients.
- This technique carries a higher risk for complications when performed in the thumb than in the digits.
- In severe cases, this technique may be useful as a preliminary procedure before definitive removal of diseased tissue.
- Injuries to flexor tendons and digital nerves as well as chronic regional pain syndromes have been reported after percutaneous releases.

Open Palm Fasciectomy

- This method was first used by Dupuytren, who left the transverse palmar incision wound open after fasciectomy.
- This method is indicated for extensive involvement of the palmar fascia and if primary closure is not possible and skin grafting is not desired.
- Satisfactory results with this method continue to be reported in the literature, including less pain, better motion, and low rates of complication. The primary disadvantage is prolonged postoperative wound healing.

Partial Fasciectomy

- Partial fasciectomy is the excision of the diseased tissue with preservation of normal-appearing fascia.
- Other terms for this procedure are selective, regional, or limited fasciectomy.
- Partial fasciectomy remains the most widely used technique for treatment of DD among hand surgeons today. It is associated with a lower recurrence rate than fasciotomy.

Dermofasciectomy

- Dermofasciectomy involves excision of skin and diseased tissue simultaneously followed by grafting of the skin defect.
- Dermofasciectomy is the procedure of choice for recurrent or aggressive disease with marked adherence of skin to underlying diseased cords. It was reported to have lower recurrence rates compared to other surgical techniques even for recurrent disease.

Extensive Fasciectomy

- Extensive fasciectomy involves a wide, generous fasciectomy of diseased tissue involving most of the palmar fascial complex.
- This can be combined if necessary with partial fasciectomy in the digits.
- This technique is indicated when broad involvement of the palmar fascial complex is present.
- The NL and TLP may be involved in severe DD and these can be included in the extensive fasciectomy.
- After extensive fasciectomy, the skin sometimes can be closed primarily. If a defect is present, the wound can be skin grafted or left open.
- Total or radical fasciectomy entails removal of the entire diseased and normal palmar fascia with or without excision of the overlying skin.
- This highly morbid, radical approach is not warranted.

Positioning

- The patient is positioned supine and the hand is placed on a hand table with the shoulder abducted 90 degrees.
A padded pneumatic tourniquet is placed on the arm as proximally as possible. The upper extremity is exsanguinated and the tourniquet is inflated to 250 mm Hg.

**Approach**

- The most commonly used incision is the Brunner zigzag incision (**FIG 4A**).
- A midline longitudinal incision that is closed with multiple Z-plasties can be also used (**FIG 4B**).
- Transverse palmar incisions can be used for the open palm method or for removal of extensive palmar fascial complex disease.
- Local rotation flaps sometimes should be used to cover exposed flexor tendons or neurovascular structures, and the remaining secondary defect can be grafted with full-thickness skin.

**PERCUTANEOUS FASCIOTOMY**

- Local anesthesia is used.
- A tourniquet is not necessary.
- Select the point of fasciotomy adjacent to the cord.
- Use a no. 11 blade held vertically (**TECH FIG 1**).
- Make a stab wound and turn the blade horizontally to cut the cord while the digit is manually extended.
- A gratifying snap is felt and the finger should extend.

**TECH FIG 1** • The no. 11 blade is used to incise the midline cord to improve the proximal interphalangeal joint contracture in this elderly patient.

**OPEN PALM FASCIECTOMY**

- Make a transverse incision in the middle of the palm and extend it if necessary to the digits as a zigzag Brunner incision.
- Undermine the skin flaps and identify the diseased tissue.
- Carry the dissection proximally until a transition between normal and diseased fascia is identified.
  - Isolate the neurovascular structures from the diseased tissue and protect them.
- Release the diseased tissue proximally; dissection is followed distally and excised.
- Leave the transverse incision open to heal by secondary intention but close any extensions of the original incision into the fingers.
- Apply nonadherent gauze to the wound and immobilize the hand in a forearm-based splint with the fingers in extension.

**PARTIAL FASCIECTOMY**

- Make a zigzag Brunner incision; it may extend from the proximal palm to the digital pulp in cases of palmar and digital disease.
- Undermine the skin flaps by careful dissection to separate relatively normal dermis from the diseased tissue.
- This can be difficult in recurrent cases. Make every effort not to buttonhole the flaps.
- It is better to leave diseased tissue in the dermal flap rather than thinning the flap too much and running the risk of buttonholing the flap.
Identify the neurovascular structures, dissect them from the diseased cords, retract them, and protect them during the entire procedure (TECH FIG 2A).

Begin the dissection proximally in the palm until a transition between relatively normal and diseased fascia is identified.

Carry the dissection in a proximal-to-distal direction.

Transect the pretendinous cord proximally and follow the cord distally, dividing all connections to adjacent normal fascia.

If present, include in the excised specimen a vertical cord from the diseased septa of Legueu and Juvara and a natatory cord from the diseased NL (TECH FIG 2B).

Special attention must be given to a spiral cord (TECH FIG 2C) to prevent injury to the digital nerve and vessel, which are intertwined with and spiraled around the diseased cord.

If the diseased tissue is confined to the palm in the form of a pretendinous cord, the distal end of the cord can be seen inserted in the flexor tendon sheath distal to the MCP joint. The cord can be excised at this level.

If the diseased tissue extends to the digit, follow the digital cord into the finger.

Pretendinous cord extension in the digit can be in the form of lateral, central, or spiral cord.

The digital cord must be dissected in the finger with great care because of its proximity to the neurovascular bundle.

Identify and release the distal insertion of the digital cord.

Release the tourniquet and coagulate bleeders with a bipolar forceps.

After adequate hemostasis is achieved, close the wound without a drain.

If skin shortage is present, perform full-thickness skin grafting.

If the neurovascular bundle or flexor tendons are exposed, a flap may be rotated to cover these structures, and skin grafting is done for the secondary defect (TECH FIG 2D,E).

A palmar plaster splint with the digits in the corrected extended position is used for 1 week or less.
DERMOFASCIECTOMY

- Plan the incision by mapping the area of diseased tissue and skin with a marker. The remaining exposure is done through a zigzag Brunner incision that extends from the dermofascial island (TECH FIG 3).
- Remove the diseased fascia and adherent overlying skin as one component.
- Close the zigzag Brunner incision and cover the skin defect with full-thickness skin graft from the volar wrist.

TECH FIG 3 • In a patient with recurrent Dupuytren disease with two pretendinous cords in the palm in line with the small and ring fingers causing severe metacarpophalangeal and proximal interphalangeal flexion contracture of the small finger, dermofasciectomy was done for the small finger and partial fasciectomy through a zigzag Brunner incision was done for the ring finger. Correction of the contractures was achieved. Skin shortage in the small finger was covered with a full-thickness skin graft from the volar wrist.

EXTENSIVE FASCIECTOMY

- Make either a transverse incision in the middle of the palm or a U-shaped incision in the distal palm (TECH FIG 4A).
- The incision has two limbs extending proximally on the ulnar and radial aspect of the digits, forming a broad proximally based skin flap. These can be continued if necessary to the digits with zigzag Brunner incisions.
- Undermine the proximal skin flap and distal skin margin by separating the skin from the extensive diseased palmar fascial complex. Retract the flap proximally to expose the deeper structures (TECH FIG 4B).
- Carry the dissection proximally and distally to expose the majority of the palmar fascia. A transition between normal and diseased fascia may not be identified. Leave

TECH FIG 4 • A. A U-shaped incision is planned in a patient with diffuse Dupuytren palmar fascial disease with nodular thickening in the entire palm. B. The diseased fascia is exposed after reflection of the proximally based skin flap. C. The excised specimen includes a pretendinous cord from the ring finger and diseased transverse ligament of the palmar aponeurosis. D. The surgical wound after skin closure.
Injury to digital nerves is more common in cases with severe MCP and PIP joint contracture and altered nerve anatomy by a spiral cord. Separating diseased tissue from adherent skin is difficult, especially in recurrent cases. To reduce the risk of buttonholing the skin, vascular injury can be in the form of an arterial laceration, arterial spasm, intimal hemorrhage, or vessel rupture from vigorous correction of severe digital joint contracture. Arterial laceration that results in vascular compromise requires immediate repair or interposition vein graft. Arterial spasm and intimal hemorrhage are treated first by repositioning the digit in flexion, then irrigating with warm saline, applying topical lidocaine, even using intravenous heparin, and, if all else fails, vascular reconstruction.

Separating diseased tissue from adherent skin is difficult, especially in recurrent cases. To reduce the risk of buttonholing the skin, using a no. 15C scalpel and the back of the knife as a dissector will allow precise separation of diseased tissue from normal skin. In addition, using an operating room light to transilluminate from the epidermal side of the skin allows visualization of the thickness of the flap and can alert the surgeon when the dissection is too superficial.

PEARLS AND PITFALLS

- Injury to digital nerves is more common in cases with severe MCP and PIP joint contracture and altered nerve anatomy by a spiral cord. Such a complication is especially common in previously operated cases with an exuberant amount of scar tissue. Preventive measures include isolation of the neurovascular bundle by careful dissection, using loupe magnification, and knowledge of pathoanatomy. The dissection is carried out in a proximal-to-distal direction and is sometimes combined with distal-to-proximal dissection before removal of the diseased cord. If the nerve is transected, a primary repair should be performed.

- Vascular injury can be in the form of an arterial laceration, arterial spasm, intimal hemorrhage, or vessel rupture from vigorous correction of severe digital joint contracture. Arterial laceration that results in vascular compromise requires immediate repair or interposition vein graft. Arterial spasm and intimal hemorrhage are treated first by repositioning the digit in flexion, then irrigating with warm saline, applying topical lidocaine, even using intravenous heparin, and, if all else fails, vascular reconstruction.

- Separating diseased tissue from adherent skin is difficult, especially in recurrent cases. To reduce the risk of buttonholing the skin, using a no. 15C scalpel and the back of the knife as a dissector will allow precise separation of diseased tissue from normal skin. In addition, using an operating room light to transilluminate from the epidermal side of the skin allows visualization of the thickness of the flap and can alert the surgeon when the dissection is too superficial.

POSTOPERATIVE CARE

Open Palm Fasciectomy

- The surgical wound is covered with sterile nonadhesive gauze, which can be changed daily. By 4 weeks no dressings should be necessary.
- Forty-eight to 72 hours after surgery the patient begins active range of motion every 2 to 3 hours but maintains nocturnal extension splint immobilization.
- Whirlpool therapy can be used early in the postoperative period if unwarranted or excessive bleeding occurred.
- Wound healing takes place within 6 to 8 weeks, depending on the extent of the incision.

Partial Fasciectomy and Dermofasciectomy

- Range-of-motion exercises are encouraged out of the splint after 1 week. The sutures are removed and splint use is discontinued 2 weeks after surgery in uncomplicated cases.
- Formal hand therapy is used after surgery for extensive disease, especially if residual flexion deformity is present. Range of motion alternating with extension splinting is emphasized.

COMPLICATIONS

- Complications related to patient physiology include postoperative stiffness, chronic regional pain syndromes, recurrence, loss of digital flexion, and reflex symptomatic dystrophy. The surgeon has little influence in preventing these complications.
- Early postoperative complications
  - Hematoma is prevented by tourniquet deflation and adequate hemostasis before wound closure. Deflating the tourniquet and assessing the skin vascularity before closure to ensure adequate circulation is the best way to prevent skin necrosis.
  - Closure under tension should be avoided and consideration should be given to grafting or the open palm method if a primary closure is too tight.
  - Skin necrosis develops after excessive thinning of skin flaps and tight skin closure. Small areas of skin necrosis may be allowed to heal by secondary intention, but large areas of necrotic tissue should be excised, and skin graft or flap coverage is done.
  - Reflex sympathetic dystrophy, also referred to as a “flare” reaction, may occur after surgery. The patient presents with swelling, hyperemia, dysesthesias, and pain out of proportion to that expected. Direct trauma to the nerve and excessive dissection or stretch of the nerves are thought to be predisposing factors. A simultaneous carpal tunnel release with DD surgery, especially in women, is a predisposing factor. Atraumatic technique and gentle handling of nerves and tissues during surgery should minimize the risk of this complication. If no cause can be identified, the treatment is therapy for pain control. In recalcitrant cases a series of stellate sympathetic ganglion blocks can be helpful.
- Late postoperative complications
  - Inclusion cysts can occur near the scar due to dermal tissue entrapment in the subcutaneous space. This can be prevented by careful attention to skin approximation during wound closure. The risk of hypertrophic scar formation is lessened by careful attention to placement of the skin incisions.
OUTCOMES

- The recurrence rate varies between 2% and 60%, with an average of 33%. This may be a true recurrence (recurrent disease at the operated site) or disease extension (disease outside the area of prior surgery). Recurrence is more common in patients with PIP joint involvement, disease in the small finger, more than one digit affected, a longer time since surgery, and a secondary fasciectomy.
- Roush and Stern\(^{17}\) reported that the postoperative total range of motion of recurrent DD was better after fasciectomy and flap converge compared to skin grafting or arthrodesis.
- DD has intrigued basic scientists and clinicians for centuries. Both ancient\(^{6}\) and current publications\(^{5,18}\) underscore the interest in and the advances toward understanding the pathophysiology of this disease and improving its treatment.

REFERENCES

DEFINITION

- Vascular tumors are diverse, ranging from benign vascular malformations to malignant lesions.
- The incidence of vascular tumors is about 2% to 6%.\(^{14,16}\)
- About 26% of vascular and lymphatic tumors are found in the extremities.\(^{17}\)
  - When found in the upper extremity, they are more common in the hand and forearm.
  - Vascular tumors are fourth in frequency of upper extremity tumors, after ganglions, giant cell tumors, and inclusion cysts.
- Most vascular tumors are congenital, and 10% of pediatric tumors involve the upper extremity. Of these, 90% can be classified as hemangiomas or vascular malformations.\(^{23}\)
- Benign vascular tumors can be congenital or acquired and include hemangiomas, lymphangiomas, congenital arteriovenous fistulas, aneurysms, vascular leiomyomas, glomus tumors, and pyogenic granulomas.
- Malignant vascular tumors include hemangioendotheliomas, hemangiosarcomas, glomangiosarcomas, and malignant hemangiopericytomas.

ANATOMY

- The ulnar and radial arteries form the superficial and deep arches of the hand, which then branch into the common digital arteries. There are multiple anatomic variants.\(^{5}\) The common digital arteries then branch into the proper digital arteries that course along the midlateral aspect of each digit, slightly volar to midline.
- The arteries terminate at either a capillary bed or a glomus body. The glomus is a neuromyoarterial mechanoreceptor—that is, a specialized arteriovenous shunt. It lies in the stratum reticulum of the skin, especially in the subungual region and distal pads of the digits. The glomus body acts as a thermoregulator, and it regulates peripheral blood flow in the digits and possibly controls peripheral blood pressure. It contains the glomus cells surrounding the Sucquet-Hoyer canals, which are narrow vascular anastomotic channels.

PATHOGENESIS

- The theory is that vascular tumors occur as a failure of differentiation of the common embryonic vascular channels, which results in the congenital lesions.\(^{17}\) These are more commonly seen in the pediatric population, but they may be discovered late, in adults.
- Acquired vascular tumors are usually due to trauma that induces aneurysms or fistulas.

NATURAL HISTORY

Congenital Lesions

Hemangiomas

- Thirteen percent of hemangiomas are visible at birth, but this increases to 70% to 90% before the infant is 4 weeks old.
- These lesions show rapid growth, then slower growth that is proportional to the child. Next a slow involutional process occurs.\(^{29}\) Fifty percent of hemangiomas will involute by the time the child is 5 years old and 70% will involute by the age of 7.
- Hemangiomas consist of plump endothelial cells with high turnover rates.\(^{14}\) They may be classified by histology, location (superficial, subcutaneous, or intramuscular), or involutional status.\(^{17}\) Thirty percent of upper extremity hemangiomas will ulcerate. This becomes a problem with these hand and finger tumors that may present with acute or chronic paronychia, especially in children who suck their fingers.\(^{23}\)
- They present as reddish lesions that become raised during the growth phase.

Congenital Aneurysms

- The histologic classification of congenital aneurysms includes capillary hemangiomas, sclerosing hemangiomas, and venous or cavernous hemangiomas (FIG 1).\(^{17}\)
- Capillary hemangiomas consist primarily of proliferated capillaries. There is a compact mass of endothelial cells where

FIG 1 • A. Hemangioma of the volar fourth web space of the left hand. This patient had a raised, ulcerated lesion and pathology showing a polypoid lesion with central capillary and slightly larger vascular spaces. B. Cavernous hemangioma of the thumb. There is a pinkish hue to the skin without any raised tissue. Although the lesion appears ulcerated, on pathologic examination there were no ulcerations and large vascular spaces were found immediately beneath the epidermis.
there are small or no capillary lumina. These extend from the dermis into the subcutaneous tissue and make up about 57% of subcutaneous hemangiomas.  
- If the hemangioma is associated with thrombocytopenia and consumptive coagulopathy, it is termed Kasabach-Merritt syndrome. This is unrelated to the size of the hemangioma and may be life-threatening if untreated.  
- If there are thin-walled sinuses secondary to widely dilated thin-walled spaces with little stroma, they become cavernous or venous hemangiomas. These make up about 23% of hemangiomas.  
- Sclerosing hemangiomas contain a perivascular thickening of the lymphatic cells. There is a fibrous, not hematogenous, origin to these lesions. This type represents 10% of all hemangiomas.  

**Lymphangioma**  
- Lymphangiomas are rare and classified as simple, cavernous, and cystic. The most common variety is cavernous lymphangiomas. These present at birth or soon thereafter and are composed of dilated lymphatic sinuses.  

**Congenital Arteriovenous Fistula**  
- Congenital arteriovenous fistulas (AVFs) develop early in the embryo. The upper extremity is the second most common location for these lesions after the head and neck. They have several arteriovenous communications at birth and are associated with syndromes such as Parkes-Weber syndrome and Klippel-Trenaunay syndrome.  
- Parkes-Weber syndrome is a combination of multiple AVFs, vascular malformations, and skeletal hypertrophy of the affected limb.  
- Klippel-Trenaunay syndrome is characterized by a combined type of vascular malformation and limb enlargement due to hypertrophy of soft tissue and bone.  
- Both of these syndromes may have significant medical sequelae, including congestive heart failure, pulmonary embolism, venous thrombosis, bleeding, and cellulitis.  

**Vascular Malformations**  
- Vascular malformations are uniformly present at birth but may not be visible until childhood, adolescence, or adulthood. Most appear by ages 2 to 5 years. They enlarge proportionately with the child unless they are stimulated by trauma, hormones, infection, or surgery. These lesions have an equal sex distribution. Malformations generally have flat, slowly dividing endothelial cells.  
- They can be categorized as low-flow or high-flow lesions based on their hemodynamic features at the time of angiography.  
  - High-flow lesions have an arterial component. Marked enlargement and increased number of arteries, small vessels, and veins are consistent findings.  
  - Low-flow malformations have large channels without intervening parenchyma and often with associated phleboliths. These lesions are more common than high-flow lesions. They are subdivided into capillary, venous, lymphatic, and combined.  
- Capillary malformations (port wine stain, nevus flammeus) show dilated capillaries and postcapillary venules in the upper dermis. They are dark red to purple and may have another associated vascular lesion. Over time, they become darker and have a cobblestone appearance. They may be associated with limb or digit overgrowth.

**FIG 2** Venous malformation of the ulnar side of the left hand. Notice the blue color and slightly raised appearance.

- Seventy-five percent of venous malformations are recognized at birth. They are the most common anomaly of the low-flow group (40%). It is important to differentiate them from hemangiomas because venous malformations do not involute. They, like lymphatic malformations, present with a mass or skin discoloration. They enlarge shortly after birth and grow with the child. Slow commensurate growth, compressibility, and phleboliths are pathognomonic for venous malformation (FIG 2).  
- Patients with vascular malformations will complain of the mass effect of the lesion, increased size with exercise, or pain due to thrombosis. Elevation of the extremity eases symptoms. They may lead to nerve compression at the forearm and wrist, and digital compression may be seen with localized thrombosis.  
- Lymphatic malformations enlarge secondary to fluid accumulation, cellulitis, or inadequate drainage of lymphatic channels. They can limit hand motion, and infections are common. They can cause bone hypertrophy.  
- Mixed vascular malformations share the characteristics of their combination of vascular malformations.  
- High-flow malformations present early as a painless mass. They have a bimodal occurrence: 40% show up at birth and another 34% after 10 years old. They are not compressible. These lesions can lead to distal ischemia or even high-output heart failure if large and untreated. They have been divided into three types (FIG 3):  
  - Type A lesions have single or multiple arteriovenous fistulas, aneurysms, or ectasias of the arterial side.  
  - Type B lesions consist of arteriovenous anomalies with microfistulas or macrofistulas that are localized to a single limb, hand, or digit. They have stable flow characteristics and provoke minimal to no distal symptoms. As with type A lesions, they remain localized to a specific anatomic region.  
  - Type C lesions enlarge slowly. They are diffuse, with microfistulas and macrofistulas involving all limb tissues. With increasing size, vascular steal occurs. The lesions and associated symptoms worsen with pregnancy and do not reverse with delivery. They can cause distal ischemic pain, tachycardia, and congestive heart failure. Compartment syndrome, compression neuropathies, and ulceration secondary to ischemia or attempted surgical interventions can also occur. The result can be unremitting, progressive pain, eventually leading to amputation.
True aneurysms contain all three layers of the vessel wall: intima, media, and adventitia. False or pseudoaneurysms do not contain all three layers of the vessel wall.

**True Aneurysms**
- True aneurysms account for 6% of all tumors of the hand.\(^{17}\)
- True aneurysms, most notably hypothenar hammer syndrome, usually follow blunt trauma in the area of the vessel. The trauma may be a single event or repeated injury. The vessel dilates in response to injury to the arterial media, leading to a fusiform vessel.
- Aneurysms occur secondary to other disease processes such as arteriosclerosis, metabolic disorders, Kawasaki disease, Buerger disease, hemophilia, osteogenesis imperfecta tarda, granulomatous arteritis, and cystic adventitial disease (FIG 4).\(^ {14}\)

**Pseudoaneurysms**
- False or pseudoaneurysms account for most (83%) aneurysms of the hand and generally occur on the palmar surface of the hand.
- They may be secondary to a puncture wound (such as from a knife or pencil lead) or complete rupture of the vessel wall with continuity maintained by the surrounding soft tissues.\(^ {14,17}\)
- Pseudoaneurysms occur slowly over time and are usually not evident for weeks to months after the injury.
- A bruit may be noted on examination. Like true aneurysms, the most common site is in the ulnar artery.

**Acquired Arteriovenous Fistulas**
- Acquired AVFs occur secondary to trauma or surgical intervention. AVFs consist of a communication between an artery and a vein that shunts away from the higher-resistance capillary system.

---

**Acquired Lesions**
- Acquired lesions comprise both true and false aneurysms of the vessels, glomus tumors, pyogenic granulomas, fistulas, and vascular leiomyomas.

---

**FIG 3**
- **A.** Arteriovenous malformation of the digit. The margins are indistinct and it is difficult to dissect from the surrounding tissues. **B.** Arteriovenous malformation of the palm at the ulnar artery. There is a bulblous region where the malformation has occurred.

**FIG 4**
- **A.** Venous aneurysm of the palm. Again, a bluish tinge is noticeable over the lesion. **B.** Intraoperative view of a venous aneurysm. There is dilatation present at the vein. **C.** Ulnar digit artery false aneurysm. The patient sustained a traumatic injury at work and noted an increase in the size of the lesion over the ensuing 6 weeks. **D.** Hypothenar hammer syndrome. The patient was releasing a mechanical latch of a machine by using the heel of his hand, which caused a sharp pain. The patient presented with coolness of the ring finger-tip and associated pain.
Traumatic AVFs occur when there is penetrating injury to an artery and the adjacent vein, leading to a hematoma and shunting. This may occur secondary to injury with such objects as small knives or pencils, but it may also be due to venipuncture, arterial cannulation, or catheterization procedures. AVFs secondary to iatrogenic vascular injuries tend to occur slowly, while those that occur secondary to trauma are usually rapid in onset. This may be secondary to the size of the puncture that occurs; iatrogenic injuries tend to be smaller punctures than traumatic ones. Patients with intrinsic coagulation deficiencies are more vulnerable to this complication.

Surgical AVFs are formed for dialysis access in renal failure patients and can cause similar symptoms, including steal, ischemia, venous arterialization, and hand edema.

**Glomus Tumors**

- Glomus tumors make up 8% of the vascular tumors of the hand and 1% to 4.5% of all hand tumors. They arise in the neuromyoarterial apparatus that was first described by Wood in 1812 and then again by Masson in 1924. These lesions have been found in the stomach, trachea, and retina but are most commonly found in the digits. Glomus tumors are more consistent with a hamartoma than a true tumor. Sixty-five percent of these lesions are found in women 30 to 50 years old.
- Between 26% and 90% of solitary glomus tumors are located in the subungual region. These lesions tend to be small—normally 5 mm and usually less than 1 cm. They are encapsulated and contain numerous small lumina when found as single tumors. Multiple tumors tend to be unencapsulated, rarely subungual, with larger-shaped vascular spaces.
- Multiple glomus tumors tend to be asymptomatic and present earlier in life, whereas solitary tumors often go undiagnosed or misdiagnosed for years because the lesions are small and not palpable and with varying presentations. Glomus tumors are more commonly found on the glabrous portion of the palm and digits as well as in the mouth and around the lips and face. In adults, these are more commonly found on the fingers and toes.
- They may occur spontaneously but are more frequently present as an overgrowth of granulation tissue in an area of previous penetrating trauma.

**Vascular Leiomyomas**

- Vascular leiomyomas are very rare tumors of the hand. They arise in the smooth muscle of the tunica media of veins in 50% of cases. These masses are typically well encapsulated, small, round, firm, colorless, and curable.

**Pyogenic Granulomas**

- Pyogenic granulomas make up 20% of the vascular tumors of the hand and may be a variation of a capillary hemangioma. They appear as a circumscribed lesion.
- They develop rapidly and become a pedunculated, friable lesion that is easily traumatized and bleeds. In children, these lesions are more commonly found on the glabrous portion of the palm and digits as well as in the mouth and around the lips and face. In adults, these are more commonly found on the fingers and toes.
- They may occur spontaneously but are more frequently present as an overgrowth of granulation tissue in an area of previous penetrating trauma.

**Malignant Tumors**

- Malignant vascular tumors account for less than 1% of all vascular hand and forearm tumors. There are several types of malignant vascular tumors: hemangioendothelioma, glomangiosarcoma (malignant glomus tumors), angiosarcoma, Kaposi sarcoma, lymphangiosarcoma, and hemangiopericytoma.
- Hemangioendotheliomas tend to arise adjacent to or within veins. They extend centrifugally from the vessel. They are slow-growing tumors, and tumors that show more than one mitosis per high-power field on histology are more likely to metastasize. Metastasis may occur locally to nodes or be distant to the lungs, liver, or bone.
- Glomangiosarcomas are extremely rare and were first described in 1972 by Lumley and Stansfield. They tend to be...
low-grade tumors that are locally invasive. They occur in adults ages 20 to 89 years. There are three categories of glomangiosarcoma: locally infiltrative glomus tumor (LIGT), glomangiosarcoma arising in a benign glomus tumor (GABG), and de novo glomangiosarcoma (GADN).

- **LIGT** is identical to solitary glomus tumors except that it has infiltrating growth and tends to recur with resection.
- **GABG** is a sarcomatous tumor in association with a benign glomus tumor.
- **GADN** is a sarcoma with round cells and features of a benign glomus tumor.12,19,20

Angiosarcomas are rare and aggressive and metastasize early. They may occur after radiation therapy or long-term exposure to polyvinyl chloride. They are sometimes mistaken for hemangioendotheliomas on histology. The prognosis is extremely poor with these tumors, with survival times averaging 2.5 years.14,17,29

First described by Kaposi in 1872 in elderly men of Jewish and Mediterranean heritage, Kaposi sarcoma present as small, purple macules. They are a malignant degeneration of the reticuloendothelial system. These lesions tend to start on the hands or lower extremities, progress onto the trunk, and coalesce into large papules. In this patient population, the disease has an indolent course and may be treatable with surgery and radiation. In the age of HIV/AIDS, however, the disease is much more aggressive, with a larger number of lesions. In these patients, it is associated with human herpes virus 8.14,17,29

Lymphangiosarcoma is a rare cancer that occurs after longstanding lymphedema, as seen in some postmastectomy patients. These lesions metastasize rapidly.

Hemangiopericytoma is a diffuse proliferation of capillaries, encased in connective tissue and surrounded by pericytes. They have no nerve elements and are generally painless. Patients tend to delay treatment secondary to lack of pain. They may present as a nonpigmented bleeding mole, an ulceration with prominent telangiectasia, or a dark blue, hemorrhagic swelling. Histologically, they have sheets of spindle cells surrounding capillaries, regular oval nuclei without anaplasia, indistinct cytoplasmic borders, and a reticulin sheath surrounding each cell on silver stain.11,28 Pathologists have described three histologic grades based on the above criteria: benign, borderline malignant, and malignant. It has an unpredictable behavior and may metastasize years after excision; therefore, long-term (5 to 10 years) follow-up is recommended (FIG 8).

### Patient History and Physical Findings

- It is imperative to get a complete history and physical examination of the patient and family.
- Determine whether the lesion was present at birth or infancy or whether it appeared later in adolescence or adulthood.
- Rate of growth should be sought. This may help to differentiate between a hemangioma and an arteriovenous malformation in early childhood. Hemangiomas grow out of proportion to the growth of the child.

**Hemangiomas**

- Hemangiomas will appear as a reddish lesion that becomes raised. Lesions of the axilla or interdigital region will be chronically macerated. Fingertip hemangiomas may present with findings similar to an acute or chronic paronychial infection, especially in children who suck on their fingers.23
- Vascular malformations
  - Low-flow malformations most commonly present as a mass or skin discoloration. If a capillary component is present, there may be a reddish stain of the skin. The physician should ascertain whether there are any compressive symptoms from the lesion consistent with a mass effect, distention, or pain with exercise that would indicate a venous malformation.
  - Ulceration is uncommon in these lesions.
  - If there is a lymphatic component, patients may present with intralymphatic infections secondary to ruptured vesi- cules and maceration of large lesions.
  - They may also be found in association with syndromes such as Parkes-Weber, Klippel-Trenaunay, proteus (capillary malformations, venous malformations, macroactyly, hemihypertrophy, lipomas, scoliosis, and pigmented
nevi), and Mafucci (lymphaticovenous malformations and enchondromas).23

- High-flow malformations tend to be painless early on but then progress to be warm, painful masses with palpable thrills and bruits as the child grows.
- Asking the patient if he or she gets relief of the pain with elevation, if there is increased pain with exercise, and increased warmth in the lesion may help to distinguish these from low-flow lesions.
- It is also important to ask about any symptoms of congestive heart failure, which may occur as sequelae of an untreated high-flow malformation.23
- Any patient evaluated in the office for a suspected arteriovenous malformation should be evaluated for other lesions, Nicoldani sign (decrease in pulse with occlusion of the fistula), and any evidence of distal ischemia.14

- Aneurysms and pyogenic granulomas
  - For evaluation of possible aneurysms and pyogenic granulomas, it is important to know whether there is a history of trauma in the region, how long the lesion has been present, whether it is a pulsatile mass, and whether it has bled.

- Glomus tumors
  - The classic triad of paroxysmal pain, pinpoint tenderness, and temperature intolerance, especially cold, should be elicited if glomus tumors are in the differential.
  - On physical examination, the physician should look for a bluish discoloration (found in 28% of patients) and a pulp nodule or nail deformity (found in 33% of patients).15
  - The length of time that the patient has had symptoms can assist in differentiating glomus tumors from other tumors of the upper extremities, since most patients tend to have symptoms for more than 10 years. If the patient has had previous excisions of glomus tumors, it is necessary to find out the amount of time between resection and recurrence. This can help to determine whether the lesion is an incomplete excision or a new tumor.26
  - During the physical examination, the patient should also be evaluated for multiple glomus tumors, which tend to be less symptomatic.

- Patients with lesions of the hand, wrist, or distal forearm should have an Allen’s test performed.
  - The hand is elevated and the patient is asked to make a tight fist for about 30 seconds. The ulnar and radial arteries are occluded and the patient opens his or her hand slowly. The ulnar artery is then released and the color should return in 5 seconds. If color returns to the radial aspect of the hand within 5 seconds, the superficial arch is complete and the radial artery may be ligated.
  - A thorough evaluation of the rest of the patient’s medical history, including a history of axillary dissections, HIV/AIDS status, and irradiation, is also necessary if the patient presents with a lesion that may be cancerous.

- Methods for examining the vascular lesions of the hand
  - The examiner should look at the hand to check for blue spots, nail ridging, reddish, raised lesions, pulsatile masses, or traumatic injury, which helps to differentiate between malformations, aneurysms, pyogenic granulomas, and glomus tumors.
  - A stethoscope is gently placed over the lesion to listen for bruits or thrills. In fast-flow arteriovenous malformations, a bruit or thrill may be heard, which would not be found in other vascular lesions.
  - The mass is gently palpated. If a pulsatile mass is felt, the examiner should ascertain whether the lesion is compressible and whether there is associated pain.
  - Love pin test: The head of a pin or paperclip is gently pressed against the tender area to localize the pain. This locates a glomus tumor. In subungual tumors, the pin is placed on the nail plate at various locations to find the tumor.15
  - Hildreth test: The digit is exsanguinated by placing a tourniquet at its base or the hand is exsanguinated by elevating it and making a tight fist. The point of tenderness located by the Love pin test is then repalpated. If the patient has diminished or resolved pain with this maneuver, then the test is considered positive for a glomus tumor.8

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs of the digits and hands
  - Phleboliths (in 6%) and bony hypertrophy may be noted.14,17
  - There may be evidence of a soft tissue mass or signs of bone erosion or destruction of the cortical surface, which is seen in about 6% of patients with hemangiomas.17
  - Doppler ultrasonic flow detection is a noninvasive study that does not require the use of contrast.
  - It has been used to confirm high-flow anomalies and to help differentiate between hemangiomas and malformations.24 Doppler ultrasonography will show these lesions to be monophasic with low-flow velocity averaging 0.22 kHz.22
  - Computed tomography with contrast enhancement may show bony involvement of the tumor, especially in type A high-flow malformations.24
  - MRI can be used to evaluate the site, size, flow rate, and characteristics of the lesion as well as involvement of contiguous structures.24
  - It may be used to determine whether a malformation is low-flow or high-flow and can also distinguish between dense parenchymal lesions and malformations with large vascular channels.14
  - It can also be used to evaluate glomus tumors, which have a high signal intensity on T2-weighted spin-echo MRI or after gadolinium injection.15
  - MRI has a sensitivity of 90% and a specificity of 50% for glomus tumors, so that it cannot be used as the single diagnostic study for glomus tumors, especially if they are less than 2 to 3 mm in size.1
  - Hemangiomas will appear as well-circumscribed mass lesions that enhance with gadolinium and will have a high T1 signal secondary to infiltrative margins and fatty tissue overgrowth as well an extremely high, heterogeneous T2 signal. A serpentine pattern in the mass may also be seen on MRI.29
  - MR angiography may be performed at the time of MRI to evaluate lesions in patients who are unable to undergo angiography secondary to renal problems or contrast allergies. It can be used to define the anatomic extent of lesions and their relationship with the surrounding tissue. It can be used to evaluate for both arterial and venous tumors without contrast enhancement.7
  - Technetium-99m red blood cell perfusion and blood pool scintigraphy will show increased activity on early and late blood pool images with increased perfusion in hemangiomas and may be useful in their diagnosis.29
  - Angiography is the gold-standard evaluation of certain tumors, including vascular malformations. No longer routinely used for diagnosis of a lesion, it is used as an evaluation for
operation or embolization. It may show a cluster of anomalous arterial branches with multiple communications with venous trunks draining the site of involvement.

Closed venous angiography uses contrast injected into the venous system distal to a proximal arterial tourniquet applied on the upper arm. Dye is injected into the exsanguinated extremity distal to the tumor and radiographs are taken as the vascular tumor fills to get an accurate assessment of the anatomy. Arterial angiography is performed through a stick into the femoral artery with a catheter that is fed into the involved extremity. Dye is then injected and both the arterial and venous phases of circulation are evaluated. This can be used to evaluate the size of the tumor, locate the feeding vessels, and embolize feeding vessels before operation (FIG 9).

DIFFERENTIAL DIAGNOSIS

- Foreign body
- Bacillary angiomatosis
- Pyogenic granuloma
- Glomus tumor
- Hemangioma
- Arteriovenous or lymphatic malformation
- AVFs (traumatic, congenital, iatrogenic)
- Traumatic aneurysm (true or false)
- Mycotic aneurysm (hematogenous or exogenous)
- Arteriosclerotic aneurysm
- Congenital aneurysm
- Metabolic aneurysm (eg, osteogenesis imperfecta, granulomatous arteritis, Buerger disease)
- Vascular leiomyomas
- Glomangiosarcoma
- Angiosarcoma
- Hemangioendothelioma
- Hemangiopericytoma
- Kaposi sarcoma
- Lymphangiosarcoma

NONOPERATIVE MANAGEMENT

- Observation is important for hemangiomas. Up to 70% of these lesions will involute by the age of 7.
- Large venous or capillary malformations should be observed for limb growth disturbances and a possible underlying high-flow lesion.
- Limb compression garments can be used to compress massive congenital arteriovenous fistulas that are inoperable, giant venous malformations, lymphatic malformations, or large hemangiomas in the arm and forearm. For larger lymphatic lesions, home compression pumps can be used to decrease edema at night.
- Antibiotic prophylaxis is indicated in patients who have recurrent infections in lymphatic malformations. The bacteria most commonly responsible for these infections is penicillin-sensitive beta-hemolytic streptococcus.
- If a patient with venous malformations or capillary-venolymphatic malformation has recurrent intralesional thrombosis, then low-dose aspirin may be added to the compression garments for effective therapy.
- Local wound care and dressings may be required if ulcerations occur in the periangual regions or the central portions of large lesions during the involutional phase.
- Pulsed-dye laser or argon laser may be used with some hemangiomas to treat the pigmented lesion without damaging the overlying skin, sweat glands, and hair follicles. Lasers of 585-nm wavelength work well on vascular lesions, such as hemangiomas, which are rich in hemoglobin. The laser heats the hemoglobin, causing coagulation of the vessels in the dermis. Scar formation ensues and replaces the damaged blood vessels.
- Sclerotherapy with 1% sodium tetradecylsulfate, for small superficial lesions, or 100% ethanol, for large, deep saccular lesions, may be used in treating venous malformations.
- With the larger lesions, there is a possibility of skin ulceration, necrosis, inflammatory changes, and contracture due to the treatment, and patients should be warned to watch for these sequelae.
- In arteriovenous malformations interventional radiology may be used for embolization of selectively catheterized vessels with polyvinyl alcohol foam or tissue adhesive. This may be helpful if surgical resection is performed 24 to 48 hours later. If the lesion is small, this may completely occlude the malformation and destroy the lesion, eliminating the need for surgical resection. Several embolizations may be necessary to fully destroy small lesions.

FIG 9 • A. Angiogram of hypothenar hammer syndrome. The ulnar artery flow is absent and collaterals have formed to allow for flow in the palmar arch. This patient was relatively asymptomatic until a trauma to the hand. B. Angiogram of a second patient with hypothenar hammer syndrome. In this patient, there are no collaterals present, and he presented with coldness of the ulnar distribution digits.
■ Embolization may lead to residual tissue loss, neurologic deficit, and enlargement of the malformation if the lesion is large and not excised promptly.9,16
■ Either intralésional or systemic steroids may be useful for the treatment of hemangiomas, and a 6-week course may help to treat life-threatening or tissue-threatening lesions. This is also true for interferon alpha-2a or 2b. However, neither of these medications has been shown to have any effects on malformations, and the morbidity (neutropenia, elevation of liver enzymes, and spastic diparesis) of interferon must be considered before its use.24,29
■ Radiation therapy was used in the past for sclerosis of hemangiomas; however, it leads to atrophic changes in the skin and subcutaneous tissue as well as arrest of skeletal growth.17

SURGICAL MANAGEMENT
■ Indications for surgery include pain, intralésional thrombi, episodic bleeding or ulceration, recurrent infection, or functional problems related to the size or weight of the extremity. It is important to consider whether the extremity will be functional after the proposed surgical treatment; in many cases amputation may be a better option.23
■ Lymphatic malformations have the added difficulties of beta-hemolytic streptococcal sepsis, skin maceration, and vesicular eruptions. This makes the planning of surgical resection complex. Complications occur in 25% of all procedures. The surgeon should be aware that tumor-free tissues, such as grafts or flaps, may be necessary for coverage.23

Preoperative Planning
■ Radiographic studies should be reviewed carefully to plan resection of large or complex lesions.
■ An Allen’s test should be performed on the patient to evaluate for the patency of the superficial palmar arch and to see if the patient has an adequate ulnar artery.
■ If the Allen’s test is positive, reconstruction of the radial artery is necessary if it is to be resected.

Positioning
■ The patient should be placed in supine position with the arm abducted.
■ A proximal arm tourniquet is used, but the arm should not be exsanguinated with an Esmarch bandage to avoid the proximal spread or localized compression of the tumor. Exsanguination with the Esmarch bandage may also obscure the margins of hemangiomas and malformations.
■ Injections around the tumor should also be avoided to reduce the risk of local spread and compression of the mass, which could cause incomplete resection.

Approach
■ The technique chosen is based on the location of the lesion and the access necessary for excision.

Ligation of Feeding Vessel
■ For lesions that are small, with few feeder vessels, direct exploration and ligation of the feeding vessels can lead to involution of the lesion without significant tissue loss.
■ If tissue loss occurs, excision of the area and either primary closure, skin grafting, or flap reconstruction can be performed.

Staged Excision
■ Staged excision is useful for venous malformations, lymphatic malformations, combined malformations, and types A and B high-flow malformations.24
■ For larger lesions, the interventional radiologist may be helpful in embolizing feeding vessels. This will decrease or limit the amount of open exposure necessary in the first stage.
■ In this approach, the extremity is not exsanguinated completely to allow identification of the vessels more readily.
■ In the first stage, the tributary and exiting vessels are ligated proximal and distal to the tumor. It is possible that ligation of the vessels may induce distal ischemia. If this occurs, the surgeon should be prepared to bypass the anatomic defect with autogenous vein grafts.
■ At a second stage, the lesion is removed after the above procedure and depending on the condition of the patient. If necessary, the second procedure may be delayed. If the tumor is adherent to the skin, that portion of tissue is excised as well and the area is covered with grafts or flaps.17

Amputation
■ Amputation is the treatment choice for highly aggressive malignancies such as hemangiosarcoma, lymphangiosarcoma, aggressive hemangioendothelioma, and massive arteriovenous malformations that have created a nonfunctional extremity.
■ This should be performed with a proximal tourniquet for operative hemostasis.
■ If the lesion is too proximal for a tourniquet, an internal vascular balloon can be used to occlude the feeding vessel or vessels.
■ Guillotine amputation is an option if infection is present; otherwise, closure should be performed at the time of amputation.
■ The most common error we have seen after amputation of a digit or hand is failure to obtain adequate, tension-free soft tissue coverage.
■ Wide local excision may be considered for less aggressive hemangioendothelioma, hemangiopericytomas, malformations, and hemangiomas that have not involuted.

TRANSUNGUAL EXCISION
■ Transungual excision is an approach to subungual lesions, such as glomus tumors.
■ Make small radial and ulnar corner incisions over the nail fold (TECH FIG 1A,B).
■ Half the nail is then elevated and folded over, allowing for visualization of the nail matrix (TECH FIG 1C).
■ The nail can be completely removed with a Freer elevator if necessary for access to the tumor (TECH FIG 1D).

Approach
■ Make a longitudinal incision with a no. 15 blade into the nail matrix, directly over the tumor, and excise the lesion circumferentially down to the phalanx (TECH FIG 1E,F).
■ Curette the bone before the nail bed is closed with 6-0 plain gut.
■ Replace the nail into the eponychial fold as a dressing for the nail bed and suture the corner incision closed (TECH FIG 1G).15,21
TECH FIG 1 • A. Radial and/or ulnar incisions of the nail fold are drawn. If the lesion is proximal in the nail bed, one or both of these incisions may be necessary to access the lesion. B. The incisions are at oblique angles to the nail fold to avoid contracture of the area. C,D. The nail plate is elevated off the nail bed with a Freer elevator. Half the nail is elevated primarily (C), but the entire nail may be removed to allow for access to the lesion (D). Incision(s) are then extended, if necessary, to allow for visualization. E,F. A longitudinal incision is made in the nail bed to allow for removal of the lesion. The bone is curetted to remove any tumor and the nail bed is then closed with 6-0 or 7-0 plain gut. G. The nail plate is then replaced as the dressing and the incision(s) are closed with 5-0 or 6-0 nylon or chromic.

LATERAL INCISION

- This is an alternative to the transungual excision and allows exposure of the dorsal distal phalanx without violating the nail matrix. Because the view of the tumor is narrower, we do not recommend this approach.15
- If this approach is to be used, then a longitudinal midaxial incision slightly dorsal to the neurovascular bundle is used (TECH FIG 2A).
  - The incision is placed on the radial or ulnar surface of the digit, based on the location of the lesion.
  - Sharp dissection is carried out to the distal phalanx without manipulating the surrounding soft tissue.

- A small, sharp elevator is used to create a subperiosteal dorsal flap (TECH FIG 2B).
- A small curette or elevator is used to excise the lesion.
- The flap is replaced and the incision is closed with interrupted or running nylon suture.21,27

TECH FIG 2 • A. A midlateral incision is drawn just dorsal to the midaxial line. The incision is carried sharply down to the bone, keeping the neurovascular bundle volar to the incision and dissection. B. A Freer elevator is then used to create a subperiosteal flap to allow removal of the lesion. The incision is then closed with 5-0 or 6-0 nylon.
**EPIPHYSIODESIS**

- Epiphysiodesis, destroying the growth plate by scraping or drilling, may help to diminish hypertrophy in patients whose digits have reached adult size.
- Make a midaxial incision sharply, with dissection continued to the bone.
  - Retract the neurovascular bundle volarly to avoid injury (TECH FIG 3A).

- The dorsal branches may be transected if it is necessary to gain access to the dorsal aspect of the phalanx.
- Use a drill to destroy the growth plate of the phalanx (TECH FIG 3B).
- Close the incision with 5-0 or 6-0 nylon.

**PEARLS AND PITFALLS**

| Have a tourniquet on the extremity before the incision for arteriovenous malformations. | Avoid overly aggressive resection of lesions. |
| Make the family aware of the guarded prognosis for complete removal of arteriovenous malformations and the possibility of overgrowth or recurrence of the lesions. | Exsanguination of an arteriovenous malformation may lead to incomplete excision. |
| Insist on multiple high-quality imaging studies to evaluate the lesions | For small lesions, imaging may not fully show the lesion. |
| Check patient for associated syndromic abnormalities. | |

**POSTOPERATIVE CARE**

- After excision of the lesion, most patients will require a bulky dressing, and most will be able to return to their normal activity within 1 to 2 weeks.
  - Patients with partial resection of arteriovenous malformations may need to continue wearing compressive garments postoperatively when the dressings are removed.

- If patients required skin grafts or flaps, dressings and splints can be left in place to keep the patient from shearing the graft or pulling at the flap until the incisions are healed.
  - Graft bolsters or splints should be left in place for about 3 to 5 days to allow the graft to adhere well.
  - For patients who require amputations, prosthetics may be formed, depending on the level of the amputation. These are
more readily available for patients who have below- or above-elbow amputations, although patients who have forequarter amputations may also be candidates for specialized prosthetics.

- Patients will require physical therapy to teach them how to use prosthetics or to relearn hand function, if wide excisions were necessary.

OUTCOMES

- The prognosis of hemangiomas is not affected by race, gender, tumor site, size, or presence at birth.\textsuperscript{16}
- Attempts to excise arteriovenous malformations may lead to serious complications.
  - Complications are seen in about 22% of slow-flow lesions and 28% of fast-flow lesions. Wound dehiscence, seromas, and hematomas are noted early on. Partial skin loss and incision site infection are seen in the late postoperative period.
  - In fast-flow malformations, episodic bleeding and wound breakdown are more common.\textsuperscript{21}
  - After resection of venous malformations and lymphatic malformations, persistent edema and swelling are more frequent. Patients with type C malformations more consistently require multiple operative procedures due to complications.
  - Disseminated intravascular coagulation has been reported, and coagulation studies should be obtained before any intervention.
  - In the study by Mendel and Louis,\textsuperscript{16} 13 of 17 lesions persisted after excision through extension or recurrence. Ten of these lesions were diffuse. Thus, two thirds of lesions that are thought to be localized are diffuse and will require more than one procedure for complete excision.
  - In view of the high recurrence rate, excision should be considered in specific situations. Partial resection might be chosen to provide relief of symptoms, but as a balance between aggressive resection and preservation of function.\textsuperscript{16}
  - Patients who had wide local excision of venous malformations were found to have a 2% recurrence rate.\textsuperscript{14}
- It is generally accepted that primary tumor excision is the treatment of choice in all adults with venous malformations and children who have been observed for 1 year without regression of the lesion.
- Glomus tumors recur in 15% to 24% of patients, with an average time before recurrence of 2.9 years.
- Late presentation of recurrence is thought to be due to a new tumor near the site of excision. Patients who had incomplete excisions had recurrence of the tumor within weeks of surgery.
- In patients who had transungual excisions, nail deformities were noted in 26% of patients postoperatively.
- The prognosis of hemangiendothelioma depends on the grade of the tumor. Patients with low-grade lesions have a good long-term survival rate, and those with aggressive tumors may not survive longer than 2 years.\textsuperscript{11}
- Kaposi sarcoma in elderly non-HIV patients may be cured with wide-local excision; however, the accepted treatment for these patients is chemoradiation and alpha-interferon therapy. The 5-year survival rate of these patients is only 19%. In patients with HIV/AIDS, the mortality rate of Kaposi sarcoma was 80% at 2 years, but this has improved with highly active antiretroviral therapy (HAART).\textsuperscript{17}
- For patients with hemangiosarcoma, early radical amputation is the treatment of choice. Palliative radiation has also been used. The average survival is 2.5 years, and the 5-year survival rate is less than 20%. One third of patients with hemangiosarcoma have hemorrhage or coagulopathy, and 45% have nodal metastases.\textsuperscript{4,17}
- Glomangiosarcomas are believed to be low-grade malignancies; however, more than 25% of reported cases develop metastases.\textsuperscript{12} Wide local excision is the treatment of choice for these lesions, and close long-term follow-up is necessary.

COMPLICATIONS

- High-output cardiac failure
- Consumptive coagulopathy
- Bacterial endocarditis
- Distal ischemia
- Tissue loss
- Local infection
- Compartment syndrome
- Arterial steal
- Hematoma
- Seroma
- Partial wound dehiscence
- Cellulitis at the operative site
- Hypertrophic scarring
- Joint contracture
- Neuromas
- Reflex sympathetic dystrophy
- Pain
- Partial or total extremity gangrene
- Vesicle formation
- Recurrence
- Amputation

REFERENCES

DEFINITION
- Squamous cell carcinoma and melanoma represent malignant transformation of specific cells in either cutaneous or noncutaneous regions of the body.
- Both squamous cell carcinoma and melanoma demonstrate ability to extend locally, involve regional lymph node basins, and metastasize to distant sites.
- In the upper extremity, the nail matrix is the noncutaneous location for these malignancies (FIG 1).
- In 1886, Hutchinson first described subungual melanoma and initially termed it melanotic whitlow, because it often resembled an infection. Subungual melanoma is rare, accounting for only 1% to 3% of all cases of melanoma.
- Critical to management of squamous cell carcinoma and melanoma of the hand and upper extremity are early diagnosis, accurate histopathologic evaluation, detailed staging, appropriate surgical, medical, and radiation management, and appropriate follow-up.

ANATOMY
- Both squamous cell carcinoma and melanoma develop from different skin layers. Intact skin demonstrates histologic features of the epidermis and dermis that act as physiologic barriers to infection and malignancy.
- Squamous cell carcinomas develop from epidermal keratinocyte cell layers but can develop in the nail matrix complex.
- Melanoma cells derive from the dendritic cells of the epidermis; they originate from neural crest cells. These neural crest cell–derived melanocytes migrate to both cutaneous and noncutaneous locations. For the hand and upper extremity, the nail apparatus is a significant migration site. Melanomas are not always pigmented (amelanotic melanomas). However, melanomas are typically pigmented and reflect irregular color, surface, and perimeter.

PATHOGENESIS
- Squamous cell carcinomas develop from epidermal keratinocyte cell layers. Risk factors include the following:
  - Damage from sun, heat, and wind
  - Severe burns and chronic ulcers
  - Increasing age
  - Immune compromise (organ transplantation and AIDS)
- The typical squamous cell carcinoma lesion is a rapidly growing, firm, scaly papule or nodule that develops a central ulcer and an indurated raised border with some surrounding inflammation (FIG 2A–D).
- In contrast to basal cell carcinomas, there is no pearly telangiectatic perimeter.
- Major risks for melanoma include:
  - Personal or family history of melanoma. Patients with a history of melanoma have a 3.5% chance of developing a second melanoma.
  - The presence of a mole that has changed over time
  - Other general risk factors for skin cancer, including sun sensitivity; excessive sun exposure; immune compromise; prior basal cell or squamous cell cancers; or exposure to coal tar, pitch, arsenical compounds, x-radiation, or radium.

FIG 1 • Thumb eponychial lesion treated as both an infection and mucous cyst. Histopathology demonstrated invasive squamous cell carcinoma. Treatment included amputation at the IP joint level and selective lymph node sampling.

NATURAL HISTORY

- In 2007, the American Cancer Society estimated 59,940 new cases of melanoma for both sexes, with an estimated 8110 deaths. Additionally, an estimated 48,290 cases of melanoma in situ were diagnosed.
- The probability of developing melanoma from birth to death is 2.04 (1 in 49) in males and 1.38 (1 in 73) in females. Neither basal cell carcinoma nor squamous cell carcinoma is a reportable disease. Basal cell carcinoma is the most common form of skin cancer and squamous cell carcinoma is the second most common type.
- For 2007, the American Cancer Society estimated more than 1 million new diagnoses of basal and squamous cell carcinomas of the skin. However, basal and squamous cell skin cancers account for less than 0.1% of patient deaths caused by all cancers.
- Nail matrix and nail bed squamous cell carcinoma or melanoma account for less than 1% of respective cutaneous malignancies. The histologic features of the epidermis and dermis, including physiologic barriers, are absent in the nail complex. In the nail complex, the matrix is adherent to the underlying phalanx.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients typically present for evaluation of skin findings or after noting a change.
- Change or variation in an existing lesion and the presence of other risk factors are the important components of patient history.
  - Changes in size, shape, or color of a skin or matrix lesion or the development of a new skin or matrix lesion over a limited time should be monitored.
  - Such changes over a limited time must be diagnosed by histopathology.
- The lesion should be precisely characterized on physical examination. Critical findings include:
  - Irregularity or asymmetry
  - Diameter more than 6 mm
  - Presence of satellite lesions
  - Regional lymph nodes (epitrochlear and axillary) should be routinely examined in all suspected cases of squamous cell carcinoma and melanoma.
- Close regional lymph node examination is required in cases of squamous cell carcinoma arising in sites of chronic ulceration or inflammation, burn scars, or sites of previous radiation therapy, especially for high-risk areas of the hand.
- Melanoma and squamous cell carcinoma can metastasize. A full local, regional, and metastatic workup is necessary.
- Nail matrix and nail bed squamous cell carcinoma or melanoma requires specific consideration during the physical examination.
- The presence of the Hutchinson sign (extension of brown-black pigment from the nail bed, matrix, and nail plate onto the adjacent cuticle and proximal or lateral nail folds) is consistent with a subungual melanoma.
- Subungual melanoma is also suspected when the nail bed contains a new or enlarging pigmented streak wider than 3 mm.
- The absence of periungual pigmentation does not preclude the diagnosis of subungual melanoma.
- Although there have been reports of amelanotic melanoma of the nail bed, the actual incidence is unknown and has never been reported in the literature.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiographic evaluation with plain views can reveal bone involvement, especially for matrix lesions.
- For both squamous cell carcinoma and melanoma, a chest radiograph, complete blood count, and liver panel should be obtained.
- More detailed imaging studies (CT, MRI, and PET) are performed to evaluate specific organ systems (central nervous system, pulmonary, gastrointestinal, and others) as indicated.
- Diagnosis of these pathologies requires adequate histopathologic evaluation. Full-thickness (surface to full depth) perimeter and core samples are required. Suspicious lesions must never be shaved, cauterized, or vaporized.
- If the initial surgical pathologist is uncertain of the histopathology, the specimen slides and appropriate imaging studies must be forwarded to an independent qualified pathologist for review.
- There is significant discordance among pathologists in the histologic diagnosis regarding melanoma and benign pigmented lesions. One study noted discordance in 37 of 140 cases examined by a panel of experienced dermatopathologists.
on melanoma versus benign lesions. Another study noted a 38% discordance rate in cases examined by an expert pathologist panel.

- Squamous cell carcinoma is graded 1 to 4 based on the proportion of differentiating cells present, the degree of atypicality of tumor cells, and the depth of tumor penetration.
- The clinicopathologic cellular malignant melanoma subtypes are (these are descriptive, not prognostic or therapeutic):
  - Superficial spreading: most common, 70%
  - Nodular: 15% to 30%, more aggressive
  - Lentigo maligna: most common subtype among Asians and African-Americans
  - Acral lentiginous (palmar–plantar and subungal)
  - Miscellaneous unusual types:
    - Mucosal lentiginous (oral and genital)
    - Desmoplastic
    - Verrucous
- Malignant melanoma microstage is determined by histopathologic evaluation of the vertical thickness of the lesion in millimeters (Breslow classification) or the anatomic level of local invasion (Clark classification).
- The Breslow thickness is more reproducible and more accurately predicts subsequent behavior of malignant melanoma in lesions thicker than 1.5 mm. Estimates of prognostic should be modified by sex and anatomic site in coordination with clinical and histologic evaluation.
- For cutaneous melanoma, Breslow thickness and presence of ulceration demonstrated the highest concordance. Discordance was significant for Clark level of invasion, presence of regression, and lymphocytic infiltration.
- The Clark classification ranges from level I (in situ lesions involving only the epidermis) to level V (invasion through the reticular dermis into the subcutaneous tissue).
- Micrometastases are diagnosed by elective sentinel lymphadenectomy; macrometastases are defined as clinically detectable lymph node metastases confirmed by therapeutic lymphadenectomy, or when any lymph node metastasis exhibits gross extracapsular extension.
- Clinical staging includes microstaging of the primary melanoma and clinical or radiologic (or both) evaluation for metastases. By convention, AFCC stage should be assigned after complete excision of the primary melanoma with clinical assessment for regional and distant metastases.
- With the exception of clinical stage 0 or stage IA patients (who have a low risk of lymphatic involvement and do not require pathologic evaluation of the lymph nodes), pathologic staging includes microstaging of the primary melanoma and pathologic information about the regional lymph nodes after sentinel node biopsy and, if indicated, complete lymphadenectomy.

**DIFFERENTIAL DIAGNOSIS**

- Seborrheic keratosis
- Pigmented actinic keratosis
- Hemangioma
- Dermatofibroma
- Blue nevus
- Basal cell carcinoma
- Cutaneous T-cell lymphomas (e.g., mycosis fungoides)
- Kaposi sarcoma
- Extramammary Paget disease

- Apocrine carcinoma of the skin
- Metastatic malignancies from various primary sites
- The differential diagnosis of subungal melanoma includes chronic paronychia and onychomycosis, subungal hematoma, pyogenic granuloma, and glomus tumor.

**NONOPERATIVE MANAGEMENT**

**Squamous Cell Carcinoma**

- Electrodessication and curettage, and cryosurgery may be useful for small, well-defined in situ tumors in patients with medical conditions limiting excisional surgery.
- Depth of treatment may not correlate with depth of tumor and therefore may be inadequate.
- Cryosurgery should not be used for carcinomas fixed to the underlying bone, cartilage, or tendons.
- Proximity of nerves limits cryosurgery use, such as in tumors situated on the lateral margins of the digits and at the cubital tunnel.
- Cryosurgery is complicated by significant morbidity, particularly edema, which is common after treatment. Permanent depigmentation and atrophy are common.
- Radiation therapy is a logical treatment choice, particularly for medically compromised patients with primary lesions requiring difficult or extensive surgery.
- Radiation therapy can be used for recurrent lesions after a primary surgical removal.
- Radiation therapy is contraindicated for patients with xeroderma pigmentosum, epidermodysplasia verruciformis, or the basal cell nevus syndrome.
- Topical fluorouracil (5-FU) may be helpful in the management of selected in situ squamous cell carcinomas (Bowen disease).
- Deep follicular tumors may not be reached by topical 5-FU. In these instances, recurrence or progression can occur.
- Close follow-up over time is required.
- Carbon dioxide laser treatment may be useful in a subset of medically compromised patients with small squamous cell carcinoma in situ.
- Since the CO₂ laser coagulates, this technique is valuable for patients with a bleeding diathesis.
- Malignant melanoma can spontaneously regress, but the incidence of spontaneous, complete regressions is less than 1%

**SURGICAL MANAGEMENT**

- The fundamental oncologic principle of tumor clearance first and then reconstruction second should be followed without compromising tumor ablation.
- Lymph node management is directed by clinical involvement or selective lymph node sampling results.
- Wide local excision is recommended for melanomas.

**Cutaneous Squamous Cell Carcinoma**

- The two primary methods of treatment are surgical excision with frozen or permanent histopathologic sections and Mohs micrographic surgery.
- When surgically excising these lesions, the surgeon should maintain a 3- to 10-mm margin of disease-free tissue (depending on the diameter).
- Surgical excision without Mohs technique, using either frozen or permanent histopathologic control, is associated with a significant recurrence rate.
The Mohs technique to microscopically track subclinical tumor extensions results in the highest cure rate with maximal preservation of normal tissue.

**Nail Matrix Squamous Cell Carcinoma**
- For invasive squamous cell carcinoma of the nail matrix (FIG 3), the appropriate technique is amputation at the distal joint level for that digit.
- However, Mohs technique with grafting has been reported in small series of invasive squamous cell carcinoma of the nail matrix with limited follow-up.
- For noninvasive nail matrix squamous cell carcinoma, Mohs technique with grafting is performed.

**Cutaneous Melanoma**
- Melanomas of the hands and feet less than 1.5 mm thick have a low incidence of nodal metastases and are treated effectively with wide excision of the primary tumor with a 1-cm margin.
- Thicker melanomas are associated with a more than 50% rate of regional or systemic failure. In the absence of metastatic disease, these individuals should undergo local excision with a 2-cm margin and intraoperative lymphatic mapping followed by lymphadenectomy if the sentinel node is positive (FIG 4A,B).
- Specific recommendations are individualized for each patient. Factors that affect these recommendations include the primary tumor's anatomic location, specific tumor features, healing ability, and medical risk factors.
- The surgical goal is to minimize local and regional recurrence and metastasis while maintaining acceptable risks to minimize morbidity and mortality.

**Nail Matrix Melanoma**
- Melanomas of the nail complex (FIG 5) are unique because of the lack of the biologic barriers of skin and the proximity of the underlying phalanx and tendons.
- These features cause Breslow thickness and Clark level to be less useful.
- Complete digital or ray amputations of the thumb or fingers result in significant functional deficits without significant survival benefit.
- The respective digit is amputated proximal to the distal interphalangeal joint of the fingers and the interphalangeal joint of the thumb if the extent of nail apparatus involvement allows.
- For more proximal digital melanoma with bone involvement or perineural invasion, either complete digital amputation or ray amputation is indicated for more proximal phalangeal or metacarpal bony involvement respectively or nerve invasion.
- Without bony involvement or perineural invasion, the area of wide local excision is directed by the Breslow thickness.
Specific recommendations are individualized for each patient. Other significant factors, such as the primary tumor anatomic location, specific tumor features, healing ability, and medical risk factors, must be considered. The surgical goal is to minimize local and regional recurrence and metastasis while maintaining acceptable risks to minimize morbidity and mortality.

**Coverage and Reconstruction**
- After wide local excision, most wounds can be closed primarily without tension using minimal perimeter undermining and layered closure.
- If time is required to establish final histopathology, a temporary negative-pressure wound system can be used.
- Coverage and reconstruction must match requirements at the ablation site.
- The coverage options progress from less to more complex: closure, skin graft, local flap, regional flap, then microsurgically transplanted flap.
- Exposed vessels, nerves, tendons, and bone often necessitate flap coverage.
- Surgical flaps benefit poorly vascularized and chronic (more than 3 weeks) wounds.
- Skin grafting can be either split or full thickness depending on the wound bed vascularity, anatomic area, and aesthetics.
- Digital V-Y flaps, cross-finger flaps, flag flaps, dorsal metacarpal artery flaps, and radial forearm flaps are commonly used local and regional flaps.

**Preoperative Planning**
- To direct management of local tumor, regional lymph nodes, and metastatic disease, the patient must be staged for both squamous cell carcinoma and melanoma. The histopathology of the primary tumor is determined by an accurate histopathologic diagnosis.
- Mohs micrographic surgery requires the assistance of a trained dermatologist.
- Before resection, plans must be made for coverage.

**Positioning**
- Positioning is supine with the upper extremity supported on an arm table.
- Positioning should allow approach to the primary tumor and the regional lymph node basin.
- A sterile tourniquet is used. When access to the axillary lymph nodes is required, the tourniquet is removed.

**Approach**
- For wide local excision, the primary lesion is marked and the indicated margin is measured around the lesion using calipers.
- Wide local excision includes the intact tumor or biopsy site en bloc with a defined perimeter of normal skin and underlying subcutaneous tissue. The underlying muscular fascia is not typically included.
- Inadequate, narrow excisions increase the risk of local and regional failure and affect survival.
- For primary closure, an ellipse is marked out incorporating the required margins for wide local excision.
- The excised length-to-lesion-diameter is at least 3:1.
- For amputation, the distal joint level is marked, along with the fish-mouth dorsal and volar flaps.
- For selective lymph node sampling, a grid is marked over the axillary area. The point of highest radioactivity is marked on the grid.

**MOHS MICROGRAPHIC SURGERY**
- Remove all gross tumor.
- Excise a thin layer of tissue with 2- to 3-mm margins. Flatten the specimen with the beveled peripheral skin edge positioned in the same horizontal plane with the deep margin.
- Map the tissue with color-coded three-dimensional orientation.
- Send the specimen for frozen-section processing.
- Both the deep and peripheral margins are examined in one horizontal plane by frozen-section analysis with total (theoretically 100%) margin control.
- After histologic interpretation of the frozen-section specimens, the precise anatomic location of any residual tumor is identified and re-excised until tumor-free three-dimensional margins are obtained.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Chronic or nonhealing skin or matrix lesion</th>
<th>Send tissue biopsy for histopathologic evaluation and culture (bacterial, fungal, and tuberculosis).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient referred for treatment with histopathologic report</td>
<td>Obtain and review original histopathologic slides before treatment.</td>
</tr>
<tr>
<td>Nonpigmented chronic or nonhealing skin or matrix lesion</td>
<td>Remember amelanotic melanoma. Send tissue biopsy for histopathologic evaluation and culture (bacterial, fungal, and tuberculosis).</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE
- Initial postoperative care focuses on pain control and protection of the operated part.
- Occupational therapy is by protocol, depending primarily on the coverage performed.
- Patients must be monitored.
  - Squamous cell carcinoma has metastatic potential. Depending on the relative risk for recurrence and invasion, patients should be re-examined every 3 months for the first several years, then every 6 months for 3 years, and then yearly indefinitely. Evaluation is for local recurrence, lymph node involvement, metastasis, additional nonmelanoma skin cancers, and melanomas. Laboratory evaluation, blood count, and liver enzymes may be useful for monitoring particularly aggressive squamous cell tumors.
  - For melanoma, the follow-up schedule for patients who have surgically resected disease is based on the primary lesion’s Breslow thickness and the nodal involvement. Patients with thin primary melanoma and negative nodes are followed with clinical examination for evidence of occurrence every 6 months for the first 2 to 3 years and then yearly for 2 to 3 years beyond that. Patients with intermediate or thick melanomas and negative regional nodes are followed every 3 to 6 months for the first 2 to 3 years and every 6 to 12 months for the next 2 to 3 years. Patients with resected regional disease require follow-up every 3 to 4 months for the first 2 years, then every 6 months up to year 5, and yearly beyond that. All patients must maintain routine lifelong dermatologic screening. Patients with one melanoma remain at higher-than-average risk for a second primary melanoma and are at risk for basal cell and squamous cell carcinomas.

OUTCOMES
- Squamous cell carcinoma is the second most common type of skin malignancy. Although the basal cell and squamous types of skin cancer are the most common of all malignancies, they account for less than 0.1% of cancer deaths.
- The overall cure rate for squamous cell carcinoma is directly related to the stage of the disease and the type of treatment used. Since squamous cell carcinoma is not a reportable disease, precise 5-year cure rates are not known.
- Melanoma 5-year survival rates are related to stage and range from 18% for stage IV to 99% for stage IA.

COMPLICATIONS
- Sentinel lymph node biopsy is not without complications. The most common complications are hematoma and seroma. The rate of lymphedema after sentinel lymph node biopsy has been reported to be 0.7% to 1.7%, compared with 4.6% (axillary) and 31.5% (inguinal) with completion lymphadenectomy.
- Inadequate margin for squamous cell carcinoma on final pathology is corrected by re-excision using the Mohs technique.
- Inadequate margin for melanoma on final pathology is corrected by appropriate increase or expansion of the surgical margins.
- Excessive tension on wound closure is corrected by skin graft or appropriate flap coverage.

REFERENCES
DEFINITION

Ganglion Cysts

- Ganglion cysts, although not true cysts, are the most common tumors of the hand and wrist.
- These fluid-filled cysts are a frequent cause of hand and wrist pain.
- Ganglion cysts typically arise from either a joint or tendon sheath.
- Most ganglion cysts occur in the wrist. Dorsal wrist ganglion cysts account for 60% to 70% of all ganglion cysts, with volar wrist ganglion cysts accounting for about 18% to 20%.
- Ganglion cysts may also arise from a tendon sheath (volar retinacular cyst), or occur in association with arthritis (degenerative mucous cyst).

Giant Cell Tumors

- Giant cell tumors of the tendon sheath—also referred to as localized nodular synovitis, fibrous xanthoma, and pigmented villonodular synovitis—are benign, slow-growing soft tissue tumors.
- After ganglion cyst cysts, these lesions are the second most common tumor in the hand.

Epidermal Inclusion Cysts

- Epidermal inclusion cysts are well-circumscribed, firm, and slightly mobile lesions.
- They are often superficial and adherent to overlying skin.
- They may be flesh-colored, yellow, or white.
- They contain a thick white keratinous material.
- Cysts in the fingertip may erode into the distal phalanx, causing a lytic lesion.
- Histologically, they are cysts filled with keratin and lined with epithelial cells.

ANATOMY

Ganglion Cysts

- Ganglion cysts typically consist of a cyst sac that communicates through a stalk to an underlying joint or tendon sheath (FIG 1).
- The cyst sac may have a single cavity or be multilobulated.
- Although not a true cyst, lacking an epithelial lining, ganglion cysts are typically filled with a clear, viscous, jelly-like mucinous fluid made up of glucosamine, albumin, globulin, and a high concentration of hyaluronic acid.

Giant Cell Tumors

- The tumor is usually a multilobular, well-circumscribed mass, ranging in size from 0.5 to 7 cm.
- The color ranges from yellow to deep brown depending on the amount of hemosiderin, histiocytes, and collagen present in the lesion.
- These lesions have a thin pseudocapsule. Aggressive lesions may invade adjacent soft tissue, tendon, and capsular structures and can envelop neurovascular bundles. A large study showed joint involvement in one fifth of all cases.
- Longstanding lesions may erode into cortical bone but will not involve cartilage or the medullary canal of bone. Satellite lesions may occur.
- Histologically, giant cell tumors contain collagen-producing polyhedral-shaped histiocytes, scattered multinucleated giant cells, and hemosiderin deposits.

Epidermal Inclusion Cysts

- Epidermal inclusion cysts are well-circumscribed, firm, and slightly mobile lesions.
- They are often superficial and adherent to overlying skin.
- They may be flesh-colored, yellow, or white.
- They contain a thick white keratinous material.
- Cysts in the fingertip may erode into the distal phalanx, causing a lytic lesion.
- Histologically, they are cysts filled with keratin and lined with epithelial cells.
PATHOGENESIS

Ganglion Cysts
- The true causes of ganglion cysts remain unclear, although multiple theories have been proposed.
- Some early investigators theorized that ganglion cysts occurred as the result of synovial herniation, and others felt that ganglion cysts resulted from mucoid degeneration.
- A more recent theory proposes that ganglion cysts arise from stress at the synovial capsular interface. This stress, such as stretching of the capsular and ligamentous structures, stimulates the production of mucin from modified synovial, mesenchymal, and fibroblast cells, all of which have been shown to produce hyaluronic acid. The mucin then dissect through the capsular and ligamentous tissues, forming the main cyst. The fluid may enter the cyst from the capsular ligamentous interface via a one-way valve type of mechanism and then decrease as the water component is resorbed, accounting for the often-fluctuating cyst size.1

Giant Cell Tumors
- The cause of giant cell tumors is not known. There is a strong association of giant cell tumors with rheumatoid arthritis. There are no clinical studies associating these tumors with trauma.6
- Although these tumors are histologically similar to the pigmented villonodular synovitis seen in large joints in the lower extremity, they are thought to be clinically distinct lesions.

Epidermal Inclusion Cysts
- Epidermal inclusion cysts occur as a result of trauma when epithelial cells are introduced into the underlying subcutaneous tissues or bone. These cells slowly grow to produce a cyst lined with epithelial cells and filled with keratin.

NATURAL HISTORY

Ganglion Cysts
- Ganglion cysts typically arise spontaneously and are most common in the second through the fourth decade but may arise in the pediatric population20 as well as the aged.
- Once present, ganglion cysts tend to fluctuate in size depending on the amount of fluid present in the cyst at any given time. Patients often note that the cyst becomes larger after increased periods of activity and decreases in size with inactivity.
- Ganglion cysts tend to be self-limiting and do not typically continue to expand in size.
- If left untreated, ganglion cysts can persist for years. They may resolve or rupture spontaneously. One cannot predict how long that they will persist or if and when they will resolve.
- Resolution is far more common in the pediatric population.

Giant Cell Tumors
- The lesion begins as a single nodule, becoming multinodular as it enlarges.
- Malignant transformation of giant cell tumor of the tendon sheath in the hand has not been reported.8

Epidermal Inclusion Cysts
- These lesions occur months to years after a traumatic event. They grow slowly to produce a painless mass, most commonly seen in the fingertip.
- Malignant transformation of these lesions in the hand has not been reported.12

PATIENT HISTORY AND PHYSICAL FINDINGS

Ganglion Cysts
- Patients often present with an asymptomatic mass that has been present for weeks to years.
- A history of trauma is often absent.
- Pain if present is often described as a dull ache. Nocturnal pain is uncommon and pain is more common with active hand use.
- Paresthesias are rare but can occur if the ganglion cyst compresses any local nerves.
- Patients often report that the mass tends to fluctuate in size, a characteristic typical of ganglion cysts and not typical of other types of soft tissue tumors.
- Patients with wrist ganglion cysts—particularly dorsal wrist cysts—will often complain of weakness of grip.
- Patients with dorsal wrist ganglion cysts most commonly note a mass over the dorsum of the wrist, typically over the dorsal scapholunate region. In contrast, patients with volar wrist ganglion cysts typically note a mass over the volar aspect of the wrist in the interval between the flexor carpi radialis and first extensor compartment tendons.
- Volar retinacular cysts or ganglion cysts of tendon sheath usually present as a mass in the palm in the region of the first and second annular pulleys. The cyst is typically fluctuant but may feel like a firm nodule. The cyst is usually slightly mobile but does not often glide with flexor tendon movement.
- These types of cysts are often painless at rest but become painful when patients perform activities that involve forceful grip.
- Degenerative mucous cysts are ganglion cysts that arise from the distal interphalangeal joint, usually in association with underlying osteoarthritis.4 Patients often note a painless soft tissue mass that arises from the dorsal surface of the joint, radially or ulnarly (less commonly in the midline), often extending into the eponychial fold region.
- Commonly, the cyst will thin the overlying dermis, resulting in rupture of the skin, and the patient often reports drainage.
- Physical examination begins with inspection (FIG 2).
- Being fluid-filled, ganglion cysts will often transilluminate, whereas other more solid soft tissue lesions will not.
- Ganglion cysts usually occur in specific locations in the hand and wrist. Swelling or masses in these locations are diagnostic clues that a ganglion cyst may be present.
- The examiner should palpate the mass for fluctuance and mobility and assess tenderness.
- Ganglion cysts are generally fluctuant and slightly mobile. When they become more distended with fluid they may feel more firm and less fluctuant. Firm, less mobile masses suggest the possibility of other soft tissue lesions.
- Ganglion cysts of tendon sheath do not usually glide with tendon motion, but less common ganglion cysts, such as those that arise in the fourth extensor compartment, are often adherent and do glide with tendon motion.
- The examiner should assess joint mobility through the range of motion. With the exception of dorsal wrist ganglion cysts, which may cause some loss of wrist dorsiflexion secondary to impingement, loss of joint range of motion suggests the possibility of an underlying joint abnormality.
Giant Cell Tumors
- Giant cell tumors are most common in the fourth to sixth decade, with a slight predominance in women.
- Patients typically present with a slow-growing, multinodulated, firm, painless mass present for several months to years.
- Lesions usually occur in the radial three digits of the hand on the volar surface. Dorsal involvement, particularly around the distal interphalangeal joint, is not uncommon.7
- These lesions are typically firmer than ganglion cysts and do not transilluminate.
- Large lesions may limit range of motion or result in neuropathic symptoms as a result of compression of digital nerves.
- Direct palpation typically reveals a firm, multinodular, non-tender lesion.
- Loss of range of motion may occur when large lesions occur near the interphalangeal joints.
- Patients may have sensory deficits secondary to digital nerve compression. These can be revealed by testing two-point discrimination.

Epidermal Inclusion Cysts
- Epidermal inclusion cysts are more common in men than in women and occur in the third to fourth decade.2
- Patients commonly present with a painless, slow-growing mass after a laceration, puncture wound, or traumatic amputation of the finger.2
- These lesions should be suspected in laborers who have a painless mass in the palm.12
- Erythematous and painful lesions have been reported. One study reported two cases mimicking a collar button abscess resulting from rupture of the cyst in the palmar soft tissues.21
- These lesions are typically firmer than ganglion cysts and do not transilluminate.
- Direct palpation will reveal a lesion that is firm, nontender, superficial, and mobile.
- Loss of range of motion may occur when large lesions occur near the interphalangeal joints.

Two-point discrimination testing may reveal sensory deficits secondary to digital nerve compression.

IMAGING AND OTHER DIAGNOSTIC STUDIES
Ganglion Cysts
- Radiographs are obtained if there is clinical suspicion of an underlying bony abnormality noted on physical examination, such as joint crepitation, swelling, carpal instability, or a history of trauma.
- Radiographs are also useful in identifying an intrasosseous ganglion cyst in patients with wrist pain of uncertain cause (FIG 3A).
- Radiographs are also often obtained in patients with a degenerative mucous cyst of the digit since the cysts typically arise as the result of degenerative arthritis of the distal interphalangeal joint.
- If the clinical findings suggest the possibility of an occult ganglion cyst, or if there is suspicion that the patient may have a symptomatic intrasosseous ganglion cyst, magnetic resonance imaging (MRI) can be a useful tool to confirm the diagnosis (FIG 3B).
- MRI can also be used to better localize the site of origin as part of preoperative planning in ganglion cysts that occur in atypical locations (FIG 3C,D).
- Ultrasound can also be used to diagnose ganglion cysts, but this test is examiner-dependent and less sensitive and specific than MRI.
- Computed tomography scans are generally obtained only for preoperative planning to better localize and evaluate the bony architecture of intrasosseous ganglion cysts.

Giant Cell Tumors
- Plain radiographs show a soft tissue mass. Juxtacortical lesions may show bony erosion.
- MRI demonstrates a benign-appearing encapsulated mass, with decreased signal on T1- and T2-weighted images.
Epidermal Inclusion Cysts
- Plain radiographs show a soft tissue mass.
- A lytic lesion may be seen in the distal phalanx if it erodes into bone.

DIFFERENTIAL DIAGNOSIS
Ganglion Cysts
- Epidermoid inclusion cyst
- Giant cell tumor of tendon sheath
- Lipoma
- Synovial cyst

Giant Cell Tumors
- Fibroma of the tendon sheath, synovial chondromatosis, synovial hemangioma, tophaceous gout, foreign body granuloma, periosteal chondroma

Epidermal Inclusion Cysts
- Tophaceous gout, foreign body granuloma, giant cell tumor, ganglion cyst, sebaceous cyst
- Bony destruction may mimic a malignant or infectious process. Some patients with these lesions have been treated with primary amputation before pathologic diagnosis.

NONOPERATIVE MANAGEMENT
- Of the three tumors discussed in this chapter, only ganglion cysts can be managed without surgery.
- Ganglion cysts are benign cysts that may resolve spontaneously. Treatment often depends on the level of a patient’s symptoms. Many patients seek medical care because they are concerned about the presence of a soft tissue mass and possibility of malignancy. Once a diagnosis of a ganglion cyst is made, with proper counseling as to the nature of these lesions, many patients will be satisfied with a course of observation.
- In patients who are symptomatic, typical nonoperative treatments include rest and immobilization, oral analgesics such as nonsteroidal anti-inflammatories and acetaminophen, and aspiration of the cyst with or without injection. In wrist ganglion cysts, the results of aspiration have variable cure rates in the literature, ranging from 15% to 89%. Various agents have been injected into the ganglion cyst after aspiration, including hyaluronidase and methylprednisolone. On average, injection does not seem to increase the cure rate after aspiration, and we now typically perform aspiration alone. We generally inform patients that aspiration has about a 50% cure rate. The use of sclerosing agents is frowned on since these agents may cause articular damage.
- Traditional methods of traumatic rupture of the cyst from a direct blow with an object such as a large book (hence the term “Bible cyst”) are mostly of historical significance.
- Ganglion cysts of tendon sheath (volar retinacular cysts) when symptomatic often respond to aspiration and injection and rarely require surgery when not associated with stenosing tenosynovitis. When they occur in association with stenosing tenosynovitis (trigger finger, De Quervain tendinitis), they often resolve with successful treatment of the underlying tendinitis.
- We typically do not aspirate ganglion cysts of tendon sheath but have had great success by injecting these cysts with local anesthetic and a small amount of corticosteroid (1.5 to 2 mL of 1% lidocaine and 10 mg of Depo-Medrol). The cyst is entered with a 25-gauge needle and then distended...
to the point of rupture. The remaining fluid in the syringe is then injected into the tendon sheath. If necessary, gentle digital massage can be used to rupture the cyst after injection if the cyst fails to rupture with distention.

**SURGICAL MANAGEMENT**

**Indications**

**Ganglion Cysts**
- Surgery is generally indicated in patients who have symptoms and who either have failed nonoperative treatment or choose to proceed directly with surgery.
- In patients who have been diagnosed with a symptomatic wrist ganglion cyst, we generally describe the nature of the condition and outline the available forms of treatment, allowing the patient to decide which treatment is best for him or her. Some patients will choose observation, others will elect to undergo an aspiration, and some will chose to proceed directly with surgical excision.
- In the case of symptomatic ganglion cysts of tendon sheath, most of these will resolve with a corticosteroid injection, and surgery is reserved for cysts that continue to recur.
- Degenerative mucous cysts that are draining or have a history of draining should be treated operatively, since these cysts are at risk for infection that may extend into the distal interphalangeal joint and result in septic arthritis. If not draining, these cysts can be treated nonoperatively or surgically, depending on the patient’s symptoms and choice of treatment.
- Intraosseous ganglion cysts that are symptomatic or have resulted in pathologic fracture or may exhibit an impending pathologic fracture are often treated operatively.

**Giant Cell Tumors**
- Indications for surgery include appearance, neuropathic symptoms, or loss of function.
- Careful, meticulous marginal excision of the lesion is the treatment of choice.
- Care must be taken to protect the neurovascular structures.
- Satellite lesions must be identified and carefully removed to minimize the chance of recurrence.

**Epidermal Inclusion Cysts**
- Indications for surgery include appearance, diagnosis, pain, and loss of function.
- Marginal excision of the lesion is the treatment of choice.

**Preoperative Planning**

**Ganglion Cysts**
- When removing ganglion cysts arising in atypical locations, MRI studies can help to identify the cyst origin and plan appropriate surgical exposure.
- MRI and CT scans, along with plain radiographs, are valuable to determine the ideal exposure and for treating intraosseous ganglion cysts with curettage and bone grafting.
- Plain radiographs are reviewed before excising degenerative mucous cysts to determine the extent of underlying osteophytes that may need to be addressed.

**Giant Cell Tumors**
- While the diagnosis of giant cell tumor is primarily made based on history and clinical examination, radiographic studies should be reviewed to rule out other conditions.
- The patient should be advised that even with careful surgical techniques, the recurrence rate can be as high as 5% to 50%. Risk factors for local recurrence include proximity to the distal interphalangeal joint, degenerative joint disease, and bony erosion.
- Temporary digital nerve neurapraxias may also occur after extrication of these tumors during surgery.

**Epidermal Inclusion Cysts**
- While the diagnosis of epidermal inclusion cyst is primarily made based on history and clinical examination, radiographic studies should be reviewed to rule out other conditions.
- If a lytic lesion is present in the distal phalanx, a biopsy should be considered before surgical removal.
- The recurrence rate after marginal excision is low.

**Positioning**
- Patients undergoing hand or wrist surgery are positioned supine on the operating table with the operative extremity resting on a hand table. This position allows for circumferential access to the hand and wrist.
- The procedure is performed under regional anesthesia with a tourniquet applied to the upper arm, or under a digital block with a tourniquet applied to the digit.
- For arthroscopic procedures, a traction tower or longitudinal fingertrap traction is used (FIG 4).

**Approach**

**Ganglion Cysts**
- Standard approaches to the hand and wrist are used, depending on the location of the cyst.
- It is important to have a good understanding of the anatomy and the most likely origin of the cyst to best plan the incision and dissection to avoid injury to important neurovascular structures.
- When treating ganglion cysts in atypical locations, preoperative studies can aid in determining the best surgical
approach, since the origin of the cyst can be remote from the cyst (Fig 3D).

- Volar giant cell tumors and epidermal inclusion cysts are approached through Brunner zigzag incisions (FIG 5A).
- Dorsal giant cell tumors require dorsal midline or curvilinear incisions, whereas dorsal epidermal inclusion cysts can be approached through small longitudinal incisions directly over the lesion (FIG 5B).
- Incisions should be designed for a possible extensile exposure, which may be necessary for complete excision of the lesion.

**OPEN EXCISION OF A DORSAL WRIST GANGLION CYST**

- The location of the cyst is typically dorsal to the scapholunate interosseous ligament. The incision needs to provide access to this ligament. The scapholunate ligament is found just distal to the tubercle of Lister in the third and fourth extensor compartment interval (TECH FIG 1A).
- We generally perform a transverse skin incision centered over the scapholunate ligament region and cyst. This incision heals with the best appearance (TECH FIG 1B).
- Dissect the subcutaneous tissues with blunt dissection, taking care to protect and preserve any branches of the dorsal radial and ulnar sensory nerves. Loupe magnification is often helpful.
- The extensor retinaculum is generally not well developed at this level and is incised transversely as the cyst is dissected from the surrounding soft tissues (TECH FIG 1C).
- The cyst is identified typically in the interval between the third and fourth extensor compartments. Retract the second and third extensor compartment tendons radially and the fourth extensor compartment tendons ulnarly (TECH FIG 1D).
- The dorsal wrist capsule is also incised transversely as the cyst is traced to a stalk, which usually arises from the dorsal aspect of the scapholunate interosseous membrane, just proximal to the dorsal scapholunate ligament (TECH FIG 1E).
- Excise the cyst at the base of the stalk and send it for pathologic examination (TECH FIG 1F).
- Although excision of a small window of tissue at the site of cyst origin has been previously recommended, we have concern that overzealous excision may lead to injury to the scapholunate ligamentous complex. We
recommend the use of a bipolar cautery to precisely cauterize the site of origin (TECH FIG 1G).
- After excision of the cyst, inspect the joint for any abnormalities.
- Allow the capsular tissues and tendons to return to their anatomic position. Avoid capsular closure, as this may lead to joint stiffness.
- Skin closure is usually accomplished with a running subcuticular nonabsorbable monofilament suture (TECH FIG 1H).

We prefer to dress the wound with an antibiotic ointment and petroleum gauze, and a bulky hand dressing is applied with a plaster palmar splint maintaining the wrist in a neutral position.
- The dressing is removed along with the sutures at about 1 week postoperatively and Steri-Strips are applied to the wound.

**OPEN EXCISION OF A VOLAR WRIST GANGLION CYST**

- Volar wrist ganglion cysts most often arise from the volar radiocarpal ligaments. They may also arise from the scaphotrapezial joint or at times from the flexor carpi radialis (FCR) sheath. The cysts are typically located in the interval between the FCR sheath and first extensor compartment tendons, just proximal to the wrist flexion crease.
- Under tourniquet control, we prefer to use a zigzag type of incision that begins at the wrist flexion crease and extends proximally over the cyst in the FCR and first extensor compartment interval. This incision provides access in both the longitudinal and transverse planes. A longitudinal incision may heal with scar contracture, whereas a transverse incision may not provide adequate exposure in the longitudinal plane (TECH FIG 2A).
- Under loupe magnification, the subcutaneous tissues are carefully dissected and branches of the lateral antebrachial cutaneous nerve and dorsal radial sensory nerve are carefully protected. If dissection ulnar to the FCR tendon is required, the palmar cutaneous branch of the median nerve must also be identified and protected.
- Ganglion cysts in this location are commonly adherent to the radial artery and its venae comitantes (TECH FIG 2B). Take care to avoid injury to the artery. If the cyst cannot be freely dissected from the artery, a small cuff of cyst wall can be left adherent to the artery without a significant increase in recurrence.
- The cyst is traced to a stalk that most often arises from the volar radial carpal ligaments (TECH FIG 2C). The cyst
is excised at the base of the stalk. We routinely send the cyst for pathologic evaluation.

- As with dorsal ganglion cysts, we cauterize the site of origin of the cyst with a bipolar electrocautery.
- After excision of the cyst, the tourniquet is deflated to ensure that the radial artery is uninjured. Satisfactory hemostasis is achieved.
- We generally close the wound with a running subcuticular suture, removed about 7 to 10 days after surgery.

- We prefer to dress the wound with antibiotic ointment and petroleum gauze, and a bulky hand dressing is applied with a plaster palmar splint maintaining the wrist in a neutral position.
- The dressing is removed along with the sutures at about 1 week postoperatively and Steri-Strips are applied to the wound.

**OPEN CURETTAGE AND BONE GRAFTING OF AN INTRAOSSEOUS GANGLION CYST**

- The patient is positioned supine on the operating table with the operative hand resting on a hand table.
- Symptomatic intraosseous ganglion cysts most often involve the carpal bones. Surgical incisions are planned according to the preoperative studies (MRI and CT scans) to identify the best location for creating a cortical window and avoiding injury to cartilaginous surfaces.
- Under tourniquet control, make an appropriate incision and carry dissection to the level of the wrist capsule. Loupe magnification is often helpful during the dissection. Enter the wrist capsule, preserving important capsular ligaments.
- The bony cortex is generally weakened in the area of the cyst and access is easily accomplished with a handheld curette. If the cortex is not weak, a small cortical window can be created using 0.045-inch Kirschner wires to create small drill holes to create a cortical window.
- Curette the cyst cavity along with any mucinous material. Remove the cyst membrane.
- Pack the cyst cavity with bone graft or a bone graft substitute.
- Wound closure is accomplished in the usual manner.
- We usually immobilize the patient in a plaster splint for 1 week and then a cast for 3 to 5 weeks, depending on the cyst size and bone integrity.
- Obtain postoperative radiographs to monitor and ensure incorporation of the bone graft.

**EXCISION OF A DEGENERATIVE MUCOUS CYST**

- Mucous cysts can be excised under local digital block anesthesia.
- The hand is prepared in the standard fashion.
- A finger tourniquet is applied to the involved digit.
- We usually use a Brunner type of incision or a simple transverse incision incorporating the cyst and allowing access to the origin of the cyst, which arises from the distal interphalangeal joint capsule between the terminal extensor tendon and collateral ligament (TECH FIG 3A).
- During the dissection, take care to avoid injury to the germinal matrix of the nail bed (TECH FIG 3B).
- Excise the cyst at the base of its stalk along with a portion of the joint capsule (TECH FIG 3C).
- Excising underlying osteophytes and hypertrophic synovial tissue is the key to preventing recurrence of the cyst (TECH FIG 3D).
- The wound is irrigated, the tourniquet is removed, and hemostasis is achieved with bipolar cautery.
- Wound closure is accomplished with nonabsorbable monofilament sutures.
- I dress the wound with antibiotic ointment, petroleum gauze, gauze fluff, and tube gauze dressing.
- The patient is instructed to remove the dressing in 3 to 5 days and then cleanse the wound daily with antibacterial soap and water.
- Sutures are removed at 7 to 10 days.

**TECH FIG 3** • A. Degenerative mucous cyst in the eponychial region resulting in nail plate deformity. B. Aggressive dissection is avoided distally to protect the nail germinal matrix. The cyst is traced proximally to its origin at the distal interphalangeal joint. C. The cyst is excised along with a portion of the joint capsule at its point of origin between the central tendon and collateral ligament. D. A rongeur is used to débride underlying osteophytes.
EXCISION OF A GANGLION CYST OF TENDON SHEATH (VOLAR RETINACULAR CYST)

- The patient is supine on the operating table with the involved upper extremity resting on a hand table.
- Anesthesia is usually accomplished with local anesthetic.
- Under tourniquet control (well tolerated by most awake patients for the 10 to 15 minutes required), a skin incision is made over the suspected ganglion cyst.
- Loupe magnification aids in limiting the size of the incision and identifying important anatomic structures. Retract the soft tissues and the digital neurovascular bundles.
- The ganglion cyst is commonly identified arising from the first or second annular pulley region.
- Dissect the ganglion cyst from the surrounding soft tissues and excise it at its base. We usually cauterize the site of origin with the bipolar cautery, which lowers the chance of a recurrence.
- The tourniquet is released, hemostasis is achieved, and wound closure is performed.
- A light hand dressing is applied for 7 to 10 days.

ARTHROSCOPIC EXCISION OF A DORSAL WRIST GANGLION CYST

- The patient is positioned supine on the operating room table with the operative upper extremity positioned in an arthroscopic traction tower (TECH FIG 4).
- Identify the standard wrist arthroscopic and anatomic landmarks.
- The 3–4, 4–5, 6R, and 6U portals are typically used.
- Under tourniquet control, insert a 2.7-mm small joint arthrooscope into the 3–4 or 4–5 portal sites to inspect the joint and identify the ganglion stalk. The stalk in the typical dorsal wrist ganglion cysts is found arising from the dorsal distal margin of the scapholunate intraligamentous membrane just proximal to the dorsal scapholunate intraligamentous ligament. The stalk is not always identifiable or visualized.17
- Introduce a 2.9-mm resector shaver into the joint and excise the stalk (when visible) along with a 1-cm portion of dorsal wrist capsule and ganglion cyst.
- Use extreme caution when resecting the ganglion stalk and capsule to avoid injury to the scapholunate ligament and intraligamentous membrane as well as the overlying extensor carpi radialis brevis and extensor digitorum communis tendons.
- Midcarpal arthroscopy is performed if indicated, but routine inspection is not necessary when treating a dorsal wrist ganglion cyst.
- The portal sites are typically closed with a removable monofilament suture.
- A light hand dressing is applied with a plaster palmar splint, which is left in place for about 5 to 7 days.

EXCISION OF A GIANT CELL TUMOR OF THE TENDON SHEATH

- The standard treatment is complete surgical removal.
- Careful surgical dissection is performed under loupe magnification (TECH FIG 5A).
- After initial exposure, isolate the neurovascular bundle proximal and distal to the lesion (TECH FIG 5B).
- Once the pseudocapsule is identified, it can be bluntly dissected or teased away from underlying structures with a Freer elevator, with care taken not to seed the surrounding tissues.6 Alternatively, a small portion of the tendon sheath may be excised with the tumor origin and the area cauterized with bipolar electrocautery12 (TECH FIG 5C,D).
- Carefully examine the local tissues for satellite lesions, which may be only a few millimeters in size. These lesions need to be completely excised (TECH FIG 5E).
- If the extensor tendon is involved, surgical excision of a portion of the tendon may be required. In rare cases, tendon reconstruction may be necessary. Lesions eroding into bone may require local curettage.
- If the tumor appears to arise from an underlying joint, it is important to perform a capsulotomy to inspect the joint and débride any pigmented tissue.11
- Arthrodesis of the distal interphalangeal joint may be necessary to completely excise some lesions.
TECHNIQUES

TECH FIG 5 • A. Careful surgical dissection of the subcutaneous tissues through a Brunner incision. B. The digital nerve is identified distal to the lesion and protected throughout the procedure. C. The tumor should be carefully removed from surrounding soft tissues. D. Excision demonstrates a firm multinodular lesion. E. Any satellite lesions should be carefully identified and removed.

MARGINAL EXCISION OF AN EPIDERMAL INCLUSION CYST

- Careful surgical dissection is undertaken under loupe magnification.
- After initial exposure, isolate the neurovascular bundles in the area of the lesion.
- Once the capsule is identified, it can be sharply dissected from overlying skin and bluntly dissected from deeper soft tissues (TECH FIG 6).
- Take care to remove the entire capsule.
- Lesions eroding into bone may require local curettage and bone graft.
- In rare cases with advanced bony destruction, amputation is an alternative.

TECH FIG 6 • A. Through a small longitudinal incision directly over the lesion, the cyst is bluntly excised from surrounding soft tissues. B. Excision of the lesion demonstrates a firm, white, encapsulated mass.

PEARLS AND PITFALLS

Dorsal ganglion cysts
- The scapholunate ligament is just distal to the tubercle of Lister. Dorsal ganglion cysts almost always arise from the distal margin of the dorsal scapholunate intraosseous membrane, just proximal to the dorsal scapholunate ligament.
- Excise the cyst at the base of the stalk, which is the site of origin.
- Cauterize the site of origin with a bipolar cautery to decrease the chances of recurrence.
- Take care to avoid injury to the dorsal scapholunate ligament.
- If the ganglion cyst recedes in size before surgery, dissect to identify the scapholunate ligament, which will often reveal the cyst.
## POSTOPERATIVE CARE

### Ganglion Cysts of the Wrist
- The splint and sutures are removed about 1 week postoperatively and Steri-Strips applied to the wound.
- Range-of-motion exercises and light use of the hand are initiated at 1 week, with gradual advancement of activities as tolerated.
- Scar massage is encouraged at 2 weeks.

### Ganglion Cyst of Tendon Sheath and Degenerative Mucous Cyst
- Patients are instructed to remove their postoperative dressing 4 to 5 days after surgery. We prefer to have the patients clean their wound at least twice daily with antibacterial soap and water. The wound is redressed with light gauze or an adhesive bandage.
- Sutures are generally removed at 1 week and Steri-Strips applied to the wound.
- Range-of-motion exercises and light use of the hand are initiated, with gradual advancement of activities as tolerated.
- Scar massage is encouraged at 2 weeks.

### Intraosseous Ganglion Cysts
- Postoperative dressing and sutures are removed at 1 week and Steri-Strips applied to the wound.
- We generally apply a short-arm cast for 3 to 5 weeks. The cast is removed and range-of-motion exercises and light hand use are initiated.
- Incorporation of the bone graft is monitored with use of serial radiographs. If the intraosseous ganglion cyst has weakened the bone, a protective splint may be used once the cast is removed until incorporation of the bone graft.

### Giant Cell Tumors and Epidermal Inclusion Cysts
- Patients should be instructed about the high rate of recurrence of giant cell tumors.
- Range-of-motion exercises and antiedema techniques should be started immediately after surgery.
- Sutures can be removed at 8 to 10 days.

## OUTCOMES

### Ganglion Cysts
- Symptomatic relief is often accomplished after excision of most ganglion cysts.
- Recurrence rates after ganglion cyst surgery have been reported to range from 4% to 40%. With adherence to the above principles, however, the recurrence rate in our experience is less than 5%.
- Complications of ganglion cyst removal are infrequent.
- The recurrence rate of giant cell tumors has varied from 5% to 50%. The high rate of recurrence is due to incomplete excision or satellite lesions.  
- Recurrence rates are even higher after excision of a recurrent tumor.
- In contrast, the recurrence rate after epidermal inclusion cyst excision, even with bony involvement, is low.

## COMPLICATIONS
- Wound complications (e.g., painful or unsightly scar), infection, digital neurapraxia, or recurrence can occur.
- Ganglion cyst excision can result in a neurovascular injury. This complication is rare with adherence to good surgical technique and a good understanding of the local anatomy. Volar wrist ganglion cysts are adherent to the radial artery and can be difficult to dissect free from the artery. If necessary, a cuff of the cyst is left attached to the artery. If injury to the artery does occur, a repair should be performed.
- Stiffness is a complication of ganglion cyst excision. Avoiding direct capsular closure reduces the risk of this complication.
- Complications associated with degenerative mucous cysts include extensor lag, joint stiffness, infection, nail plate deformity, and distal interphalangeal joint deformity.

## REFERENCES
DEFINITION
- Nerve tumors make up less than 5% of tumors about the hand and wrist.11
- Most nerve tumors are benign and grow without causing neural dysfunction. As a result, the neural origin of a mass is often not anticipated and unexpected loss of function may occur after surgery.
- The key is to prepare for excision of any mass by discussing the possibility of a nerve tumor with the patient, by recognizing patients and masses with a high likelihood of a nerve tumor, and by being familiar with surgical techniques that allow preservation or, if necessary, reconstruction of the affected nerve.

ANATOMY
- Peripheral nerves consists of axons surrounded by a nerve sheath (FIG 1).
- The epineurium is a thin outer layer of connective tissue containing blood vessels that supply the nerve.
- Perineural cells form a strong cellular layer, the perineurium, surrounding each fascicle (bundle) of axons.
- An endoneurial layer of protective Schwann cells surrounds each individual axon.

PATHOGENESIS
- Tumors of the peripheral nerve arise from and resemble components of the nerve sheath.
- Most nerve tumors arise from the Schwann cell and are informally called schwannomas (or neurilemomas) and neurofibromas, depending on the pattern of growth and histology.
- Other benign peripheral nerve sheath tumors (BPNSTs) include the granular cell tumor, neurothekeoma, nerve sheath myxoma, and perineurioma. Electron microscopy and immunohistochemistry may be necessary to determine the type of tumor and cell of origin in some cases.³
- Malignant peripheral nerve sheath tumors (MPNSTs) arise de novo or from malignant change within a BPNST.
- About half of MPNSTs occur in patients with neurofibromatosis (NF) type I (von Recklinghausen disease).
- The incidence of a MPNST in patients with NF type I is 2%,7 although the lifetime risk rises to 13%.²

NATURAL HISTORY
- Upper extremity BPNSTs are usually solitary, and most occur in middle-aged adults.⁴,⁶
- Pediatric nerve tumors are uncommon.¹
- BPNSTs are typically painless and slow-growing, with malignant degeneration being exceedingly rare. Most tumors are relatively small (less than 2.5 cm), although they may cause nerve dysfunction due to focal impingement on the adjacent axons.
- Patients with NF type I often have multiple schwannomas, neurofibromas, or both of major upper extremity nerves. Thick tortuous “plexiform” neurofibromas are common in NF type I and have a high risk of progression to malignancy.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The history should include the duration, growth characteristics, and local effects of the mass. Mild discomfort is common with nerve tumors but paresthesias are the exception rather than the rule. Hence, the possibility of a nerve tumor must often be entertained for the sake of completeness alone. Similarly, physical examination may suggest but cannot definitively diagnose a nerve tumor.
- A complete examination of a distal upper extremity soft tissue mass should evaluate other nonneural possibilities within the differential diagnosis.
- Ganglia: Arise from joint and tendon sheaths in characteristic locations. The mass will typically transilluminate and the diagnosis can be confirmed by aspiration of highly viscous mucinoid material. Ganglia may mimic nerve tumors by causing compression of an adjacent nerve (eg, a ganglion in the canal of Guyon may cause ulnar neuropathy) (FIG 2).
- Giant cell tumors (GCTs) of the tendon sheath: Reactive lesions of synovium that occur about the palm and fingers in similar locations to nerve tumors. GCTs are often palpably nodular, compared to the smooth margins of a nerve tumor.
- Lipomas: These fatty tumors are usually more superficial and mobile than a nerve tumor. Rarely, lipomas grow in the carpal canal, causing median neuropathy.
- Epidermal inclusion cysts: Should be suspected when examination reveals evidence of prior penetrating trauma. Unlike neurites, these cysts do not cause nerve symptoms and a Tinel sign is not present.
- Nodular fasciitis: A firm, reactive soft tissue proliferation that may grow rapidly on the volar surface of the forearm.
or hand. The location may suggest a nerve tumor and the aggressive spread mimics sarcoma. While most nerve tumors are mobile in the transverse plane, palpation of nodular fasciitis reveals dense adhesions to the adjacent subcutaneous tissue.

- Patients with NF type I may have multiple nerve tumors, along with features such as café-au-lait spots, freckling in the axilla or groin, optic pathway tumors, iris hamartomas, and bone dysplasias. In patients with NF type 1, rapid growth of a neurofibroma, severe pain, and a new neurologic deficit often herald malignant degeneration.

- Examination techniques include the following:
  - Palpation: The examiner moves the mass transversely and longitudinally. Nerve tumors may be translated transversely but are tethered in the longitudinal plane.
  - Sensory testing using Semmes-Weinstein monofilament. Early nerve compression increases threshold while innervation density (two-point) remains normal. In a busy clinical practice, light moving touch may be as reliable (Stauch).
  - The examiner assesses visible atrophy and weakness in motor units innervated by the affected nerve. Manual strength testing is usually normal.
  - Direct pressure is applied over the nerve just proximal to the mass. Nerves under compression by a mass are sometimes sensitive to touch and may produce paresthesias when manipulated.
  - The nerve is percussed immediately adjacent to the mass. A positive result is paresthesias in the cutaneous distribution of the nerve. The Tinel sign is positive only when an injured nerve is attempting to regenerate. Most nerve tumors do not have a positive Tinel sign.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs should be obtained to look for intraleisonal calcification or invasion of adjacent bony architecture.
- Intraleisonal calcification is rarely seen in BPNST and should alert the surgeon to the more likely possibility of a lipoma, hemangioma, giant cell tumor of tendon sheath, synovial chondromatosis, calcific tendonitis, myositis ossificans, or synovial sarcoma.
- A malignant nerve tumor may invade nearby osseous structures.
- An MRI is useful for evaluating tumor characteristics, delineating the surrounding anatomy, and planning a surgical approach.
- Localization of the tumor to the vicinity of a large nerve trunk suggests a peripheral nerve tumor (**FIG 3A**).
- MRI may also occasionally demonstrate subtle muscle atrophy of the distally innervated musculature. Tumor margins are smooth and there is mild intraleisonal inhomogeneity.
- Nerve tumors have intermediate signal intensity on T1-weighted images secondary to intermingled adipose tissue (**FIG 3B**).
- BPNSTs are bright on T2-weighted images.\(^1\) These MRI features are similar to those of other soft tissue neoplasms and are not diagnostic.\(^5\)
- Irregular margins may be seen with plexiform neurofibromas or malignant tumors.
- Other characteristics of a malignant neoplasm include size more than 5 cm, invasion into adjacent tissues, and tumor necrosis.
- Electrodiagnostic studies are most useful in the rare case of a clinically significant preoperative nerve deficit. Slowing of the nerve conduction velocity at the site of the tumor manifests as increases in the distal motor and sensory latencies, while electromyography will detect subtle muscle denervation.

**DIFFERENTIAL DIAGNOSIS**

- Neuroma
- Lipofibromatous hamartoma (fibrofatty infiltration)
- Nerve sheath ganglion
- Intraneural tumors of nonneural origin
  - Intraneural lipoma
  - Intraneural hemangioma

**NONOPERATIVE MANAGEMENT**

- In the absence of rapid growth, pain, or nerve dysfunction it is reasonable to observe a distal upper extremity mass. An MRI may be obtained to identify features consistent with a BPNST and to exclude signs of malignancy (see above).
Patients with NF type I often have multiple neurofibromas, including dermal and plexiform types.

- Dermal neurofibromas grow through the dermis and subcutaneous tissue to form plaque-like swellings. While sometimes unsightly, these tumors are routinely observed as the surgical defects are no more cosmetically pleasing.
- Plexiform neurofibromas are visible as nodular masses lying longitudinally along the course of peripheral nerves. These tumors must be carefully followed as progression to a MPNST (neurofibrosarcoma) is common.
- Pain is the most predictive symptom of malignant change. If there is no concern for malignancy, surgical excision is generally avoided as it frequently results in nerve deficits postoperatively.
- Children and young adults may develop masses of fibrofatty tissue infiltrating major nerves and their branches, particularly the median nerve.
- These lipofibromatous hamartomas cause slow progressive nodular swelling and, at times, distal soft tissue overgrowth (macrodactyly).

- When asymptomatic, nonoperative management may be preferred, particularly if MRI shows pathognomonic features of this lesion.13
- Carpal tunnel symptoms may be treated with limited surgery, including an open carpal tunnel release and a definitive biopsy of a small cutaneous branch of the nerve.

**SURGICAL MANAGEMENT**

- An isolated distal upper extremity mass is treated surgically for definitive diagnosis, to control symptoms, or to exclude malignancy.

**Preoperative Planning**

- MRI is reviewed to confirm characteristics of a BPNST and to plan a surgical approach.
- Nerve reconstruction options are discussed with the patient.
- We consider synthetic absorbable nerve conduits for defects of up to 2 cm, particularly in the palm.
- We avoid conduits when there is any concern of extrusion (eg, about joints in the digits) or in superficial sites where foreign body reaction may be confused with a tumor recurrence.
- The medial antebrachial cutaneous nerve (MABC) is a suitable graft for the common and proper digital nerves.
- A sural nerve cable graft may be necessary for major peripheral nerve defects.
- If significant nerve dysfunction is present before surgery (or is expected afterward), consideration should be given to performing concomitant tendon transfers, particularly in adults.

**Positioning**

- The patient is positioned supine with the affected extremity placed on a hand table. A brachial tourniquet is applied proximally, allowing access to the medial elbow for MABC nerve harvest if necessary.
- If sural nerve harvest is considered a possibility, we place a proximal thigh tourniquet and prepare and drape the contralateral lower extremity so that a second team may operate unencumbered.

**Approach**

- The surgical approach varies with tumor location.
  - A midlateral approach to digital nerve lesions allows excellent visualization of the tumor, protection of the adjacent digital artery, and good soft tissue coverage of the adjacent flexor tendon sheath.
  - Lesions in the palm are approached with a Brunner zigzag type of skin incision, which provides excellent visualization and minimizes restrictive postoperative longitudinal scar formation.
  - An open carpal tunnel approach is included for tumors close to the median nerve to decrease nerve compression from postoperative edema.
- Any suspected malignancy is managed according to the principles described in the oncology section of this text: a biopsy incision must allow optimal definitive resection options later. For example, a biopsy of a possible neurofibrosarcoma of the radial sensory nerve should be made through the mobile wad compartment as opposed to the more familiar Henry approach to this region.
ENUCLEATION

- Most isolated BPNSTs are schwannomas and arise eccentrically from the nerve sheath (TECH FIG 1A). The tumor is encapsulated and can be safely enucleated without removing nerve fascicles.
- The nerve is exposed and fascicles are seen to drape over the mass, sometimes with a pedicled or multilobulated appearance. Inspect the nerve circumferentially for the window of splayed fascicles that affords the best resection plane (TECH FIG 1B).
- Incise the nerve sheath longitudinally, preserving the vessels running in the epineurium. Expand the window by carefully peeling away the fascicles and, ultimately, delivering the tumor out of the nerve (TECH FIG 1C).
- The resected specimen contains no nerve fascicles (TECH FIG 1D).

NERVE REPAIRS, GRAFTS, AND CONDUITS

- Surgical exploration of a nerve tumor may reveal a centrally placed expansile lesion with characteristic incorporation of nerve fascicles within the mass—the neurofibroma (TECH FIG 2A). While poorly encapsulated within the nerve, these tumors are typically free of adhesions to the adjacent soft tissues. Complete excision may require resection of the involved section of the nerve.
- The neurofibroma is exposed similar to the schwannoma. In this case, fusiform expansion of the posterior interosseous nerve is identified. Fascicles are seen entering the lesion at its proximal and distal extent, confirming the diagnosis of a neurofibroma (TECH FIG 2B).
- A microscope may allow identification of a prominent fascicular group that can be microdissected from the adjacent normal fascicles. If no prominent fascicular group or groups can be identified, then tumor resection will require nerve transection through normal fascicles at each end of the mass.
- Direct reapproximation of the nerve ends is optimal but should be done only with minimal joint flexion and tension. Direct repairs done with significant joint flexion or high tension have poor results.
- The MABC is harvested if an autologous nerve graft is required (TECH FIG 2C). The nerve exits the brachial fascia adjacent to the basilic vein at the junction of the middle and distal third of the forearm.
- The length of the nerve may be harvested for a nerve cable graft if a major peripheral nerve has been sacrificed.
- The small anterior branch of the MABC may be harvested an inch anterior and distal to the medial epicondyle. The anterior branch is generally a good size match for a digital nerve, as seen in this case of a nerve tumor with iatrogenic soft tissue loss (TECH FIG 2D).
- Alternatively, a nerve tube may be used to bridge an intercalary nerve defect (TECH FIG 2E).
- A digital neurofibroma can be resected and the defect bridged with a nerve tube (TECH FIG 2F). Studies suggest that nerve conduits are best suited for defects of 2 cm or less.
Digital nerve schwannomas may sometimes require microdissection to preserve axons. The nerve is isolated under loupe magnification. The operating microscope facilitates identification of normal nerve fibers proximally. These axon bundles are traced distally and carefully dissected free of the mass. Occasionally, microdissection will allow the surgeon to identify and preserve normal fascicles from a neurofibroma of a large peripheral nerve.
LIPOFIBROMATOUS HAMARTOMA: LIMITED RESECTION AND SURAL NERVE GRAFTING

- A lipofibromatous hamartoma of the median nerve is most apparent about the proximal and distal extent of the transverse carpal ligament (TECH FIG 3A). The contained space of the carpal canal limits outward expansion of the hamartoma causing compression of nerve fascicles. Open carpal tunnel release may improve pain and nerve dysfunction. However, a mass that continues to grow, causing pain and nerve dysfunction, may need to be resected. Nerve grafts should be considered, especially in young patients. Management in adults is controversial.

- Sagittal-plane MRI images will show the extent of the lesion (TECH FIG 3B).
- Surgical exposure begins with an open carpal tunnel release to identify the transition zone between normal and abnormal nerve. The incision is carried distally in a Brunner zigzag type of fashion to find the end of the lesion (TECH FIG 3C).
- The hamartoma is excised en bloc at healthy-appearing fascicular margins (TECH FIG 3D).
- A sural nerve is harvested and interposed as a cable graft (TECH FIG 3E).
### PEARLS AND PITFALLS

| Diagnosis | A nerve tumor must be part of the differential diagnosis for any distal upper extremity mass.  
| Nonsurgical management | Watch for signs of malignancy, including increasing nerve dysfunction, rapid growth, and pain.  
| Surgical approach | Masses should be resected through an extensile approach; avoid transverse incisions.  
| Tumor resection | A microscope should be available should microdissection or nerve resection and reconstruction become necessary (neurofibroma).  

### POSTOPERATIVE CARE

- At a minimum, short arcs of joint motion are initiated early to discourage adhesion formation between the cutaneous scar and the underlying nerve.
- If necessary, the end range of motion may be avoided for up to 1 month to protect nerve repairs or reconstructions.
- When axons have been injured, a hand therapist may assist with desensitization or sensory re-education.
- A Tinel sign may be followed for reinnervation along the course of the affected nerve.
- Late changes in nerve function or swelling suggest the possibility of recurrence.

### OUTCOMES

- Transient paresthesias are common after enucleation of a schwannoma; however, long-term nerve function is generally the same as or improved compared to the preoperative state. Tumor recurrence is rare.
- Permanent neurologic deficits follow en bloc resection of a neurofibroma, thus limiting the surgical indications for this procedure. Microdissection preserves nerve function but likely has an increased risk of recurrence.
- Resection of a lipofibromatous hamartoma of the median nerve (including partial excision or interfascicular dissection) often results in permanent nerve deficits. There is limited long-term follow-up for nerve grafting of these lesions.

### COMPLICATIONS

- Loss of nerve function after tumor resection
- Loss of motion due to prolonged immobilization
- Neuroma formation at a nerve donor site (eg, MABC neuroma)
- Wound breakdown over a nerve conduit, especially in the digits

### REFERENCES

DEFINITION

- Enchondromas are benign cartilaginous neoplasms that are commonly seen in the medullary cavity of phalanges and metacarpals and less commonly the radius and ulna. Enchondroma is the most common neoplasm of bone arising in the hand.
- Unicameral bone cysts are benign endothelial-lined fluid-filled cavities arising in metaphyseal bone; they are occasionally seen in the distal radius and rarely seen in the hand.
- Giant cell tumor of bone is an uncommon benign neoplasm of bone, which is locally aggressive and can metastasize. While its histology suggests a benign process, behaves as a low-grade malignancy.

ANATOMY

- Enchondroma most commonly arises in the proximal phalanx or metacarpal when seen in the hand (FIG 1A). It can be seen in metaphyseal and epiphyseal regions and is typically confined to the bone. The enchondroma may distend the bone and pathologic fracture may be seen.
- Unicameral bone cysts are rarely seen in the hand. When presenting in the radius they are often metaphyseal and may be in continuity with the distal radial physis (FIG 1B). Unicameral bone cysts are typically confined to bone and pathologic fracture may be seen.
- Giant cell tumor of bone most commonly arises in the epiphyseal region except in the skeletally immature patient, in whom it may arise in the metaphysis. The distal radius is the third most frequent location for these tumors (FIG 1C), after the distal femur and the proximal tibia. Hand lesions account for 2% of giant cell tumors of bone.

PATHOGENESIS

- The pathogenesis of enchondroma, unicameral bone cyst, and giant cell tumor of bone is uncertain. Enchondroma and unicameral bone cysts may be associated with bone development and growth.
- Enchondroma, unicameral bone cyst, and giant cell tumor of bone can weaken the bone and predispose the patient to pathologic fracture.

NATURAL HISTORY

- Enchondromas are most commonly identified incidentally during unrelated evaluation. They also can present after pathologic fracture. On occasion, a patient may complain of painful swelling in the bone.
- Enchondromas found incidentally and not causing considerable mechanical weakness may be observed if typical radiographic findings are seen.
- Enchondromas causing substantial fracture risk and those presenting after pathologic fracture can be treated surgically with a low risk of recurrence.
- Enchondroma can extremely rarely transform to chondrosarcoma.
- Unicameral bone cysts are most commonly seen during adolescence or childhood. They are most commonly identified after pathologic fracture. Proximal humerus lesions may be seen.
- Unicameral bone cysts with a low risk of fracture may be observed with activity modification.
- Unicameral bone cysts causing substantial weakness and fracture risk may be treated with surgery or injection.
- Suspected unicameral bone cysts in the bones of the hand are sufficiently rare that strong consideration should be given to biopsy when this lesion is suspected.

FIG 1 • A. Enchondroma of the proximal phalanx. B. Unicameral bone cyst of the distal radius. C. Giant cell tumor of the distal radius.
Giant cell tumor of bone is locally aggressive. Patients may present with pain and swelling or after pathologic fracture. Giant cell tumor of bone metastasizes 2% to 10% of the time, with metastasis more frequently seen with distal radius and hand lesions.\(^1,2,4,5\) Metastasis most frequently occurs concurrent with or after a local recurrence. Patients with giant cell tumor of bone require systemic staging, treatment, and long-term surveillance, as recurrence may be seen late.

**PATIENT HISTORY AND PHYSICAL FINDINGS**
- Enchondroma is most often an incidental finding and is asymptomatic. Pain and deformity can be seen after pathologic fracture. On occasion there will be bone distention and tenderness with palpation.
- Unicameral bone cysts are most commonly seen after pathologic fracture. On occasion there will be swelling and tenderness.
- Giant cell tumor of bone may cause swelling, pain, tenderness, and a sense of weakness. Loss of range of motion is common as these lesions are typically periarticular. Pathologic fracture may be seen.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Plain radiographs are indispensable in the initial evaluation of primary bone tumors (**FIG 2A**).

MRI is useful when an aggressive lesion or soft tissue extension is suspected. MRI may allow better identification of the local extent of disease and may assist in operative planning (**FIG 2B**).
- Campanacci et al’s\(^3\) grading system may be used:
  - Grade 1 lesions are confined to the intramedullary cavity without distention or distortion of the cortex.
  - Grade 2 lesions distend the cortex but do not extend into the surrounding soft tissues.
  - Grade 3 lesions destroy the cortex and extend into the surrounding soft tissues.
- Total body bone scan and lung CT scan are required for staging patients with giant cell tumor of bone.
- Incision or needle biopsy may be required when radiographs and MRI are not diagnostic.

**DIFFERENTIAL DIAGNOSIS**
- Enchondroma
- Chondromyxoid fibroma
- Chondrosarcoma
- Unicameral bone cyst
- Infection
- Aneurysmal bone cyst
- Giant cell tumor of bone
- Primary malignant bone neoplasms
- Acrometastasis

**NONOPERATIVE MANAGEMENT**
- Enchondroma and unicameral bone cyst may be observed provided radiographic assessment is diagnostic or the differential is limited to benign, nonaggressive lesions with an indolent natural history. The assessment of risk of pathologic fracture is paramount. Lesions with a substantial risk of pathologic fracture in the context of the patient’s activity level are best treated operatively.
- The rare risk of malignant degeneration of enchondromas should be considered and discussed with the patient.
- Suspected giant cell tumor of bone requires biopsy. Rarely these can be treated with radiation alone; however, this approach is the exception and should not be considered first-line treatment. Radiation is associated with a risk of subsequent true malignant degeneration to a highly malignant giant cell tumor of bone.

**SURGICAL MANAGEMENT**
- All suspected giant cell tumors of bone and those enchondromas and unicameral bone cysts with a high risk of fracture are best treated surgically.

**Preoperative Planning**
- The radiographic extent of disease must be assessed.
- The approach will vary depending on the anatomic location.
- Bone graft source (autologous or allograft) must be considered.
- Precautions to prevent donor-site cross-contamination must be considered and reviewed with the operating room team.
- The surgeon must determine the anticipated need for frozen section and discuss this with the pathologist and review radiographs before any anticipated frozen section.

**FIG 2 • A.** Radiograph showing giant cell tumor of the metacarpal. B. MRI axial image of grade 3 giant cell tumor of the distal radius (arrow).
• The surgeon must secure and confirm the availability of any necessary grafting materials, instruments, implants, or adjuvants (ie, liquid nitrogen).
• The surgeon must confirm the availability of intraoperative imaging. Radiographs will give better resolution than fluoroscopy.

Positioning
• Surgery is typically done in the supine position with the arm extended on a radiolucent armboard.
• Proximal humerus lesions may be approached in a modified beach-chair position.

Approach
• Phalanx lesions may be approached from the dorsal or lateral approach.

**TECHNIQUES**

**CURETTAGE AND EXCISION OF PROXIMAL PHALANGEAL ENCHONDROMA**

- The mid-axial approach from the ulnar side is preferred whenever possible (**TECH FIG 1A**).
- After making the incision under tourniquet control, identify the lateral band and retract it dorsally.
- Reflect the periosteum and create a bone window using curettes, rongeur, or drill (**TECH FIG 1B**).
- Curette the lesion in its entirety. The use of flexible fiberoptic lights may improve visualization.
- Pack the cavity with preferred bone grafting material.
- Obtain plain radiographs in the operating room to confirm complete excision and appropriate grafting.

**CURETTAGE AND EXCISION OF METACARPAL ENCHONDROMA**

- Metacarpal lesions are approached dorsally through longitudinal incisions.
- Reflect the periosteum and create a bone window using curettes, rongeur, or drill.
- Curette the lesion in its entirety. Ensure adequate visualization through a longitudinal bone trough.
- Pack the cavity with preferred bone grafting material.
- Obtain plain radiographs in the operating room to confirm complete excision and appropriate grafting.
CURETTAGE, CRYOSURGERY, AND CEMENTATION OF DISTAL RADIUS GIANT CELL TUMOR OF BONE

- Preoperative preparation includes confirming the availability of liquid nitrogen, proper storage containers, cryosurgery instruments, and trained operative staff.
- Grade 1, 2, or 3 lesions with a single plane of palmar perforation can be approached from a palmar radial incision between the first dorsal compartment and the radial artery (TECH FIG 2A,B).
  - A branch of the superficial radial nerve may be encountered and should be retracted and protected.
  - The radial 50% of the pronator quadratus is exposed.
- When palmar soft tissue perforation is present it will commonly be contained by the pronator quadratus. The pronator overlying the region of perforation should be excised en bloc with the bone window, effectively converting a grade 3 lesion to a grade 2 lesion with a palmar bone window.
- Wide exteriorization of the lesion with a window roughly two-thirds the maximum dimension of the lesion is needed to ensure adequate visualization.
- Thoroughly curette the lesion. Fiberoptic lighting may assist in viewing the extent of radial styloid involvement.
- Burr the endosteal surface if it is sufficiently thick. Irrigate and dry the cavity.
- The argon beam coagulator may be used to achieve hemostasis in the cavity and may have a beneficial effect as an adjuvant causing surface necrosis.
- Perform cryosurgery using three separate freeze–thaw cycles with either the direct pour technique or the spray gun (TECH FIG 2C).
- Fill the cavity with polymethylmethacrylate bone cement. Reinforcing Rush pins (Rush Pin, Meridian, MS) may be used (TECH FIG 2D).
- Apply a bulky compressive bandage and volar splint.

TECH FIG 2 • A. The right radius is approached from the palmar radial aspect between the first dorsal compartment and the radial artery. B. The radial border of the pronator quadratus is exposed to gain access to the lesion for creation of the bone window. C. Cryosurgery is performed after wide retraction and soft tissue protection. D. The defect is filled with bone cement.
**WIDE EN BLOC EXTRA-ARTICULAR DISTAL RADIUS RESECTION**

- Wide extra-articular excision of the distal radius may be indicated for grade 3 giant cell tumors with extensive cortical destruction, recurrent lesions, and those with pathologic fracture into the radiocarpal articulation.
- A dorsal approach maximizes exposure and facilitates subsequent intercalary arthrodesis.
- Finger extensors are released from the retinaculum while wrist extensors and often thumb extensors or abductors may need to be sacrificed.
- Cut the radius proximal to the tumor. Cut the ulna proximal to the distal radioulnar joint, away from the ulnar extent of the lesion (*TECH FIG 3A*).
- “Evert” the radius and ulna into the wound while the interosseous membrane is transected (*TECH FIG 3B*).

Dissect the flexor pollicis longus and the radial artery away from the tumor-bearing segment.
- Mobilize the flexor tendons, median nerve, and ulnar nerve away from the tumor-bearing segment.
- The midcarpal articulation can be disarticulated initially from a dorsal approach and then circumferentially to complete the resection (*TECH FIG 3C*).
- Alternatively, the midcarpal articulation can be excised en bloc with the tumor-bearing segment by cutting with an oscillating saw from dorsal to palmar through the distal aspect of the distal carpal row bones.
- Reconstruction is readily accomplished by means of a vascularized or nonvascularized fibula graft (*TECH FIG 3D*). Spanning rigid internal fixation with a 3.5-mm dynamic compression plate lowers the risk of nonunion.

*TECH FIG 3* • **A.** Dorsal exposure of the distal radius and ulna with transection of the radius and ulna proximally. **B.** The radius and ulna are everted into the dorsal wound to allow palmar exposure and dissection of palmar soft tissues. **C.** The resection specimen, demonstrating the midcarpal articulation of the proximal carpal row. **D.** Reconstruction is by means of an osteoseptocutaneous vascularized fibula graft for intercalary arthrodesis. A spanning 3.5-mm compression plate is used for fixation.
PEACE AND PITFALLS

“Exteriorization”
- Make the bone window to the lesion two-thirds the greatest dimension of the lesion to allow adequate visualization of the cavity.

Pathology consultation
- Consult the pathologist in advance. Frozen section analysis of cartilaginous lesions is notoriously difficult.

Approach
- A lateral approach to phalanx lesions provides more rapid return to normal motion and a better appearance. A volar radial approach for distal radius grade 1 and 2 giant cell tumors of bone allows excellent visualization and limits local contamination risk.
- The dorsal approach for large grade 3 giant cell tumor distal radius lesions is best when wide excision and reconstruction or arthrodesis is anticipated.

Monitoring
- Surveillance monitoring is mandatory, particularly for giant cell tumor of bone, which can recur late and metastasize.

POSTOPERATIVE CARE
- Phalanx or metacarpal enchondroma
  - Bulky protective dressings are applied and range of motion is initiated at the first dressing change, usually 8 to 10 days postoperatively.
  - Protective splinting is continued for 6 weeks after surgery. High-risk activities are restricted for 12 to 16 weeks.
  - Periodic surveillance continues for 3 to 5 years.
  - Curettage, cryosurgery, and cementation of distal radius giant cell tumor of bone
    - Dressings are changed 10 days postoperatively. Sutures are removed and the patient is fitted with a removable splint.
    - Active range-of-motion exercises are initiated. Active-assisted and passive range-of-motion exercises are added at week 6.
    - Activities are gradually increased, with high-risk activities being restricted for up to 2 years due to cryonecrosis of bone caused by cryosurgery.
- Wide en bloc extra-articular distal radius resection
  - Patients are dressed in a bulky compressive dressing, most commonly with a volar splint.
  - Elevation is encouraged for the first 48 hours and digit range of motion is encouraged.
  - Formal supervised therapy is initiated at the first dressing change, typically 8 to 10 days after surgery.
    - At that time bandages are removed and sutures can be removed.
    - Most commonly, active and active-assisted range-of-motion exercises are initiated. When not exercising, patients are asked to use a protective splint for an additional month. Activities are progressively increased as soft tissue and bone healing allows.
    - Range-of-motion exercises are initiated no later than 10 days after surgery.
    - Protective splinting continues a total of 6 weeks minimum after intralesional procedures and until bone healing is confirmed after arthrodesis.
    - Sporting activities are typically restricted for 12 to 18 weeks. High-risk activities are avoided for longer periods.
    - Surveillance for local recurrence should continue for 5 years for benign lesions and 10 years for giant cell tumor of bone.

OUTCOMES
- Local recurrence
  - The local recurrence rate after curettage and bone grafting of enchondromas is about 5%. When recurrence is seen, the question of malignant transformation should be considered.
  - The local recurrence rate after curettage and bone grafting of giant cell tumor of bone in the distal radius is about 50%, and adjuvants such as liquid nitrogen can lower this to about 20%. Intralesional treatment (curettage) is best reserved for lesions without soft tissue extension (grade 1 and 2 lesions).
  - Wide excision of distal radius lesions is associated with local recurrence rates of less than 10%; however, reconstruction in the form of articular allograft or intercalary arthrodesis results in inferior function, motion, and strength and higher levels of pain.
  - The local recurrence rate after curettage and bone grafting of giant cell tumor of bones of the hand is about 80%. Isolated curettage without the use of adjuvants cannot be advocated in this setting. There are several successful examples of curettage cryosurgery and cementation of giant cell tumor of the small bones of the hand. This type of procedure is best done at a tumor referral center.
  - Wide excision or amputation has been advocated for giant cell tumor of bone when it arises in the phalanges or metacarpals. Local recurrence may still be seen, but the rate is probably less than 10%.
  - The local recurrence rate after curettage of enchondromas arising in the hand is about 5%.
  - The local recurrence rate after wide excision or amputation for giant cell tumor of the bones of the hand is less than 10%.
  - The local recurrence rate after curettage, cryosurgery, and cementation of distal radius giant cell tumor of bone is about 20% to 25% and correlates with soft tissue extension.
  - The local recurrence rate after wide excision of distal radius giant cell tumor of bone is likely less than 10%.
- Metastasis
  - Benign giant cell tumor of bone metastasizes in 2% to 8% in general case series.
  - Motion and strength
    - Range of digit motion is typically excellent after curettage for enchondroma.
    - Range of motion of the wrist may be slightly diminished after curettage of enchondromas in the distal radius.
    - Grip strength is reduced to 60% of normal after wide excision of the distal radius for giant cell tumor with intercalary segmental arthrodesis. Forearm rotation is typically preserved.
COMPLICATIONS

- Infection, hematoma, nerve injury, intraoperative fracture, postoperative fracture, nonunion, limited range of motion, and tendon gliding problems may be seen after treatment of enchondroma or giant cell tumor of bone when arising in the upper extremity.
- Delayed complications include extensor tendon rupture due to prominent residual ulna, nonunion, and fracture after hardware removal.

REFERENCES

Chapter 1
Anatomy of the Shoulder and Elbow 3042

Chapter 2
Surgical Approaches to the Shoulder and Elbow 3056

Chapter 3
Bankart Repair and Inferior Capsular Shift 3073

Chapter 4
Treatment of Recurrent Posterior Shoulder Instability 3085

Chapter 5
Latarjet Procedure for Instability With Bone Loss 3100

Chapter 6
Glenoid Bone Graft for Instability With Bone Loss 3107

Chapter 7
Management of Glenohumeral Instability With Humeral Bone Loss 3116

Chapter 8
Acromioplasty, Distal Clavicle Excision, and Posterosuperior Rotator Cuff Repair 3124

Chapter 9
Subscapularis Repair, Coracoid Recession, and Biceps Tenodesis 3134
Chapter 10  
Latissimus Transfer for Irreparable Posterosuperior Rotator Cuff Tear  3141

Chapter 11  
Pectoralis Major Transfer for Irreparable Subscapularis Tears  3152

Chapter 12  
Acute Repair and Reconstruction of Sternoclavicular Dislocation  3159

Chapter 13  
Medial Clavicle Excision and Sternoclavicular Joint Reconstruction  3170

Chapter 14  
Plate Fixation of Clavicle Fractures  3177

Chapter 15  
Intramedullary Fixation of Clavicle Fractures  3181

Chapter 16  
Percutaneous Pinning for Proximal Humerus Fractures  3191

Chapter 17  
Open Reduction and Internal Fixation of Proximal Humerus Fractures  3200

Chapter 18  
Intramedullary Fixation of Proximal Humerus Fractures  3209

Chapter 19  
Hemiarthroplasty for Proximal Humerus Fractures  3217

Chapter 20  
Plate Fixation of Humeral Shaft Fractures  3226
Chapter 21
Intramedullary Fixation of Humeral Shaft Fractures 3234

Chapter 22
Open Reduction and Internal Fixation of Nonarticular Scapular Fractures 3243

Chapter 23
Open Reduction and Internal Fixation of Intra-articular Scapular Fractures 3249

Chapter 24
Glenulohumeral Arthrodesis 3256

Chapter 25
Hemiarthroplasty, Total Shoulder Arthroplasty, and Biologic Glenoid Resurfacing for Glenohumeral Arthritis With an Intact Rotator Cuff 3261

Chapter 26
Hemiarthroplasty and Total Shoulder Arthroplasty for Glenohumeral Arthritis With an Irreparable Rotator Cuff 3275

Chapter 27
Pectoralis Major Repair 3288

Chapter 28
Snapping Scapula Syndrome 3293

Chapter 29
Eden-Lange Procedure for Trapezius Palsy 3301

Chapter 30
Pectoralis Major Transfer for Long Thoracic Nerve Palsy 3308
Chapter 31  
**Scapulothoracic Arthrodesis** 3316

Chapter 32  
**Suprascapular Nerve Decompression** 3323

Chapter 33  
**Open Reduction and Internal Fixation of Supracondylar and Intercondylar Fractures** 3329

Chapter 34  
**Open Reduction and Internal Fixation of Capitellum and Capitellar–Trochlear Shear Fractures** 3337

Chapter 35  
**Open Reduction and Internal Fixation of Radial Head and Neck Fractures** 3343

Chapter 36  
**Radial Head Replacement** 3352

Chapter 37  
**Open Reduction and Internal Fixation of Olecranon Fractures** 3362

Chapter 38  
**Management of Simple Elbow Dislocation** 3369

Chapter 39  
**Open Reduction and Internal Fixation of Fracture-Dislocations of the Elbow With Complex Instability** 3377

Chapter 40  
**Monteggia Fractures in Adults** 3385

Chapter 41  
**Lateral Collateral Ligament Reconstruction of the Elbow** 3392
Chapter 42
Ulnohumeral (Outerbridge-Kashiwagi) Arthroplasty 3400

Chapter 43
Lateral Columnar Release for Extracapsular Elbow Contracture 3406

Chapter 44
Extrinsic Contracture Release: Medial Over-the-Top Approach 3413

Chapter 45
Total Elbow Arthroplasty for Rheumatoid Arthritis 3420

Chapter 46
Elbow Replacement for Acute Trauma 3433

Chapter 47
Management of Primary Degenerative Arthritis of the Elbow: Linkable Total Elbow Replacement 3444

Chapter 48
Surgical Management of Traumatic Conditions of the Elbow 3453

Chapter 49
Elbow Arthrodesis 3462
OVERVIEW OF SHOULDER AND ELBOW SURGERY

- In order to diagnose and treat problems of the shoulder and elbow, one must fully understand the anatomy of the region and appreciate how this translates to functional rearrangements.
- There is no line of demarcation between the shoulder and elbow regions. Pain in the arm may originate at the neck or shoulder and refer down the arm. Less often pain noted by patients at the elbow or forearm have local origin. If the slightest doubt exists as to the etiology of the pain, the patient is examined from neck to fingers.
- The upper extremity functions to position and move the hand in space. The upper extremities are attached to the body by the sternoclavicular joint. Otherwise, they are suspended from the neck and held fast to the torso by soft tissues (muscles and fascia).
- The upper extremity gains leverage against the posterior aspect of the thorax by virtue of the broad, flat body of the scapula.
- The elbow along the upper extremity is a complex modified hinge articulation. Unlike the shoulder, the elbow has a much more intrinsic stability based on its bony architecture. The primary purpose of the elbow is to position the hands in space. The elbow joint is perhaps the main joint responsible for communicating the actions of the hand to the trunk.
- The surgical management of major shoulder and elbow conditions has rapidly progressed over the last 30 years as our understanding of the pathoanatomy and biomechanics has greatly enhanced our ability to treat certain problems. Consequently, new surgical techniques have allowed the surgeon to more effectively treat many disorders.
- Arthroscopic surgery in particular has significantly increased our ability to surgically manage conditions and reduce morbidity. The sports medicine portion of this textbook handles the arthroscopic management of shoulder and elbow disorders.
- The art of any surgery lies in the reconstruction of diseased or injured tissues with minimal additional destruction. Skillful handling of the soft tissues is the hallmark of all upper extremity surgery, including the shoulder and elbow. Knowledge of anatomy defines the precision and safety of surgery. Approaches to any joint in the body are developed on this foundation, with particular emphasis on the exploitation of internervous planes. Familiarity with the intricate anatomy and multiple approaches to the shoulder and elbow allows the surgeon to confidently embark on the repair or reconstruction of the injury or disorder of the joint.

OSTEOLOGY

Clavicle

- This is a relatively straight bone when viewed anteriorly, whereas in the transverse plane, it resembles an italic S (FIG 1).
- There are three bony impressions for ligament attachment to the clavicle:
  - On the medial side is an impression for the costoclavicular ligament, which at times may be a rhomboid fossa.
  - At the lateral end of the bone is the conoid tubercle.
  - Just lateral to the conoid tubercle is the trapezoid tubercle.
- Muscles that insert on the clavicle are the trapezius on the posterosuperior surface of the distal end and the subclavius muscle, which has an insertion on the inferior surface of the middle third of the clavicle.
- Functionally, the clavicle acts mainly as a point of muscle attachment.
- Some of the literature suggests that with good repair of the muscle, the only functional consequences of surgical removal of the clavicle are with heavy overhead and that, therefore, its function as a strut is less important.
- Four muscles take origin from the clavicle: deltoid, pectoralis major, sternocleidomastoid, and sternohyoid.
- Important relations to the clavicle are the subclavian vein and artery and the brachial plexus posteriorly.

Scapula

- This is a thin sheet of bone that functions mainly as a site of muscle attachment (FIG 2A).
- It is thicker at its superior and inferior angles in its lateral border, where some of the more powerful muscles are attached.
Chapter 1
ANATOMY OF THE SHOULDER AND ELBOW

The acromion is the most studied process of the scapula because of the amount of pathology involving the acromion and the rotator cuff.

Three types of acromion morphologies have been defined by Bigliani and Morrison (FIG 3).

Type 1, with its flat surface, provided the least compromise of the supraspinatus outlet, whereas type 3, which has a hook, was associated with the highest rate of rotator cuff pathology in a series of cadaver dissections.

The glenoid articular surface is within 10 degrees of being perpendicular to the blade of the scapula, with the mean being 6 degrees of retroversion.

More caudad portions face more anteriorly than cephalad.

Three processes—the spine, the coracoid, and the glenoid—create two notches in the scapula.

Suprascapular notch is at the base of the coracoid.

Spinoglenoid, or greater scapular notch, is at the base of the spine.

Major ligaments that take origin from the scapula are:

- Coracoclavicular
- Coracoacromial
- Acromioclavicular
- Glenohumeral
- Coracohumeral

Blood supply to the scapula derives from vessels in the muscles that take fleshy origin from the scapula.

Vessels cross these indirect insertions and communicate with bony vessels.

**Humerus**

The articular surface of the humerus at the shoulder is spheroid, with a radius of curvature of about 2.25 cm.

With the arm in the anatomic position (ie, with the epicondyles of the humerus in the coronal plane), the head of humerus has retroversion of about 30 degrees, with a wide range of normal values.

The intertubercular groove lies about 1 cm lateral to the midline of the humerus (FIG 4).

The axis of the humeral head crosses the greater tuberosity at about 9 mm posterior to the bicipital groove.

The lesser tuberosity lies directly anterior, and the greater tuberosity lines up on the lateral side.

The lesser tuberosity is the insertion for the subscapularis tendon.

The greater tuberosity bears the insertion of the supraspinatus, infraspinatus, and teres minor in a superior to inferior order.
Greater and lesser tuberosities make up the boundaries of the intertubercular groove through which the long head of the biceps passes from its origin on the superior lip of the glenoid. The intertubercular groove has a peripheral roof referred to as the intertubercular ligament or the transverse humeral ligament, which has varying degrees of strength. In the coronal plane, the head–shaft angle is about 135 degrees. The space between the articular cartilage and the ligamentous and tendon attachments is referred to as the anatomic neck of the humerus. Below the level of the tuberosities, the humerus narrows in a region that is referred to as the surgical neck of the humerus because of the frequent occurrence of fractures at this level.

**STERNOCLAVICULAR JOINT**
- This is the only skeletal articulation between the upper limb and the axial skeleton.

**Ligaments**
- The major ligaments of the sternoclavicular joint are the anterior and posterior sternoclavicular ligaments.
- The most important ligament of this group, the posterior sternoclavicular ligament, is the strongest.

**Blood Supply**
- Blood supply of the sternoclavicular joint derives from the clavicular branch of the thoracoacromial artery, with additional contributions from the internal mammary and the suprascapular arteries.

**Nerve Supply**
- Innervation of the joint is supplied by the lateral pectoral, axillary, and suprascapular nerves.

**ACROMIOCLAVICULAR JOINT**
- Only articulation between the clavicle and the scapula

**Ligaments**
- Ligaments about the acromioclavicular articulation are the trapezoid and the conoid ligaments (FIG 5).
- The anteroposterior stability of the acromioclavicular joint is controlled by the acromioclavicular ligaments, and the vertical stability is controlled by the coracoclavicular ligaments.

**Blood Supply**
- Blood supply derives mainly from the acromial artery, a branch of the deltoid artery of the thoracoacromial axis.

There are rich anastomoses between the thoracoacromial artery, suprascapular artery, and posterior humeral circumflex artery. The acromial artery comes on to the thoracoacromial axis anterior to the clavipectoral fascia and perforates back through the clavipectoral fascia to supply the joint.

**Nerve Supply**
- Innervation of the joint is supplied by the lateral pectoral, axillary, and suprascapular nerves.

**SHOULDER LIGAMENTS: CAPSULOLIGAMENTOUS AND LABRAL ANATOMY (FIG 6)**

**Superior Glenohumeral Ligament (SGHL)**
- Arises near the origin of the long head of the biceps brachii
- If the glenoid had the markings of a clock, with the 12-o’clock position superiorly and the 3-o’clock position anteriorly, the origin of the superior glenohumeral ligament would correspond to the area from the 12-o’clock to the 2-o’clock positions.
- SGHL runs inferiorly and laterally to insert on the humerus, superior to the lesser tuberosity.

**Middle Glenohumeral Ligament (MGHL)**
- Usually arises from the neck of the glenoid just inferior to the origin of the SGHL and inserts into the humerus just medial to the lesser tuberosity
- Presence of the MGHL most variable of any shoulder ligament

**Inferior Glenohumeral Ligament (IGHL)**
- Most important ligament for providing anterior and posterior shoulder stability
- IGHL has been described as having an anterior and posterior band, with an axillary pouch between the bands.
With abduction and external rotation, the anterior band fans out and the posterior band becomes cordlike.

Likewise, with internal rotation, the posterior band fans out and the anterior band appears cordlike.

Anterior band of the IGHL arises from various areas corresponding to the 2- to 4-o’clock positions on the glenoid.

Insertion site of this ligament has two attachments, one to the glenoid labrum and the other directly to the anterior neck of the glenoid.

Posterior band originates at the 7-o’clock to 9-o’clock positions.

With the arm at the side, both the anterior and the posterior bands pass through a 90-degree arc and insert on the humerus.

Labrum

Surrounds the periphery of the glenoid and is a site of attachment of the capsuloligamentous structures.

It is composed of dense fibrous connective tissue, with a small fibrocartilaginous transition zone at the anteroinferior attachment of the osseous glenoid rim.

The labrum acts as a load-bearing structure for the humeral head and serves to increase the surface area of the glenoid.

Howell and Galinat showed that the labrum deepened the glenoid socket by nearly 50%.

Lippett and coworkers have shown that removal of the labrum decreases the joint’s stability to sheer stress by 20%.

Triangular cross-section of the labrum allows it to act as a chock-block to help prevent subluxation.

SCAPULOTHORACIC MUSCLES

Trapezius

Largest and most superficial of scapulothoracic muscles

Takes origin from spinous process of C7 through T12 vertebrae

Insertion of the upper fibers is over the distal one third of the clavicle.

Lower cervical and upper thoracic fibers of the trapezius have their insertion over the acromion and spinous scapula.

Lower portion of the muscle takes insertion at the base of the scapular spine.

Acts as a scapular retractor, with the upper fibers used mostly for elevation of the lateral angle

Spinal accessory nerve is the motor supply.

Arterial supply is derived from transverse cervical artery.

Rhombooids

Similar in function to the midportion of the trapezius, with origin from the lower ligamentum nuchae, C7 and T1 for the rhomboid minor and T2 through T5 for the rhomboid major

Rhomboind minor inserts on the posterior portion of the medial base of the spine of the scapula.

Rhomboind major inserts to the posterior surface of the medial border, from where the minor leaves off down to the inferior angle of the scapula.

Action of the rhomboids is retraction of the scapula, and because of their oblique course they also participate in elevation of the scapula.

Innervation is the dorsal scapular nerve (C5), which may arise off the brachial plexus in common with the nerve to the subclavius or with the C5 branches of the long thoracic nerve.

Dorsal scapular artery provides arterial supply to the muscles through their deep surfaces.

levator Scapula and Serratus Anterior

The levator scapula and the serratus anterior are often discussed together because of their close relationship anatomically and functionally.

The levator scapula takes origin from the posterior tubercles of the transverse process from C1 through C3 and sometimes C4.

Inserts on the superior angle of the scapula

Acts to elevate the superior angle of the scapula

In conjunction with the serratus anterior, produces upward rotation of the scapula

Innervation is from the deep branches of C3 and C4.

Serratus anterior takes origin from the ribs on the anterior lateral wall of the thoracic cage.

Bounded medially by the ribs and intercostal muscles and laterally by the axillary space

Protracts the scapula and participates in upward rotation of the scapula

More active in flexion than in abduction because straight abduction requires some retraction of the scapula

Absence of serratus activity, usually because of paralysis, produces a winging of the scapula with forward flexion of the arm and loss of strength in that motion.

Innervation is supplied by the long thoracic nerve (C5, C6, and C7).

Blood supply is from the lateral thoracic artery, with a large contribution from the thoracodorsal artery.

pectoralis Minor

Takes fleshy origin anteriorly on the chest wall, and second through fifth ribs, and has its insertion onto the base of the medial side of the coracoid.
Function is protraction of the scapula if the scapula is retracted and depression of the lateral angle or downward rotation of the scapula if the scapula is upwardly rotated.

Innervation is from the medial pectoral nerve (C8 and T1).

Blood supply is through the pectoral branch of the thoracoacromial artery.

GLENOHUMERAL MUSCLES (FIG 7)

Deltoid

Largest and most important of the glenohumeral muscles, consisting of three major sections:

- Anterior deltoid takes origin off the lateral third of the clavicle, middle third of the deltoid takes origin off the acromion, and posterior deltoid takes origin from the spine of the scapula.
- The deltoid is supplied by the axillary nerve (C5 and C6), which enters the posterior portion of the shoulder through the quadrilateral space and innervates the teres minor in this position.
- Nerves to the posterior third of the deltoid enter the muscle very close to their exit from the quadrilateral space, traveling in the deltoid muscle along the medial and inferior borders of the posterior deltoid.
- Branch of the axillary nerve that supplies the anterior two thirds of the deltoid ascends superiorly and then travels anteriorly, about 2 inches inferior to the rim of the acromion.
- Vascular supply to the deltoid is largely derived from the posterior humeral circumflex artery, which travels with the axillary nerve through the quadrilateral space of the deep surface of the muscle.
- Deltoid is also supplied by the deltoid branch of the thoracoacromial artery.

Supraspinatus

- Lies on the superior portion of the scapula
- It takes origin from the supraspinatus fossa and overlying fascia and inserts into the greater tuberosity.
- Its tendinous insertion is in common with the infraspinatus posteriorly.
- It is active in any motion involving elevation.
- It exerts maximum effort at about 30 degrees of elevation.
- Innervation of the supraspinatus is supplied by the suprascapular nerve (C5, C6).
- Arterial supply is the suprascapular artery.
- Nerve comes through the suprascapular notch and is bound above by the transverse scapular ligament.
- Artery travels above this ligament.
- Suprascapular vessels and nerve supply the deep surface of the muscle.

Infraspinatus

- Second most active rotator cuff muscle
- Its tendinous insertion is in common with the supraspinatus anterosuperiorly and the teres minor inferiorly at the greater tuberosity.
- One of the two main external rotators of the humerus and accounts for as much as 60% of external rotation force
- Also functions as a depressor of the humeral head
- Even in a passive state, it is an important stabilizer against posterior subluxation.
- Innervated by the suprascapular nerve
- Blood supply is from two large branches of the suprascapular artery.

Teres Minor

- One of the few external rotators of the humerus
- It provides up to 45% of the external rotation force.
- It is important in controlling stability in the anterior direction.
- Innervated by the posterior branch of the axillary nerve (C5 and C6)
- Blood supply is derived from several vessels in the area, especially the posterior humeral scapular circumflex artery.

Subscapularis
- Makes up the anterior portion of the rotator cuff
- Takes origin from the subscapularis fossa, which covers most of the anterior surface of the scapula
- Its upper 60% inserts through a cartilaginous tendon into the lesser tuberosity of the humerus, and its lower 40% has a flimsy insertion into the humerus below the lesser tuberosity cupping the head and neck.
- Functions as an internal rotator and passive stabilizer to anterior subluxation and serves in its lower fibers to depress the humeral head
- Innervation usually supplied by two sources:
  - Upper subscapular nerve (C5) and lower subscapular nerves (C5 and C6)
  - Upper subscapular nerves usually come off the posterior cord.
- Blood supply originates from the axillary and subscapular arteries.

Teres Major
- Takes origin from the posterior surface of the scapula along the inferior portion of the lateral border
- It has a muscular origin and a common tendinous insertion with the latissimus dorsi into the humerus along the medial lip of the bicipital groove.
- In their course, both the latissimus dorsi and the teres major undergo a 180-degree spiral; thus, the formerly posterior surface of the muscle is represented by fibers on the anterior surface of the tendon.
- Function is internal rotation, adduction, and extension of the arm.
- Innervation is supplied by the lower subscapular nerve C5 and C6.
- Blood supply is derived from the subscapular artery.

Coracobrachialis
- Originates from the coracoid process, in common with and medial to the short head of the biceps, and inserts onto the anteromedial surface in the midportion of the humerus
- Action is flexion and adduction of the glenohumeral joint.
- Innervation supplied by small branches from the lateral cord and the musculocutaneous nerve
- Because the larger musculocutaneous nerve’s entrance to the muscle may be situated as high as 1.5 cm from the tip of the coracoid to as low as 7 to 8 cm, it must be protected during certain types of repair.
- Major blood supply is usually off the axillary.

MULTIPLE JOINT MUSCLES

Pectoralis Major
- Consists of three portions:
  - Upper portion takes origin from the medial one half to two thirds of the clavicle and inserts along the lateral lip of the bicipital groove.
  - Middle portion takes origin from the manubrium and upper two thirds of the body of the sternum and ribs 2 through 4.
  - It inserts directly behind the clavicular portion and maintains a parallel fiber arrangement.
  - Inferior portion of the pectoralis major takes origin from the distal body of the sternum, the fifth and sixth ribs, and the external oblique muscle fascia.
- Action
  - Clavicular portion participates somewhat in flexion with the anterior portion of the deltoid while the lower fibers are antagonistic.
  - Is active in internal rotation against resistance and will extend the shoulder from flexion until the neutral position is reached.
  - Powerful adductor of the glenohumeral joint.
- Innervation is supplied by two sources:
  - Lateral pectoral nerve (C5, C6, and C7) innervates the clavicular portion of the muscle.
  - Loop contribution from the lateral to the medial pectoral nerve carrying C7 fibers into the upper sternal portion.
- Major blood supply derives from two sources:
  - The deltoïd branch of the thoracodorsal artery supplies the clavicular portion and the pectoral artery supplies the sternocostal portion of the muscle.

Latissimus Dorsi
- Takes origin by the large and broad aponeurosis from the dorsal spines of T7 through L5, a portion of the sacrum, and the crest of the ilium.
- Wraps around the teres major and inserts into the medial crest and floor of the bicipital or intertubercular groove.
- Actions are inward rotation and abduction of the humerus, shoulder extension, and indirectly through its pull on the humerus downward rotation of the scapula.
- Innervation is through the thoracodorsal nerve (C6 and C7).
- Major blood supply is derived from the thoracodorsal artery.

Biceps Brachii
- There are two origins of the biceps muscle in the shoulder:
  - The long head takes origin from the bicipital tubercle at the superior rim of the glenoid.
  - The short head takes origin from the coracoid tip lateral.
- Has two distal tendinous insertions:
  - Lateral insertion is to the posterior part of the tuberosity of the radius.
  - Medial insertion is aponeurotic (lacertus fibrosus), passing medially across and into the deep fascia of the muscles of the volar forearm.
- Loss of the long head attachment expresses itself mainly as loss of supination strength (20%), with a smaller loss (8%) of elbow flexion strength.
- Actions of the biceps are flexion and supination at the elbow.
- Main action is at the elbow rather than the shoulder.
- Innervation is supplied by branches of the musculocutaneous nerve (C5 and C6).
- Blood supply derives from a single large bicipital artery from the brachial artery (35%), multiple very small arteries (40%), or combination of two types.

Triceps Brachii
- Long head takes origin from the infraglenoid tubercle.
- Major action of the muscle is extension at the elbow.
Innervation is supplied by the radial nerve with root innervation C6 to C8.
Arterial supply is derived mainly from the profunda brachial artery and the superior ulnar collateral artery.

**BRACHIAL PLEXUS**

- The standard brachial plexus is made up of distal distribution of the anterior rami of spinal nerve roots C5, C6, C7, C8, and T1. The plexus has contributions from C4 and T1 (FIG 8).

**Trunks, Divisions, and Cords**

- The roots combine to form trunks: C5 and C6 form the superior trunk; C7 forms the middle trunk; and C8 and T1 form the inferior trunk.
- The trunks then separate into anterior and posterior divisions.
- The posterior divisions combine to form the posterior cord, the anterior division of the inferior trunk forms the medial cord, and the anterior division of the superior and middle trunks forms the lateral cord.
- These cords give off the remaining largest number of the terminal nerves of the brachial plexus, and roots from the lateral and medial cords come together to form the median nerve.
- The brachial plexus leaves the cervical spine and progresses through the interval between the anterior and middle scalene muscles.
- The subclavian artery follows the same course. The plexus splits into cords at or before it passes below the clavicle.
- As the cords enter the axilla, they become closely related to the axillary artery, attaining positions relative to the artery indicated by their names: lateral, posterior, and medial.

**Terminal Branches**

- Plexus gives off some terminal branches above the clavicle.
- The dorsal scapular nerve comes off C5 with some C4 fibers and penetrates the scalenus medius and the levator scapulae, sometimes contributing with C4 fibers to the latter.
- The dorsal scapular nerve accompanies the deep branch of the transverse cervical artery or the dorsal scapular artery on the undersurface of the rhomboids and innervates them.
- Rootlets of the nerves C5, C6, and C7 immediately adjacent to the intravertebral foramina contribute to the formation of the long thoracic nerve, which immediately passes between the middle and posterior scalene muscles or penetrates the middle scalene.
- Next most proximal nerve is the suprascapular nerve.
- It arises from the superolateral aspect of the upper trunk shortly after its formation at Erb’s point.
- The lateral cord generally contains fibers of C5, C6, and C7 and gives off three terminal branches:
  - Musculocutaneous
  - Lateral pectoral
  - Lateral root of the median nerve
- Posterior cord supplies most of the innervations of the muscles of the shoulder, in this order:
  - Upper subscapularis, thoracodorsal, lower subscapular, axillary, and radial
- Medial cord has five branches, in the following order:
  - Medial pectoral nerve, medial brachial cutaneous, medial antebrachial cutaneous, medial root of the median nerve, and ulnar nerve

![The brachial plexus](FIG 8 - The brachial plexus.)
**ARTERIES**

Subclavian Artery
- Blood supply to limb begins with the subclavian artery, which ends at the lateral border of the first rib.
- Divided into three portions in relation to the insertion of the scalenus anterior muscle.
- Vertebral artery takes origin in the first portion, and the costocervical trunk and thyrocervical trunk take origin in the second portion.
- There are usually no branches in the third portion of the artery.
- Two vessels encountered more frequently by the shoulder surgeon are the transverse cervical artery and the suprascapular artery.
  - Come off the thyrocervical trunk in 70% of dissections.
  - In the remaining cases, they come off directly, or in common from the subclavian artery.

Axillary
- Is the continuation of the subclavian artery.
- It begins at the lateral border of the first rib and continues along the inferior border of the latissimus dorsi, at which point it becomes the brachial artery.
- This artery is traditionally divided into three portions:
  - First portion is above the superior border of the pectoralis minor.
  - Second portion is deep to the pectoralis minor.
  - Third portion is distal to lateral border of the pectoralis minor.
- Usual number of branches for each of the three sections corresponds to the name of the section: one branch in the first portion, two in the second, and three in the third.
  - First section gives off the superior thoracic artery.
  - Second portion gives off the thoracoacromial artery and the lateral thoracic artery.
  - Third portion gives off the following:
    - Largest branch is the subscapular artery, and this is the largest branch of the axillary.
    - Next branch is the posterior humeral circumflex artery, and the third branch is the anterior humeral circumflex artery.
    - Anterior humeral circumflex artery is an important surgical landmark because it travels laterally at the inferior border of the subscapularis tendon, marking the border between the upper tendinous insertion of the subscapularis and the lower muscular insertion.

**VEINS**

Axillary Vein
- Begins at the inferior border of the latissimus dorsi as the continuation of the basilic vein, continues along the lateral border of the first rib, and becomes the subclavian vein.

Cephalic
- Cephalic vein is the superficial vein in the arm that lies deep to the deep fascia after reaching the deltopectoral groove and finally pierces the clavipectoral fascia, emptying into the axillary vein.

**OSTEOMETRY**

Distal Humerus
- The distal humerus consists of two condyles, which form the articular surfaces of the trochlea and capitellum (FIG 9A).

Trochlea
- Hyperbolic, pulley-like surface that articulates with the semilunar notch of the ulna, covered by articular cartilage over an arc of 300 degrees.
- Medial margin is large and projects more distally than does the lateral margin.
- The prominent medial and lateral margins are separated by a groove that courses in a helical manner from an anterolateral to the posteromedial direction.

Capitellum
- Capitellum is almost spheroidal in shape and is covered with hyaline cartilage, which is about 2 mm thick anteriorly.
- Postero-medial limit of the capitellum is marked by a prominent tubercle.
- A groove separates the capitellum from the trochlea, and the rim of the radial head articulates with this groove throughout the arc of flexion and during pronation and supination.

Joint Surface Orientation
- In the lateral plane, the orientation of the articular surface of the distal humerus is located anteriorly about 30 degrees with respect to the long axis of the humerus (FIG 9B).
- The center of the concentric arc formed by the trochlea and capitellum is on a line that is coplanar with the anterior and distal cortex of the humerus.
- In the transverse plane, the articular surface is rotated inwardly about 5 degrees, and in the frontal plane, it is tilted about 6 degrees in valgus (FIG 9C).

Epicondyles of Humerus
- Medial epicondyle serves as the source of attachment of the ulnar collateral ligament and the flexor pronator group of muscles.
- Lateral epicondyle is located just above the capitellum and is much less prominent than the medial epicondyle.
- The lateral collateral ligament and the supinator extensor muscle group originate from the flat, irregular surfaces of the lateral epicondyle.

Anterior Surface of Humerus
- Anteriorly, the radial and coronoid fossae accommodate the radial head and coronoid, respectively, during flexion.

Posterior Surface of Humerus
- Posteriorly, the olecranon fossa receives the tip of the olecranon in extension (FIG 9D).

Radius
- The proximal radius includes the radial head, which articulates with the capitellum and exhibits a cylindrical depression in the midportion to accommodate the capitellum.
- Hyaline cartilage covers the depression of the radial head. The outside circumference of the radial head articulates with the ulna at the lesser sigmoid notch.
- About 240 degrees of the circumference of the radial head is covered with cartilage. With the arm in neutral rotation, the anterolateral third of the circumference of the radial head is void of cartilage.
- This part of the radial head lacks subchondral bone, and thus is not as strong as the part that supports the articular cartilage.
- This part has been demonstrated to be the portion most often fractured.
- The disc-shaped head is held against the ulna by the annular ligament distal to the radial head.
- The head and neck of the radius are not colinear with the rest of the bone. The head and neck are offset by an angle of about 15 degrees with respect to the shaft of the radius opposite to the radial tuberosity (FIG 10).
- The neck of the radius is tapered, and the angular relationship between the head and neck has been implicated in the etiology of radial neck fractures.

**Ulna**
- The proximal ulna provides the major articulation of the elbow that is responsible for its inherent stability (FIG 11A,B).
- The broad, thick proximal aspect of the ulna consists of the greater sigmoid notch (incisura semilunaris), which articulates with the trochlea of the humerus.
- The sloped cortical surface of the coronoid process serves as the site of insertion of the brachialis muscle.
- The olecranon comprises the posterior portion of the articulation of the ulnohumeral joint and is the site of attachment for the triceps tendon.
- On the lateral aspect of the coronoid process, the lesser sigmoid or radial notch articulates with the radial head and is oriented roughly perpendicular to the long axis of the bone.
- On the lateral aspect of the proximal ulna, a tuberosity, the crista supinatoris, is the site of the insertion of the lateral ulnar collateral ligament (FIG 11C).
- This stabilizes the humeroulnar joint to resist varus and rotational stresses.
- The medial aspect of the coronoid process (sublime tubercle) serves as the site of attachment of the anterior bundle of the medial collateral ligament.
SURVEY OF TOPICAL ANATOMY

Landmarks

Lateral Landmark
- The tip of the olecranon, the lateral epicondyle, and the radial head form an equilateral triangle, providing an important landmark for entry into the elbow for such things as joint aspiration.

Flexion Crease
- The flexion crease of the elbow is in line with the medial and lateral epicondyles. It is actually 1 to 2 cm proximal to the joint line when the elbow is extended.

Antecubital Fossa
- Inverted triangular depression on the anterior aspect of the elbow that is just distal to the epicondyles

Topographical Regions of the Elbow and Corresponding Musculature

Lateral Margin of Antecubital Fossa
- Extensor forearm musculature originates from the lateral epicondyle and has been termed the mobile wad.
- This forms the lateral margin of the antecubital fossa and the lateral contour of the forearm and comprises the brachioradialis and the extensor carpi radialis longus and brevis muscles.


Medial Margin of the Antecubital Fossa
- Muscles making up the contour of the medial anterior forearm include the pronator teres, flexor carpi radialis, palmaris longus, and flexor carpi ulnaris.

Dorsum
- The dorsum of the forearm is contoured by the extensor musculature, consisting of the anconeus, extensor carpi ulnaris, extensor digitorum quinti, and extensor digitorum communis.

Cutaneous Innervation

Proximal Elbow
- Skin about the proximal elbow is innervated by the lower lateral cutaneous (C5, C6) and the medial cutaneous (radial nerve, C8, T1, and T2) nerves of the arm.

Forearm
- Forearm skin is innervated by the medial (C8, T1), lateral (musculocutaneous, C5, C6), and posterior (radial nerve, C6 through C8) cutaneous nerves of the forearm.

Elbow Joint Structure

Joint Articulation
- The elbow joint consists of two types of articulations:
  - The ulnohumeral joint resembles a hinge (ginglymus), allowing flexion and extension.
  - The radiohumeral and the proximal radioulnar joint allow actual rotation or pivoting type of motion.
- Because of this joint articulation, the elbow is classified as a trochoginglymoid joint and is one of the most congruent joints of the body.

Carrying Angle
- Angle formed by the long axis of the humerus and the ulna with the elbow fully extended
  - In males, mean carrying angle is 11 to 14 degrees.
  - In females, mean carrying angle 13 to 16 degrees.

Joint Capsule
- The anterior capsule inserts proximally above the coronoid and radial fossae.
- Distally, the capsule attaches to the anterior margin of the coronoid medially as well as to the annular ligament laterally.
- Posteriorly, the capsule attaches just above the olecranon fossa, distally along the supracondylar bony columns, and then down along the medial and lateral margins of the trochlea.
- Distally, the attachment is along the medial and lateral articular margin of the sigmoid notch; laterally, it occurs along the lateral aspect of the sigmoid notch and blends with the annular ligament.
- Normal capacity of the fully extended joint capsule is 25 to 30 mL.
- The joint capsule is innervated by branches from all major nerves crossing the joint, including contributions from the musculocutaneous nerve.

LIGAMENTS OF THE ELBOW
- Ligaments of the elbow consist of specialized thickening of the medial and lateral capsule that forms medial and lateral collateral ligament complexes.

Medial Collateral Ligament Complex
- The medial collateral ligament consists of three parts: anterior, posterior, and transverse segments.
- Anterior bundle is the most discrete component.
- The posterior portion, being a thickening of the posterior capsule, is well defined only in about 90 degrees of flexion.
- The transverse component appears to contribute a little or nothing to elbow stability.
- Clinically and experimentally, the anterior bundle is clearly the major portion of the medial ligament complex.

Lateral Collateral Ligament Complex
- Unlike the medial collateral ligament complex, with a rather consistent pattern, the lateral ligaments of the elbow joint are less discrete and some individual variation is common.
- Several components make up the lateral ligament complex: radial collateral ligament, the annular ligament, a variably present accessory lateral collateral ligament, and the lateral ulnar collateral ligament.

Lateral Ulnar Collateral Ligament
- This structure originates from the lateral epicondyle and blends with the fibers of the annular ligament, but arching superficial and distal to it.
- Insertion is through the tubercle of the crest of the supinator on the ulna.
- The function of this ligament is to provide stability to the ulnohumeral joint; it was shown to be deficient in posterolateral rotary instability of the joint.
- This ligament represents the primary lateral stabilizer of the elbow and is taut on flexion and extension.

Accessory Lateral Collateral Ligament
- Its function is to further stabilize the annular ligament during varus stress.

VESSELS

Brachial Artery and Its Branches
- The brachial artery descends in the arm, crossing in front of the intramuscular septum to lie anterior to the medial aspect of the brachialis muscle.
- The median nerve crosses in front of and medial to the artery at this point, near the middle of the arm. The artery continues distally at the medial margin of the biceps muscle and enters the antecubital space medial to the biceps tendon and lateral to the nerve.
- At the level of the radial head, it gives off its terminal branches, the ulnar and radial arteries, which continue into the forearm.

Radial Artery
- Usually the radial artery originates at the level of the radial head, emerges from the antecubital fossa between the brachioradialis and the pronator teres muscle, and continues down the forearm under the brachioradialis muscle.

Ulnar Artery
- The ulnar artery is the larger of the two terminal branches of the brachial artery.
- The artery traverses the pronator teres between its two heads and continues distally and medially behind the flexor digitorum superficialis muscle.
- It emerges medially to continue down the medial aspect of the forearm under the cover of the flexor carpi ulnaris.

**NERVES**

**Musculocutaneous Nerve**
- Originates from C5 through C8 nerve roots and is a continuation of the lateral cord.
- Innervates the major elbow flexors and the biceps and brachialis and continues through the brachial fascia lateral to the biceps tendon, terminating as the lateral antebrachial cutaneous nerve.
- Motor branch enters the biceps about 15 cm distal to the acromion; it enters the brachialis about 20 cm below the tip of the acromion.

**Median Nerve**
- Median nerve arises from C5 through C8 and T1 nerve roots.
- The nerve enters the anterior aspect of the brachium, crossing in front of the brachial artery as it passes across the intramuscular septum.
  - It follows a straight course into the medial aspect of the antecubital fossa, medial to the biceps tendon and the brachial artery.
  - It then passes under the bicipital aponeurosis.
- There are no branches of the median nerve in the arm.
- The first motor branch is given to the pronator teres, through which it passes.
- In the antecubital fossa, a few small articular branches are given off before the motor branches to the pronator teres, the flexor carpi radialis, the palmaris longus, and the flexor digitorum superficialis.

**Anterior Interosseous Nerve**
- Arises from the median nerve near the inferior border of the pronator teres and travels along the anterior aspect of the interosseous membrane in the company of the anterior interosseous artery.
- Innervates the flexor pollicis longus and the lateral portion of the flexor digitorum profundus.

**Radial Nerve**
- Is a continuation of the posterior cord and originates from the C6, C7, and C8 nerve roots, with variable contributions of the C5 and T1 roots.
- In the midportion of the arm, the nerve courses laterally just distal to the deltoid insertion to occupy the groove in the humerus that bears its name.
- It then emerges in a spiral path inferiorly and laterally to penetrate the lateral intramuscular septum.
- Before entering the anterior aspect of the arm, it gives off the motor branches to the medial and lateral heads of the triceps, accompanied by the deep branch of the brachial artery.
- After penetrating the lateral intramuscular septum in the distal third of the arm, it descends anterior to the lateral epicondyle behind the brachioradialis.
- It innervates the brachioradialis with a single branch to this muscle.
- In the antecubital space, the nerve divides into the superficial and deep branches. The superficial branch is the continuation of the radial nerve and extends into the forearm to innervate the mid-dorsal cutaneous aspect of the forearm.
- Motor branches of the radial nerve are given off to the triceps above the spiral groove, except for the branch to the medial head of the triceps, which originates at the entry to the spiral groove.
- This branch continues distally through the medial head to terminate as a muscular branch to the anconeus.
- In the antecubital space, the recurrent radial nerve curves around the posterolateral aspect of the radius, passing deep through supinator muscle, which it innervates. During its course through the supinator muscle, the nerve lies over the bare area, which is distal to and opposite to the radial tuberosity. The nerve is believed to be at risk at this site with fractures of the proximal radius. It emerges from the muscle as the posterior interosseous nerve, and the recurrent branch innervates the extensor digitorum minimi, the extensor carpi ulnaris, and occasionally the anconeus.
- The posterior interosseous nerve is accompanied by the posterior interosseous artery and sends further muscle branches distally to supply the abductor pollicis longus, the extensor pollicis longus, the extensor pollicis brevis, and the extensor indicis on the dorsum of the forearm.

**Ulnar Nerve**
- The ulnar nerve is derived from the medial cord of the brachial plexus from roots C8 and T1. In the mid-arm, it passes posteriorly through the medial intramuscular septum and continues distally along the medial margin of the triceps in the company of the superior ulnar collateral branch of the brachial artery and the ulnar collateral branch of the radial artery.
- There are no branches of this nerve in the brachium.
- The ulnar nerve may undergo compression as it passes behind the medial epicondyle, emerging into the forearm through the cubital tunnel.
- The roof of the cubital tunnel has been defined by a structure termed the cubital tunnel retinaculum.
- The first motor branch is the single nerve to the ulnar origin of the pronator and another one to the epicondylar head of the flexor carpi ulnaris. Distally, the nerve sends a motor branch to the ulnar half of the flexor digitorum profundus.
- Two cutaneous nerves arise from the ulnar nerve in the distal half of the forearm to innervate the skin of the wrist and the hand.

**MUSCLES**

**Elbow Flexors**

**Biceps**
- Covers the brachialis muscle in the distal arm and passes into the cubital fossa as the biceps tendon, which attaches to the posterior aspect of the radial tuberosity.
- Bicipital aponeurosis or lacertus fibrosus is a broad, thin band of tissue that is a continuation of the anterior, medial, and distal muscle fascia. It runs obliquely to cover the median nerve and the brachial artery and inserts into the deep fascia of the forearm and possibly into the ulna as well.
- The biceps is a flexor of the elbow that has a large cross-sectional area but an intermediate mechanical advantage because it passes relatively close to the axis of rotation.
- In the pronated position, the biceps is a strong supinator of the forearm.
Brachialis
- Largest cross-sectional area of any of the elbow flexors but suffers from a poor mechanical advantage because it crosses so close to the axis of rotation
- Origin consists of the entire anterior distal half of the humerus, and it extends medially and laterally to the respective intermuscular septa.
- Crosses the anterior capsule, with some fibers inserting into the capsule that are said to help retract the capsule during elbow flexion.
- Insertion of the brachialis is along the base of the coronoid and into the tuberosity of the ulna.
- More than 95% of the cross-sectional area is muscle tissue at the elbow joint, a relationship that may account for high incidence of trauma to this muscle with elbow dislocation.

Brachioradialis
- Has a lengthy origin along the lateral supracondylar column that extends proximally to the level of the junction of the middle and distal humerus.
- Origin separates the lateral head of the triceps and the brachialis muscle.
- Lateral border of the cubital fossa is formed by this muscle, which crosses the elbow joint with the greatest mechanical advantage of any elbow flexor. It progresses distally to insert into the base of the radial styloid.
- Protects and is innervated by radial nerve (C5 and C6) as it emerges from the spiral groove.
- Major function is elbow flexion.

Extensor Carpi Radialis Longus
- Originates from the supracondylar bony column just below the origin of the brachioradialis.
- As it continues into the midportion of the dorsum of the forearm, it becomes largely tendinous and inserts to the dorsal base of the second metacarpal.
- Innervated by the radial nerve.
- Functions as wrist extensor, and possibly an elbow flexor.

Extensor Carpi Radialis Brevis
- Originates from the lateral superior aspect of the lateral epicondyle.
- Its origin is the most lateral of the extensor group and is covered by the extensor carpi radialis longus.
- This relationship is important as the most commonly implicated site of lateral epicondylitis.
- Extensor carpi radialis brevis shares the same extensor compartment as the longus as it crosses the wrist under the extensor retinaculum and inserts into the dorsal base of the third metacarpal.
- Function of the extensor carpi radialis brevis is pure wrist extension, with little or no radial or ulnar deviation.

Extensor Digitorum Communis
- Originating from the anterior distal aspect of the lateral epicondyle, the extensor digitorum communis accounts for most of the contour of the extensor surface of the forearm.
- Extends and abducts fingers.
- Innervation is from the deep branch of the radial nerve, with contributions from the sixth through eighth cervical nerves.

Supinator
- This flat muscle is characterized by the virtual absence of tendinous tissue and has a complex origin and insertion.
- It originates from three sites above and below the elbow joint: the lateral anterior aspect of the lateral epicondyle; the lateral collateral ligament; and the proximal anterior crest of the ulna along the crista supinatoris, which is just anterior to the depression for the insertion of the anconeus.
- Form of the muscle is roughly that of a rhomboid as it runs obliquely, distally, and radially to wrap around and insert diffusely on the proximal radius, beginning lateral and proximal to the radial tuberosity and continuing distal to the insertion of the pronator teres at the junction of the proximal middle third of the radius.
- The radial nerve passes through the supinator to gain access to the extensor surface of the forearm.
- This anatomic feature is clinically significant with regard to exposure of the lateral aspect of the elbow joint and the proximal radius and in certain entrapment syndromes.
- Functions as a supinator of the forearm, but it is a weaker supinator than the biceps.
- Unlike the biceps, however, the effectiveness of the supinator is not altered by the position of the elbow flexion.
- Innervation is derived from the muscular branch given off by the radial nerve just before and during its course through the muscle.

Elbow Extensors

Triceps Brachii
- Comprises the entire musculature of the arm posteriorly.
- Two of its three heads originate from the posterior aspect of the humerus.
- The long head has a discrete origin from the infraglenoid tuberosity of the scapula.
- The lateral head originates in a linear fashion from the proximal lateral intramuscular septum on the posterior surface of the humerus.
- The medial head originates from the entire distal half of the posteromedial surface of the humerus, bounded laterally by the radial groove and medially by the intramuscular septum.
- Each head originates distal to the other with progressively larger areas of origin.
- The long and lateral heads are superficial to the deep medial head, blending in the midline of the humerus to form a common muscle that then tapers into the triceps tendon and attaches to the tip of the olecranon with Sharpey fibers.
- The tendon is usually separated from the olecranon by the subcutaneous olecranon bursa.
- Innervated by the radial nerve, the long and lateral heads are supplied by branches that arise proximal to the entrance of the radial nerve into the groove.
- The medial head is innervated distal to the groove with a branch that enters proximally and passes through the entire medial head to terminate by innervating the anconeus.

Anconeus
- This muscle has little tendinous tissue because it originates from a rather broad site on the posterior aspect of the lateral epicondyle and from the lateral triceps fascia and inserts into the lateral dorsal surface of the proximal ulna.
Innervated by the terminal branch of the nerve to the medial head of the triceps
Function of this muscle has been the subject of considerable speculation.
Some suggest that the primary role is that of a joint stabilizer.
Covers the lateral portion of the annular ligament and the radial head
For the surgeon, the major significance of this muscle is its position as a key landmark in various lateral and posterolateral exposures, and it is used for some reconstructive procedures.

**Flexor Pronator Muscle Group**

**Pronator Teres**
- There are usually two heads of origin; the larger arises from the anterosuperior aspect of the medial epicondyle and the second from the coronoid process of the ulna, which is absent in about 10% of individuals.
- Innervated by two motor branches from the median nerve

**Flexor Carpi Radialis**
- The flexor carpi radialis originates inferior to the origin of the pronator teres and the common flexor tendon at the anteroinferior aspect of the medial epicondyle.
- It continues distally and radially to the wrist, where it can be easily palpated before it inserts into the base of the second and sometimes third metacarpal.
- Innervation is from one or two branches of the median nerve.

**Palmaris Longus**
- When present, it arises from the medial epicondyle and from the septa it shares with the flexor carpi radialis and flexor carpi ulnaris.
- It becomes tendinous in the proximal portion of the forearm and inserts into and becomes continuous with the palmar aponeurosis.
- Absent in about 10% of the extremities
- Innervated by a branch of the median nerve

**Flexor Carpi Ulnaris**
- Most posterior of the common flexor tendons originating from the medial epicondyle
- Second and largest source of origin is from the medial border of the coronoid and the proximal aspect of the ulna.
- Ulnar nerve enters and innervates the muscle between these two sites of origin with two or three motor branches given off just after the nerve has entered the muscle. The muscle continues distally to insert into the pisiform, where the tendon is easily palpable, because it serves as a wrist flexor and ulnar deviator.
- With an origin posterior to the axis of rotation, weak elbow extension may also be provided by the flexor carpi ulnaris.

**Flexor Digitorum Superficialis**
- The flexor digitorum superficialis muscle is deep to those originating from the common flexor tendon but superficial to the flexor digitorum profundus; thus it is considered the intermediate muscle layer.
- Innervated by two motor branches from the median nerve

**Flexor Digitorum Profundus**
- Originates from the proximal ulna distal to the elbow joint and is involved in flexion of the distal interphalangeal joints.
SHOULDER APPROACHES

ANTERIOR APPROACH TO THE SHOULDER

Indications
- Surgical stabilization for recurrent dislocations
- Subscapularis and biceps tendon repair
- Shoulder arthroplasty
- Fracture fixation

Incisions
- Anterior shoulder can be approached through two different incisions.
  - Anterior incision: 10- to 15-cm incision along the deltopectoral interval (FIG 1A)
    - Incision begins just above the coracoid process and progresses toward the deltoid tuberosity.
  - Axillary incision
    - Vertical incision 8 to 10 cm long (FIG 1B)
    - Incision begins inferior to the tip of the coracoid and progresses toward the anterior axillary fold.

Internervous Plane
- Deltoid muscle is supplied by the axillary nerve.
- Pectoralis major muscle is supplied by medial and lateral pectoral nerves.

Surgical Dissection
- Skin flaps are developed around the deltopectoral interval.
- The deltopectoral interval, with its cephalic vein, is identified.
- The deltopectoral interval is developed by retracting the pectoralis major medially and the deltoid laterally.
  - Vein may be retracted either medially or laterally.
  - We prefer to take it laterally, as fewer tributaries are disrupted.
- The lateral border of the conjoint tendon is identified and the short head of the biceps (supplied by the musculocutaneous nerve) and coracobrachialis (supplied by the musculocutaneous nerve) are displaced medially to allow access to the anterior aspect of the shoulder joint.
  - Simple medial retraction of the conjoined tendon may be enough for a procedure such as subscapularis repair or capsular repair.
  - If more exposure is necessary, the conjoint tendon can be detached with the tip of the coracoid process.
  - The axillary artery is surrounded by cords of brachial plexus, which lie behind the pectoralis minor muscle.
  - To minimize risk for nerve injury, the arm should be kept adducted while work is being done around the coracoid process.
  - Remember, the musculocutaneous nerve enters the coracobrachialis on its medial side.
  - Overly aggressive retraction can cause a neurapraxia of the musculocutaneous nerve.
  - Behind the conjoined tendon of the coracobrachialis and the short head of biceps lies the subscapularis muscle.
  - Externally rotating the arm brings the subscapularis further into the operative field.
  - This maneuver increases the distance between the subscapularis and axillary nerve as it disappears below the lower border of the muscle.
  - Identifiable landmarks on the inferior border of the subscapularis are three small vessels (from the anterior humeral circumflex artery) that run transversely and often require ligation or cauterization.
    - These vessels run as a triad (often called the “three sisters”): a small artery with its two surrounding venae comitantes.
    - The superior border of the subscapularis muscle blends in with the fibers of the supraspinatus muscle in the rotator interval (FIG 1C).
    - The tendon of the subscapularis is tagged with stay sutures.
    - There are various ways of taking down the subscapularis as per surgeon preference.
      - Some divide the subscapularis 1 to 2 cm from its insertion onto the lesser tuberosity.
      - Some detach this insertion with a small flake of bone using an osteotome.
    - Inferior border of the subscapularis is the easiest location to allow separation between the subscapularis and capsule.
    - The capsule is incised longitudinally to enter the joint wherever the selected repair must be performed.

ANTEROSUPERIOR APPROACH TO THE SHOULDER

Indications
- Rotator cuff repair
- Subacromial decompression of the shoulder
- Acromioclavicular reconstructions
- Greater tuberosity fractures
- Removal of calcific deposits from the subacromial bursa
- Reverse shoulder replacement

Incision
- An incision is made paralleling the lateral acromion that begins at the anterolateral corner of the acromion and ends just lateral to the tip of the coracoid (FIG 2A).

Internervous Plane
- The deltoid muscle is detached proximal to its nerve supply; therefore, there is no internervous plane with this approach.

Surgical Dissection
- The incision is deepened to the deep deltoid fascia.
- Subcutaneous flaps are raised.
The location of the deltoid split depends on the pathology being managed. When the pathology requires more exposure, moving the deltoid split posteriorly will improve exposure (FIG 2B).

Subperiosteally, the anterior deltoid is elevated from the acromion and the acromioclavicular joint. Continue the detachment by sharp dissection laterally to expose the anterior aspect of the acromion.

- Bleeding will be encountered during this dissection as a result of the division of the acromial branch of the coracoacromial artery.
- The surgeon should not detach more of the deltoid than is necessary.
- The deltoid split is extended 2 to 3 cm distal to the acromion.
- Stay sutures are inserted in the apex of the split to prevent the muscle from inadvertently splitting distally during retraction and damaging the axillary nerve.

FIG 1 • A. Deltopectoral incision. B. Axillary incision beginning inferior to the tip of the coracoid and progressing toward the anterior axillary fold. C. In this dissection, the subscapularis tendon is being tagged at the superior border of the rotator interval.

FIG 2 • A. Anterosuperior approach to the shoulder. A transverse incision begins at the anterolateral corner of the acromion and ends just lateral to the coracoid. B. The posterior curve of the deltoid incision can be moved more posteriorly, as depicted here, to allow necessary exposure as dictated by the pathology.
POSTERIOR APPROACH TO THE SHOULDER

Indications
- Repair in cases of recurrent posterior dislocation or subluxation of the shoulder
- Glenoid osteotomy
- Treatment of fractures of the scapular neck
- Treatment of posterior fracture and dislocations of the proximal humerus
- Spinoglenoid notch cyst drainage

Incision
- A horizontal incision is made along the scapular spine extending to the posterolateral corner of the acromion (FIG 3A)

Internervous Plane
- Between teres minor (axillary nerve) and infraspinatus (suprascapular nerve)
- The suprascapular nerve passes around the base of the spine of the scapula as it runs from the supraspinatus fossa to the infraspinatus fossa.

Surgical Dissection
- The origin of the deltoid is identified on the scapular spine. There are three ways to manage the deltoid during posterior exposures:
  - Detach the origin on the scapular spine
  - Split the deltoid muscle along the length of its fibers
  - Elevate the deltoid from the inferior margin
- The plane between the deltoid muscle and the underlying infraspinatus muscle is identified.
- The plane is easier to locate at the lateral end of the incision.
- The internervous plane between the infraspinatus and teres minor muscles is identified (FIG 3B).
- The axillary nerve runs longitudinally in the quadrangular space beneath the teres minor.
- The posterior circumflex humeral artery runs with the axillary nerve in the quadrangular space between the inferior borders of the teres minor muscle.
- The infraspinatus is retracted superiorly and the teres minor inferiorly to reach the posterior regions of the glenoid cavity and the neck of the scapula.
- The posteroinferior corner of the shoulder joint capsule should be visible.

HUMERUS APPROACHES

ANTERIOR APPROACH TO THE HUMERUS

Indications
- Internal fixation of fractures of the humerus
- Management of humeral nonunions
- Osteotomy of the humerus

Incision
- A longitudinal incision is made over the tip of the coracoid process of the scapula; it runs distally and laterally in the line of the deltopectoral interval to the insertion of the deltoid muscle on the lateral aspect of the humerus, about halfway down its shaft.
- The incision should be continued distally as far as necessary, following the lateral border of the biceps muscle (FIG 4A).

Internervous Plane
- Between teres minor (axillary nerve) and pectoralis major muscle (supplied by medial and lateral pectoral nerves) (FIG 4B).
- Distally, the plane lies between the medial fibers of the brachialis muscle (musculocutaneous nerve) and the lateral fibers of the brachialis muscle (radial nerve) (FIG 4C).

Surgical Dissection

Proximal Humeral Shaft
- The deltopectoral interval is identified using the cephalic vein as a guide and the two muscles are separated, retracting the cephalic vein either medially with the pectoralis major or laterally with the deltoid.
FIG 4 • A. Patient prepared for an anterior approach to the humerus. B. The internervous plane between the deltoid muscle and the pectoralis major muscle. C. Further distally, one can appreciate the internervous plane between the medial fibers of the brachialis (musculocutaneous nerve) medially and the lateral fibers of the brachialis (radial nerve) laterally. D. Deltopectoral incision: developing the interval between the deltoid and pectoralis major. The cephalic vein can be seen separating these two structures. E. With deeper dissection, the biceps tendon is seen running in the rotator interval. F. Further distal dissection reveals the musculocutaneous nerve passing along the medial border of the biceps muscle. G. To expose the distal third of the humerus, the fibers of the brachialis are split. Flexion of the elbow will relieve the tension off the brachialis, making the exposure easier. (A: Courtesy of Matthew J. Garberina, MD, and Charles L. Getz, MD.)
The muscular interval is developed distally down to the insertion of the deltoid into the deltoid tuberosity and the insertion of the pectoralis major into the lateral lip of the bicipital groove (FIG 4D,E).
- To expose the bone fully, the surgeon may need to detach part or all of the insertion of pectoralis major muscle.
- The minimum amount of soft tissue should be detached to allow adequate visualization and reduction of the fracture.
- If further exposure is needed, the surgeon dissects medially in a subperiosteal manner to avoid damage to the radial nerve, which lies in the spiral groove of the humerus and crosses the back of the middle third of the bone in a medial to lateral direction.

**Distal Humeral Shaft**
- The surgeon identifies the muscular interval between the biceps brachii and brachialis.
- The interval is developed by retracting the biceps medially (FIG 4F).
- Beneath it lies the brachialis muscle, which covers the humeral shaft.
- The fibers of the brachialis are split longitudinally in the interval between the medial 2/3 and the lateral 1/3 to expose the periosteum on the anterior surface of the humeral shaft.
- The periosteum is incised longitudinally in line with the muscle dissection, and the brachialis is stripped off the anterior surface of the bone (FIG 4G).
- In the anterior compartment of the distal third of the arm, the radial nerve pierces the lateral intermuscular septum and lies between the brachioradialis and brachialis muscles.

**POSTERIOR APPROACH TO THE HUMERUS**

**Indications**
- Open reduction and internal fixation of a fracture of the humerus
- Treatment of nonunion
- Exploration of the radial nerve in the spiral groove

**Incision**
- A longitudinal incision is made in the midline of the posterior aspect of the arm, from 8 cm below the acromion to the olecranon fossa (FIG 5A).

**Internervous Plane**
- There is no true internervous plane; dissection involves separating the heads of the triceps brachii muscles, all of which are supplied by the radial nerve.
- The medial head, which is the deepest, has a dual nerve supply (radial and ulnar nerves).

**Surgical Dissection**
- The surgeon incises the deep fascia of the arm in line with the skin incision.
- The triceps muscle has two layers:
  - The outer layer consists of two heads: the lateral head arises from the lateral lip of the spiral groove, and the long head arises from the infraglenoid tubercle of the scapula (FIG 5B).
  - The inner layer consists of the medial head, which arises from the whole width of the posterior aspect of the humerus.

*FIG 5 • A. Posterior approach to the humerus, showing the longitudinal incision along the midline of the posterior aspect of the arm. B. Once the outer layer of the triceps is isolated, one can see the two heads, the lateral head and long head. (continued)*
below the spiral groove all the way down to the distal fourth of the bone.
  - The spiral groove contains the radial nerve; the radial nerve separates the origins of the lateral and medial heads (FIG 5C).
  - To avoid iatrogenic nerve injury, the surgeon should never continue dissection down to bone in the proximal two thirds of the arm until the radial nerve has been identified.

**MODIFIED POSTERIOR APPROACH TO THE HUMERUS**

**Indications**
- Open reduction and internal fixation of humeral shaft fractures
- Open reduction and internal fixation of lateral condyle fractures
- Treatment of humeral nonunion
- Exploration of the radial nerve in the spiral groove

**Incision**
- The surgeon makes a straight incision along a line between the posterolateral aspect of the acromion and the lateral edge of the olecranon.
- The length of the incision is dictated by the requirement for exposure.
- Extensile exposure is limited proximally by the axillary nerve.

**Internervous Plane**
- There is no true internervous plane, because both the medial and lateral heads of the triceps are supplied by the radial nerve.

**Surgical Dissection**
- The deep fascia is incised in line with the skin incision along the lateral aspect of the triceps.
Triceps-Splitting Approaches

Posterior Triceps-Splitting Approach (Campbell)
- Care must be exercised to maintain the medial portion of the triceps expansion over the forearm fascia in continuity with the flexor carpi ulnaris.
- Laterally, the anconeus and triceps are more stable, with less chance of disruption.

Indications
- Total elbow arthroplasty
- Distal humerus fracture
- Removal of loose bodies
- Capsulectomies
- Posterior exposure of the joint for ankylosis, sepsis, synovectomy, and ulnohumeral arthroplasty

Approach
- Skin incision begins in the midline over the triceps, about 10 cm above the joint line, and is generally placed laterally or medially across the tip of the olecranon. It continues distally over the lateral aspect of the subcutaneous border of the proximal ulna for about 5 to 6 cm (FIG 7A).
- Triceps is exposed, along with the proximal 4 cm of the ulna.
- A midline incision is made through the triceps fascia and tendon as it is continued distally across the insertion of the triceps tendon at the tip of the olecranon and down the subcutaneous crest of the ulna (FIG 7B).
- Triceps tendon and muscle are split longitudinally, exposing the distal humerus.
- Anconeus is then reflected subperiosteally laterally, while the flexor carpi ulnaris is similarly retracted medially.
- Insertion of the triceps is carefully released from the olecranon, leaving the extensor mechanism in continuity with the forearm fascia and muscles medially and laterally (FIG 7C).
- Ulnar nerve is visualized and protected in the cubital tunnel.
- Closure of the triceps fascia is required only proximal to the olecranon, but the insertion should be repaired to the olecranon with a suture passed through the ulna.
- The incision is then closed in layers.

Triceps-Splitting, Tendon-Reflecting Approach (Van Gorder)
- A variation of the technique described earlier
- Allows lengthening of the triceps if necessary
- Has been largely abandoned in favor of the triceps-reflecting techniques

Indications
- Same as those for midline-splitting approach described earlier

Approach
- A posterior midline incision begins 10 cm proximal to the olecranon and extends distally onto the subcutaneous border of the ulna between the anconeus and the flexor carpi ulnaris.
- Triceps fascia and aponeurosis are exposed along the tendinous insertion into the ulna.
■ Tendon is reflected from the muscle in a proximal to distal direction, freeing the underlying muscle fibers while preserving the tendinous attachment to the olecranon (FIG 8).
■ Triceps muscle is then split in midline, and the distal humerus is exposed subperiosteally.
■ Periosteum and triceps are elevated for a distance of about 5 cm proximal to the olecranon fossa, exposing the posterior aspect of the joint.
■ If more extensive exposure is desired, the subperiosteal dissection is extended to the level of the joint, exposing the condyles both medially and laterally.
■ Ulnar nerve should be identified and protected.
■ After the procedure, if an elbow contracture has been corrected, the joint should be maximally flexed.
■ The tendon slides distally from its initial position, and the proximal muscle and tendon are reapproximated in the lengthened relationship.

The distal part of the triceps is then securely sutured to the fascia of the triceps expansion, and the remainder of the wound is closed in layers.

**Triceps-Reflecting Approaches**

■ The triceps mechanism may be preserved in continuity with the anconeus and simply reflected to one side or the other.
■ Three surgical approaches have been described that preserve the triceps muscle and tendon in continuity with the distal musculature of the forearm fascia and expose the entire joint.

**Bryan-Morrey Posteromedial Triceps-Reflecting Approach**

■ Developed to preserve the continuity of the triceps with the anconeus

**INDICATIONS**

■ Total elbow arthroplasty
■ Interposition arthroplasty
Elbow dislocation
Distal humerus fracture
Synovial disease
Infection

**APPROACH**

- A straight posterior incision is made medial to the midline, about 9 cm proximal and 8 cm distal to the tip of the olecranon (FIG 9A).
- The ulnar nerve is identified proximally at the margin of the medial head of the triceps and, depending on the procedure, is either protected or carefully dissected to its first motor branch and transposed anteriorly.
- The medial aspect of the triceps is elevated from the posterior capsule.
- The fascia of the forearm between the anconeus and the flexor carpi ulnaris is incised distally for about 6 cm.
- The triceps and the anconeus are elevated as one flap from medial to lateral, skeletonizing the olecranon and subcutaneous border of the ulna (FIG 9B). This should be performed at 20 to 30 degrees of flexion to relieve tension on the insertion, thereby facilitating dissection.
- The collateral ligaments may be released from the humerus for exposure as needed (FIG 9C).
- If stability is important, these ligaments should be preserved or anatomically repaired at the conclusion of the surgery.
- When performing a linked total elbow replacement, it is not necessary to preserve or repair the collateral ligaments.

---

**FIG 8** Triceps-splitting, tendon-reflecting approach. The tendon is reflected from the muscle in a proximal to distal direction.

**FIG 9** The Bryan-Morrey posterior approach. **A.** Straight posterior skin incision. **B.** The ulnar nerve has been translocated anteriorly. The medial border of the triceps is identified and released and the superficial forearm fascia is sharply incised to allow reflection of the fascia and periosteum from the proximal ulna. **C.** The extensor mechanism has been reflected laterally and the collateral ligaments have been released.
Chapter 2 SURGICAL APPROACHES TO THE SHOULDER AND ELBOW

Triceps

Ulnar nerve

Anconeus

FIG 10 • Posterior view of the right elbow demonstrates a straight fascial incision to the lateral aspect of the tip of the olecranon. A. The line of release after the ulnar nerve has been identified and protected. (continued)

- The triceps attachment can be thin at the attachment to the ulna and it is not uncommon for a buttonhole to be created when reflecting the triceps.
  - To prevent this, the flap can be raised as an osteoperiosteal flap (see osteocutaneous flap approach).
  - A small osteotome is used to elevate the fascia with the petals of bone.
  - The flap is mobilized laterally, elevating the anconeus origin from the distal humerus until it can be folded over the lateral humeral condyle.
  - At this point, the radial head can be visualized.
  - The tip of the olecranon can be excised to help expose the trochlea.

Osteoanconeus Flap Approach

- This provides excellent extension and reliable healing of the osseous attachment to the olecranon.
- This approach exposes only the ulnar nerve, whereas the Mayo approach translocates the nerve.

INDICATIONS
- This is a triceps-reflecting approach similar in concept to the Bryan-Morrey triceps-reflecting approach.
- Most often used for joint replacement or distal humeral fractures

APPROACH
- A straight posterior incision is made medial to the midline, about 9 cm proximal and 8 cm distal to the tip of the olecranon.
- The ulnar nerve is identified and protected, but not translocated.
- The triceps attachment is released from the ulna by osteotomizing the attachment with a thin wafer of bone.
  - This is the essential difference from the Bryan-Morrey approach.
  - The medial aspect of the triceps, in continuity with the anconeus, is elevated from the ulna (FIG 10A,B).
  - The collateral ligaments are either maintained or released, depending on the pathology being addressed and the need for stability.
  - After the surgical procedure, the wafer of bone is secured to its bed by nonabsorbable sutures placed through bone holes (FIG 10C).
  - Interrupted sutures are used to repair the remaining distal portion of the extensor mechanism.

Extensile Kocher Posterolateral Triceps-Reflecting Approach

INDICATIONS
- Joint arthroplasty
- Ankylosis
- Distal humerus fractures
- Synovectomy
- Radial head excision
- Infection

APPROACH
- Extensile exposure from the Kocher approach
- Skin incision begins 8 cm proximal to the joint just posterior to the supracondylar ridge and continues distally over the Kocher interval between the anconeus and extensor carpi ulnaris about 6 cm distal to the tip of the olecranon
- Proximally, the triceps is identified and freed from the brachioradialis and extensor carpi radialis longus along the intramuscular septum to the level of the joint capsule.
- The interval between the extensor carpi ulnaris and the anconeus is identified distally.
- The triceps in continuity with the anconeus is subperiosteally reflected. Sharp dissection frees the bony attachment of the triceps expansion to the anconeus from the lateral epicondyle.
- The triceps remains attached to the tip of the olecranon.
- The lateral collateral ligament complex is released from the humerus.
- The joint may be dislocated with varus stress. If additional exposure is necessary, the anterior and posterior capsule can be released.
- Routine closure of layers is performed, but the radial collateral ligament should be reattached to the bone through holes placed in the lateral epicondyle.

A
Mayo Modified Extensile Kocher Approach
- The extensile Kocher approach and the Mayo modification of the extensile Kocher approach provide sequentially greater exposure from the initial Kocher approach.

INDICATIONS
- Release of ankylosed joint
- Interposition arthroplasty
- Replacement arthroplasty

APPROACH
- A modification of the extensile Kocher approach consists of reflecting the anconeus and triceps expansion from the tip of the olecranon by sharp dissection.
- The extensor mechanism (triceps in continuity with the anconeus) may be reflected from lateral to medial.
- The ulnar nerve should be decompressed or transposed if an extensile lateral approach is used.
- The triceps is reattached in a fashion identical to that described for the Mayo approach.

Triceps-Preserving Approaches
Posterior Triceps-Sparing Approach
- Because the triceps is not elevated from the tip of the olecranon, rapid rehabilitation is possible.

**INDICATIONS**
- Tumor resection
- Joint reconstruction for resection of humeral nonunion
- Joint replacement

**APPROACH**
- A posterior incision is made medial to the tip of the olecranon.
- Medial and lateral subcutaneous skin flaps are elevated.
- The ulnar nerve is identified and transposed anteriorly.
- The medial and lateral aspects of the triceps are identified and developed distally to the triceps attachment on the ulna.
- For distal humerus fractures fixation:
  - The common flexors and common extensors are partially released from the distal humerus to expose the supracondylar column for plate fixation.
- For total elbow arthroplasty or tumor resection:
  - The common flexors and extensors are fully released from the medial and lateral epicondyle. The collateral ligaments and capsule are released and the distal humerus is excised.
  - The distal humerus is exposed by bringing it through the defect along the lateral margin of the triceps.
  - The ulna is exposed by supinating the forearm.
  - After the implant has been inserted, the joint is articulated.
There is no need to close or repair the extensor mechanism with this approach.

**Olecranon Osteotomy**

- Worldwide, the transosseous approach is probably the exposure most often used, especially for distal humeral fractures. The oblique osteotomy has almost been abandoned, and the transverse osteotomy has largely been replaced by the chevron.

**Chevron Transolecranon Osteotomy**

- Intra-articular osteotomy, first described by MacAusland, was originally recommended for ankylosed joints.
- It has been adapted by some for radial head excision and synovectomy and used or modified by others for T and Y condylar fractures.
- The chevron osteotomy enhances rotational stability compared to a transverse osteotomy.

**INDICATIONS**

- Ankylosed joints
- T or Y condylar fractures

**APPROACH**

- A posterior incision is made medial to the tip of the olecranon.
- Medial and lateral subcutaneous skin flaps are elevated.
- The ulnar nerve is identified and transposed anteriorly.
- The medial and lateral aspects of the triceps are identified and developed distally to the triceps attachment on the ulna.
- An apex-distal chevron or V osteotomy is performed with a thin oscillating saw but not completed through the subchondral bone. An osteotome completes the osteotomy, creating irregular surfaces that interdigitate increasing stability (**FIG 11A,B**).
- The triceps tendon, along with the osteotomized portion of the olecranon, may then be retracted proximally, and by flexing the elbow joint, the joint can be exposed (**FIG 11C**).

Occasionally the medial or lateral collateral ligaments are released for better exposure.
- These ligaments are then repaired at the end of the procedure.
- At the completion of the procedure, the tip of the olecranon is secured via tension-band or plate fixation.

**LATERAL APPROACH TO THE ELBOW**

- Lateral exposures to the elbow are widely used to treat a variety of elbow pathologies. The exposures differ according to the deep interval used.
- With any of the lateral exposures to the joint or to the proximal radius, the surgeon must be constantly aware of the possibility of injury to the posterior interosseous or recurrent branch of the radial nerve.

**Anterolateral Approach to the Elbow (Kaplan)**

**Indications**

- Anterior capsular release
- Posterior interosseous nerve exposure
- Capitellar/lateral column fractures

**Approach**

- Deep interval for the anterolateral approach lies between the extensor digitorum communis and the extensor carpi radialis longus muscles. (Intermuscular interval is best found by observing where vessels penetrate the fascia along the anterior margin of the extensor digitorum communis aponeurosis.)
- Fascia is split longitudinally between the extensor digitorum communis and the extensor carpi radialis longus. (As the dissection is carried deep through the extensor carpi radialis longus, the extensor carpi radialis brevis is encountered.)
- Deep to the extensor carpi radialis brevis, the transversely oriented fibers of the supinator are encountered, along with the posterior interosseous nerve. The posterior interosseous
nerve defines the distal extent of the exposure. Pronation moves the radial nerve away from the surgical field.

- If required, proximal dissection with elevation of the extensor carpi radialis longus, extensor carpi radialis brevis, and brachioradialis anteriorly from the lateral supracondylar ridge of the humerus provides exposure of the anterior joint capsule.

**Modified Distal Kocher Approach**

**Indications**

- Reconstruction of the lateral ulnar collateral ligament

**Approach**

- The skin incision begins just proximal to the lateral epicondyle of the humerus and extends obliquely for about 6 cm in line with the fascia of the anconeus and extensor carpi ulnaris muscles (FIG 12A).
- The Kocher interval between the anconeus and flexor carpi ulnaris is incised (FIG 12B).
- Development of the Kocher interval reveals the lateral joint capsule.

- The anconeus is then reflected posteriorly off the joint capsule distally to expose the crista supinatoris.
- The extensor carpi ulnaris and the common extensor tendon are released from the lateral epicondyle and reflected anteriorly, exposing the lateral capsule. The radial nerve is at a safe distance from the dissection, and it is protected by the extensor carpi ulnaris and extensor digitorum communis muscle mass (FIG 12C).
- A longitudinal incision is made through the capsules to expose the radiocapitellar joint.

**Boyd (Posterolateral) Approach**

**Indications**

- Monteggia fracture-dislocations
- Radial head fractures
- Radioulnar synostosis

**Approach**

- The incision begins just posterior to the lateral epicondyle lateral to the triceps tendon and continues distally to the lat-
eral tip of the olecranon and then down to the subcutaneous border of the ulna.
- The anconeus and supinator are subperiosteally elevated from the subcutaneous border of the ulna (anconeus and supinator) (FIG 13A,B).
- Retraction of the anconeus and supinator exposes the joint capsule overlying the radial head and neck.
- The supinatis muscle protects the posterior interosseous nerve.
- This lateral capsule contains the lateral ulnar collateral ligament, and its division can lead to posterolateral rotatory instability.
- To expose the radial shaft, the incision may be continued along the subcutaneous ulnar border, elevating the muscles off the lateral aspect of the ulna (extensor carpi ulnaris, abductor pollicis longus, and extensor pollicis longus).
- The posterior interosseous and recurrent interosseous arteries may need ligation.

**MEDIAL APPROACH TO THE ELBOW**
- There are relatively few indications for medial exposure of the elbow joint. This has been superseded by arthroscopic approaches.
- The most valuable contribution to medial joint exposure is that described by Hotchkiss. This extensile exposure provides greater flexibility, particularly for exposure of the coronoid and for contracture release.

**Extensile Medial Over-the-Top Approach**
- Excellent visualization of the anteromedial and posteromedial elbow
- Not a sufficient approach for excision of heterotopic bone on the lateral side of the joint
- Does not provide adequate access to the radial head

**Indications**
- Coronoid fractures
- Contracture release (when ulnar nerve exploration required)
- Anterior and posterior access to the joint
- May be converted to a triceps-reflecting exposure of Bryan-Morrey

**Approach**
- Superficial dissection
  - Skin incision can vary between the boundaries of a pure posterior skin incision and midline medial incision (FIG 14A).
  - Subcutaneous skin is elevated.
  - The medial supracondylar ridge of the humerus, the medial intramuscular septum, the origin of the flexor pronator mass, and the ulnar nerve are identified.
  - Anterior to the septum, running just on top of the fascia (not in the subdermal tissue), the medial antebrachial cutaneous nerve is identified and protected.
  - The ulnar nerve is identified. If the patient previously had surgery, the ulnar nerve should be identified proximally before the surgeon proceeds distally.
  - If anterior transposition was performed previously, the nerve should be mobilized carefully before the operation proceeds.
  - The surface of the flexor pronator muscle mass origin is found by sweeping the subcutaneous tissue laterally with the medial antebrachial cutaneous nerve in this flap of subcutaneous tissue.
  - The medial intramuscular septum divides the anterior and posterior compartments of the elbow. The medial intramuscular septum is ultimately excised from the medial epicondyle to 5 cm proximal to it (FIG 14B).
  - The ulnar nerve is protected and the veins at the base of the septum are cauterized.
- Deep anterior exposure
  - The flexor pronator mass origin is identified and totally or partially released from the medial epicondyle.
  - If extensile exposure is needed, the entire flexor pronator mass is elevated from the medial epicondyle (FIG 14C,D).
  - If less extensile exposure is needed, the flexor pronator mass is divided parallel to the fibers, leaving about 1.5 cm of flexor carpi ulnaris tendon attached to the epicondyle.
  - A small cuff of fibrous tissue of the origin can be left on the supracondylar ridge as the muscle is elevated; this facilitates reattachment when closing.
  - The flexor pronator origin should be dissected down to the level of bone but superficial to the joint capsule. As this

---

**FIG 13** • The Boyd approach. A, The incision begins along the lateral border of the triceps about 2 to 3 cm above the epicondyle and extends distally over the lateral subcutaneous border of the ulna about 6 to 8 cm past the tip of the olecranon. The ulnar insertion of the anconeus and the origin of the supinator muscle are elevated subperiosteally. More distally, the subperiosteal reflection includes the abductor pollicis longus, the extensor carpi ulnaris, and the extensor pollicis longus muscles. The origin of the supinator at the crista supinatorus of the ulna is released, and the entire muscle flap is retracted radially, exposing the radiohumeral joint. B. The posterior interosseous nerve is protected in the substance of the supinator.
plane is developed, the brachialis muscle is encountered from the underside.
- The brachialis muscle is identified along the supracondylar ridge and released in continuity with the flexor pronator mass.
- These muscles should be kept anterior and elevated from the capsule and anterior surface of the distal humerus.
- The median nerve and the brachial vein and artery are superficial to the brachialis muscle and protected with the subperiosteal release of the brachialis.
- Dissection of the capsule proceeds laterally and distally to separate it from the brachialis.
- In the case of contracture, the capsule, once separated from the overlying brachialis and brachioradialis, can be sharply excised (FIG 14E).

Deep posterior capsule exposure
- The ulnar nerve is mobilized to permit anterior transposition with a dissection carried distally to the first motor branch to allow the nerve to rest in the anterior position without being sharply angled as it enters the flexor carpi ulnaris.
- With the Cobb elevator, the triceps is elevated from the posterior distal surface of the humerus.
- The posterior capsule can be separated from the triceps as the elevator sweeps from the proximal to distal.

Closure
- The flexor pronator mass should be reattached to the supracondylar ridge.
- The ulnar nerve should be transposed and secured with a fascial sling to prevent posterior subluxation.

FIG 14 • A. Medial skin incision along the midline. 
B. The medial intermuscular septum (light blue) is excised from the medial epicondyle to 5 cm proximal to it. The ulnar nerve is shown tagged with a suture loop. 
C,D. If the extensile exposure is needed, the entire flexor pronator muscle mass is elevated from the medial epicondyle. 
E. The capsule can be sharply excised in cases of capsular contracture.
ANTERIOR APPROACH TO THE ELBOW

- Because of the vulnerability of the brachial artery and median nerve, the anterior medial approach to the elbow is not recommended.
- The extensile exposure described by Henry, and modified by Fiolle and Delmas, is best known and is the most useful for anterior exposure of the joint. Minor modifications of the Henry approach have been described, and a limited anterolateral exposure has been described by Darrach.

Modified Anterior Henry Approach

**Indications**
- Anteriorly displaced fracture fragments
- Excision of tumors in this region
- Reattachment of the biceps tendon to the radial tuberosity
- Exploration of nerve entrapment syndromes
- Anterior capsular release for contracture

**Approach**
- The skin incision begins about 5 cm proximal to the flexor crease of the elbow joint and extends distally along the anterior margin of the brachioradialis muscle to the flexion crease.
- At the elbow flexion crease, the incision turns medially to avoid crossing the flexor crease at a right angle. The incision continues transversely to the biceps tendon and then turns distally over the medial volar aspect of the forearm (FIG 15A).
- The fascia is released distally between the brachioradialis and pronator teres (FIG 15B).
- The interval between the brachioradialis laterally and the biceps and brachialis medially is identified. This interval is entered proximally, and gentle, blunt dissection demonstrates the radial nerve coursing on the inner surface of the brachioradialis muscle (FIG 15C).
- Care is taken to avoid injury to the superficial sensory branch of the radial nerve.
- Because the radial nerve gives off its branches laterally, it can safely be retracted with the brachioradialis muscle.
- At the level of the elbow joint, as the brachioradialis is retracted laterally and the pronator teres is gently retracted medially, the radial artery can be observed where it emerges from the medial aspect of the biceps tendon, giving off its muscular and recurrent branches in a mediolateral direction.
- The muscle branch is ligated, but the recurrent radial artery should be sacrificed only if the lesion warrants an extensive exposure.
- The posterior interosseous nerve enters the supinator and continues along the dorsum of the forearm distally.
- Dissection continues distally, exposing the supinator muscle, which covers the proximal aspect of the radius and the anterolateral aspect of the capsule (FIG 15C).
- Muscle attachments to the anterior aspect of the radius and those distal to the supinator include the discrete tendinous insertion of the pronator teres and the origins of the flexor digitorum sublimis and the flexor pollicis longus.
- The brachialis muscle is identified, elevated, and retracted medially to expose the proximal capsule.
- If more distal exposure is needed, the forearm is fully supinated, demonstrating the insertion of the supinator muscle along the proximal radius.
- This insertion is incised and the supinator is subperiosteally retracted laterally (FIG 15D).
- The supinator serves as a protection to the deep interosseous branch of the radial nerve, but excessive retraction of the muscle should be avoided.
- The proximal aspect of the radius and the capitellum are thus exposed.
- Additional visualization may be obtained both proximally and distally, because the radial nerve has been identified and can be avoided proximally.
- The posterior interosseous nerve is protected distally by the supinator muscle, and the radial artery is visualized and protected medially if a more extensile exposure is required.

<table>
<thead>
<tr>
<th>Indication</th>
<th>Recommended Approach</th>
<th>Alternative Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total elbow arthroplasty</td>
<td>Bryan-Morrey, extended Kocher</td>
<td>Gschwend et al, Campbell, and Wadsworth</td>
</tr>
<tr>
<td>Soft tissue reconstruction</td>
<td>Global</td>
<td>Kocher, Bryan-Morrey, and Hotchkiss</td>
</tr>
<tr>
<td>T intercondylar fracture</td>
<td>MacAusland with chevron olecranon osteotomy</td>
<td>Alonso-Llames</td>
</tr>
<tr>
<td>Radial head fracture</td>
<td>Kocher</td>
<td>Kaplan</td>
</tr>
<tr>
<td>Capitellum fracture</td>
<td>Kaplan extended lateral approach</td>
<td>Kocher with or without Kaplan</td>
</tr>
<tr>
<td>Coronoid fracture</td>
<td>Taylor and Scham</td>
<td>Hotchkiss</td>
</tr>
<tr>
<td>Extra-articular distal humerus fracture</td>
<td>Alonso-Llames</td>
<td>Bryan-Morrey, Campbell</td>
</tr>
<tr>
<td>Monteggia fracture-dislocation</td>
<td>Gordon</td>
<td>Boyd</td>
</tr>
<tr>
<td>Radioulnar synostosis excision</td>
<td>Kocher or Gordon</td>
<td>Boyd or Henry</td>
</tr>
</tbody>
</table>

Table 1: Indications and Recommended and Alternative Surgical Approaches
The anterior Henry approach. 

A. An incision is made about 5 cm proximal to the elbow crease on the lateral margin of the biceps tendon. It extends transversely across the joint line and curves distally over the medial aspect of the forearm. The interval between the brachioradialis and brachialis proximally and the biceps tendon and pronator teres in the distal portion of the wound is identified. The radial nerve is protected and retracted along with the brachialis.

B. The supinator muscle is released from the anterior aspect of the radius, which is fully supinated.

C. The radial recurrent branches of the radial artery and its muscular branches are identified and sacrificed if more extensive exposure is required. The biceps tendon is retracted medially along with the brachialis muscle.

D. This interval may now be developed to expose the anterior aspect of the elbow joint.
DEFINITION
- Shoulder instability is caused by a disruption of the normal stabilizing anatomic structures of the shoulder, leading to recurrent dislocation or subluxation of the glenohumeral joint.

ANATOMY
- Glenohumeral stability depends on the integrity of static and dynamic components.
- Dynamic stabilizers include the rotator cuff muscles, which provide a concavity compression effect, the scapular stabilizers, and the biceps tendon, which contributes to anterior stability when the arm is in an abducted and externally rotated position (FIG 1A,B).
- Static stabilizers consist of the bony and articular anatomy of the glenoid and humeral head, the negative intra-articular pressure supplied by the intact glenohumeral capsule, and the capsule-labral complex, which contains the glenoid labrum and anterior, middle, and superior glenohumeral ligaments (FIG 1C).
- The glenoid labrum plays an important role in deepening the glenoid socket and as an attachment site for the glenohumeral ligaments (FIG 1D).
- The primary restraint to anterior inferior translation of the humeral head in 90 degrees of abduction and external rotation is the inferior glenohumeral ligament (IGHL).
- The middle glenohumeral ligament (MGHL) has a variable attachment site into the glenoid labrum, glenoid neck, and biceps tendon origin. The MGHL is important in resisting anterior subluxation of the humeral head in the middle range of shoulder abduction (45 degrees).
- The superior glenohumeral ligament (SGHL) is located in the rotator interval capsule, and prevents inferior and posterior subluxation of the humeral head with the arm in an ad-
ducted and neutral or internally rotated position. The SGHL is important in inferior and posterior translation of the humeral head.

PATHOGENESIS
- Glenohumeral instability (subluxation or dislocation) occurs when the static or dynamic stabilizers of the gleno-humeral joint are disrupted, either from acute rupture or repetitive microtrauma.
- The “essential anatomical defect,” or Bankart lesion, was first described by a British pathologist, A. Blundell Bankart, in 1923, and the operative procedure was first described in 1938 (FIG 2A).³,²⁰
  - The Bankart lesion is present in at least 40% of shoulders undergoing anterior instability procedures.
  - The “essential” nature of the Bankart lesion has been challenged, since a simulated Bankart lesion without capsular stretching does not lead to significant increases in gleno-humeral translation.
- In addition to tearing of the glenoid labrum, the labrum may also be avulsed from the glenoid rim as a sleeve of tissue (anterior labral periosteal sleeve avulsion [ALPSA]) (FIG 2B).¹⁷
- Recurrent major trauma and repetitive microtrauma creates substantial deformation to the IGHL, producing subsequent episodes of symptomatic subluxation.
- Biomechanical studies of this ligament have demonstrated that failure typically occurs at the glenoid insertion (40%), followed by the ligament substance (35%) and the humeral attachment (25%). Significant capsular stretching can occur (23% to 34%) before failure.
- Osseous deficiency on the anterior rim (bony Bankart) may contribute to glenohumeral instability (FIG 2C).
- Significant defects accounting for instability occur when 30% of the glenoid is involved, and the glenoid acquires an “inverted pear” appearance (FIG 2D).

NATURAL HISTORY
- The incidence of glenohumeral instability has been estimated at 8.2 to 23.9 per 100,000 person-years.²³
- The incidence in at-risk populations is significantly higher (military population, 1.69 per 1000 person-years; NCAA athletes, 0.12 injuries/1000 athletic exposures).¹⁹
- Overhead athletes are prone to this repeat injury as their motions in the abducted, externally rotated position put stress on the capsulolabral structures. Contact athletes (football players and wrestlers) have the highest incidence of shoulder dislocations as compared to other sports.
- Depending on the patient’s age and activity level, redislocation rates in active patients may be as high as 92% with non-operative treatment.¹³,¹⁹,²⁴

PATIENT HISTORY AND PHYSICAL FINDINGS
- Evaluation of the patient with suspected instability begins with a thorough history.
- Arm dominance, sport, position, and level of competition should be noted, as well as associated factors, including other sporting activities, training modalities, and past history of injuries.
- Traumatic causes of instability should be determined, as these are more likely to be associated with Bankart lesions.
- The character of the problem should be elicited.
  - Does the athlete complain of pain or instability?
  - Does the shoulder subluxate or dislocate?
  - What arm positions reproduce symptoms?
- Any prior treatments (physical therapy, training modifications, medication, and surgery) should be noted.
- Physical examination should include assessment of both shoulders.
- Inspection should be performed to identify any skin incisions, evidence of wasting in the deltoid, rotator cuff, or periscapular...
musculature, and gross evidence of laxity, including sulcus signs or signs of generalized ligamentous laxity.

- Palpation is performed to identify point tenderness; anterior joint line tenderness may be present in acute anterior dislocations; subacromial tenderness may be present with impingement secondary to subtle instability.
- Active and passive motion tests are an important part of the instability examination. Significant variations in motion are encountered in throwing athletes, with increased external rotation and decreased internal rotation common in the affected shoulder.
- Provocative testing is perhaps the most important aspect in the clinical evaluation of shoulder instability.
  - The sulcus sign is often elicited in patients with inferior instability.
  - Anterior translation and posterior translation are similarly graded with the patient supine and with an anterior or posterior load and shift test, although this test is performed only in the anesthetized patient.
  - In the awake patient, signs of instability can be more subtle. The apprehension test is routinely performed with the arm abducted, extended, and externally rotated. A sensation of impending subluxation or dislocation in the patient is diagnostic of instability. Pain is less specific and may instead indicate internal impingement of the articular surface of the rotator cuff or functional impingement of the bursal side of the rotator cuff on a prominent coracoacromial ligament.
  - A posterior-directed force on the arm by the examiner that relieves the apprehension in this position (Jobe relocation test) suggests an unstable shoulder.
  - Subscapularis integrity and strength should be evaluated in patients with glenohumeral instability.
    - Inability to press the hand to the belly is a positive result of the belly press test and indicates subscapularis muscle weakness or tear.
    - Inability to lift the hand from the back is a positive result in the lift-off test and indicates subscapularis muscle weakness or tear.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Radiographs include anteroposterior (AP), lateral, and axillary views (**FIG 3A, B**).
  - The axillary view is particularly important for assessing anterior glenoid rim defects.

- The Hill-Sachs lesion of the posterosuperior humeral head is best seen on the AP internal rotation or Stryker notch views.
- CT scan is not necessary in all cases but may be helpful in patients with bony defects (see Fig 2C,D).
- MRI scan is not necessary in all cases but can be useful in identifying labral lesions as well as subscapularis tears (**FIG 3C**).
- MRI arthrogram is more sensitive in identifying labral pathology and may be necessary when superior or posterior labral pathology is suspected.

**DIFFERENTIAL DIAGNOSIS**

- External impingement, subacromial bursitis, rotator cuff tendinitis
- Internal impingement
- SLAP (superior labral tear)
- Voluntary instability
- Collagen disorder (Ehlers-Danlos syndrome, Marfan syndrome)
- Subscapularis insufficiency, tear

**NONOPERATIVE MANAGEMENT**

- After reduction of an acute dislocation, a sling is used for immobilization. The duration of immobilization has been controversial, but 3 to 6 weeks is recommended.21
  - Some surgeons recommend immobilization in a position of abduction and external rotation to improve healing. However, many patients will not tolerate this position, and a position of adduction and internal rotation therefore is more commonly used.
  - For treatment of acute injuries, rotational and scapular strengthening exercises of the affected shoulder are started after the initial immobilization period. The program is progressed toward normalization of strength and motion through increased resistance training.
  - Return to sports is allowed when the patient has a full and pain-free range of motion, normal strength, and little or no apprehension.21
  - For chronic and recurrent instability, strengthening is focused on the rotator cuff and scapular stabilizers, as well as core strengthening of the abdominal and trunk musculature. Resistive exercises of the rotator cuff are begun with the arm in neutral below 90 degrees and are progressed gradually. Strengthening of scapular stabilizers is particularly important.
The rate of redislocation after nonoperative treatment depends on the patient’s age and activity level. In young patients participating in high-risk activities (eg, military cadets), the rate of redislocation is as high as 92%.24

In a meta-analysis comparing operative to nonoperative treatment for first-time dislocators, 50% of the conservatively treated patients eventually opted for surgery.19

**SURGICAL MANAGEMENT**

- Surgical treatment options are generally categorized into anatomic and nonanatomic procedures.
- Nonanatomic procedures (Putti-Platt, Magnuson-Stack) are aimed at tightening the anterior structures and preventing at-risk arm positions (ie, abduction and external rotation). These procedures have largely been abandoned after it was discovered that overtightening the anterior structures could lead to posterior subluxation and glenohumeral arthritis.11,18
  - The Putti-Platt procedure consists of a vertical incision through both the subscapularis tendon and capsule followed by repair of the lateral flap to the soft tissue at the glenoid rim.18
  - The Magnuson-Stack procedure is a transfer of the subscapularis tendon lateral to the bicipital groove (FIG 4A).
- Coracoid transfer procedures are other nonanatomic procedures where the coracoid process, with its attached short head of the biceps and coracobrachialis tendons, is transferred to the anterior glenoid rim and secured with screws.1
  - The Bristow procedure uses the tip of the coracoid and typically a single bicortical cancellous screw.
  - The Laterjet procedure lays the coracoid on its side and is typically secured with two screws (FIG 4B).
- Although several authors have achieved excellent success with these procedures, the concern for hardware migration and late resorption of the bone block have made these procedures less popular than the anatomic procedures. They are used mainly for revision procedures and in cases where there is deficient glenoid bone stock.
- Anatomic reconstruction procedures have been aimed at reconstructing the anterior labrum using sutures, staples, or tacks.2,8,9,12,22 These anatomic procedures have had excellent success, with minimal (less than 5%) recurrence rates, and therefore are the procedure of choice in the surgical treatment of glenohumeral instability.
- The Bankart repair and inferior capsular shift procedures are the most commonly used anatomic reconstruction procedures.
- Although recurrence rates for arthroscopic Bankart repair and capsular shift were initially higher than open procedures, these rates have become comparable to open as the arthroscopic techniques have evolved.
- Open treatment, however, is recommended over arthroscopic treatment in the following situations:
  - Significant bony Bankart lesions (over 30%)
  - Significant Hill-Sachs defects where the defect “engages” the glenoid rim with external rotation as visualized during diagnostic arthroscopy
  - Revision procedures
  - Some contact athletes (football) and extreme sports, where a slightly lower recurrence rate can be expected in comparison to the arthroscopic procedure

**Preoperative Planning**

A careful assessment of the patient’s expectations of the surgery and postoperative care, including thorough discussions with the patient and family, are required as part of the preoperative plan.

- Noncompliance with the postoperative restrictions will increase the risk of redislocation after surgical repair.
- It is important to assess mental status and any secondary gain issues in patients with multidirectional instability. Patients with voluntary dislocations and malingering (Munchausen syndrome) patients have a high rate of failure and should be identified before surgery.
- It is important to identify before surgery any glenoid bony deficiency that may require bony augmentation via coracoid transfer or allograft reconstruction. Special equipment (allograft bone and instrumentation to perform ORIF) may be required and should be arranged before surgery.

**Positioning**

- Interscalene block anesthesia is preferred because of the excellent muscle relaxation and postoperative pain relief it offers. If an adequate block cannot be performed, however, general anesthesia can also be used.
- The patient is positioned in the beach-chair position with the back elevated. The patient should be moved to the edge of the table or the shoulder cut-out removed to allow access to the anterior and posterior shoulder as required.
- A hydraulic arm positioner (Tenet Spider) is particularly helpful and can obviate the need for an additional assistant to hold the arm (FIG 5).
Approach

- The bony landmarks of the shoulder are identified, including the acromion, clavicle, and coracoid process.
- Approaches to the shoulder that may be used include the deltopectoral, the concealed axillary incision, and the mini-incision approach. All of these are variations of the standard deltopectoral approach.
  - Standard deltopectoral approach
    - This is the utility approach to the shoulder.
    - A 7- to 15-cm incision is made lateral to the coracoid process beginning below the clavicle and extending toward the anterior humeral shaft at the deltoid insertion. Skin flaps are elevated and the deltopectoral interval is identified.
    - The remainder of this approach is described in detail below.
  - Concealed axillary incision
    - Whereas the traditional deltopectoral approach is about 15 cm in length, the concealed axillary incision begins 3 cm inferior to the coracoid and extends only 7 cm into the axillary crease (Fig. 6A). Skin flaps are widely elevated and the deltopectoral interval is identified.
    - This incision is cosmetically appealing and is useful in patients where cosmesis is important.
  - Mini-incision approach
    - A 5-cm incision just lateral to the coracoid process can be used in shoulder stabilization procedures (Fig. 6B). Wide subcutaneous flaps are created and the deltopectoral interval is identified. The remainder of the exposure is similar to the standard deltopectoral approach.
    - The location of this incision is important to achieve direct access to the glenoid without extending the incision: one third of the incision should be above and two thirds below the coracoid process.

BANKART PROCEDURE

- The skin incision is based on surgeon preference as described above. The concealed axillary incision is the most commonly used.
- Skin flaps are elevated and the deltopectoral interval is identified (Tech Fig 1A).
- The cephalic vein is taken laterally with the deltoid muscle, and the clavipectoral fascia overlying the subscapularis tendon and strap muscles is exposed.
- When additional exposure is needed, it is helpful to incise and tag with a suture the upper third of the pectoralis major insertion into the humerus. Great care should be taken not to injure the biceps tendon, which lies just underneath the pectoralis major insertion.
- The clavipectoral fascia is incised lateral to the strap muscles, and a retractor is placed between them to expose the subscapularis muscle and tendon.
- A small wedge of the coracohumeral ligament can be removed to increase superior exposure (Tech Fig 1B). The branches of the anterior circumflex humeral vessels at the inferior margin of the subscapularis muscle should be cauterized at this time to control bleeding.
- The subscapularis tendon is exposed and incised vertically just medial to its insertion. The tendon can be peeled off the underlying capsule with a combination of the periosteal elevator for blunt dissection and the needle-tip Bovie cautery for sharp dissection (Tech Fig 1C,D).
The anterior capsule is then incised vertically at the level of the glenoid rim (TECH FIG 1E,F).

With a curette or osteotome, the anterior glenoid rim is roughened and any soft tissue removed to allow for healing of the repair (TECH FIG 1G).

Transosseous sutures are passed through holes made with pointed forceps or a drill.

Alternatively, suture anchors may be placed at the margin of remaining articular cartilage. Often, two and sometimes three anchors are used between the 2:30 and 6:00 positions (TECH FIG 1H).

The capsule is shifted or repaired anatomically as required. Typically, an inferior capsular shift procedure is performed in combination with the Bankart procedure as described below.

The subscapularis tendon is repaired anatomically at its insertion.
T-PLASTY MODIFICATION OF THE BANKART PROCEDURE

- To address capsular laxity in addition to the Bankart lesion, Altchek and Warren described a modification of the Bankart procedure by performing a T incision in the capsule.
- The approach is the same as in the Bankart procedure described and involves dissection of the subscapularis from the anterior glenohumeral capsule.
- Unlike the inferior capsular shift procedure, the T-plasty involves a medially based capsular incision at the glenoid margin.
  - The T capsulotomy is made two thirds from the top of the capsule, with the vertical component adjacent to the glenoid rim (TECH FIG 2).
- The Bankart lesion is repaired using suture anchors or transosseous sutures.
- The laterally based inferior flap of capsule is advanced superiorly and medially and secured to the glenoid rim.
- The superior flap is then advanced medially and oversewn to the inferior flap.
- The subscapularis tendon is repaired anatomically at its insertion.

ANTERIOR CAPSULOLABRAL RECONSTRUCTION

- Because of the loss of strength and velocity in throwing athletes undergoing anterior stabilization procedures, Jobe in 1991 proposed a subscapularis-sparing procedure in which the tendon is split in line with its fibers and its humeral attachment left intact.
- A deltopectoral approach to the shoulder is used and the strap muscles are retracted medially to expose the subscapularis tendon.
- The subscapularis is then divided horizontally in line with its fibers at the junction of the upper two thirds and lower one third (TECH FIG 3A,B).
- A horizontal capsulotomy is now made in the middle of the capsule extending medial to the glenoid rim. The capsule is elevated off the glenoid subperiosteally to allow for superior and inferior capsular advancement (TECH FIG 3C).
The capsule is elevated off the glenoid subperiosteally to allow for superior and inferior capsular advancement. The laterally based inferior flap is shifted superiorly and secured to the intra-articular portion of the glenoid rim using transosseous sutures to attempt to recreate the labral "bumper" (TECH FIG 3D,E). The superior flap is then shifted medially and oversewn to the inferior flap.

Because the subscapularis tendon is not detached, active assistive rehabilitation exercises are begun immediately on postoperative day 1, and rehabilitation is progressed more rapidly.

**ANTEROIOR INFERIOR CAPSULAR SHIFT**

- The anterior inferior capsular shift operation was first described by Charles Neer in 1980.
- The procedure was designed to treat involuntary inferior and multidirectional instability of the shoulder that could not be addressed by repair of the anterior glenoid labrum alone (the Bankart procedure).
- The skin incision may be chosen based on the desired approach.

The subscapularis tendon is incised about 1 to 2 cm medial to its insertion at the lesser tuberosity, leaving an adequate cuff of tissue for repair.

The subscapularis consists of both a superior tendinous portion (two thirds) and inferior muscular (one third) portion.

To expose the inferior portion of the glenohumeral joint capsule, it is important to carefully separate the
muscle fibers’ insertion from the underlying anterior capsule using a combination of sharp and blunt dissection. The arm should be in a position of adduction and external rotation during this inferior dissection, and great care is taken to protect the axillary nerve.

- A laterally based capsular shift is then performed by incising the capsule vertically about 5 to 10 mm medial to its insertion on the humeral neck (see Tech Fig 1E,F).
- The medial leaf of the capsule is tagged sequentially with nonabsorbable sutures as the capsular incision is continued inferiorly to at least the 6 o’clock position (TECH FIG 4A).
- By placing traction on the capsular tag sutures in a superior and lateral direction, the axillary pouch should be obliterated when an adequate amount of capsular dissection has been performed.
- It is important to release the inferior capsular attachments to the humerus, which have a broad insertion inferior to the articular surface. This is typically done with blunt subperiosteal dissection with the periosteal elevator and needle-tip Bovie cautery (TECH FIG 4B, C).
- The medial insertion of the glenohumeral ligaments and glenoid labrum should then be assessed for avulsion or tear. Bankart lesion and ALPSA both describe a disruption of the medial capsulolabral complex that must be repaired.
- This technique is described in the Bankart repair technique section.
- Once secure fixation to bone is achieved, the capsule is shifted superiorly and laterally and the nonabsorbable sutures are passed through the capsule from an intra-articular to extra-articular location.
- It is important to place the sutures as close to the glenoid rim as possible so that the capsule is not shortened by medial plication.
- A bimanual technique can be used in which one needle driver is used to pass the suture and a second to “catch” the needle on the extra-articular side. The sutures are then tied on the extra-articular side to secure the capsule to the glenoid rim.
- If excess anteromedial capsular redundancy (AMCR) exists after the Bankart repair, a “barrel stitch” technique has been described in which a nonabsorbable pursestring suture is placed to imbricate the anterior capsule.7 The barrel stitch is placed vertically at the level of the glenoid rim and tied on the extra-articular side. Its size is titrated to the amount of AMCR encountered (TECH FIG 4D, E).

**TECH FIG 4** • **A.** In the inferior capsule shift procedure, the laterally based capsular incision is continued inferiorly using tag stitches on the released anterior capsule to apply traction. **B.** There is a dual attachment of the inferior capsule on the humeral neck. **C.** Release of the dual inferior capsular attachment, allowing a complete shift of the capsule. **D.** An anterior crimping (barrel) stitch is used to decrease the redundancy of the anteroinferior capsule. This is a mattress stitch started on the superficial side of the capsule. **E.** Once tied, the barrel stitch reduces anterior medial capsular redundancy and an anterior inferior bolster is created. *(continued)*
PEARLS AND PITFALLS

Voluntary instability

- Patients with voluntary instability should be carefully screened before surgery. If there are significant issues of secondary gain, surgical treatment will not be successful and should be discouraged. Preoperative psychiatric evaluation has been suggested but is seldom helpful in screening these patients.

Humeral bone defects (Hill-Sachs lesions)

- It is important to recognize and quantitate humeral bone defects, which are best seen on the radiograph (AP in internal rotation or Stryker notch view), CT scan, or MRI, or by diagnostic arthroscopy. With “engaging” defects, open treatment is favored over arthroscopic, and filling of the defect (autograft, allograft) may be considered.

Glenoid bone defects (bone Bankart)

- Glenoid defects can be assessed with preoperative imaging (radiographs, CT scan, MRI) and diagnostic arthroscopy. Significant defects (more than 30% of the glenoid) require a coracoid transfer (Bristow or Laterjet) procedure.
POSTOPERATIVE CARE

- The rehabilitation protocol must be planned individually.
- The patient remains in a sling for 4 weeks postoperatively.
- Passive forward elevation to 110 degrees and external rotation to 15 degrees is begun at 10 days to 2 weeks, and is gradually increased to 140 degrees forward elevation and 30 degrees external rotation by 4 weeks. During this period, isometric strengthening exercises are begun.
- From 4 to 6 weeks, elevation is increased to about 160 degrees and external rotation to 40 degrees.
- After 6 weeks, motion is increased to achieve a normal range.
- Exercises should be progressed slowly to avoid apprehension and resubluxation.
- Resistive exercises are begun with the arm in neutral below 90 degrees and progressed gradually.
- Strengthening of scapular stabilizers is particularly important.
- Full motion and strength should be regained before contact sports are resumed, usually between 6 and 9 months, depending on the sport and the patient.

OUTCOMES

- The first long-term follow-up study of the Bankart procedure was reported by Carter Rowe in 1978, with only a 3.5% rate of redislocation.
- Neer reported on 40 unstable shoulders that were repaired with the anterior inferior capsular shift between 1974 and 1979, 11 of which had undergone prior procedures for glenohumeral instability. Satisfactory results were achieved in all except one patient, who had postoperative subluxation of the shoulder.
- Since Neer’s initial report, multiple series have been published that have used the anterior inferior capsular shift procedure for anteroinferior instability. Although the surgical technique and the extent of capsular shift may vary with different surgeons, recurrence rates have ranged from 1.5% to 9%.5,6,9,16,25
- T-plasty results: In 42 shoulders with an average of 3 years of follow-up in this initial series, 95% of the patients were satisfied and there were four recurrences (10%).
- A report on the results of anterior capsulolabral reconstruction at an average of 39 months of follow-up in 25 throwing athletes found excellent or good results in 92% of patients, and 17 (68%) returned to their prior level of competition.
- A subsequent series of 22 subluxators and 9 dislocators found 97% good to excellent results and 94% return to sport.
- Return-to-sport rates of 32% to 94% have been reported for open surgical treatment of anteroinferior instability in various series.2,5,12

COMPLICATIONS

- Injury to the axillary nerve can occur as it travels an average of only 2.5 mm deep to the IGHL and lies only 12 mm from the glenoid at the 6 o’clock position.
- Nerve injury typically involves sensory function only, and function usually recovers spontaneously.
- Recurrent dislocations may occur in up to 5% of patients. However, this rate may be higher when appropriate indications for surgery are not strictly followed.
- Hardware-related complications may occur owing to loosening, bending or breakage of screws, anchors, or tacks (FIG 7).
- Synovitis in response to PLLA absorbable implants has also been described.
- Misplacement of labral tacks or suture anchors, both metallic and absorbable, may lead to early arthritis or arthritis.
- Complications due to positioning have been described including deep venous thrombosis and compression neurapraxia. Bony prominences should be well padded and constrictive bandaging avoided during and after surgery.
- Infection in shoulder surgery is uncommon. When it occurs, however, *Propionibacterium acnes* is a common organism, and specific cultures should be requested.

REFERENCES

DEFINITION
- Symptomatic recurrent posterior instability represents up to 12% of all cases of shoulder instability and is subdivided into two discrete entities.\textsuperscript{28,35}
- The first, true posterior dislocation is acute in nature and often related to trauma. It is readily managed with shoulder re-reduction and carries a low recurrence rate if not associated with a large engaging humeral head defect or a primary uncontrolled seizure disorder.
- If the primary dislocation is overlooked, this condition can manifest itself as a chronic locked posterior dislocation with its pathognomonic internally rotated position and loss of external rotation on physical examination.
- The second entity is recurrent unidirectional posterior subluxation, which often represents the more challenging dilemma confronting the orthopaedic surgeon and will be the principal topic of this chapter.
  - Whether due to an increase in awareness by physicians or a more active athletic population, recurrent posterior instability is being recognized, diagnosed, and treated more frequently.
  - Patients with recurrent posterior subluxation complain primarily of pain and weakness. As time progresses, symptoms of posterior subluxation become a secondary complaint. Eventually patients often learn the selected muscular contractions, scapular winging, and arm position (forward elevation, adduction, and internal rotation) needed to demonstrate their instability.
  - See Table 1 for the classification of posterior instability.

ANATOMY
- Posterior instability may be secondary to a tear of the posteroinferior labrum or a patulous posterior capsule.
- Rarely it can involve a posterior labrocapsular periosteal sleeve avulsion or an avulsion of the posterior glenohumeral ligaments as they insert on the humerus (posterior HAGL lesion).
- Recently Kim described a concealed and incomplete avulsion of the posteroinferior labrum (type II marginal crack or Kim lesion).\textsuperscript{20}
- Pathology may also be bony in nature and secondary to posterior glenoid avulsions, erosions, increased glenoid retroversion or large engaging reverse Hill-Sachs impression defects.

PATHOGENESIS
- A significant percentage of patients (40% to 50%) with recurrent posterior subluxation relate a history of trauma. Usually athletes, these individuals are 18 to 30 years of age and are involved in competitive contact sports.
- Traumatic cases are often associated with the arm in a straight and locked position such as in weight lifting or during football while line blocking. A fall or collision with the individual’s arm in at-risk position (forward elevation, adduction, internal rotation) can also be the cause.
- Frequently, instead of a traumatic event, subluxation episodes with a poorly defined onset are clearly documented.
- In many cases, especially with repetitive overhead endeavors such as swimming, gymnastics, baseball, and volleyball, the athlete recalls first the gradual onset of discomfort, with subluxation episodes occurring later. Such an onset is thought to be atraumatic and involves repetitive “microtrauma” with resultant stretching of the capsular restraints.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Whether the patient presents with a clear traumatic episode or a longer atraumatic course, he or she often has a feeling of the shoulder “coming out.” Such instability episodes occur when the arm is in the at-risk position of forward elevation, adduction, and internal rotation.
- Patients often describe a vague discomfort, pain, or weakness as their principal complaint. This actually may lead to misdiagnosis at first.
- True apprehension or a feeling of “impending doom” when the extremity is placed in the provocative position is less common but can be present.
- Overhead throwers may complain of a loss of velocity, fatigue, or aching over the posterior shoulder.
- Usually there is no obvious asymmetry of the muscles on inspection.
- Palpation may elicit some tenderness along the posterior glenohumeral joint line.
- Crepitation or a click along the posterior joint line due to labral pathology may be noted.
- The range of motion is full, often with a decrease in internal rotation and an excess of external rotation.
 Often patients, if voluntary subluxators, can reproduce the subluxation episode on command with arm position and selective muscular contraction (FIG 1).

Physical examination should include the following:
- Modified load shift test: documents direction and degree of instability
- Supine load shift test (Gerber and Ganz)\(^1\): documents direction and degree of instability
- Seated load shift test: documents direction and degree of instability
- Posterior stress test: documents direction and degree of instability
- Sulcus sign: evaluates for an inferior component of the posterior instability (bidirectional) or a more global instability (ie, multidirectional instability)
- Scapular compression test: verifies the importance of scapular winging in the patient’s ability to reproduce the instability and proves to the patient the need to strengthen the periscapular musculature to control instability
- Jerk test: to document instability. A painful jerk test suggests a posteroinferior labral lesion and is a predictor of the success of nonoperative treatment.
- Kim test: evaluates for the presence of a labral tear posteriorly
- Pivot shift of the shoulder: documents direction of the instability

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographic evaluation includes a three-view trauma series of the shoulder, including a true anteroposterior (AP) view of the shoulder, a scapular lateral, and, more importantly, an axillary view.
- A Velpeau axillary view can be substituted if the attempted axillary view is impossible because of painful abduction of the shoulder.
- Axillary radiographs of patients with a voluntary component to their instability can be taken while the patient reproduces and maintains the subluxation episode to document the direction (FIG 2A).
- A computed tomography (CT) scan is rarely needed but can be helpful to evaluate humeral head defects and associated fractures of the tuberosities, humeral shaft, and posterior glenoid rim. Significant posterior glenoid retroversion can also be demonstrated on CT scanning (FIG 2B).

MRI is the imaging modality of choice after plain radiographs to evaluate the posterior capsule and labrum for tears and associated pathology.
- In certain situations a MRI arthrogram can help diagnose a posteroinferior labral tear.

DIFFERENTIAL DIAGNOSIS
- Superior labrum anterior from posterior tear (SLAP)
- Anterior instability
- Multidirectional instability
- Internal impingement
- Posterior Bennett lesion

NONOPERATIVE MANAGEMENT
- Nonsurgical treatment of posterior unidirectional instability is reportedly successful in up to 80% of the patients.\(^9,18\)
- The physical therapy program consists of concentric and eccentric resistive band exercises that strengthen the external rotators, the deltoid, and the important periscapular musculature.
- Resistive upright and seated rows, with an emphasis on trying to pinch the medial scapular borders together during the exercise, are key, especially in patients whose scapular winging contributes to their instability.
- A strengthening program as well as a sport-specific attempt to decrease those activities that place the arm at risk is key.
- The length of nonoperative treatment must be individualized.
- Patients who have lower physical demands, are younger, and have an atraumatic history are treated 6 months or more.
- Higher-level athletes or those who have a traumatic cause with an associated labral tear are more likely to respond to surgical treatment. Despite their associated labral tears, such
elite athletes are often treated with an exercise strengthening program for at least 3 months.

**SURGICAL MANAGEMENT**
- Although open procedures have been the mainstay and gold standard in the treatment of patients with recurrent unidirectional posterior subluxation, when nonoperative care has failed, arthroscopic treatment has become common.
  - As with anterior instability 20 years ago, arthroscopic evaluation in posterior instability patients has led to the diagnosis and treatment of an increasing number of associated soft tissue and articular injuries. Obviously, arthroscopic treatment of posterior capsular avulsions or redundancy in the absence of soft tissue deficiencies or bony abnormalities can have similar success rates without the morbidity of more extensive open surgery.2,6,20,33
  - Surgical treatment is considered only after an adequate trial of strengthening has failed and the patient remains significantly symptomatic.
  - The ideal surgical candidates are those with recurrent posterior unidirectional subluxation secondary to a traumatic episode. These patients often have an associated traumatic posterior labral tear, which is optimal for arthroscopic repair.

**Site Preparation**
- The anterior portal is established in the rotator interval under direct visualization using needle localization.
- A 6.5-mm cannula is established to allow insertion of the arthroscope and an 8-mm cannula is placed in the posterior portal to allow the passage of the Spectrum crescent suture-passing devices (ConMed Linvatec, Largo, FL).

**Portal Placement**
- Most posterior reconstructions are performed using only two portals.
- The first is a posterior portal established just lateral to the posterior lateral corner of the acromion.
  - This differs from the traditional posterior viewing portal, which is 1 cm medial and 2 cm inferior from the posterior lateral corner of the acromion.
  - Lateralization of this portal and moving it somewhat superiorly provides an optimal angle of attack to the posterior and inferior portion of the posterior glenoid.
- Patients with atraumatic subluxation due to capsular redundancy can be managed either through an open procedure or an arthroscopic capsular shift or plication procedure.
- Patients who have multifactorial causes for their instability or are revision situations are better treated with an open approach.

**Preoperative Planning**
- An extensive history and physical examination are key to establishing the direction and degree of the patient’s instability.
- All imaging studies are reviewed. Plain films and MRI studies are reviewed for the presence of old fractures, loose bodies, and hardware from previous procedures. More importantly, the MRI establishes whether the instability is due to an associated traumatic posterior labral tear or capsular redundancy.
- Associated bony pathology (traumatic glenoid avulsions, glenoid retroversion) and soft tissue deficiencies (from previous procedures) should be addressed concurrently.
- Examination, this time under anesthesia, should be accomplished before positioning to confirm the direction and degree of the instability.
Suturing

- A Spectrum 45-degree-offset suture passer, preloaded with a number 0 polydioxanone (PDS) monofilament suture (Ethicon, Somerville NJ), is passed through the posterior cannula, capturing the inferior capsule in the area of the posterior band of the IGHL (TECH FIG 2A).
  - This tissue is brought superiorly and the second pass comes deep, exiting at the posterior labral defect.
  - The PDS suture is reeled into the joint through the passer and retrieved in the posterior cannula using a ring grasper (TECH FIG 2B,C).
  - The deep limb of the PDS is tied to one limb of the anchor suture, and using a pulling technique, the PDS is drawn in a retrograde fashion, with the anchor suture attached, through the capsule and labral tissue, thereby creating a simple stitch (TECH FIG 2D).
- This allows the inferior capsule to be drawn superiorly and medially while at the same time closing the posterior Bankart lesion.
A second suture is placed after tying the first suture in a similar fashion, again incorporating the capsule as well as labrum (TECH FIG 2E,F).

This process is repeated as many times as is necessary, moving superiorly at 6-mm to 8-mm increments, thereby obliterating any labral defect and capsular redundancy (TECH FIG 2G,H).

Capsular Plication

Alternatively, if no labral detachment is identified and only excessive capsular redundancy exists, a posterior superior capsular shift without anchors is performed.

The posterior capsule is lightly abraded with a synovial shaver or rasp to promote healing.

A Spectrum suture passer is used again to pierce the capsule 1 cm lateral to the labrum at the 6:30 position on the glenoid.

The capsule is then advanced superiorly and medially, with the suture passer re-entering the joint at the junction between the intact labrum and the glenoid rim articular cartilage.

This is repeated at least two or three times, depending on amount of laxity.

With each suture the capsule is advanced about one hour’s position on the glenoid face (ie, 6:30 capsular stitch to the 7:30 labral position, 7:30 to 8:30, and so on).

Rotator Interval Plication

In individuals with a significant component of ligamentous laxity, additional closure of the rotator interval is accomplished by moving the arthroscope back to the posterior portal.

Through the anterior portal, a number 0 PDS suture is passed through the upper border of the middle glenohumeral ligament, capturing the superior glenohumeral ligament and rotator interval capsule.

This suture is used as a pulling stitch for a number 2 braided polyester fiber (Ti•CRON) suture (Tyco, United States Surgical, Norwalk, CT).

This is repeated again and sutures are tied just outside the capsule.
OPEN POSTERIOR HUMERAL-BASED CAPSULAR SHIFT (AUTHORS’ PREFERRED TECHNIQUE)

Positioning
- Under general anesthesia the patient is positioned in the lateral decubitus position using a full-length beanbag.
- A large axillary roll is placed under the down nonsurgical axilla.
- The operative arm and shoulder are draped free.

Incision and Dissection
- A longitudinal incision in the posterior axillary fold is made beginning at a point 2 cm medial to the posterolateral corner of the acromion and extending distally, following the posterior axillary line (TECH FIG 3).
- The underlying deltoid muscle is split along its fibers bluntly, and a self-retaining retractor is placed.34
  - Caution should be exercised as to not split the deltoid distally greater than 4 to 5 cm to avoid injuring the axillary nerve.8,34
  - If the individual is larger and more exposure is needed, the deltoid can be detached from its scapular origin for a short distance, leaving a small tendinous attachment to repair later.
  - Repair of the deltoid origin can also be accomplished by placing drill holes along the scapular spine for suture passage.
- The underlying infraspinatus is identified by its bipennate nature, a central fatty raphe dividing the muscle, and the fiber direction change compared with the teres minor inferiorly.
- The infraspinatus can be handled in three ways:
  - It can be split horizontally to expose the underlying capsule.32 Care is taken with this technique not to extend the split farther than 1.5 to 2 cm medial to the glenoid rim, as the infraspinatus branches of the suprascapular nerve are coursing along the inferior fascia of the infraspinatus directly on the scapular surface. Extension of the split into the branches or elevation of the fascia off the scapula will injure a number of, if not all, the branches to the infraspinatus.
  - The second method is to identify the interval between the infraspinatus and teres minor. This interval is developed with the muscle being worked superiorly, thereby exposing underlying capsule.
  - Third, the infraspinatus may be completely detached, leaving a 2-cm remnant of the tendon still attached for later repair (TECH FIG 4). It is tagged and carefully released from the underlying thin capsule.

Capsulotomy
- A vertical capsulotomy is made on the humeral side with the arm in neutral rotation (TECH FIG 5A).

TECH FIG 3 • The posterior longitudinal incision begins about 2 cm medial to the posterolateral corner of the acromion and extends into the axillary crease.

TECH FIG 4 • With the deltoid fibers bluntly split, a vertical incision is made directly through the infraspinatus while keeping a small stump of infraspinatus tendon attached laterally for reattachment later.
Chapter 4 TREATMENT OF RECURRENT POSTERIOR SHOULDER INSTABILITY

**Techniques**

- A small amount of capsule, 3 to 4 mm, can be left on its humeral attachment to aid in repair of the capsular flaps laterally during the shift.
- Care is taken to protect the axillary nerve inferiorly from retractors as it is traversing from anterior to posterior to exit in the quadrangular space inferiorly.
- With the vertical capsulotomy completed, two traction stitches are placed at the midposition and the capsule is horizontally divided, between the stitches, toward the middle of the glenoid rim, stopping 1 to 2 mm from the posterior glenoid labrum (*TECH FIG 5B*).

**Capsulorrhaphy**

- Although both medial and lateral capsular shifts have been described, we prefer a humeral-based T capsulorrhaphy because we believe tensioning of the capsular flaps is easier to control and a larger volume reduction can be achieved, if desired.
- Those who prefer a glenoid-based T-capsular shift cite advantages of a muscle-splitting approach and ease of repair if an associated reverse Bankart lesion is encountered.
- If a glenoid-based shift is selected, most authors position the arm in 20 degrees of abduction and neutral to 20 degrees of external rotation while doing the capsular repair.

**Posterior Inferior Capsular Shift**

- The posterior glenoid labrum is inspected and if there is a small detachment, it is repaired before completing the capsular shift procedure.
- The inferior flap of the capsule is carefully mobilized past the 6-o’clock position, inferiorly on the humerus.
- This step is critical as an inadequate release of the inferior capsule will prevent correction of the posteriorinferior capsular redundancy and volume.
- The nonarticular sulcus, medial to the capsular remnant left behind, is then decorticated with a high-speed burr to facilitate healing (*TECH FIG 6A*).
- The inferior capsular flap is brought superiorly and slightly laterally with the arm held in 40 to 45 degrees of abduction and 15 to 20 degrees of external rotation.
- This inferior flap is sutured in place with multiple figure eight nonabsorbable sutures.
- If the capsular remnant to suture to is of poor quality, suture anchors are used for repair. In a similar fashion, the superior capsular flap is shifted inferiorly down over the inferior flap and sutured (*TECH FIG 6B,C*).
- The horizontal portion of the T capsulorrhaphy is then closed and reinforced with nonabsorbable sutures.
- The degree of closure of this horizontal portion can further tighten the posterior capsule if desired.
- If the infraspinatus was released with a small remnant left attached to the humeral side, the infraspinatus is sutured back to its tendinous stump anatomically with nonabsorbable suture.
- If the infraspinatus was split, it is allowed to fall back in position and the fascia is closed with absorbable suture.
- Routine closure is performed, and the arm is placed into a shoulder orthosis or spica cast depending on patient compliance, incorporating 20 degrees of abduction and 20 degrees of external rotation.
The patient positioning and surgical exposure are similar down to the infraspinatus musculature.

The infraspinatus can be split, as is our preference, or a horizontal incision can be made 2 cm lateral to the glenoid rim through both the infraspinatus and capsule as one layer.

The posterior capsulolabral tissue is freely mobilized from the glenoid neck.

The scapular neck is then decorticated with a motorized burr to promote healing and the labrum is reattached using the surgeon’s preferred commercially available absorbable suture anchors or through transosseous tunnels.

Again, the goal is to roll the labrum up onto the posterior glenoid rim, restoring the capsulolabral bumper effect.

Although this procedure is usually done as a primary procedure, it may be combined with a humeral or glenoid based posterior-inferior T-capsular shift in patients with excessive laxity or instability on clinical examination.

Care must be taken not to overtighten the repair when both procedures are used, since postoperative stiffness and loss of motion, especially internal rotation, can occur.

TECH FIG 6 • A. With the capsular flaps fully developed, the metaphyseal area between the capsular insertion and the articular surface is decorticated using a motorized burr. B,C. The arm is then brought into slight extension and the inferior capsular flap is first shifted superiorly with the arm positioned in about 45 degrees of abduction. The superior capsular flap is subsequently shifted inferiorly.
OPEN POSTERIOR INFRASPINATUS CAPSULAR TENODESIS

- The posterior infraspinatus and capsular tenodesis, as described by Hawkins, is reproducible and takes advantage of the thick quality of the infraspinatus tendon and underlying capsule layer.\(^4,16\)
- It is extremely useful, in our opinion, in situations of poor-quality capsular tissue, since often the posterior capsule is only 1 to 2 mm thick, and in revision cases in which multiple posterior procedures have failed (TECH FIG 7).

Positioning

- This technique is performed using the same positioning and exposure as described earlier down to the infraspinatus musculature.
- Preoperatively the patient can be placed into an outrigger shoulder spica cast with a fiberglass long-arm component and a detachable spica bar or a shoulder orthosis.
- Preparation and draping are done with the involved arm free.

Incision and Approach

- The same posterior axillary incision and split of the underlying deltoid muscle described earlier are used.
- With the arm in neutral position, the glenoid rim is located under the infraspinatus using a spinal needle, starting medially and walking the needle laterally over the glenoid rim until the exact location of the joint is identified.
- This position is then marked to confirm the lateral extent of the glenoid rim.
  - This is a crucial step because if the vertical incision to be made through both the infraspinatus and capsule is made too far laterally, severe overtightening will result.

Vertical Arthrotomy

- A single vertical incision is made through the infraspinatus tendon and underlying capsule parallel to and 1.0 to 1.5 cm lateral to the joint line with the arm in neutral rotation (TECH FIG 8).
  - Most of the infraspinatus tendon runs on its inferior surface, with visible overlying muscle. This anatomic situation leads to a feeling of uneasiness as the surgeon begins to incise through the fleshy infraspinatus musculature portion posteriorly.
  - However, one should not worry, since the thicker tendinous portion of the infraspinatus will be encountered deeper during the vertical incision.
- With the capsulotomy complete, a Fukuda retractor is placed in the joint and the posterior labrum is inspected.

Posterior Repair

- The retractor is then removed and the arm is externally rotated 20 degrees (TECH FIG 9A).
- The lateral stump of the infraspinatus and capsule (one layer) is sutured to the intact posterior labrum using nonabsorbable sutures (TECH FIG 9B).
- The remaining medial portion of the infraspinatus and capsule is then reflected laterally overlapping the primary repair and sutured, again with nonabsorbable sutures (TECH FIG 9C).
- The deltoid is allowed to fall back together and the fascia is closed. Routine wound closure is performed.
TECH FIG 9 • A. After completing the posterior capsulotomy, the arm is positioned in about 20 degrees of external rotation and the lateral tendon portion of the infraspinatus and capsule are sutured to the intact posterior labrum. B. The arm is then externally rotated 20 degrees and the lateral flap of infraspinatus and capsule is sutured to the posterior glenoid labrum. C. The medial flap of the infraspinatus is then overlapped and sutured to its lateral tendon.

OPEN POSTERIOR GLENOID OSTEOTOMY

- Preoperative evaluation will rarely identify a patient who demonstrates excessive glenoid retroversion in excess of 20 degrees.30,31
- In these situations, the surgeon may need to consider a posterior glenoid osteotomy as the primary procedure or in combination with a posterior capsulorrhaphy or shift.17
- This procedure is rarely needed, however, and is reserved for those special circumstances. This procedure is technically demanding and should be performed by a surgeon with previous exposure to the procedure.
Positioning and Approach

- The initial steps, including preoperative spica application and positioning, are repeated.
- The standard approach down to the infraspinatus is used, with the infraspinatus released from its lateral insertion.

Vertical Capsulotomy

- A vertical capsulotomy is made 1 cm lateral to the glenoid rim.
- The medial capsule is detached sharply from the posterior aspect of the glenoid, with the labrum left attached to the posterior glenoid rim.
  - Caution is again exercised because the suprascapular nerve is running superiorly around the spine of the scapula about 2 to 3 cm from the glenoid rim.
- The Fukuda retractor is placed into the joint to permit visualization of the glenoid retroversion and orientation of the plane of the glenoid.

Glenoid Osteotomy

- With the orientation determined and the line of the osteotomy marked, drill holes are made through both anterior and posterior cortices.
  - These holes should be no closer than 1 cm from the glenoid articular surface.
  - The concavity of the glenohumeral joint as well as its superior to inferior and anterior to posterior orientation is kept in mind to avoid accidental intra-articular penetration and fracture.
  - A depth gauge is used to measure each hole to get an idea of the depth of the glenoid neck.
  - The oscillating saw blade is marked just short of this glenoid depth, thus decreasing the potential for traversing both the anterior and posterior cortices with the saw blade, which would result in creation of a free-floating glenoid (TECH FIG 10A).
  - With the osteotomy complete, a 1-inch osteotome is gently tapped into place and the osteotomy is opened by moving the osteotome and glenoid laterally.
  - The partially intact anterior periosteum and cortex maintain the appropriate position of the glenoid fragment.
- The osteotomy is then opened with a 1-inch osteotome and a quarter-inch osteotome is placed perpendicular to the osteotomy at either the superior or inferior margin to hold the osteotomy in the open position (TECH FIG 10B).
- A tricortical graft harvested from the posterior acromion or iliac crest is placed into the osteotomy and its position and stability are checked.
  - Usually the humeral head against the graft will provide an adequate compressive force to close down the osteotomy and stabilize its position without hardware or internal fixation (TECH FIG 10C). If fixation is required, small fascial or hand set plates are ideal.
  - This procedure can be combined, depending on how the infraspinatus is handled, with a humeral-based posteroinferior capsular shift or infraspinatus capsular tenodesis.
  - The arm is placed in a shoulder spica postoperatively and held for 4 to 6 weeks to allow consolidation of the posterior bone graft.

TECH FIG 10 • A. Bicortical drill holes are created about 1 cm medial and parallel to the posterior glenoid rim. An oscillating saw then completes the osteotomy posteriorly. B. A small osteotome is used to gently hinge open the osteotomy site laterally, thus preserving somewhat the integrity of the anterior cortex and its periosteal and soft tissue attachments. (continued)
TECH FIG 10 • (continued) C. A tricortical graft is harvested from the posterior acromion or iliac spine and inserted into the osteotomy site. This procedure can be also combined with a posteroinferior capsular shift or also infraspinatus tenodesis.

OPEN POSTERIOR BONE BLOCK GRAFT AUGMENTATION

- A posterior-placed bone block may be selected as the primary procedure but is usually needed as an additional augmentation procedure to back up a soft tissue procedure in revision situations with inadequate capsular tissue.
  - This technique has been used only twice in 10 years as an augmentation procedure by the authors.
  - We prefer a bone block placed extra-articularly in those often-difficult patients with soft tissue deficiencies, such as seen in Ehlers-Danlos syndrome.
  - Using the bone block extra-articularly allows the capsular repair anterior to the graft to act as a soft tissue interposition.
  - The positioning and exposure down to the capsule are as earlier described.

- After the posterior capsule has been shifted, a 3 × 2-cm, 8- to 10-mm-thick bone graft is obtained either from the posterior acromial spine or iliac crest.
- After the glenoid neck is exposed and the glenoid neck decorticated, the cancellous side of the graft is placed posterior and inferior and fixated with two cancellous screws.
- The graft is tailored to its final desired shape using a motorized burr.
- Care must be used such that the graft is not placed excessively lateral to the glenoid rim with secondary impingement on the humeral head or too medial to the glenoid rim, rendering it ineffective. The goal is to increase the width and depth of the glenoid without contacting the humeral head.

PEARLS AND PITFALLS

| Indications | • Failure to make an accurate diagnosis of the direction or degree of instability
|            | • A complete history and physical examination is crucial and must be performed. If needed, an examination under anesthesia to rule out a more global instability is useful.
|            | • Patient selection is key for each planned procedure.
|            | • Failure to identify the habitual “pathologic” voluntary dislocator
| Soft tissue management | • Failure to address associated ligamentous laxity
| | • It is imperative to rule out a more global instability (multidirectional instability).
| | • Beware of patients with previous failure from an extensive thermal capsulorrhaphy procedure. |
**POSTOPERATIVE CARE**

- Using these techniques, the procedure can be tailored to meet the patient’s clinical instability; however, the rehabilitation is similar in all patients regardless of technique.
- After completion of the repair, the arm can be removed from traction and posterior translation reassessed.
- The patient is then placed in a 30-degree external rotation brace and held in this position for 3 to 4 weeks postoperatively (Ultra-Sling, DonJoy, Carlsbad, CA).
- At that point, gentle active-assisted range-of-motion exercises are begun, avoiding all internal rotation posterior to the coronal plane for the first 6 weeks.
- At the 6-week mark postoperatively, a gentle isometric strengthening program is started.
- Throwing activities are not started until the fourth month, with resumption of athletic endeavors anticipated at 6 months.
- While the surgical approach may vary, all posterior reconstructions are treated similarly in their postoperative regimen.

**COMPLICATIONS**

- Recurrent or residual instability
- Postoperative loss of motion or stiffness
- Neurovascular injury, especially posterior cord or axillary or suprascapular nerve
- Anchor pullout or hardware failure
- Infection
- Post–instability repair arthritis (capsulorrhaphy arthropathy)
- Chondral injury
- Chondrolysis secondary to thermal capsular shrinkage
- Hematoma
- Postoperative rotator cuff atrophy or weakness

- Subcoracoid impingement (obligate anterior humeral head shift due to posterior capsular tightness or glenoid osteotomy)

**OUTCOMES**

- Posterior instability encompasses a continuum from acute and chronic posterior dislocation to the more frequently encountered recurrent posterior subluxation. Earlier reports in the literature have often involved small patient populations and isolated case reports with minimal follow-up.
- Past surgical treatment options included a number of nonanatomic reconstruction procedures to indirectly control posterior subluxation or dislocation.
- Eventually, a more anatomic approach developed, with procedures designed to openly repair the detached labrum (reverse Bankart repair) or address the patient’s excessive capsular redundancy (posterosuperior capsular shift).
- Preliminary results, published in 1980 by Neer and Foster, described a humeral-based posterior and inferior capsular shift with early good results. Since then, multiple authors have advocated the use of Neer’s posterosuperior capsular shift with excellent results. Other authors have modified this concept by using a glenoid-based posterior T-capsular shift to similarly tighten the posterior capsule.
- More recently, Misamore and Facibene reported promising results in unidirectional posterior instability patients using such an open posterior glenoid-based capsular shift. Excellent results were achieved, with 12 of 14 returning to competitive sports.
- Fronek and colleagues, using a similar capsular shift, reported on 10 of 11 patients without further episodes of instability and overall good results. However, only 3 patients were able to return to their preinjury ability level during...
sports. If the capsular laxity was not eliminated by this medi- 
dialized shift, then an additional lateral incision in the capsule and an H-type repair was used.

- Osseous reconstructions, including a posterior opening wedge gelenoid osteotomy,\textsuperscript{4,7,14,23,32} and posterior bone block procedures,\textsuperscript{1,10,11,19,26} to augment or address bony deficiencies have been described and although rarely used still have a place under certain circumstances. Hernandez and Drez\textsuperscript{17} combined geleno-plasty with a capsularorrhaphy and infraspinatus advancement.

- The posterior infraspinatus tenodesis, as illustrated, remains a valuable procedure, especially in cases of poor posterior capsular tissue or in revision cases. Hawkins and colleagues\textsuperscript{16} reported an 85% success rate using such a tenodesis as a primary procedure. Even when including revision cases, Pollock and Bigliani\textsuperscript{29} reported an 80% success rate using the same technique.

- Papendick and Savoie,\textsuperscript{28} followed by McIntyre and associates,\textsuperscript{24} were among the first of many to describe their arthroscopic techniques in the treatment of unidirectional posterior subluxation with encouraging results.

- Further improvements in arthroscopic suture repair techniques and instruments have led to the effective and reproducible arthroscopic treatment of recurrent posterior subluxation. The most promising arthroscopic repair techniques include posterior labral repair using suture anchor fixation, posterior capsulolabral plication, and the increasing role of rotator cuff interval plication as an augmentation to the primary repair.

- Kim and colleagues\textsuperscript{21} prospectively reported on 27 athletes with unidirectional recurrent posterior subluxation due to a distinct traumatic event. All were treated with an arthroscopic posterior Bankart repair and capsular shifting superiorly. Suture anchors were used in all cases and, if an incomplete labral lesion was encountered, it was converted to a complete detachment before repair. At a mean of 39 months postoperatively, patients had improved functional scores and only 1 patient out of 27 (4%) had a recurrence.

- Recently, Bradley and colleagues,\textsuperscript{6} in the largest prospective study to date, reviewed 91 athletes (100 shoulders) with unidirectional, recurrent posterior instability. Three types of capsulolabral repairs were performed based on preoperative clinical examination and arthroscopic findings: capsulolabral plication without suture anchors, capsulolabral plication with suture anchors and additional plication sutures, and capsulolabral plication with suture anchors.

- The capsulolabral repair without suture anchors was used in cases of significant posterior capsular laxity even though the labrum was not detached. The labrum was advanced superiorly and medially. Patients with acute traumatic injuries with minimal capsular stretching underwent minimal capsular advancement during the repair. Patients with chronic capsular redundancy required more advancement.\textsuperscript{6}

- The mean follow-up in the study was 27 months. All were involved in athletics, and 51% were involved in contact sports. Of these, 66% had an isolated posterior labral tear. Of the eight failures due to recurrent instability, pain, or decreased function, only one had a traumatic reinjuring event. All failures had a patulous capsule and 25% had a recurrent labral tear. Twenty-five percent of the failures had a previous thermal capsulorrhaphy before being referred for treatment. Only 11% of the patients in the study group did not return to their sport, and 33% returned but were unable to perform at the same level of competition.\textsuperscript{6}

REFERENCES

DEFINITION
- Glenoid bone loss after anterior dislocation is the loss of bone due to fracture, abrasion, or compression at the anteroinferior glenoid.
- This bone loss is frequently seen after anterior dislocation and varies greatly in its extent and significance.\(^4,6\)
- The use of a coracoid bone block to prevent anterior dislocation was first proposed by Latarjet\(^7\) in 1954.
- In 1958 Helfet\(^5\) described the Bristow technique, in which the tip of the coracoid is sutured to the capsuloperiosteal elements of the anterior glenoid. This was later modified to screw fixation.
- Patte\(^9\) described the effectiveness of the Latarjet procedure as being due to the “triple blocking effect”:
  - The effect of the conjoint tendon when the arm is in the abducted and externally rotated position, where it acts as a sling on the inferior subscapularis and the inferior capsule (FIG 1).
  - The effect of the anterior bone block
  - The effect of repairing the capsule to the stump of the conjoint tendon
  - The original technique described by Latarjet involved cutting the subscapularis tendon, but this has been modified to a subscapularis split, thus preserving the integrity of its fibers.

ANATOMY
- The glenoid has a pear shape, with an average height of 35 mm and an average width of 25 mm.
- The fibrous glenoid labrum provides attachment for the glenohumeral ligaments to the bony glenoid and increases the depth of the glenoid by 50%.
- The inferior glenohumeral ligament (IGHL) attaches to the glenoid between the 2 o’clock and 4 o’clock positions in a right shoulder.

FIG 1 • A. In normal circumstances the subscapularis provides no inferior support. B. Completed Latarjet procedure with the arm in neutral. C. The inferior displacement of the subscapularis creates a sling beneath the inferior capsule, especially in the abducted, externally rotated at-risk position.
The coracoid is directed anteriorly and then hooks laterally and inferiorly from its origin on the anterior scapular neck. The distal and lateral coracoid is the portion osteotomized for the Latarjet procedure. It is the origin for the short head of biceps and the coracobrachialis tendons (conjoint tendon) at its tip. Medially the pectoralis minor is attached, and laterally there is the insertion of the coracoacromial and the coraco-humeral ligaments.

- Proximal to the “knee” of the coracoid and untouched by the osteotomy are the conoid and trapezoid ligaments.
- The musculocutaneous nerve enters the conjoint tendon from the medial aspect on its deep surface at an average of 5 cm from the tip of the coracoid (range 1.5 to 9 cm).
- The axillary nerve runs on the anterior surface of the subscapularis muscle lateral to the axillary artery before it enters the quadrilateral space at the inferior portion of the subscapularis.
- The anterior inferior glenohumeral ligament lies deep to the middle and lower portions of the subscapularis muscle.

**PATHOGENESIS**

- Anterior glenoid bone loss occurs because of either impaction of the humeral head on the anterior glenoid at the moment of dislocation or recurrent subluxation or dislocation.
- Acute impaction may result in anteroinferior glenoid fractures, the so-called bony Bankart lesions.
- Recurrent subluxation or dislocation may also result in erosion or impaction of the glenoid rim.
- Recurrent dislocation occurs owing to multiple factors, one of which is the presence of a bony lesion.
- Following Bankart repair, loss of external rotation is 25 degrees per centimeter of anterior glenoid defect. This is due to anterior capsular tightness. An osseous defect with a width that is at least 21% of the glenoid length may cause instability.
- The normally pear-shaped glenoid assumes the shape of an inverted pear.
- Redislocation in contact athletes after arthroscopic anterior stabilization occurs more frequently in those with anterior bone loss.

**NATURAL HISTORY**

- Bone loss of varying degrees is seen in 90% to 95% of individuals with anterior shoulder instability.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The history should include the mechanism of dislocation (although this is often not clear), the site of the pain, maneuvers required for reduction, recurrence, and associated injuries.
- Recurrent anterior subluxation may be difficult to diagnose. A history of pain in the abducted externally rotated arm, pain resulting in a temporarily useless arm (dead arm syndrome), and more subtle variations can occur. Diagnosis is aided by a good clinical examination and imaging showing lesions of passage.
- The clinician should always assess for axillary nerve injury by checking sensation in the regimental badge area and motor power in the deltoid.

**IMAGING AND DIAGNOSTIC STUDIES**

- Plain radiographs should include anteroposterior (AP) views in neutral, internal and external rotation, and a profile view of the glenoid (ie, as per Bernageau) of the normal and abnormal sides.
- Radiographic accuracy and quality are improved when images are taken with fluoroscopic assistance.
- CT scanning may supplement radiographs.
DIFFERENTIAL DIAGNOSIS
- Posterior dislocation
- Posterosuperior cuff pathology in throwers
- Voluntary subluxation or dislocation
- Recurrent subluxation or dislocation

SURGICAL MANAGEMENT

Preoperative Planning
- Preoperative radiographs are analyzed to establish the presence and size of any bony glenoid defect.
- We use the Latarjet procedure for all individuals with anterior instability requiring surgery. The size of the glenoid defect does not change our operative technique.
- MRI or CT scans are not part of the standard preoperative planning but may assist in the diagnosis in cases of subtle instability.
- The presence of large Hill-Sachs lesions, SLAP lesions (superior labrum, from anterior to posterior), or other intra-articular pathology has no influence on outcome after the Latarjet procedure and hence does not influence the operative technique.

Positioning
- Under general anesthesia in association with an interscalene block for postoperative pain control, the patient is placed in the beach-chair position.
- A folded sheet is placed under the scapula to reduce scapula protraction and enable better access to the coracoid and glenoid (FIG 3).
- The arm is draped free to allow intraoperative abduction and external rotation.

CORACOID OSTEOTOMY AND PREPARATION
- Maintain the arm in abduction and external rotation to tension the coracoacromial ligament, which is incised 1 cm from its coracoid attachment.
- Partially incise at the same time the coracohumeral ligament lying deep to the coracoacromial ligament and free the upper lateral aspect of the superior conjoint tendon (TECH FIG 1A).
- Now adduct and internally rotate the arm to allow exposure of the medial side of the coracoid process. The pectoralis minor is released from this attachment with electrocautery, taking care not to go past the tip of the coracoid and damage its blood supply.
- A periosteal elevator is then used to remove any soft tissue from the undersurface of the coracoid. This elevator also aids visualization of the “knee” of the coracoid, which is the site of the osteotomy.
- Using a 90-degree oscillating saw, the osteotomy is made from medial to lateral.
- The arm is then placed in abduction and external rotation for the second time. The coracoid is grasped with a toothed forceps and any remnants of the coracohumeral ligament are released.

FIG 3 • Placement of the folded sheet on the medial border of the scapula reduces scapula protraction, making it easier to place your drill holes in the glenoid parallel to the articular surface.

Approach
- A deltopectoral approach is used.
- The skin incision is from the tip of the coracoid extending 4 to 5 cm toward the axillary crease.
- The cephalic vein is taken laterally and its large medial branch is ligated.
- A self-retaining retractor is used to maintain exposure between the deltoid and pectoralis major.
- The arm is placed in abduction and external rotation and a Hohmann retractor is placed over the top of the coracoid process.
The arm is then returned to a neutral position and the coracoid is delivered onto a swab at the inferior aspect of the wound (TECH FIG 1B).

Preparation of the bed of the coracoid is important to avoid a pseudarthrosis. Soft tissue is removed with a scalpel and then the oscillating saw is used to remove the cortical bone, exposing a cancellous bed for graft healing (TECH FIG 1C).

An osteotome is placed beneath the coracoid to protect the skin and two drill holes are made using a 3.2-mm drill (TECH FIG 1D). The holes are in the central axis of the coracoid and about 1 cm apart.

The swab protecting the skin is removed, the arm is externally rotated, keeping the elbow by the side, and the lateral border of the conjoint tendon is released for about 5 cm using a Mayo scissors.

The coracoid is then pushed beneath the pectoralis major, exposing the underlying subscapularis muscle.

GLENOID EXPOSURE

- Identify the superior and inferior margins of the subscapularis; the location for the subscapularis split is at the junction of its superior two thirds and inferior one third (TECH FIG 2A).

- A Mayo scissors is used to create the split. It is pushed between the fibers as far as the capsule, then opened perpendicular to the plane of the muscle fibers. Keeping the scissors open, push a small swab into the subscapular fossa in a superomedial direction and then place a Hohmann retractor on the swab in the subscapularis fossa (TECH FIG 2B).

- Using a curved retractor such as a Bennett retractor on the inferior part of the subscapularis, extend the lateral part of the split with a scalpel to the lesser...
tuberosity. The joint line is then more easily visualized and incised for about 1.5 to 2 cm, allowing a retractor to be placed in the joint (Trillat or Fukuda retractor; TECH FIG 2C).

- Superior exposure is created when a Steinmann pin is hammered into the superior scapular neck as high as possible.
- The medial Hohmann retractor is now exchanged for a link retractor and placed as medial as possible on the scapula neck.
- A small Hohmann retractor is placed inferiorly between the capsule on the inferior neck and the inferior part of the subscapularis.
- The anteroinferior part of the glenoid should now be easily visualized.

**PREPARATION OF THE GLENOID AND CORACOID FIXATION**

- The anteroinferior labrum and periosteum are incised with the electrocautery, exposing the glenoid 2 cm medially and from about 5 o’clock to 2 o’clock in a right shoulder (a vertical distance of 2 to 3 cm).
- An osteotome is then used to elevate this labral–periosteal flap from lateral to medial (TECH FIG 3A). The frequent presence of a Bankart lesion makes this quite simple.
- The osteotome is then used to decorticate this anteroinferior surface of the glenoid. We aim to create a flat surface on which to place our graft.
- The use of bone graft (excepting the coracoid process) is not required.
- Using the 3.2-mm drill, drill the inferior hole in the glenoid (TECH FIG 3B). This is at the 5 o’clock position, parallel to the plane of the glenoid and sufficiently medial that the coracoid will not overhang the glenoid (generally 7 mm, but depends on coracoid morphology). Both anterior and posterior cortices are drilled.
- The coracoid is now retrieved from its position under the pectoralis major and grasped at the cut end in a medial–lateral fashion.
- A 4.5-mm partially threaded malleolar screw is fully inserted into the inferior hole (tendinous end). The length of this screw is typically 35 mm but can be verified by adding together the depth of the coracoid and the depth of the glenoid hole (TECH FIG 3C).
- The screw is then placed into the already drilled inferior hole and tightened into position, ensuring that the coracoid comes to lie parallel to the anterior border of the glenoid with no overhang. A slightly medial position (2 to 3 mm) is acceptable. Rotation of the coracoid is adjusted using a heavy forceps.
- When the position of the coracoid is parallel to the glenoid, the second drill hole is made through the superior hole already drilled in the coracoid (TECH FIG 3D). It is important to avoid rotation of the coracoid at this stage.
The hole is measured and the correct-sized malleolar screw is inserted into position.

Repair of the capsule is then carried out by suturing the capsule to the stump of the coracoacromial ligament using a number 1 Dexon suture with the arm in external rotation, after removing the intra-articular retractor.

The retractors are removed, as is the sponge that was on the medial scapula neck.

There is no need to close the split in the subscapularis muscle.

**PEARLS AND PITFALLS**

- Dissection on the medial side of the coracoid is not necessary and risks nerve injury.
- The surgeon should not cut the subscapularis to gain access to the glenoid; the subscapularis split is used instead.
- The surgeon should decorticate the undersurface of the coracoid and the anterior glenoid to bleeding bone to avoid coracoid pseudarthrosis.
- Coracoid fracture can be avoided by using the two-fingers technique when tightening screws.
- Screws must be bicortical.
- Placing the coracoid in the “lying” position increases the coracoid–glenoid contact and decreases the risk of pseudarthrosis.
- If the coracoid fractures longitudinally, it should be turned 90 degrees. If it fractures transversely, the tip should be placed in a standing position.
- The coracoid must never overhang the glenoid, as this leads to arthritis (FIG 4).

**FIG 4** Postoperative AP and lateral views showing correct placement of screws and no overhanging of the coracoid.
**POSTOPERATIVE CARE**

- A simple sling is used for 2 weeks.
- Rehabilitation begins on the first postoperative day with gentle active range-of-motion exercises.
- Full activities of daily living are allowed at 6 weeks and a return to all sports is permitted at 3 months.

**OUTCOMES**

- In a study of 160 Latarjet procedures, we had a recurrence rate of 1%. Of those who played sports, 83% returned to their preinjury level or better. Overall, 98% rated their result as excellent or good and 76% had excellent or good results using the modified Rowe score.11
- The occurrence of postoperative shoulder arthritis is related to preventable factors (ie, lateral overhang of the coracoid) and pre-existing factors (eg, increased age at the time of first dislocation, increased age at the time of surgery and the presence of arthritis before to surgery).

**COMPLICATIONS**

- Intraoperative fracture of the coracoid
- Infection
- Hematoma formation
- Pseudarthrosis (not associated with poor outcome)
- Pain related to screws (2% incidence of screw removal)
- Recurrence
- Arthritis (if graft overhangs the anterior glenoid)

**REFERENCES**

DEFINITION
- Anterior shoulder instability typically results from an injury to the capsule, ligaments, and labrum that stabilize the glenohumeral joint.
- In cases of higher-energy trauma or recurrent dislocation, however, there can be significant bone loss or erosion of the anterior glenoid rim.
- The key to correctly treating anterior shoulder instability is recognizing whether the lesion involves injury to only capsulolabroligamentous structures or if it also involves the anterior glenoid bone.

ANATOMY
- Shoulder stability is provided by both dynamic and static stabilizers (Fig 1).
- Dynamic stabilizers include:
  - Rotator cuff
  - Biceps
  - Coordinated scapulothoracic motion
  - Proprioception
- Static stabilizers include:
  - Bony anatomy of the glenoid and humeral head
  - Labrum
  - Glenohumeral capsule and ligaments
  - Negative intra-articular pressure
- The inferior glenohumeral ligament (IGHL) complex limits anterior translation of the humeral head on the glenoid in abduction. It takes origin from the labrum on the glenoid inferiorly. The complex consists of an anterior band, posterior band, and intervening pouch. The anterior band is responsible for anterior restraint with the arm in high degrees of abduction with external rotation.
- Normal glenoid morphology is the shape of a pear. There is normally a surface area mismatch of the glenohumeral joint whereby only 20% to 30% of the humeral head contacts the glenoid surface at any point in time (Fig 1).
- The synchronized contraction of the rotator cuff and biceps provides a compressive force directing the convex humeral head into the concave glenoid and labrum unit. This is known as concavity compression.

PATHOGENESIS
- Anterior shoulder instability typically follows a dislocation event that results from a fall or collision with the arm in external rotation and abduction.
- First-time dislocators typically require a closed reduction of their shoulder after muscle relaxation and sedation, while recurrent dislocators can often reduce their shoulders with minimal effort.
- An injury to the labrum in the anteroinferior quadrant of the glenoid destabilizing the IGHL complex as well as stretching or a tear of the anteroinferior capsule can result in anterior shoulder instability.
- A rotator cuff tear should be suspected in patients greater than 40 years old who suffer from a dislocation episode.
- Recurrent anterior glenohumeral instability can also occur in the setting of anterior glenoid bone loss due to glenoid fracture after a single dislocation event or erosion as a result of recurrent subluxations or dislocations.
PATIENT HISTORY AND PHYSICAL FINDINGS

- A complete examination of the shoulder should also include the evaluation of other concomitant injuries and ruling out differential diagnoses. A thorough examination includes but is not limited to the following:
  - Apprehension test: Apprehension, not simply pain, is required for a positive apprehension test.
  - Relocation test: Relief of apprehension with posterior pressure is necessary for a positive relocation maneuver.
  - Load and shift test: The examiner should note the degree of displacement of the humeral head on the glenoid rim.
  - Belly press: A positive belly press test is when the patient must flex the wrist and extend the arm to maintain the palm of the hand on the abdomen.
  - Assessment for generalized ligamentous laxity: Specifically, hyperextension of the elbows and knees as well as the ability to oppose the thumb to the forearm should be noted.
  - Rotator cuff: Manual strength testing of the subscapularis, supraspinatus, infraspinatus, and teres minor muscles must be done. Rotator cuff tears can contribute to instability.
  - Subscapularis insufficiency: Weakness of internal rotation with the shoulder adducted to the side suggests a subscapularis injury but is not specific. Increased external rotation of the injured side with the shoulder adducted compared to the contralateral shoulder, pain with external rotation of the shoulder, a positive belly press sign, or positive lift-off sign should raise suspicion for subscapularis insufficiency.
  - Axillary nerve injury: Both the deltoid motor strength and sensation in the distribution of the axillary nerve should be assessed. Atrophy of the deltoid muscle should be noted.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs are useful to detect Hill-Sachs lesion, glenoid dysplasia, and anterior glenoid fractures or erosion. Standard images should include a true anteroposterior (AP) view of the glenoid, an axillary view, and a Stryker notch view. Fractures and erosions of the glenoid as well as the position of the humerus on the glenoid should be noted.
- If a significant anterior bony glenoid lesion is suspected owing to plain film findings or a history of recurrent dislocations, a CT arthrogram should be obtained. This allows an evaluation of the subscapularis tendon, bony architecture of the glenoid, humeral head, and tuberosities as well the degree of capsulolabral injury and redundancy.
- Both Itoi\textsuperscript{5,6} and Gerber\textsuperscript{3} have described techniques to assess anterior glenoid bone quantitatively that serve as a guide for when bony augmentation is indicated for recurrent anterior shoulder instability. Gerber’s method\textsuperscript{3} is easily performed on oblique sagittal or 3D reconstructions of the glenoid surface (FIG 3). Cadaveric studies have shown that the force required for anterior dislocation is reduced by 70% from an intact glenoid if the length of the glenoid defect exceeds the maximum radius of the glenoid.

DIFFERENTIAL DIAGNOSIS

- Bankart lesion
- Multidirectional instability
- Hill-Sachs lesion
- Tuberosity fracture
Rotator cuff tear (especially subscapularis)
Scapular winging (especially serratus anterior dysfunction)
Axillary nerve injury

NONOPERATIVE MANAGEMENT
Conservative therapy for recurrent anterior shoulder dislocation includes strengthening of the rotator cuff musculature as well as the periscapular stabilizers. Deltoid muscle strengthening should be incorporated into a rotator cuff strengthening protocol. Periscapular strengthening should focus on the rhomboids, trapezius, serratus, and latissimus dorsi muscles.
Conservative treatment of recurrent shoulder dislocation in the setting of a bony glenoid defect, however, is rarely successful.

SURGICAL MANAGEMENT
Preoperative Planning
All imaging studies, including plain radiographs (true AP glenoid view, axillary view, Stryker notch view) and CT scan with intra-articular gadolinium, are reviewed. Additional radiographic views can be helpful. The apical oblique can demonstrate anterior glenoid lip defects as well as posterolateral impression fractures of the humeral head. Both the West Point and Bernageau views are useful to note defects of the anteroinferior glenoid rim.
The CT arthrogram is examined for evidence of anterior glenoid bone loss:
The degree of bone loss is assessed on oblique sagittal reconstruction or a 3D reconstruction of the glenoid face (FIG 4).
The length of the anterior glenoid defect is measured.
If the length of the glenoid defect exceeds half of the maximum diameter of the glenoid, an anatomic glenoid reconstruction of the anterior glenoid with autologous iliac crest bone graft is considered.
Often, the anterior erosion is extensive, making it difficult to accurately measure the glenoid diameter. In these instances, the superoinferior axis of the glenoid should be drawn on the glenoid face image and the maximum radius determined from this line to the posterior aspect of the glenoid (Fig 4).
Associated superior labral tears, biceps pathology, rotator cuff tears, and the presence of articular erosion and osteoarthritis should be noted preoperatively and treated appropriately at the index operation.
An examination under anesthesia should assess passive range of motion, noting any restrictions as well as excessive motion, which may indicate subscapularis insufficiency. In addition, the glenohumeral joint should be assessed for laxity to ensure there is not a bidirectional or multidirectional component.

Positioning
Although some surgeons choose to use a bean bag, we prefer to use a beach chair with an attachable hydraulic articulated arm holder (Spider Limb Positioner, Tenet Medical Engineering, Calgary, Canada) (FIG 5).
The head of the beach chair is elevated 30 to 45 degrees to allow access to the ipsilateral iliac crest.

FIG 3 • A 3D CT reconstruction effectively demonstrates the degree of anterior glenoid bone loss.

FIG 4 • Gerber’s method for evaluating the degree of glenoid erosion. \( x \) is the length of the glenoid defect. Half of the maximum diameter of the glenoid, \( r \), can be measured from a vertical line (blue) connecting the superior glenoid rim to the inferior glenoid rim in cases of significant erosion. If \( x > r \), then the force for dislocation is decreased by 70%.

FIG 5 • The patient is secured into a beach chair with an attachable hydraulic articulated arm holder (Spider Limb Positioner, Tenet Medical Engineering, Calgary, Canada). The upper body is positioned at 30 to 45 degrees to allow access to the ipsilateral iliac crest.
EXPOSURE OF GLENOID

- A well-padded bump is placed behind the ipsilateral buttock and hip to ensure that the iliac crest is prominent for ease of dissection.
- The shoulder and iliac crest are prepared and draped in the standard sterile fashion.

Approach

- Anterior glenoid reconstruction with iliac crest bone graft requires two approaches:
  - Deltopectoral approach for glenoid preparation
  - Tricortical anterior iliac crest bone graft harvesting

- The clavipectoral fascia is sharply incised lateral to the conjoint tendon, making sure to stay lateral to any muscle of the short head of the biceps.
- The musculocutaneous nerve can then be palpated on the deep surface of the conjoint tendon. The conjoint tendon is retracted medially, exposing the subscapularis tendon and muscle.
- The coracoacromial ligament can be released if additional exposure is needed superiorly.
- The circumflex vessels are then identified and ligated or coagulated (TECH FIG 1B).
- The axillary nerve can be palpated as it passes over the inferior portion of the subscapularis and loops under the inferior capsule. A blunt retractor can be placed lateral and deep to the axillary nerve, thus retracting it gently medially away from the subscapularis musculotendinous junction.
- The subscapularis tendon is then incised from bone off the lesser tuberosity to avoid disrupting the long head of the biceps tendon in the bicipital groove (TECH FIG 1C).
- Through sharp dissection, an interval between the subscapularis tendon and capsule is developed, leaving the capsule intact. It is often easier to start inferiorly and use a blunt elevator to dissect the interval.
- The subscapularis tendon and muscle are retracted medially using an anterior glenoid neck retractor.
- A blunt retractor is repositioned deep to the axillary nerve to retract away from the capsule, which should be widely exposed at this point.
- An inverted L-shaped capsulotomy is then created based on the humeral neck and extending horizontally across the rotator interval region (TECH FIG 1D).

TECH FIG 1 - A. The pectoralis major and deltoid muscles are retracted to reveal a broad exposure of the conjoint tendon (CT) and muscle belly passing over the subscapularis muscle (SS). The coracoacromial ligament (CA) can be released if needed for additional exposure. B. A blunt curved retractor can be placed inferiorly along the subscapularis to protect the axillary nerve. (continued)
The anterior glenoid and scapular neck are then exposed (TECH FIG 2).

After the L-shaped capsulotomy, a periosteal elevator is used to strip the periosteal sleeve from the anterior scapular neck.

An anterior glenoid neck retractor is positioned to retract the capsule medially.

The iliac crest is harvested as a tricortical bone graft (TECH FIG 3).

A 2- to 3-cm curved incision is made overlying the iliac crest and posterior to the anterosuperior iliac spine.

A Fukuda retractor or similar blunt retractor is used to retract the humeral head posteriorly, thus exposing the face of the glenoid.

The length of the osseous defect is measured and compared to the width of the maximum AP radius of the glenoid. The measured defect length will be the basis for the size of the iliac crest bone graft harvested.

Soft tissue and scar tissue are removed from the anterior glenoid, and this bone and the adjacent scapular neck are roughened with a high-speed burr to create punctate bleeding and a smooth surface for bone grafting.

The incision is carried sharply through subcutaneous tissue down to the periosteum, which is incised sharply and superiosteally elevated to expose the inner and outer tables. Self-retaining retractors are placed be-
Part 7 SHOULDER AND ELBOW • Section II GLENOHUMERAL INSTABILITY

TECHNIQUES

**TECH FIG 3** • Tricortical iliac crest bone graft. **A.** Bone graft is harvested from the iliac crest using an oscillating saw and preserving both the inner and outer tables. A high-speed burr is used to contour the graft. **B.** The size of the graft is typically 3 cm in length and 2 cm in width but should be based on the measured size of the defect. A fixator for the graft is used to secure the graft to the glenoid.

**TECH FIG 4** • Fixation of graft to the glenoid. **A.** The graft is positioned to establish concavity to the glenoid as well as a smooth transition between the graft and native glenoid to avoid an articular step-off. **B.** A number 2 braided polyethylene suture is placed around each 4.0-mm screw before it is fully tightened to assist in later capsular repair. (continued)

**TECH FIG 5** • Glenoid defect. **A.** The glenoid defect is visualized. **B.** The contour of the graft is viewed from the side.

**TECH FIG 6** • Glenoid defect. **A.** The graft is placed into the glenoid defect. **B.** The graft is secured with screws and sutures.

**TECH FIG 7** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 8** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 9** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 10** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 11** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 12** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 13** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 14** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 15** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 16** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 17** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 18** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 19** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 20** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 21** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 22** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 23** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 24** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 25** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 26** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 27** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 28** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 29** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 30** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 31** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 32** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 33** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 34** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 35** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 36** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 37** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 38** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 39** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 40** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 41** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 42** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 43** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 44** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 45** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 46** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 47** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 48** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 49** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 50** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 51** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 52** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 53** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 54** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 55** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 56** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 57** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 58** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.

**TECH FIG 59** • Glenoid defect. **A.** The graft is secured with screws and sutures. **B.** The graft is secured with screws and sutures.
The capsulotomy and subscapularis are then repaired (TECH FIG 5).

- The sutures from the graft fixation screws are passed through the capsule–periosteal sleeve as horizontal mattress stitches and tied.

- Avoid too vertical of an angle, as this may result in humeral impingement.
- Avoid too horizontal of an angle, as this may fail to re-establish glenoid concavity.
- With the graft correctly positioned, it can be temporarily secured to the anterior glenoid using two or three terminally threaded Kirschner wires from the stainless steel AO 4.0-mm cannulated screw set (AO/Synthes, Paoli, PA).
- Two or three partially threaded 4.0-mm cannulated screws are then placed over the Kirschner wires to secure the graft.
- A number 2 braided polyethylene suture is placed around the shaft of each screw before the screw is fully seated and compressing the graft. These sutures may be used for later capsular repair.
- The Fukuda retractor is gently removed and the position of the humeral head is noted. The glenohumeral joint is ranged and any incongruity or instability noted should prompt a change in graft position.

- The capsulotomy can be further repaired in one of two ways:
  - If the L-shaped capsulotomy can be repaired primarily, it is reapproximated using number 2 braided polyethylene suture. Often, though, the graft occupies enough space and the capsule is contracted so that a primary repair of the capsulotomy is not possible.
  - If the L-shaped capsulotomy cannot be repaired primarily to the neck of the humerus with the arm in at least 30 degrees of external rotation, then the capsule is repaired to the lateral portion of the subscapularis tendon. This will tension the anterior capsule as the subscapularis becomes more taut with external rotation.
  - The lesser tuberosity is gently abraded with a high-speed burr to cause punctate bleeding.
  - The subscapularis is then meticulously repaired to the lesser tuberosity with two or three suture anchors using a modified Mason-Allen stitch.
  - The shoulder incision is closed in layers.

REPAIR OF CAPSULE AND SUBSCAPULARIS

- The capsulotomy and subscapularis are then repaired (TECH FIG 5).

- The sutures from the graft fixation screws are passed through the capsule–periosteal sleeve as horizontal mattress stitches and tied.
**PEARLS AND PITFALLS**

**Indications**
- A complete history and physical should be performed.
- Associated pathology must be recognized and addressed:
  - The glenohumeral joint must be assessed for osteoarthrosis.
  - The humeral head must be assessed for a significant engaging Hill-Sachs lesion. It is rare for the lesion to be engaging after reconstruction of the width of the glenoid.

**Tricortical graft harvest**
- Care should be exercised to avoid disrupting the anterosuperior iliac spine.
- The lateral femoral cutaneous and ilioinguinal nerves are at risk during dissection of the anterior ilium.

**Tricortical graft placement**
- Placement of the graft in too vertical of a position may result in impingement of the humeral head and articular erosion.
- Placement of the graft in too horizontal of a position does not recreate concavity of the glenoid.
- There must be a smooth transition between the native glenoid and bone graft. This is ensured by proper positioning. A burr can be used to remove any prominences from the graft that remain after fixation.

**Stiffness**
- Patients should be counseled to expect some limitation of external rotation postoperatively.
- The goal is to achieve a stable joint with no more than 20 degrees loss of external rotation to limit the risk of capsulorrhaphy arthropathy. This should be considered during capsular repair.

**POSTOPERATIVE CARE**
- Radiographs are obtained to judge graft placement and screw position. A CT scan is helpful to estimate graft incorporation (FIG 6).
- The shoulder is maintained in a sling immobilizer for 4 weeks.
- Pendulum exercises are allowed after the first week.
  - At 4 weeks, the sling is removed to allow:
    - Activities of daily living
    - Passive range of motion, active assisted range of motion, water therapy
  - At 3 months, strengthening is initiated.
  - Participation in overhead recreational sport (golf, tennis, swimming) is allowed at 4 months.
  - Participation in contact or collision sports is allowed at 6 months.

**OUTCOMES**
- With appropriate preoperative workup, diagnosis, and surgical technique, anatomic reconstruction of the glenoid with tricortical iliac crest bone graft is very effective at treating recurrent dislocations in the setting of a bony glenoid defect.
- Hutchinson and colleagues demonstrated no recurrent dislocations after tricortical iliac crest bone grafting in a population of epileptics who continued to have seizures postoperatively.
- Warner and associates reported no recurrent dislocations or subluxations after anterior glenoid bone grafting in a population of athletes with traumatic recurrent anterior instability. There was a mean loss of external rotation in abduction of 14 degrees.

**COMPLICATIONS**
- Subscapularis insufficiency
- Hardware failure and migration
- Stiffness
- Brachial plexus injury

---

**FIG 6 • Postoperative imaging of glenoid reconstruction with tricortical iliac crest bone graft.**
- A. Axillary lateral.
- B. Anterior view of 3D CT reconstruction demonstrating position and incorporation of graft.
- C. Posterior view of 3D CT reconstruction demonstrating restored glenoid width, depth, and concavity.
REFERENCES

DEFINITION
- The glenohumeral joint is one of the most commonly dislocated joints in the body.
- With anterior dislocations, bony defects of the anterior glenoid and posterosuperior aspect of the humeral head occur with relative frequency.
- One of the first descriptions of the lesions found on the humeral head was by Flower in 1861, with many subsequent investigators reporting on these bony defects. In 1940, two radiologists, Hill and Sachs, reported that these defects were actually compression fractures produced when the posterosilateral humeral head impinged against the anterior rim of the glenoid.
- Since then, Hill-Sachs lesions have been found to occur with an incidence between 32% and 51% at the time of initial anterior glenohumeral dislocation.
- In shoulders sustaining a Hill-Sachs lesion at the initial dislocation, there exists a statistically significant association with recurrent dislocation. Although Hill-Sachs lesions are common after anterior glenohumeral dislocations, there are relatively few publications describing specific treatments for these humeral head defects.
- In general, specific surgical procedures to address Hill-Sachs lesions have not been recommended in the initial surgical management of recurrent anterior dislocations because the majority of these lesions are small to moderate in size and do not routinely cause significant symptoms of instability.
- Certain subsets of patients exist with more significant bony defects and ongoing symptoms of “instability” or painful clicking, catching, or popping. This occurs even after surgical procedures directed at treating their anterior instability.

ANATOMY
- With an anterior shoulder dislocation, the humeral head is positioned anterior to the glenoid rim.
- The posterosuperior aspect of the humeral head then impacts upon the anterior aspect of the glenoid rim and creates the Hill-Sachs lesion (FIG 1A).
- Only after the shoulder joint is relocated can the influence of the size and shape of the Hill-Sachs lesion on overall shoulder stability be determined (FIG 1B, C).
- Although there is not scientific proof, our clinical experience suggests that lesions representing 25% to 30% of the articular surface area of the humeral head often lead to symptoms.

PATHOGENESIS
- The concept of “articular arc length mismatch” has been recently put forth by Burkhart to “explain the ongoing sensation of catching or popping” arising in the shoulder with a large Hill-Sachs lesion alone or in combination with glenoid defects. Patients with these symptoms have often undergone previous anterior stabilization procedures and reconstruction of damaged glenohumeral ligaments at that time.
- This phenomenon, debatably referred to as “instability,” occurs mainly in a position of abduction and external rotation of the shoulder.
- In this position, a large “engaging” Hill-Sachs lesion encounters the anterior glenoid rim, resulting in the rim “dropping into” the Hill-Sachs lesion.
- The sudden loss of smooth articular surface on the humeral side of the joint presents an irregularly contoured area to the glenoid, causing an uneasy sensation in the patient that feels much like subluxation.
- As Burkhart and DeBeer pointed out, for every “Hill-Sachs lesion, there is a position of the shoulder at which the humeral bone defect will engage the anterior glenoid.”
- Clinically, it is important to differentiate between “engaging” and “nonengaging” Hill-Sachs lesions.
- An engaging Hill-Sachs lesion is one that presents the long axis of its defect parallel to the anterior glenoid with the shoulder in a functional position of abduction and external rotation, such that the Hill-Sachs lesion encounters the rim of the glenoid.
- Lesions can be considered engaging even in positions that are considered “nonfunctional,” such as in some degree of extension, or in lesser degrees of abduction.
- Apprehension and instability in lesser degrees of shoulder abduction often indicate a significant bony defect that is leading to the perceived instability.
- A nonengaging Hill-Sachs lesion is one that either fails to engage the glenoid or engages the glenoid only in a nonfunctional arm position. For example, the Hill-Sachs defect can pass diagonally across the anterior glenoid with external rotation; therefore, there is continual contact of the articulating surfaces and no engagement of the Hill-Sachs lesion by the anterior glenoid.
- Hence, when a patient has symptomatic anterior instability associated with an engaging Hill-Sachs lesion with an articular arc deficit, treatment must be directed at both repairing the Bankart lesion, if present, and preventing the Hill-Sachs lesion from engaging the anterior glenoid.
- We believe that the treatment of symptomatic anterior glenohumeral instability, involving an engaging Hill-Sachs lesion with an articular arc deficit, can be accomplished satisfactorily with a technique of anatomic allograft reconstruction of the humeral head using a side- and size-matched humeral head osteoarticular allograft.
- This technique involves an anatomic reconstruction that eliminates the structural pathology while maintaining the range of motion of the glenohumeral joint.

NATURAL HISTORY
- One of the most clearly documented series of nonoperatively treated shoulder dislocations placed into immobilization is that of Hovelius and associates.
Chapter 7  MANAGEMENT OF GLENOHUMERAL INSTABILITY WITH HUMERAL BONE LOSS

- They determined that the “type and duration of the initial treatment had no effect on the rate of recurrence; with a higher rate of recurrence the younger the patient.”
- Overall, 52% of 247 primary anterior dislocations had no further dislocations.
- Patients who were 12 to 22 years old had a 34% redislocation rate, while those who were 30 to 40 years had a rate of 9%.
- Ninety-nine of 185 shoulders that were evaluated with radiographs had evidence of a Hill-Sachs lesion; and of these 99 shoulders, 60 redislocated at least once and 51 redislocated at least twice during the 10-year follow-up.
- This compares with 38 (44%) of the 86 shoulders that did not have such a lesion documented ($P < 0.04$).
- Acute first-time shoulder dislocations have traditionally been treated nonoperatively with reduction followed by a form of immobilization.
- Currently recommended types of immobilization after shoulder dislocations are as follows:
  - Simple sling immobilization with the arm in internal rotation$^{11}$
  - Immobilization in external rotation$^{9,10}$
- No clear evidence has quieted this discussion.

**PATIENT HISTORY AND PHYSICAL FINDINGS**
- All patients are initially evaluated with complete history and physical examination.
- Specifics of the history include questioning for the mode of onset and timing of initial symptoms, and for the details of present symptoms, including pain, frequency, instability, and level of function.
- All previous surgical procedures performed on the shoulder should be noted.
- Most patients will give a history of recurrent dislocations or multiple surgical attempts to correct the instability.
- Although thought to be a procedure for failed attempts at shoulder stabilization after dislocation, there are other situations that might lead the surgeon to consider this procedure initially.
- Significant traumatic mechanism with an extensive Hill-Sachs lesion (more than 25% to 30% of the articulating surface of the humeral head)

---

**FIG 1** • Posterior views of an anterior glenohumeral dislocation (A), an “engaging” Hill-Sachs lesion after relocation of the gleno-humeral joint (B), and a humeral head with a large Hill-Sachs lesion (C).
• Patients with a history of grand mal seizures often have fairly large Hill-Sachs defects and significant apprehension about the use of their arm. Also, as a result of the violence of the dislocations, the amount of bone pathology present, and the inability to predict the onset of epileptic events, it is worth considering treating this group of patients with an allograft reconstruction of the humeral head defect at the index procedure, as soft tissue repairs alone may not be enough to prevent recurrent injury.

• Physical examination should focus on inspection for previous scars, a thorough determination of active and passive range of motion, and evaluation of the integrity and strength of the rotator cuff.

• The clinician should perform a detailed examination for glenohumeral laxity in the anterior, posterior, and inferior directions.

• Examination for apprehension should be performed in multiple positions, as patients with large Hill-Sachs lesions usually exhibit apprehension that often occurs with the arm in significantly less than 90 degrees abduction and 90 degrees external rotation.13,14

• A comprehensive examination should include but is not limited to:
  - Anterior apprehension test: Positive apprehension can be associated with anterior labral injuries.
  - Bony apprehension test: Apprehension with fewer degrees of abduction may indicate a significant and symptomatic bony contribution to the instability.

IMAGING AND OTHER DIAGNOSTIC STUDIES

• Preoperative imaging includes a comprehensive plain film evaluation with anteroposterior (AP), true AP, axillary, and Stryker notch views of the involved shoulder (FIG 2A).

• All patients require a preoperative axial imaging study (CT or MRI) to more fully define the bony architecture of the glenoid and humeral head and specifically the details of the Hill-Sachs lesion (FIG 2B).

• One must be careful when interpreting these studies, since the plane of the Hill-Sachs defect is oblique to the plane of the axial image. Therefore, the size of these defects is often underestimated in standard axial imaging.

• Three-dimensional reconstruction can be a useful tool to more clearly define the size and location of the defect and to estimate the amount of the articular surface involved.

• While the volume and depth of the lesion certainly affect the stability of the shoulder, even more important may be the size of the defect in the articular arc.

DIFFERENTIAL DIAGNOSIS

• Anterior shoulder dislocation with or without:
  - Bankart lesion
  - “Bony Bankart” or an anterior glenoid lesion
  - Hill-Sachs lesion
  - Combination of the above

• Posterior shoulder dislocation with or without associated soft tissue and bony lesions

• Inferior shoulder dislocation with or without associated soft tissue and bony lesions

NONOPERATIVE MANAGEMENT

• Given a mechanism of shoulder dislocation, the presence of significant bony defects to the glenoid or the humeral head, and associated functional instability, there are not anticipated gains through nonoperative management.

SURGICAL MANAGEMENT

• Several techniques have been described in the literature to address symptomatic engaging Hill-Sachs lesions.

  - Open anterior procedures, such as an East–West plication to limit external rotation, designed to limit external rotation such that the humeral head defect is kept from engaging1,2
  - Rotational proximal humeral osteotomy as described by Weber and colleagues17
  - Transfer of the infraspinatus into the defect to render the lesion essentially extra-articular3,18
  - Filling in of the Hill-Sachs defect so that it can no longer engage, using either a corticocancellous iliac graft or a femoral head osteoarticular allograft

  - If the defect is severe, prosthetic replacement using a hemiarthroplasty may become necessary.16

  - In the case of posterior glenohumeral dislocation, Gerber and coworkers5 have reported on the successful reconstruction of the humeral head by elevation of the depressed cartilage and subchondral buttressing with cancellous bone graft, as well as femoral head osteoarticular allograft reconstruction of the humeral head defect.

  - The indications for anatomic allograft reconstruction of the humeral head are as follows:
    - Ongoing symptomatic anterior glenohumeral instability or painful clicking, catching, or popping in a patient with a large engaging Hill-Sachs lesion in patients who have failed to respond to previous soft-tissue stabilization procedures
    - A large engaging Hill-Sachs lesion is identified before undergoing initial surgical treatment.

  - Clinical experience suggests that lesions involving more than 25% to 30% of the articular surface may be significant.14
The entire tendon is transected vertically about 0.5 cm medial to its insertion onto the lesser tuberosity.
- Tag sutures of number 2 Control Release Ethibond Excel (#DC494, Ethicon, Somerville, NJ) are placed in the lateral aspect of the subscapularis tendon as it is released from the lesser tuberosity.
- The interval between the subscapularis and the anterior capsule is then carefully developed using sharp dissection, continuing medially to the neck of the glenoid.
- The inferior capsule is then further isolated using careful blunt dissection.
- A laterally based capsulotomy is made with the vertical limb in line with the subscapularis incision and continuing superiorly.
- The anteroinferior capsule is then released off the surgical neck of the humerus with intra-articular dissection using a periosteal elevator.
EXPOSURE OF THE HILL-SACHS LESION

- The humeral head retractor is withdrawn and the humerus is brought into maximal external rotation to expose the Hill-Sachs lesion.
- Unroof the synovial expansion of the supraspinatus to allow the humerus to be more fully externally rotated, allowing better visualization and access to the Hill-Sachs lesion.
- A flat narrow retractor (e.g., Darach) is then placed over the reflected undersurface of the subscapularis tendon and behind the neck of the humerus on the posterior rotator cuff in order to lever out the humeral head (TECH FIG 1).

TECH FIG 1 • Intraoperative exposure of large Hill-Sachs lesion to be reconstructed.

HUMERAL HEAD OSTEOTOMY

- With the Hill-Sachs lesion adequately exposed, a micro-sagittal saw is used to smooth and reshape the defect into a chevron-type configuration.
- The piece of matching allograft humeral head to be inserted should resemble a deep-dish slice of pie (TECH FIG 2A,B).
- The base and side of the defect can then be further smoothed using a hand rasp to achieve precise, flat surfaces.
- The base (X), height (Y), length (Z), and rough outside partial circumference (C) of the defect are then measured to the nearest millimeter (TECH FIG 2C).

OSTEOTOMY OF THE HUMERAL HEAD ALLOGRAFT

- A corresponding piece is cut from the matched humeral head allograft that is 2 to 3 mm larger in all dimensions than the measured defect.
- The allograft segment is then provisionally placed into the Hill-Sachs defect and resized in all three planes.
- Excess graft is then carefully trimmed with the micro-sagittal saw and is reshaped in the other two planes as well.
- Fine-tuning of graft size is then continued in one plane at a time until a perfect size match is achieved in all planes, including base (X), height (Y), length (Z), and outside partial circumference (C).
The allograft segment is placed into the defect and aligned so as to achieve a congruent articular surface. It is provisionally secured in place with two or three smooth 0.045-inch Kirschner wires (TECH FIG 3A,B). The wires are then sequentially replaced with 3.5-mm fully threaded cortical or 4.0-mm cancellous screws placed in a lag fashion (TECH FIG 3C,D).

Ensure that the screw heads are countersunk so that they are below the level of the articular surface. The joint is irrigated and taken through a range of motion to ensure that the reconstructed humeral head provides a smooth congruent articulating surface.

The capsulotomy is closed with absorbable suture, tying any previously placed sutures used to repair the capsulolabral pathology if present. The subscapularis tendon is then reapproximated to its stump anatomically, without shortening, using suture anchors or a soft tissue repair with nonabsorbable suture. Allow the conjoined tendon, deltoid, and pectoralis major muscles to return to their normal anatomic positions. A routine subcutaneous and skin closure is then performed. Sterile dressing is applied. The arm is placed into a shoulder immobilizer.
This area of the humeral head can be accessed through external rotation and forward flexion of the joint. Anchors or sutures are placed in the anterior glenoid for later labral repair after reconstruction of the Hill-Sachs lesion. Exposure of the posterior superior humeral head This area of the humeral head can be accessed through external rotation and forward flexion of the upper extremity. Appropriately placed retractors assist in this exposure. Allograft sizing The surgeon should ensure the allograft obtained is larger in dimension by 2 to 3 mm than the actual defect. This allows for in situ sizing. Screw placement It is easier to initially place two 0.045-inch Kirschner wires for fixation and then replace them with two 3.5-mm stainless steel AO screws lagged into position. Screw heads are countersunk beneath the surface of the allograft articular surface to prevent hardware penetration.

**POSTOPERATIVE CARE**

- After surgery, patients are given a sling for comfort and allowed full passive range of motion immediately as tolerated.
- Because of the subscapularis detachment, we protect against active and resisted internal rotation for 6 weeks.
- After the initial 6-week period, patients are allowed terminal stretching and strengthening exercises.
- The shoulders are imaged with repeat radiographs at 6 weeks and 6 months, and with CT scans at 6 months to assess for consolidation and incorporation of the graft.

**OUTCOMES**

- Between 1995 and 2001, we performed and reviewed this procedure in 18 patients who had failed previous attempts at surgical stabilization.13,14
- Fifteen patients had a history of traumatic anterior glenohumeral instability related to sports, and three patients had instability related to seizures or other trauma.
- All had posterolateral humeral head defects (Hill-Sachs lesions) that represented greater than about 25% to 30% of the humeral head.
- One patient had both anterior and posterior humeral head defects from bidirectional shoulder instability sustained as a result of a seizure disorder.
- No patients had true multidirectional instability.
- Patients in the formal review were assessed preoperatively and postoperatively with:
  - Detailed history
  - Physical examination
  - Radiographic evaluation (plain films and axial imaging [CT, MRI, or both])
  - Validated clinical evaluation measures (Constant-Murley shoulder scale, Western Ontario Shoulder Instability Index [WOSII], and SF-36)
- Findings at the time of surgery included:
  - Nine patients with recurrent Bankart lesions
  - Nine patients with capsular redundancy only
  - No patients with subscapularis tears
  - One patient with posterior glenoid erosion
  - Three patients with anterior glenoid deficiency (less than 20%), which was not reconstructed
  - Mean length of follow-up was 50 months (range 24 to 96 months).
  - There were no episodes of recurrent instability. Sixteen of 18 (89%) patients returned to work.
- The average Constant-Murley score postoperatively was 78.5. The WOSII, which is a validated quality-of-life scale specific to shoulder instability using a visual analog scale response format, decreased and patients were significantly improved.
- Overall, this represents the first reported series of anatomic allograft reconstruction of Hill-Sachs defects for recurrent traumatic anterior instability after failed repairs.
- This technique has been shown to be effective for a difficult problem with few available treatment options.
- The patients demonstrated improvement in stability, loss of apprehension, and high subjective approval, allowing return to near-normal function with no further episodes of instability.
- Although infrequently a cause for clinical concern, Hill-Sachs defects can be the source of significant disability and recurrent instability in a subset of patients.
- One should consider anatomic allograft reconstruction of these defects as a viable treatment alternative.

**COMPLICATIONS**

- Complications that occurred in our series of humeral osteoarticular allograft reconstruction of the Hill-Sachs lesions included radiographic follow-up evidence of partial graft collapse in 2 of 18 patients, early evidence of osteoarthritis in 3 patients (marginal osteophytes), and 1 mild subluxation (posterior).12–14
- Hardware complications developed in two patients, who complained of pain with extreme external rotation.
- The screws were removed at about 2 years postoperatively in both patients, thereby relieving their symptoms.
- One must weigh the risks of continued shoulder dysfunction versus the risk associated with the use of fresh osteoarticular allografts.

**REFERENCES**

4. Flower WH. On the pathological changes produced in the shoulder-joint by traumatic dislocations, as derived from an examination of all specimens illustrating this injury in the museums of London. Trans Pathol Soc London 1861;12:179.
DEFINITION

- Posterosuperior tears of the rotator cuff involve the supraspinatus, infraspinatus, and occasionally the teres minor.
- Some of the surgical techniques to be described here are not commonly used currently, as most tears can be repaired by arthroscopic approaches, either with mini-open or all-arthroscopic techniques.
- These approaches, however, are still useful for treating those massive tears that may need special procedures to accomplish the repair.

ANATOMY

- The rotator cuff is a group of four musculotendinous structures arising from the scapula: the supraspinatus, the infraspinatus, the teres minor, and the subscapularis. The first three insert on the greater tuberosity of the humerus, while the subscapularis inserts on the lesser tuberosity. The cuff muscles not only rotate the humerus at the glenohumeral joint but also act to keep the humeral head centered in the glenoid fossa, providing a fixed fulcrum for the arm to be elevated, primarily by the deltoid. The subacromial bursa overlies the tendons.
- These structures, in turn, sit under the coracoacromial arch, which consists of the acromion, the coracoacromial ligament, and the outer end of the clavicle at the acromioclavicular joint.
- The three parts of the deltoid arise from the acromion and lateral clavicle, and this muscle lies over the cuff and bursa. It acts to elevate, abduct, and extend the humerus at the shoulder joint.

PATHOGENESIS

- Rotator cuff tears have a multifactorial pathogenesis.
- Among the factors are tendon insertion degeneration (enthesopathy), shear (the inferior third of the cuff tendons being more susceptible to shear failure than the superior two thirds), hypovascularity, impingement, and microtrauma.
- Although impingement was felt to be the sole underlying cause of cuff disease for some time, it is now felt to be a secondary factor, in that it likely comes into play once the cuff is weakened and is unable to balance the upward pull of the deltoid. This then brings the cuff into contact with the undersurface of the anteroinferior acromion and the rest of the coracoacromial arch.
- Major injury is uncommonly a factor and usually involves an already degenerative tendon. A common major injury, which can result in a rotator cuff tear, is a primary, or a first-time, anterior dislocation of the shoulder in a patient over age 40. The older the patient, the more likely there is a cuff tear.

NATURAL HISTORY

- The natural history of rotator cuff tears is unknown. There have been several studies in cadavers and by MRI that have confirmed that the incidence of asymptomatic cuff tears over the age of 60 is around 33%. These subjects have been pain-free and fully functional.
- Any study that has tried to follow asymptomatic tears prospectively over time has suffered from an unacceptably high loss of patients being followed, thereby negating any conclusions.
- Even the condition of cuff tear arthropathy does not occur regularly with known cuff tears, even massive ones.
- It has been shown that after a traumatic tear, the outcome is influenced by the time interval to repair—in other words, those repaired within the first 3 weeks do better than those repaired between 3 and 6 weeks, and those older than 6 weeks do even worse. These outcomes apply only to the uncommon traumatic tear, not to the far more common degenerative type.
- Therefore, treatment should be based purely on the presenting symptoms of pain and functional limitation, not on the possibility that a tear may progress in size or develop into cuff tear arthropathy, since the latter possibilities cannot be predicted.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Barring the unusual history of a significant injury, such as a primary anterior glenohumeral dislocation over the age of 40 resulting in a traumatic tear, most patients will present with a complaint of pain of indeterminate onset.
- The pain is often worse at night and with use, especially overhead.
- Use of nonsteroidal anti-inflammatories (NSAIDs) may provide some temporary relief, as might stretching.
- The pain can radiate, but not to below the elbow or into the neck and occiput.
- There rarely will be significant motion loss (ie, motion will be unaffected) nor will the patient often notice weakness.
- The first step in the physical examination is to examine the neck to eliminate that as a source of the pain.
- One should inspect the shoulder for atrophy of the supraspinatus and infraspinatus or rupture of the tendon of the long head of the biceps, which usually occurs with a large or massive tear. One should also palpate the region of the greater tuberosity and the bicipital groove for tenderness. In thin patients, it is possible to feel the cuff defect through the skin and deltoid.
- Motion is assessed by having the patient elevate the arms actively and comparing this to passive motion and by placing the arms in 90 degrees of abduction and maximal external rotation, as well as maximal external rotation with the arm at the side.
- The inability to hold the arm in maximum active external rotation in abduction or at the side, causing the arm to drift toward internal rotation, is a positive lag sign, indicating a major defect in the musculotendinous unit.
Internal rotation is evaluated by having the patient reach up the back to the highest point possible. Further testing for this (subscapularis function) is discussed in another chapter.

Strength of the external rotators is tested with the arm at the side and in maximal external rotation, having the patient resist a force directed toward the body. Strength in elevation is assessed by resisting the patient’s attempt to raise the arm.

Provocative signs for cuff and biceps disease include the following:

- Impingement sign: Forcing the fully forward elevated arm against the fixed scapula helps to localize the finding to the rotator cuff when the patient experiences pain.
- Palm-down abduction test: By internally rotating the arm, the supraspinatus and anterior infraspinatus tendons are placed directly under the coracoacromial arch. Elevating the arm in the scapular plane when it is in internal rotation compresses these tendons against the undersurface of the acromion.
- Biceps resistance test (Speed’s test): Pain during this maneuver indicates involvement of the long head of the biceps tendon.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Standard radiographs, including anteroposterior (AP) views in internal and external rotation, an axillary view, and an outlet view at minimum, should always be taken to look for the type of acromion (FIG 1A), acromioclavicular joint changes, and narrowing of the acromial–humeral interval (FIG 1B) and to rule out other conditions.
- Additional preoperative studies include MRI, ultrasound, and arthrography.
- Ultrasound is institutional-specific and operator-dependent, so it is not widely used.
- Arthrography once was the gold standard but now is used only under rare circumstances (ie, when an MRI cannot be done). It can show a full-thickness cuff tear (FIG 1C) but requires an intra-articular injection with fluoroscopy and radiography.
- The most commonly used study is an MRI. It not only shows the integrity of the tendons but also provides a three-dimensional view of it (FIG 1D–G). This capacity makes the MRI a versatile preoperative planning tool.

FIG 1 • A,B. Type III acromion, the so-called hooked acromion, on the outlet and AP views. C. Arthrogram confirming the presence of a rotator cuff tear with dye in the glenohumeral joint and the subacromial bursa simultaneously. D. T2-weighted coronal MRI showing cuff tear and its lateral-to-medial extent. E. T2-weighted sagittal oblique MRI showing the AP extent of the cuff defect. F. Another T2 sagittal oblique MRI showing the tear involving the teres minor but not the subscapularis. G. Axial T2 MRI of the same tear showing rupture of the teres minor with an intact subscapularis.
DIFFERENTIAL DIAGNOSIS

- Cuff tendinitis without tear
- Incomplete rotator cuff tear
- Bicipital tendinitis
- Calcific tendinitis
- Suprascapular neuropathy

NONOPERATIVE MANAGEMENT

- If there is a history of an acute injury with immediate inability to raise the arm, the patient can be treated symptomatically and followed every 5 to 7 days for the first 2 weeks. If the ability to raise the arm does not recover, then nonoperative treatment should be abandoned and surgery undertaken.
- The objective of treating rotator cuff disorders, in the absence of an acute injury with immediate loss of elevation, is primarily to relieve pain and secondarily to restore function or strength. Pain relief is a more predictable outcome of treatment than is restoration of function or strength. Therefore, nonoperative treatment should be directed at relieving pain.
- Although NSAIDs can help with pain, a subacromial steroid injection is often more effective and immediate in its relief.
- Once the pain is improved, physical therapy should be instituted. This involves two aspects: stretching and strengthening of the rotators and elevators.

SURGICAL MANAGEMENT

- As noted earlier, in the unusual case in which there is an acute injury resulting in an immediate loss of elevation of the arm, if symptomatic treatment fails to restore the ability to raise the arm, surgical repair should be undertaken before the 3-week mark.
- For the more common chronic attritional tear, surgery is considered if the injection, NSAIDs, and physical therapy fail to produce a level of pain relief and function that is acceptable to the patient.
- Patients make the decision to have surgery based on whether they can live with the pain and functional limitation that they have. They need to understand that the operation can help them but can also leave them unchanged or worse.

Preoperative Planning

- The radiographs and MRI should be reviewed preoperatively.
- The radiographs will help in planning the need for and extent of acromioplasty.
- The MRI will show which tendons are torn and the degree to which they are torn. It will also show the presence or absence of fatty infiltration of the muscles.

Positioning

- The patient is positioned in a sitting position, even more upright than the so-called beach chair position (FIG 2A). The arm is draped free to allow uninhibited mobility of the extremity (FIG 2B).
- This allows the surgeon to look down on the cuff from above, therefore, being able to see posterosuperiorly as well as superiorly and anteriorly. It also permits better access to the posterior part of the infraspinatus and the teres minor.

Approach

- There are basically three approaches to cuff repair:
  - The all-arthroscopic approach (discussed in another chapter)
  - Arthroscopic decompression and mini-open repair of the cuff
  - Open repair of the cuff: includes direct repair, grafting, and tendon transfers

FIG 2 • A. Sitting position for surgery allows the surgeon to look down on the cuff and see posterior superior. B. The arm is draped free, giving extensive access to the entire shoulder.
ARThROSOCopIC SUBACROMIAL DECOMPRESSION AND MINI-OPEN CUFF REPAIR

- The standard posterior viewing portal is established, and the glenohumeral joint is evaluated. The defect in the cuff is viewed from the articular side, and the long head of the biceps is assessed.
  - Any débridement or other intra-articular procedures deemed necessary can be carried out at this time.
- The arthroscope is then redirected into the subacromial space and enough bursa resected to allow adequate visualization of the cuff tear, the anterior inferior surface of the acromion, and the coracoacromial ligament. If deemed appropriate (as discussed later), the ligament is released and the anterior and anterolateral margins of the acromion are defined.
  - A burr is used to perform an acromioplasty to the same degree that is done in the open technique. This is an important point. Although the means of accomplishing the decompression differ, the ultimate result is the same: an adequate decompression.
- Through a small lateral portal, a suture punch is used to pass several traction sutures through the leading edge of the torn tendons. Using these sutures as handles to control and apply traction to the cuff, a small elevator is introduced through the same lateral portal and used to free the surrounding adhesions on both surfaces of the cuff. The degree of mobility achieved can be assessed by applying traction through the previously placed sutures.
  - Once enough mobility of the cuff has been restored, an incision is made at the anterolateral corner of the acromion for about 1.5 to 2 cm (TECH FIG 1). The deltoid is split in the same line as the skin, and additional subdeltoid freeing is done. Narrow retractors are placed under the acromion and anteriorly to expose the tear.
  - The procedure at this point is the same as described in the next section.

OPEN REPAIR OF THE CUFF

Incision and Dissection

- With the patient in the position described above and the arm draped free, an incision is made beginning superiorly at the posterior aspect of the acromioclavicular joint, continuing over the top of the joint, and ending at a point at the lateral tip of the coracoid (TECH FIG 2A).
  - After mobilization of the skin flaps, the deltotrapezial aponeurosis and the superior acromioclavicular ligament are incised into the acromioclavicular joint.
  - The deltoid muscle is split in line with its fibers only as far distally as the tip of the coracoid.

TECH FIG 1 • Skin incision for the mini-open repair technique.

TECH FIG 2 • A. Skin incision for the standard anterosuperior approach. B. Subperiosteal dissection of deltoid origin from superior aspect of the lateral clavicle, acromioclavicular joint, and anterior acromion, without cutting across the deltoid origin. (continued)
Using a sharp knife blade, the deltoid origin is dissected subperiosteally from the lateral clavicle for about 1 cm. It is also dissected from the anterior, superior, and undersurface of the acromion out to the anterolateral corner of the acromion (TECH FIG 2B–D).

No incision is made across the tendon of origin of the deltoid on the acromion; that is, the deltoid is not detached from the acromion.

**Clavicular Resection and Acromioplasty**

The coracoacromial ligament is identified and isolated. If, in the judgment of the surgeon, the cuff can be securely repaired, the ligament is released from its attachment on the acromion. If the repair is tenuous, the ligament is not released, or if it is, it is dissected from the undersurface of the acromion to achieve maximal length and repaired back to the acromion through drill holes in the acromion at the end of the procedure.

This is necessary to prevent anterosuperior escape of the humerus, which occurs when the cuff is deficient and there is no coracoacromial arch to contain the humeral head, which is being pulled upward by the unopposed deltoid.

Using a reciprocating saw, the lateral 7 to 8 mm of the lateral end of the clavicle are removed without damaging the periosteum or posterior capsule. The portion removed is trapezoidal in shape, with the larger base being posterior, to prevent contact of the clavicle with the acromion posteriorly.

The clavicular resection allows the acromion and scapula to be rotated posteriorly more easily and gives greater access to the posterior cuff.

Using the same instrument, an acromioplasty is performed by removing the anteroinferior surface of the acromion from the medial articular margin out to the anterolateral corner. The anterior edge is not recessed beyond its normal anatomy, and it is not the removal of the full thickness of the acromion, creating a type I acromion (TECH FIG 3). The portion removed is a triangular piece, with its base being the anterior edge.
The entire subacromial space is freed bluntly of adhesions between the bursa and the undersurface of the deltoid. retractors are placed into the subacromial space under the acromion to avoid tension on the deltoid.

**Tear Repair**

- The bursa is incised, undermined, and reflected. The tear in the cuff can now be seen. The friable, avascular edges are trimmed with a sharp knife. This resection is minimal—only until healthy tendon is seen (TECH FIG 4A), not to bleeding tendon. This usually requires the removal of only a few millimeters.
- Number 1 nonabsorbable traction sutures are placed in the edges of the freshened cuff. Applying traction through these sutures, blunt mobilization is done using an elevator, dissecting scissors, or the surgeon’s finger. This step of mobilization is critical, and as the musculotendinous unit becomes free, additional sutures are placed successively medially until the apex of the tear is identified (TECH FIG 4B).
- If the cuff edge cannot be brought sufficiently far to reach its original insertion, interval releases are done by incising between the supraspinatus and the subscapularis and between the infraspinatus and the teres minor. This restores the differential gliding between these adjacent tendons.
- When the leading edge of the cuff can be brought to its insertion on the greater tuberosity, a shallow trough is made in the anatomic neck at the greater tuberosity (TECH FIG 4A).
- Drill holes are made in the trough and the lateral side of the tuberosity and connected with a punch. Locking horizontal mattress sutures or modified Mason-Allen sutures are placed in the cuff and passed through the bone tunnels created by connecting the drill holes (TECH FIG 4C). Suture anchors can also be used in the trough and the tuberosity in a double-row fashion instead of the bone tunnels.
- With the arm in some internal rotation and slight abduction, the sutures are tied securely to bring the free edge of the cuff into the trough.
- This leaves a longitudinal split, which is sutured side to side, not only closing the split but also helping to relieve tension on the cuff advanced into the trough (TECH FIG 4D).

**BICEPS GRAFT**

- If the cuff cannot be brought to the greater tuberosity and there is a residual defect of modest size, an interpositional graft of the tendon of the long head of the biceps can be used. The critical requirement to use this or any graft is that the musculotendinous motor must be functional, not fixed and immobile. If there is no springy give when traction is applied to the tendon, no graft should be done.
- First, the tendon of the long head is tenodesed to the transverse humeral ligament in the bicipital groove using three figure 8 nonabsorbable number 1 sutures. The tendon is transected just above the most proximal suture and then released from its origin at the supraglenoid tubercle.
- This segment of tendon is filleted (TECH FIG 5A) and placed into the cuff defect. It is trimmed to fit the defect and contoured to accommodate it.
- It is sutured side to side to the cuff and to a trough in the anatomic neck at the greater tuberosity, as described above (TECH FIG 5B).

**FREEZE-DRIED CADAVER ROTATOR CUFF GRAFT**

- If the residual defect is too large for a biceps graft to cover, a larger graft is needed. The best choice is a freeze-dried graft of human rotator cuff. As with every graft, the musculotendinous motor (ie, the native rotator cuff) must be a functional unit, as noted above.
- After the described mobilization techniques have reduced the size of the defect as much as possible, the graft is reconstituted in sterile saline for 30 minutes so that it becomes soft and pliable (TECH FIG 6A).
- It is then trimmed and contoured to accommodate the free edge of the native cuff and then sutured to it with nonabsorbable number 1 sutures.
- It is also trimmed to reach a trough in the anatomic neck adjacent to the greater tuberosity and secured in the same fashion as the direct repair through drill holes in the bone or by anchors, as previously described (TECH FIG 6B).
LOCAL TENDON TRANSFERS

- When the cuff cannot be closed by direct repair and the proximal native cuff is not mobile, the subscapularis and teres minor can be used as local tendon transfers.
- The interval between the subscapularis and the anterior capsule is identified near the musculotendinous junction and traced laterally toward the insertion on the lesser tuberosity.
- The tendon is separated from the capsule and released from the insertion. A traction suture is placed in the tendon, and the subscapularis is mobilized so that it can be shifted superiorly.
- The subscapularis is then transferred superiorly (TECH FIG 7A) to close the residual defect. Its superior border is sutured to the intact portion of the cuff, its distal end to the greater tuberosity, and its inferior border to the superior edge of the undisturbed anterior capsule (TECH FIG 7B,C).
- If the subscapularis alone does not provide adequate closure of the tear, the teres minor can also be transferred from posterior to superior. The interval between the tendon of the teres minor and the posterior capsule is developed (TECH FIG 7D), starting medially at the musculotendinous junction, and freed laterally to its insertion on the greater tuberosity. It is detached from the tuberosity.
- The muscle–tendon unit is mobilized bluntly and transferred superiorly to meet the transposed subscapularis (TECH FIG 7E).
- The two tendons are sutured together to form a new broad tendon, which is inserted into a trough at the greater tuberosity, as described earlier.
- The inferior borders of the respective tendons are sutured to the superior edges of the undisturbed capsules (teres minor to the posterior capsule and the subscapularis to the anterior capsule) (TECH FIG 7F,G).
- If none of these techniques allows the cuff to be reconstructed satisfactorily, a latissimus dorsi transfer is undertaken; this is described elsewhere.

**TECH FIG 7** • A. Detached subscapularis mobilized and moved superiorly. B. Subscapularis transferred and sutured to residual cuff, the greater tuberosity, and the superior border of the undisturbed anterior capsule. C. Subscapularis transferred and sutured. D. Interval between the teres minor and posterior capsule developed. (continued)
### CLOSURE

- The closure is the same for all procedures.
- Since the deltoid has not been detached from its origin, it is allowed to fall back to its normal anatomic position or brought back by the surgeon. Simple sutures with the knots buried under the deltoid are placed to repair the side-to-side split, being sure to pass the suture through the external muscle fascia, the muscle itself, and the internal muscle fascia.
- If the deltopectoral aponeurosis and superior acromioclavicular ligament have been incised, they are repaired side to side with figure 8 sutures.
- The skin is closed with a subcuticular 3-0 nylon suture and Steri-Strips. A sterile dressing is applied, and the extremity is immobilized in an immobilizer with the elbow forward of the midline of the body and the shoulder in internal rotation.

### PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Condition</th>
<th>Advice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postoperative deltoid detachment</td>
<td>This can be avoided by subperiosteally elevating the origin and not incising across it.</td>
</tr>
<tr>
<td>Axillary nerve injury with deltoid split</td>
<td>This can be avoided by not splitting the deltoid beyond the tip of the coracoid. Exposure is achieved by superior access, not distally.</td>
</tr>
<tr>
<td>Excessive tendon resection</td>
<td>Friable, poor-quality tendon should be trimmed only to healthy fibers, not to bleeding tendon.</td>
</tr>
<tr>
<td>Postoperative repair failure</td>
<td>Tendons should be repaired to bone under only normal resting tension. If this is not possible, the described grafts or tendon transfers should be used. The early postoperative rehabilitation program is used to regain motion; strengthening is avoided until at least 3 weeks.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

■ Within 24 to 72 hours of the surgery, the dressing is changed. The patient is instructed in passive-only forward elevation and external rotation at the side while lying supine. The operative arm must be completely relaxed with no muscle activity at all, and the arm is elevated to at least 90 degrees forward and external rotation to neutral only.

■ Over the next 4 to 6 weeks the amount of passive forward elevation is slowly increased, as is the external rotation at the side, but the latter should not go beyond 10 to 15 degrees of external rotation at most.

■ The extremity is kept in the immobilizer at all other times during this period. At 4 to 6 weeks postoperatively, depending on the security of the repair and the technique used, formal active and assisted exercises are permitted, along with continued passive stretching. Strengthening, weights, or resistive exercises are avoided until at least 3 months.

OUTCOMES

■ Repairs of small and medium-sized tears have a high rate of success in relieving pain and recovering motion and function while remaining structurally intact, regardless of whether repaired by arthroscopic, mini-open, or open techniques.

■ Repairs of large and massive tears also have resulted in good pain relief and functional recovery but have a much lower incidence of remaining intact structurally.

COMPLICATIONS

■ Deltoid origin detachment
■ Cuff repair dehiscence
■ Anterosuperior instability or escape
■ Infection
■ Loss of motion
■ Cuff tear arthropathy

REFERENCES

Subscapularis tears are less common than supraspinatus or infraspinatus tears. They occur in 2% to 8% of rotator cuff tears and are often missed.\textsuperscript{5,12}

Subscapularis tears can be:
- Isolated tears (partial or complete)
- Partial-thickness tears
- Anterosuperior (involving the supraspinatus)
- Rotator interval lesions (with associated biceps tendon injury)

There is a high association of concomitant biceps tendon pathology.\textsuperscript{12,18}

ANATOMY

- The subscapularis is innervated by the upper and lower subscapular nerves (C5–C8). Its origin is at the subscapularis fossa, and the upper two thirds inserts onto the lesser tuberosity, while the inferior third inserts onto the humeral metaphysis.
- The subscapularis is the strongest of the rotator cuff muscles. It acts to internally rotate the humerus along with the teres major, latissimus dorsi, and pectoralis major muscles. It resists anterior and inferior translation of the humeral head.\textsuperscript{10,17}
- The upper fibers of the subscapularis and the anterior fibers of the supraspinatus contribute to the rotator interval as well as the transverse humeral ligament.
- The coracohumeral ligament is the roof of the rotator interval and blends with the supraspinatus and subscapularis. The coracohumeral ligament and the superior glenohumeral liga-
- The biceps muscle is innervated by the musculocutaneous nerve (C5–C6). It is composed of a long head, which originates from the supraglenoid tubercle, and a short head, which originates from the coracoid process. Both heads insert onto the bicipital tuberosity of the radius and the ulnar fascia of the forearm.
- The long head of the biceps tendon provides superior shoulder stability when the arm is abducted. It also provides posterior shoulder stability when the arm is in midranges of elevation.
- The coracoid is located just anterior to the superior border of the subscapularis. It projects laterally, anteriorly, and inferiorly toward the glenoid.
- The subcoracoid bursa does not communicate with the glenohumeral joint but can communicate with the subacromial bursa.

PATHOGENESIS

- In the young patient, subscapularis tears occur as a result of trauma. The typical mechanisms include hyperextension of an externally rotated arm or forced external rotation of an abducted arm.\textsuperscript{5,8}
- In older patients a tear is typically degenerative in nature, although it may be the result of a glenohumeral dislocation or other trauma.\textsuperscript{13,15,16}

Frequently, there is associated long head of the biceps pathology. This may include tenosynovitis, subluxation, dislocation, degeneration, or complete rupture.\textsuperscript{12,19}

Subcoracoid impingement may also be a cause of subscapularis tendon tears.

NATURAL HISTORY

- Isolated subscapularis tendon ruptures are relatively rare. Subscapularis tears are often associated with tears of the supraspinatus and infraspinatus.
- One study found that subscapularis tears occur in 8% of rotator cuff tears.\textsuperscript{7}
- An MRI study was performed on 2167 patients with rotator cuff tears.\textsuperscript{12}
  - 2% of the patients had subscapularis tendon tears.
  - 27% of those tears were partial-thickness tears and 73% were full-thickness tears.
- One study found a high correlation between subscapularis tendon tears and medial biceps subluxation, biceps tendinopathy, superior labral pathology, and fluid within the subscapular recess or the subcoracoid space.\textsuperscript{12,18}
- The above-listed MRI study found that 25 of the 45 patients with subscapularis tendon tears had associated biceps pathology.

PHYSICAL FINDINGS

- Patients with complete tears of the subscapularis have increased passive external rotation compared with the unaffected shoulder.
- Several muscles contribute to internal rotation of the shoulder, including the pectoralis major, latissimus dorsi, and teres major, and can compensate for loss of the subscapularis.
- Passive external rotation: Increased passive external rotation may indicate a complete rupture of the subscapularis.
- Passive forward flexion, external rotation, and internal rotation: Limited passive range of motion is indicative of adhesive capsulitis.
- Active forward flexion: Limited active forward flexion is indicative of a possible large rotator cuff tear.
- The lift-off test isolates the subscapularis muscle. Inability to lift the hand off the back is a positive test.
- Internal rotation lag sign: The examiner measures the lag between maximal internal rotation and the amount the patient can maintain. A positive sign shows increased sensitivity over the classic lift-off test.
- Belly press (Napoleon test): A positive test is the inability to bring the elbow forward. An intermediate test is the ability to bring the elbow forward partially. A positive test indicates a complete rupture, while an intermediate test indicates a partial tear of the subscapularis.
- The bear hug test: If the examiner is able to lift the hand off the shoulder, then the patient likely has a partial or complete.
tear of the upper subscapularis tendon. This is perhaps the most sensitive test for a subscapularis tear.

- Coracoid impingement: Reproduction of pain or a painful click indicates a positive test. A positive test indicates impingement of the coracoid onto the subscapularis.
- Speed’s test: If the maneuver produces pain or tenderness, the test is positive, which may indicate bicipital pathology, although the test is not specific.
- Yergeson test: The patient will experience pain as the biceps tendon subluxes out of the groove with a positive test; this indicates biceps instability.

Pain may inhibit a patient from maneuvering the arm behind the body into the lift-off position, thereby preventing assessment.

- A complete rupture of the long head of the biceps tendon will result in an obvious cosmetic deformity in the anterior arm as the muscle retracts distally.
- Tests used to diagnose superior labral lesions will be discussed in a separate section.

**IMAGING AND DIAGNOSTIC STUDIES**

- Anteroposterior (AP), outlet, and axillary view radiographs should be obtained to rule out any fractures or associated injuries.
- In chronic cases of subscapularis tears, anterior subluxation of the humeral head may be noted on the axillary view.
- MRI is the modality of choice for diagnosing subscapularis tears. MR arthrography improves the study accuracy to detect partial-thickness tears.
- Fatty degeneration of the subscapularis correlates with poor tendon quality.
- Although not sensitive, these signs are highly specific for subscapularis tears:
  - Leakage of contrast material onto the lesser tuberosity
  - Fatty degeneration of the subscapularis muscle
  - Abnormalities in the course of the long biceps tendon
  - Biceps dislocation deep to the subscapularis tendon is pathognomonic for a subscapularis tear.

Ultrasound is a noninvasive method for assessing the subscapularis and can be performed in the office. It is less expensive than MRI, but results are operator-dependent.

**DIFFERENTIAL DIAGNOSIS**

- Impingement syndrome
- Subscapularis tendinitis
- Bicipital tendinitis
- Posterosuperior rotator cuff tear (supraspinatus, infraspinatus, teres minor)
- Biceps pathology
- Coracoid impingement
- Labral tear
- Glenoid fracture
- Glenohumeral instability
- Glenohumeral arthritis
- Pectoralis major injury
- Contusion
- Cervical radiculopathy

**NONOPERATIVE MANAGEMENT**

- For subscapularis tears, nonoperative management is reserved for some chronic and atraumatic, degenerative, and asymptomatic tears.
- Treatment includes activity modification, anti-inflammatory medications, and physical therapy.
- Corticosteroid injections may be performed in the bicipital groove or subcoracoid bursa to treat biceps tendinitis and coracoid impingement.

It is likely that some degenerative subscapularis tendon tears are successfully treated nonsurgically without ever being diagnosed.

- In most cases, an acute symptomatic subscapularis tear should be managed operatively and whenever possible within the first 6 to 8 weeks, when retraction and scarring are minimal, to reduce the risks of dissection in the axillary recess.
- In young, active patients, attempts are made to repair acute biceps ruptures.
- In older, less active patients and in cases of chronic biceps ruptures more than 8 weeks old, biceps repair is discouraged.

**SURGICAL MANAGEMENT**

**Preoperative Planning**

- Physical therapy or a home exercise program emphasizing range of motion may be used to prevent stiffness and improve range of motion before surgery.
- All imaging studies are reviewed.
- An examination under anesthesia is performed before beginning surgery to evaluate for instability, increased external rotation, or decreased range of motion.

**Positioning**

- The patient is placed in a low beach chair position with the arm draped free.
- A McConnell arm holder (McConnell Orthopedic Manufacturing Co., Greenville, TX) is useful for maintaining arm positions throughout the case.

**FIG 1 • Axial T2-weighted MR images of right shoulders with an intact subscapularis tendon (A; arrow) and a complete rupture of the subscapularis tendon.**
Approach
- Both the deltopectoral and anterolateral deltid-splitting approaches have been described.\(^{20}\)
- The anterolateral deltid-splitting approach is useful for partial tears of the upper subscapularis and tears associated with supraspinatus tears. It is not recommended for large, retracted full-thickness subscapularis tears.
- The deltopectoral approach provides greater visualization and access to the inferior portion of the subscapularis. It also allows for concomitant biceps tenodesis and coracoplasty.

INCISION AND DISSECTION

- The deltopectoral approach is started just proximal to the coracoid process and extended distally 8 to 10 cm.
- Adducting the arm identifies the major axillary crease.
- The cephalic vein and deltoid muscle are carefully retracted laterally and the pectoralis muscle is retracted medially to facilitate exposure (TECH FIG 1A).
- Once the deltopectoral interval is developed, the clavpectoral fascia is identified.
- The clavpectoral fascia is divided at the lateral aspect of the conjoined tendon.
- Avoid excessive retraction on the conjoined tendon to avoid injuring the musculocutaneous nerve.
- The tendon of the subscapularis is often retracted inferiorly and medially and requires mobilization.
- A layer of scar tissue may be seen overlying the lesser tuberosity, which can mimic the subscapularis tendon.

- If the subscapularis tendon cannot be brought back to the lesser tuberosity easily, then the subscapularis requires systematic release from the glenohumeral ligaments.
- Begin by releasing the superior aspect of the tendon from the coracohumeral ligament. The rotator interval is opened from the glenoid to the bicipital groove to facilitate the release.
- Next release the inferior portion of the tendon from the capsular attachments. Care must be taken to identify and protect the axillary nerve and vascular supply inferiorly.
- Finally, release the remaining capsular attachments on the undersurface of the subscapularis (TECH FIG 1B).
BICEPS TENODESIS

- If a biceps tenotomy is performed, it is important to warn the patient of the resultant cosmetic deformity when the biceps retracts distally.
- Indications for biceps tenodesis include the following:
  - Tears involving more than 50% of the biceps tendon
  - Medial subluxation of the biceps tendon
- Open the bicipital groove from the medial side to expose the biceps tendon.

- The biceps tendon is released from the superior glenoid with curved scissors.
- The tendon is retracted distally from the bicipital groove.
- To ensure proper tensioning of the biceps tendon, the proximal portion of the tendon is resected to leave about 20 to 25 mm of tendon proximal to the musculotendinous junction.
- Running locking Krakow or whipstitches are placed up and down the proximal 15 mm of the biceps tendon.
- Abrade the bicipital groove to develop a bleeding surface.
- A burr hole the size of the biceps tendon is made in the bicipital groove about 15 mm from the articular surface. Two smaller 3.2-mm holes are made 15 mm distal to the burr hole in a triangular configuration.
- The tendon end is passed into the proximal hole by pulling the sutures out the distal holes. The sutures are then passed through and tied over the overlying biceps tendon (TECH FIG 2A,B).
- Another fixation option is to use a biotenodesis screw for the biceps tendon.
  - The tendon is prepared as above.
  - An 8-mm reamer is used to make a 25-mm-deep bone tunnel about 15 mm from the articular surface.
  - An 8 × 23-mm Arthrex Bio-Tenodesis screw is used for fixation.
  - One end of the suture is passed through the biotenodesis screw while the other suture passes outside of the screw. This ensures that the tendon will be pulled into the hole as the screw is advanced.
  - When the screw is flush with the bone tunnel, the sutures are tied over the screw (TECH FIG 2C). This provides both an interference fit and suture anchor stability.

TECH FIG 2 • A,B. The tunnel technique uses bone tunnels to fix the biceps tendon upon itself. C. A biceps tenodesis with interference screw fixation.
CORACOPLASTY

- The conjoined tendons are identified.
- Care is taken not to retract vigorously on the conjoined tendons to avoid injury to the musculocutaneous nerve.
- The coracoacromial ligament is released from the coracoid.
- The posterior aspect of the coracoid is exposed by removing the overlying soft tissue. The posterolateral portion is then resected in line with the subscapularis muscle with an osteotome (TECH FIG 3). Alternatively, a burr may be used to accomplish the same resection. Protect the neurovascular structures by placing a retractor on the posterior aspect of the coracoid.
- A rasp is then used to smooth out the bony surface.
- The goal is a 7- to 10-mm clearance between the coracoid and subscapularis.

- Confirmation of adequate decompression can be determined by manipulating the arm into the impingement position and confirming that there is adequate clearance for the subscapularis.

SUBSCAPULARIS REPAIR

- The residual soft tissue is cleaned from the lesser tuberosity. A burr is then used to expose bleeding bone for the tendon to heal to.
- To recreate the anatomic footprint of the subscapularis insertion, four suture anchors are used for the repair.
- Two anchors are placed at 1-cm intervals along the medial aspect of the lesser tuberosity and two are placed at the lateral aspect of the lesser tuberosity (TECH FIG 4A).
- The sutures from the medial anchors are passed in a mattress fashion near the musculotendinous junction of the subscapularis (TECH FIG 4B).

- The sutures from the lateral anchor are passed through the lateral edge of the tendon in a simple fashion and tied down to the lesser tuberosity.
- After repair of the subscapularis tendon, the shoulder is taken through a gentle range of motion to determine the safe arcs for postoperative rehabilitation.
- The lateral aspect of the rotator interval is closed while maintaining about 30 degrees of external rotation of the arm to prevent overtightening of the subscapularis repair.
PEARLS AND PITFALLS

**Indications**
- A complete history and physical examination should be performed.
- The surgeon should identify and address all associated pathology.
- Any limitations of motion should be addressed before surgery.

**Coracoplasty**
- The surgeon should take care to protect the musculocutaneous nerve.
- A 7- to 10-mm clearance should be achieved for the subscapularis.

**Biceps tenodesis**
- Tears in the biceps tendon of over 50% and subluxing tendons should be tenodesed.
- The surgeon should maintain proper tension of the biceps muscle; typically, 20 to 25 mm of tendon should be maintained proximal to the musculotendinous junction.
- A “hidden lesion” describes the presence of a partial undersurface subscapularis tear with a medially dislocated or subluxed biceps. This injury can be missed at the time of open surgery because the bursal surface of the subscapularis remains intact. Diagnostic arthroscopy or proper imaging will prevent missing this lesion.

**Subscapularis repair**
- In chronic cases, a scar layer covers the lesser tuberosity and is usually attached at its medial extent to the retracted and scarred subscapularis tendon. The presence of this scar layer may lead to the misdiagnosis of an intact subscapularis.
- The surgeon should prepare a bleeding bony surface for the tendon to heal to.
- The rotator interval is closed in external rotation to avoid loss of motion.
- External rotation is limited for 6 weeks postoperatively to protect the repair.
POSTOPERATIVE CARE

- The most important postoperative management for subscapularis tears is limitation of external rotation for 6 weeks to avoid stressing the repair.
  - Complete tears are not allowed to externally rotate past 0 degrees.
  - Partial tears are allowed to externally rotate 20 to 30 degrees.
  - At 6 weeks the patient may begin active and active-assisted external rotation exercises, as well as overhead stretching.
  - At 12 weeks strengthening exercises are initiated for partial tears. At 16 weeks strengthening exercises are initiated for complete tears.

OUTCOMES

- Isolated subscapularis tears have favorable surgical outcomes.
  - At 2 years of follow-up, good or excellent results were reported in 13 of 14 isolated subscapularis tears.4
  - Another study demonstrated good or excellent results in 13 of 16 patients with acute traumatic subscapularis tears at 43 months of follow-up. The Constant scores were 82% of age-matched controls.8
  - Poor prognostic factors include chronic tears (symptoms for more than 6 months), fatty degeneration of the subscapularis muscle, and anterosuperior tears (combination of subscapularis and supraspinatus tears).19
  - Comparative outcomes between open and arthroscopic techniques remain to be determined.

COMPLICATIONS

- Repair failure
- Infection
- Loss of motion
- Axillary nerve injury
- Vascular injury

REFERENCES

DEFINITION

- Irreparable posterosuperior rotator cuff tears are tears that involve the supraspinatus and infraspinatus tendons, where there is an inability to repair the tendons back to the anatomic footprint of the greater tuberosity with the arm at the side.
- Some tears can be determined to be irreparable preoperatively, if the MRI or CT scans demonstrate severe muscle atrophy of the supraspinatus or infraspinatus muscles.
- This may help indicate that a patient has an irreparable tear and may be a candidate for muscle transfer, but the final determination of whether a tear is reparable is made at the time of surgery.

ANATOMY

- The latissimus dorsi is normally an adductor and internal rotator of the humerus however, after transfer it is expected to act as an abductor and external rotator of the humerus.
- The ability of the patient to retrain his or her neural pathways to achieve this active in-phase function varies dramatically.
- In some cases, the latissimus dorsi transfer has only a tenodesis effect.
- Originating from the supraspinatus and infraspinatus fossa respectively, the supraspinatus and infraspinatus muscle-tendon units become confluent and insert as a common tendon on the greater tuberosity of the humerus immediately lateral to the humeral head articular margin.
- Their combined footprint area averages 4.02 cm².
- The insertion of the supraspinatus averages 1.27 cm from medial to lateral and 1.63 cm from anterior to posterior.
- The infraspinatus insertion averages 1.34 cm medial to lateral and 1.64 cm anterior to posterior.
- Over the superior aspect of the glenohumeral joint, the deepest fibers of the supraspinatus and infraspinatus tendons are intimately interwoven with the joint capsule such that the rotator cuff tendons and joint capsule function as a single unit. As a result, rotator cuff tears involving the supraspinatus or infraspinatus tendons result in direct communication between the glenohumeral and subacromial spaces.
- The latissimus dorsi muscle has a broad origin from the aponeurosis of spinous processes T7 through L5, the sacrum, the iliac wing, ribs 9 through 12, and the inferior border of the scapula.
- The latissimus dorsi tendon averages 3.1 cm wide and 8.4 cm long at its insertion between the pectoralis major and teres major tendons on the proximal, medial humerus.
- The fibers of the latissimus dorsi twist 180 degrees from origin to insertion, allowing the latissimus dorsi muscle to originate posterior to the teres major muscle on the posterior chest wall but insert immediately anterior to the teres major tendon on the proximal humerus.
- The latissimus dorsi humeral insertion never extends more distal along the shaft than that of the teres major.
- In most patients, the latissimus dorsi and teres major tendons insert separately onto the proximal humerus; however, 30% of patients have conjoined latissimus dorsi and teres major tendons that cannot be separated without sharp dissection.
- The neurovascular pedicle to the latissimus dorsi is the thoracodorsal artery and nerve (posterior cord, C6 and C7). The thoracodorsal artery and nerve enter the anterior, inferior surface of the latissimus dorsi, about 13 cm from the humeral insertion site.
- Anatomic studies have shown that this neurovascular pedicle is of adequate length to allow transfer and excursion of the latissimus dorsi without risk of undue tension, once any adhesions and fibrous bands have been released from the anterior surface of the muscle belly.
- Several important neurovascular structures lie close to the latissimus dorsi insertion, and careful attention to these structures must be given at the time of its release from the humerus to avoid injury.
- Anterior to the latissimus, the radial nerve passes an average of 2.4 cm medial to the humeral shaft at the superior border of the tendon.
- This distance increases with external rotation and abduction and decreases with internal rotation and adduction² (FIG 1A,B).
The axillary nerve runs superior to the latissimus dorsi tendon before exiting the quadrangular space (FIG 1C). In neural rotation and adduction, the average distance between the nerve and the superior border of the tendon is 1.9 cm.

This distance increases with external rotation and abduction and decreases with internal rotation.²

The anterior humeral circumflex artery runs along the superior border of the latissimus dorsi tendon.

**PATHOGENESIS**

| The axillary nerve runs superior to the latissimus dorsi tendon before exiting the quadrangular space (FIG 1C). In neural rotation and adduction, the average distance between the nerve and the superior border of the tendon is 1.9 cm. |
| This distance increases with external rotation and abduction and decreases with internal rotation.² |
| The anterior humeral circumflex artery runs along the superior border of the latissimus dorsi tendon. |

Multiple causes have been proposed for the development of rotator cuff tears, including decreased vascular supply, mechanical compression between the humeral head and the coracoacromial ligament or the undersurface of the acromion, and traumatic causes such as humeral head dislocation, or rapid or repetitive eccentric loading of the rotator cuff muscle–tendon units.

Isolated, acute traumatic events may cause massive rotator cuff tears, the majority of which can be repaired open or arthroscopically if diagnosis and surgical intervention are timely.

Alternatively, most degenerative tendon tears start small and progressively get larger until the muscle retraction, muscle atrophy, and tendon loss prevent primary repair.

Tear size may not predict reparability at the time of surgery, but it does influence healing postoperatively, with larger tears having a lower incidence of healing.

Tissue quality and tendon retraction are the major determinants intraoperatively of whether a repair is possible. These factors also influence healing of a primary repair.

Increased size and duration of a tear lead to retraction of the rotator cuff and fatty infiltration of the muscle belly within weeks to months of developing a tear. These changes result in decreased tendon excursion and tissue compliance that is often irreversible (FIG 2).

**FIG 1 • (continued)** B. Cadaveric dissection demonstrating the insertion of the latissimus dorsi (L) and teres major (TMa) tendons viewed from an anterior exposure. The pectoralis major (PMa) tendon has been reflected laterally and the long head of the biceps (B) tendon remains in the bicipital groove. Note the more distal insertion of the teres major relative to the latissimus dorsi. Ax, axillary nerve; P, posterior humeral circumflex vessel; R, radial nerve. C. Cadaveric dissection of the superficial muscular anatomy of the posterior shoulder. The axillary nerve (Ax) and posterior humeral circumflex artery are seen exiting the quadrilateral space before entering the posterior deltoid (D). L, latissimus dorsi; TMa, teres major; TMi, teres minor; I, infraspinatus; T, triceps.

**FIG 2 • A.** Coronal MRI of a massive cuff tear showing tendon retraction to the midhumeral head. B. Sagittal MRI through lateral supraspinatus and infraspinatus fossae showing fatty degeneration and muscle wasting consistent with decreased muscle compliance and increased risk of repair failure at the time of surgery. The suprascapular nerve (SN) can be seen crossing through the spinoglenoid notch. SS, supraspinatus; IS, infraspinatus; Sub scap, subscapularis.
As a result, the longer these massive tears go untreated, the higher the likelihood that the tear will be irreparable at the time of surgery.

Presentation of the patient with a massive irreparable cuff tear is often precipitated by a minor traumatic event such as a fall onto an outstretched hand, resulting in an acute-on-chronic tear and functional decompensation of the shoulder. Others present with a history of longstanding, worsening symptoms that finally reach a point that is no longer tolerable to the patient.

**NATURAL HISTORY**

- Massive posterosuperior rotator cuff tears are uncommon, representing less than one third of all rotator cuff tears even in practices limited to the treatment of shoulder pathology.\(^1\)\(^5\)
  - Not all patients with large posterosuperior cuff tears experience enough loss of function or pain to require surgery or even seek treatment.
  - It can be difficult to predict who will have significant shoulder dysfunction based on radiographic or MRI findings or direct inspection of a torn rotator cuff.
  - Some patients with large tears can still use their arm for many activities, and some even retain the ability to perform overhead activities.
  - Others with smaller tears may have significant difficulty or an inability to use their arm for anything above chest level.

Regardless of tear size, it is loss of the rotator cuff muscles’ ability to perform their role as humeral head stabilizers that eventually leads to functional decompensation.

As the tear progresses in size, behavioral and biomechanical compensation will allow maintenance of function to a point. However, once the rotator cuff can no longer stabilize the humeral head to create a fulcrum around which the deltoid can act to forward flex and abduct the arm, rapid decompensation, loss of function, and increased pain ensue.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The patient history should elicit the mechanism and duration of the current symptoms with the intent of determining if there was a specific traumatic event leading to the rotator cuff tear and whether symptoms of rotator cuff pathology were present before any such event.
- Determining if the tear is a result of an acute injury as opposed to an acute-on-chronic process will help in estimating the quality of the tissues and whether they will be amenable to repair at the time of surgery.
- The duration of dysfunction is also important in determining the likelihood of being able to repair any rotator cuff tear, since fatty degeneration of the supraspinatus and infraspinatus muscle bellies may start within weeks of the injury and will greatly decrease tissue compliance and increase tension placed on a potential repair.\(^9\)\(^,16\)
- A careful neurologic examination, starting with the neck, must be performed to rule out neurologic causes of shoulder symptoms.
- An understanding of the patient’s current functional limitations as well as expectations for postoperative function is necessary to elicit whether the patient’s disability is significant enough to benefit from the procedure.
- A focused examination for the rotator cuff-deficient shoulder includes but is not limited to:
  - Active forward flexion examination: Patients with function at or above shoulder level are more likely to have improved active forward flexion postoperatively.
  - Active external rotation examination: Decreased external rotation on the affected side indicates partial or complete loss of infraspinatus function due to tear involvement or muscle dysfunction.
  - External rotation lag sign: Inability to maintain maximal external rotation (greater than or equal to a 20-degree lag sign) suggests tear extension well into the infraspinatus.
  - Passive range of motion should be compared to the contralateral limb. Decreased range of motion suggests joint contracture, which requires treatment before consideration for muscle transfer.
  - Modified belly press test: Inability to perform this action demonstrates a dysfunctional or torn subscapularis tendon, and these patients will have a higher rate of clinical failure with muscle transfer.
  - Abduction strength testing: This tests deltoid muscle strength. A weak deltoid suggests less postoperative active range of motion secondary to inadequate strength.
  - External rotation strength testing: Full strength suggests no infraspinatus tear involvement, whereas weakness suggests progressive infraspinatus involvement or dysfunction.
  - Evaluation for superior escape: Superior escape suggests an incompetent coracoacromial arch and a high likelihood of failure to improve with muscle transfer.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- A true anteroposterior (AP) radiographic view of the shoulder in the plane of the scapula and axillary view is obtained (FIG 3A,B).
  - This allows evaluation of glenohumeral arthritis, superior migration of the humeral head, and identification of any abnormal bony anatomy (FIG 3C,D).
MRI allows evaluation of the rotator cuff, biceps tendon, and labral and capsular pathology (see Fig 2):
- The size of the rotator cuff tear, especially the extent of subscapularis and infraspinatus involvement
- Distance of tendon retraction from the greater tuberosity
- Extent of fatty degeneration seen in involved muscle bellies
- Electromyography is used to evaluate nerve function around the shoulder girdle.
- It is necessary when nerve pathology is suspected as a cause of shoulder dysfunction.

DIFFERENTIAL DIAGNOSIS
- Frozen shoulder
- Adhesive capsulitis
- Massive rotator cuff tear that can be repaired
- Cervical nerve root compression
- Suprascapular nerve palsy
- Deltoid dysfunction

NONOPERATIVE MANAGEMENT
- Nonoperative management is directed toward optimizing the patient’s current function, managing pain, and modifying activities and expectations.
- Treatment of irreparable cuff tears begins with physical therapy focused on maintaining motion and strengthening the deltoid and scapular stabilizers.
- Physical therapy includes strengthening of the periscapular muscles and internal and external rotators, and stretching to prevent stiffness and further loss of motion.
- Cortisone injection: Forty to 80 mg triamcinolone with 5 to 10 mL 1% Xylocaine is placed in the subacromial–glenohumeral space to decrease synovitis and bursitis, improve pain, and facilitate physical therapy.
- Activity and expectation modification: The physician should explain avoidance of inciting activities that increase pain and discuss realistic functional goals for patients with irreparable cuff tears.
- Most patients with irreparable cuff tears who fail to gain adequate improvement from physical therapy and activity modification are still not good candidates for latissimus dorsi muscle transfers. For these patients, alternative surgical interventions such as limited-goals arthroscopic débridement or reverse total shoulder arthroplasty in low-demand patients, versus shoulder fusion in young, high-demand manual laborers, may be options.
- Limited-goals arthroscopy: If nonoperative management has failed but the patient is not a good candidate for latissimus transfer, an arthroscopic glenohumeral and subacromial débridement may be an option.
- The ideal patient is over the age of 65 and retired, has low functional demands, and has an irreparable tear, and the primary indication for surgery is pain (not weakness).
- These patients should have at least shoulder-level active elevation with an improvement in active elevation after having a positive injection test (10 cc lidocaine into the glenohumeral joint) and without shoulder arthritis.
- This débridement can include synovial débridement, bursectomy, abrasion chondroplasty, acromioplasty–greater tuberosity-plasty, and biceps tenotomy or tenodesis to decrease mechanical symptoms and remove inflamed and painful tissues.
- Successful results are characterized by a decrease in pain followed by a fairly aggressive postoperative strengthening program.

SURGICAL MANAGEMENT
- The treatment decisions regarding management of massive irreparable rotator cuff tears must be made in the context of the patient’s current functional deficits, level of pain and its suspected cause, and physical examination findings.
- What the patient should expect in terms of postoperative pain relief and functional improvement must be clearly delineated before surgery, since return of full (normal) strength, active range of motion, and complete resolution of pain are not realistic goals for even the best latissimus transfer candidates.
- Only a carefully selected subset of patients with irreparable rotator cuff tears are good candidates for latissimus dorsi transfers.
- Ideal patients are younger and have good deltoid and subscapularis muscle strength, limited glenohumeral arthritis, and the ability to get shoulder-level active forward flexion preoperatively.
- Table 1 lists specific prognostic factors.
Preoperative Planning

- Before surgery, plain radiographs and MRI must be reviewed to rule out other sources of pathology.
- Glenohumeral osteoarthritis should be ruled out as a predominant cause of the patient’s current pain.
- An estimate should be made of the likelihood of successful primary repair based on the degree of cuff retraction and tissue quality.
- The equipment needed for both an attempted cuff repair and for muscle transfer should be available at the time of surgery.

Positioning

- The patient is placed in the lateral decubitus position and secured with a bean-bag or hip positioner posts (FIG 4A).
- The patient is draped to keep the affected arm free during the case and allow access to the back, the superior aspect of the shoulder, and the arm down to the elbow (FIG 4B,C).
- An arm holder attached to the opposite side of the table will allow abduction, flexion, and rotation for positioning of the arm during the case.

Approach

- The surgical approach must allow wide access to the rotator cuff and to the muscle belly of the latissimus dorsi and its insertion.
- Although a single-incision technique has been described, most authors prefer a two-incision technique—one incision for exposure and preparation of the rotator cuff and a second for dissection and release of the latissimus dorsi.

Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Better Prognosis</th>
<th>Worse Prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>&lt;60 years</td>
<td>&gt;60 years</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Function</td>
<td>Chest level or better</td>
<td>Below chest level</td>
</tr>
<tr>
<td>Subscapularis condition</td>
<td>Intact, functional</td>
<td>Torn, dysfunctional</td>
</tr>
<tr>
<td>Deltoid condition</td>
<td>Intact</td>
<td>Detached, dysfunctional</td>
</tr>
<tr>
<td>Previous surgery</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- The possibility of needing to use autograft or allograft tendon to augment the length of the latissimus dorsi transfer should be discussed with the patient and the site for autograft harvest must be draped appropriately at the time of surgery, or allograft tissue must be available.

**Superior Approach to the Rotator Cuff**

- An incision is made at the lateral edge of the acromion parallel to the acromion’s lateral border (TECH FIG 1A).
- Subcutaneous flaps are raised just superficial to the deltoit fascia.
- The anterior deltoit is taken off the acromion from the acromioclavicular joint to the midpoint between the anterior and posterior borders of the acromion.
  - This dissection is done in the subperiosteal plane to ensure strong fascial and periosteal tissue for later closure.
- The deltoid is split distally in line with its muscle fibers at the mid-lateral or posterolateral corner of the acromion (depending on the amount of deltoit released), and a stay suture is placed in the deltoit about 5 cm distal to the lateral edge of the acromion to prevent propagation of the split distally, which may result in injury to the axillary nerve (TECH FIG 1B).
- This exposure removes at least half and in some cases all of the middle deltoit origin. This extensive exposure helps in repair of the cuff as well as for transfer and repair of the latissimus dorsi tendon.
- A complete bursectomy is performed, the size and pattern of the rotator cuff tear are delineated, and the leading edge of the cuff tear is debrided (TECH FIG 1C).
- Inspection of the subscapularis tendon should be performed at this stage and partial detachments should be repaired.
- Irreparable subscapularis tears should be considered for concomitant pectoralis major transfers.
- Double muscle transfers are rarely performed and have a worse prognosis than single muscle transfers.

**Index of Commonly Used Abbreviations**

- Acromion: The anterior projection of the scapula.
- Acromioclavicular joint: The joint between the acromion and clavicle.
- Deltoit: The large muscle of the shoulder that moves the arm.
TECH FIG 1 • A. Location of the skin incision for exposure of the subacromial space, at the lateral border of the acromion. B. View of the superior approach to the shoulder with the patient in a lateral decubitus position. A subperiosteal release of the anterior deltoid (AD) from the acromioclavicular joint to the midpoint of the lateral border of the acromion (A) ensures strong tissue for later deltoid reattachment. A stay suture is placed in the deltoid split 5 cm distal to the lateral acromial edge to prevent traction injury to the axillary nerve. PD, posterior deltoid. C. The subacromial space after complete bursectomy and débridement of the irreparable rotator cuff tear. A, acromion; B, biceps tendon; H, humeral head; TMi, teres minor. D. A Cobb or periosteal elevator is used to perform a capsulotomy and release of adhesions around the superior glenoid rim. Articular and subacromial-sided release of adhesions from the retracted rotator cuff allows full mobilization of the torn tendons for an attempted primary repair. E. The prepared greater tuberosity, lightly decorticated, with sutures in place to allow tendon fixation.

- An acromioplasty is performed as needed.
- Remove only that portion of the acromion that extends inferior to the plane of the posterior acromion.
- Avoid decreasing the anteroposterior dimension of the acromion, which can increase the risk of superior escape of the humeral head.
- Keep the coracoacromial ligament at its maximum length and attached to the deep surface of the deltoid.
- At wound closure, place sutures in the acromial end of the coracoacromial ligament and suture this back to the anterior acromion to reconstruct the coracoacromial arch.
Reconstruction of the coracoacromial arch also helps minimize the risk of postoperative superior subluxation of the humeral head.

If degenerative changes are seen in the biceps tendon, it can be tenodesed in the bicipital groove and the intra-articular portion excised to remove it as a potential pain generator.

Complete mobilization of the retracted rotator cuff should be performed on both the intra-articular and extra-articular sides of the tendon.

This is best performed with a scalpel, Cobb or periosteal elevator, and use of electrocautery where necessary on the intra-articular side of the tendons.

Do not exceed 1.5 to 2.0 cm of medial dissection of the rotator cuff muscles within the fossa. Excessive medial dissection could injure the suprascapular nerve (TECH FIG 1D).

Débridement of remaining tissue and light decortication of the greater tuberosity with a rongeur or burr is performed to prepare the site for rotator cuff reattachment or muscle transfer.

Any portion of the cuff that is reparable to the tuberosity should be attached with number 2 or larger nonabsorbable suture to bone.

Bone tunnels or suture anchors are placed in the lateral edge of the greater tuberosity (TECH FIG 1E).

If full mobilization of the rotator cuff will not allow solid repair of the tendon back to the greater tuberosity with the arm at the side, then the decision is made to proceed with the latissimus dorsi transfer.

If a full repair is achieved but the quality of the repair or the tissue quality is fair or poor, we still prefer to perform the latissimus transfer when the likelihood for healing of the primary repair is low and the need for postoperative strength is high and of primary importance to the patient.

SURGICAL APPROACH TO THE LATISSIMUS DORSI

A 15-cm incision is made along the posterolateral border of the latissimus dorsi, extending proximally to the posterior axillary fold (TECH FIG 2A).

The incision can be extended proximally as needed for exposure, being careful to change directions when crossing skin creases in the axilla to avoid webbing and excessive scarring in the skin of the posterior axillary crease.

Skin flaps are raised just superficial to the muscular fascia of the latissimus dorsi, and the upper and lower borders of the muscle are defined (TECH FIG 2B, C).

Identification of the inferior (lateral) border of the latissimus is the most reliable method for correctly identifying the muscle belly, as there is no large muscle inferior (lateral) to the latissimus on the posterior chest wall.

Blunt dissection is used to define and trace the tendon proximally toward its insertion on the proximal humerus (TECH FIG 2D).

Abduction and internal rotation of the arm provides the best visualization of the tendon at its insertion. Careful attention to neurovascular structures is critical at this stage, as the axillary and radial nerves, brachial plexus, and humeral circumflex vessels are all in proximity to the surgical field during this phase of the procedure.

Internal rotation of the arm in abduction is necessary for adequate exposure but also brings the radial nerve closer to the latissimus dorsi tendon along its anterior, medial surface.

The axillary nerve and posterior humeral circumflex artery run along the superior border of the teres
TECH FIG 2 • (continued) D. Exposure of the tendinous insertion of the latissimus dorsi (L) and teres major (TMa) on the proximal, medial humerus is facilitated by abduction and internal rotation of the arm.

- Exposure of the tendinous insertion of the latissimus dorsi (L) and teres major (TMa) just proximal to the latissimus dorsi before exiting the quadrangular space.
- The anterior humeral circumflex vessels run along the superior border of the latissimus dorsi tendon and can be a source of significant bleeding if inadvertently cut.
- Dissection and release of the tendon should be carried out by working from the posterior surface of the humerus, as this keeps all important neurovascular structures anterior (deep) to the tendon.
- A significant number of patients will have latissimus dorsi and teres major tendons that fuse into one tendon along their superior border where they insert on the humerus, a condition that requires sharp dissection to separate the two.
- Once the humeral insertion of the latissimus dorsi has been identified, it should be released directly off the bone on the humeral shaft to ensure adequate tendon length for transfer.

TRANSFER AND FIXATION OF THE LATISSIMUS DORSI TO THE HUMERAL HEAD

- Once released from its insertion, the latissimus dorsi tendon is prepared by weaving number 2 fiberwire (Arthrex, Naples FL) through the tendon with a locking Krackow technique along both its superior and inferior borders (TECH FIG 3A, B).
- These locking sutures should be placed as soon as the tendon is released to minimize extensive handling of the tendon itself, which is easily frayed because it has few crossing fibers.
- These sutures can now be used as traction stitches, and the latissimus is freed from any adhesions on its anterior surface.
  - Be sure to pull the sutures in line with the long axis of the tendon.
  - Do not pull the locking sutures in divergent directions as it will separate the parallel fibers of the tendon.
- The neurovascular pedicle is identified and freed as well to prevent traction and damage to these structures during the transfer.
  - The pedicle is located on the deep surface of the muscle about 13 cm from the musculotendinous junction.
  - It is best seen and dissected after the tendon is released from its insertion and the muscle is flipped posteriorly, thereby exposing the undersurface of the muscle.
- Mobilization of the latissimus dorsi for transfer requires dissection of the deep fascial investments of the muscle from surrounding tissues into the chest wall.
  - If this is not performed, maximum excursion of the transfer will not be achieved and the tendon will not be long enough to reach the top of the humeral head.
Using sharp and scissor dissection and some blunt dissection, the plane underneath the deltoid and superficial to the rotator cuff muscles across the back of the shoulder is developed (about 4 to 6 cm wide) to connect the superior (rotator cuff exposure) and the posterior (latissimus exposure) wounds.

A large Kelly clamp is passed in this plane from the superior to the posterior wounds. Attention must be paid to enlarging this plane (4 to 6 cm) to prevent binding of the latissimus muscle belly within the tunnel, compromising its excursion.

Grasping the previously placed traction sutures with the large curved Kelly clamp, the surgeon then passes the latissimus dorsi deep to the deltoid and into the subacromial space with the arm in adduction and neutral rotation (TECH FIG 3C).

The effectiveness of this transfer depends on achieving a tenodesis effect of the transfer, thereby creating a passive humeral head depressor effect.

To accomplish this, the arm is positioned in 45 degrees of abduction and at least 30 degrees of external rotation.

In this position the transferred tendon is pulled to its maximum length over the top of the humeral head, and the traction sutures placed along the sides of the tendon are passed through the leading edge of the subscapularis tendon and tied. This step establishes the tendon transfer tension and places the tendon over the top of the humeral head (TECH FIG 3D,E).

When the arm is brought to the patient’s side and in internal rotation, the transfer is tensioned further, bringing the humeral head lower within the glenoid fossa.

We believe that this is one of the most important steps in the surgery to achieve proper transfer function.

The lateral border of the latissimus dorsi tendon is now fixed to the greater tuberosity with three number 2 fiberwires passed through bone tunnels or with 5.5-mm biocorkscrew suture anchors (TECH FIG 3F).
The medial edge of the latissimus tendon is sutured to the retracted edge of the supraspinatus and infraspinatus tendons with several nonabsorbable sutures. Although some authors believe that the latissimus tendon should be attached only to the greater tuberosity to act as an external rotator of the humerus, we believe that repair of the leading edge to the upper border of the subscapularis allows the transfer to act as a humeral head depressor (either passively by a tenodesis effect or actively if the patient can learn how to fire the muscle isotonically in phase with external rotation or forward elevation). This suturing of the latissimus to the subscapularis can be done with two heavy, nonabsorbable sutures.

**WOUND CLOSURE**

- The anterior deltoid and middle deltoid are reattached to the acromion with nonabsorbable sutures placed through bone tunnels in the acromion as well as to the intact fascia (TECH FIG 4A).
- A drain is placed in the latissimus dorsi harvest site as needed, and both skin incisions are closed without closure of any deep fascial layers. Before emergence from general anesthesia, the patient is placed in a brace with 20 degrees of abduction and neutral rotation (TECH FIG 4B).

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Indications and patient selection</th>
<th>Ideal candidates: physiologically young, thin, male gender, minimal muscle wasting, shoulder level function, minimal glenohumeral arthritis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poor candidates: older, obese (big heavy arm), female gender, deltoid weakness, moderate arthritis, poorly compliant patient, subscapularis involvement, more limited preoperative function (less than shoulder-level active elevation), superior humeral head escape</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Preoperative assessment of whether cuff can be repaired</th>
<th>Duration: Within weeks to months, rotator cuff muscle–tendon units demonstrate decreased compliance and inferior mechanical properties.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cuff retraction: Retraction of torn tendons medial to the midpoint of the humeral head on MRI suggests the need for significant mobilization at the time of surgery to attempt a primary repair.</td>
</tr>
<tr>
<td></td>
<td>Muscle degeneration: MRI or CT imaging showing fatty degeneration of the rotator cuff muscle bellies suggests tendons will have limited excursion and inferior mechanical properties at the time of attempted repair.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surgical</th>
<th>The surgeon should internally rotate the arm to fully visualize the latissimus insertion on the humerus. Inadequate exposure limits the ability to harvest the entire length of tendon, necessitating additional tendon graft.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The released latissimus tendon should be handled carefully to prevent fraying.</td>
</tr>
<tr>
<td></td>
<td>Release and mobilization of the latissimus dorsi muscle belly along the chest wall</td>
</tr>
<tr>
<td></td>
<td>The surgeon should ensure that the tunnel for the latissimus rerouting is large enough to prevent constriction of the latissimus muscle belly in the subdeltoid space.</td>
</tr>
</tbody>
</table>

| Postoperative | Retraining of the latissimus to work in phase with forward flexion and external rotation of the arm                                                                                           |
POSTOPERATIVE CARE

- The patient is placed into a brace postoperatively for 4 to 6 weeks to prevent internal rotation.
- During this time the brace can be removed for dressing and bathing, keeping the arm in neutral rotation.
- Passive forward flexion and external rotation is performed during the first 4 weeks to prevent shoulder stiffness.
- At 4 weeks, bracing is discontinued and passive range of motion in all planes is performed.
- At 7 to 9 weeks, active range of motion is started and physical therapy is begun, focused on retraining the latissimus dorsi to function as an abductor and external rotator of the arm.
- External rotation training: A pillow is placed between the arm and chest wall holding the arm abducted 30 degrees. The patient is told to actively externally rotate the arm while adducting the arm against the pillow.
- Forward elevation training: The patient squeezes a large rubber ball between the palms of the hands while raising both arms forward over the head.
- Biofeedback can also be used to show the patient when he or she is actively contracting the latissimus during external rotation and forward elevation.

OUTCOMES

- Significant improvement in pain scores postoperatively is a consistent finding (80% to 100% of patients) across outcome studies, even for patients less satisfied with their final results.\(^7\)\(^11\)
- Sixty-six to 81% of patients report satisfaction postoperatively. Patient satisfaction tends to be associated more with improved active shoulder function than pain relief.\(^7\)\(^11\)
- Patients with better preoperative function tend to have greater postoperative improvements in range of motion and strength compared to patients starting with greater shoulder dysfunction.
- Based on our experience and that reported in the literature, postoperative range of motion improves by an average of 35 to 50 degrees in forward flexion and 9 to 40 degrees of external rotation.\(^7\)\(^11\)\(^16\)
- Patients undergoing latissimus transfer as the first procedure to treat their rotator cuff pathology can expect better outcomes with regard to satisfaction, pain relief, and active range of motion compared to patients undergoing latissimus transfer who have had prior failed surgery for treatment of their rotator cuff.\(^16\)
- Electromyographic studies show that about 40% to 50% of patients can be retrained to use in-phase latissimus dorsi contraction with active forward flexion or external rotation.\(^7\)\(^11\)
- Female gender and advanced age are associated with worse outcomes.
- Subscapularis tendon tears and superior escape of the humeral head are associated with a higher failure rate.

- Patients with multiple negative preoperative prognostic factors should not undergo isolated latissimus muscle transfer, and other options should be considered either alone or in conjunction with a latissimus transfer.

COMPLICATIONS

- Deltoid detachment
- Wound infection
- Rupture of the transferred tendon
- Decreased active forward flexion

REFERENCES

DEFINITION
- The subscapularis is one of four muscles making up the rotator cuff. Tears can result from chronic attenuation secondary to age or overuse, but more commonly they result from trauma.
- Subscapularis tears commonly occur after a fall on the outstretched arm, traction injuries resulting in a strong external rotation force applied to the arm, or an anterior shoulder dislocation.
- Many tears affect only the upper tendinous portion of the insertion. Other tears result in a complete tear of the tendinous and muscular portions of the insertion.
- Subscapularis tears are often missed early in the course of treatment. Tears older than about 6 months are usually not reparable because of atrophy and degeneration of the muscle, necessitating a pectoralis major muscle transfer.

ANATOMY
- The subscapularis muscle (FIG 1A) arises from the deep, volar surface of the scapular body (the subscapular fossa) and inserts on the lesser tuberosity. The upper two thirds of the insertion is tendinous and the lower third is a muscular insertion.
- The anterior humeral circumflex artery courses laterally along the demarcation between the tendinous and muscular portions of the muscle.
- Tears of the subscapularis differ from tears of the other rotator cuff muscles in that there is often an intact soft tissue sleeve across the front of the shoulder with the torn tendon retracted medially within this “sheath.” In contrast, the supraspinatus and infraspinatus tear leaving exposed humeral head. The remaining soft tissue over the anterior humeral head after a subscapularis tear can be mistaken for an intact or partially torn tendon.
- The pectoralis major muscle is composed of two major heads (FIG 1B).
- The clavicular head originates from the medial third of the clavicle. The sternal head originates from the manubrium, the upper two thirds of the sternum, and ribs 2 to 4. The muscle courses laterally to insert on the lateral lip of the biceps groove.
- The sternal head lies deep to the clavicular head, forming the posterior lamina, and inserts slightly superior to the clavicular head. The clavicular head forms the anterior lamina. The laminae are usually continuous inferiorly.
- Some of the deep muscular fibers from the inferior aspect of the pectoralis major muscle course toward and insert on the more proximal or superior aspect of the muscle insertion. These inferior-to-superior–directed fibers tend to make the muscle “flip” when it is released. The superior corner should be tagged to assist with orientation if used for the transfer.
- The mean width of the pectoralis major insertion is 5.7 cm (range, 4.8 to 6.5 cm).* The undersurface of the insertion has a broad tendinous insertion, whereas the anterior surface is primarily muscular; only the most distal insertion is tendinous.
- The pectoralis major muscle is innervated by the medial and lateral pectoral nerves, which arise from the medial and lateral cords of the brachial plexus, respectively.
- The medial pectoral nerve enters the pectoralis major muscle about 11.9 cm (range, 9.0 to 14.5 cm) from the

---

**FIG 1** • A. Anterior view of the subscapularis muscle. B. Clavicular and sternal heads of the pectoralis muscle.
Chapter 11 PECTORALIS MAJOR TRANSFER FOR IRREPARABLE SUBSCAPULARIS TEARS

Subscapularis tears result from:
- Anterior shoulder dislocations
- Traction injuries to the arm with extension and external rotation forces to the arm
- Rarely, chronic attenuation from age and overuse
- Possible relationship to coracoid impingement
- The subscapularis muscle is particularly prone to atrophy and degeneration after a tear. With complete, retracted tears of the muscle, there is a window of opportunity for about 6 months when a primary repair can be performed. Beyond that time point, the muscle is increasingly difficult to mobilize and repair is under substantial tension, leading to early failure.

DIFFERENTIAL DIAGNOSIS
- Subscapularis tears result from:
  - Anterior shoulder dislocations
  - Traction injuries to the arm with extension and external rotation forces to the arm
  - Rarely, chronic attenuation from age and overuse
  - Possible relationship to coracoid impingement
- The subscapularis muscle is particularly prone to atrophy and degeneration after a tear. With complete, retracted tears of the muscle, there is a window of opportunity for about 6 months when a primary repair can be performed. Beyond that time point, the muscle is increasingly difficult to mobilize and repair is under substantial tension, leading to early failure.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Lift-off test: The patient will not be able to lift the hand off the back if the subscapularis is deficient.
- Abdominal compression test: With a tear, the patient will not be able to maintain this position and will flex wrist or hand will release from the belly if positive.
- Range-of-motion testing: A subscapularis tear will result in increased external rotation at the side, with a “softer” endpoint.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- A standard shoulder series of radiographs comprising a shoulder anteroposterior (AP) view, a true scapular AP view, an axillary view, and a scapular Y view is obtained to rule out fractures, arthritis, or other injury.
- A subscapularis tear may result in proximal migration of the humeral head relative to the glenoid, depending on the degree of tear and involvement of other rotator cuff muscles.
- In the absence of a subscapularis tear, slight anterior subluxation of the humeral head may be noted on the axillary view.
- An MRI will reveal the tear and also be helpful in assessing the degree of retraction, atrophy, and fatty degeneration of the subscapularis muscle. The proximal portion of the long head of the biceps tendon becomes unstable from the intertubercular groove when the subscapularis tears. An MRI can demonstrate a dislocated or subluxed biceps tendon.
- A CT arthrogram is an alternative to an MRI.
- Subscapularis tears can be diagnosed with ultrasound if performed by a competent, experienced ultrasonographer. Ultrasound is very sensitive for biceps tendon subluxation or dislocation from the groove.

DIFFERENTIAL DIAGNOSIS
- Supraspinatus tears
- Infraspinatus tears
- Biceps tendon pathology
- Anterior instability
- Rotator cuff insufficiency secondary to neurologic etiology

NONOPERATIVE MANAGEMENT
- Physical therapy focusing on strengthening the intact rotator cuff muscles can be beneficial to maximize the function of remaining musculature.
- Range-of-motion exercises focus on any areas of loss of motion or capsular contracture.
- Rotator cuff strengthening with the use of light-resistance Therabands at waist level is an effective initial exercise. Progression to higher-resistance exercises is as tolerated.
- Cortisone injections may give some temporary pain relief but are unlikely to result in permanent resolution of symptoms.
- Nonsteroidal anti-inflammatory medication may be helpful for pain relief of mild to moderate pain.

SURGICAL MANAGEMENT
- An attempt is made at the time of surgery to repair the native subscapularis. Within reasonable limits, the subscapularis is mobilized by releasing surrounding soft tissues. Even a partial repair is recommended in conjunction with a pectoralis major transfer.
- Surrounding soft tissues include the rotator interval and coracohumeral ligament, the anterior capsule of the shoulder (middle and inferior glenohumeral ligaments), and superficial soft tissue adhesions deep to the coracoid and conjoint tendon.
- The subscapularis differs from the other rotator cuff muscles in that it has a fascial sleeve that remains attached to the lesser tuberosity and covers the anterior humeral head. This is in contrast to the other rotator cuff muscles, which leave exposed greater tuberosity and cartilage without soft tissue coverage. This material is easily mistaken for an intact subscapularis, emphasizing the significance of preoperative evaluation.

Preoperative Planning
- Patient history, physical examination, and all imaging studies are reviewed. A soft tissue imaging study such as MRI or ultrasound of the rotator cuff is a necessity.
Plain films should be assessed for proximal migration, anterior subluxation, and deformity secondary to trauma and arthritis. An MRI is useful for assessing the condition of the subscapularis. A high degree of retraction and degeneration of the muscle is highly suggestive of a chronic, irreparable tear that will necessitate a pectoralis major muscle transfer.

Subscapularis tears result in instability of the long head of the biceps tendon with medial subluxation into the joint. The surgeon should be prepared to perform a biceps tenotomy or tenodesis of the tendon if it has not already ruptured from chronic, attritional changes.

Associated tears of the other rotator cuff muscles are addressed concurrently. Isolated arthritic lesions are débrided, as is degenerative labral fraying or tear.

Positioning

The pectoralis major transfer is most easily performed with the patient in the beach chair position. The head of the bed or positioning device is elevated about 60 degrees. The head is secured to avoid cervical injury. The arm is prepared and draped free and held in a commercially available arm holder that allows flexible arm positioning.5

Approach

Several different variations of the pectoralis major transfer have been described.

- Wirth and Rockwood8 described a split pectoralis major muscle transfer superficial to the coracoid.
- Resch and colleagues7 described a split pectoralis major transfer deep to the coracoid.
- Jost and colleagues4 and Gerber and associates3 recommended transfer of the whole pectoralis major muscle superficial to the coracoid.
- Gerber and associates3 described transfer of the sternal head of the pectoralis major with or without the teres major tendon.

The procedure can be performed through a deltopectoral or anterior axillary incision.

- The deltopectoral incision allows a more extensile approach and is recommended in revision cases.
- The anterior axillary incision from the coracoid to the anterior axillary crease is useful in primary cases in smaller patients.
- Both incisions use the deltopectoral interval for deep exposure.

**SPLIT PECTORALIS MAJOR MUSCLE TRANSFER**

- The deltopectoral interval is identified. The cephalic vein is usually retracted laterally with the deltoid. The subdeltoid and subacromial spaces are released of adhesions.
- Regardless of technique, the native subscapularis is examined and mobilized to its full extent. If repair is not possible, a muscle transfer is performed.
- The superior 2.5 to 3 cm of the pectoralis major insertion is identified along the lateral edge of the biceps groove. This contains portions of both the anterior and posterior laminae. The identified portion of the pectoralis major insertion is released sharply from its insertion. Care is taken to avoid injury to the long head of the biceps tendon, which lies directly under the insertion in this case. The distal tendon is tagged with three or four stay sutures.
- Tension is applied to the stay sutures to facilitate the muscle split of the pectoralis major muscle. Muscle dissection is performed bluntly in a medial direction at the inferior portion of the split to mobilize the superior muscle for transfer. Dissection should be limited to 6 to 8 cm to preserve the medial pectoral nerve (TECH FIG 1A).

**TECH FIG 1**

- **A.** The medial pectoral nerve (arrow) arises from the medial cord of the brachial plexus and enters the pectoralis major muscle 6 to 8 cm medial to the muscle insertion. Thus, medial dissection and mobilization is limited to 6 to 8 cm to avoid denervating the muscle. **B.** The superior half of the pectoralis major insertion is freed from the humerus and mobilized. This half is transferred to the humeral head and secured in a small bone trough with drill holes for the sutures.


- The humerus is rotated internally to expose the greater tuberosity and humeral shaft lateral to the biceps groove. An osteotome or burr is used to make a bone trough measuring $5 \times 25$ mm oriented in a vertical position for reinsertion of the transferred pectoralis muscle.
- Three or four holes are drilled just lateral to the edge of the trough and a curved awl is used to connect the drill holes to the trough (TECH FIG 1B).
- The sutures in the tendon are passed into the trough and out through the drill holes. Tension is placed on the sutures, bringing the tendon into the trough. The sutures are then tied over the bone bridges between the holes, securing the tendon.
- A biceps tenotomy or tenodesis is performed as needed.

### TECHNIQUES

#### SUBCORACOID MUSCLE TRANSFER OF THE CLAVICULAR HEAD

- A deltopectoral incision and approach are used (TECH FIG 2A).
- The tendon of the pectoralis major insertion is exposed along its full length (TECH FIG 2B).
- The superior half to two thirds of the clavicular head is detached from the humerus. The muscle fibers corresponding to the detached section of the tendon are split or separated from the remaining muscle using blunt dissection in a medial direction. The blunt dissection is performed between the sternal and clavicular heads so that only the clavicular head muscle is released and preserved for the transfer (TECH FIG 2C). The muscle fibers of the sternal portion that course into the proximal portion of the muscle are transected.
- The space between the medial border of the conjoint tendon and the pectoralis minor is gently dissected bluntly. The musculocutaneous nerve and its entry into the conjoint tendon are identified. The space deep to the conjoint tendon and superficial to the musculocutaneous nerve is developed for the muscle transfer (TECH FIG 2D).
- Stay sutures are attached to the distal pectoralis major tendon. The sutures are grasped with a curved forceps.

---

**TECH FIG 2** • A. This cadaveric dissection illustrates the deltopectoral approach (black arrow, pectoralis major; white arrow, deltoid). The incision should be long enough to allow adequate exposure of the pectoralis major and the proximal humerus for reattachment. B. Cadaveric dissection illustrating the pectoralis major and its insertion (arrow). C. The pectoralis major has two heads, the superficial clavicular head (white arrow) and the deeper sternal head (black arrow). In this photo, the insertion has been released and is reflected medially. (continued)
WHOLE PECTORALIS MUSCLE TRANSFER

- The deltopectoral approach is identical to that described above.
- An attempt is made to mobilize and repair the subscapularis. Releases are performed at the rotator interval, the base of the coracoid, the brachial plexus, and the subscapularis fossa. A partial repair is performed if possible.
- The entire tendon of the pectoralis major tendon is exposed and released from its insertion of the humerus.
- Three nonabsorbable sutures are passed through the tendon using a modified Mason-Allen technique.
- The muscle and tendon is mobilized and brought over (superficial) the coracoid to the medial aspect of the greater tuberosity, where it is secured using anchor fixation or to a bone trough (TECH FIG 3).
- If a bone trough is used, the sutures are routed through the trough and the knots are tied over a small titanium plate to prevent suture pullout. The uppermost corner of the tendon is sutured to the anterolateral supraspinatus. Care is taken not to overtighten the rotator interval.

TECH FIG 3 • The whole pectoralis major muscle is released from its insertion on the humerus and transferred and secured to the humeral head using anchor fixation or a bone trough with tunnels.
SPLIT PECTORALIS MAJOR AND TERES MAJOR TENDON TRANSFER

- Setup and exposure are as described above.
- The plane between the sternal and clavicular heads is located and developed. The sternal head is sharply released from the humerus. Nonabsorbable sutures (no. 2) are placed in the tendon in Mason-Allen fashion.
- The sternal head is mobilized and pulled underneath the clavicular head to the lesser tuberosity, where it is secured (TECH FIG 4A). The transfer is superficial to the coracoid process and should be tight but allow 30 degrees of external rotation.
- If the subscapularis tear is completely irreparable, the authors recommend combining this transfer with the teres major muscle.
- To expose the teres major, the arm is externally rotated.
- The latissimus dorsi insertion is located and the superior and inferior aspects are demarcated. The latissimus is released, leaving a cuff of tissue laterally for repair.
- The teres major insertion is deep to the latissimus. The teres major is tagged and released. Often, the muscle must be released from confluence with the latissimus.
- The axillary nerve and posterior humeral circumflex artery lie at the superior border of the teres major muscle. The radial nerve and brachial artery are in close approximation to the inferior border of the teres major.
- Finally, the teres major is transferred to the inferior portion of the lesser tuberosity, where it is secured with nonabsorbable sutures (TECH FIG 4B).

**TECH FIG 4** • **A.** This transfer uses the sternal head of the pectoralis major muscle. It is released and mobilized underneath the clavicular head to the lesser tuberosity. **B.** The teres major muscle is released from its insertion on the humerus and transferred along with the sternal head of the pectoralis major to the lesser tuberosity. The teres major inserts deep to the latissimus dorsi, which is reattached in its anatomic position.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Indications</th>
<th>Subscapularis tears are often missed, resulting in a delayed diagnosis.</th>
<th>Elderly patients with generalized atrophy should be considered for a whole muscle transfer, whereas more muscular individuals are better candidates for split or sternal head transfers.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pectoralis major muscle detachment and mobilization</td>
<td>Mobilization of the muscle should not proceed greater than 8 cm from the insertion in order to protect the pectoral nerves.</td>
<td>In whole muscle transfers, the medial pectoral nerve can enter the muscle within 1.2 cm of the inferior edge.</td>
</tr>
</tbody>
</table>
Subcoracoid transfer of the pectoralis major muscle
- The musculocutaneous nerve and its proximal branches are at risk.
- The musculocutaneous nerve is identified.
- Transferred muscle should course deep to the conjoint tendon and superficial to the nerve to avoid excessive traction and neurapraxia.
- Scar in revision cases can make this dissection difficult; an intraoperative nerve stimulator may help identify structures of the brachial plexus if necessary.

Fixation problems
- Mason-Allen or Krackow sutures are used to grasp the tendon securely.

Orientation
- Before release of the muscle, the superior corner is tagged to keep muscle in its anatomic orientation (some inferior muscle fibers course to the superior insertion, so the muscle tends to flip after release).

POSTOPERATIVE CARE
- A drain should always be used because release and transfer of the pectoralis major muscle results in dead space, and hematoma formation is common.
- The operative arm is placed in a sling postoperatively. Passive exercises are started on postoperative day 1.
  - The surgeon should evaluate tension on the transfer intraoperatively before closure to determine the limits of external rotation during early rehabilitation.
  - Forward elevation is performed in internal rotation or neutral rotation to minimize tension on the transfer.
  - Active internal rotation and extension are avoided for 6 weeks.
  - Active assisted and active range-of-motion exercises are started 6 weeks after surgery. Resistance exercises commence as tolerated thereafter. No internal rotation resistance exercises are recommended until 12 weeks postoperatively.

OUTCOMES
- Jost and associates reported a series of 30 transfers in 28 patients. Twelve had isolated subscapularis tears and 18 had concomitant supraspinatus–infraspinatus tears. The mean relative Constant score improved from 47% to 70% at an average of 32 months of follow-up. Thirteen patients were very satisfied, 10 patients were satisfied, 2 patients were dissatisfied, and 3 patients were dissatisfied.
- Resch and colleagues reported on a series of 12 patients with a subcoracoid transfer. The Constant score increased from 26.9% to 67.1%. Nine assessed their final result as good or excellent, three as fair, and none as poor. Four unstable shoulders were stable at the average of 28 months of follow-up.
- Rockwood reported a series of 13 patients. Seven had a pectoralis major transfer and six had a pectoralis minor transfer. Ten of the 13 were satisfied, but the results were not separated between the patients with the pectoralis major and minor transfers.
- Galatz and associates reported on the subcoracoid pectoralis major transfer in 14 patients as a salvage procedure for iatrogenic anterior superior instability. Nine of the 14 had satisfactory results in terms of pain relief, but the functional results are not as predictable for this particular indication.
- Gerber and colleagues reported a combination of sternal head and sternal head plus teres major transfers. In the sternal head patients, 9 of 11 had pain relief. Two had a rupture that required revision. In the sternal head plus teres major group, seven of nine patients had pain relief. One had a rupture discovered at the time of revision surgery (fusion). Final ASES scores were 61 in the sternal group and 55 in the sternal plus teres group.
- In all series, most of the patients had had surgery before the transfer, and in most cases a pectoralis major transfer was performed for revision purposes. This has dramatic implications on outcome.

COMPLICATIONS
- Musculocutaneous nerve injury
- Pectoral nerve injury
- Fixation failure
- Mechanical impingement with the coracoid, either deep or superficial to the conjoint tendon

REFERENCES
Sternoclavicular dislocation is one of the rarest dislocations, but one most shoulder surgeons will encounter several times during a career (more in a practice with significant exposure to high-energy trauma).

Sternoclavicular dislocations represented 3% of a series of 1603 injuries of the shoulder girdle reported by Cave et al.6 The true ratio of anterior to posterior dislocations is unknown, since most reports focus on the rarer posterior type. Estimates range from a ratio of 20 anterior dislocations to each posterior by Nettles and Linscheid,19 in a series of 60 patients (57 anterior and 3 posterior), to a ratio of approximately three to one (135 anterior and 50 posterior) in our series25 of 185 traumatic sternoclavicular injuries.

Not all sternoclavicular dislocations require surgery. Avoiding inappropriate patient selection, preventing hardware-related complications, and repairing or reconstructing the capsule and the rhomboid ligament if the medial clavicle has been resected require special emphasis.

Although this region can be an intimidating one because of the surrounding anatomic structures, a knowledgeable and careful surgeon can treat this joint safely and reliably produce good results.

ANATOMY

The epiphysis of the medial clavicle is the last epiphysis of the long bones to appear and the last to close. It does not ossify until the 18th to 20th year, and it generally fuses with the shaft of the clavicle around age 23 to 25.14,15 For this reason, many sternoclavicular “dislocations” in young adults are in fact physeal fractures.

The articular surface of the medial clavicle is much larger than that of the sternum. It is bulbous and concave front to back and convex vertically, creating a saddle-type joint with the curved clavicular notch of the sternum.14,15

A small facet on the inferior aspect of the medial clavicle articulates with the superior aspect of the first rib in 2.5% of subjects.5

There is little congruence and the least bony stability of any major joint in the body. Almost all of its integrity comes from the surrounding ligaments.

Ligaments

The intra-articular disc ligament is dense and fibrous, arises from the synchondral junction of the first rib to the sternum, passes through the sternoclavicular joint, and divides it into two separate spaces14,15 (FIG 1). It attaches on the superior and posterior medial clavicle and acts as a checkrein against medial displacement of the inner clavicle.

The costoclavicular (rhomboid) ligament attaches the upper surface of the medial first rib to the rhomboid fossa on the inferior surface of the medial end of the clavicle.14,15 It averages 1.3 cm long, 1.9 cm wide, and 1.3 cm thick.5

The anterior fasciculus arises anteromedially, runs upward and laterally, and resists lateral displacement and upward rotation of the clavicle.

The posterior fasciculus is shorter, arises laterally, runs upward and medially, and resists medial displacement and excessive downward rotation1,5,15 (FIGS 1 AND 2).

The interclavicular ligament (see Fig 1) connects the superomedial aspects of each clavicle with the capsular ligaments and the upper sternum. Comparable to the wishbone of birds, it helps the capsular ligaments to produce “shoulder poise”; that is, to hold up the lateral aspect of the clavicle.14

The capsular ligaments cover the anterosuperior and posterior aspects of the joint and represent thickenings of the joint capsule (Figs 1 and 2). The clavicular attachment of the ligament is primarily onto the epiphysis of the medial clavicle, with some blending of the fibers into the metaphysis.3,8

In sectioning studies, the capsular ligaments are the most important structures in preventing upward displacement of the medial clavicle caused by a downward force on the distal end of the shoulder.1

This lateral poise of the shoulder (ie, the force that holds the shoulder up) is attributed to a locking mechanism of the ligaments of the sternoclavicular joint.

Other single ligament sectioning studies26 have shown that the posterior capsule is the most important primary stabilizer to anterior and posterior translation. The anterior capsule is an important restraint to anterior translation. The costoclavicular ligament is unimportant if the capsule remains intact, although it may be an important secondary restraint if the capsular ligaments are torn, much like the coracoclavicular ligament laterally.

Applied Surgical Anatomy

A “curtain” of muscles—the sternohyoid, sternothyroid, and scaleni—lies posterior to the sternoclavicular joint and the inner third of the clavicle and blocks the view of vital structures—the innominate artery, innominate vein, vagus nerve, phrenic nerve, internal jugular vein, trachea, and esophagus.

The anterior jugular vein lies between the clavicle and the curtain of muscles. Variable in size and as large as 1.5 cm in diameter, it has no valves and bleeds like someone has opened a floodgate when nicked.

The surgeon who is considering stabilizing the sternoclavicular joint by running a pin down from the clavicle into the sternum should not do it and should remember that the arch of the aorta, the superior vena cava, and the right pulmonary artery are also very close at hand.

PATHOGENESIS

Most sternoclavicular joint dislocations result from high-energy trauma, usually a motor vehicle accident. They occasionally result from contact sports.
A force applied directly to the anteromedial aspect of the clavicle can push the medial clavicle back behind the sternum and into the mediastinum. More commonly, a force is applied indirectly, from the lateral aspect of the shoulder. If the shoulder is compressed and rolled forward, a posterior dislocation results; if the shoulder is compressed and rolled backward, an anterior dislocation results.

As noted above, many injuries of the sternoclavicular joint in patients under 25 years of age are, in fact, fractures through the medial physis of the clavicle.

NATURAL HISTORY

- Mild or moderate sprain
  - The mildly sprained sternoclavicular joint is stable but painful.
  - The moderately sprained joint may be slightly subluxated anteriorly or posteriorly, and may often be reduced by drawing the shoulders backward as if reducing and holding a fracture of the clavicle.

- Anterior dislocation
  - Although most anterior dislocations are unstable after closed reduction, we still recommend an attempt to reduce the dislocation closed.
  - Occasionally the clavicle remains reduced, but typically the clavicle remains unstable after closed reduction. We usually accept the deformity, because an anteriorly dislocated sternoclavicular joint typically becomes asymptomatic, and we believe that the deformity is less of a problem than the potential complications of operative fixation.

- Posterior dislocation
  - In contrast to anterior dislocations, the complications of an unreduced posterior dislocation are numerous: thoracic outlet syndrome, vascular compromise, and erosion of the medial clavicle into any of the vital structures that lie posterior to the sternoclavicular joint.
  - Closed reduction for acute posterior sternoclavicular dislocation can usually be obtained, and the reduction is generally stable. Often, general anesthesia is necessary. However, when a posterior dislocation is irreducible or the reduction is unstable, an open reduction should be performed.
  - When chronic posterior dislocation is present, late complications may arise from mediastinal impingement, so we recommend medial clavicle resection and ligament reconstruction.

- Physeal injuries
  - The typical history for physeal injuries is the same as for other traumatic dislocations. The difference between these injuries and pure dislocations is that most of these injuries will heal with time, without surgical intervention.
  - In very young patients, the remodeling process can eliminate deformity because of the osteogenic potential of an intact periosteal tube. Zaslav, Rockwood, and Hsu et al have all reported successful treatment of displaced medial clavicle physeal injury in adolescents and provided radiographic evidence of remodeling.
  - Anterior physeal injuries may be reduced, but if reduction cannot be obtained, they can be left alone without problem. Posterior physeal injuries should likewise undergo an attempt at reduction. If a posterior dislocation cannot be reduced closed and the patient is having no significant symptoms, the displacement can be observed while remod-

---

**FIG 1**

A. Normal anatomy around the sternoclavicular joint. The articular disc ligament divides the sternoclavicular joint cavity into two separate spaces and inserts onto the superior and posterior aspects of the medial clavicle. B. The articular disc ligament acts as a checkrein for medial displacement of the proximal clavicle.

**FIG 2**

Normal anatomy around the sternoclavicular and acromioclavicular joints. The tendon of the subclavius muscle arises in the vicinity of the costoclavicular ligament from the first rib and has a long tendon structure.
Plain films, at present they have been replaced with CT scans. In the past, tomograms were useful in distinguishing a sternoclavicular dislocation from a fracture of the medial clavicle and defining questionable anterior and posterior injuries of the sternoclavicular joint. Although they provide more information than plain films, at present they have been replaced with CT scans. Without question, CT scanning is the best technique to study the sternoclavicular joint. It distinguishes dislocations of the joint from fractures of the medial clavicle and clearly defines minor subluxations (FIG 5). The patient should lie supine. The scan should include both sternoclavicular joints and the medial halves of both clavicles so that the injured side can be compared with the normal. If symptoms of mediastinal compression are present or displacement of the medial clavicle is severe, the use of intravenous contrast will aid in the imaging of the vascular structures in the mediastinum.

DIFFERENTIAL DIAGNOSIS

- Arthritic conditions: sternocostoclavicular hyperostosis, osteitis condensans, Friedrich disease, Tietze syndrome, and osteoarthritis
- Atraumatic (spontaneous) subluxation or dislocation: One or both of the sternoclavicular joints may spontaneously subluxate or dislocate during abduction or flexion during overhead motion. Typically seen in ligamentously lax females in their late teens or early 20s, it is not painful, it is almost always anterior, and it should almost always be managed nonoperatively.
- Congenital or developmental or acquired subluxation or dislocation: Birth trauma, congenital defects with loss of bone substance on either side of the joint, or neuromuscular or other developmental disorders can predispose the patient to subluxation or dislocation.
- Iatrogenic instability may be due to failure to reconstruct the ligaments of the sternoclavicular joint adequately or to an excessive medial clavicle resection. History is significant for a prior procedure on the sternoclavicular joint.

NONOPERATIVE MANAGEMENT

- A mild sprain is stable but painful. We treat mild sprains with a sling, cold packs, and resumption of activity as comfort dictates.

FIG 3 • Serendipity view. Positioning of the patient to take the serendipity view of the sternoclavicular joints. The x-ray tube is tilted 40 degrees from the vertical position and aimed directly at the manubrium. The nongrid cassette should be large enough to receive the projected images of the medial halves of both clavicles. In children the tube distance from the patient should be 45 inches; in thicker-chested adults the distance should be 60 inches.

FIG 4 • Interpretation of the cephalic tilt films of the sternoclavicular joints. A. In a normal person, both clavicles appear on the same imaginary line drawn horizontally across the film. (continued)
arm combined with pressure on the medial clavicle will generally reduce the dislocation.

- Posterior dislocation in a stoic patient may possibly be reducible under intravenous narcotics and muscle relaxation. However, general anesthesia is usually required for reduction of a posterior dislocation, because of pain and muscle spasm.
- Our preferred method is the abduction traction technique.

  - The patient is placed supine, with the dislocated side near the edge of the table. A 3- to 4-inch-thick sandbag is placed between the scapulae (FIG 6). Lateral traction is applied to the abducted arm, which is then gradually brought back into extension. The clavicle usually reduces with an audible snap or pop, and it is almost always stable. Too much extension can bind the anterior surface of the dislocated medial clavicle on the back of the manubrium.
  - Occasionally it is necessary to grasp the medial clavicle with one’s fingers to dislodge it from behind the sternum. If this fails, the skin is prepared, and a sterile towel clip is used to grasp the medial clavicle to apply lateral and anterior traction (see Fig 6C). If the joint is stable after reduction, the shoulders should be held back for 4 to 6 weeks with a figure 8 dressing to allow ligament healing.
  - Many investigators have reported that closed reduction usually cannot be accomplished after 48 hours. However, others have reported closed reductions as late as 4 and 5 days after the injury.4

- Physeal fractures are reduced in the same manner as dislocations, with immobilization in a figure 8 strap for 4 weeks to protect stable reductions. Fractures that cannot be reduced and are being managed nonoperatively are treated with a figure 8 strap or a sling for comfort and mobilized as symptoms permit.

**SURGICAL MANAGEMENT**

- A posterior displacement of the medial clavicle that is irreducible or redislocates after closed reduction is a well-accepted surgical indication.
- More controversial is anterior displacement that fails to maintain a stable reduction.

  - The patient is supine on the table, with a 3- to 4-inch-thick pad between the shoulders. Direct gentle pressure over the anteriorly displaced clavicle or traction on the outstretched arm combined with pressure on the medial clavicle will generally reduce the dislocation.
  - Posterior dislocation in a stoic patient may possibly be reducible under intravenous narcotics and muscle relaxation. However, general anesthesia is usually required for reduction of a posterior dislocation, because of pain and muscle spasm.
  - Our preferred method is the abduction traction technique.

  - The patient is placed supine, with the dislocated side near the edge of the table. A 3- to 4-inch-thick sandbag is placed between the scapulae (FIG 6). Lateral traction is applied to the abducted arm, which is then gradually brought back into extension. The clavicle usually reduces with an audible snap or pop, and it is almost always stable. Too much extension can bind the anterior surface of the dislocated medial clavicle on the back of the manubrium.
  - Occasionally it is necessary to grasp the medial clavicle with one’s fingers to dislodge it from behind the sternum. If this fails, the skin is prepared, and a sterile towel clip is used to grasp the medial clavicle to apply lateral and anterior traction (see Fig 6C). If the joint is stable after reduction, the shoulders should be held back for 4 to 6 weeks with a figure 8 dressing to allow ligament healing.
  - Many investigators have reported that closed reduction usually cannot be accomplished after 48 hours. However, others have reported closed reductions as late as 4 and 5 days after the injury.4

- Physeal fractures are reduced in the same manner as dislocations, with immobilization in a figure 8 strap for 4 weeks to protect stable reductions. Fractures that cannot be reduced and are being managed nonoperatively are treated with a figure 8 strap or a sling for comfort and mobilized as symptoms permit.

**SURGICAL MANAGEMENT**

- A posterior displacement of the medial clavicle that is irreducible or redislocates after closed reduction is a well-accepted surgical indication.
- More controversial is anterior displacement that fails to maintain a stable reduction.

  - The patient is supine on the table, with a 3- to 4-inch-thick pad between the shoulders. Direct gentle pressure over the anteriorly displaced clavicle or traction on the outstretched arm combined with pressure on the medial clavicle will generally reduce the dislocation.
- Posterior dislocation in a stoic patient may possibly be reducible under intravenous narcotics and muscle relaxation. However, general anesthesia is usually required for reduction of a posterior dislocation, because of pain and muscle spasm.
- Our preferred method is the abduction traction technique.

  - The patient is placed supine, with the dislocated side near the edge of the table. A 3- to 4-inch-thick sandbag is placed between the scapulae (FIG 6). Lateral traction is applied to the abducted arm, which is then gradually brought back into extension. The clavicle usually reduces with an audible snap or pop, and it is almost always stable. Too much extension can bind the anterior surface of the dislocated medial clavicle on the back of the manubrium.
  - Occasionally it is necessary to grasp the medial clavicle with one’s fingers to dislodge it from behind the sternum. If this fails, the skin is prepared, and a sterile towel clip is used to grasp the medial clavicle to apply lateral and anterior traction (see Fig 6C). If the joint is stable after reduction, the shoulders should be held back for 4 to 6 weeks with a figure 8 dressing to allow ligament healing.
  - Many investigators have reported that closed reduction usually cannot be accomplished after 48 hours. However, others have reported closed reductions as late as 4 and 5 days after the injury.4

- Physeal fractures are reduced in the same manner as dislocations, with immobilization in a figure 8 strap for 4 weeks to protect stable reductions. Fractures that cannot be reduced and are being managed nonoperatively are treated with a figure 8 strap or a sling for comfort and mobilized as symptoms permit.

**SURGICAL MANAGEMENT**

- A posterior displacement of the medial clavicle that is irreducible or redislocates after closed reduction is a well-accepted surgical indication.
- More controversial is anterior displacement that fails to maintain a stable reduction.

  - The patient is supine on the table, with a 3- to 4-inch-thick pad between the shoulders. Direct gentle pressure over the anteriorly displaced clavicle or traction on the outstretched arm combined with pressure on the medial clavicle will generally reduce the dislocation.
Chapter 12  ACUTE REPAIR AND RECONSTRUCTION OF STERNOCLAVICULAR DISLOCATION 3163

![Diagram of closed reduction technique](image)

**FIG 6** • Technique for closed reduction of the sternoclavicular joint. A. The patient is positioned supine with a sandbag placed between the two shoulders. Traction is then applied to the arm against countertraction in an abducted and slightly extended position. In anterior dislocations, direct pressure over the medial end of the clavicle may reduce the joint. B. In posterior dislocations, in addition to the traction it may be necessary to manipulate the medial end of the clavicle with the fingers to dislodge the clavicle from behind the manubrium. C. In stubborn posterior dislocations, it may be necessary to prepare the medial end of the clavicle sterilely and use a towel clip to grasp around the medial clavicle to lift it back into position.

- We now consider operative treatment when the entire medial clavicle is torn out of the deltotrapezial sleeve.

**Preoperative Planning**

- Careful review of the history and examination for symptoms of mediastinal compression is crucial.
- Review of the CT scan for the direction and degree of displacement and determination of a very medial fracture versus pure dislocation follows.
- If history or radiographic evidence of mediastinal compromise or potential compromise is present, a cardiothoracic surgeon should be either present or readily available.
- Very medial fractures can occasionally be repaired with independent small-fragment lag screws or orthogonal minifragment plates. For pure dislocations, heavy nonabsorbable suture will sometimes suffice. Suture anchors are useful for augmenting ligament repairs. Allograft tendons may be used if the capsule is irreparable and must be reconstructed.
- Closed reduction under anesthesia is then attempted and the stability of the joint is evaluated after reduction.

**Positioning**

- To begin, the patient is positioned supine on the table, and three or four towels or a sandbag placed between the scapulae.
- The upper extremity should be draped free so that lateral traction can be applied during the open reduction.

- A folded sheet may be left in place around the patient’s thorax so that it can be used for countertraction.
- If there is concern regarding the mediastinum, the entire sternum should be draped into the field.

**Approach**

- An anterior incision that parallels the superior border of the medial 3 to 4 inches of the clavicle and then extends downward over the sternum just medial to the involved sternoclavicular joint is used (FIG 7A).
- As an alternative, a necklace-type incision may be created in Langer’s lines, beginning at the midline and sweeping lateral and up along the clavicle.
- Careful subperiosteal dissection around the medial clavicle and onto the surface of the manubrium allows exposure of the articular surfaces.
- If the medial clavicle is resting posteriorly, it is safer to identify the shaft more laterally and then trace it back medially along the subperiosteal plane (FIG 7B).
- Traction and blunt retractors can then be used to lever the medial clavicle back up into its anatomic location (FIG 7C). These retractors may be used behind the medial clavicle and manubrium to protect the posterior structures.
- If one has chosen to operate on an anterior medial clavicle because of extreme displacement, it may generally be simply pushed back into place.
FIG 7 • A. Proposed skin incision for open reduction of a posterior dislocation. B. Subperiosteal exposure of the medial clavicle shows a posteriorly displaced medial clavicular shaft (left) resting posterior to the medial clavicular physis (arrow, right). C. The medial shaft of the clavicle has been lifted anteriorly with a clamp and now rests adjacent to the medial physis (arrow, right).

PRIMARY REPAIR: MEDIAL FRACTURE

- In children and in young adults, the dislocation of the medial clavicle may occur through the medial physis or as a fracture, leaving a small amount of bone articulating with the manubrium.
- Because much of the capsule remains intact to this medial fragment, it can serve as an anchor for internal fixation of the medial clavicle shaft. Depending on the amount of bone, the type of fixation will vary.
- The smallest fragments will permit only osseous suture fixation, but the medial clavicle is cancellous bone and heals very quickly (TECH FIG 1A).
- As the fragment gets larger, independent lag screw fixation may be possible (TECH FIG 1B,C).
- For very medial shaft fractures, it may even be possible to use two orthogonal minifragment plates.

TECH FIG 1 • A. Heavy nonabsorbable suture has been placed through drill holes in the medial clavicle and through the physis to secure the fracture shown in Figure 7B,C. B, C. A symptomatic medial clavicle nonunion had a medial fragment large enough to allow fixation with three cortical lag screws.
Chapter 12  ACUTE REPAIR AND RECONSTRUCTION OF STERNOCLAVICULAR DISLOCATION

TECH FIG 2
Suture anchors may be used to create a sling to hold the medial clavicle reduced while the capsular ligaments heal.

TECHNIQUES

PRIMARY REPAIR: CAPSULAR LIGAMENTS AND SUTURE AUGMENTATION

- After reduction, the ligaments may be repaired primarily with heavy nonabsorbable suture. This usually allows repair of the anterior and superior capsule, but, for obvious reasons, does not allow repair of the important posterior capsule.
- The reduction is often reinforced with either simple osseous sutures through drill holes in the medial clavicle and manubrium or with suture anchors (TECH FIG 2). The costoclavicular ligament may also occasionally be repaired primarily.
- This technique has generally been employed in children but may also be used in adults.

IMMEDIATE RECONSTRUCTION: CAPSULAR LIGAMENTS

- At times the joint may be reducible but the ligaments are damaged to the point where primary repair is not feasible. In this circumstance, the ligaments may be immediately reconstructed using tendon graft.
- This may be done by passing a tendon from the front of the sternum, through the articular surfaces and intra-articular disc, and out the front of the medial clavicle and tying the tendon to itself anteriorly. Autograft or allograft tendon may be used.
- The capsule may also be reconstructed in the manner described by Spencer and Kuhn (TECH FIG 3).
  - Drill holes 4 mm in diameter are created from anterior to posterior through the medial clavicle and the adjacent manubrium.
  - A free semitendinosus tendon graft is woven through the drill holes so the tendon strands are parallel to each other posterior to the joint and cross each other anterior to it.
  - The tendon is tied in a square knot and secured with no. 2 Ethibond suture.
  - This technique has the advantage of reconstructing both the anterior and the posterior ligament in a very strong and secure manner.

TECH FIG 3 • A. Semitendinosus may be used to reconstruct the capsular ligaments. B,C. The allograft tendon is pulled through the medial clavicle (left) and manubrium (right) and tied. (continued)
If there is concern about the stability of a reconstruction or repair, if the dislocation is subacute and posterior, or if there is a question of impingement on the mediastinal structures, one may elect to resect the medial clavicle entirely. In this situation, it is important to repair or reconstruct the costoclavicular ligament (akin to a modified Weaver-Dunn procedure).

The medullary canal can also be used to create an attachment point for an additional medial tether. We prefer to use the patient’s own tissue, such as the sternoclavicular ligament, whenever possible (TECH FIG 4).

The medial clavicle is resected and the canal curetted and prepared with drill holes on the superior surface.

Grasping suture is woven through the remaining ligament, pulled through the superior drill holes, and tied over bone.

Heavy nonabsorbable sutures are then passed through the remaining costoclavicular ligament and around the clavicle, and the periosteal tube is closed.

If adequate local tissue is not present, an allograft such as Achilles tendon may also be used.2


TECH FIG 4 • The residual capsule may be used to reconstruct a medial clavicular restraint, akin to a medial Weaver-Dunn procedure, as described by Rockwood and Wirth.23
**REDUCTION AND BALSER PLATE FIXATION**

- The use of K-wires around the sternoclavicular joint has been routinely condemned, and they should not be used.
  - There are reports, however, of temporary plate fixation from the medial clavicle to the sternum to maintain a reduced joint while the soft tissues heal.
- The Balser plate is a hook plate used in Europe for treatment of acromioclavicular joint separations and distal clavicle fractures. It has been used for sternoclavicular dislocations by placing the hook into the sternum and using screws to fix the plate onto the medial clavicle (TECH FIG 5).
  - Franck et al.\(^\text{12}\) published good results for 10 patients treated with Balser plates. They thought that the stability of this construct allowed a more rapid rehabilitation. The implant is quite bulky and removal is generally required.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Conventional studies are unreliable. A high index of suspicion, a thorough examination, and a prompt CT scan will ensure correct diagnosis.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individualize treatment when necessary</td>
<td>Although anterior dislocations are generally treated nonoperatively, a severely anteriorly displaced medial clavicle may be reduced and fixed acutely, with a low risk of complications, in a reliable patient. Posterior dislocations generally mandate surgery because delayed impingement on mediastinal contents may occur. However, there may be situations where displacement is mild and chronic and the risks of surgery may outweigh the benefits.</td>
</tr>
<tr>
<td>Prepare for complications</td>
<td>Although complications are uncommon, they are spectacular, and not in a good way. The surgeon needs to be ready for both pneumothorax and the unlikely possibility of a vascular injury. A cardiothoracic surgeon should be immediately available.</td>
</tr>
<tr>
<td>Use the medial clavicle</td>
<td>Even a medial epiphysis or a tiny piece of medial clavicle in its anatomic location provides an excellent anchor for heavy suture or lag screws for primary fracture repair.</td>
</tr>
<tr>
<td>Be flexible intraoperatively</td>
<td>Preserving the native joint is an admirable goal, but poor ligament and bone quality sometimes precludes primary repair, especially in the subacute dislocation. If the stability of the joint cannot be ensured, medial clavicle resection and costoclavicular reconstruction should be strongly considered.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- For sternoclavicular strains and anteriorly dislocated medial clavicles accepted in this position, a sling or figure 8 strap is prescribed and the patient is allowed to mobilize the extremity as function permits.
- Medial clavicle fractures that are stable after reduction are immobilized in a figure 8 strap for 4 to 6 weeks and then mobilized as comfort allows.
- Acute dislocations that have been reduced and are stable or have been surgically repaired receive a sling or figure 8 strap for 6 weeks to protect the reduction and allow ligament healing.
- Patients in the figure 8 strap are allowed use of the elbow and hand with the arm at the side for light activities of daily living, but the strap is conscientiously maintained.
- At 4 to 6 weeks they move to a sling and perform their own mobilization. Because the glenohumeral joint is unaffected, motion usually returns quickly to near full range.
  - When full range of motion has been obtained, gentle progressive strengthening and resumption of normal activities commence.
  - In general, patients treated with joint preservation can return to all activities, including heavy labor, but we have seen traumatic failure of costoclavicular reconstructions and do ask patients who have undergone medial clavicle resection and ligament reconstruction to avoid heavy overhead labor for their lifetimes.

**OUTCOMES**

- A recent Medline search for “sternoclavicular” and “dislocation” yielded 320 citations, most dealing with sternoclavicular instability and its sequelae. Most were case reports, a series of three or four patients, or a discussion of the complications of the injury or its treatment. There are very few large series, which makes discussing outcomes difficult. However, several themes do emerge.
The need for proper patient selection becomes evident when one considers that some forms of sternoclavicular instability generally do well when treated without surgery. Sadr and Swan
tand Rockwood and Odor have both documented the good long-term results obtained with nonoperative treatment of atraumatic sternoclavicular instability. De Jong has documented good long-term results in 13 patients with anterior dislocations treated nonoperatively. Several larger series have reported on about a dozen patients treated with open reduction, ligament repair or reconstruction, and fixation with pins or sternoclavicular wiring. Good results were obtained when the medial clavicle was successfully stabilized. Eskola, however, noted a high failure rate if the remaining medial clavicle was not successfully stabilized to the first rib. In a separate study, Rockwood et al reported on seven patients who had previously undergone medial clavicle resection without ligament reconstruction. Six of the seven had worse symptoms than before their index procedure.

COMPLICATIONS

Complications of injury
- Anterior dislocation: cosmetic “bump” (which may occasionally be pronounced) and late degenerative changes
- Posterior dislocation: Great vessel injuries, including laceration, compression, and occlusion, pneumothorax, rupture of the esophagus with abscess and osteomyelitis of the clavicle, fatal tracheoesophageal fistula, brachial plexus compression, stridor and dysphagia, hoarseness of the voice, onset of snoring, and voice changes from normal to falsetto with movement of the arm have all been reported. These all may occur acutely or in a delayed fashion. Worman and Leagus reported that 16 of 60 patients with posterior dislocations had suffered complications of the trachea, esophagus, or great vessels.

Errors of patient selection
- Operating in unindicated circumstances introduces another set of complications. Rockwood and Odor reviewed 37 patients with spontaneous atraumatic subluxation.
- Twenty-nine managed without surgery had no limitations of activity or lifestyle at over 8 years average follow-up. Eight treated (elsewhere) with surgical reconstruction had increased pain, limitation of activity, alteration of lifestyle, persistent instability, and significant scars. Before surgery, most of these patients had minimal discomfort and excellent motion and complained only of a “bump” that slipped in and out of place with certain motions.

Intraoperative complications
- Little has been written about these, but a veritable jungle of vitally important structures lurks immediately behind the sternoclavicular joint. We always perform these operations with an available, in-house cardiothoracic surgeon on notice and request his or her presence in the operating suite for all but the most routine cases.

Postoperative complications
- Hardware migration: Because of the motion at the sternoclavicular joint, tremendous leverage is applied to pins that cross it; fatigue breakage of the pins is common. Numerous authors have reported deaths and many near-deaths from K-wires and Steinmann pins migrating into the heart, pulmonary artery, innominate artery, aorta, and elsewhere in the mediastinum. Despite numerous admonitions in the literature regarding the use of sternoclavicular pins, there have been continued reports of intrathoracic K-wire migration, most recently in 2005.
- For this reason, we do not recommend the use of any transfixing pins—large or small, smooth or threaded, bent or straight—across the sternoclavicular joint.
- Iatrogenic instability: Failure to preserve the costoclavicular ligament when it is intact and failure to reconstruct it when it is deficient both severely compromise the surgical result. As noted above, both Rockwood and Eskola noted vastly inferior results when the residual medial clavicle was not stabilized to the first rib, and an inability to obtain equivalent results when the costoclavicular ligament was reconstructed in a delayed fashion.

Iatrogenic instability: An excessive resection that removes bone to a point lateral to the costoclavicular ligament is an extremely difficult problem that is best avoided because there is no reconstructive option. In these difficult cases, we have occasionally performed a subtotal claviculectomy to a point just medial to the coracoclavicular ligaments. This leaves the extremity without a “strut” connecting it to the thorax but can produce substantial relief of pain and improvement in motion and activity.

REFERENCES
DEFINITION

- Many pathologic disorders affect the medial clavicle, the most common of which is osteoarthritis.
- Other conditions include rheumatoid arthritis, seronegative spondyloarthropathies, crystal deposition disease, sternoclavicular hyperostosis, condensing osteitis, and avascular necrosis.\(^6\)
- Infection, while rare, must be considered. When suspected, the sternoclavicular joint should be aspirated for culture, Gram stain, and cell counts and then treated with irrigation and débridement.
- Instability of the sternoclavicular joint is rare but potentially fatal.
- Traumatic instability is defined by the direction of displacement of the clavicular head and is superior, anterior, or posterior.
- Posterior instability has been associated with a variety of potentially fatal comorbidities.
- Atraumatic instability is usually anterior and is often seen in people with generalized ligamentous laxity.
- Symptomatic traumatic instability is best treated with closed reduction and possible reconstruction of the joint, not resection of the clavicle head.

ANATOMY

- The sternoclavicular joint is a saddle-shaped joint that is the most unconstrained joint in the human body.
- Important ligamentous restraints to motion include the anterior capsule (restrains anterior and posterior translation), the posterior capsule (restrains posterior translation),\(^10\) and the costoclavicular ligament (which is the pivot point for motion in the axial plane).\(^2\)
- The interclavicular ligament seems to provide little function (FIG 1).

PATHOGENESIS

- Osteoarthritis is the most common disorder affecting the medial clavicle that may require surgical excision.
- Osteoarthritis is most commonly seen in male laborers, in women in the perimenopausal years, and after radical neck dissection.
- Rheumatologic disorders can affect the sternoclavicular joint as part of the systemic disease. Involvement of the sternoclavicular joint is usually late.
- Other atraumatic conditions are less common and the pathogenesis is largely unknown.
- Traumatic instability typically develops from a blow to the shoulder girdle.
- If the force impacts the anterior shoulder, it will push the shoulder girdle posteriorly. The clavicle pivots over the first rib, forcing the head of the clavicle anteriorly.
- If the force impacts the posterior shoulder, it will push the shoulder girdle anteriorly. The clavicle pivots over the first rib, dislocating the head of the clavicle posteriorly.
- Direct blows to the sternoclavicular joint can also dislocate the clavicle head posteriorly.
- Atraumatic instability develops insidiously without a history of trauma.

NATURAL HISTORY

- Many people have asymptomatic sternoclavicular joint arthritis.
- Patients with symptoms may find relief with activity modification and time. This is particularly true with the pain and swelling seen in perimenopausal women.
- Infection may present with a relatively benign clinical picture but will progress and may become serious.
- It is rare for the sternoclavicular joint to be the primary joint involved in rheumatologic conditions or crystal deposition disease.
Traumatic instability may result from high-energy injuries (eg, motor vehicle collision) or may be related to contact in athletics.

Posterior instability may be life-threatening as the clavicular head may compress vascular structures, the trachea, or the esophagus.

Atraumatic instability may have an insidious onset and is often associated with other signs of generalized ligamentous laxity (eg, patellar subluxation, glenohumeral subluxation).

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- **Atraumatic disorders**
  - Pain at the sternoclavicular joint is localized to the joint and may be referred up the sternocleidomastoid and trapezius.\(^5\)
  - Infection typically is unilateral and has significant pain and erythema (Table 1).
  - Osteoarthritis, rheumatoid arthritis, seronegative spondyloarthropathies, and sternoclavicular hyperostosis are typically bilateral, with mild pain, and rare erythema.
  - Crystal deposition diseases, condensing osteitis, and Friedreich’s disease are typically unilateral, and mildly painful.

- **Traumatic disorders**
  - With acute traumatic injuries, patients will have significant pain and will be unwilling to raise the arm. They may describe difficulty with swallowing or breathing in posterior dislocations.
  - The sternoclavicular joint is often swollen and tender.
  - The affected arm may demonstrate circulatory changes with arm swelling.
  - Physical examination may not be helpful in determining if the instability is anterior or posterior.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Special radiographic projections include the Rockwood (serendipity), Hobbs, Heinig, and Kattan views but are somewhat difficult to interpret (Table 2).\(^4\)
- Computed tomography is particularly useful in trauma as it demonstrates displacement of the joint and bony anatomy.\(^4\)
- It is very useful to determine whether a dislocation is anterior or posterior.
- Arteriography should be considered in posterior dislocations if vascular injury is suspected.
- MRI is helpful in atraumatic disorders to evaluate the soft tissues and can delineate marrow abnormalities, joint effusions, and disc and cartilage injury.\(^4\)
- Laboratory findings in atraumatic disorders of the sternoclavicular joint are covered in Table 3.

**Table 1** Clinical Features of Atraumatic Disorders of the Sternoclavicular Joint

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Age (yr)</th>
<th>Gender</th>
<th>Side</th>
<th>Pain</th>
<th>Erythema</th>
<th>Associated Conditions and Risk Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteoarthritis</td>
<td>&gt;40</td>
<td>M=F</td>
<td>B</td>
<td>+</td>
<td>Rare</td>
<td>Manual labor, radical neck dissection, postmenopausal women</td>
</tr>
<tr>
<td>Rheumatoid arthritis</td>
<td>Any</td>
<td>F&gt;M</td>
<td>B</td>
<td>+</td>
<td>+</td>
<td>Symmetric polyarthritis</td>
</tr>
<tr>
<td>Seronegative spondyloarthropathies</td>
<td>&lt;40</td>
<td>M&gt;F</td>
<td>B</td>
<td>Occasional</td>
<td>–</td>
<td>Urethritis, uveitis, nail pitting</td>
</tr>
<tr>
<td>Septic arthritis</td>
<td>Any</td>
<td>M=F</td>
<td>U</td>
<td>++++</td>
<td>++++</td>
<td>HIV, IVDA, DM</td>
</tr>
<tr>
<td>Crystal deposition disease</td>
<td>&gt;40</td>
<td>M=F</td>
<td>U</td>
<td>++++</td>
<td>++</td>
<td>Other joint involvement</td>
</tr>
<tr>
<td>Sternoclavicular hyperostosis</td>
<td>30–60</td>
<td>M&gt;F</td>
<td>B</td>
<td>+</td>
<td>–</td>
<td>Synovitis, acne, pustulosis, hyperostosis, osteitis</td>
</tr>
<tr>
<td>Condensing osteitis</td>
<td>25–40</td>
<td>F&gt;M</td>
<td>U</td>
<td>+</td>
<td>–</td>
<td>None</td>
</tr>
<tr>
<td>Friedreich’s disease</td>
<td>Any</td>
<td>F&gt;M</td>
<td>U</td>
<td>+</td>
<td>–</td>
<td>None</td>
</tr>
<tr>
<td>Atraumatic subluxation</td>
<td>10–30</td>
<td>F&gt;M</td>
<td>U</td>
<td>Infrequent</td>
<td>–</td>
<td>Generalized ligamentous laxity</td>
</tr>
</tbody>
</table>

DM, diabetes mellitus; F, female; IVDA, intravenous drug abuse; M, male.

**Table 2** Radiographic Features of Atraumatic Disorders of the Sternoclavicular Joint

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Radiographic Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteoarthritis</td>
<td>Sclerosis, osteophytes</td>
</tr>
<tr>
<td>Rheumatoid arthritis</td>
<td>Minimal change</td>
</tr>
<tr>
<td>Seronegative spondyloarthropathies</td>
<td>Marginal erosions, cysts</td>
</tr>
<tr>
<td>Septic arthritis</td>
<td>Sclerotic, lytic, or mixed lesions</td>
</tr>
<tr>
<td>Crystal deposition disease</td>
<td>Calcification of soft tissue</td>
</tr>
<tr>
<td>Sternoclavicular hyperostosis</td>
<td>Hyperostosis, ossification of intercostal ligaments</td>
</tr>
<tr>
<td>Condensing osteitis</td>
<td>Medial clavicle enlargement, preserved joint space, marrow obliteration</td>
</tr>
<tr>
<td>Friedreich’s disease</td>
<td>Normal</td>
</tr>
<tr>
<td>Atraumatic subluxation</td>
<td>Normal</td>
</tr>
</tbody>
</table>
**Positioning**
- The patient is positioned supine on the operating room table with a small rolled towel behind the middle of the back (FIG 2A).
- The entire chest is exposed for treatment of complications should they occur.
- Important structures, including the clavicle, manubrium, sternocleidomastoid, and costoclavicular ligament, are marked (FIG 2B).
- The ipsilateral hand is prepared and draped as well if the surgeon desires to use palmaris as an interposition graft.
- For reconstructions of the sternoclavicular joint, an ipsilateral hamstring may be used; as such, the knee should be prepared and draped.

**Approach**
- The approach is anterior. Care is taken to protect important structures during dissection, particularly the origin of the sternocleidomastoid muscle and the costoclavicular ligament.

**INCISION AND DISSECTION**
- The incision is made in the lines of Langer, which follow a necklace pattern over the head of the clavicle and manubrium (TECH FIG 1A).
- After undermining in the subcutaneous plane, the platysma is incised in line with the skin incision, exposing the joint capsule and sternocleidomastoid origin (TECH FIG 1B).
- The capsule of the joint is marked. Care must be taken to avoid incising the entire sternal head of the sternocleidomastoid tendon (TECH FIG 1C).

---

**Laboratory Features of Atraumatic Disorders of the Sternoclavicular Joint**

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Laboratory Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteoarthritis</td>
<td>Normal</td>
</tr>
<tr>
<td>Rheumatoid arthritis</td>
<td>May have + RF, + ANA, +HLA-B27</td>
</tr>
<tr>
<td>Seronegative spondyloarthropathies</td>
<td>WBC, ESR, CRP elevated</td>
</tr>
<tr>
<td>Septic arthritis</td>
<td>+BRFC, -BRFC</td>
</tr>
<tr>
<td>Crystal deposition disease</td>
<td>ESR elevated, other markers of rheumatologic disease normal</td>
</tr>
<tr>
<td>Sternoclavicular Hyperostosis</td>
<td>Normal</td>
</tr>
<tr>
<td>Condensing osteitis</td>
<td>Normal</td>
</tr>
<tr>
<td>Friedrich’s disease</td>
<td>Normal</td>
</tr>
<tr>
<td>Atraumatic subluxation</td>
<td>Normal</td>
</tr>
</tbody>
</table>

ANA, antinuclear antibodies; BRFC, birefringence crystals; CRP, C-reactive protein; ESR, sedimentation rate; RF, rheumatoid factor; WBC, white blood cell count.
**ATRAUMATIC DISORDERS: REMOVING THE BONE**

- Electrocautery can be used to carefully elevate the capsule from the clavicular head. It is important to avoid straying too far laterally to avoid detaching the capsule and injuring the costoclavicular ligament (TECH FIG 2A).
- The intra-articular disc is removed and the capsule is carefully dissected around the cartilaginous margin of the head of the clavicle (TECH FIG 2B).
- A self-retaining retractor is placed on the capsule, a blunt retractor is placed next to the articular surface, and a small oscillating saw is used to remove between 0.5 and 1.0 cm of the medial clavicle (TECH FIG 2C).
- An osteotome may be used to lever the medial clavicle head out of the joint (TECH FIG 2D).
- Electrocautery is used to carefully dissect the posterior capsule from the back of the clavicular head (TECH FIG 2E).
- The resected head should be between 0.5 and 1.0 cm in size to preserve the costoclavicular ligaments (TECH FIG 2F).^3^
HARVESTING THE TENDON

- The palmaris tendon is isolated with a small incision in the wrist crease (TECH FIG 3A).
- After sutures are passed in the end of the palmaris, the tendon is removed percutaneously with a tendon stripper (TECH FIG 3B).
- The harvested tendon is rolled over a small spool and sutured to itself to create a rolled tendon (TECH FIG 3C,D).
- When resecting the clavicular head for atraumatic disorders, the rolled palmaris tendon is inserted into the defect to create a soft tissue interposition between the cut surface of the clavicle and the manubrial joint surface (TECH FIG 3E).
- Alternatively, the palmaris can be used to augment a reconstruction of an unstable sternoclavicular joint by passing it around the clavicle and first rib (see below).

A B C

D E

TECH FIG 3 • A. Palmaris tendon is identified. B. Percutaneous harvesting of palmaris longus tendon. C. Rolling the palmaris tendon graft. D. The rolled palmaris is sutured to itself. E. Insertion of the palmaris as interposition graft.

RECONSTRUCTION OF THE STERNOCLAVICULAR JOINT IN INSTABILITY

- A variety of techniques have been described. A figure 8 reconstruction has the best biomechanical properties.11
- With the assistance of a thoracic surgeon, the plane behind the manubrium is developed by dissecting above the sternal notch (TECH FIG 4A).
- With a ribbon retractor behind the manubrium, two drill holes are made in the manubrium and sutures are passed (TECH FIG 4B).
- Two drill holes are placed in the medial clavicle from anterior to posterior (TECH FIG 4C).
- The semitendinosus autograft is passed in figure 8 fashion and secured to itself (TECH FIG 4D–F).
- Additionally, the palmaris tendon may be passed around the first rib. This dissection behind the first rib should be performed by the thoracic surgeon to avoid injury to the internal mammary artery (TECH FIG 4G).

A B

TECH FIG 4 • A. Development of the surgical plane behind manubrium. B. Drill holes are in manubrium with protection of mediastinal structures with an Army-Navy retractor. (continued)
WOUND CLOSURE

- The capsule is closed with figure 8 interrupted permanent number 2 suture, and the sternal head of the sternocleidomastoid falls into place (TECH FIG 5A).
- The wound is closed in layers with 0 Vicryl in the platysma (TECH FIG 5B), 2-0 Vicryl in the subcutaneous layer, and 3-0 Monocryl in the skin (TECH FIG 5C).

TECH FIG 5 • A. Repair of the joint capsule. B. Repair of the platysma. C. Surgical wound is closed.
CT and MRI imaging will help differentiate arthritis from other less common conditions.

The surgeon must always be diligent for infection, which may have a relatively benign appearance.

If it is unclear whether the sternoclavicular joint is the source of pain, a diagnostic injection with lidocaine can be helpful.

CT is extremely helpful to determine if a dislocation is anterior or posterior.

Preserving the clavicular head is important for reconstructions of unstable sternoclavicular joints.

If the costoclavicular ligament is sacrificed, the intra-articular disc and disc ligament can be passed completely off the clavicle, suture anchors in the clavicle can help restore stability.

Ten of 14 patients reported good to excellent outcomes; six were considered (three of five excellent).

Patients are typically admitted overnight for observation.

Patients wear a sling with pillow support to support the arm when upright for 6 weeks.

Patients are instructed to avoid moving the arm for 6 weeks to allow for capsular healing and preventing instability.

After 6 weeks, patients gradually increase range of motion.

After 12 weeks, patients can begin strengthening activities.

After 16 weeks, patients have unrestricted activity.

POSTOPERATIVE CARE

Patients were graded as good to excellent, and 93% had significant pain relief and would have the procedure again.

Ribin and coworkers1 reported on 15 patients with a variety of pathologies. Sixty percent were graded as good to excellent, and 93% had significant pain relief and would have the procedure again.

Pingsmann and colleagues8 found seven of eight women with sternoclavicular joint arthritis had good to excellent results with medial clavicle excision after 31 months of follow-up.

Meis and coworkers7 modified the technique by interposing the sternal head of the sternocleidomastoid into the intramedullary canal.

A variety of case reports exist for other sternoclavicular joint reconstructions. To date, no reports are in the peer-reviewed literature for the figure 8 reconstruction.

PEARLS AND PITFALLS

CT and MRI imaging will help differentiate arthritis from other less common conditions.

The surgeon must always be diligent for infection, which may have a relatively benign appearance.

If it is unclear whether the sternoclavicular joint is the source of pain, a diagnostic injection with lidocaine can be helpful.

CT is extremely helpful to determine if a dislocation is anterior or posterior.

General surgery

It is wise to have a thoracic surgeon available should complications develop in the mediastinum.

POSTOPERATIVE CARE

Patients are typically admitted overnight for observation.

Patients wear a sling with pillow support to support the arm when upright for 6 weeks.

Patients are instructed to avoid moving the arm for 6 weeks to allow for capsular healing and preventing instability.

After 6 weeks, patients gradually increase range of motion.

After 12 weeks, patients can begin strengthening activities.

After 16 weeks, patients have unrestricted activity.

OUTCOMES

There is little reported on the outcomes after this procedure. All reports are level 4 case series.

Rockwood and colleagues9 reported that outcomes were improved if the costoclavicular ligament remained intact (eight of eight excellent with complete satisfaction). If the costoclavicular ligament was disrupted, however, the results were less predictable (three of five excellent).

Arcus and associates1 reported on 15 patients with a variety of pathologies. Sixty percent were graded as good to excellent, and 93% had significant pain relief and would have the procedure again.

Pingsmann and colleagues8 found seven of eight women with sternoclavicular joint arthritis had good to excellent results with medial clavicle excision after 31 months of follow-up.


Heterotopic ossification has been reported in about half of the patients but seems to be asymptomatic.1

Although not reported to date, complications involving the great vessels, trachea, and other mediastinal contents are possible. A thoracic surgeon should be available for assistance if required.

REFERENCES


DEFINITION
- Displaced, comminuted fractures of the clavicle are at risk for nonunion and malunion and can be considered for open reduction and internal fixation with a plate and screws.

ANATOMY
- The clavicle and scapula are tightly linked through the strong coracoclavicular and acromioclavicular ligaments and link the axial skeleton to the upper extremity.
- Clavicles are present only in brachiating animals and apparently serve to help hold the upper limb away from the trunk to enhance more global positioning and use of the limb.
- The clavicle is named for its S-shaped curvature, with an apex anteromedially and an apex posterolaterally, similar to the musical symbol clavicula. The larger medial curvature widens the space for passage of neurovascular structures from the neck into the upper extremity through the costoclavicular interval.
- The clavicle is made up of very dense trabecular bone lacking a well-defined medullary canal. In cross section, the clavicle changes gradually between a flat lateral aspect, a tubular midportion, and an expanded prismatic medial end.
- The clavicle is subcutaneous throughout its length and makes a prominent aesthetic contribution to the contour of the neck and upper part of the chest.
- The supraclavicular nerves run obliquely across the clavicle just superior to the platysma muscle and should be identified and protected during operative exposure to offset the development of hyperesthesia or dysesthesia over the chest wall.

PATHOGENESIS
- Clavicle fractures usually result from a direct blow to the point of the shoulder.
- This is usually a moderate- to high-energy injury in younger adults but can result from a low-energy fall from a standing height in an older individual.

NATURAL HISTORY
- The overall nonunion rate for diaphyseal clavicle fractures is 4.5%. 7
- The risk of nonunion increases with age, female gender, displacement, and comminution. 7
- The risk of nonunion for completely displaced (no apposition) and comminuted fractures is between 10% and 20% (FIG 1). 9
- Malunion of the clavicle can result in shoulder girdle deformity and weakness. 3,5,9
- Malunion and nonunion of the clavicle can result in brachial plexus compression.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The mechanism and date of injury should be elicited.
- A careful neurologic examination should be performed.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- An anteroposterior (AP) radiograph can be supplemented by a 20- to 60-degree cephalad-tilted view.
- The so-called apical oblique view (tilted 45 degrees anterior and 20 degrees cephalad) may facilitate the diagnosis of minimally displaced fractures (eg, birth fractures, fractures in children).
- The abduction lordotic view taken with the shoulder abducted above 135 degrees and the central ray angled 25 degrees cephalad is useful in evaluating the clavicle after internal fixation. Abduction of the shoulder results in rotation of the clavicle on its longitudinal axis, which causes the plate to rotate superiorty and thereby expose the shaft of the clavicle and the fracture site under the plate.
- Computed tomography with 3D reconstructions can help understand 3D deformity.

DIFFERENTIAL DIAGNOSIS
- Lateral or medial clavicle fracture
- Acromioclavicular or sternoclavicular dislocation

NONOPERATIVE MANAGEMENT
- Closed reduction of clavicular fractures is rarely attempted because the reduction is usually unstable and no reliable means of providing external support is available.
- A simple sling provides comfort and limits activity during healing. A figure 8 bandage leaves the arm free, but it cannot improve alignment.

FIG 1 • An AP radiograph shows greater than 100% displacement and comminution with a vertical fracture fragment. The clavicle is shortened. (Copyright David Ring, MD.)
There is no need to be concerned about shoulder stiffness, and patients should be encouraged to keep the arm at the side and limit activity for the first 4 to 6 weeks.

**SURGICAL MANAGEMENT**
- Intramedullary fixation is an option when comminution is limited, but otherwise plate-and-screw fixation is preferred.
- The plate can be placed on either the superior or the anterior aspect of the clavicle.

**Preoperative Planning**
- Planning of the surgery using tracings of radiographs helps limit intraoperative decision making and helps the surgeon anticipate problems and contingencies.

**Positioning**
- The patient is supine with a variable amount of flexion of the trunk according to surgeon preference (FIG 2).

**Approach**
- A longitudinal incision is made in line with the clavicle.

**SUPERIOR PLATE-AND-SCREW FIXATION**
- An incision is made parallel and just inferior to the long axis of the clavicle (TECH FIG 1A). Infiltration with dilute epinephrine can help limit bleeding.
- The crossing supraclavicular nerves are identified under loupe magnification and preserved (TECH FIG 1B).
- Muscle attachments and periosteum are preserved as much as possible.
- Realignment and provisional fixation may be facilitated by the use of a small distractor or temporary external fixator (TECH FIG 1C).
- A 3.5-mm limited-contact dynamic compression plate (LCDC plate, Synthes) or a precontoured plate is applied to the superior aspect of the clavicle (TECH FIG 1D). A minimum of three screws should be placed in each major fragment. If the fracture pattern is amenable, placement of an interfragmentary screw greatly enhances the stability of the construct.
- When the vascularity of the fragments has been preserved, no bone graft is needed (TECH FIG 1E). When extensive stripping or gaps have occurred in the cortex...

**TECH FIG 1**
- **A.** A straight incision in line with the clavicle and just inferior to it is infiltrated with dilute epinephrine. **B.** The supraclavicular nerves cross the clavicle at the level of the platysma, and an effort should be made to protect them. **C.** A small distractor or temporary external fixator can be used to facilitate realignment and provide provisional fixation. **D.** In this patient, a superior 3.5-mm LC-DCP is applied. An oscillating drill is used to limit the risk to nerves. **E.** Final plate placement. (continued)
opposite the plate, one might consider adding a small amount of autogenous iliac crest cancellous bone graft.

- Close the platysma (TECH FIG 1F).

- If the skin condition is suitable, wound closure is accomplished in atraumatic fashion with a subcuticular suture (TECH FIG 1G,H).

ANTERIOR PLATE-AND-SCREW FIXATION

- The technique is identical for an anterior plate placement with the exception that the origins of the pectoralis major and deltoid are partially extraperiosteally elevated off the anterior clavicle (TECH FIG 2).

- The anterior plate placement may help to decrease hardware prominence, and the drill and screws are directed posterior rather than directly inferior to the clavicle, which may increase the margin of safety.

TECH FIG 2 • An alternative is to place the plate on the anterior surface of the clavicle. This limits plate prominence but requires greater stripping and muscle elevation. (Copyright David Ring, MD.)

PEARLS AND PITFALLS

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Supraclavicular nerve neuroma</td>
<td>Attempts to identify and protect these nerves are worthwhile.</td>
</tr>
<tr>
<td>Brachial plexus stretch injury</td>
<td>Realignment should be done gradually and can be facilitated by temporary external fixation. Pulling fragments out of the wound should be limited.</td>
</tr>
<tr>
<td>Loosening of fixation</td>
<td>At least three good bicortical screws should be placed on each side of the fracture.</td>
</tr>
<tr>
<td>Axial pull-out of locked screws</td>
<td>Locking screws may be troublesome when used on the lateral fragment with the plate in a superior position.</td>
</tr>
<tr>
<td>Plate prominence</td>
<td>Anterior plate placement may diminish plate prominence.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Confident use of the hand at the side is encouraged immediately.
- Shoulder abduction and handling of more than 15 pounds is delayed until early healing is established.
- Shoulder stiffness is unusual and usually responds quickly to exercises. Shoulder exercises can therefore be delayed until healing is established.

OUTCOMES

- Plate loosening and nonunion occur in 3% to 5% of cases.6
- Healing leads to good function.

COMPLICATIONS

- Infection and wound complications occur but are uncommon.
- Neurovascular injury is very uncommon and pneumothorax has not been described.
REFERENCES

DEFINITION
- The clavicle is one of the most commonly fractured bones.
- The site on the clavicle most often fractured is the middle third. The midclavicular region is the thinnest and narrowest portion of the bone.
- It is the only area not supported by ligament or muscle attachments.
- It represents a transitional region of both cross-sectional anatomy and curvature.
- It is the transition point between the lateral part, with a flatter cross section, and the more tubular medial.
- Because of the clavicle’s S shape, an axial load creates a very high tensile force along the anterior midcortex. (Axial load makes a virtual right angle at midclavicle.)

ANATOMY
- The clavicle is the only long bone to ossify by a combination of intramembranous and endochondral ossification.
- Its configuration is S-shaped, a double curve; the medial curve is apex anterior and the lateral curve is apex posterior (FIG 1A).
- The larger medial curvature widens the space for the neurovascular structures, providing bony protection.
- The clavicle is made up of very dense trabecular bone, lacking a well-defined medullary canal.
- The cross-sectional anatomy gradually changes from flat laterally, to tubular in the midportion, to expanded prismatic medially.
- The clavicle is subcutaneous throughout, covered by the thin platysma muscle.
- The supraclavicular nerves that provide sensation to the overlying skin of the clavicle are found deep to the platysma muscle.
- Very strong capsular and extracapsular ligaments attach the medial end to the sternum and first rib and the lateral end to the acromion and coracoid.
- Proximal muscle attachments include the sternocleidomastoid, pectoralis major, and subclavius. Distal muscle attachments include the deltoid and trapezius (FIG 1B).
- The clavicle functions by providing a fixed-length strut through which the muscles attached to the shoulder girdle can generate and transmit large forces to the upper extremity.

PATHOGENESIS
- The mechanism of clavicle fractures in the vast majority is a direct injury to the shoulder. Stanley and associates studied 106 injured patients; 87% had fallen onto the shoulder, 7% were injured by a direct blow on the point of the shoulder, and only 6% reported falling onto an outstretched hand.
- Stanley suggests that in the patients who described hitting the ground with an outstretched hand, the shoulder became the next contact point with the ground, causing the fracture. Stanley
stated that a compressive force equivalent to body weight would exceed the critical buckling load to cause the clavicle fracture.

**NATURAL HISTORY**

- In the 1960s, both Neer and Rowe published large series of midclavicle fractures, showing very low nonunion rate (0.1% and 0.8%) with closed treatment and a higher nonunion rate (4.6% and 3.7%) with operative treatment.
- More recent studies have shown that nonunion is more common than previously recognized and that a significant percentage of patients with nonunion are symptomatic.
- Malunion with shortening greater than 15 to 20 mm has also been shown to be associated with significant shoulder dysfunction.
- McKee and colleagues identified 15 patients with malunion of the midclavicle after closed treatment. All patients had shortening of more than 15 mm, all were symptomatic and unsatisfied, and all underwent corrective osteotomy. Postoperatively all 15 patients improved in terms of function and satisfaction.
- Hill and associates reviewed 52 completely displaced mid-shaft clavicle fractures and found that shortening of more than 20 mm had a significant association with nonunion and unsatisfactory results.
- Eskola and coworkers reported on 89 malunions of the midclavicle, showing that shortening of more than 15 mm was associated with shoulder discomfort and dysfunction.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The diagnosis is usually straightforward and is based on obtaining the mechanism of injury from a good history.
- On visual inspection the examiner will frequently see notable swelling or ecchymosis at the fracture site and possibly deformity of the clavicle, with drooping of the shoulder downward and forward if the fracture is significantly displaced. The skin is inspected for tenting at the fracture site and characteristic bruising and abrasions that might suggest a direct blow or seatbelt shoulder strap injury (FIG 2A,B).
- Palpation over the fracture site will reveal tenderness, and gentle manipulation of the upper extremity or clavicle itself may reveal crepitus and motion at the fracture site.
- The amount of shortening is identified by clinically measuring the distance of a straight line (in centimeters) from both acromioclavicular joints to the sternal notch and noting the difference (FIG 2C).
- It is important to perform a complete musculoskeletal and neurovascular examination of the upper extremity and auscultation of the chest to identify the rare associated injuries; these are more closely related to high-energy injuries.
  - Rib and scapula fracture
  - Brachial plexus injury (usually traction to upper cervical root)
  - Vascular injury (subclavian artery or vein injury associated with scapulothoracic dissociation)
  - Pneumothorax and hemothorax

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Two orthogonal radiographic projections are necessary to determine the fracture pattern and displacement, ideally 45-degree cephalic tilt and 45-degree caudad tilt views.
- Usually a standard anteroposterior (AP) view and a 45-degree cephalic tilt view (FIG 3) view are adequate.
- In practice, a 20- to 60-degree cephalic tilt view will minimize interference of thoracic structures.
- The film should be large enough to include the acromioclavicular and sternoclavicular joints, the scapula, and the upper lung fields to evaluate for associated injuries.
- An AP view of bilateral clavicles on a wide cassette to include the acromioclavicular joints and sternum is fairly helpful in determining the amount of shortening; however, this is a multiplanar deformity and a CT scan would have greater accuracy, although it is rarely required.
DIFFERENTIAL DIAGNOSIS
- Sprain of acromioclavicular joint
- Sprain of sternoclavicular joint
- Rib fracture
- Muscle injury
- Contusion
- Hematoma
- Kehr sign: referred pain to the left shoulder from irritation of the diaphragm, signaled by the phrenic nerve. Irritation may be caused by diaphragmatic or peridiaphragmatic lesions, renal calculi, splenic injury, or ectopic pregnancy.

NONOPERATIVE MANAGEMENT
- If the clavicle fracture alignment is acceptable, generally a simple configuration with less than 15 mm of shortening, then any of a number of methods of supporting the upper extremity are adequate, including a figure 8 bandage, sling, sling and swathe, Sayre bandage, Velpeau dressing, and benign neglect, just to name a few.
- Nordqvist and colleagues\(^8\) reported on 35 clavicle fracture malunions with shortening of less than 15 mm. They were all treated nonoperatively in a sling. All 35 had normal mobility, strength, and function compared to the normal shoulder.
- A prospective, randomized study\(^2\) comparing sling versus figure 8 bandage showed that a greater percentage of patients were dissatisfied with the figure 8 bandage, and there was no difference in overall healing and alignment. The study concluded that the figure 8 bandage does little to obtain reduction.

SURGICAL MANAGEMENT
- Indications for operative treatment of acute midshaft clavicle fractures are as follows:
  - Open fractures
  - Fractures with neurovascular injury
  - Fractures with severe associated chest injury or multiple trauma: patients who require their upper extremity for transfer and ambulation
  - “Floating shoulder”
  - Impending skin necrosis
  - Severe displacement: possibly 15 to 20 mm of shortening
- In a multicenter, randomized, prospective clinical trial of displaced midshaft clavicle fractures, Altamimi and McKee\(^1\) showed that operative fixation compared to nonoperative treatment improved functional outcome and had a lower rate of both malunion and nonunion.
- Potential advantages of intramedullary fixation of the clavicle are as follows:
  - Less soft tissue stripping and therefore potentially better healing
  - Smaller incision
  - Better cosmesis
  - Easier hardware removal
  - Less weakness of bone after hardware removal
- Potential disadvantages of intramedullary fixation of the clavicle are as follows:
  - Less ability to resist torsional forces
  - Skin breakdown from prominence distally
  - Pin breakage
  - Pin migration
- Newer designs and techniques prevent pin migration by placing a locking nut on the lateral end and technically avoiding penetration of the medial fragment cortex.

Preoperative Planning
- After the decision has been made to fix a clavicle fracture, one must evaluate whether the fracture pattern is amenable to intramedullary pin fixation.
- A simple fracture pattern in the middle third of the bone is ideal.
- The fracture should not extend past the middle third of the bone.
- Comminution and butterfly fragments (usually anterior) are common and do not preclude intramedullary fixation as long as the medial and distal main fragments have cortical contact.

Positioning
- There are two good options for patient positioning that facilitate use of an image intensifier or C-arm device, which will aid you during pin placement.
- The patient can be placed supine on a Jackson radiolucent surgical table so the C-arm can be brought in perpendicular from the opposite side of the table, which is out of the way of the surgeon (FIG 4A,B).

FIG 4 • A,B. The patient is placed supine on a Jackson radiolucent surgical table. A 1-L bag is placed under the affected shoulder, medial to the scapula, and the arm is prepared free and placed in an arm holder to aid in fracture reduction. The C-arm can be brought in perpendicular from the opposite side of the table, which is out of the way of the surgeon and facilitates getting orthogonal radiographic views of the fracture: 45-degree caudad tilt view (A) and 45-degree cephalic tilt view (B). C,D. Alternatively, the patient is placed in the beach chair position on the OR table, using a radiolucent shoulder-positioning device. C. The arm is prepared free and placed in an arm holder to facilitate fracture reduction. The C-arm is brought in from the head of the bed with the gantry rotated upside down and slightly away from the operative shoulder and oriented with a cephalic tilt. D. The same beach chair positioning shown steriley draped.
- A 1-L bag is placed under the affected shoulder, medial to the scapula, to aid in fracture reduction.
- The arm is also prepared free and placed in an arm holder to facilitate fracture reduction.
- This is our preferred method due to the ease and speed of the set-up and the ease of getting orthogonal radiographic views of the fracture (45-degree cephalic and caudad tilt views).

The other option is placing the patient in the beach chair position on the OR table, using a radiolucent shoulder-positioning device (FIG 4C,D).
- The C-arm is brought in from the head of the bed with the gantry rotated upside down and slightly away from the operative shoulder and oriented with a cephalic tilt.
- The arm is also prepared free and placed in an arm holder to facilitate fracture reduction.

### INCISION AND DISSECTION

- Mark out the clavicle, fracture site, and surrounding anatomy (TECH FIG 1A).
- Use the C-arm to identify the appropriate position for the incision, which should be over the distal end of the medial fragment, in the Langer lines of the normal skin crease around the neck (TECH FIG 1B).
- Make an incision of about 2 to 3 cm over the fracture site.
- Divide the subcutaneous fat down to the platysma muscle using electrocautery (TECH FIG 1C).
- Although there is usually very little subcutaneous fat, gently make full-thickness flaps to include skin and subcutaneous tissue around the entire incision to facilitate exposure.
- Bluntly split the platysma muscle in line of its fibers to identify, protect, and retract the underlying supraclavicular nerves; its middle branches are frequently found near the midclavicle (TECH FIG 1D,E).
- The fracture site is then usually easily identifiable in acute injuries because the periosteum is disrupted and usually requires no further division.
- Remove any debris, hematoma, or interposed muscle from the fracture site.
- If there are butterfly fragments, be careful to keep any soft tissue attachments.

**TECH FIG 1**  
A. Displaced right clavicle fracture, showing the clavicle and fracture site marked out. B. A skin incision of about 2 to 3 cm is made over the distal end of the medial clavicular fragment, in the Langer lines of normal skin creases around the neck. C. Incision over a clavicle fracture site, showing full-thickness flaps to include skin and subcutaneous tissue around the entire incision. This exposes the fascia that covers the platysma muscle. D. Skin incision over a displaced clavicle fracture, with underlying platysma muscle and the middle supraclavicular nerves. E. Intraoperative photo showing the platysma muscle bluntly split in the line of its fibers to identify an underlying supraclavicular nerve, which is under the clamp. The fracture site is usually easily identifiable in acute injuries because the periosteum is disrupted and usually requires no further division; as shown here, the medial clavicular fragment is easily seen. (B, D: Courtesy of Steven B. Lippitt, MD.)
CLAVICLE PREPARATION

- The following technique uses a modified Hagie pin called the Rockwood Clavicle Pin (DePuy Orthopaedics, Warsaw, IN) (TECH FIG 2A).
- Use a bone-reducing clamp or towel clip to grab and elevate the medial clavicular fragment through the incision (TECH FIG 2B).
- Size the diameter of the canal with the appropriate-size drill bit; the C-arm can be useful to judge canal fill and orientation of the drill.
  - The fit should be snug to maximize fixation, but not too tight, to prevent splitting the bone.
- Attach the chosen drill to the T-handle and ream out the intramedullary canal without penetrating the anterior cortex (TECH FIG 2C–E).
- Next, attach the appropriate-sized tap (that corresponds to the drill size) to the T-handle and tap the intramedullary canal to the anterior cortex (TECH FIG 2F,G).
- Elevate the lateral clavicular fragment through the incision; this can be facilitated by externally rotating the arm.
- Use the same drill bit attached to the T-handle to ream out the lateral fragment, but this time, under C-arm guidance, penetrate the posterolateral cortex of the clavicle (TECH FIG 2H,I).
  - The drill should exit posterior and medial to the acromioclavicular joint capsule (TECH FIG 2J).
  - To prevent the pin nuts from being too prominent, make sure the drill does not exit in the upper half of the posterolateral clavicle.
- Attach the appropriate-sized tap to the T-handle and tap the intramedullary canal of the lateral fragment (TECH FIG 2K).

**TECH FIG 2 • A.** The Rockwood Clavicle Pin instrument set by DePuy Orthopaedics, Warsaw, IN, which is a modified Hagie pin. **B.** A bone-reducing clamp is used to elevate the medial clavicular fragment through the incision. **C–E.** The chosen drill is attached to a T-handle and the intramedullary canal of the medial clavicular fragment is reamed without penetrating the anterior cortex. **F,G.** An appropriate-sized tap is attached to a T-handle and the intramedullary canal of the medial clavicular fragment is tapped to the anterior cortex. **H,I.** The chosen drill is attached to a T-handle and the intramedullary canal of the lateral clavicular fragment is reamed out, penetrating the posterolateral cortex under direct C-arm guidance. (continued)
J. When drilling out the posterolateral cortex of the lateral clavicular fragment, the drill should exit posterior and medial to the acromioclavicular joint capsule. To prevent the pin nuts from being too prominent, the drill should not exit in the upper half of the posterolateral clavicle. K. The appropriate-sized tap is attached to the T-handle and the intramedullary canal of the lateral fragment is tapped. (C,H,J,K: Courtesy of Steven B. Lippitt, MD.)

PIN INSERTION AND FRACTURE REDUCTION

- Remove the nuts from the pin assembly and attach the T-handle using a Jacobs chuck to the medial end of the clavicle pin.
  - This is the end with the large threads.
  - Never tighten the chuck over the machined threads at either end.
- Continue firmly holding the lateral fragment while passing the trocar end (lateral end) of the clavicle pin into the intramedullary canal, out the previously drilled hole in the posterolateral cortex (TECH FIG 3A).
- Once you are just through the cortex, make a small incision over the palpable tip.
- Bluntly dissect the subcutaneous tissue with a hemostat until the tip of the pin can be felt, and then place the hemostat or a small elevator under the tip of the pin to facilitate the pin’s passage through the incision (TECH FIG 3B).
- Drill the pin out laterally until the large medial threads engage the lateral fragment.
- Now switch the T-handle to the lateral end of the pin and retract the pin into the lateral fragment (TECH FIG 3C,D).
- Reduce the fracture by lifting the arm, and pass the pin into the medial fragment.
- Use the C-arm to ensure that the pin advances correctly down the line of the medial fragment and that all the medial threads cross the fracture site.

TECH FIG 3 • A. The surgeon continues firmly holding the lateral fragment while passing the trocar end (lateral end) of the clavicle pin into the intramedullary canal, out the previously drilled hole in the posterolateral cortex. Once just through the cortex, the surgeon makes a small incision over the palpable tip. (continued)
**FINAL POSITIONING OF PIN AND FRACTURE COMPRESSION**

- Cold-weld the two nuts onto the lateral end of the pin.
  - First place the medial nut onto the pin, followed by the smaller lateral nut.
  - Grasp the medial nut with a needle-nose pliers and then tighten the lateral nut against the medial nut using the lateral nut wrench (TECH FIG 4A,B).
- Using the lateral nut wrench and C-arm guidance, now advance the pin assembly into the medial fragment until it contacts the anterior cortex (TECH FIG 4C).
- Break the cold weld by grasping the medial nut with needle-nose pliers and then loosen the lateral nut by turning it counterclockwise using the lateral nut wrench.
- Advance the medial nut against the posterolateral cortex of the clavicle to get desired compression across the fracture site.
- Cold-weld the lateral nut back onto the medial nut again.
- Use the medial nut wrench to back the pin assembly out of the soft tissues far enough to expose the nuts, usually about 1 cm. This will enable the pin to be cut flush to the lateral nut (TECH FIG 4D,E).
- Finally, use the lateral nut wrench to advance the pin assembly back into the medial fragment with the same desired fracture site compression (TECH FIG 4F,G).

**TECH FIG 3 • (continued)** B. The subcutaneous tissue is bluntly dissected with a hemostat until the tip of the pin can be felt, and then the hemostat or a small elevator is placed under the tip of the pin to facilitate the pin’s passage through the incision. C,D. The T-handle is switched to the lateral end of the pin and the pin is retracted into the lateral fragment. (A,C: Courtesy of Steven B. Lippitt, MD.)

**TECH FIG 4 • A.** The lateral end of the pin with the larger medial nut is placed first, closest to the skin, followed by the smaller lateral nut, in preparation for cold welding. B. To cold weld the joint, the medial nut is grasped with a needle-nose pliers, and then the lateral nut is tightened against the medial nut using the lateral nut wrench. C. Using the lateral nut wrench and C-arm guidance, the surgeon advances the pin assembly into the medial fragment until it contacts the anterior cortex. (continued)
If an anterior butterfly fragment exists, cerclage is done using no. 0 or no. 1 absorbable suture.
- Pass an elevator under the clavicle to deflect the sutures (TECH FIG 5A).
- Then pass the suture in a figure 8 manner through the periosteum of the butterfly fragment and around the fragment and the clavicle (TECH FIG 5B).
- Close the periosteum overlying the fracture site with no. 0 absorbable suture in an interrupted figure 8 manner.
- Reapproximate the fascia of the platysma muscle using 2-0 absorbable suture in an interrupted figure 8 manner.
- Close the subcutaneous tissue and skin of both incisions.
**POSTOPERATIVE CARE**

- A sling is worn for 4 weeks. During this time the sling is removed at least five times a day for active range of motion of the elbow and active assisted range of motion of the shoulder to 90 degrees of forward flexion.
- The sling is discontinued and full active range of motion of the shoulder is started at 4 weeks.
- Progressive resistance exercises are started at 6 weeks if the patient achieved full range of motion and there is clinical and radiographic evidence of healing.
- Once the clavicle fracture has healed, the pin is removed at 10 to 12 weeks, as described in the Techniques section (FIG 5).

**PEARLS AND PITFALLS**

| Avoid splitting the clavicular fragments and aid in pin insertion | If tapping the medial or lateral clavicular fragments is too tight, the surgeon should redrill with the next larger drill size. |
| Achieve a more anatomic fracture reduction | When advancing the pin into the medial clavicular fragment, the surgeon should avoid starting too superior and anterior, which can lead to malreduction. Instead, the pin should be inserted more inferior and posterior to achieve a more anatomic reduction. |

**PIN REMOVAL**

- The pin is removed at 10 to 12 weeks if the fracture has healed.
- The patient is positioned on his or her side and a local anesthetic is delivered (TECH FIG 6A).
- An incision is made over the same previous lateral incision and the subcutaneous tissue is dissected using the hemostat until the medial nut is identified.
- The medial nut wrench is used to extract the pin assembly (TECH FIG 6B,C).
- If the nut is stripped, the T-handle and chuck can be used to extract the pin assembly.

**TECH FIG 6**

A. The patient is positioned on his or her side and the lateral incision is infiltrated with local anesthesia. B,C. The surgeon makes an incision over the same previous lateral incision, dissecting through the subcutaneous tissue using the hemostat until the medial nut is identified and freed up. The medial nut wrench is then used to extract the pin assembly. (B: Courtesy of Steven B. Lippitt, MD.)

**FIG 5**

Radiograph showing a healed clavicle fracture after pin assembly removal.
OUTCOMES

- One of the authors (C.B.) has performed intramedullary fixation of some 300 acute fractures; there have been 60 malunions and 30 nonunions of the clavicle, with a nonunion rate of 1.2%.
- Most of the nonunions occurred in older, sick patients with polytrauma.

COMPLICATIONS

- Pin migration is rare with this technique because of the locking nut on the lateral end of the pin, the blunt tip on the medial end of the pin, and technically avoiding penetration of the medial fragment cortex.
- The risk of skin breakdown from pin prominence laterally can be minimized by making sure the drill exits the posterolateral clavicle in the lower half.
- Neurovascular complications are rare.
  - There is no drilling toward the neurovascular structures with this technique.
  - When exposing the fracture site, the surgeon should stay on bone at all times.
- Nonunion rates are low as long as general fracture principles are maintained, soft tissue stripping of the fracture site is minimized, the technique is followed to get adequate fracture site compression and alignment, and the patient is compliant with the postoperative protocol.
- Malunion can rarely occur, especially in fractures with large butterfly fragments. Good imaging with the C-arm allows the surgeon to start inserting the pin more inferior and posterior down the line of the medial clavicular fragment to achieve a more anatomic reduction.
- Infection is rare, especially with this technique, which has a relatively short surgical time and small exposure. Preoperative antibiotics, meticulous handling of the soft tissues, and adequate irrigation should be part of any surgical technique.

REFERENCES

DEFINITION
- **Proximal humerus fractures** are defined as those of the proximal portion of the humerus involving the shoulder joint.
- **Fracture lines** divide the proximal humerus into parts defined by anatomic structures that arise from early centers of ossification.
  - These “parts” first were described by Codman, and led to development of the Neer classification, which is commonly used today.
  - The parts refer to the head of the humerus, the greater tuberosity, the lesser tuberosity, and the shaft (FIG 1).
  - Proximal humerus fractures are classified as two-, three-, or four-part fractures according to the Neer classification.
  - Displacement of a “part” is classically defined as 1 cm of displacement or 45 degrees of angulation. Importantly, displacement is not necessarily an indication for surgery, but only a criterion for classification.
  - The type of fracture and degree of displacement, as well as patient considerations, all factor into surgical decision-making.

ANATOMY
- The proximal humerus arises from four distinct centers of ossification: the humeral head, the greater tuberosity, the lesser tuberosity, and the shaft.
  - The greater tuberosity has three distinct facets for the insertion of the supraspinatus, the infraspinatus, and the teres minor muscles of the rotator cuff.
  - The lesser tuberosity is the insertion site for the subscapularis muscle.
  - The rotator interval lies between the upper subscapularis and the anterior border of the supraspinatus.
  - The long head of the biceps tendon lies in a shallow groove on the anterior proximal humerus and enters the glenohumeral joint at the rotator interval.
  - The proximal 3 cm of the long head of the biceps tendon lies deep to the interval tissue intra-articularly.
  - The anterior humeral circumflex artery (FIG 2) courses laterally along the inferior subscapularis.
  - The anterolateral branch of the anterior humeral circumflex artery travels superiorly along the lateral aspect of the biceps groove and enters the humeral head at the proximal-most aspect of the groove, providing about 85% of the blood supply to the humeral head.
  - The posterior humeral circumflex artery gives off several small branches that run adjacent to the inferior capsule of the shoulder, providing most of the remaining blood supply.
  - The pectoralis major muscle inserts on the proximal shaft of the humerus lateral to the long head of the biceps tendon. The latissimus dorsi muscle inserts onto the proximal shaft medial to the biceps groove.

![FIG 1](image1.png) Fractures of the proximal humerus are classified as two-, three-, or four-part fractures based on fracture and degree of displacement of the greater tuberosity, the lesser tuberosity, the humeral head, and the humeral shaft.

![FIG 2](image2.png) The rotator interval lies between the upper border of the subscapularis and the anterior border of the supraspinatus. The biceps tendon runs deep to the rotator interval tissue. Importantly, the fracture line between the greater and lesser tuberosities lies just posterior to the biceps groove. The ascending branch of the anterior humeral circumflex artery provides 85% of the blood supply to the humeral head.
PATHOGENESIS

- Proximal humerus fractures occur in a bimodal distribution.
  - Most proximal humerus fractures are “fractures of senescence” in older individuals with age-related osteopenia. They commonly result from low-energy injuries such as tripping and falling.
  - They also occur in younger individuals as the result of high-energy injuries such as motorcycle or automobile accidents.
  - Associated nerve injuries can occur and usually resolve spontaneously. Axillary nerve neurapraxia is the most common.

NATURAL HISTORY

- Eighty-five percent of proximal humerus fractures can be treated nonoperatively.6
  - Displacement at the surgical neck is better tolerated than displacement at the greater tuberosity.
  - Because of the vast range of motion (ROM) of the shoulder in multiple planes, the arm can compensate for translational displacement or angulation at the surgical neck.
  - Displacement of the tuberosities, however, affects the mechanics of the rotator cuff and is very poorly tolerated.

- Four-part fractures have an extremely high incidence of avascular necrosis—45% in Neer’s classic series—with the exception of valgus impacted four-part fractures, in which the incidence is only 11%.7
  - In most four-part fractures, the blood supply from the anterior humeral circumflex artery is disrupted, contributing to the high incidence of avascular necrosis.
  - The blood supply is maintained in most valgus impacted fractures by the branches from the posterior humeral circumflex artery along the intact medial periosteal hinge (FIG 3), making this particular fracture configuration very amenable to fixation.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A complete history of injury is important to determine the mechanism of injury. It is helpful to differentiate low-energy from high-energy injuries.
  - Elderly individuals often sustain proximal humerus fractures as the result of low-energy injuries such as slipping and falling. These injuries often are very amenable to minimally invasive fixation techniques, because the displacement is manageable and the periosteal sleeve between fracture fragments often is intact. The rotator cuff often is intact as a sleeve. All these qualities facilitate minimally invasive reduction and fixation techniques.
  - In younger individuals, proximal humerus fractures often result from higher-energy injuries. These fractures commonly have greater fracture fragment displacement, rotator cuff tears between the tuberosities, and disruption of the periosteal sleeve. These factors do not necessarily preclude percutaneous pinning, but make it more challenging and should be considered in preoperative planning.

- Other important aspects of the history include:
  - Previous history of injury to the affected shoulder
  - Previous shoulder function
  - History of numbness or tingling in the affected extremity
  - Rule out elbow and wrist fractures, especially in osteoporotic patients with injuries resulting from a fall on an outstretched arm.
  - Patients often hold the shoulder inferior on the affected side.
  - Examination should include skin integrity, presence of ecchymosis, downward carriage of shoulder girdle, and deformity consistent with shoulder dislocation or acromioclavicular joint separation.
  - Examine for possible associated nerve injury (usually neurapraxia) by testing sensation to light touch in individual nerve distribution, two-point discrimination, and muscle strength (testing is limited to isometric at shoulder because of limited ROM and pain).
  - Possible associated vascular injury can be determined by testing radial pulse and capillary refill.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- A trauma series of radiographs of the shoulder should be obtained (FIG 4).
  - The series includes an AP view of the shoulder, a scapular AP view, a scapular Y view, and an axillary view.
  - A complete series with these views allows the fracture configuration to be determined in sufficient detail.
  - A CT scan is helpful in many cases and should be obtained if there is any question regarding the extent of fracture involvement or the level of displacement of the fragments. It also is helpful if there is any question of joint dislocation or glenoid fracture.
  - Radiographs are used to determine whether the fracture is a two-, three-, or four-part fracture and to assess the degree of displacement.

FIG 3 • Valgus impacted fractures maintain blood supply to the articular surface via ascending branches off the posterior humeral circumflex artery along the intact medial periosteal hinge.
Three-dimensional reconstructions of the CT scan can be helpful in fracture evaluation, but are not routinely required.

DIFFERENTIAL DIAGNOSIS
- Acromioclavicular joint separation
- Glenohumeral joint dislocation
- Humeral shaft fracture
- Scapulothoracic dissociation
- Elbow and wrist fractures (may coexist)

NONOPERATIVE MANAGEMENT
- Minimally displaced fractures can be treated nonoperatively.
- Displacement at the surgical neck is well tolerated.
  - An AP view of the shoulder can be misleading in the case of a surgical neck fracture.
  - The pectoralis major muscle exerts an anterior force on the shaft, resulting in anterior displacement of the shaft relative to the humeral head.
  - A scapular Y or axillary view can exhibit this angular deformity.
- Displacement of the greater tuberosity is less well tolerated.
  - Historically, 1 cm of displacement has been used as the criterion for clinically significant tuberosity displacement.
  - Recently, however, even 5 mm of displacement has been considered an operative indication.
- Patients wear a sling for 2 to 3 weeks or until the proximal humerus feels stable with gentle internal or external rotation of the arm.
  - Patients should be instructed to remove the sling for elbow and hand ROM to avoid stiffness of these joints.
  - Early signs of healing (eg, callus formation) also are helpful indicators of when it is safe to commence ROM exercises.
  - In borderline instances, it is better to err toward a longer period of immobilization to ensure healing, because shoulder stiffness is easier to address than a nonunion.
- Therapy begins with passive stretching until 6 weeks when active ROM and strengthening can be started, progressing as tolerated.

SURGICAL MANAGEMENT
Preoperative Planning
- All imaging studies should be reviewed carefully to determine the type of fracture, the degree of displacement, fracture configuration, and bone quality.
- Certain radiographic findings that can suggest that minimally invasive fracture fixation is not appropriate for a given fracture are as follows:
  - Poor bone quality. The bone may not hold the pins and screws well and may be better treated with a more stable construct.
  - Commination of the greater tuberosity. A comminuted bone fragment is not amenable to fixation with screws. Fractures with a comminuted greater tuberosity require suture fixation through the tendon–bone junction (required open approach).
  - Commination of the medial calcar region leads to unstable reduction of the head onto the shaft.
- Fractures amenable to minimally invasive fixation are two-part, three-part, and valgus impacted four-part fractures with:
  - Good bone quality
  - Substantial fracture fragments with minimal comminution of the tuberosities
  - Minimal or no comminution at the medial calcar region
  - Minimally invasive fixation is not appropriate for noncompliant or unreliable patients. This procedure should be performed only in patients committed to consistent follow-up in the postoperative period.
    - The pins require close surveillance in the early postoperative period.
    - Pin migration is possible and must be caught early in order to avoid potential injury to thoracic structures.
Positioning
- Percutaneous pinning is performed with the patient in the straight supine or 10- to 15-degree beach chair position (FIG 5).
- This allows easy intraoperative evaluation with C-arm fluoroscopy.
shoulder can be imaged in the anteroposterior plane without the table obstructing the view.
  ▪ This image should be checked before prepping and draping to confirm adequate visualization.
  ▪ The entire upper extremity is draped free.

Approach
  ▪ Closed fracture reductions are performed with the aid of a “reduction portal” (FIG 6).^2
  ▪ The reduction portal is a portal (analogous to that of an arthroscopic portal) or small incision used to access the fracture fragments.
  ▪ Instruments can be introduced through this portal to lever fracture fragments or pull fragments into reduced position.
  ▪ The surgeon also can insert a finger through this portal to palpate fragments.
  ▪ Medially, the biceps tendon can be palpated.
  ▪ The surgical neck fracture is located just deep to the portal.
  ▪ By sweeping posterior and superior, the greater tuberosity and its extent of displacement can be palpated.
  ▪ The location of the reduction portal is critical (FIG 6B).
  ▪ In three- and four-part fractures, the fracture line of the greater tuberosity is reliably 0.5 to 1 cm posterior and lateral to the biceps groove.
  ▪ Therefore, the reduction portal is located at the level of the surgical neck and 1 cm posterior to the biceps groove.

FIG 5 • The patient is placed in the supine or gently upright position. The C-arm is brought in parallel to the patient, leaving the lateral aspect of the arm free for instrumentation. The patient should be positioned laterally on the table such that an adequate fluoroscopic view can be obtained.
  ▪ The C-arm fluoroscope is placed parallel to the patient, extending over the shoulder from the cephalad direction.
  ▪ This position leaves the lateral shoulder completely accessible for instrumentation and pin fixation.
  ▪ The patient must be positioned far lateral on the table or on a specialized shoulder surgery positioning device such that the shoulder can be imaged in the anteroposterior plane without the table obstructing the view.

FIG 6 • A. The reduction portal is established off the anterolateral corner of the acromion. Instruments can be introduced through this portal to help reduce the fracture. B. The reduction portal is located at the level of the surgical neck fracture approximately 0.5 to 1 cm posterior to the biceps groove. The reduction portal is definitively localized using C-arm imagery. A hemostat is applied to the skin (C) and then imaged (D) to confirm that this portal will be directly at the level of the surgical neck fracture. E. A small incision is made in the skin, and the deltoid is spread bluntly to avoid injury to the underlying axillary nerve.
Reduction

- The pectoralis major muscle provides the major deforming force resulting in displacement of surgical neck fractures. The shaft usually is displaced anteriorly and medially with respect to the head.
- An axillary or scapular Y radiograph is necessary to evaluate the extent of this displacement.
- The reduction maneuver involves flexion, adduction, and possibly some slight internal rotation to relax the pull of the pectoralis major muscle3 (TECH FIG 1).
- Longitudinal traction is applied to the arm, and a posteriorly directed force is applied to the proximal shaft of the humerus.
- A blunt instrument can be inserted into the fracture at the surgical neck to lever the head back onto the shaft. This maneuver can be a powerful reduction tool, but care should be used to avoid further damage or fracture to the humeral head during this maneuver, especially on osteopenic patients.
- The long head of the biceps tendon can become interposed between the fracture fragments, precluding reduction. Therefore, if reduction is not achieved, check the biceps tendon through the reduction portal (or consider open reduction).

Fixation

- Two or three retrograde pins are placed from the shaft into the humeral head (TECH FIG 2).
- The starting point for the pins is approximately 5 to 6 cm distal to the surgical neck fracture line.
- The pins must angle steeply to enter the head fragment and not cut out posteriorly (TECH FIG 2B,C).
- Pins should be smooth to avoid injury to soft tissue upon insertion, and terminally threaded to avoid backing out.
- 2.5- or 2.7-mm smooth, terminally threaded pins commonly are found in external fixation or 7.3-mm cannulated screw sets of instruments.
- The pins should enter at different directions to enhance stability of fixation construct.
- One pin should enter lateral to the biceps in a primarily anterior-to-posterior direction.
- Another pin should enter further laterally in a primarily lateral-to-medial direction.
- Stability should be checked under fluoroscopic imaging with live, gentle internal and external rotation.

Fixation

- The arm is held in neutral rotation.
- The level of the surgical neck is located using fluoroscopic imagery (FIG 6C,D).
- The location of the biceps tendon is estimated based on surface anatomic landmarks.
- A 2-cm incision is made in the skin (FIG 6E).
- Subcutaneous tissues and the deltoid muscle are spread bluntly using a straight hemostat to avoid injury to the axillary nerve on the deep surface of the deltoid. Subdeltoid adhesions are gently released by sweeping finger if necessary.

Surgical Neck Fracture

Reduction

- The pectoralis major muscle provides the major deforming force resulting in displacement of surgical neck fractures. The shaft usually is displaced anteriorly and medially with respect to the head.
- An axillary or scapular Y radiograph is necessary to evaluate the extent of this displacement.
- The reduction maneuver involves flexion, adduction, and possibly some slight internal rotation to relax the pull of the pectoralis major muscle3 (TECH FIG 1).
- Longitudinal traction is applied to the arm, and a posteriorly directed force is applied to the proximal shaft of the humerus.
- A blunt instrument can be inserted into the fracture at the surgical neck to lever the head back onto the shaft. This maneuver can be a powerful reduction tool, but care should be used to avoid further damage or fracture to the humeral head during this maneuver, especially on osteopenic patients.
- The long head of the biceps tendon can become interposed between the fracture fragments, precluding reduction. Therefore, if reduction is not achieved, check the biceps tendon through the reduction portal (or consider open reduction).

Fixation

- Two or three retrograde pins are placed from the shaft into the humeral head (TECH FIG 2).
- The starting point for the pins is approximately 5 to 6 cm distal to the surgical neck fracture line.
- The pins must angle steeply to enter the head fragment and not cut out posteriorly (TECH FIG 2B,C).
- Pins should be smooth to avoid injury to soft tissue upon insertion, and terminally threaded to avoid backing out.
- 2.5- or 2.7-mm smooth, terminally threaded pins commonly are found in external fixation or 7.3-mm cannulated screw sets of instruments.
- The pins should enter at different directions to enhance stability of fixation construct.
- One pin should enter lateral to the biceps in a primarily anterior-to-posterior direction.
- Another pin should enter further laterally in a primarily lateral-to-medial direction.
- Stability should be checked under fluoroscopic imaging with live, gentle internal and external rotation.
Reduction

- Deforming forces influencing displacement of three-part fractures include the pectoralis major, as described earlier, and the rotator cuff muscles. The rotator cuff pulls the tuberosity medially (to a certain extent) and posteriorly. Posterior displacement and rotation often are underappreciated and must be considered.
- The surgical neck component is addressed first. (See Surgical Neck Fractures earlier in this section).
- The greater tuberosity fracture is reduced using the “reduction portal.” A dental pick or small hooked instrument is inserted through the portal to engage the tuberosity and pull it inferior and anterior into a reduced position.

Fixation

- 4.5-mm cannulated screws are used to fix the tuberosity fragment.
- The screw is placed through the tuberosity fragment distal to the cuff insertion through bone on the lateral cortex (TECH FIG 3A).
- The proper location is confirmed with fluoroscopic imaging.
- The guidewire is first passed through a small incision in the skin just large enough to pass the drill guide and screw through the deltoid (TECH FIG 3B,C).
- The guidewire is passed through the tuberosity, across the surgical neck fracture, and engages the medial cortex of the proximal humeral shaft.

Pins are cut below the skin to prevent pin site infection (TECH FIG 2D).

Any suggestion of instability or motion at the fracture is an indication for open reduction and plate fixation at that point.

The reduction portal is closed with interrupted nylon sutures.

A soft dressing and sling are applied.

THREE-PART GREATER TUBEROSITY FRACTURES

TECH FIG 2 • (continued) C. Fluoroscopic view of two retrograde pins in place. D. The pins should be cut below the skin after insertion to prevent pin site infection. They are easily removed a couple of weeks later with a small procedure in the office or operating room.
Valgus impacted fractures are recognized by the 90-degree angle between the long axis of the humeral shaft and the articular surface of the humeral head with loss of the normal neck shaft angle. The tuberosities are displaced laterally from the head of the humerus and slightly proximally.

This fracture configuration results in a low incidence of avascular necrosis compared to that of other four-part fractures, because the medial periosteal hinge of soft tissues is intact along the medial and posterior anatomic neck, preserving the blood supply provided by the posterior humeral circumflex artery and its ascending vessels.

The reduction maneuver for this fracture requires raising the humeral head back into its anatomic position.

The reduction portal described previously is created, and an instrument such as a blunt elevator or small bone tamp is inserted beneath the humeral head.

The instrument passes through the surgical neck fracture and through the fracture line between the tuberosities, which reliably exists 0.5 to 1 cm posterior and lateral to the biceps groove.

After the guidewire is overdrilled, the screw is passed over the guidewire. We use a partially threaded screw with a washer (TECH FIG 3D–F).

If the greater tuberosity fragment is large enough, a second cancellous screw is directed through the tuberosity fragment, engaging cancellous bone of the humeral head.

Pins are cut beneath the skin.

Incisions are closed with nylon interrupted sutures.

A dressing and sling are applied.
POSTOPERATIVE CARE

- The operative arm is immobilized in a sling.
- The patient is instructed to begin active elbow, wrist, and hand ROM exercises.
- Radiographs are checked weekly to monitor for pin migration or loss of fixation.
- Pins are removed as a short procedure in the office or operating room about 3 to 4 weeks postoperatively or when early signs of healing are evident radiographically.
- Pendulum exercises are initiated 2 to 3 weeks postoperatively, and passive stretching (forward elevation in scapular plane), external rotation, and internal rotation (all in supine position) is initiated when pins are removed.
- Ideally, pins should be out and motion started no later than 4 weeks postoperatively.
- Active ROM progressing as tolerated to resistance exercises commences at 6 weeks postoperatively.

OUTCOMES

- Jaberg et al. reported good to excellent results in 38 of 48 fractures. There were 29 surgical neck, 3 anatomic neck, 8 three-part, and 5 four-part fractures.
Resch et al\textsuperscript{8} reported results of 9 three-part fractures and 18 four-part fractures. In the four-part fractures, the incidence of avascular necrosis was 11%. Good results correlated with anatomic reconstruction.

Keener et al\textsuperscript{5} reported a multicenter study of 35 patients—7 two-part, 8 three-part, and 12 valgus impacted fractures. Average duration of follow-up was 35 months. All fractures healed. American Shoulder and Elbow Surgeons and Constant scores were 83.4 and 73.9, respectively. Four patients had some residual malunion, and four developed posttraumatic arthritis. Neither of these affected outcome at this early follow-up period, however.

Most studies report very satisfactory results with this procedure. Patient selection is critical. In published studies, patients are not randomized to percutaneous pinning, but, rather, careful patient selection is left to the treating surgeon. Therefore, it can be concluded that this is an appropriate technique in certain patients who meet the outlined criteria.

**COMPLICATIONS**

- Nerve injury\textsuperscript{9}
- Pin migration
- Loss of fixation
- Malunion
- Nonunion
- Infection
- Glenohumeral joint stiffness

**REFERENCES**

DEFINITION

- Proximal humerus fractures may involve the surgical neck, the greater tuberosity, or the lesser tuberosity.
- The Neer classification, which is most commonly used, categorizes fractures based on the number of displaced parts ([FIG 1](#)), This classification system involves four segments: the articular surface, the greater tuberosity, the lesser tuberosity, and the humeral shaft. Fracture fragments displaced 1 cm or angulated 45 degrees are considered displaced.\(^\text{17,18}\)
- The AO/ASIF (Arbeitsgemeinschaft fuer Osteosynthese-fragen–Association for the Study of Internal Fixation) broadly classifies fractures into three types: type 1, unifocal extra-articular; type 2, bifocal extra-articular, and type 3, intra-articular.
  - Each type is then further divided into groups and subgroups.\(^\text{16}\)
  - This system places more emphasis on the vascular supply to the humerus, with intra-articular fracture patterns having the highest risk of avascular necrosis.\(^\text{26}\)
- Studies have demonstrated that interobserver reliability for both classification systems is not high.\(^\text{1,23,24}\)

- Although not included in Neer’s original classification, valgus impacted fractures are a unique entity that is important to recognize:
  - Four-part fractures in which the humeral articular surface is impacted upon the shaft segment
  - Often minimally displaced owing to an intact rotator cuff\(^\text{5}\)
  - Have a lower incidence of avascular necrosis, because the blood supply to the head is less likely to be disrupted

ANATOMY

- The osseous anatomy of the proximal humerus consists of the greater tuberosity, the lesser tuberosity, and the articular surface.
- The subscapularis inserts onto the lesser tuberosity, whereas the supraspinatus, infraspinatus, and teres minor insert onto the greater tuberosity.
- Knowledge of deforming forces associated with humerus fracture allows the surgeon to better treat proximal humerus fractures by both operative and nonoperative means.
- In a two-part surgical neck fracture, the pectoralis major pulls the humeral shaft anteromedial.
- In a two-part greater tuberosity fracture, the pull of the supraspinatus, infraspinatus, and teres minor tendons displace the greater tuberosity superiorly and/or posteriorly.

[FIG 1](#) • Simplified Neer classification for fractures of the proximal humerus.
With a three-part fracture involving the lesser tuberosity, the attachment site of these tendons into the greater tuberosity is intact, and the articular surface of the humeral head rotates externally to face anteriorly.

Three-part fractures involving the greater tuberosity result in unopposed subscapularis function, and the humeral articular surface rotates posteriorly.

Four-part fractures result in displacement of the shaft and both tuberosities, leaving a free head fragment with little soft tissue attachment.

An understanding of the vascular anatomy is crucial to treat fractures of the proximal humerus effectively.

The main blood supply to the humeral head is the anterolateral ascending branch of the anterior circumflex artery.

This branch of the axillary artery runs just lateral to the bicipital groove, entering the humeral head at the proximal portion of the transition from bicipital groove to greater tuberosity.

The intraosseous portion of this vessel, known as the arcuate artery, has been shown to supply the entire epiphyseal portion of the proximal humerus except for a small portion of the greater tuberosity and the posteroinferior humeral head, which is supplied by the posterior humeral circumflex artery.

**PATHOGENESIS**

- In older patients, proximal humerus fractures usually result from a ground-level fall. Younger patients may sustain such an injury from a higher-energy mechanism such as an automobile collision or from sports.
- The presence of an associated glenohumeral dislocation also must be determined.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- On presentation, patients with proximal humerus fractures complain of pain in the shoulder that is made worse with attempted movement. Palpation of the proximal humerus results in diffuse pain.
- Visual inspection reveals ecchymosis and swelling of the arm.
- It is necessary to determine the stability of the fracture. If the shaft and the proximal portion move as a unit when taken through internal and external rotation, the fracture usually is stable. Unstable fractures will not move as a unit, and crepitus often is appreciated.
- If there is an associated dislocation, it may be possible to palpate the humeral head as an anterior fullness.
- It is crucial to perform a thorough neurovascular examination to determine the presence of associated injuries.
- Patients over 50 years of age are more prone to nerve injuries. One study demonstrated nerve injury, usually of the axillary nerve, in nearly 40% of patients in this age group who sustained shoulder dislocations or surgical neck fractures.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Initial imaging studies consist of anteroposterior, scapular Y, and axillary views.
- Additional views also may include internal and external rotation views if the fracture pattern is stable. Internal rotation views help to visualize the lesser tuberosity, whereas external rotation shows the greater tuberosity.
- Traction views also may prove helpful if tolerated by the patient.
- A CT scan may be helpful if radiographs do not demonstrate the fracture pattern adequately.
- Studies have shown that the addition of a CT scan improves intraobserver reproducibility only minimally and does not affect interobserver reliability. However, CT scanning may prove valuable in determining the method of fixation as well as identifying associated injuries such as Hill-Sachs fractures and bony Bankart lesions.
- Indications for MRI are limited, although it may prove useful if there is any concern regarding soft tissue injuries, including the glenoid labrum and rotator cuff.

**DIFFERENTIAL DIAGNOSIS**

- Glenohumeral dislocation
- Scapula fracture
- Head-splitting fracture
- Clavicle fracture
- Humeral shaft fracture
- Neurovascular injury
- Neuropathic arthropathy

**NONOPERATIVE MANAGEMENT**

- Historically, conservative treatment usually is recommended for fractures with less than 1 cm of displacement and 45 degrees of angulation. About 85% of proximal humerus fractures can be treated nonoperatively. With newer fixation devices, however, indications for surgical management have been expanded. Whether a more aggressive approach leads to improved outcomes remains to be seen.
- There is less tolerance for displacement in isolated greater tuberosity fractures. It has been suggested that more than 5 mm of displacement leads to poor functional results.
- For proximal humerus fractures not involving the humeral head, patients initially are immobilized in a simple sling.
- When pain improves and the fracture moves as a unit, passive range of motion (ROM) is started. Patients begin with pendulum exercises, usually 2 to 3 weeks after injury, then progress to ROM in all planes.
- Between 6 and 10 weeks, the fracture usually has healed enough that strengthening exercises may be started.
- Physical therapy is very important when treating proximal humerus fractures conservatively. Koval et al showed significant improvement with one-part fractures when physical therapy was initiated before 2 weeks.
- Several studies have shown that nonoperative management can lead to acceptable results with proximal humerus fractures.
- Studies comparing patients treated surgically and nonsurgically have shown no difference in outcome with two-part surgical neck fractures and displaced three- and four-part fractures, although these studies were done before the advent of anatomic proximal humeral plating.

**SURGICAL MANAGEMENT**

- It is imperative that patients have reasonable expectations of their outcome following surgery. Patients also must be aware of the importance of physical therapy postoperatively.
Preoperative Planning

- Acceptable imaging studies, either plain radiographs or a CT scan, are necessary before proceeding to surgery.
- Each proximal humerus fracture is unique, and in most cases a planned method of fixation is chosen before entering the operating room. However, the definitive choice of fixation is not made until the fracture is visualized at surgery. Consequently, the surgeon should be prepared with an arsenal of different fixation techniques.
- If the fracture is not deemed suitable for internal fixation intraoperatively, the surgeon must be prepared to perform a hemiarthroplasty.
- Multiple techniques can be employed for surgical fixation of the proximal humerus. In this chapter, we describe several current techniques. The final choice of appropriate manner of fixation should be based on the individual patient, the fracture pattern, and the surgeon’s own comfort level.

Positioning

- The techniques discussed in this section are easiest to perform with the patient in the beach chair position. With the patient nearly seated, the hips and knees are flexed. The patient is moved as far laterally as possible on the table to allow full ROM of the shoulder. A lateral buttress is used to help keep the patient in position on the table.
- C-arm fluoroscopy is helpful in determining the quality of reduction. The C-arm is best positioned with the intensifier posterior to the shoulder and the arm over the patient (FIG 2).

Approach

- The approach depends on the surgical technique to be used and is discussed further in the Techniques section.
- The deltopectoral approach is most commonly employed.

FIXATION OF ISOLATED TUBEROSITY FRACTURES

- The patient is placed in the beach chair position.
- An incision is made from the tip of the acromion extending laterally down the arm.
- Alternatively, an incision can be made parallel to the lateral border of the acromion, as used in open rotator cuff repair.
- Skin flaps are then raised.
- The deltoid is split in line with its fibers, and the anterior portion of the deltoid may be detached from the acromion.
- A deltopectoral approach also could be used.
- The deltoid fibers should not be split further than 5 cm below the acromion, to prevent damage to the axillary nerve. A suture at the distal aspect of the split can help prevent inadvertent extension.10
- As with all open procedures described in this chapter, the fracture should be cleaned of hematoma to facilitate reduction.
- The greater tuberosity usually is displaced posteriorly or superiorly. Abducting and externally rotating the shoulder will take tension off the posterosuperior rotator cuff, allowing the greater tuberosity fragment to be more easily reduced.
- Traction sutures in the rotator cuff may prove valuable in obtaining reduction.
- Provisional fixation can then be obtained with a K-wire (TECH FIG 1A,B).
- Cannulated screws placed over the wire may then be used for definitive fixation if placed in an acceptable location.
- Screws should be of the appropriate length to gain adequate purchase (TECH FIG 1C,D) but not so long that they are symptomatic.
- The use of washers may prove beneficial.
- Alternatively, suture fixation of the greater tuberosity back to the humerus may provide better fixation than cannulated screws in those patients with poor bone quality.
- This can be accomplished by placing two suture anchors into the fracture bed (TECH FIG 1E).
- Both limbs of each anchor can then be brought through drill holes in the fragment and tied over the top (TECH FIG 1F).
- Suture also can be placed at the bone–tendon interface of the tuberosity fragment and then through bone tunnels in the shaft, as discussed later in this section.
- If the anterior deltoid was detached during the approach, it must be repaired back to the acromion using nonabsorbable sutures.
TECH FIG 1 • A. Traction sutures are placed through the rotator cuff tendon to aid in reduction of the displaced greater tuberosity. B. Wires may be used to maintain reduction of the tuberosity. C. Screw fixation with 4.5-mm cannulated screws. D. Final fixation. Screws should obtain purchase in the far cortex, but they must not be long enough to damage the axillary nerve. E. Placement of suture anchors into the fracture bed. F. Reduced fracture with sutures tied over the greater tuberosity.
OPEN REDUCTION AND SUTURE FIXATION

- The patient is placed in the beach chair position. Depending on the pattern, the fracture may be approached via the deltopectoral interval or a deltoid-splitting approach.
- The rotator interval tissue may be incised. This "interval split" allows visualization of the humeral head articular surface, if needed, in the setting of intact tuberosities and rotator cuff, as with head split patterns.
- Multiple sutures are placed through the tendons of the rotator cuff, preferably no. 5 nonabsorbable sutures or 1-mm tapes.
  - Both the subscapularis tendon and the posterosuperior cuff tendons should be incorporated (TECH FIG 2A).
- Drill holes should be placed distal to the fracture site. The bone on either side of the bicipital groove is of excellent quality and should hold sutures well (TECH FIG 2B,C).
- In most cases, anatomic reduction is desired.
- With three-part fractures involving the greater tuberosity, the head fragment should first be secured to the shaft, followed by reduction of the greater tuberosity.20
- For high surgical neck fractures, sutures should be placed into any remaining tuberosity on the head fragment to help maintain fixation.

OPEN REDUCTION AND INTERNAL FIXATION USING ANATOMIC PLATING

Exposure

- Anatomic plating of the proximal humerus commonly is performed through the deltopectoral interval.
- With the patient in the beach chair position, an incision is made starting from above the coracoid process and extending distally as needed along the deltopectoral groove (TECH FIG 3A).
- The plane between the deltoid and pectoralis major is developed, mobilizing the cephalic vein.
- Cobb elevators can be used to develop this plane, making it easier for the surgeon to identify
AB C

TECH FIG 4 • A. Traction sutures through the tendinous attachments of the rotator cuff may be helpful in correcting varus deformity.
B. Reducing the fracture by elevating the proximal fragment.
C. Correct placement of the plate is lateral to the biceps tendon (not seen here). Suture fixation has been used to help maintain fixation and supplement the plate.

and ligate branches of the cephalic vein (TECH FIG 3B,C).
■ The underlying clavipectoral fascia is identified and incised laterally to the conjoined tendon.10
■ The conjoined tendon is carefully retracted medially with the pectoralis major and the deltoid retracted laterally.

Reduction
■ The fracture and rotator cuff are now visible. With fractures involving displaced tuberosities, we recommend obtaining control of the tuberosities with sutures placed at the bone–tendon interface (TECH FIG 4A).
■ Heavy sutures may be placed through the insertions of the cuff tendons and later used as supplemental fixation if necessary.
■ For fractures with minimally displaced tuberosities, sutures may not be needed before a reduction maneuver.
■ A Cobb elevator placed in the fracture site will aid in reducing the fracture (TECH FIG 4B).
■ The pectoralis major insertion is elevated in a subperiosteal fashion if necessary. The plate should be placed lateral to the biceps tendon so as not to disrupt the blood supply to the humeral head (TECH FIG 4C).
■ Often, it may be necessary to release a small portion of the anterior deltoid insertion before placing the plate.

Plate Fixation
■ Fluoroscopy should be used to confirm the reduction before placement of the plate, especially in regard to the superior aspect of the plate.
■ A plate positioned too high or a fracture fixed in varus may result in the plate impinging on the undersurface of the acromion. K-wires may be used to temporarily maintain fixation proximally and distally.
■ Alternatively, multiple guidewires may be placed into drill sleeves (TECH FIG 5A). Confirm plate location

TECH FIG 3 • A. The incision is made extending from the coracoid process distally along the deltopectoral groove.
B. Identifying the interval between the deltoid and pectoralis major.
C. Using two Cobb elevators to develop the interval, bringing the cephalic vein laterally.
again, both proximally and distally, before placing screws.

- Locking screws usually are placed proximally into the head first, and multiple configurations of screws are possible.
- Once the head is secured to the shaft, distal screws can be placed (TECH FIG 5B).
- Final plate placement should be confirmed fluoroscopically (TECH FIG 5C,D).
- Sutures placed through the cuff tendons also may be secured to the plate, shaft, or other tuberosity.
- At the completion of the procedure, the pectoralis major may be secured with sutures through holes in the plate.

In osteoporotic bone, the tuberosities can first be attached to the shaft with sutures, following which a locking plate may be placed along the lateral aspect of the proximal humerus.

- Fixation of displaced two-part proximal humerus fractures also can be performed using a locking plate in a percutaneous fashion. With this technique, great care must be taken to prevent injury to the axillary nerve.
- A recent cadaveric study demonstrated that the axillary nerve was an average of 3 mm from the second most proximal diaphyseal screw hole, and an average of 7 mm from the third most proximal screw hole. All other screw holes were more than 1 cm from the nerve.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>An understanding of the neurovascular anatomy as well as the deforming forces present in proximal humerus fractures is vital to treating these injuries effectively.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>Avoid devascularizing fracture fragments by stripping pieces minimally. Development of the “interval split” aids in fracture visualization and reduction and does not require detachment of the rotator cuff tendons. This is especially helpful when trying to fix a head-splitting fracture in a young patient.</td>
</tr>
<tr>
<td>Maintaining fixation</td>
<td>K-wires are useful for maintaining initial fixation. With suture fixation, the strong bone along the bicipital groove of the distal fragment will hold sutures the best.</td>
</tr>
<tr>
<td>Poor bone quality</td>
<td>With osteoporotic three-part fractures, consider suture fixation first, followed by a proximal humeral locking plate. Anatomic plating is very helpful when medial comminution is present.</td>
</tr>
<tr>
<td>Superior impingement</td>
<td>Avoid placing the locking plate too high on greater tuberosity.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE
- Stable fixation must be obtained to allow for immediate ROM.
- A physical therapy regimen should be established based on the stability of fixation, the fracture pattern, the quality of the bone, and individual patient factors.
- Ideally, the fixation should allow pendulum exercises on the first postoperative day and 130 degrees of passive forward flexion and 30 degrees of passive external rotation.
- Between 4 and 6 weeks after surgery, an overhead pulley can be added, with stretching and active motion added at 6 to 8 weeks.
- Formal strengthening with elastic bands is not started until 10 to 12 weeks after surgery.3
- As with nonoperative treatment, participation in physical therapy is key to a successful outcome.
- In a recent study looking at fixation of two- and three-part fractures, the only patients with unsatisfactory outcomes were those who were noncompliant with physical therapy.20

OUTCOMES
- Neer’s original description called for fixation of greater tuberosity fractures when there was more than 1 cm of displacement.17
- One recent study had excellent or good results in 12 of 16 patients with fixation of greater tuberosity fractures displaced more than 1 cm.7 Forward elevation averaged 170 degrees, and external rotation averaged 63 degrees.
- Some authors believe that greater tuberosity displacement of greater than 5 mm may lead to poor outcomes.
- McLaughlin14 first suggested that patients in whom a greater tuberosity healed with residual displacement of more than 5 mm had longstanding pain with poor function. Displacement of less than 5 mm does not appear to warrant surgery.
- Platzer et al13 looked at minimally displaced fractures of the greater tuberosity and found no statistical significance with varying degrees of displacement less than 5 mm.
- Open reduction with suture or wire fixation can achieve acceptable fixation, especially in older patients with osteoporotic bone. The technique can be used reliably in two- and three-part fractures.
- One study showed nearly 80% excellent results with average motion of 155 degrees of average forward flexion, 46 degrees average external rotation, and internal rotation to T11. Furthermore, there were no reported cases of osteonecrosis of the humeral head.20
- Early open reduction and internal fixation with a laterally placed T-plate failed to yield consistently good results, especially for four-part fractures.12,19 Other early osteosynthesis techniques include the cloverleaf and the blade-plate, but the current trend is toward anatomic plating technology.
- Recent studies show promise with the use of such locking plates, although this technique is not without complications.6

COMPLICATIONS
- Infection
- Nonunion
- Malunion
- Avascular necrosis
- Nerve injury
- Impingement secondary to fixation or residual tuberosity displacement
- Failure of fixation, including varus malposition and plate fracture with proximal humeral anatomic plating6

REFERENCES


DEFINITION

■ From 50% to 80% of proximal humerus fractures are nondisplaced or minimally displaced and stable. Early range of motion after a short period of immobilization usually is sufficient to treat these fractures and has been shown to result in satisfactory outcomes. The remaining 20% to 50% of patients with proximal humerus fractures may benefit from operative management.

■ Numerous techniques of internal fixation for proximal humerus fractures have been described and reported, including cloverleaf and blade plating, Rush pinning, spiral pinning, Kirschner wire and tension band fixation, and intramedullary nail fixation.

■ Extensive dissection and inadequate biomechanical fixation in the context of severe soft tissue injury and devascularization associated with these complex fracture types are the commonly cited reasons for failure of internal fixation devices.

■ Prosthetic arthroplasty traditionally has been the recommended treatment for three-part fractures with osteoporosis, four-part fractures, head-splitting fractures, and articular compression fractures that involve more than 40% of the articular surface. Recent studies have reported satisfactory results with various types of osteosynthesis for four-part fractures, leading them to recommend an attempt at internal fixation in younger patients. The basis of this recommendation is that subsequent published series have been unable to reproduce Neer’s results with early hemiarthroplasty for four-part fractures.

■ Various reports have been made on the use of intramedullary nails in the proximal humerus. We prefer to use an intramedullary nail that permits stable fixation of the head to the shaft of the humerus using a minimally invasive rotator cuff-splitting approach (DePuy Inc., Warsaw, IN).

■ The method for treatment of proximal humeral fractures described in this chapter involves a minimally invasive anterior acromial surgical approach, an indirect method of reduction, and a unique intramedullary rod designed to permit a variety of proximal interlocking configurations.

ANATOMY

Osteology

■ The proximal humerus includes the humeral head, the lesser tuberosity, the greater tuberosity, and the proximal humeral metaphysis.

■ The position of the head is higher than the tuberosities, and changes in this relationship will cause impingement. The humeral head is slightly medial (3 mm) and posterior (7 mm) in relation to the humeral shaft (FIG 1).

■ The humeral head is retroverted approximately 30 degrees (range 20 to 60 degrees).

Vascular Supply of the Proximal Humerus

■ The anterior and posterior humeral circumflex arteries are branches of the axillary artery.

■ The arcuate artery, the terminal vessel of the ascending branch of the anterior humeral circumflex artery, supplies most of the humeral head.

■ Avascularity of the humeral head can occur if this vessel is disrupted during a fracture of the anatomic neck.

■ The posterior circumflex artery becomes important in patients with proximal humerus fractures.

■ It may be the primary source of blood supply to the fractured head, so care should be taken to prevent additional devascularization.

■ Traumatic and iatrogenic vascular insult may lead to devascularization of the fracture fragments, resulting in delayed union, nonunion, and avascular necrosis. Traumatic injury cannot be predicted; well-planned minimally invasive procedures should reduce the risk of further damage, however.

Innervation

■ The brachial plexus is at risk in patients with upper extremity injury, and thorough neurologic evaluation is mandatory.
The axillary nerve courses through the quadrilateral space, where it is at risk during fracture dislocation.

The lateral entry site for locking screw fixation (4–5 cm distal to the tip of the acromion) places the axillary nerve at risk.

PATHOGENESIS

A blow to the anterior, lateral, or posterolateral aspect of the humerus typically is the cause.

Axial load transmitted to the humerus may cause impacted fracture in osteoporotic bone.

Violent muscle contractures, as in grand mal seizures and electric shock, are associated with posterior dislocation due to overpowering internal rotators and adductors.

Pathologic causes include tumor, multiple myeloma, and metastatic or metabolic disorders.

Osteoporosis is associated with fractures of the proximal humerus (more than any other fracture).

In a three-part fracture with intact greater tuberosity, the humeral head is pulled by the supraspinatus and infraspinatus tendons; if the tendons are intact, the humeral head is externally rotated. The inverse is seen when the greater tuberosity is avulsed: the intact subscapularis internally rotates the humeral head (FIG 2).

NATURAL HISTORY

Epidemiology

4% to 5% of all fractures

Increased incidence in osteoporosis, older middle-aged and elderly persons (third most common fracture in elderly)

In persons older than 50 years of age, the female: male ratio is 4:1 (osteoarthritis). Minor falls and trauma may cause comminuted fracture.

In patients younger than 50 years of age, violent trauma, contact sports, and falls from heights are responsible for fractures.

Surgical neck fracture is common.

Consequences of Injury

Nondisplaced fractures may heal without major consequences.

Acute, recurrent, or chronic dislocation

Rotator cuff tears

Neurovascular injury: axillary nerve, brachial plexus

Avascular necrosis of the humeral head often results from disruption of the arcuate artery. The axillary artery also may be damaged, but less commonly, in fracture-dislocations.

Malunion: loss of humeral length may cause deltoid weakness

Posttraumatic arthrosis

Adhesive capsulitis

Chronic pain

PATIENT HISTORY AND PHYSICAL FINDINGS

Associated injuries:

Rotator cuff tears

Dislocation

Forearm fractures

Brachial plexus, axillary, radial and ulnar nerve injuries (5%–30% of complex proximal humerus fractures)

IMAGING AND OTHER DIAGNOSTIC STUDIES

Trauma series

Scapular anteroposterior (glenoid view)

Trans-scapular

Axillary

Rotational views

CT scan

SURGICAL MANAGEMENT

Indications

Two-part proximal humerus fracture

Three-part proximal humerus fracture

Certain four-part proximal humerus fractures

Prerequisites

Shoulder table, image intensification, and experienced radiology technician

Be aware of the learning curve (do not attempt nailing of a four-part fracture before acquiring adequate experience with two- and three-part fractures).

FIG 2 • A. Fracture pattern and deforming forces. The muscular attachments of the greater and lesser tuberosities will cause abduction, external rotation, and internal rotation, respectively. The head will follow whichever tuberosity is intact. B, C. In four-part fractures, the head often is in a neutrally rotated position. (Copyright J. Dean Cole, MD.)
When treating patients with complex fractures, obtain the patient’s consent for a hemiarthroplasty if that is determined to be the best treatment, and have the implant available in case it is found to be necessary.

Contraindication: head-splitting, comminuted displaced humeral head fragment devoid of soft tissue attachment

Preoperative Planning

- Successful intramedullary nailing of the proximal humerus fracture depends on consistent integration between image intensification and the surgical steps.
- Patient positioning on a radiolucent table will allow the surgeon to use a minimally invasive approach.
- Any error on the entry site will cause inevitable problems with the rest of the procedure.
- It is crucial that the surgeon follow the surgical technique precisely.

Positioning

- Positioning on the table must allow orthogonal and overhead axillary views.

The patient is placed supine in the beach chair position on a radiolucent table tilted at 60 to 70 degrees. The C-arm should be positioned on the opposite side of the table to allow the surgeon easy access to the proximal humerus (FIG 3).

A bolster is used to elevate the shoulder from the table and to allow shoulder extension. Extension of the shoulder is necessary to expose the entry site in the humeral head. Flexion of the shoulder will result in the acromion overlying the center of the humeral head in the sagittal plane, obscuring the entry site or errantly directing an entry angle. Anterior cutout of the nail in the head fragment can easily occur in an osteoporotic humeral head with an associated greater tuberosity fracture.

Approach

- Intramedullary nailing for isolated surgical neck fractures may be performed completely percutaneously using most of the techniques described in the following paragraphs. However, when tuberosity reduction and fixation are required, a wider approach often is necessary.
- The timing of the open approach depends on the sequencing of head, shaft, and tuberosity fixation. In the technique we describe in this chapter, head–shaft fixation is accomplished percutaneously using nailing and interlocking screws before tuberosity fixation. Alternatively, an open approach with tuberosity reduction and fixation can be performed before nail insertion.
- The surgical approach for viewing tuberosity fractures that require fixation is a lateral deltoid-splitting approach made just below the acromion, approximately 4 cm long, that does not extend distally, to avoid injury to the axillary nerve (FIG 4A).
- For a lesser tuberosity approach, a separate, small deltopectoral incision is centered just over the lesser tuberosity, and the lesser tuberosity fixation or fixation to the subscapularis tendon is performed in that plane (FIG 4B).
- The rotator cuff is incised longitudinally away from the lateral watershed area of the rotator cuff and away from Sharpey’s fibers and the connection of the tendon to the bone.
- Significant rotator cuff defect is not created with this approach, as confirmed in cadaver dissection. The longitudinal incision on the rotator cuff does not weaken the cuff.
K-WIRE PLACEMENT

Placement of K-wires allows fragment reduction and helps dictate placement of the skin incision and surgical approach. Hence, the first step involves placement of a K-wire in the subacromial space; it is inserted through the anterolateral aspect of the shoulder using the image intensifier (C-arm) and directed posteromedial toward the glenoid (TECH FIG 1A,B).

- This initial pin will serve as a guide for the retroversion of the humeral head.
- Next, two K-wires are placed in the humeral head, directed lateral to medial, one anterior and one posterior to the central aspect of the head (TECH FIG 1C,D). The wires should be separated by enough distance to allow insertion of the nail between them (1.5 cm).

The K-wires should be directed in the longest axis of the humeral head in the axial plane. Allowing for retroversion is important. Confirmation of the correct placement in the axial plane is done by the overhead axillary view. Then the C-arm is positioned to view the advancement of the pins in the coronal plane projection.

With longer K-wires, the surgeon’s hand can be kept out of radiographs. Unfortunately, with internal rotation, extension also occurs in the humerus and the humeral head, depending on the soft tissue attachments.

TECH FIG 1 • A,B. AP and axial views of initial K-wire insertion: This initial pin will serve to orient the humeral head, specifically the desired degree of retroversion. C,D. AP and axial views of pins to control head fragment. These pins are inserted to control the head fragment in a joystick fashion. (Copyright J. Dean Cole, MD.)
## Fragment Reduction

- The K-wires can then be used in a joystick fashion to adduct and extend the head, exposing the supraspinatus tendon and optimal entry site in the head from beneath the anterior edge of the acromion (TECH FIG 2A,B).
- Image intensification can be used to place a K-wire through the head in line with intramedullary axis of the humerus. This maneuver includes two important aspects:
  - The first is to use the joysticks to extend and adduct the proximal humeral head, exposing the anterolateral portion of the head from under the acromion while simultaneously distracting the distal shaft, thereby aligning the longitudinal intramedullary axis of the proximal and distal fragments (TECH FIG 2C,D).
  - The second is to drive the K-wire into the head in a central position with reference to the medullary canal in the sagittal plane and lateral to central in reference to the canal in the frontal or coronal plane (TECH FIG 2E).
- To achieve fracture reduction, the joysticks in the proximal fragment must be used to rotate the head while simultaneously rotating the distal shaft manually to obtain true orthogonal views of the head in reference to the shaft.

![TECH FIG 2 • Fragment reduction maneuver. A,B. Combining rotation of the head fragment (K-wires) with the shaft (arm) is used to assist in fracture reduction. C,D. AP and axial views of humeral head reduction maneuver. Manipulation of the fracture fragments with the K-wires allows disimpaction of the fracture, improving the varus or valgus alignment. E. Pin entry site in humeral head. (Copyright J. Dean Cole, MD.)](image)

## Guidewire Placement

- The nail can be placed percutaneous just anterior to the anterior edge of the acromion.
- The anterior edge may be difficult to palpate and to differentiate from the humeral head because of edema and hematoma from the fracture. Therefore, it is helpful to locate the anterior edge of the angle of the acromion under image intensification with a K-wire where it intersects the longitudinal axis of the humerus.
ENTRY SITE REAMING

- Reaming of the entry site should be performed carefully, as the percutaneous incision is small.
- The reamer is inserted over the guidewire, and the soft tissues are retracted and protected. The reamer is advanced through the rotator cuff in “reverse” until bone contact, then on “forward” through the humeral head. The reamer is left in place.
- The guidewire that was used to initiate the entry site is removed, and a longer guidewire is passed to the shaft fragment. Manipulation of the shaft fragment sometimes is necessary. The reamer’s sound must be used to gauge the canal diameter. It is necessary to ream 1 mm greater than the anticipated nail size.
- On some occasions, even external fixator placement from the scapular spine to the distal humerus is necessary. The external fixator is applied and distraction accomplished with manipulation of the proximal aspect of the shaft; guidewire passage usually is simple.

NAIL INSERTION

- Once the nail is inserted, confirm the rotation of the humerus in the axial plane; it is necessary to ensure proper alignment before impaction (TECH FIG 3).
- Usually, impaction of the distal fragment by blows against the olecranon, while supporting the proximal humeral head indirectly through the soft tissues, is adequate.
- Large gaps are not acceptable, and it may be necessary to use filler substance.

INTERLOCKING SCREW FIXATION

- We recommend that the oblique distal screw be the initial locking screw (TECH FIG 4). The goal of this screw is to attach the head to the shaft before fixation of the tuberosities.
- Screw placement puts the axillary nerve at risk. Careful blunt dissection to bone, drilling within the sheath, and placing the screw within the confines of the sheath are necessary. Drilling should be done very carefully, although it certainly does not completely negate the risk of drilling through the humeral head. Careful observation is important.
- It is occasionally helpful to remove the drill and then use a blunt guidewire and assure good humeral head subchondral bone contact before further drilling or screw placement.
- Central placement of the distal oblique screw in the humeral head is important. This step should flow very smoothly if the initial K-wires have been placed in the correct axial plane alignment.
- Errant placement or acceptance of poorly positioned K-wires will result only in further deviation. If the distal oblique screw is not placed at the appropriate
angle, the radiographs may be deceptive and may result in screw penetration.

- Screw placement on the subchondral bone is important for fixation. However, patients with osteoporosis do have a risk of the fracture fragment settling.

- A and B screws are placed depending on goals of fixation.
- Overdrilling to countersink the more proximal screw usually is necessary to avoid impingement.
- These screws rarely are helpful in tuberosity fixation.

The sequence of fixation should involve passing sutures through the musculotendinous junction of the subscapularis, infraspinatus, and supraspinatus. Sutures passed over the superior aspect of the head from the infraspinatus and subscapularis and sutures passed laterally around the head provide helpful, reliable fixation points. With practice, these maneuvers can be performed in a minimally invasive manner.

Comminuted tuberosity fixation is challenging. It is difficult to achieve consistent fixation with screws. A headless screw has been used with some success in limited cases.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Indications</th>
<th>Two-part proximal humerus fracture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Three-part proximal humerus fracture</td>
</tr>
<tr>
<td></td>
<td>Select four-part proximal humerus fracture</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prerequisites</th>
<th>Shoulder table, image intensification, and experienced radiology technician</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Be aware of the learning curve.</td>
</tr>
<tr>
<td></td>
<td>Plan B: for complex fractures, obtain consent for a hemiarthroplasty and have an implant available.</td>
</tr>
</tbody>
</table>

| Contraindication             | Head-splitting, comminuted displaced humeral head fragment devoid of soft tissue attachment |

| Positioning                  | Beach chair position to allow clear fluoroscopic images. Chair with metal extensions positioned to allow overhead axillary C-arm views. |
## Postoperative Care

- The postoperative regimen depends on the stability of the fixation and the soft tissues.
  - Sling with abduction pillow that allows the proximal humerus to rest in neutral rotation and slight abduction (relax the rotator cuff and decrease tension on the greater tuberosity)
  - Gentle passive, pendulum, and active-assisted exercises of the shoulder
  - Active elbow and wrist exercises
  - Once fracture healing is detected on radiographic imaging, range of motion can be increased; weight lifting restrictions must be maintained until healing is complete.

## Complications

- **Early**
  - Injury to axillary nerve
  - Joint penetration
  - Loss of reduction
  - Infection

- **Late**
  - Nonunion
  - Posttraumatic arthrosis
  - Avascular necrosis of humeral head
  - Prominent hardware

## References

**DEFINITION**

- Proximal humerus fractures involve isolated or combined injuries to the greater tuberosity, lesser tuberosity, articular segment, and proximal humeral shaft.
- Overall, proximal humerus fractures account for 4% to 5% of all fractures. \(^8,^13\)

**ANATOMY**

- The proximal humerus consists of four segments: the greater tuberosity, lesser tuberosity, articular segment, and humeral shaft (FIG 1).
- The most cephalad surface of the articular segment is, on average, 8 mm above the greater tuberosity. \(^16\) Humeral version averages 29.8 degrees (range 10 to 55 degrees). \(^5^3\)
- The intertubercular groove lies between the tuberosities and forms the passageway for the long head of the biceps as it traverses from the intra-articular origin into the distal arm.
- The tuberosities attach to the articular segment at the anatomic neck. The greater tuberosity has three facets for the corresponding insertions of the supraspinatus, infraspinatus, and teres minor tendons; the lesser tuberosity has a single facet for the subscapularis.
- The deltoid, pectoralis major, and latissimus dorsi all insert on the humerus distal to the surgical neck. These soft tissue attachments contribute to the deforming forces sustained with proximal humerus fractures.
- The anterolateral branch of the anterior humeral circumflex artery (the arcuate artery of Laing) is the major blood supply to the humeral head. This vessel courses parallel to the lateral aspect of the long head of the biceps and enters the humeral head at the interface between the intertubercular groove and the greater tuberosity. Injury to the arcuate artery can result in osteonecrosis of the articular segment. \(^10,^18\)

**PATHOGENESIS**

- The incidence of proximal humerus fractures is increasing with an aging population and associated osteoporosis.
- The mechanism of injury may be indirect or direct and secondary to high-energy collisions in younger patients (eg, motor vehicle accidents, athletic injuries) or falls from standing height in elderly patients.
- Pathologic fractures from primary or metastatic disease should be included in the differential diagnosis.
- Risk factors for the development of proximal humerus fractures in the elderly patient population include low bone density, lack of hormone replacement therapy, previous fracture history, three or more chronic illnesses, and smoking. \(^15\)

**NATURAL HISTORY**

- Neer’s classic study in 1970 compared the results of nonoperative treatment with hemiarthroplasty for three- and four-part displaced proximal humerus fractures. No satisfactory results were found in the nonoperative group owing to inadequate reduction, nonunion, malunion, and humeral head osteonecrosis with collapse. \(^20\)
- Stableforth \(^24\) reaffirmed this in a study in which patients were randomized to nonoperative management or prosthetic replacement. The patients with displaced fractures treated nonoperatively had worse overall results for pain, range of motion, and activities of daily living.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- A thorough history and complete physical examination should be performed. History should include mechanism of injury, pre-morbid level of function, occupation, hand dominance, history of malignancy, and ability to participate in a structured rehabilitation program. \(^14\)
- A review of systems should involve queries regarding loss of consciousness, paresthesias, and ipsilateral elbow or wrist pain.
- On physical examination, the orthopaedic surgeon should look for swelling, soft tissue injuries, ecchymosis, and deformity. Posterior fracture-dislocations will demonstrate flattening of the anterior aspect of the shoulder with an associated posterior prominence. Anterior fracture-dislocations present with opposite findings. \(^14\)

**FIG 1 • Neer classification of proximal humerus fractures:**

1. greater tuberosity; 2. lesser tuberosity; 3. articular surface; 4. shaft.
IMAGING AND OTHER DIAGNOSTIC STUDIES

- Appropriate radiographs include anteroposterior and axillary views of the shoulder (FIG 2). If the axillary view cannot be obtained because of patient discomfort, alternate views such as the Velpeau trauma axillary view can be used to evaluate and classify the glenohumeral articulation.2
- The Neer classification is based on the four anatomic segments of the proximal humerus: the humeral head, the greater and lesser tuberosities, and the humeral shaft (see Fig 1).11 Number of parts is based on 45 degrees of angulation or 1 cm of displacement from neighboring segments.
- The AO/ASIF/OTA Comprehensive Long Bone Classification system distinguishes the valgus impacted four-part proximal humerus fracture from other four-part fractures with partial preservation of the vascular inflow to the articular segment through an intact medial capsule.17,22
- The current fracture classification systems have fair interobserver reliability, even with the addition of CT scans. Despite the limitations of these systems, they remain clinically useful when deciding on nonoperative versus operative treatment.2,11
- CT scans may be helpful in evaluating tuberosity displacement and articular surface involvement.14

DIFFERENTIAL DIAGNOSIS

- Acute hemorrhagic bursitis
- Traumatic rotator cuff tear
- Simple dislocation
- Acromioclavicular separation
- Calcific tendinitis 2

NONOPERATIVE MANAGEMENT

- Nonoperative treatment usually is reserved for minimally displaced fractures of the proximal humerus, which account for nearly 80% of these injuries.
- The characteristics of the fracture (ie, bone quality, fracture orientation, concurrent soft tissue injuries), the personality of the patient (eg, compliant, realistic expectations, mental status), and surgeon experience all affect the decision to proceed with operative intervention.
- Moribund individuals and patients unable to cooperate with a postoperative rehabilitation program (eg, closed head injury) are not appropriate candidates for operative intervention.
- In general, nonoperative management of complex, displaced proximal humerus fractures has not proven as successful.
- Initial immobilization with a sling and axillary pad may be helpful. Gentle range-of-motion exercises may be started by 7 to 10 days after the fracture when pain has decreased and the patient is less apprehensive.2
- Intermittent biplanar radiographs are essential to determine additional displacement and the interval stage of healing.2
- Active and active assisted range-of-motion exercises are initiated with evidence of radiographic union. Inform the patient that he or she may never attain symmetric range of motion or strength when comparing the affected versus the uninjured side.

SURGICAL MANAGEMENT

- The goal of surgery is to anatomically reconstruct the glenohumeral joint with restoration of humeral length, placement of appropriate prosthetic retroversion, and establishment of secure tuberosity fixation.
- Prosthetic replacement is the preferred treatment of most four-part fractures, three-part fractures and dislocations in elderly patients with osteoporotic bone, head-splitting articular segment fractures, and chronic anterior or posterior humeral head dislocations with more than 40% of the articular surface involved.25
- Several studies have indicated that the outcome of primary hemiarthroplasty for acute proximal humerus fractures is superior to that from late reconstruction.6,21

Preoperative Planning

- Although some studies have suggested urgent intervention (ie, within less than 48 hours), most authors recommend preoperative planning with a careful neurovascular assessment of the injured shoulder, medical optimization of the patient, and preoperative templating with standard radiographs of the contralateral uninjured shoulder.12
- An interscalene block (regional anesthesia) may be used to supplement general anesthesia.
- Endotracheal intubation is recommended to allow for intraoperative muscle relaxation, but laryngeal mask intubation may be used.12,14
Positioning
- The patient is placed on an operating table in the beach chair position with the arm positioned in a sterile articulating arm holder or draped free if an appropriate number of assistants are available (FIG 3).

Approach
- The surgical prep site should include the entire upper extremity and shoulder region, including the scapular and pectoral regions.
- Appropriate prophylactic intravenous antibiotics are given to the patient before skin incision.
- A standard deltopectoral incision is used. Care is taken to minimize injury (eg, surgical detachment, contusion secondary to retractors) to the deltoid muscle. The musculocutaneous and axillary nerves are identified and protected during the procedure.

DE尔TOPECTORAL APPROACH
- The incision begins superior and medial to the coracoid process and extends toward the anterior aspect of the deltoid insertion (TECH FIG 1A).
- The cephalic vein is identified, preserved, and retracted laterally with the deltoid muscle. The pectoralis major is mobilized medially. If additional exposure is necessary, the proximal 1 cm of the pectoralis major insertion is released (TECH FIG 1B).
- Fracture hematoma usually is encountered once the clavipectoral fascia is incised. At this time, fracture fragments and the rotator cuff musculature become evident. The axillary and musculocutaneous nerves can be identified through digital palpation of the anteroinferior aspect of the subscapularis muscle and the posterior aspect of the coracoid muscles respectively. External rotation of the humerus results in reduced tension on the axillary nerve.

TUBEROSITY MOBILIZATION
- The tendon of the long head of the biceps is identified as it courses in the bicipital groove toward the rotator interval. The tendon serves as a key landmark when re-establishing the anatomic relationship between the greater and lesser tuberosities.
- The rotator interval and coracohumeral ligament are both released to allow for mobilization of the tuberosities (TECH FIG 2A,B).
- If the fracture does not involve the bicipital groove, an osteotome or saw may be used to create a cleavage plane for tuberosity mobilization. Preservation of the coracocromial ligament is advisable to maintain the coracocromial arch.
- Heavy, nonabsorbable traction sutures (eg, 1-mm cottony Dacron) are placed through the rotator cuff insertions on the tuberosities. Two or three sutures should be placed through the subscapularis tendon, and three or four sutures through the supraspinatus.
- Tuberosity fragments vary in size and may require trimming for reduction and repair (TECH FIG 2C,D).
With the tuberosities retracted on their muscular insertions, the humeral head and shaft fragments are removed.

The native articular surface is removed and sized with a template for trial humeral head replacement (TECH FIG 2E).

The glenoid must be examined for concomitant pathology. Hematoma and cartilaginous or bony fragments are removed with sterile saline irrigation.

Glenoid fractures should be stabilized with internal fixation. If the glenoid exhibits significant degenerative wear or irreparable damage, a glenoid component must be used.
HUMERAL SHAFT PREPARATION

- The proximal end of the humeral shaft is delivered into the incisional wound. Loose endosteal bone fragments and hematoma are removed from the canal of the humeral shaft.
- Axial reamers, preferably without power, are used to prepare the humeral shaft for trial implantation.
- The trial humeral implant is placed with the lateral fin slightly posterior to the bicipital groove, and with the medial aspect of the trial head at least at the height of the medial calcar.
- Formerly, we used a sponge to anchor the trial stem within the intramedullary canal of the humerus. We currently use a commercially available fracture jig that can maintain the height and retroversion of the trial component through a functional range of motion (TECH FIG 3).12,14

DETERMINATION OF HUMERAL RETROVERSION

- Correct humeral retroversion is critical when recreating the glenohumeral articulation. Most techniques suggest 30 degrees as a guide during reconstruction, although native retroversion may vary from 10 to 50 degrees.
- Several methods are employed to gauge this angle:
  - External rotation of the humerus to 30 degrees from the sagittal plane of the body with the humeral head component facing straight medially
  - An imaginary line from the distal humeral epicondylar axis that bisects the axis of the prosthesis
  - Positioning of the lateral fin of the prosthesis about 8 mm posterior to the biceps groove (TECH FIG 4).

DETERMINATION OF PROSTHETIC HEIGHT

- The prosthetic height also is critical in re-establishing appropriate muscle tension and shoulder mechanics.
- Preoperative templating may be helpful.
- Intraoperative examination of soft tissue tension, including the deltoid, rotator cuff, and the long head of the biceps, combined with fluoroscopic imaging aids in prosthetic height placement.
- Common errors involve placing the prosthesis too low, resulting in poor deltoid muscle tension and no room for the tuberosities (TECH FIG 5).
- Drill holes are placed in the proximal humerus medial and lateral to the bicipital groove, with 1-mm cottony Dacron sutures subsequently passed for fixation of the tuberosity to the shaft (TECH FIG 6A).

- A trial reduction is then performed with the mobilized tuberosities fitted below the head of the modular prosthesis.

- A towel clip can be used to hold the tuberosities for fluoroscopic examination and assessment of glenohumeral stability.

- Intraoperative fluoroscopy is helpful in confirming appropriate implant height and glenohumeral stability (TECH FIG 6B).

- The humeral head should not subluxate more than 25% to 30% of the glenoid height inferiorly.

**TECH FIG 5** Height adjustment. A commercially available fracture jig permits intraoperative height adjustment. Similarly, a sponge may be placed holding the trial stem at a determined level, allowing for intraoperative assessment. (Copyright Steven B. Lippitt, MD.)

**TECH FIG 6** • A. Humeral shaft preparation. Drill holes are placed in the proximal humerus medial and lateral to the bicipital groove with 1-mm cottony Dacron sutures. B. Trial reduction. A trial reduction may be performed with the fracture jig in place, allowing assessment of the functional range of motion. (Copyright Steven B. Lippitt, MD.)

**FINAL IMPLANT PLACEMENT**

- The final humeral component should be cemented in all fracture patients.
  - A cement restrictor is placed to prevent cement extravasation distally.

- Pulsatile lavage and retrograde injection of cement with suction pressurization also is used (TECH FIG 7A). Excess cement is removed during the curing phase.
- Spaces between the tuberosities, prosthesis, and shaft are packed with autogenous cancellous bone graft from the resected humeral head (TECH FIG 7B).
- A second trial reduction may be performed with a trial head after cement fixation of the humeral stem.
- The final head may be impacted before stem implantation or after the repeat trial reduction.
- A cerclage suture is placed circumferentially around the greater tuberosity and through the supraspinatus insertion, and then medial to the prosthesis and through the subscapularis insertion (lesser tuberosity). Several authors have indicated superior fixation with the cerclage suture when compared to tuberosity-to-tuberosity and tuberosity-to-fin fixation alone.\textsuperscript{23}
- Overreduction of the tuberosities should be avoided to prevent limitations in external (lesser tuberosity) and internal (greater tuberosity) rotation.
- Sutures are then tied, beginning with tuberosity-to-shaft reapproximation, followed by tuberosity-to-tuberosity closure using the previously placed suture limbs (TECH FIG 7C).
- The lateral portion of the rotator interval is closed with the arm in approximately 30 degrees of external rotation.

**TECH FIG 7**  
A. A cement restrictor is placed to prevent cement extravasation distally. Pulsatile lavage and retrograde injection of cement with suction pressurization is also used.  
B. Morselized cancellous bone graft is placed between the tuberosities and shaft.  
C. Tuberosity fixation. Previously placed suture limbs through the tuberosities and shaft are reapproximated. Not shown: a medial cerclage suture is placed circumferentially around the greater tuberosity and through the supraspinatus insertion, and then medial to the prosthesis and through the subscapularis insertion (lesser tuberosity) and tied.  
D. The rotator interval is closed with no. 2 nonabsorbable suture with the arm in about 30 degrees of external rotation. (A, C, D: Copyright Steven B. Lippitt, MD. B: Courtesy of DePuy Orthopaedics.)

**SURGICAL WOUND CLOSURE**

- The deltopectoral interval usually is not closed. Drain suction is recommended in both acute and chronic injuries to prevent hematoma formation.
- A commercially available pain pump may be used to augment postoperative analgesia and to reduce narcotic medication use.
- The subcutaneous tissues are reapproximated with 2-0 absorbable suture. Subcuticular closure is performed with 2-0 monofilament suture.
- The patient is then placed in a sling or shoulder immobilizer with 45 degrees of abduction for comfort.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Use the long head of the biceps to define the tuberosities for mobilization.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imaging studies</td>
<td>Appropriate plain radiographs with possible CT scan supplementation aid in the surgical decision-making.</td>
</tr>
<tr>
<td>Tuberosity identification</td>
<td>Know the specifics of the implant system, including its limitations.</td>
</tr>
<tr>
<td>Implant placement</td>
<td>Place the implant in appropriate retroversion (approximately 20 to 30 degrees).</td>
</tr>
<tr>
<td>Tuberosity fixation</td>
<td>Avoid loss of external rotation or internal rotation with overreduction of the lesser and greater tuberosities, respectively.</td>
</tr>
<tr>
<td>Postoperative rehabilitation</td>
<td>On postoperative day 1, initiate gentle pendulum exercises, with passive forward flexion and external rotation (at 0 degrees of abduction). Always modify rehabilitation protocol based on intraoperative assessment of soft tissue compromise and patient neurologic status.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Physician-directed therapy is initiated on postoperative day 1 with gentle, gravity-assisted pendulum exercises, as well as passive pulley-and-stick exercises to maintain forward flexion and external rotation (motion limits placed by surgeon based upon intraoperative stability).
- After discharge, the patient’s wound is re-examined and sutures removed at 10 to 14 days. Gentle range-of-motion exercises are continued.
- At 6 weeks, repeat radiographs are obtained to evaluate tuberosity healing. When tuberosity healing is evident, phase 2 exercises are initiated with isometric rotator cuff exercises and active assisted elevation with the pulley.
- At 3 months, strength training with graduated rubber bands (phase 3) is implemented. Maximal motion and function are obtained at about 12 months from date of surgery.

OUTCOMES

- About 90% of patients treated with hemiarthroplasty demonstrate minimal pain, despite a wide range of function, motion, and strength.
- Factors that portend a poor outcome after hemiarthroplasty for fractures include tuberosity malposition, superior migration of the humeral prosthesis, stiffness, persistent pain, poor initial positioning of the implant (excessive retroversion, decreased height), and age over 75 years in women.4
- When comparing acute intervention versus late reconstruction, most authors report poorer outcomes with delayed surgical intervention (more than 2 weeks), particularly with functional results.20,25,26

COMPLICATIONS

- Complications include delays in wound healing, infection, nerve injury, humeral fracture, component malposition, instability, nonunion of the tuberosities, rotator cuff tearing, regional pain syndrome, periarticular fibrosis, heterotopic bone formation, component loosening, and glenoid arthritis.3,7,19
- The most common problems in acute fracture treatment involve stiffness, nonunion, malunion or resorption of the tuberosities.7,19
- In patients with chronic fractures treated with hemiarthroplasty, the most common problems encountered were instability, heterotopic ossification, tuberosity malunion or nonunion, and rotator cuff tears.19

REFERENCES


DEFINITION
- Humeral shaft fractures, which account for about 3% of adult fractures, usually result from a direct blow or indirect twisting injury to the brachium.
- These injuries are most commonly treated nonoperatively with a prefabricated fracture brace. The humerus is the most freely movable long bone, and anatomic reduction is not required.
- Patients often can tolerate up to 20 degrees of anterior angulation, 30 degrees of varus angulation, and 3 cm of shortening without significant functional loss.
- There are, however, several indications for surgical treatment of humeral shaft fractures:
  - Open fracture
  - Bilateral humeral shaft fractures or polytrauma; floating elbow
  - Segmental fracture
  - Inability to maintain acceptable alignment with closed treatment (ie, angulation greater than 15 degrees)—seen more commonly with transverse fractures
  - Humeral shaft nonunion
  - Pathologic fractures
  - Arterial or brachial plexus injury
- Open reduction with internal plate fixation requires extensive dissection and operative skill. However, it offers advantages over intramedullary fixation because the rotator cuff is not violated, which leads to improved postoperative shoulder function.

ANATOMY
- The humeral shaft is defined using Key’s landmarks: the area between the upper margin of the pectoralis major tendon and the supracondylar ridge.
- The blood supply of the humeral shaft comes from the posterior humeral circumflex vessels and branches of the brachial and profunda brachial arteries.
- The radial nerve and profunda brachial artery pass through the triangular interval (bordered superiorly by the teres major, medially by the medial head of the triceps, and laterally by the humeral shaft). The nerve then transverses from medial to lateral behind the humeral shaft and travels distally to a location between the brachialis and brachioradialis muscles.
- The musculocutaneous nerve lies on the undersurface of the biceps muscle and terminates distally as the lateral antebrachial cutaneous nerve.
- The humeral shaft has anteromedial, anterolateral, and posterior surfaces. Proximal and midshaft fractures are more amenable to plating on the anterolateral surface, whereas distal fractures often require posterior plate fixation.

PATHOGENESIS
- Humeral shaft fractures occur after both direct and indirect injuries. Direct blows to the brachium can fracture the humeral shaft in a transverse pattern, often with a butterfly fragment. Injuries with high degrees of energy often result in a greater degree of fracture comminution.
- Indirect injuries, such as those that can occur with activities such as arm wrestling, often involve a twisting mechanism and result in a spiral fracture pattern. Higher-energy injuries may result in muscle interposition between the fracture fragments, which can inhibit reduction and healing.
- A study of 240 humeral shaft fractures revealed radial nerve palsies in 42 patients, for an overall rate of 18% (17% in closed injuries). Fractures in the midshaft were more likely to have concomitant radial nerve palsy. Twenty-five of these patients had complete recovery in a range of 1 day to 10 months. Ten patients did not have radial nerve recovery. Median and ulnar nerve palsies were seen very rarely in patients with open fractures.
- Concomitant vascular injuries are present in about 3% of patients with humeral shaft fractures.

NATURAL HISTORY
- Almost all humeral shaft fractures heal with nonoperative management. The most common treatment method is initial splinting from shoulder to wrist, followed by application of a prefabricated fracture brace when the patient is comfortable, usually within 2 weeks of the injury.
- Studies by Sarmiento and coauthors have shown the effectiveness of functional bracing in the treatment of humeral shaft fractures. Nonunion rates with this method of treatment are in the 4% range, lower than seen when treating with external fixators, plates, or intramedullary nails.
- Closed fractures with initial radial nerve palsy can be observed, with expected recovery over a period of 3 to 6 months. Late-developing radial nerve palsies require surgical exploration.
- Angulation of the humeral shaft after fracture healing is expected and is well tolerated when it is less than 20 degrees. Varus deformity is most common.
- Adjacent joint stiffness of the shoulder and elbow also is common. If the situation dictates treatment, physical therapy reliably restores joint motion in these patients.
- Relative contraindications to closed treatment include bilateral humeral shaft fractures or patients with polytrauma who require an intact brachium to ambulate. Transverse fractures and those with significant muscle imposition also are more amenable to operative fixation.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The examining physician must perform a complete examination of the affected limb to rule out concomitant injuries.
- The skin should be thoroughly evaluated for evidence of an open fracture. This includes examination of the axilla.
and exit wounds are sought in gunshot victims. Swelling is common, and the patient may have an obvious deformity.

- The patient often braces the affected limb to his or her side, making evaluation of shoulder and elbow range of motion difficult. Bony prominences should be gently palpated to evaluate for other injuries, such as an olecranon fracture.
- Evaluate the appearance and skeletal stability of the forearm to rule out the presence of a co-existing both-bone forearm fracture (“floating elbow”). This finding necessitates operative fixation of humeral, radial, and ulnar fractures.
- Determine the vascular status of the upper extremity by palpating the radial and ulnar pulses at the wrist. Compare these findings with the unaffected limb. Selected cases may require Doppler arterial examination.\(^2\)
- A complete neurologic assessment is necessary, with particular attention focused on the status of the radial nerve. This structure is at risk proximally as it passes posterior to the humeral shaft after emerging from the triangular interval, as well as distally, as it lies adjacent to the supracondylar ridge (near the location of the Holstein-Lewis distal one-third spiral humeral shaft fracture).
- Examine sensory function in the first dorsal web space, wrist extension, and thumb interphalangeal joint extension to determine the functional status of the radial nerve.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- At least two plain radiographs at 90-degree angles to each other are necessary to evaluate the displacement, shortening, and comminution of the humeral shaft fracture.
- Radiographic views of the shoulder and elbow are necessary to rule out proximal extension of the shaft fracture or concomitant elbow injury (ie, olecranon fracture). This is especially important in high-energy injuries
- If swelling or evidence of skeletal instability about the forearm is present, dedicated forearm radiographs can determine the presence of a floating elbow (ie, ipsilateral humeral shaft fracture plus both-bone forearm fractures).

**DIFFERENTIAL DIAGNOSIS**

- Distal humerus fracture
- Proximal humerus fracture
- Elbow dislocation
- Shoulder dislocation

**NONOPERATIVE MANAGEMENT**

- Most isolated humeral shaft fractures can be treated nonoperatively. Initial treatment can vary with fracture location and involves splinting in either a posterior elbow or coaptation splint. The elbow is positioned in 90 degrees of flexion. An isolated humeral shaft fracture rarely necessitates an overnight hospital stay.
- In the past, definitive nonoperative treatment involved coaptation splinting or the use of hanging arm casts. Currently, functional fracture bracing provides adequate bony alignment, while local muscle compression and fracture motion promote osteogenesis. These braces provide soft tissue compression and allow functional use of the extremity.\(^11\)
- Timing of brace application depends on the degree of swelling and patient discomfort. On average, the brace is applied about 2 weeks after the injury. A collar and cuff help with initial patient comfort and should be worn during recumbency until the fracture heals.
- The brace often requires frequent retightening over the first 2 weeks as swelling subsides. Elbow and wrist range-of-motion exercises out of the sling are encouraged.
- Functional bracing requires that the patient be able to sit erect, and weight bearing on the humerus is not allowed. The level of humeral shaft fracture does not preclude the use of functional bracing, even if the fracture line extends above or below the brace.
- Anatomic alignment of the humerus rarely is achieved, with varus deformity most common. However, patients often are able to tolerate the bony angulation and still perform activities of daily living after injury. A cosmetic deformity rarely exists.
- Pendulum exercises are encouraged as soon as possible post-injury. Active elevation and abduction are avoided until bony healing has occurred, to prevent fracture angulation. The surgeon obtains radiographs after brace application and again 1 week later. If alignment is acceptable, repeat radiographs are obtained at 3- to 4-week intervals until fracture healing occurs.\(^10,11\)

**SURGICAL MANAGEMENT**

- Certain humeral shaft fractures are not amenable to conservative treatment. Open fractures or high-energy injuries with significant axial distraction are treated with open reduction and internal fixation. Patients with polytrauma, bilateral humeral shaft fractures, vascular injury, or an inability to sit erect are best treated with operative fixation. Unacceptable fracture alignment requires abandonment of nonoperative treatment. Finally, humeral shaft nonunion is a clear indication for open reduction and internal fixation with bone grafting.\(^4,9\)

**Preoperative Planning**

- The surgeon must review all radiographic images and must rule out ipsilateral elbow or shoulder injury.
- Preoperative radiographs help the surgeon estimate the required plate length. Higher-energy injuries with comminution may benefit from plating and supplemental bone grafting. The surgeon must plan for various scenarios based on these studies: moderate comminution or bone loss can be addressed with cancellous allograft or autograft bone, whereas more extensive bone defects may require strut grafting.
- Proximal and middle-third humeral shaft fractures are addressed using an anterolateral approach. Distal-third humeral shaft fractures often are treated via a posterior approach, because the distal humeral shaft is flat posteriorly, making it an ideal location for plate placement.
- Fracture patterns with extension into the proximal humerus can be exposed with a deltopectoral extension to the anterolateral humeral dissection.
- The surgeon notes any pre-existing scars that may affect the desired surgical approach, and neurovascular status is documented, with particular attention to radial nerve function.

**Positioning**

- Positioning depends on the intended surgical approach. For an anterolateral or medial approach, the patient is brought to the edge of the bed in the supine position. A hand table is attached to the bed and the patient’s injured arm is placed on the hand table in slight abduction (FIG 1A).
For a posterior approach, the patient can be placed prone or in the lateral decubitus position. A stack of pillows can support the brachium during the procedure (FIG 1B).

**Approach**

- The approach depends on fracture location and the presence of any previous surgical incisions. The anterolateral and posterior approaches to the humerus are used most commonly, for proximal two-third and distal third fractures, respectively.
- In patients who have already undergone multiple procedures to the affected extremity, Jupiter recommends consideration of a medial approach to take advantage of virgin tissue planes.

**ANTEROLATERAL APPROACH TO THE HUMERUS**

- The incision courses over the lateral aspect of the biceps, beginning proximally at the deltoid tubercle and terminating just proximal to the antecubital crease (TECH FIG 1).
- A tourniquet rarely is used, because it often limits proximal exposure.
- The lateral antebrachial cutaneous nerve lies in the distal aspect of the incision and must be protected during exposure.
- Bluntly enter the interval between the biceps and brachialis by sweeping a finger from proximal to distal.

---

TECH FIG 1 • A. Anterolateral incision. B. Skin and subcutaneous tissue incised. C. Retractor on brachialis muscle, forceps on brachioradialis. D. Musculocutaneous nerve on undersurface of biceps muscle. E. Radial nerve in interval between brachialis and brachioradialis. (continued)
At the level of the midhumerus, identify the musculocutaneous nerve on the undersurface of the biceps muscle. Trace this nerve out distally to protect its terminal branch, which forms the lateral antebrachial cutaneous nerve.

Distally, the interval between the brachialis and brachioradialis is dissected to expose the radial nerve. Protect the radial nerve with a vessel loop so that it can be identified at all times.

The brachialis is split in line with its fibers between the medial two thirds and lateral one third. This is an intermuscular plane between the radial nerve medially and the musculocutaneous nerve laterally.

Identify the fracture site and proceed with reduction and fixation.

**POSTERIOR APPROACH TO THE HUMERUS**

Make a generous incision over the midline of the posterior arm extending to the olecranon fossa (TECH FIG 2).

Identify the interval between the long and lateral heads of the triceps proximally. Bluntly dissect this interval, taking the long head medially and the lateral head laterally.

Distally, several blood vessels cross this plane; they require coagulation before transection.

Identify the radial nerve proximal to the medial head of the triceps in the spiral groove. Protect the radial nerve throughout the case.

Split the medial head of the triceps in its midline from proximal to distal to expose the fracture site.
FRACTURE REDUCTION

- Sharp periosteal dissection exposes the fracture site. Evaluate the degree, if any, of comminution.
- Limit periosteal stripping to adequately expose the fracture. Make every attempt to leave some soft tissue attached to each fragment so as not to devascularize the fragments.
- Gentle traction and rotation often can bring the fracture fragments into better alignment.
- Anatomically reduce the fracture with one or more reduction clamps. It is advisable to reduce the fracture completely before definitive fixation, and this often requires the use of multiple reduction clamps (TECH FIG 3).
- After the fracture is reduced, the fragments can be provisionally fixed with Kirschner wires. Place the wires so as not to interfere with plate fixation.
- Alternatively, 3.5- or 4.5-mm interfragmentary screws can be used to hold the fracture aligned until plate fixation.
- Transverse fractures with minimal comminution often can be directly reduced with the plate and Faberge clamps.

TECH FIG 3 • A. Fracture reduction maintained temporarily. B. Hold the plate over the reduced fracture with a plate-holding clamp.

EXPOSURE OF FRACTURE NONUNION

- Exposure of the radial nerve is more challenging, but it is very important in this situation. In many cases it is best to dissect out the nerve distally in the interval between the brachialis and brachioradialis and proximally medial to the spiral groove. The nerve is then carefully dissected free from the nonunion site.
- Pinpoint the exact location of the nonunion with a no. 15 scalpel.
- The ends of the nonunion can be brought out through the wound, and all fibrous material is extracted.
- After thorough fracture débridement, the amount of bone loss becomes clear. The surgeon can now determine whether standard cancellous bone grafting or strut grafting is necessary.
PLATE FIXATION OF HUMERAL SHAFT FRACTURES

**PLATE APPLICATION**

- After fracture reduction, the plate length is determined.
- Humeral shaft fractures require at least six cortices of fixation above and below the fracture site.
- In larger bones, a broad 4.5-mm dynamic compression plate can provide optimal fixation. In smaller bones, a 4.5-mm limited contour dynamic compression plate often provides a better fit.
- Provisionally place the plate on a flat surface of the humerus and hold it in place with a plate-holding clamp.
- 4.5-mm cortical screws are placed through the plate holes proximal and distal to the fracture. Compression techniques can be used, where appropriate.
- Ensure that no soft tissue, especially nerve, is trapped between the plate and the bone.
- Make sure to obtain screw purchase in at least six cortices above and below the fracture (TECH FIG 4).
- Cerclage wiring over the plate can add supplemental fixation, especially in weak bone.
- Rotate the arm and flex and extend the elbow to evaluate fracture stability.
- Apply cancellous bone graft into defects as needed.

**TECH FIG 4**

**A.** Plate spanning the fracture site with at least six cortices of fixation proximally and distally. **B.** Anterior plate with a probe pointing to the radial nerve as it exits the spiral groove posteriorly (proximal is to the right, distal to the left). **C.** Supplemental cerclage wire fixation can augment stability in weak bone.

**MEDIAL APPROACH**

- Positioning is similar to the anterolateral approach.
- Make an incision over the medial intermuscular septum from the axilla to 5 cm proximal to the medial epicondyle (TECH FIG 5).
- Mobilize the ulnar nerve.
- Resect the medial intermuscular septum; identify and coagulate the adjacent venous plexus with bipolar electrocautery.
- Mobilize the triceps posteriorly and the biceps/brachialis anteriorly.
- Expose the fracture site.
- The axillary incision raises concern for infection; there is also concern that the ulnar nerve can scar to the plate.

**TECH FIG 5**

**A.** Incision for the medial approach. (continued)
PEARLS AND PITFALLS

Indications
■ Operative treatment is reserved for open fractures, patients with multiple fractures, and fractures with inadequate reduction.

Preoperative planning
■ Review all radiographs and determine the best surgical approach.
■ Estimate potential plate length and prepare for possible bone grafting.

Surgical exposure
■ Locate and protect the radial nerve.
■ Expose and reduce fracture fragments and temporarily hold them in place with pins or clamps.
■ Alternatively, fix larger fragments with interfragmentary screws.

Plate fixation
■ Ensure that plate length allows six cortices of fixation proximal and distal to the fracture.
■ Use 4.5-mm dynamic compression plates or limited contact dynamic compression plates.
■ Use compressive techniques when indicated.

Radial nerve function
■ Preoperatively, document a detailed neurovascular examination.
■ Ensure that the radial nerve is not trapped within the plate before closure.

POSTOPERATIVE CARE
■ Postoperative radiographs ensure proper fracture alignment and plate placement (FIG 2).
■ Initially, the patient can be placed in a sling or posterior elbow splint. This is removed and range-of-motion exercises are started when patient comfort allows (usually 1 to 2 days postoperative).
■ Weight bearing on the affected upper extremity is allowed based on patient comfort.12
■ Initial therapy consists of elbow range-of-motion and shoulder pendulum and passive self-assist exercises.
■ The patient can come out of the sling after 2 weeks and start waist-level activities with the operative arm.
■ At 6 weeks, elbow motion should be near normal range, and shoulder strengthening is added to the patient’s physical therapy.
■ At 3 months, radiographs should reveal some callus formation. If no callus is evident, radiographs are repeated every 6 weeks until evidence of healing appears.
OUTCOMES

- Plate fixation leads to union in 90% to 98% of cases.
- Plating offers decreased complication rates compared to intramedullary nailing, especially in terms of shoulder dysfunction.8
- Iatrogenic radial nerve palsy occurs in about 2% to 5% of cases and usually resolves in 3 to 6 months. Electromyography helps monitor return of nerve function in patients with prolonged palsy. Radial nerve exploration is indicated when no nerve function returns by 6 months.
- Elbow and shoulder range of motion usually return to normal postoperatively.

COMPLICATIONS

- Infection
- Nonunion
- Malunion
- Hardware failure
- Radial nerve palsy
- Shoulder impingement
- Elbow stiffness

REFERENCES

DEFINITION
- Incidence: 3% to 5% of all fractures
- The AO/ASIF classification of humeral shaft fractures is based on increasing fracture comminution and is divided into three types according to the contact between the two main fragments:
  - Type A: simple (contact > 90%)
  - Type B: wedge/butterfly fragment (some contact)
  - Type C: complex/comminuted (no contact)
- Intramedullary nailing (IMN) can be used to stabilize fractures 2 cm distal to the surgical neck to 3 cm proximal to the olecranon fossa.
- The precise role of IMN is not defined. Proponents offer the following benefits over formal open reduction with internal fixation (ORIF): it is minimally invasive, causing limited soft tissue damage and no periosteal stripping (preservation of vascular innervation); it is biomechanically superior; it is cosmetically advantageous (smaller incision); it is capable of indirect diaphyseal fracture reduction and metaphyseal fracture approximation.
- Complications such as shoulder pain, delayed union or nonunion, fracture about the implant, iatrogenic fracture comminution, and difficulty in the reconstruction of failures, raise questions regarding the usefulness of intramedullary nailing over ORIF.
- Biomechanically, intramedullary nails are closer to the normal mechanical axis; consequently they act as a load-sharing device if there is cortical contact.
- Unlike plate-and-screw fixation, a load-bearing construct, intramedullary nails are subjected to lower bending forces, making fatigue failure and cortical osteopenia secondary to stress shielding less likely.

ANATOMY
- Comparatively, there are several anatomic differences between the long bones of the upper extremity versus the long bones of the lower extremity (femur, tibia):
  - The medullary canal terminates at the metaphysis (versus diaphysis).
  - Isthmus: junction is at the middle-distal third (versus proximal-middle third).
  - Trumpet shape: the proximal two thirds of the humeral canal is cylindrical; distally, the medullary canal rapidly tapers to a prismatic end at the diaphysis (hard cortical bone) versus the wide flare of the metaphysis (soft cancellous bone).
  - Because of the funnel shape of the humeral shaft, a true interference fit is difficult to obtain; therefore, proximal and distal static locking has become the standard of care for IMN of humeral fractures.
- Neurovascular considerations include average distances of key structures from notable bony landmarks:
  - Axillary nerve to proximal humerus, 6.1 ± 0.7 cm (range 4.5 to 6.9 cm)

PATHOGENESIS
- Biomodal distribution
- Young, male 21 to 30 years old: high-energy trauma
- Older, female 60 to 80 years old: simple fall/rotational injury
- 5% open
- 63% AO/ASIF type A fracture patterns
- Various loading modes and the characteristic fracture patterns they create
  - Tension: transverse
  - Compression: oblique
  - Torsion: spiral
  - Bending: butterfly
  - High-energy: comminuted
- Red flags:
  - Minimal trauma indicates a pathologic process
  - Disconnect between history and fracture type suggests domestic abuse.

NATURAL HISTORY
- The humerus is well enveloped in muscle and soft tissue, hence its good prognosis for healing in most uncomplicated fractures.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients with humeral shaft fractures present with arm pain, deformity, and swelling.
- Demographics, medical history, and information regarding the circumstance and mechanism of injury should be obtained.
- Particularly significant in upper extremity trauma: hand dominance, occupation, age, and pertinent comorbidities must be solicited from the patient. All of these factors play a major role in determining whether to pursue surgical versus nonsurgical treatment.
- On physical examination, the arm is typically shortened, angulated, or grossly deformed, with motion and crepitus on manipulation.
- Document the status of the skin (open versus closed fracture) and perform a careful neurovascular evaluation of the limb.
Chapter 21  INTRAMEDULLARY FIXATION OF HUMERAL SHAFT FRACTURES

NONOPERATIVE MANAGEMENT

- Most non- or minimally displaced humeral shaft fractures can be successfully treated nonoperatively, with union rates of more than 90% often reported.12
- Common closed techniques include hanging arm cast; coaptation splint; Velpeau dressing; abduction humeral/shoulder spica cast; functional brace; and traction.
  - Each of these modalities has been successfully employed, but most commonly either a hanging arm cast or coaptation splint is used for 1 to 2 weeks, followed by a functional brace, tightened as the swelling decreases.
  - Hanging arm casts are a very good option for displaced, midshaft humeral fractures with shortening, especially oblique or spiral fracture patterns, if the cast is able to extend 2 cm or more proximal to the fracture site.
  - For nonoperative treatment to be effective, the patient should remain upright, either standing or sitting, and avoid leaning on the elbow for support. This allows for gravitational force to assist in fracture reduction.
  - As soon as possible, the patient should begin range-of-motion exercises of the fingers, wrist, elbow, and shoulder to minimize dependent swelling and joint stiffness.
  - Acceptable alignment of humeral shaft fractures is considered to be 3 cm of shortening, 30 degrees of varus/valgus angulation, and 20 degrees of anterior/posterior angulation.10
  - Varus/valgus angulation is tolerated better proximally, and more angulation may be tolerated better in patients with obesity.
  - Patients with large pendulous breasts are at increased risk for varus angulation if treated nonsurgically.
  - No set values for acceptable malrotation exist, but compensatory shoulder motion allows for considerable tolerance of rotational deformity.10
  - Low-velocity gunshot wounds act as closed injuries after initial treatment. Following irrigation and débridement of skin at entry and exit sites, tetanus status confirmation, and prophylactic antibiotic initiation, nonoperative treatment modalities are commonly employed.10

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Initial studies must always include orthogonal views (anteroposterior [AP] and lateral radiographs) of the fracture site, shoulder, and elbow (FIG 1). To obtain these radiographs, move the patient rather than rotating the injured limb through the fracture site.
  - Traction radiographs may be helpful with comminuted or severely displaced fractures, and comparison radiographs of the contralateral side may be helpful for determining preoperative length.
  - CT scans rarely are indicated. Rare situations in which they should be obtained include significant rotational abnormality, precluding accurate orthogonal radiographs, and suspicion of possible intra-articular extension or an additional fracture or fractures at a different level.
  - Doppler pulse and compartment pressures should be checked if indicated following a thorough physical examination.
  - Suspicion of vascular injuries warrants an angiogram.

DIFFERENTIAL DIAGNOSIS

- Osteoporosis
- Pathologic fractures
- High- or low-energy trauma
- Open or closed fractures
- Domestic abuse

FIG 1 • AP and lateral radiographs of a displaced humeral shaft fracture, shortened and in varus angulation.
Polytrauma
- Spinal cord or brachial plexus injuries
- Poor soft tissue over the fracture site(s), such as thermal burns
- The most commonly cited overall best indication for IMN from this extensive list is a pathologic or impending pathologic fracture.
- The need for operative intervention secondary to radial nerve dysfunction after closed manipulation is controversial.
- There are advocates for both early nerve exploration and observation.
- This condition was once thought to be an automatic indication for surgery; however, this assumption has since been called into question.  
- Isolated comminution is not an indication for operative treatment. However, if surgical fixation is chosen over nonoperative management, antegrade IMN currently is favored over plate fixation for comminuted fractures.  

Relative contraindications include:
- Open epiphyses
- Narrow intramedullary canal (ie, < 9 mm)
- Prefracture deformity of the humeral shaft
- Open fractures with obvious radial nerve palsy and neurologic loss after penetrating stab injuries
- The last two conditions require nerve exploration with subsequent plate-and-screw fixation.
- Chronically displaced fractures should be treated with ORIF rather than IMN to prevent traction-induced brachial plexus palsy and radial nerve injury.

Preoperative Planning
- When selecting implant size, consider canal diameter, fracture pattern, patient anatomy, and postoperative protocol.
- Nail length and diameter should take into account the distal narrowing of the humerus.
- Estimations of the nail diameter, length, and necessity of reaming can be made using preoperative roentgenograms of the uninjured humerus.
- Alternatively, the length and diameter of the medullary canal can be ascertained intraoperatively using a radiopaque gauge and C-arm imaging of the intact humerus. Use of a radiolucent table top will substantially improve the quality of the image as well as the ability to obtain accurate C-arm images.
- Position the gauge anterior to the unaffected humerus with its distal end 2.5 cm or more proximal to the superior edge of the olecranon fossa and 1 cm distal to the superior edge of the articular surface.
- Move the C-arm to the proximal end of the humerus and read the correct length directly from the stamped measurements on the nail length gauge. The IMN should end approximately 1 to 2 cm proximal to the olecranon fossa.
- Measure the length of the IMN to allow the proximal end to be buried. This will reduce the incidence of subacromial impingement if an antegrade technique is used, or encroachment on the olecranon fossa and blocked elbow extension if a retrograde approach is chosen.
- In comminuted fractures, carefully chose the length to avoid distracting the humerus, which predisposes the patient to delayed union or nonunion.
- Measure the diameter of the medullary canal at the narrowest part that will contain the nail.

- In retrograde nailing, it is important to determine the relation between alignment of the humeral canal and the entry point of the nail by measuring the anterior deviation/distal humeral offset of the distal canal on the preoperative lateral radiograph.
- Based on these calculations, if the deviation is small, make a distal, long entry portal that includes the superior border of the olecranon fossa.
- If the anterior deviation is large, however, make the entry portal more proximal and shorter in length.

Positioning
- The patient’s position for surgery is determined based on the method chosen for fixation.

Antegrade Intramedullary Nailing
- Place the patient in either a beach chair or supine position on a radiolucent table with the head of the bed elevated 30 to 40 degrees (FIG 2).
- Put a small roll between the medial borders of the scapula and rotate the head to the contralateral side to increase exposure of the shoulder.
- Certain fracture patterns may call for skeletal traction.
- If it is used, place an olecranon pin and apply intermittent traction to avoid brachial plexus palsy.
- Clinically assess the rotational alignment by placing the shoulder in an anatomic position and rotating the distal fragment of the fracture humerus so that the arm and hand point toward the ceiling and the elbow is flexed 90 degrees.
- Prepare the affected extremity and drape the arm free in the typical manner. The operative area should encompass the shoulder proximal to the nipple line, the midline of the chest to the nape of the neck, and the entire affected extremity to the fingertips.
- Bring the patient to the edge of the radiolucent table to improve the ability to obtain orthogonal C-arm images of the affected extremity.
- It may be necessary to have the patient lying partially off the table on a radiolucent support.
- Cover the C-arm imager with a sterile isolation drape. Most commonly, the C-arm is brought in directly lateral on the injured side, although some surgeons favor coming in from the contralateral side.
- Regardless of which direction the C-arm is brought into the field, it is imperative to obtain orthogonal views of the entire humerus before the first incision is made.

Retrograde Intramedullary Nailing
- Put the patient in the lateral decubitus or prone position with dorsum placed near the edge of the operating table.
- If the patient is in the prone position, the affected arm may be supported on a radiolucent arm board, or placed over a bolster or paint roller upper extremity support. The latter two options facilitate access to the olecranon fossa and prevent a traction injury to the brachial plexus. The arm should be positioned in 80 degrees of abduction with the elbow flexed at least 90 degrees.
- If the lateral decubitus position is used, suspend the fractured extremity, taking care not to distract the fracture site or cause neurovascular compromise. Suspension can be aided by an olecranon pin.
Prepare the affected extremity and drape the arm free in the typical manner. Include the distal clavicle, the acromion, the medial scapula, and the entire arm and hand in the operative field.

Cover the C-arm imager with a sterile isolation drape.

Bring the C-arm from the ipsilateral side and make sure that adequate orthogonal C-arm images are possible before making the surgical approach.

**Approach**

- Standard locked intramedullary humeral nails can be inserted either antegrade or retrograde.

## Antegrade Intramedullary Nailing

**Approach**

- The antegrade approach, which has been the traditional method of IMN, typically involves a starting point at the proximal humerus—either through the rotator cuff, where the tissue is less vascular, or just lateral to the articular surface, where the blood supply is higher (TECH FIG 1).

- Palpate and outline the surface anatomy of the acromion, clavicle, and humeral head.
  - Feel the anterior and posterior borders of the humeral head to locate and mark the midline.
  - Make a small longitudinal incision at the anterolateral corner of the acromion centered over the top of the greater tuberosity. Extend it distally 3 cm.

- The C-arm can be used to locate the exact entry point before performing the anterior acromial approach.
  - Place a K-wire into the ideal entry point under C-arm imaging guidance. Confirm the location on orthogonal images.
  - Leave the K-wire intact while making an anterior acromial approach.
  - Split the deltoid fibers in line with the longitudinal cutaneous incision.
  - Do not extend the incision distally more than 4 or 5 cm in the deltoid muscle, to avoid damage to the axillary nerve.

**TECH FIG 1** Postoperative AP and lateral radiographs of antegrade intramedullary nailing for a midshaft humerus fracture.
Excise any visible subdeltoid bursae to improve your visualization of the rotator cuff.

Longitudinally incise the supraspinatus in line with the deltoid/cutaneous incision for 1 to 2 cm, just posterior to the bicapital tuberosity.

Placing suture tags at the margins of the supraspinatus will help retract its edges during the remainder of the procedure and assist in achieving an optimal rotator cuff repair during wound closure.

There is insufficient evidence to indicate that a larger incision, in cases in which the rotator cuff is identified and purposely incised, is superior to a smaller incision made with the aid of C-arm imaging.\(^{13}\)

**Entry Hole**

Make the entry hole medial to the tip of the greater tuberosity, just lateral to the articular margin and approximately 0.5 cm posterior to the bicipital groove to minimize damage to the supraspinatus.

Linear access to the humeral medullary canal is possible only though an entry portal made in this sulcus between the greater tuberosity and the articular surface.

Make sure the entry portal is centered on AP and lateral C-arm images to ensure the nail will be in the midplane of the humerus.

If the entry hole is too medial, it will violate the supraspinatus; if the entry portal is too lateral, it will cause some degree of varus angulation (in proximal fractures) or substantially increase the risk of an iatrogenic fracture during nail insertion.

Proximal third fractures may require a more medially located entry hole to avoid varus angulation at the fracture site.

**Entrance into Medullary Canal**

After establishing the entry hole, insert a K-wire through the portal into the medullary canal to the level of the lesser tuberosity.

Next, to open the medullary canal, either use a cannulated awl or pass a cannulated drill bit over the K-wire, through a protection sleeve, and drill to the depth of the lesser tuberosity.

Adduct the proximal component of the fractured humerus and extend the shoulder to improve clear ance of the acromion and facilitate awl or starter reamer access to the correct portal location.

Once the medullary canal has been opened, remove the guidewire and insert a long, ball-tipped guidewire. Bending the tip of the guidewire may aid in its passage across the fracture site.

**Provisional Reduction/ Guidewire Passage**

Manipulate the extremity to reduce the fracture. In many cases, reduction is obtained through a combination of adduction, neutral forearm rotation, and longitudinal traction.

While advancing the guidewire down the canal, rotate the arm about its longitudinal axis and take several C-arm images to confirm that the guidewire remains contained in the canal.

This is especially important if the humerus is substantially comminuted.

Slowly and deliberately pass the guidewire across the fracture site.

Difficult passage may be a tip-off that soft tissue may be interposed (possibly the radial nerve).

An open fracture is advantageous in this situation because it provides the opportunity to directly visualize and clear the fracture site of any problematic soft tissue.

After crossing the fracture site, advance the ball-tipped guidewire into the center of the distal fragment until the tip is 1 to 2 cm proximal to the olecranon fossa.

Avoid shortening or distracting the fracture site while firmly securing the guidewire into the distal fragment.

**Determined Nail Length**

Determine the correct nail length by one of two methods:

- **Guide rod method:** with the distal end of the rod 1 to 2 cm proximal to the olecranon fossa, overlap a second guide rod extending proximally from the humeral entry portal. Subtract the length in mm of the overlapped guide rod from the total length of an identical guidewire to determine the correct nail length.

- **Nail length gauge:** position the radiopaque gauge anterior to the fractured humerus. Move the C-arm to the proximal end of the humerus and read the length from the stamped measurements on the gauge.

The ideal length of an IMN should be measured 1 cm distal to the articular surface of the humeral head to a point 1 to 2 cm proximal to the olecranon fossa.

If the calculated length falls between two standardized nail lengths of the chosen implant, always choose the smaller size.

Long nails are a risk factor for subacromial impingement and fracture site distraction.

- Burying a long nail proximally below the subcondral surface has the potential to iatrogenically split the distal humerus or create a supracondylar fracture when the tip of the nail is wedged too close to the olecranon fossa.

**Reaming the Humeral Shaft**

Reaming the humeral shaft usually is avoided, especially in comminuted fractures, to avoid reaming injury to the radial nerve or the rotator cuff.

If it is warranted, slowly ream the entire humerus over the ball-tipped reamer guidewire in 0.5-mm increments.

Exercise greater caution when reaming the humerus than when reaming the long bones of the lower extremity, because the cortical thickness of the humerus is substantially less than that of the tibia or femur.

Ream 0.5 mm to 1 mm larger than the selected nail diameter. Ream minimally until the sound of cortical chatter becomes audible.

Choose a nail 1 mm smaller in diameter than the last reamer used.

Some implant systems require that the ball-tipped guidewire be replaced with a rod that does not have a tip.

Use the medullary exchange tube when replacing the guidewire to maintain fracture reduction.
Inserting the Nail

- Once the correct nail length and the diameter of the selected implant have been verified, attach the nail adapter, place the nail-holding screw through the nail adapter, and then attach the radiolucent targeting device onto the nail adapter.
- Verify that this assembly is locked in the appropriate position and that its alignment is correct by inserting a drill bit through the assembled tissue protection/drill sleeve placed in the required holes of the targeting device.
- Insert the nail with sustained manual pressure.
  - Aggressive placement can result in iatrogenic fractures or displacement of the fracture fragments.
  - Use the C-arm image intensifier to identify the source of the problem if the IMN does not easily advance.
- Insert the nail at least to the first circumferential groove on the nail adapter but no deeper than the second groove.
- Ideally, the IMN should be countersunk about 5 mm below the articular surface to avoid subacromial impingement.
- Sinking the nail more than 1 cm below the articular surface may place the proximal interlocking screws at the level of the axillary nerve.
- If the proximal end of the nail is properly countersunk, the incidence of shoulder pain is reportedly less than 2%.4
- Attach a strike plate to the targeting device and use a mallet to impact the proximal jig assembly to eliminate any fracture gap or advance the IMN.
- Do not hit the targeting device or the nail-holding screw directly.
- The distal end of the IMN should come to lie about 2 cm proximal to the olecranon fossa.
- Remove the guidewire.

Compression

- Before proximal interlock insertion, make sure that optimal fracture site compression is present.
- Proximal compression locking can be used for transverse or short oblique fracture patterns. Severe osteopenia is a contraindication to its use.
  - Explore the radial nerve before compression locking if any possibility of radial nerve entrapment exists.
  - The nail must be overinserted by the same distance of anticipated interfragmentary travel because otherwise, during compression, the nail will back out and cause subacromial impingement.
- Additionally, if the fracture is suitable for compression, the chosen implant should be 6 to 10 mm shorter than the calculated measurement to avoid proximal migration of the nail beyond the insertion site.
- Proximal locking screw placement
  - Oblique proximal locking screws are preferred because their insertion point is cephalad to axillary nerve.
  - Only lateral-to-medial placement is recommended for proximal interlocking screws.
  - It is important to make sure that these screws are inserted above the level of the humeral neck to avoid axillary nerve injury.

Determining Rotation

- Confirm rotational alignment before placing distal interlocking screws. Rotational alignment can be ascertained clinically and radiographically.
  - Magnified C-arm AP images of the fracture site can be used to judge the medial and lateral cortical width of the most proximal and most distal aspects of the fracture site.
  - Proper rotation is achieved when these widths are identical.

Distal Locking Screws

- Place anterior, then posterior and/or lateral, then medial directed distal interlocking screws.
- Insert distal interlocking screws using a freehand technique.
  - To place AP-directed screws, advance the C-arm over the distal humerus until the oval slot is seen to be in maximal relief—that is, “perfect circle.”
  - Under C-arm imaging, place a scalpel over the skin to precisely determine the location of the incision. Make every attempt to keep this incision just lateral to the biceps tendon. This will decrease the risk to brachial artery, median nerve, and musculocutaneous nerve.
- Carefully make the incision though the skin and use a blunt hemostat to spread under the brachialis muscle down to the bone.
- Insert a short drill bit through a soft tissue protector.
  - Center the drill bit in the locking hole and then position it perpendicular to the nail.
  - Ideally, place the drill bit distally in the oval hole to allow axial compression to occur postoperatively.
- Attach the drill and penetrate the near cortex.
  - The distal screws usually are 24 mm in length.
  - Use C-arm image intensification to confirm screw position through the nail as well as screw length.
  - Avoid articular penetration into the glenohumeral joint.
- Lateral-to-medial directed distal locking screws
  - Either in combination with or as an alternative to anterior-to-posterior screws, insert lateral-to-medial screws.
- Make the initial entry portal in one of two ways:
  - Traditional metaphyseal entry portal: created by reaming in the midline of the distal metaphyseal triangle 2.5 cm proximal to the olecranon fossa.
  - Olecranon fossa entry portal: established by reaming the proximal slope of the olecranon at the superior border of the olecranon fossa.
- The more distal location of the nontraditional olecranon fossa entry portal increases the effective working length of the distal segment and provides a straighter alignment with the medullary canal.
- However, biomechanical investigation has found that the olecranon fossa entry portal provides greater reduction in torque resistance and load to failure, which may increase the probability of an iatrogenic or postoperative fracture.16
- When making either entry portal, pay careful attention to the relation between the olecranon fossa and the longitudinal axis of the humerus in order to place the entry portal in line with the humeral shaft. The axis of the humerus usually is colinear with the lateral aspect of the olecranon fossa.
- Make the initial entry portal in one of two ways:
  - Open the near cortex with a 4.5-mm drill bit. Continue drilling while progressively lowering the drill toward the arm until the drill bit is in line with the medullary canal on the lateral C-arm images.
  - Drill three small pilot holes in a triangular configuration perpendicular to the cortical surface. Connect these holes with a large drill bit and small rongeur or enlarge the triangular site with a small curved awl to create a long, oval hole 1 cm wide × 2 cm long that leads directly into the medullary canal.
- Undercut the internal aspect of the posterior cortex in addition to the medial and lateral walls of the entry portal to create a distal bevel along the path of nail insertion.
- This will facilitate easy passage of the guidewire, optional reamer, and final implant.

**Retrograde Intramedullary Nailing**

**Approach**
- Make a limited posterior approach centered over the distal humerus, starting at the olecranon tip to a point 6 cm proximal.
- Longitudinally split the triceps in line with its fibers to the cortical surface of the humerus and identify the olecranon fossa.
- Make every attempt to avoid entering the elbow joint, to decrease the possibility of periarticular scarring.

**Starting or Entry Portals**
- As previously discussed in the Approach section, the coronal deviation of the distal humerus is variable, and, therefore, two potential starting portals exist:
  - Traditional metaphyseal entry portal: created by reaming in the midline of the distal metaphyseal triangle 2.5 cm proximal to the olecranon fossa.
  - Olecranon fossa entry portal: established by reaming the proximal slope of the olecranon at the superior border of the olecranon fossa.
- The more distal location of the nontraditional olecranon fossa entry portal increases the effective working length of the distal segment and provides a straighter alignment with the medullary canal.
- However, biomechanical investigation has found that the olecranon fossa entry portal provides greater reduction in torque resistance and load to failure, which may increase the probability of an iatrogenic or postoperative fracture.16
- When making either entry portal, pay careful attention to the relation between the olecranon fossa and the longitudinal axis of the humerus in order to place the entry portal in line with the humeral shaft. The axis of the humerus usually is colinear with the lateral aspect of the olecranon fossa.
- Make a generous 5 cm incision to decrease the risk to the radial nerve.
- Use the same technique employed when placing AP-directed screws: blunt dissection, a protecting drill/screw insertion sleeve, and perfect circle free-hand technique.
- Finally, confirm the IMN position, fracture reduction, and interlocking screw(s) placement with multiple orthogonal C-arm images.
- After orthogonal C-arm images demonstrate satisfactory reduction and hardware implantation, remove the proximal targeting device and place an end cap (this last step is optional, depending on surgeon preference).
- Carefully select the length of the end cap to avoid impingement.

**Wound Closure**
- Copiously irrigate all wounds before they are closed.
- During closure of the proximal insertion site, formally repair the surgically incised rotator cuff and deltoid raphe; side-to-side nonabsorbable sutures commonly are recommended.

**Provisional Reduction and Guidewire Passage**
- Now follow the same steps outlined in the antegrade IMN technique section to pass the guidewire, reduce the fracture, ream (optional), measure the desired nail length and diameter, and insert the chosen implant.
- Reduction of the fracture usually involves gentle longitudinal traction on the distal humerus and correction of the varus–valgus displacement.
Reaming (Optional)

- If it is necessary to ream, carefully select the reamer size to avoid damage to the posterior cortex. In addition, slowly advance the reamer under C-arm image guidance to avoid excessive reaming of the anterior humeral cortex.
- Both of these steps decrease the risk of possible iatrogenically induced fractures.

Distal Locking Screws

- Next, distally lock the nail to prevent backing out, that is, blocked elbow extension.
- Place the distal locking screws from posterior to anterior using a guide.
- Make an indentation with the guide, incise the cutaneous layer, and then use a blunt hemostat to spread down to the bone.
- Follow the remaining steps unique to the chosen implant.

- After distal interlocking, gently tap the insertion bolt with a mallet to compress the fracture site. Assess the reduction with C-arm images.

Proximal Locking Screws

- Next, place a proximal interlocking screw, either anterior to posterior, posterior to anterior, or lateral to medial.
- Incise the skin and use a blunt hemostat to spread down to bone to protect the biceps tendon (anterior-to-posterior directed screws) or axillary nerve (posterior-to-anterior and lateral-to-medial directed screws).
- Use C-arm image intensification to confirm screw position through the nail as well as screw length.

Wound Closure

- Copiously irrigate each wound before closing it. Close triceps split with interrupted nonabsorbable sutures.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>IMN contraindications</th>
<th>Pre-existing shoulder pathology (eg, impingement, rotator cuff)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Permanent upper extremity weight bearers (eg, para- or tetraplegics)</td>
</tr>
<tr>
<td></td>
<td>Narrow-diameter (&lt;9 mm) canals: excessive reaming is not desirable in the humerus because of the risk of thermal necrosis or radial nerve injury.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Antegrade IMN entry site</th>
<th>If the entry portal is too far lateral, the lateral wall of the proximal humerus can be reamed out or fractured during nail insertion.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pushing the reamer shaft medially may prevent this complication.</td>
</tr>
</tbody>
</table>

| Nail insertion | If any resistance is met while attempting to pass the nail, either antegrade or retrograde, make a small incision to ensure that the radial nerve is not entrapped in the fracture site. |

<table>
<thead>
<tr>
<th>Interlock screws</th>
<th>In most cases, soft tissues should be bluntly spread down to the bone with a hemostat before holes are drilled for any interlocking screw, to minimize neurovascular injury.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Antegrade IMN distal interlock screws: An alternate and possibly safer method involves placing the screw posteroanteriorly to avoid neurovascular risk when AP (musculocutaneous nerve, brachial artery) or LM (radial nerve) direction is used. When placing interlock screws using the freehand technique, tie an absorbable suture to the screw so that if the screw becomes dislodged from the screwdriver, it will not be displaced in the soft tissues.</td>
</tr>
<tr>
<td></td>
<td>Antegrade IMN: rotate the C-arm 180 degrees, so the top can be used as a table to support the arm for placing the distal locking screws.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nail length</th>
<th>Always err on the side of a shorter nail: do not distract the fracture site or cause iatrogenic fractures by trying to impact a nail that is excessively long.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The retrograde IMN must be long enough to engage the cancellous part of the humeral head; the wide medullary flare of the proximal one third of the shaft does not provide sufficient stability to the inserted nail.</td>
</tr>
</tbody>
</table>

| Open fractures: reaming | After a thorough irrigation and débridement is performed and the guidewire is successfully passed across the fracture site, close the deep muscle layer around the fracture site to keep the osteogenic reaming debris from washing away. |

POSTOPERATIVE CARE

- Tailor the postoperative rehabilitation regimen to the method of nailing (antegrade versus retrograde), stability of the fracture, overall patient health, and preinjury level of activity/workplace demands.
- Antegrade IMN
  - Place the affected arm in a sling or shoulder immobilizer at the end of surgery.

- Postoperative day 2: remove the dressing and begin gentle shoulder pendulum and elbow ROM exercises.
- Postoperative days 10 to 14: remove the sutures. Institute a structured, supervised physical therapy program. Close patient monitoring and formal therapy are key components to achieving maximum postoperative function.
- Subsequently, schedule follow-up visits at 4- to 6-week intervals, depending on the patient’s clinical and radiographic progression. Healing often takes 12 weeks or longer.
As union progresses, the therapist may begin supervised exercises to recover upper extremity strength. Caution the therapist against instituting programs or exercises that create large rotational stresses to the arm until radiographic healing becomes evident.

Retrograde IMN
- Initial postoperative management is identical to treatment following antegrade nailing, unless weight bearing is necessary for wheelchair transfers, walkers, or crutch ambulation. Use a posterior splint and platform attachment if clutches are necessary.
- It is important to institute early elbow active ROM or gentle passive ROM by the patient to prevent elbow stiffness.
- Avoid
  - Aggressive PROM or stretching to decrease the risk of myositis ossificans formation
  - Resisted elbow extension for the first 6 weeks after surgery to protect the repair of the triceps split.

OUTCOMES
- Randomized clinical trials comparing IMN to compression plating show a higher reoperation rate and greater shoulder morbidity with the use of nails.\(^1\)
- Locked antegrade IMN has resulted in loss of shoulder motion in 6% to 37% of cases.\(^13\)
- Recent antegrade nails designed to eliminate insertion site shoulder morbidity though an extra-articular start point have been introduced, and prospective randomized trials are pending.
- Retrograde IMN union rates range from 91% to 98%, and the mean healing time is 13.7 weeks.\(^15\)
- Retrospective reviews of retrograde IMN have found shoulder function to be excellent in 92.3% of patients and elbow function excellent in 87.2% of patients after fracture consolidation.\(^15\)
- Functional end results were excellent in 84.6% of patients, moderate in 10.3% of patients, and bad in 5.1% of patients.
- Biomechanical studies have shown that, for midshaft fractures, both antegrade and retrograde nailing showed similar initial stability and bending and torsional stiffness—20% to 30% of normal humeral shafts.\(^8\)
- In proximal fractures (ie, 10 cm distal to the greater tuberosity tip), antegrade nails demonstrated significantly more initial stability and higher bending and torsional stiffness, as was true for distal fractures with retrograde nailing.

COMPLICATIONS
- Nonunion\(^3\)
  - Antegrade IMN: 11.6%
  - Retrograde IMN: 4.5%
- Infection: 1% to 2%
- Insertion site morbidity
  - Antegrade IMN: shoulder pain, impingement, stiffness, and weakness
  - Retrograde IMN: elbow pain, stiffness, and triceps weakness
- Iatrogenic fractures\(^3\)
- Antegrade IMN: 5.1%
- Retrograde IMN: 7.1%
- Iatrogenic comminution and distraction at the fracture site
- Neurovascular risk
  - Risk to the radial nerve in the spiral groove from canal preparation and nail insertion
  - Risk to the axillary nerve from proximal interlocking
  - Risk to the radial, musculocutaneous, and median nerves or brachial artery from distal interlocking
- Heat-induced segmental avascularity after reaming

REFERENCES
3. Court-Brown C. Paper presented at the Orthopaedic Trauma Association Specialty Day Meeting; February 26, 2005; Washington, DC.
DEFINITION
- Nonarticular scapular fractures include fractures of the glenoid neck, scapular spine and body, acromial process, and coracoid process. They account for 90% of scapular fractures.6
- Most nonarticular scapular fractures can be treated nonoperatively, including all isolated scapular body–spine fractures.
- Significant displacement at one or more of these sites, alone or in conjunction with ligamentous disruptions of the superior shoulder suspensory complex, require evaluation for surgical intervention.1,10

ANATOMY
- The scapula is a flat triangular bone with three processes laterally: the glenoid process, the acromial process, and the coracoid process.
- The glenoid process consists of the glenoid fossa, the glenoid rim, and the glenoid neck.
- The superior shoulder suspensory complex is a bone and soft tissue ring at the end of a superior and an inferior bony strut (FIG 1). This ring is composed of the glenoid process, the coracoid process, the coracoclavicular ligament, the distal clavicle, the acromioclavicular joint, and the acromial process. The superior strut is the middle third of the clavicle, whereas the inferior strut is the junction of the most lateral portion of the scapular body and the most medial portion of the glenoid neck.1

PATHOGENESIS
- Scapular fractures usually are the result of high-energy trauma and have a high rate of associated musculoskeletal and underlying thoracic injuries.3
- Fractures of the acromion process may be the result of direct trauma due to its subdermal location, whereas coracoid process fractures may be due to a sudden muscular contraction.4

NATURAL HISTORY
- The results of nonoperative treatment of nonarticular scapular fractures generally are good. Nonunion is rare because the area has a rich blood supply. Angular deformities often are well compensated for by the wide range of motion of the glenohumeral joint and scapulothoracic articulation.

PATIENT HISTORY AND PHYSICAL FINDINGS
- In addition to the specifics of the injury, it is helpful to obtain an understanding of the functional demands on the extremity. Hand dominance, occupation, and sports participation are all relevant.
- A thorough neurovascular examination must be performed and deficits evaluated with angiography and electromyography, as necessary.
- A thorough soft tissue examination also is warranted, as wounds may represent an open fracture and warrant exploration. Blisters or swelling may delay surgery.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Nonarticular scapular fractures usually are identified on routine shoulder trauma series radiographs: a true anteroposterior (AP) view of the shoulder with the arm in neutral rotation, a true axillary view of the glenohumeral joint, and a true lateral scapular view. An AP weight-bearing view may be indicated.
- CT scans and three-dimensional reconstructions can be helpful for identification and classification of fractures owing to the complex bony anatomy in this region. In addition, the bony relationships should be evaluated for evidence of any ligamentous disruption.

DIFFERENTIAL DIAGNOSIS
- Nonarticular scapular fractures
- Intra-articular scapular fractures
- Double disruptions of the superior shoulder suspensory complex including a floating shoulder (ie, glenoid neck fracture with ipsilateral middle third clavicle fracture)
- Scapulothoracic dissociation
NONOPERATIVE MANAGEMENT

- Most (over 90%) scapular fractures can be treated nonoperatively.
- Glenoid fossa and rim fractures may require operative management and are discussed in Chapter SE-23.
- Glenoid neck fractures with more than 40 degrees of angulation in the coronal or sagittal plane or translational displacement of 1 cm or more require surgical management. Anatomic neck fractures (lateral to the coracoid process) are inherently unstable and should also be considered for operative intervention.²
- Isolated acromial and coracoid process fractures usually are minimally displaced and can be managed nonoperatively. Significant displacement or fractures in conjunction with other bony and soft tissue injuries to the shoulder girdle may require surgical stabilization.⁴

SURGICAL MANAGEMENT

Preoperative Planning

- Imaging studies should be reviewed and available for reference in the operating room. A draped fluoroscopy unit and competent technician should be available during the surgery.

Positioning

- Open reduction with internal fixation (ORIF) of scapular fractures requires wide access to the entire shoulder girdle. The patient may be placed in either the lateral decubitus position (FIG 2A) or in the beach chair position (FIG 2B), but care must be taken to allow adequate exposure of the entire scapula and clavicle.
- The shoulder girdle is prepped and draped widely, and the entire upper extremity is prepped and draped “free.”
- Alternatively, a staged procedure can be performed using separate positions, sterile preparations, and separate exposures.⁹

Approach

- Glenoid neck fractures are approached posteriorly.
- A superior approach can added for control and positioning of a difficult-to-control glenoid fragment.
- An anterior approach is used for coracoid process fractures.
- A superior approach is used for access to acromial process fractures.

POSTERIOR APPROACH TO GLENOID NECK

- Bony landmarks are outlined with marking pen (TECH FIG 1A).
- An incision is made along the scapular spine and acromion and down the lateral aspect of the shoulder, as needed.
- The origins of the posterior and middle heads of the deltoid muscle are sharply detached from the scapular spine–acromial process and retracted distally (TECH FIG 1B).
- The interval between infraspinatus and teres minor is developed.
- If access to the glenoid fossa is necessary, the infraspinatus tendon and underlying posterior gleno-humeral joint capsule are incised 2 cm lateral to their insertion on the greater tuberosity and reflected laterally (TECH FIG 1C,D).
- Mobilization of the teres minor muscle allows access to the lateral scapular border.

FIG 2 • A. The lateral decubitus position is used for posterior and posterosuperior approaches to the glenoid process. B. The beach chair position.
Reduction of the fracture is performed with lateral traction on the draped arm and manipulation of the fracture site.

Temporary fixation may be obtained with K-wires.

Rigid fixation may be obtained with a contoured reconstruction plate and 3.5-mm cortical screws (TECH FIG 1D).

Care must be taken to avoid violating the glenoid fossa with the screws in the glenoid fragment.

Meticulous repair of the deltoid origin to the scapular spine–acromion should be performed with permanent sutures through drill holes.

SUPERIOR APPROACH TO GLENOID NECK

The superior approach to the glenoid neck is made in an extensile fashion by extending the posterior incision superiorly.

The trapezius and underlying supraspinatus muscles are split in the line of their fibers (TECH FIG 2).

ORIF OF ACROMIAL PROCESS FRACTURE

Incision directly over the acromial process

Subperiosteal dissection to expose the superior surface of the acromion

Anatomic fracture reduction under direct visualization

Proximal fractures: fixation with a contoured 3.5-mm reconstruction plate (TECH FIG 3A)

Distal fractures: fixation with a tension band construct (TECH FIG 3B)
TECH FIG 3 • Fixation techniques for acromion process fractures. A. Plate-and-screw construct for a fracture of the base of the acromion. B. Tension band wire construct.

ORIF OF CORACOID PROCESS FRACTURE

- Vertical incision 1 cm lateral to coracoid process (TECH FIG 4A)
- Development of deltopectoral interval or split of the deltoid muscle in line with its fibers directly over the coracoid process
- Exposure of the fracture site (may need to open the rotator interval)
- If coracoid tip has sufficient stock, cannulated screw fixation can be performed (TECH FIG 4B).
- If not, fragment excision and suture fixation of conjoint tendon to remaining coracoid is performed (TECH FIG 4C).
- Coracoid base fractures are fixed with a single cannulated cortical screw (TECH FIG 4D).

TECH FIG 4 • A. Standard anterior incision extends from the superior to inferior margin of the humeral head, centered over the glenohumeral joint. B–D. Three repair techniques for coracoid fractures. B. Cannulated screw fixation of tip avulsion with sufficient bone to repair. (continued)
POSTOPERATIVE CARE

- How aggressive the rehabilitation program following ORIF of nonarticular scapular fractures must be is determined by the rigidity of the fixation construct and the adequacy of the soft tissue repair.5
- Patients are immobilized in a sling and swathe binder and started on gentle pendulum exercises during the first 2 weeks.
- Progressive passive and active-assisted range of motion exercises are emphasized during weeks 2 through 6 postoperatively.
- All protection is discontinued by 6 weeks postoperatively.
- Strengthening is begun after 6 weeks postoperatively and after range of motion is satisfactory.
- Return to sports or labor is restricted until 4 to 6 months postoperatively.

OUTCOMES

- Relatively few outcome studies detailing the results of scapular fractures treated operatively are available.
- While most nonarticular scapular fractures are treated nonoperatively, those that warrant surgical intervention appear to benefit from this treatment.7,8

COMPLICATIONS

- When neurologic complications occur, they most commonly are caused by overly aggressive retraction or misdirected dissection.
- The musculocutaneous and axillary nerves are vulnerable in the anterior approach, the suprascapular nerve in the superior approach, and the axillary and suprascapular nerves in the posterior approach.9
REFERENCES

DEFINITION

Intra-articular scapular fractures include fractures of the glenoid cavity, which includes the glenoid rim and the glenoid fossa. They account for 10% of scapular fractures. Most scapular fractures are extra-articular, and 50% involve the body and spine.

Over 90% of fractures of the glenoid cavity are insignificantly displaced and are managed nonoperatively. Significant displacement requires evaluation for surgical intervention to achieve the best possible outcome.

ANATOMY

The scapula is a flat triangular bone with three processes: the glenoid process, the acromial process, and the coracoid process.

The glenoid process consists of the glenoid cavity (the glenoid rim and glenoid fossa) and the glenoid neck.

The glenoid cavity provides a firm concave surface with which the convex humeral head articulates. The average depth of the articular cartilage is 5 mm.

Glenoid cavity fractures are classified according to whether they involve the glenoid rim or the glenoid fossa and the direction of the fracture line (FIG 1).

PATHOGENESIS

Scapular fractures usually are the result of high-energy trauma and have a high rate (90%) of associated bony and soft tissue injuries, both local and distant.

Fractures of the glenoid rim occur when the humeral head strikes the periphery of the glenoid cavity. They are true fractures, not avulsion injuries caused by indirect forces applied to the periarticular soft tissues by the humeral head.

Fractures of the glenoid fossa occur when the humeral head is driven into the center of the concavity. The fracture then promulgates in a number of different directions, depending on the characteristics of the humeral head force.

NATURAL HISTORY

The results of nonoperative treatment of intra-articular scapular fractures usually are good if the fracture displacement is minimal and the humeral head lies concentrically within the glenoid cavity.

Significant displacement can result in posttraumatic degenerative joint disease, glenohumeral instability, and even nonunion.

PATIENT HISTORY AND PHYSICAL FINDINGS

In addition to the specifics of the injury, it is helpful to obtain an understanding of the functional demands on the extremity. Hand dominance, occupation, and sports participation are all relevant.

A thorough neurovascular examination must be performed. Deficits are evaluated with angiography and electromyography, as necessary.

A thorough soft tissue examination also is warranted. Wounds may represent an open fracture and warrant exploration. Blisters or swelling may delay surgery.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Intra-articular scapular fractures initially are evaluated with a routine scapula trauma radiographic series (a true anteroposterior view of the shoulder with the arm in neutral rotation, a true axillary view of the glenohumeral joint, and a true lateral scapular view; FIG 2A).

CT scans and three-dimensional studies with reconstructions can be helpful in evaluating articular congruity and fracture displacement (FIG 2B–D). In addition, the bony relationships should be evaluated for evidence of ligamentous disruption(s) or instability.

DIFFERENTIAL DIAGNOSIS

Intra-articular scapular fractures
Nonarticular scapular fractures
Scapulothoracic dissociation
Double disruptions of the superior shoulder suspensory complex, including a floating shoulder (a glenoid neck fracture with an ipsilateral middle third clavicle fracture)

NONOPERATIVE MANAGEMENT

Most (over 90%) intra-articular scapular fractures are insignificantly displaced and are managed nonoperatively.

Significantly displaced glenoid fossa and glenoid rim fractures require operative management.

SURGICAL MANAGEMENT

Surgical indications are as follows:

Rim fractures: 25% or more of the glenoid cavity anteriorly or 33% or more of the glenoid cavity posteriorly and displacement of the fragment 10 mm or more

Fossa fractures: an articular step-off of 5 mm or more, significant separation of the fracture fragments, or failure of the humeral head to lie in the center of the glenoid cavity

Preoperative Planning

Imaging studies should be reviewed before the surgery and should be available for reference in the operating room. A draped fluoroscopy unit and a competent technician should be available. An examination for instability can be performed while under anesthesia.

Positioning

Open reduction with internal fixation (ORIF) of intra-articular scapular fractures requires wide access to the entire Chapter 23 Open Reduction and Internal Fixation of Intra-articular Scapular Fractures Brett D. Owens, Joanna G. Branstetter, and Thomas P. Goss
FIG 1 • Goss-Ideberg classification of glenoid cavity fractures. Ia, anterior rim; Ib, posterior rim; II, inferior glenoid; III, superior glenoid; IV, transverse through the body; V, combination II-IV; VI, comminuted.

FIG 2 • A. The AP radiograph shows a type Vc glenoid cavity fracture. B. Axillary CT image shows a large anterosuperior glenoid cavity fragment including the coracoid process. (continued)
shoulder girdle. Depending on the particular fracture, the patient is placed in either the lateral decubitus position (FIG 3A) or the beach chair position (FIG 3B).
- Care must be taken to allow adequate exposure of the entire scapula and clavicle. The shoulder girdle is prepped and draped widely, and the entire upper extremity is prepped and draped “free.”
- In some cases, a staged procedure may be necessary using separate positions, sterile preparations, and exposures.10

**Approach**
- The posterior approach is used for fractures of the posterior glenoid rim and most fractures of the glenoid fossa.
- The superior approach is used, in conjunction with a posterior approach, for fractures of the glenoid fossa with a difficult-to-control superior fragment.
- The anterior approach is used for fractures of the anterior glenoid rim and some fractures involving the superior aspect of the glenoid fossa.

**POSTERIOR APPROACH TO THE GLENOID CAVITY**
- Bony landmarks are outlined with a marking pen.
- An incision is made along the scapular spine and acromion and down the midlateral aspect of the shoulder, as needed (TECH FIG 1A).
- Origins of the posterior and middle heads of the deltoid muscle are sharply detached from the scapular spine-acromial process, and the deltoid muscle is split in the line of its fibers for 2.5 cm in the midlateral line. It is then retracted distally (TECH FIG 1B).
- The interval between infraspinatus and teres minor is developed (TECH FIG 1C). To gain access to the glenoid fossa, the infraspinatus tendon and underlying posterior glenohumeral joint capsule are incised 2 cm lateral to their insertion on the greater tuberosity and reflected posteriorly (TECH FIG 1D).
- Subperiosteal mobilization of the teres minor muscle allows access to the lateral scapular border.
**SUPERIOR APPROACH TO THE GLENOID CAVITY**

- The superior approach to the glenoid cavity is made by extending the posterior incision superiorly.
- The trapezius and underlying supraspinatus muscles are split in the line of their fibers (TECH FIG 2).

**ANTERIOR APPROACH TO THE GLENOID CAVITY**

- The incision is made in Langer’s lines and centered over the glenohumeral joint from the superior to inferior level of the humeral head (TECH FIG 3A).
- The deltoid muscle is split in the line of its fibers over the palpable coracoid process and retracted medially and laterally.
- The conjoined tendon is retracted medially after division of the overlying fascia along its medial border (TECH FIG 3B).
- Care must be taken to protect all neurovascular structures from injury.
- Incise the subscapularis tendon vertically 2.5 cm medial to its insertion on the lesser tuberosity and along its superior and inferior borders.
- Dissect it off the underlying anterior glenohumeral capsule.
- Tag the corners of the subscapularis unit and turn it back medially (TECH FIG 3C).
- Incise the anterior glenohumeral capsule in the same fashion, tag its corners, and turn it back medially to gain access to the glenohumeral joint.
**TECH FIG 3** • A. Anterior approach using a skin incision made in Langer’s lines and centered over the glenohumeral joint. B. The conjoined tendon is retracted medially. C. Incise the subscapularis tendon 2 cm from its insertion on the lesser tuberosity, dissect it off the glenohumeral capsule, incise the capsule similarly, and turn both of them back medially to gain access to the glenohumeral joint. (From Goss TP. Open reduction and internal fixation of glenoid fractures. In: Craig EV, ed. Master Techniques in Orthopaedic Surgery: The Shoulder, 2nd ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

**FIXATION TECHNIQUES**

- The fracture is reduced as anatomically as possible.
- Temporary fixation may be obtained with K-wires.
- Rigid fixation may be obtained with a contoured reconstruction plate and 3.5-mm cortical screws or with cannulated interfragmentary compression screws, depending on the characteristics of the fracture.
- Care must be taken to avoid violating the glenoid fossa with any screws placed in the glenoid fragment (TECH FIG 4A,B).
- If severe comminution is present, an iliac crest tricortical bone graft is an option (TECH FIG 4C).
- All soft tissues divided to gain access to the fracture site must be meticulously repaired. With posterior approaches, the deltoid must be securely reattached to the acromion and scapular spine with permanent sutures through drill holes.

**TECH FIG 4** • A. Postoperative AP image of the patient shown in Tech Fig 1. B. Axillary radiograph showing the glenoid cavity fragments secured together with cannulated screws and the glenoid unit secured to the scapular body with a malleable reconstruction plate (the acromial fracture was reduced and stabilized with a tension band construct). (continued)

PEARLS AND PITFALLS

Indications
- Rim fractures: 25% or more of the glenoid cavity anteriorly or 33% or more of the glenoid cavity posteriorly and displacement of the fragment 10 mm or more
- Fossa fractures: an articular step-off of 5 mm or more, significant separation of the fracture fragments, or failure of the humeral head to lie in the center of the glenoid cavity

Approach
- Incising the rotator interval and leaving the subscapularis unit intact may allow adequate exposure for injuries involving a displaced superior glenoid fragment.
- Some injuries require combined anteroposterior or posterosuperior approaches.
- Deltoid detachment and retraction provide maximal posterior exposure and access.
- During the posterior approach, develop the internervous plane between the infraspinatus (a bipennate muscle) superiorly and the teres minor inferiorly.

Reduction
- K-wires can be placed to serve as “joysticks” to assist with fracture reduction. They also can be driven across the fracture site to provide temporary or permanent fixation.

Fixation
- Bone stock capable of allowing internal fixation is at a premium in the scapula. The four satisfactory areas include the glenoid neck, the acromion–scapular spine, the lateral scapular border, and the coracoid process. Reconstruction plates may be pre-contoured using a scapula model and flash-sterilized. If severe comminution is present, an iliac crest tricortical bone graft is an option. Cannulated interfragmentary screws can be inserted using previously placed K-wires as guidewires.

Closure
- If the deltoid muscle is detached, meticulous repair to the scapular spine–acromial process is necessary using nonabsorbable sutures placed through drill holes.

POSTOPERATIVE CARE
- The aggressiveness of the rehabilitation program following ORIF of intra-articular scapular fractures is determined by the rigidity of the fixation construct and the adequacy of the soft tissue repair.  
- Patients are immobilized in a sling and swathe binder and started on gentle pendulum exercises during the first 2 weeks.
- Progressive passive and active-assisted range-of-motion exercises emphasizing forward flexion and internal–external rotation are prescribed during weeks 2 through 6 postoperatively.
Chapter 23 OPEN REDUCTION AND INTERNAL FIXATION OF INTRA-ARTICULAR SCAPULAR FRACTURES 3255

- All protection is discontinued at 6 weeks postoperatively.
- Strengthening is begun after 6 weeks postoperatively and when range of motion is satisfactory.
- Return to sports or physical labor is restricted until 3 to 6 months postoperatively.
- Close outpatient follow-up with radiographs, especially early in recovery, and a well-defined, closely monitored physical therapy program are extremely important.

OUTCOMES
- Good results have been reported for the operative management of glenoid rim fractures.⁹,¹²
- Bauer et al¹ reviewed six patients treated surgically for glenoid cavity fractures. Four patients with an anatomic reduction had good results; two patients with nonanatomic reductions developed arthritic changes.
- Kavanaugh and colleagues⁷ presented their experience at the Mayo Clinic in which 10 displaced intra-articular fractures of the glenoid cavity were treated with ORIF. They found ORIF to be “a useful and safe technique” that “can restore excellent function of the shoulder.” In their series, the major articular fragments were displaced 4 to 8 mm.
- Schandelmaier and coauthors¹¹ reported a series of 22 fractures of the glenoid fossa treated with ORIF with good results.
- Leung and colleagues⁸ reviewed 14 displaced intra-articular fractures of the glenoid treated with ORIF (30.5-year average follow-up) and reported 9 excellent and 5 good results.
- On the basis of these reports, it seems reasonable to conclude that there is a definite role for surgical management in the treatment of glenoid cavity fractures.

COMPLICATIONS
- Neurologic complications most commonly are caused by overly aggressive retraction or misdirected dissection.
- The musculocutaneous and axillary nerves are vulnerable in the anterior approach.
- The supraspinatus nerve is at risk in the superior approach, and the axillary and suprascapular nerves are vulnerable in the posterior approach.¹⁰
- A variety of other complications can occur as a result of poor surgical technique, inadequately directed or managed rehabilitation, and poor patient compliance.

REFERENCES
DEFINITION
- Despite significant advances in shoulder arthroplasty and other reconstructive procedures, glenohumeral arthrodesis remains an important treatment option in appropriately selected patients.
- The goal of glenohumeral arthrodesis is to provide a stable base for the upper extremity to optimize elbow and hand function.
- Given the tremendous normal range of motion of the glenohumeral joint and the relatively small amount of surface area available for fusion, particularly on the scapular side, successful arthrodesis is technically demanding and requires meticulous surgical technique.

ANATOMY
- The surface area of the glenoid is too small to allow for predictable fusion. Therefore, to increase the area available for fusion, the glenohumeral articular surface and the articulation between the humeral head and undersurface of the acromion are decorticated (FIG 1).
- The bone of the scapula is extremely thin, with only the glenoid fossa and base of the coracoid providing sufficient strength for fixation.
- The optimal position for glenohumeral arthrodesis has been controversial.1,4
  - We use a position of 30 degrees of abduction, 30 degrees of forward flexion, and 30 degrees of internal rotation.
  - This position brings the hand to the midline anteriorly, allowing the patient to reach his or her mouth with elbow flexion.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The history and physical findings are specific to the underlying condition requiring arthrodesis.
- All patients will exhibit symptomatic dysfunction at the glenohumeral joint that prevents them from effectively using the involved extremity.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standard radiographs, including an anteroposterior, lateral, and axillary view, are used to assess any deformities as well as the bone stock available for fusion.
- If there is concern regarding bone loss on the glenoid side, especially in the setting of failed arthroplasty, this is better evaluated with a CT scan.
- When the neurologic condition of the shoulder girdle muscles is unclear, an electromyelogram of the scapular muscles is indicated.

SURGICAL MANAGEMENT
Indications
- The presence of a flail shoulder is an indication for glenohumeral arthrodesis.
  - Paralysis in patients with a flail shoulder can be the result of anterior poliomyelitis, severe proximal root or irreparable upper trunk brachial plexus lesions, or isolated axillary nerve paralysis.
  - Many patients with flail shoulders develop a painful inferior subluxation that responds well to arthrodesis.
  - The need for fusion following isolated axillary nerve injury depends on the level of impairment. Many patients, especially those with partial paralysis, have reasonable function; however, complete injury often leads to significant limitation of shoulder function.
  - Glenohumeral arthrodesis is useful following en bloc resection of periarticular malignant tumors requiring resection of the deltoid, rotator cuff, or both.
  - Fusion is useful for the treatment of joint destruction following septic arthritis of the shoulder, particularly in young patients.
Arthrodesis is a salvage option for patients with multiple failed total shoulder arthroplasties who have insufficient bone stock or soft tissue for revision arthroplasty.

- Symptomatic, uncontrolled shoulder instability that is recalcitrant to soft tissue or bony reconstructive procedures can be managed with fusion.
- Rarely, arthrodesis is indicated in young laborers with severe osteoarthritis who are poor candidates for arthroplasty because of their young age and high activity levels.

**Contraindications**

- The primary contraindication to glenohumeral arthrodesis is weakness or paralysis of the periscapular muscles, especially the trapezius, levator scapula, and serratus anterior.
- Progressive neurologic disorders that are likely to lead to paralysis of these muscles also are a contraindication.
- Arthrodesis of the opposite shoulder is a contraindication to fusion.
- Shoulder fusion requires a significant effort by the patient to rehabilitate the shoulder and is contraindicated in patients unwilling or unable to participate in such a program.

**Preoperative Planning**

- Preoperative radiographs should be evaluated for any bone defects that may require bone grafting.

- The surgeon should make sure that the pelvic reconstruction plate and a set of handheld bending irons are available (FIG 2).

**Positioning**

- The patient is placed in the beach chair position with the back of the table elevated 30 to 45 degrees.
- A folded sheet is placed medial to the scapula to elevate it from the table.
- The drapes are applied as medial as possible, allowing access to the scapula and the anterior chest wall. The arm is draped free (FIG 3).
- We do not routinely use intraoperative fluoroscopy; however, early in their experience with this procedure, surgeons may find fluoroscopy useful to confirm the position of the hardware.

**Approach**

- We perform glenohumeral arthrodesis using a 10-hole, 4.5-mm pelvic reconstruction plate.
- Compression across the glenohumeral articular surface is achieved by placing the initial screws from the plate through the proximal humerus and into the glenoid fossa.
- The plate is then anchored to the spine of the scapula by a screw directed into the base of the coracoid.

**Exposure**

- An S-shaped skin incision begins over the scapular spine, transverses anteriorly over the acromion, and extends down the anterolateral aspect of the arm (TECH FIG 1A).
- The skin and subcutaneous tissue are incised down to the fascia along the entire length of the incision.
- The spine of the scapula and acromion are exposed first by electrocautery, and then by subperiosteal dissection (TECH FIG 1B).
- Anteriorly, the deltopectoral interval is developed, and the deltoid is subperiosteally elevated off the acromion, beginning at the medial aspect of the anterior head and progressing laterally and posteriorly to the posterolateral corner of the acromion.
- Alternatively, if the deltoid is de-innervated, as may occur following brachial plexus injury, it can be split between the anterior and lateral heads. The anterior head is then elevated medially and the lateral head laterally to provide wide exposure of the proximal humerus.
- Distally, the biceps tendon is identified and tenodesed to the upper border of the pectoralis major tendon.
The rotator cuff is resected from the proximal humerus, beginning at the inferior border of the subscapularis and proceeding superiorly and then posteriorly and inferiorly to the level of the teres minor.

A ring or Hohmann retractor is placed on the posterior lip of the glenoid, and the humeral head is retracted posteriorly to expose the glenoid.

The glenoid cartilage is removed using a \( \frac{3}{8} \)-inch curved osteotome or burr (TECH FIG 2A). The glenoid labrum also is removed.

The retractors are then removed, and the arm is extended, adducted, and externally rotated to expose the humeral head.

A \( \frac{1}{2} \)-inch curved osteotome or burr is used to remove the articular surface of the humerus in its entirety.

The undersurface of the acromion is decorticated with a \( \frac{3}{4} \)-inch curved osteotome or burr.

The arm is placed in 30 degrees of flexion, 30 degrees of abduction, and 30 degrees of internal rotation, and the humerus is brought proximally to appose the decorticated surface of the acromion (TECH FIG 2B).

The arm is maintained in this position by placing folded sheets between the thorax and the extremity and having an assistant stand on the opposite side of the table to support the forearm and hand.

The 4.5-mm, 10-hole pelvic reconstruction plate is contoured to run along the spine of the scapula, over the acromion and down the shaft of the humerus (TECH FIG 2C).

The plate is bent 60 degrees between the third and fourth holes and then twisted 20 to 25 degrees just distal to the bend so it apposes the shaft of the humerus.

With the arm supported in the appropriate position and the plate held against the scapula and humerus, a hole is drilled through the plate, through the humerus, and into the glenoid using a 3.2-mm drill bit.

The screw length is measured; usually it is between 65 and 75 mm.

The humeral cortex is tapped with a 6.5-mm tap.

A short-thread 6.5-mm cancellous screw is inserted as a lag screw into the glenoid.

Depending on glenoid bone stock, one or two more screws are placed in a similar manner.

The plate is then anchored to the scapula by placing one or two fully threaded cancellous screws from the plate through the spine of the scapula and into the base of the coracoid.

Another cancellous screw is placed across the acromiohumeral fusion site.

Distally, the remaining holes are filled with cortical screws (TECH FIG 2D).

The wound is closed in standard fashion over two \( \frac{1}{8} \)-inch suction drains. Care is taken to reattach the deltoid to the acromion in an effort to cover as much of the plate as possible.
We do not routinely use bone graft when performing glenohumeral arthrodesis.

Bone grafting is indicated to fill large defects in patients who are undergoing arthrodesis for complex and revision problems as well as following tumor resection.

Nonstructural autogenous bone graft can be obtained from the ipsilateral iliac crest and is combined with revision of the internal fixation for the treatment of nonunited fusions.

Tricortical iliac crest graft can be placed between the humerus and glenoid when structural bone graft is needed (TECH FIG 3A).

- This type of graft commonly is needed to treat bone deficiency following failed shoulder arthroplasty.
- The graft is placed underneath the plate so that the compression screws pass first through the plate and any remaining proximal humerus and then through the graft and into the glenoid.

When an intercalary defect larger than 6 cm is present, the surgeon should consider a vascularized fibular bone graft (TECH FIG 3B).

- The vascularized graft should be fixed at each end with minimal internal fixation.
- The entire defect is then spanned with a very long plate.
- The vascular anastomosis is performed between the peroneal artery and its vena comitantes and a branch of either the axillary or brachial artery.
- Nonstructural autogenous graft is placed at each end of the vascularized graft to maximize the likelihood of fusion occurring.
POSTOPERATIVE CARE

- In the operating room, after the procedure, a pillow is placed between the patient’s arm and chest, and the arm is then wrapped to the chest with a swathe.
- A radiograph is obtained in the recovery room to verify position of the internal fixation.
- A thermoplastic orthosis is applied on the day after surgery and adjusted as needed.
- Patients usually are discharged from the hospital on the second postoperative day and maintained in the orthosis for 6 weeks.
- If, at 6 weeks, there are no radiographic signs of loosening of the hardware, the patient may progress to a sling.
- Another radiograph is obtained at 3 months. If there are no signs of loosening, thoracoscapular strengthening and mobilization exercises are initiated.
- Glenohumeral arthrodesis places significant stress on the periscapular musculature. The rehabilitation process is slow, and a recovery period of 6 to 12 months should be expected.

OUTCOMES

- After successful arthrodesis, the patient usually can reach the mouth, opposite axilla, belt buckle, and side pocket. The patient cannot work or reach overhead, and cannot reach the back pocket or a bra strap, and perineal care often is very difficult using the fused shoulder.
- Richards et al.3 assessed the ability to perform specific activities of daily living in 33 patients following glenohumeral arthrodesis.
- Patient satisfaction was highest in those patients undergoing the procedure for a brachial plexus injury, osteoarthritis, and failed total shoulder arthroplasty.
- Cofield and Briggs4 reported their results for glenohumeral fusion with internal fixation in 71 patients. Eighty-two percent of the patients felt that they benefited from the procedure, and 75% were able to perform activities that involved reaching their trunk.
- Scalise and Iannotti5 analyzed the results of arthrodesis in seven patients following failed prosthetic arthroplasty. Five of the seven patients eventually achieved fusion. Four patients required additional bone-grafting procedures in an attempt to achieve union, and two of these patients ultimately had a persistent nonunion despite the additional procedures.

COMPLICATIONS

- Nonunion
- Prominent hardware
- Malposition
- Infection
- Humeral shaft fracture

REFERENCES

DEFINITION

- Glenohumeral arthritis is characterized by loss of articular cartilage and varying degrees of soft tissue contracture, rotator cuff dysfunction, and bone erosion, depending on the underlying arthritic condition.
- The results of surgical treatment are largely dependent on the integrity of the rotator cuff; therefore, glenohumeral arthritides are often subdivided on this basis.
- Common arthritic and related conditions that generally involve an intact or reparable rotator cuff include osteoarthritis, posttraumatic arthritis, and avascular necrosis.
- Although some patients with inflammatory arthritides such as rheumatoid arthritis have intact or reparable rotator cuffs, the rotator cuff is torn or dysfunctional in many patients. When reference is made to patients with inflammatory arthritides in this section, it pertains to the subset of patients in whom the cuff is intact or reparable.

ANATOMY

- The pertinent surgical anatomy can be divided into bone, ligaments, muscles, and neurovascular structures.
- Normal osseous relationships include humeral head center, thickness, and radius of curvature, humeral neck–shaft angle, humeral head offset, glenohumeral offset, greater tuberosity-to-acromion distance, greater tuberosity-to-humeral-head distance, glenoid radius of curvature, glenoid size, glenoid version, and glenoid offset (FIG 1).14,22
- Humeral head radius and thickness are variable and correlate with patient size. Mean humeral head radius is about 24 mm, with a range of 19 to 28 mm. Mean humeral head thickness is about 19 mm, with a range of 15 to 24 mm.14,22
- The ratio of humeral head thickness to humeral head radius of curvature is remarkably constant at about 0.7 to 0.9, regardless of patient height or humeral shaft size.14,22
- The center of the humeral head does not coincide with the projected center of the humeral shaft. The distance between the center of the humeral head and the central axis of the intramedullary canal is defined as the humeral head offset and is about 7 to 9 mm medial and 2 to 4 mm posterior (FIG 2).2,22
- Humeral retroversion averages 20 to 30 degrees, with a wide range of about 20 to 55 degrees.2,14,22 The vertical distance between the highest point of the humeral articular surface and the highest point of the greater tuberosity (ie, head to greater tuberosity height) is about 8 mm and shows a relatively small range of interspecimen variability.14
- Humeral neck–shaft angle is defined as the angle subtended by the central intramedullary axis of the humeral shaft and the base of the articular segment and shows substantial individual variation. The average neck–shaft angle is 40 to 45 degrees (130–135) degrees, with a range of 30 to 55 (120–145) degrees.2,14,22
- Pertinent musculotendinous anatomy includes the deltoid, pectoralis major, conjointed tendon of the coracobrachialis and short head of the biceps, rotator cuff, and long head of the biceps.


FIG 2 • The humeral head center, on average, lies 2 to 4 mm posterior and 7 to 9 mm medial to the projected center of the intramedullary canal. (Adapted from Boileau P, Walch G. The three-dimensional geometry of the proximal humerus: implications for surgical technique and prosthetic design. J Bone Joint Surg Br 1997;79B:857–865.)
Ligamentous structures that are potentially important in the surgical management of glenohumeral arthritis include the coracohumeral ligament and the glenohumeral capsular ligaments. In many cases of glenohumeral arthritis with an intact cuff, the anterior and inferior capsular ligaments are contracted, resulting in restriction of external rotation and posterior humeral head subluxation.

Neurovascular structures are abundant and subject to potential injury during shoulder arthroplasty. The axillary artery and all of its branches, especially the anterior humeral circumflex, posterior humeral circumflex, and the subscapular arteries, are particularly vulnerable.

The entire brachial plexus traverses the anterior aspect of the shoulder and is subject to traction and other injuries. The two most pertinent nerves are the axillary nerve and the musculocutaneous nerve.

The axillary nerve is a terminal branch of the posterior cord of the brachial plexus and is composed primarily of motor fibers from the fifth and sixth cervical roots. It descends the anterior surface of the subscapularis to the inferior aspect of the joint capsule, where it courses through the quadrilateral space to enter the posterior aspect of the shoulder.

The musculocutaneous nerve is one of the terminal branches of the lateral cord of the brachial plexus that is anterior and lateral to the axillary nerve. It typically pierces the conjoined tendon of the coracobrachialis and short head of the biceps about 5 cm distal to the tip of the coracoid. However, this course is variable and the entry point into the conjoined tendon can be as proximal as 2 cm.

**PATHOGENESIS**

The biologic basis for glenohumeral arthritis is not known. However, the loss of articular cartilage associated with primary osteoarthritis, posttraumatic arthritis, avascular necrosis, and other arthritides is, in some way, the result of imbalance in the normal cycle of cartilage damage and repair.

In some cases of posttraumatic arthritis, catastrophic cartilage damage associated with single-event or repetitive trauma overwhelms the shoulder’s cartilage repair mechanisms and arthritis ensues.

Primary osteoarthritis may be associated with mechanical factors such as glenoid hypoplasia and increased retroversion. However, in many cases, no cause is evident. The final common pathway involves a release of degradative enzymes such as collagenase, gelatinase, and stromelysin, and a variety of inflammatory mediators, which further damage the cartilage and eventually the underlying bone.

A detailed discussion of the pathogenesis of avascular necrosis is beyond the scope of this chapter. However, the development of glenohumeral arthritis in this condition is likely the result of advanced cartilage damage following collapse of the humeral head. Involvement of glenoid articular cartilage does not occur until the later stages of the disease, when the irregular humeral head has been articulating with the previously normal glenoid surface.

Rheumatoid arthritis is characterized by activation of the immune system that leads to an influx of lymphocytes into the joint and synovial tissue, with subsequent release of a variety of cytokines, destructive enzymes, and mediators of inflammation such as interleukins and tumor necrosis factor. This autoimmune response is thought to be important in perpetuating joint destruction.\(^{25}\)

**NATURAL HISTORY**

- Glenohumeral arthritis of any type is characterized by progressive stiffness, pain, and loss of function.
- Patients with primary osteoarthritis and many types of posttraumatic arthritis develop progressive loss of external rotation, posterior subluxation, and posterior glenoid bone loss. Large osteophyte formation, especially on the inferior humeral neck, is common. Full-thickness rotator cuff tears are distinctly uncommon and occur in 5% to 10% of patients.
- Rheumatoid arthritis results in progressive regional osteopenia, central glenoid bone erosion, and rotator cuff tears. The prevalence of full-thickness rotator cuff tears in patients with rheumatoid arthritis of the shoulder is 25% to 40%.\(^{27}\)
- However, rotator cuff dysfunction and substantial partial tearing are extremely common.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Patients with glenohumeral arthritis will give a history of chronic (years) shoulder pain and restricted motion, often with a recent (months) exacerbation. Posttraumatic arthritis is typically associated with a history of prior injury, such as fracture or dislocation, or surgery.
- Pain is often worse with activity and usually interferes with sleep. Neck pain, distal radiation below the elbow, and numbness and paresthesias in the fingers and hand are uncommon and should suggest other potential causes of shoulder pain, such as cervical stenosis or cervical radiculopathy.
- Bilateral involvement is common in primary osteoarthritis. Contralateral symptoms are often present, but to a lesser extent.
- Physical findings in patients with glenohumeral arthritis and an intact rotator cuff include:
  - Posterior joint line tenderness, especially in osteoarthritis associated with posterior subluxation\(^{20}\)
  - Generalized atrophy or flattening of the shoulder from long-term lack of function
  - Posterior prominence of the humeral head in cases of posterior subluxation
  - Symmetrical loss of active and passive range of motion (FIG 3)
  - Disproportionate loss of external rotation in comparison to other motions, especially in osteoarthritis or after capsulorraphy arthropathy\(^{20}\)
  - Increased pain with passive stretch of the capsule at the end range of motion, especially external rotation
  - Intact neurologic function, except in rare patients with prior neurologic injury from trauma or surgery

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

Glenohumeral arthritis is a radiographic diagnosis. Routine radiographs should include anteroposterior (AP) views in internal and external rotation and an axillary view.

Radiographic findings in primary osteoarthritis include subchondral sclerosis and cyst formation, osteophyte formation, and asymmetrical posterior joint space narrowing (FIG 4A,B).\(^{20}\)

In cases of posttraumatic arthritis, radiographs may reveal retained hardware.
The hallmark of gleno-humeral osteoarthritis is symmetrical loss of both active and passive range of motion (A), especially external rotation (B).

Radiographic findings in osteoarthritis include osteophyte formation, especially on the inferior humerus as seen on the AP view (A), and asymmetrical posterior glenoid wear with posterior subluxation, as seen on the axillary view (B). C. CT scan reveals a large inferior humeral osteophyte and a type C glenoid, with increased glenoid retroversion. D. Coronal MR image in a patient with rheumatoid arthritis reveals an intact but very thin rotator cuff with erosion of the humeral attachment site, and evidence of rotator cuff dysfunction (ie, proximal humeral migration).
Glenoid deformity in osteoarthritis has been classified by Walch\(^\text{26}\) according to the presence of posterior subluxation and posterior bone deformity:

- **Type A**: centered
- **Type B**: posteriorly subluxated (B1) and posteriorly subluxated with posterior erosion (B2)
- **Type C**: posteriorly subluxated with increased retroversion (hypoplasia)

Computed tomographic (CT) scans are helpful in quantifying bone loss in patients with posterior subluxation (FIG 4C).

MRI is useful in patients with rheumatoid arthritis to determine rotator cuff integrity (FIG 4D).

Electromyography may be used in patients suspected of having posttraumatic or postsurgical nerve injuries.

Medical consultation is warranted in patients with substantial comorbidities.

**DIFFERENTIAL DIAGNOSIS**

- Frozen shoulder
- Posttraumatic or postsurgical infection
- Cervical stenosis
- Cervical radiculopathy
- Neoplasm

**NONOPERATIVE MANAGEMENT**

- Avoiding activities that are painful or place an undue strain on the shoulder, such as weight lifting, is important.
- Nonsteroidal anti-inflammatory medications may be helpful in reducing pain and inflammation.
- In patients with rheumatoid arthritis, rheumatologic consultation for maximizing medical treatment is helpful.
- Glucosamine chondroitin and other nutritional supplements may reduce the pain associated with arthritis, despite the relative lack of standardized data.
- Intra-articular corticosteroid injections are almost always helpful, but the relief is often only temporary.
- Hyaluronic acid derivatives are not yet approved by the U.S. Food and Drug Administration for use in the shoulder but may be of benefit in the future.
- Therapeutic exercises should be used judiciously. Stretching to maintain flexibility may be helpful, but vigorous exercises may increase pain.

**SURGICAL MANAGEMENT**

- Surgical options are considered when pain and dysfunction justify surgical intervention, nonoperative management has failed, medical comorbidities do not preclude surgery, and the patient is willing to accept the risks of surgery and the responsibility of postoperative rehabilitation and activity limitations.
- Nonprosthetic options such as arthroscopic or open debridement are indicated in patients who are too young and active for any type of prosthetic replacement.
- Prosthetic options include hemiarthroplasty, hemiarthroplasty plus biologic resurfacing, and total shoulder replacement.
- Total shoulder replacement with a polyethylene glenoid component provides the most predictable pain relief but has the disadvantage of progressive polyethylene wear and eventual component loosening.\(^{26}\)
- Hemiarthroplasty can be successful in providing pain relief, especially with minimal glenoid involvement or concentric glenoid wear. However, progressive glenoid erosion is likely and may require revision to total shoulder replacement.
- Hemiarthroplasty with resurfacing of the glenoid with biologic materials such as meniscal allograft, capsular or fascia lata autograft, fascia lata allograft, dermal allograft, Achilles tendon allograft, or xenograft materials has been performed, particularly in patients too young or active for a polyethylene glenoid component.\(^{3,21,30}\)
- The additional benefit of biologic resurfacing of the glenoid over hemiarthroplasty alone has not been clearly demonstrated, nor has its durability been confirmed.\(^{10}\)
- Hemiarthroplasty may be accomplished by replacement or resurfacing of the humeral head.
- Replacement of the humeral head is most commonly accomplished with a prosthetic head that is anchored to the shaft with a stem. However, more recently, humeral head replacements have been developed that are fixed to the metaphysis without violation of the diaphyseal canal.
- The relative indications for hemiarthroplasty, hemiarthroplasty with biologic resurfacing, and total shoulder arthroplasty are controversial, vary among surgeons, and must be individualized according to patient age, activity level, and bone deformity, among other factors.
- Similarly, the type of implant can be individualized according to patient factors and surgeon preference.
- Concentricity of the joint, without subluxation, likely improves prosthetic performance in all circumstances. Therefore, fixed subluxation should be corrected when possible. Options include contracture release and correction of bone deformity with some combination of asymmetric reaming, bone grafting, and specialized components.
- General principles that summarize procedural and implant indications in patients with glenohumeral arthritis and an intact or reparable cuff include the following:
  - Total shoulder arthroplasty is preferred with adequate glenoid bone, age greater than 50, and sedentary or moderate activity levels.
  - Hemiarthroplasty is favored in patients with normal or minimally involved glenoids, inadequate glenoid bone, age of 50 or under, and activity levels that include weight lifting or other strenuous activity.
  - Biologic resurfacing of the glenoid may be added to hemiarthroplasty but may also fail in patients who participate in heavy weight lifting or other strenuous activity.
- When substantial reaming or resurfacing of the glenoid is planned, the procedure is facilitated by removing the humeral head rather than resurfacing it. Currently stemmed implants are most popular, but implants with metaphyseal fixation may be useful in patients with adequate bone quality.
- Humeral resurfacing is useful when hemiarthroplasty is indicated in the absence of substantial glenoid deformity. Resurfacing preserves humeral bone and obviates the need to address humeral head–humeral canal offset.
- These principles are merely guidelines and should be individualized.
- The following sections will cover the technical aspects of humeral resurfacing, humeral replacement, humeral replacement combined with biologic glenoid resurfacing with allograft lateral meniscus, and total shoulder arthroplasty. Glenoid bone grafting is beyond the scope of this chapter and will not be covered.
Preoperative Planning

- Preoperative radiographs and CT scans should be reviewed to quantify humeral subluxation (especially posterior in osteoarthritis) and glenoid bone loss. This will identify the need for asymmetric glenoid reaming.
- If the goals of asymmetric reaming are to correct glenoid deformity and to contain all fixation appendages of the glenoid component within the glenoid vault, the extent of reaming should be limited to about 5 mm or 15 degrees. If greater correction is desired, arrangements for glenoid bone grafting should be made.
- Preoperative radiographs should be templated to gain an appreciation of the humeral head size, canal diameter, and neck–shaft angle. In patients with highly varus (115–120 degrees) or valgus (145–150 degrees) neck–shaft angles in whom cementless fixation of a stemmed implant is planned, alterations in the level of the humeral cut or the use of a prosthesis with neck–shaft angle variability will be required.
- MRI scans should be read for substantial rotator cuff abnormalities in rheumatoid patients and others suspected of having rotator cuff tears.
- All other relevant preoperative data should be reviewed, including consultations from medical colleagues. The presence of all surgical implants and instruments should be verified.
- Passive range of motion should be measured intraoperatively, before positioning, to determine the need for contracture release. In particular, the degree of passive external rotation loss may dictate the method of subscapularis reflection and repair.
- Subscapularis shortening is typically not a substantial factor in passive external rotation loss, unless the patient has had a prior subscapularis shortening or tightening procedure (eg, Putti-Platt or Magnuson-Stack) or the contracture is particularly severe (eg, external rotation of –30 degrees or more) and longstanding.
- Methods of managing the subscapularis include intratendinous incision and anatomic repair, lesser tuberosity osteotomy and anatomic repair, lateral tendinous release with medial advancement, and Z-lengthening.
- Recent evidence suggests that lesser tuberosity osteotomy is associated with better subscapularis function than soft tissue reflection and repair.12,23 However, randomized comparison data are not currently available. In addition, a recent study documents good postoperative subscapularis function with tenotomy and soft tissue repair.4
- My current preference for subscapularis management in primary shoulder arthroplasty is lesser tuberosity osteotomy and anatomic repair, with the following exceptions:
  - Rheumatoid arthritis with substantial erosion of the subscapularis attachment site on MRI
  - History of a subscapularis shortening or tightening procedure (eg, Putti-Platt or Magnuson-Stack procedure)
  - Passive external rotation of less than –30 degrees
  - If lesser tuberosity osteotomy is not performed, lateral detachment with medial reattachment is most often adequate. Subscapularis Z-lengthening is rarely required.

Positioning

- Shoulder arthroplasty is performed with the patient in the semirecumbent position (FIG 5A). The hips should be flexed about 30 degrees to prevent the patient from sliding down the table; the knees should be flexed about 30 degrees to relax tension on the sciatic nerves; the back should be elevated 35 to 40 degrees.
- The entire shoulder should be lateral to the edge of the table to allow adduction and extension of the arm (FIG 5B). This is
required for safe access to the humeral canal and can be accomplished by positioning the patient as far toward the operative side of the table as possible or by using a specialized table with removable cutouts behind the shoulders.

- A specialized padded, horseshoe-shaped headrest may be helpful in facilitating access to the superior aspect of the shoulder.
- An adjustable mechanical arm holder (McConnell Orthopedic Mfg. Co., Greenville, TX, or Tenet Medical Engineering, Inc., Calgary, Alberta, CA) is helpful for positioning the arm. Alternatively, a padded Mayo stand can also be used (FIG 5C).

**Approach**

- The most common approach for shoulder arthroplasty is the deltopectoral approach popularized by Neer. The advantages are preservation of the deltoid origin and insertion, extensibility, and excellent humeral exposure. The need for posterior deltoid retraction, especially in muscular men, can make posterior glenoid exposure difficult and can lead to injury of the cephalic vein, the deltoid itself, or the brachial plexus.
- The superior or anterosuperior approach was popularized by MacKenzie and involves access to the shoulder by reflecting the anterior deltoid from the acromion. Advantages include excellent anterior and posterior glenoid exposure and a lower incidence of axillary nerve traction injuries than the traditional deltopectoral approach. Disadvantages include nonextensibility, difficult medial and inferior humeral exposure, and potential deltoid dehiscence.
- Modifications of these exposures include the addition of a clavicular osteotomy and extensive takedown of the deltoid origin to aid in exposure for difficult cases.
- The deltopectoral approach is the most commonly used approach for primary arthroplasty with an intact or reparable cuff and will be used in all subsequent sections of this chapter.

### HUMERAL RESURFACING

**Superficial Dissection**

- A deltopectoral incision is made from the tip of the coracoid toward the deltoid insertion.
- The cephalic vein is taken laterally with the deltoid and the pectoralis major is taken medially.
- The upper 1 cm of the pectoralis major may be released to improve visualization of the inferior aspect of the joint, but this is not always needed.

**Deep Dissection**

- The clavipectoral fascia is incised lateral to the conjoined tendon of the short head of the biceps and coracobrachialis and is carried superiorly to the coracoacromial ligament, which does not require excision or release to attain adequate exposure.
- Digital palpation is used to verify the position of the axillary nerve, which is protected throughout the procedure. The musculocutaneous nerve is usually not easily palpable within the surgical field but can be palpated when its entrance is close to the tip of the coracoid. This should be noted so that excessive retraction of the conjoined tendon can be avoided.
- With the conjoined tendon retracted medially and the deltoid laterally, the arm is placed in slight external rotation to expose the anterior humeral circumflex artery and veins. These are clamped and coagulated or ligated to avoid inadvertent injury and bleeding during the case.
- The arm is placed in slight internal rotation and the long head of the biceps is exposed from the superior border of the pectoralis major to the supraglenoid tubercle by incising its investing soft tissue envelope and the rotator interval capsule. The long head of the biceps is tenodesed to the upper border of the pectoralis major using two nonabsorbable sutures and is then released proximal to this tenodesis site and excised from the supraglenoid tubercle.

### Lesser Tuberosity Osteotomy

- A large (2 inch) curved osteotome is used to perform a lesser tuberosity osteotomy (TECH FIG 1A). The goal is to obtain a 0.5- to 1-cm-thick, noncommitted fragment with which to reflect the subscapularis.
- This is most easily accomplished by placing the blade of the osteotome at the base of the bicapital groove with one hand, palpating the most anterior extent of the tuberosity with the index finger of the other hand, and allowing an assistant to strike the osteotome while the surgeon directs it.
- Once the osteotomy is completed, a large straight osteotome is placed in the osteotomy and is rotated about its long axis to free the osteotomy fragment from any adjacent soft tissue attachments.
- A large Cobb elevator is then placed in the osteotomy to lever the fragment anteriorly. This further frees the fragment from the underlying capsule and allows sectioning of the superior glenohumeral ligament attachment.
- The fragment should now be freely mobile. Three 1-mm nonabsorbable sutures are passed around the lesser tuberosity fragment through the bone–subscapularis tendon junction for traction and later reattachment (TECH FIG 1B,C).
- The arm is externally rotated to expose the most inferior portion of the subscapularis muscle. This may require a right-angle retractor for the pectoralis major. The muscle belly is incised superficially, in line with its fibers, about 1 cm superior to its most inferior border.
- A blunt elevator is used to dissect the interval between the subscapularis and the underlying capsule. Once this interval is adequately developed, a scalpel is placed between the subscapularis and capsule. With the lesser tuberosity pulled anteriorly, the scalpel is passed laterally so that is exits inferior to the fragment. This is continued from inferior to superior to release the subscapularis and

---

**REFERENCE**

3. Achilles tendon retraction, especially in muscular men, can make posterior glenoid exposure difficult and can lead to injury of the cephalic vein, the deltoid itself, or the brachial plexus.
4. The superior or anterosuperior approach was popularized by MacKenzie and involves access to the shoulder by reflecting the anterior deltoid from the acromion. Advantages include excellent anterior and posterior glenoid exposure and a lower incidence of axillary nerve traction injuries than the traditional deltopectoral approach. Disadvantages include nonextensibility, difficult medial and inferior humeral exposure, and potential deltoid dehiscence.
5. Modifications of these exposures include the addition of a clavicular osteotomy and extensive takedown of the deltoid origin to aid in exposure for difficult cases.
6. The deltopectoral approach is the most commonly used approach for primary arthroplasty with an intact or reparable cuff and will be used in all subsequent sections of this chapter.
lesser tuberosity from the underlying anterior and inferior capsule.

**Capsular Release and Osteophyte Excision**

- Once released, the subscapularis and attached lesser tuberosity are retracted medially to expose the anterior capsule. A blunt elevator is passed between the remaining inferior 1 cm of subscapularis and the inferior capsule to create a space for a blunt Hohmann retractor. This is used to retract and protect the axillary nerve during inferior capsular release and excision.
- The anterior capsule is released from the anatomic neck of the humerus, starting superiorly and extending inferiorly, well past the 6 o’clock position. This is facilitated by gradually flexing and externally rotating the adducted humerus.
- The humerus is then delivered into the wound with simultaneous adduction, extension, and external rotation (**TECH FIG 2A**). All humeral osteophytes are removed using a combination of rongeurs and osteotomes (**TECH FIG 2B**). This allows identification of the anatomic neck and the peripheral extent of the native articular surface.

**Humeral Preparation**

- Accurate placement of the central guide pin is the most important portion of the resurfacing procedure. This guide pin fixes the center and inclination of the articular surface in all planes. Once the guide pin is anatomically positioned, the remainder of the procedure is only a matter of choosing the appropriately sized head and placing it at the appropriate depth.

**TECH FIG 1** • A. A lesser tuberosity osteotomy is performed using a large curved osteotome placed in the base of the bicipital groove and driven medially to produce a lesser tuberosity fragment about 0.5 to 1.0 cm thick. B,C. A lesser tuberosity osteotomy has been performed in this right shoulder. B. After the fragment has been mobilized from the surrounding soft tissues, three heavy nonabsorbable sutures are placed around the fragment at the bone-tendon junction. C. The fragment is then reflected medially and the subscapularis and the accompanying lesser tuberosity are separated from the underlying capsule and retracted medially. (A: Adapted from Gerber C, Pennington SD, Yian EH, et al. Lesser tuberosity osteotomy for total shoulder arthroplasty: surgical technique. J Bone Joint Surg Am 2006; 88A[Suppl 1]:170–177.)

**TECH FIG 2** • A. The humerus is delivered into the wound with simultaneous adduction, extension, and external rotation in this right shoulder. Retractors include a Brown deltoid retractor superiorly, a large Darrach retractor medially, and a blunt Hohmann retractor anteroinferiorly on the calcar. B. All humeral osteophytes are removed at this stage to identify the anatomic neck.
In some systems, there are guides that can assist in accurate pin placement. The guides usually are hemispherical and cannulated centrally so that the edge of the guide is positioned parallel to the articular margin in the visual center of the head.

Once the surgeon is satisfied with pin placement, shaping of the humeral head to fit the deep surface of the resurfacing implant can commence.

Reamers are selected based on the anticipated size of the prosthetic humeral head, which is, in turn, decided through a combination of preoperative templating and intraoperative measurements.

Proper selection of humeral head radius and thickness (ie, neck length) is critical and there is a tendency to choose a head that is too large.

The appropriate reamer is selected and the humerus is reamed until the reamer bottoms out on the humerus (TECH FIG 3). There is a tendency to underream. Reaming can continue to within 2 to 3 mm of the rotator cuff reflection superiorly.

Trial implants are placed over the guide pin onto the reamed humeral surface. Circumferential contact is verified.

The central punch is placed over the guide pin and driven into the humeral metaphysis to prepare it for the central peg of the prosthetic head.

Substantial glenoid reaming should not be required, as these patients are treated with humeral head resection and a stemmed implant in my practice.

**Humeral Component Placement and Lesser Tuberosity Repair**

The humerus is redelivered into the wound and the appropriate humeral resurfacing implant is placed and impacted into position (TECH FIG 4). Care should be taken to ensure that the implant is completely seated. This requires removal of excess bone from around the periphery of the projected seating point of the implant.

Two small bone anchors are placed in the humerus medial to the osteotomy but lateral to the humeral prosthetic edge. The sutures on the anchors are passed in a mattress configuration through the subscapularis tendon from deep to superficial at the bone–tendon junction. The sutures are clamped but not tied yet.

With the humerus reduced and the arm in neutral rotation, the deep limbs of the three sutures previously passed around the lesser tuberosity are passed through the cancellous bone of the osteotomy bed as far laterally as possible.

**Glenoid Inspection, Capsular Excision, and Release**

The guide pin is removed and the glenoid is exposed by placing a humeral head retractor within the joint and retracting the humeral head posteriorly. Care should be taken not to damage the reamed surface of the humerus.

The axillary nerve is protected and the anteroinferior capsule is excised. If the labrum is present, it is left in place. The posterior capsule is released.
as possible, deep to the bicipital groove and out the lateral cortex of the humerus using a large, cutting free needle. A new needle is used for each pass and the sutures are clamped but not tied.

- The clamps on these three sutures are pulled laterally to hold the lesser tuberosity in a reduced position. The rotator interval is then closed laterally with a 1-mm non-absorbable suture.

- After the rotator interval suture is tied, the three interfragmentary sutures are tied, followed by the sutures from the anchors. This provides a secure lesser tuberosity and subscapularis repair.

- Passive motion achievable without undue tension on the subscapularis repair is noted for guidance of postoperative rehabilitation.

**Wound Closure**

- A drain is placed deep to the deltoid and is brought out through a separate stab wound, distal to the axillary nerve.

- The wound is closed in layers with interrupted absorbable sutures in the subcutaneous tissues and a running subcuticular monofilament suture.

### HEMIARTHROPLASTY

- Hemiarthroplasty with head resection is performed when concentric glenoid reaming is required.

- The techniques of superficial and deep dissection, lesser tuberosity osteotomy, capsular release, and osteophyte excision are the same as described previously.

### Humeral Head Resection

- The humeral head is removed with a saw at or near the anatomic neck (TECH FIG 5A). This can be accomplished freehand or with intramedullary or extramedullary guides.

- Retroversion of the cut in my practice is prescribed by the plane of the periphery of the native articular surface (ie, native retroversion). A small amount of bone (2 to 3 mm) can be left medial to the supraspinatus insertion (TECH FIG 5B).

- The neck-shaft angle of the humeral cut is determined by the type of implant used.

- With fixed neck-shaft angle devices, the cut should precisely fit the neck-shaft angle of the selected device.

- With variable neck-shaft angle implants there is more flexibility in osteotomy angle, especially if the variability of the implant neck-shaft angle is infinite within a range.

- Preoperative templating should identify the patient with an extreme varus (less than 125) or valgus (greater than 145 degrees) neck-shaft angle.

- In cases of extreme varus, use of a fixed-angle cementless stem will require a humeral cut that is more valgus than the native neck-shaft angle.

- The cut exits superiorly 2 to 3 mm medial to the cuff reflection and inferiorly through the native head. This will leave a small portion of the native head in place, even after the inferior osteophyte is removed.

- In cases of extreme valgus, use of a fixed-angle cementless stem will require a humeral cut that is more varus than the native neck-shaft angle.

- The cut exits inferiorly at the native articular margin and superiorly through the native head. This will leave a small portion of the native head medial to the cuff reflection.

- Alternatively, the cut can be made along the native neck-shaft angle and a variable neck-shaft angle device can be used to fit the native neck-shaft angle.

- The size of the humeral head is estimated by placing trial humeral heads on the cut surface of the osteotomy.

### Glenoid Exposure, Capsular Excision, and Surface Preparation

- With the humeral head resected, a Fukuda ring retractor is placed within the joint and the humerus is retracted posteriorly.

- A reverse, double-pronged Bankart retractor is placed on the scapular neck anteriorly, between the anterior capsule and the subscapularis.

- A blunt Hohmann retractor is placed along the anteroinferior portion of the scapular neck to retract and protect the axillary nerve, and the anterior and inferior capsule is excised.

**TECH FIG 5**

- **A.** After removal of all osteophytes, the location of the anatomic neck is marked with an electrocautery. This can be done freehand or using an external guide.

- **B.** The humerus is cut in native retroversion, leaving 2 to 3 mm of bone medial to the supraspinatus insertion.
The posterior capsule is released unless preoperative posterior humeral subluxation of greater than 25% was present, in which case the posterior capsule is preserved. The labrum is excised circumferentially to expose the entire periphery of the glenoid. If greater than 25% posterior humeral subluxation was present preoperatively, care is taken to preserve the posterior capsular attachment to the glenoid. The glenoid is sized with a sizing disk. The previously estimated humeral head size may give some idea of the glenoid size. The center of the glenoid is marked and a centering drill hole for the glenoid reamer is drilled. The orientation of this drill hole should be perpendicular to the estimated reamed surface. This can be estimated using preoperative CT measurements of the amount of posterior glenoid bone loss. The glenoid is reamed until a concentric surface is obtained.

Humeral Preparation and Component Placement

The humerus is redelivered into the wound and the humeral canal is reamed with sequentially larger reamers until light purchase is obtained within the intramedullary canal. A box osteotome that corresponds to the final reamer size is passed into the humerus to cut the footprint of the humeral implant. A broach that corresponds to the size of the box osteotome and final canal reamer is placed to the appropriate depth. The system I use allows either a fixed 135-degree neck–shaft angle or an infinitely variable neck–shaft angle within 120 to 150 degrees (Global AP, Depuy, Warsaw, IN). Therefore, a collar is screwed into the broach that creates a 135-degree neck–shaft angle. A calcar reamer is placed over the collar and, if the reamer is nearly parallel to the osteotomy surface, it is used to plane the surface to 135 degrees so that an implant with a fixed neck–shaft angle of 135 degrees can be used. A trial humeral head is placed over the collar, it is rotated into the offset position that provides the most symmetrical coverage of the humeral metaphysis, and the collar is locked to the broach. If the planes of the calcar reamer and the osteotomy surface are not nearly parallel, a variable neck–shaft angle implant will be used. The 135-degree collar is removed and a trial ball taper fitted with a humeral head trial is inserted into the broach. The trial head and ball taper are placed into the position that provides symmetrical coverage of the humeral metaphysis, and the taper is locked to the broach. With the trial humeral head locked into position, the remaining humeral osteophytes are removed so that the humeral bone is flush with the humerus around the entire periphery. Assuming the humerus has been reduced and adequate soft tissue tension and stability have been verified, the trial broach is removed and the real implant is assembled with either a fixed 135-degree taper or a variable ball taper in the same position as the trial. A nonabsorbable suture is passed around the neck of the prosthesis and the prosthesis is impacted into the humerus with the two ends of the suture protruding anteriorly. The humerus is then reduced.

Lesser Tuberosity Repair

The technique for lesser tuberosity repair is the same as described for humeral resurfacing, except that the suture that was placed around the prosthetic neck before impaction into the humerus takes the place of the suture anchors that were placed in the anterior humerus between the osteotomy bed and the lateral extent of the resurfacing prosthesis (TECH FIG 6A). Therefore, the osteotomy is stabilized with three suture groups: The three interfragmentary sutures from the lesser tuberosity to the osteotomy bed The rotator interval closure suture at the superior aspect of the osteotomy The suture from the prosthetic through the bone–tendon junction (TECH FIG 6B) The technique for wound closure is identical to that described for humeral resurfacing.

Tech FIG 6 • A. The final implant is seated and any remaining bone prominences are removed. The three interfragmentary sutures around the lesser tuberosity are visible posterior to the prosthesis. The strands from the suture that was placed around the neck of the prosthesis can be seen exiting the space between the prosthetic humeral head and the anterior humeral metaphysis. B. The lesser tuberosity has been repaired with a superior side-to-side suture in the lateral rotator interval, the three interfragmentary sutures tied over the bicipital groove, and the medial suture passed from the prosthetic neck through the bone–tendon junction.
HEMIARTHROPLASTY WITH BIOLOGIC RESURFACING  
(LATERAL MENISCAL ALLOGRAFT)

- All techniques are the same as described earlier for humeral resurfacing and hemiarthroplasty, except that placement of the allograft requires maximum glenoid exposure.
- The allograft can be grossly sized using glenoid sizing disks. It is prepared by suturing the anterior and posterior horns together.
- The glenoid surface should be concentric in order for biologic resurfacing with meniscal allograft to be successful. Therefore, reaming to correct glenoid bone deficiency (eg, posterior wear) should be performed before placing the allograft.
- If the labrum can be preserved, it can be used to anchor the allograft to the glenoid.
- Often, the labrum is absent or too degenerative to dependably hold sutures. Under these circumstances, absorbable suture anchors are used to attach the allograft around the periphery of the glenoid. Four to six anchoring points should be used, depending on the size of the glenoid (TECH FIG 7A).
- The sutures are passed into the periphery of the ring-shaped allograft above the wound at appropriate positions (TECH FIG 7B). The allograft is then shuttled down the sutures onto the glenoid surface and the sutures are tied (TECH FIG 7C).  
- If there is no bleeding bone exposed from reaming, drilling a few holes through the subchondral surface into the glenoid vault may assist in decompressing the glenoid vault and providing progenitor cells that can assist in healing.

TECH FIG 7 • A. The glenoid in this right shoulder is exposed with a Fukuda retractor posteriorly, a large Darrach retractor anteriorly on the neck of the scapula, and a single-prong Bankart retractor posterosuperiorly. Anchors have been placed in the four quadrants of this small glenoid. B. The meniscal allograft has been sutured into a ring and sutures from the previously placed anchors are passed through the meniscal allograft above the joint. C. The allograft is then transported down the sutures onto the glenoid surface and the sutures are tied. (From Williams G. Hemiarthroplasty and biological resurfacing of the glenoid. In: Zuckerman JD, ed. Advanced Reconstruction: Shoulder. Rosemont, IL: AAOS, 2007:545–556.)

TOTAL SHOULDER ARTHROPLASTY

- All techniques are the same as described earlier for humeral resurfacing and hemiarthroplasty except for placement of the glenoid component.
- Concentric glenoid reaming is an important step in glenoid resurfacing that improves initial seating and stability. This is accomplished by drilling a pilot hole in the center of the glenoid (TECH FIG 8A). Special glenoid reamers are used to ream concentrically around the center pilot hole (TECH FIG 8B).
- After the surface of the glenoid has been reamed concentrically, the anchoring holes for the glenoid component are created. Both pegged and keeled components are available. The technique described is for an off-axis pegged system (anchor peg glenoid, Depuy, Warsaw, IN).
- The center hole for the larger fluted central peg is drilled, followed by the holes for the three peripheral pegs (TECH FIG 8C). Penetration of any of the peripheral holes is uncommon but should be noted so that a bone plug from the humeral head can be placed before filling the hole with cement.
- A trial glenoid component is placed and complete seating and stability are verified.
- The holes are irrigated and dried.
- Bone cement is placed into the three peripheral holes using a syringe to pressurize the cement column. Any holes that required bone grafting from drill perforation should not receive pressurized cement.
- The glenoid component is impacted into position and can be held with digital pressure until the cement hardens (TECH FIG 8D).
Postoperative Care

- Early rehabilitation (6 weeks)
  - The goals of rehabilitation during the first 6 weeks after surgery are to maximize passive range of motion and to allow healing of the subscapularis or lesser tuberosity.
  - The safe range of glenohumeral motion that prevents excessive tension on the subscapularis is identified intraoperatively.
  - This range of passive motion is performed starting the first postoperative day.
  - In general, uncomplicated shoulder arthroplasty will allow passive elevation to 140 degrees and passive external rotation to 40 degrees. If there is concern for the subscapularis repair, elevation and external rotation can be dropped to 130 and 30 degrees, respectively. If the tissue is poor quality, one may even drop the limits to 90 degrees of elevation and 0 degrees of external rotation.
  - These exercises are performed for 6 weeks postoperatively, in combination with pendulum exercises.
  - The sling may be discontinued at home after the first week or 10 days, when the hand can be used as a helping hand for daily activities.
- Active elevation above 90 degrees is delayed until 6 weeks postoperatively.
- Midterm rehabilitation (6 to 12 weeks)
  - During midterm rehabilitation, active range of motion is encouraged, passive stretching is instituted, and strengthening exercises for the rotator cuff, deltoid, and scapular stabilizers are pursued.
  - Active assisted range of motion within the limits of pain is accomplished with an overhead pulley and 3-foot stick.
  - This is progressed to active range of motion as tolerated.
  - End-range stretching in all planes is begun and progressed.
  - Strengthening exercises with the Theraband commence when active range of motion is maximized.
- Late rehabilitation (12 to 24 weeks)
  - Strengthening exercises for the rotator cuff, deltoid, and scapular stabilizers continue throughout the late stage of rehabilitation.
  - Patients will be functional with most daily activities, except at the extremes of motion.
  - Total arm strengthening and gradual return to activities are encouraged.

Pearls and Pitfalls

- Imaging
  - Radiographic evaluation must include a quantification of glenoid version, asymmetrical wear, and available bone stock. This requires either a perfect axillary lateral or cross-sectional study, preferably a CT scan.
- Patient selection
  - Glenoid components should be used cautiously if at all in young (ie, under 50) or active patients. The use of biologic resurfacing is controversial and may not offer any advantage over hemiarthroplasty alone.
- Patient positioning
  - Safe access to the humerus during humeral preparation and component placement requires maximum humeral adduction. Therefore, patient positioning must prevent interference from the edge of the operating table.
- Glenoid exposure
  - Adequate glenoid exposure requires accurate humeral resection, humeral osteophyte excision, and adequate capsular excision and releases.
- Humeral preparation
  - Do not over-externally rotate or overream. This may lead to periprosthetic fracture.
- Nerve management
  - Know the position of the axillary nerve and protect it throughout the procedure. Avoid excessive traction on the conjoined tendon, especially if the musculocutaneous nerve is close to the tip of the coracoid. Take the arm out of extreme positions whenever possible.
Although improvement in function will continue for about 1 year, the vast majority of improvement from formal rehabilitation will be seen in the first 24 weeks (6 months).

OUTCOMES

Resurfacing

Reports of resurfacing arthroplasty are relatively sparse. Most data come out of a single institution.

In general, the results parallel the results of hemiarthroplasty. In one series of 103 patients with 5 to 10 years of follow-up, constant scores for patients with osteoarthritis undergoing total shoulder arthroplasty and hemiarthroplasty were 93.7% and 73.5% respectively. Lucency around the humeral component was 30.7%, and 1.9% required revision.17

In another series of patients with osteoarthritis undergoing resurfacing, hemiarthroplasty was found to be similar to total shoulder replacement.16

Hemiarthroplasty

Neer’s original article on replacement for osteoarthritis in 1974 included primarily hemiarthroplasties. Over 90% of patients had good or excellent results.20

The addition of concentric glenoid reaming to encourage the formation of a biologic membrane to resurface the glenoid has been reported by Matsen et al.8,18 The authors note that similar pain relief and function are possible with this procedure but that patients may take longer than total shoulder replacement patients to reach maximum improvement. In addition, in one of their series, 3 of 37 patients were no better or worse after the surgery.18

Additional studies have stressed the importance of concentricity of the glenoid in attaining a successful result as well as the relative difficulty in converting a painful hemiarthroplasty to total shoulder replacement.5

In addition, progressive, painful glenoid erosion can be associated with hemiarthroplasty.

Survivorship of hemiarthroplasty in one series decreased substantially with increasing follow-up, with 92%, 83%, and 73% survival at 5, 10, and 15 years, respectively.26

Hemiarthroplasty with biologic resurfacing

Although descriptions of this procedure exist before 1993, Burkhead popularized the concept of combining hemiarthroplasty with biologic glenoid resurfacing.3

A more recent report from Krishnan et al15 with long-term follow-up revealed only 5 of 39 patients with unsatisfactory results. Moreover, the patient population was relatively young and active.

Elhassan et al10 reported poor results in 13 patients undergoing hemiarthroplasty with biologic glenoid resurfacing. Ten of 13 patients required revision to total shoulder arthroplasty at a mean of 14 months after hemiarthroplasty.

Two additional studies,21,30 one with a minimum 2-year follow-up,30 confirm good early pain relief and return of function in young active patients undergoing hemiarthroplasty and glenoid resurfacing with lateral meniscal allograft. Both emphasize the importance of articular concentricity and offer data that may be interpreted to question the durability of the allograft.

Total shoulder arthroplasty

Many studies document consistent improvement in pain and function with total shoulder arthroplasty.

Several studies document better pain relief and, in some cases, better function with total shoulder arthroplasty in comparison to hemiarthroplasty. Survivorship of total shoulder arthroplasty in patients with an intact or reparable cuff is 84% to 88% at 15 years.5,26

COMPICATIONS

The reported complication rate after shoulder arthroplasty is 12% to 14.7%.1,6,31 One series reports a decrease in the complication rate with time, which may be explained by glenoid and humeral component loosening in only one shoulder.6

Complications include:

- Instability
- Rotator cuff tear
- Ectopic ossification
- Glenoid component loosening
- Intraoperative fracture
- Nerve injury
- Infection
- Humeral component loosening

REFERENCES


**DEFINITION**
- Glenohumeral arthritis is defined as loss of the normal articular cartilage covering of the humeral head and glenoid fossa.
- An irreparable rotator cuff defect is one in which a durable attachment of detached cuff tendons to the tuberosity cannot be re-established.
- The association of glenohumeral arthritis and irreparable rotator cuff defects occurs in several distinct clinical situations, each of which has unique features and specific treatment options.
- The key points in managing these conditions are to define the following:
  - The pathology
  - The deficits in comfort and function experienced by the patient
  - The options for reconstruction
  - The benefits and risks of each of the treatment options

**ANATOMY**
- The glenohumeral articulation normally is covered with hyaline articular cartilage. The glenoid fossa is a spherical concavity that is deepened because the cartilage is thicker at the periphery and the glenoid rim is surrounded by a fibrocartilaginous labrum. The humeral head is a convexity that fits into this concavity.
- The rotator cuff is a synthesis of the tendons of the subscapularis, supraspinatus, infraspinatus, and teres minor with the subjacent glenohumeral capsule.
- The rotator cuff tendons insert into the humerus just lateral to the articular cartilage and at the base of the tuberosities.
  - The spherical proximal humeral convexity is formed by the smooth blending of the cuff tendons with the tuberosities.
  - The radius of the proximal humeral convexity is the radius of the humeral head plus the thickness of the rotator cuff tendons.
- The coracoacromial arch is a spherical concavity consisting of the undersurface of the acromion and the coracoacromial ligament. The proximal humeral convexity fits into this concavity.
- The glenohumeral joint is normally stabilized by the concavity compression mechanism:
  - The rotator cuff muscles compress the humeral head into the glenoid fossa.
  - The deltoid compresses the proximal humeral convexity into the coracoacromial arch.

**PATHOGENESIS**
- Loss of glenohumeral articular cartilage can be caused by osteoarthritis, rheumatoid arthritis, neurotrophic arthritis, septic arthritis, traumatic arthritis, avascular necrosis, and iatrogenic arthritis.
- It also can arise from abrasion of the unprotected humeral head on the undersurface of the coracoacromial arch in chronic rotator cuff deficiency, a situation that often is referred to as rotator cuff tear arthropathy.
- Defects in the rotator cuff tendons arise when loads are applied to the tendon insertion that are greater than the strength of the tendon attachment to the tuberosity.
- These defects typically begin at the anterior undersurface of the supraspinatus tendon.
- Age, systemic disease, corticosteroid injections, and smoking are among the factors that weaken the insertional strength of the rotator cuff tendons, making them more susceptible to tearing and wear.
- When the superior rotator cuff is deficient, the radius of the proximal humeral convexity is decreased by the thickness of the cuff tendon.
- The loss of the spacer effect of the cuff tendon allows the humeral head to translate superiorly under the active pull of the deltoid until the uncovered head contacts the coracoacromial arch.
- The intact coracoacromial arch can provide secondary superior stability to the uncovered humeral head.
- The upward translation of the humeral head necessary to contact the arch slackens the deltoid, however, reducing its effectiveness in elevation of the arm.
- The coracoacromial arch can be compromised by progressive abrasion with the uncovered humeral head. It also can be compromised by acromioplasty and section of the coracoacromial ligament.
- Compromise of the coracoacromial arch coupled with a substantial rotator cuff defect permits anterosuperior escape of the humeral head on deltoid contraction.
- This anterosuperior escape eliminates the fulcrum needed for the deltoid to elevate the arm.
- The inability of a functioning deltoid to elevate the arm because of slackening and lack of a fulcrum is known as pseudoparalysis.

**NATURAL HISTORY**
- Rotator cuff deficiency and arthritis can occur individually or together.
  - In most cases of osteoarthritis, the rotator cuff is functionally intact.
  - In most cases of rheumatoid arthritis, the rotator cuff may be thinned but usually is functionally intact.
- In rotator cuff tear arthropathy, the integrity of the cuff, the articular cartilage, and the coracoacromial arch all characteristically degenerate in a progressive manner.
Some surgeons attempt to improve the comfort and functions of individuals with rotator cuff problems by performing an acromioplasty and coracoacromial ligament section.

- Unless cuff function is durably restored, this sacrifice of the coracoacromial arch predisposes the shoulder to anterosuperior escape.
- The rotator cuff mechanism can be damaged in the process of humeral head resection during shoulder arthroplasty.
- Individuals who have had a shoulder arthroplasty may tear their rotator cuff in a fall or while lifting.
- When a prosthesis is used to reconstruct a complex proximal humeral fracture, the tuberosities may fail to unite, resulting in the functional equivalent of rotator cuff deficiency.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Rotator cuff tendons fail by some combination of applied load and degeneration (“tear” and “wear”).
  - There need be no history of a traumatic episode, especially in older individuals who give a history of progressive loss of comfort, strength, and ability to perform functions of their daily living. These are the persons whose condition may progress to cuff tear arthropathy.
  - By contrast, individuals with acute traumatic rotator cuff tears from the application of substantial load do not typically progress to cuff tear arthropathy.
  - In patients with massive atraumatic cuff deficiency, it is important to seek historical evidence of factors that may weaken the cuff, such as systemic disease, cortisone injections, antimitabolic medications, and smoking.
  - Osteoarthritis often presents without a history of injury. Instead, it presents as progressive stiffness, pain, and loss of function.

- Rheumatoid arthritis of the shoulder presents in the context of this systemic condition.
- Important elements of the history are the patient’s self-assessment of shoulder comfort and function (such as the simple shoulder test) and an assessment of the patient’s goals for treatment.
- The integrity of the principal rotator cuff tendons is determined by the isometric strength of each of the three primary muscles in defined positions.
  - Supraspinatus integrity: weakness (ie, strength grade 3 or less) indicates a full-thickness supraspinatus tear.
  - Infraspinatus integrity: weakness (ie, strength grade 3 or less) indicates a large, full-thickness rotator cuff tear, extending into the infraspinatus.
  - Subscapularis integrity: weakness (ie, strength grade 3 or less) indicates a full-thickness subscapularis tear.
  - Defects in the rotator cuff often can be palpated just anterior to the acromion while the shoulder is passively rotated.
  - Chronic cuff defects usually are accompanied by atrophy of the muscles attached to the deficient tendons.
  - Cuff degeneration often is associated with subacromial crepitus on passive rotation of the humerus beneath the coracoacromial arch.
  - Cuff tear arthropathy often is associated with a substantial subacromial effusion.
  - Superior instability is demonstrated by having the patient relax the shoulder, hanging it at the side, and then actively contracting the deltoid while the examiner notes superior translation of the humeral head until it contacts the coracoacromial arch (FIG 1A,B).
  - Anterosuperior escape is the exaggerated form of superior instability that results when the coracoacromial arch is compromised (FIG 1C,D).

![FIG 1 • A,B. Characteristic findings of cuff tear arthropathy, including superior displacement of the humeral head, “femoralization” of the proximal humerus, and “acetabularization” of the coracoacromial arch. In such a case, a conventional hemiarthroplasty, possibly using a special cuff tear arthropathy (CTA) head, may be considered.](image)

![FIG 1 • C,D. Anterosuperior escape of the humeral head resulting from surgical compromise of the coracoacromial arch. In such a case, a conventional arthroplasty will not provide stability, and a Delta (DePuy, Warsaw, IN) or reverse prosthesis may be considered.](image)
IMAGING AND OTHER DIAGNOSTIC STUDIES

- An anteroposterior plain radiograph in the plane of the scapula may reveal:
  - Decreased acromio–humeral distance, signaling the absence of the normally interposed supraspinatus tendon
  - “Femoralization” of the proximal humerus (ie, rounding off of the tuberosities so that the proximal humerus is spherical) as well as other changes in humeral anatomy (FIG 2A,B)
  - “Acetabularization” of the acromion-coracoid-glenoid socket (ie, sculpting of a concavity matching the femoralized proximal humerus)
  - The amount of superior and medial erosion of the acromion and upper glenoid

- A true axillary view (FIG 2C,D) may reveal:
  - The degree of medial glenoid erosion, ie, the amount of glenoid bone stock available for reconstruction
  - The presence of anterior or posterior glenoid erosion and humeral subluxation, indicating a more complex pattern of instability

- An anteroposterior (AP) view of the proximal humerus with the arm in 30 degrees of external rotation with respect to the x-ray beam may reveal:
  - The approximate size of the humeral medullary cavity that may be used in prosthetic reconstruction
  - Any humeral deformities that may affect prosthetic reconstruction
  - We do not routinely use either CT or MRI scans, but they may be useful in clarifying the pathology.
    - CT scans may help with:
      - Defining glenoid bone volume and deformities
      - Defining the glenohumeral relationships
    - MRI scans may help with:
      - Determining the condition of the different rotator cuff tendons
      - Determining the condition of the different rotator cuff muscles
      - The volume and location of fluid in the joint
      - Other pathology, such as tumor or avascular necrosis

- Factors suggesting that the cuff defect is likely to be irreparable include:
  - Insidious, atraumatic onset of cuff deficiency
  - Advanced age of the patient
  - History of repeated corticosteroid injections
  - Systemic illness
  - History of smoking
  - Previous unsuccessful attempts at rotator cuff repair
  - Muscle atrophy
  - Superior displacement or superior instability of the gleno-humeral joint
  - Anterosuperior escape
  - Pseudoparalysis

FIG 2 • A. Normal glenoid and normal head–glenoid relationship are seen on this AP radiograph in the plane of the scapula. B. Superior glenoid erosion and upward displacement of the head are seen on this AP radiograph in the plane of the scapula. This demonstrates “femoralization” of the proximal humerus and “acetabularization” of the coracoacromial arch. C,D. A proper axillary view will reveal anterior, posterior, or medial glenoid erosion. (Copyright Steven B. Lippitt, MD.)
DIFFERENTIAL DIAGNOSIS

- Milwaukee shoulder
- Neurotrophic (Charcot) arthropathy
- Septic arthritis
- Nonseptic inflammatory arthropathy

NONOPERATIVE MANAGEMENT

An acute rotator cuff tear is a matter of relative urgency, but a chronic cuff defect coupled with glenohumeral arthritis provides the opportunity for nonoperative management, including:

- Range-of-motion exercises in an attempt to resolve the stiffness that may accompany this condition (eg, the four-quadrant stretching program)
- Gentle progressive strengthening exercises for the deltoid and the rotator cuff musculotendinous units that remain intact (eg, the two-hand progressive supine press)
- Mild nonnarcotic analgesics may be useful in symptom control.
- However, injections of corticosteroids into the shoulder may compromise the integrity of the remaining tendons and increase the risk of infection.

SURGICAL MANAGEMENT

Preoperative Planning

- Consideration of surgical management is based on the type of involvement (Table 1), the patient’s overall health and wellbeing, and the risk–benefit ratio in trying to meet the patient’s goals for treatment.
- With each of the procedures, the patient must be well-informed and give informed consent to the risk of infection, neurovascular injury, pain, stiffness, weakness, fracture, instability, loosening of components, anesthetic complications, and the possible need for revision surgery.

<table>
<thead>
<tr>
<th>Glenohumeral Joint Surface</th>
<th>Rotator Cuff</th>
<th>Register (Glenohumeral Joint Alignment)</th>
<th>Active Elevation</th>
<th>Coracoacromial Arch</th>
<th>Anterior Superior Escape</th>
<th>Deltoid</th>
<th>Surgical Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arthritic</td>
<td>Irreparable supraspinatus</td>
<td>Glenohumeral joint aligned</td>
<td>&gt;90 degrees, but weak</td>
<td>Intact</td>
<td>Absent</td>
<td>Intact</td>
<td>Consider conventional hemi- or total shoulder arthroplasty</td>
</tr>
<tr>
<td>Arthritic</td>
<td>Irreparable supraspinatus</td>
<td>Superior displacement with acromiohumeral stability</td>
<td>&gt;90 degrees, but weak</td>
<td>Intact</td>
<td>Absent</td>
<td>Intact</td>
<td>Consider conventional arthroplasty or special (eg, CTA) hemiarthroplasty</td>
</tr>
<tr>
<td>Arthritic</td>
<td>Irreparable supraspinatus and infraspinatus</td>
<td>Superior displacement without acromiohumeral stability</td>
<td>&lt;45 degrees</td>
<td>Compromised</td>
<td>Present</td>
<td>Intact</td>
<td>Consider Delta or reverse arthroplasty</td>
</tr>
<tr>
<td>Arthritic</td>
<td>Irreparable supraspinatus and infraspinatus</td>
<td>Superior displacement without acromiohumeral stability</td>
<td>&lt;45 degrees</td>
<td>Compromised</td>
<td>Present</td>
<td>Severe compromise</td>
<td>No good surgical options</td>
</tr>
<tr>
<td>Failed prothetic</td>
<td>Irreparable supraspinatus and infraspinatus</td>
<td>Superior displacement without acromiohumeral stability</td>
<td>&lt;45 degrees</td>
<td>Compromised</td>
<td>Present</td>
<td>Intact</td>
<td>Consider Delta or reverse arthroplasty</td>
</tr>
</tbody>
</table>

Conventional Hemiarthroplasty, Total Shoulder Arthroplasty, and Special Hemiarthroplasty

- Use AP radiograph in the plane of the scapula and axillary view to identify medial, superior, anterior, posterior, or inferior glenoid erosion.
- Use AP humeral radiograph to estimate the size and fit of the humeral component (FIG 3).
- Give prophylactic antibiotics.

Delta or Reverse Arthroplasty:

- Use AP radiograph in the plane of the scapula and transparent glenoid template to estimate the most inferior position of the glenoid that will result in the inferior screw being contained in the thick bone of the scapular axillary border.
- Use AP humeral radiograph to estimate the size and fit of the diaphyseal and metaphyseal humeral components.

Positioning

- All procedures can be performed in the beach chair position. This position is comfortable and safe for the patient, and allows good access for the anesthesiologist and the surgeon.
- The patient is positioned and secured with the glenohumeral joint at the edge of the operating table.
- The forequarter is doubly prepped, and the arm is draped so it can be moved freely.

Approach

- Although some surgeons advocate a deltoid-incising lateral approach, we prefer the deltopectoral approach, because it is effective, familiar, versatile, safe, and extensile.
- Each procedure strives to completely preserve and protect the deltoid and the axillary nerve.
- Each procedure includes a complete mobilization of the humeroscapular motion interface with resection of all scar,
suture, and suture anchors from previous surgical procedures, and hypertrophic bursa.

- This débridement permits complete assessment of the surgical anatomy.
- The integrity of the acromion and coracoacromial ligament is assessed and preserved.
- The subscapularis and subjacent capsule are incised from their attachment to the humerus at the lesser tuberosity.
- A 360-degree subscapularis release is carried out while the axillary nerve is protected.

One of two types of reconstruction is selected:

- Anatomic arthroplasty, with one of the following:
  - Hemiarthoplasty using a conventional prosthesis
  - Total glenohumeral arthroplasty
  - Hemiarthoplasty with a special head (eg, Delta CTA [cuff tear arthropathy; DePuy, Inc., Warsaw, IN])
  - Delta or reverse arthroplasty

At the conclusion of the arthroplasty, the subscapularis is repaired to the bone of the cut humeral surface adjacent to the lesser tuberosity using six sutures of no. 2 nonabsorbable suture passed through drill holes.

A suction drain is placed just anterior to the subscapularis and led out through a long subcutaneous track to exit the skin of the lateral arm.

Dry sterile dressings are applied.

Continuous passive motion is used for 36 hours for all reconstructions except for the Delta or reverse arthroplasty.

After the Delta arthroplasty, the arm is immobilized for 36 hours.

**CONVENTIONAL HEMIARTHROPLASTY, TOTAL SHOULDER ARTHROPLASTY, AND SPECIAL HEMIARTHROPLASTY**

**Incision and Approach**

- Create a deltopectoral incision.
- Lyse adhesions and remove bursa from the humeroscapular motion interface.
- Verify irreparability of the rotator cuff tear and resect useless tendon tissue. If useful cuff elements remain, tag for later reattachment.
- Incise subscapularis and capsule from insertion to lesser tuberosity, preserving maximal length of tendon.
- Release inferior capsule from humerus.
- Identify axillary nerve.
- Perform a 360-degree subscapularis release.

**Humeral Preparation and Implant Sizing**

- Insert progressively larger reamers into the canal, stopping at the first endocortical bite (**TECH FIG 1A**).
- Resect the humeral head in 30 degrees of retroversion and 45 degrees with the long axis of the shaft (**TECH FIG 1B**).
- Measure height and diameter of the curvature of the resected head (**TECH FIG 1C**).
- Mince bone of the humeral head to make autogenous graft.
- If the glenoid is rough or eroded medially, but not superiorly, and if the infraspinatus and subscapularis are intact or robustly reconstructable, and if the patient has soft glenoid bone (as in rheumatoid arthritis), consider inserting a prosthetic glenoid component.
- Using minced autogenous bone from the humeral head, perform impaction autografting of the humeral canal so that the prosthetic stem will achieve a snug press-fit (**TECH FIG 1D**).
- If a partial rotator cuff repair can be carried out, perform that before definitive sizing of component, because repair may diminish the room available for the prosthesis (**TECH FIG 1E**).
- If glenoid arthroplasty has been performed, select the humeral head prosthesis with the appropriate diameter of curvature for the glenoid.
- If glenoid arthroplasty has not been performed, select the humeral head prosthesis with the diameter equal to that of the resected head.

**Component Placement**

- With the trial component in position, resect any prominent tuberosity that may abut against the coracoacromial arch on elevation of the arm (**TECH FIG 2A,B**).
- Consider a special humeral head (eg, CTA head) to cover the area of the greater tuberosity (**TECH FIG 2C**).
Part 7 SHOULDER AND ELBOW • Section VI GLENOHUMERAL ARTHRITIS

TECH FIG 1 • A. Reaming the humerus until the first endocortical bite is achieved. B. Marking the humeral osteotomy at 45 degrees with the reamed axis of the shaft and in 30 degrees of retroversion. Care must be taken to protect the rotator cuff in making the osteotomy. C. Measuring the resected head to determine the diameter of curvature and the height. D. Impaction grafting of the medullary canal to achieve a secure press-fit without jeopardizing the strength of the diaphyseal cortex. E. Partial repair of the rotator cuff to the edge of the resected humerus. (Copyright Steven B. Lippitt, MD.)

- Select the humeral head height that, on trial reduction, allows 40 degrees of external rotation with the subscapularis approximated, 50% posterior translation on the posterior drawer test, and 60 degrees of internal rotation when the arm is abducted to 90 degrees (TECH FIG 2D–G).
- Place six no. 2 nonabsorbable sutures in the anterior humeral neck cut for reattachment of the subscapularis (TECH FIG 2H).
- Assemble the definitive humeral prosthesis.
- Insert the prosthesis in the impaction-grafted medullary canal.

Final Contouring and Wound Closure
- Ensure smooth passage of the proximal humerus beneath the coracoacromial arch. If abutment occurs, perform smoothing on the humeral side, preserving the integrity of the arch.
- Repair the subscapularis.
- Insert drain.
- Close the deltopectoral interval.
- Perform subcutaneous and skin closure.
- Apply sterile dressings.
TECH FIG 2 • A,B. Smoothing of the greater tuberosity lateral to the articular surface of the prosthetic humeral head. C. Cuff tear arthropathy (CTA) head prosthesis, providing a smooth lateral articulation for the shoulder with irreparable cuff deficiency. D–G. Balancing the soft tissue tension: 40 degrees of external rotation (D), 50% posterior translation (E,F), and 60 degrees of internal rotation in 90 degrees of abduction (G). H. Preparing for subscapularis reattachment to the cut edge of the humerus. (Copyright Steven B. Lippitt, MD.)
Incision and Approach
- Make a deltopectoral incision.
- Lyse adhesions and remove bursa from the humeroscapular motion interface, protecting deltoid, acromion, and residual cuff tissue.
- Verify irreparability of the rotator cuff tear and resect useless tendon tissue.
- Tag any potentially reparable elements of the cuff that are identified, for later use.
- Incise the subscapularis and capsule from insertion to lesser tuberosity, preserving maximal length of the tendon.
- Release the inferior capsule from the humerus.
- Identify the axillary nerve.
- Perform a 360-degree subscapularis release.

Humeral Preparation
- Insert humeral resection guide stem into medullary canal (TECH FIG 3A).
- Resect humeral head in zero degrees of retroversion (TECH FIG 3B).
- When the arm is pulled distally, the plane of the humeral cut should pass just below the inferior glenoid.

Glenoid Preparation
- Dissect the capsule from the anterior glenoid down to and around the inferior pole so that the upper axillary border of the scapula can be palpated and seen, releasing the origin of the long head of the triceps as necessary.
- Check radiographs and exposed glenoid to identify abnormal glenoid anatomy (eg, superior, inferior, anterior, posterior, inferior or medial erosion, as well as defects from previous surgery [such as earlier arthroplasty]).
  - Note the relation of the inferior glenoid lip to the axillary border of the scapula.
- Remove the labrum and cartilage from the glenoid.
- Mark a point 13 mm anterior to the posterior rim of the glenoid and 19 mm superior to the inferior glenoid rim.
  - Drill the guidewire into the glenoid at this point (TECH FIG 4A).
  - Place the metaglene of the Delta prosthesis (TECH FIG 4B) over this guidewire, with the peg laterally, to verify the appropriateness of this center point.
  - The inferior aspect of the metaglene should align with a line extended from the axillary border of the scapula.
  - When the rim of the metaglene is flush with the extrapolated axillary border, remove the metaglene and drill a central hole with the step drill (TECH FIG 4C).
  - Ream the glenoid conservatively, removing only enough bone to make the surface relatively flat and making sure the reamer handle remains perpendicular to the face of the glenoid (TECH FIG 4D).

Metaglene Placement
- Insert the metaglene peg into the central hole (TECH FIG 5A).
- Palpate the anterior and posterior aspects of the axillary border of the scapula and rotate the metaglene so the inferior screw hole is centered over the axillary border.
  - Recall that the inferior locking screw makes a 16-degree angle with the central peg.
  - Using a drill guide, drill a hole for the inferior locking screw, checking frequently to ensure that the drill is in bone by pushing on the drill while it is not rotating.
  - Use a 2-mm drill bit unless the bone is hard (TECH FIG 5B).
  - At least 36 mm of intraosseous drilling should be achieved.
  - If not, re-examine rotation of the metaglene with respect to the axillary border (TECH FIG 5C).

Screw Fixation
- Insert the inferior locking screw (TECH FIG 6A).
- Drill and insert the superior locking screw using similar technique (TECH FIG 6B,C).
**TECH FIG 4** • A. The glenoid guidewire is inserted 19 mm up from the inferior edge of the glenoid and 13 mm anterior to the posterior glenoid border. B. The Delta prosthesis. From left to right: humeral stem, polyethylene cup, glenosphere, and metaglene. C. A step drill is inserted over the guidewire. D. Glenoid reaming is performed conservatively to preserve bone stock. (Copyright Frederick A. Matsen, MD.)

**TECH FIG 5** • A. Inserting the metaglene, noting its flush position with the inferior glenoid. B. Drill guide aligned with the axillary border of the scapula. C. Verifying the intraosseous position of the inferior drill hole by direct palpation. (Copyright Frederick A. Matsen, MD.)

**TECH FIG 6** • A. Desired location of the inferior screw in the axillary border of the scapula. B. Drilling the superior hole using a fixed-angle guide. C. Inserting the superior screw. D. Drilling the anterior hole using a variable-angle guide. E. Inserting anterior screw. (continued)
Drill and insert the anterior nonlocking screw, guiding orientation by palpating the anterior glenoid neck (TECH FIG 6D–F). Drill and insert the posterior nonlocking screw (TECH FIG 6G). Once screws have been placed, check the security of metaglene fixation. Insert a trial glenosphere onto the metaglene. Inspect the inferior aspect of the glenoid, removing any bone that may abut against the humeral polyethylene component. Adequacy of bone resection can be verified by placing a trial polyethylene humeral component over the glenosphere and making sure it can be adducted fully, recalling that the humeral cup makes a 65-degree angle with the humeral shaft.

**Humeral Preparation**

Prepare the humeral canal in a manner that preserves bone stock by insertion of progressively larger reamers until cortical contact is just achieved (TECH FIG 7A,B).

Insert a trial stem with a metaphyseal reamer guide in 0 degrees of rotation (TECH FIG 7C). Ream the metaphysis until bone purchase is achieved (TECH FIG 7D).

**Trial Placement**

Perform trial reduction of the prepared humerus (without trial components) to see if the reamed metaphysis can be reduced to the glenosphere, indicating that the humeral resection is adequate (TECH FIG 8A). Assemble and insert the trial humeral component in 0 degrees of retroversion with a 3-mm trial plastic component (TECH FIG 8B). Reduce the joint (TECH FIG 8C,D) and check for:

- Medial abutment of plastic against the axillary border of the glenoid
- Stability
- Range of motion
- Minimal (<2 mm) distraction on distal traction
- If the joint cannot be reduced, consider lowering the humeral component position by sequentially resecting small amounts of humeral bone.
Final Component Placement

- Insert the glenosphere into the metaglene, making sure it is aligned to avoid cross-threading and making sure it is fully seated.
- Securely assemble the definitive humeral component with a strong crescent wrench.
- Brush and irrigate the humeral medullary canal.
- Insert a cement restrictor 13 cm distal to the lateral aspect of the humeral cut.
- Place six drill holes and no. 2 nonabsorbable sutures in the anterior neck cut for later reattachment of the subscapularis.
- Repair the posterior cuff, if possible.
- Cement the assembled humeral component in 0 degrees of retroversion without a polyethylene insert.
- Trial different heights of polyethylene liners, starting with 3 mm, reducing shoulder to discover the height that allows for reduction but less than 2 mm of distraction, checking again for abutment of adducted plastic against the lateral glenoid bone inferiorly.
- Insert the definitive polyethylene component, making sure it seats fully.
- Irrigate the wound completely.
- Reduce the joint.

Wound Closure

- Repair the subscapularis to sutures previously placed at the anterior neck cut.
- Place a suction drain.
- Close the deltopectoral interval, close the subcutaneous layer, and close the skin with staples.
- Apply dry sterile dressings and an axillary pad.

PEARLS AND PITFALLS

- Glenohumeral arthritis is a chronic condition, so there is no rush to surgical judgment.
- Try gentle range-of-motion and deltoid-strengthening exercises.
- Perform a thorough preoperative assessment and minimize surgical risk factors before surgery.
- Obtain multiple intraoperative cultures for these organisms and hold cultures for 2 weeks.
- At surgery, seek subscapularis and infraspinatus elements that are reparable.
- Treat deltoid, acromion, glenoid, and humeral bone gently.
- Drain the surgical site and rehabilitate slowly.
POSTOPERATIVE CARE

- Hemiarthroplasty with a conventional prosthesis, total glenohumeral arthroplasty, or hemiarthroplasty with a special head (eg, CTA).
- Institute a continuous passive motion (FIG 4) and early active assisted motion protocol as soon as possible postoperatively (unless major partial cuff repair has been carried out).
- Elevation of the arm to 140 degrees is achieved before the patient leaves the medical center.
- For 6 weeks, external rotation is limited to what was easily achievable on the operating table.
- Gentle progressive strengthening exercises, including the supine press, usually are started at 6 weeks.
- Delta or reverse arthroplasty
- Institute hand-gripping and active elbow flexion postoperatively.
- Motion is withheld for 36 hours to minimize the risk of hematoma formation.
- Gentle activities, such as eating, are started at 36 hours, followed by the slow, progressive addition of other activities, reminding the patient of the need for the shoulder bones and muscles to have time to remodel to their new loading patterns.
- Avoid lifting anything heavier than 1 pound for 3 months.

OUTCOMES

- The highly variable patient characteristics, shoulder pathology, and surgical techniques make general statements about functional and prosthetic survival difficult.
- For this reason, a conservative approach to surgery is advised.

COMPLICATIONS

- Atelectasis
- Cardiac events
- Local perioperative
- Intraoperative fracture of humerus, glenoid, acromion
- Axillary nerve or plexus injury
- Deltoid injury
- Postoperative
- Hematoma
- Infection
- Dislocation
- Failure of tissue repair
- Fracture of humerus, glenoid, acromion
- Prosthetic loosening
- Pain
- Weakness
- Failure to regain function

REFERENCES

DEFINITION
- Pectoralis major ruptures are injuries to the one of the largest and strongest muscles of the shoulder region.
- Injuries can be divided into complete and partial tears.
  - Complete tears typically occur at the tendon-to-bone junction and involve both heads.
  - Partial tears can occur to either the sternocostal or the clavicular head.
  - Both types may also occur at the musculotendinous junction or the muscle itself.

ANATOMY
- The pectoralis major is a broad triangular muscle that originates from the medial clavicle, anterior sternum, costal cartilages to the sixth rib, and external obliques.
- It inserts into the proximal humerus on the lateral edge of the bicipital groove. It has two distinct heads: the smaller clavicular head and the larger sternocostal head.
- The pectoralis major tendon is about 5 cm long. The insertion site has two distinct laminae. The clavicular head is anterior and distal and is about 1 cm long, and the sternocostal head inserts posterior and is 2.5 cm long.3
- The sternocostal head spirals 180 degrees on itself, inserting posterior to the clavicular head, creating a rolled inferior surface that is the axillary fold (FIG 1).
- The function of the pectoralis major varies depending on the division. Its primary function is to adduct the humerus and its secondary role is to forward flex and internally rotate. The clavicular head primarily forward flexes and horizontally adducts. The sternocostal head internally rotates and adducts.

PATHOGENESIS
- Pectoralis major ruptures typically occur when a powerful eccentric or concentric forward flexion or adduction load to the humerus (such as heavy bench pressing) occurs. The final 30 degrees of humeral extension disproportionally stretches the inferior fibers of the sternocostal head, putting it at a mechanical disadvantage and predisposing it to injury. The inferior fibers fail first, followed by progression toward the clavicular head.
- Ruptures may also occur when a traction injury such as rapid extension, abduction, or external rotation force is applied to the extremity (such as catching oneself during a fall).
- Injuries to the muscle belly can also be caused by a direct blow, which can result in hematoma formation.
- Patients often hear or feel a rip or tear in the shoulder region, feel a burning pain, and occasionally hear a pop.
- Younger patients (under 30 years) tear at the tendon–bone insertion, whereas patients over 30 tend to tear at the musculotendinous junction.
- Swelling and ecchymosis occur from several hours to days after the injury in the lateral chest wall, upper arm, or axilla.
- Medial muscle retraction along with loss of the axillary fold may not be evident for several days until the swelling subsides.
- Anabolic steroids weaken the muscle–tendon unit, making patients more susceptible to tears.1

NATURAL HISTORY
- Weakness of the affected shoulder in adduction, forward flexion, and internal rotation can be expected with nonoperative treatment of full-thickness tears of both heads or of partial tears of the sternocostal head.
- Isokinetic strength testing has demonstrated 25% to 50% deficits of strength in adduction and internal rotation in preoperative patients and people treated nonoperatively.3,4,9
- Cosmetic deformity occurs secondary to the loss of the tendon in the axillary fold as well as from the medial retraction that occurs during contraction of the muscle.
- Partial tears will elicit a variable degree of weakness and deformity, depending on the amount and location of tendon torn.
The initial pain and cramping that occurs during contraction of the pectoralis major usually subsides in 2 to 3 months. Patients treated nonoperatively for full-thickness tears will complain of weakness and fatigue with recreational and occupational activities as well as the cosmetic deformity.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- A previous history of pain is not typical.
- The patient’s occupation and involvement in sports and weight-lifting activities are important in decision making regarding treatment.
- Physical examination initially will yield painful range of motion of the shoulder and arm. When the swelling subsides, patients typically have full range of motion of the glenohumeral joint.
- Swelling and ecchymosis are variable depending on the chronicity and the degree of the tear.
- Isometric or resisted adduction and forward flexion will show the loss of the tendon in the axillary fold and medial retraction of the pectoralis muscle.
- The examiner should instruct the patient to hold the arm at 90 degrees of abduction, and the anterior head of the deltoid will be accentuated. If the arm is held in forward flexion, the clavicular head will be accentuated (FIG 2A).
- Having patients press their hands together in front of their body for isometric adduction allows inspection of both sides at the same time and simultaneous palpation (FIG 2B).
- Manual strength testing will demonstrate weakness in adduction and forward flexion.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- A standard shoulder radiographic series is obtained to rule out fractures, avulsions, or signs of instability.
- An MRI of the chest, with attention to the pectoralis major tendon, may be obtained to evaluate the location of the tear or assist in making the diagnosis.\(^6,11\) It has been shown to be beneficial in differentiating musculotendinous junction ruptures from tendinous avulsions and may change the treatment strategy.\(^11\) It is difficult, however, to distinguish between complete and partial ruptures (FIG 3).
- Ultrasound may be used to identify the location and severity of the tear. Results, however, are user-dependent.

**DIFFERENTIAL DIAGNOSIS**

- Rotator cuff tears
- Proximal biceps tear
- Anterior shoulder instability
- Deltoid rupture
- Latissimus dorsi tear
- Brachial plexus injury

**NONOPERATIVE MANAGEMENT**

- Nonoperative treatment is indicated for medial tears, intramuscular tears, or tears at the musculotendinous junction in some people. Also, nonoperative treatment should be considered in low-demand patients with complete or partial distal tendon ruptures.
- Nonoperative treatment begins with a sling for the first 7 to 10 days. Ice should be applied intermittently for the first 72 hours.
- Gentle active assisted range of motion is then begun, avoiding aggressive external rotation, abduction, or extension stretching in the initial phases.
- Strength training is typically initiated at 6 to 8 weeks. Depending on the level of occupational or sporting demands, patients may return between 8 and 12 weeks.
Strength deficits of 25% and 50% can be expected with nonoperative treatment.5

**SURGICAL MANAGEMENT**

- Pectoralis major repair is recommended for all complete distal tears, partial distal tears in high-demand patients, and musculotendinous junction tears in high-demand patients with large defects.
- A direct tendon-to-bone repair with heavy, nonabsorbable sutures is performed for complete distal tears and sternocostal tears.
- A side-to-side repair is used for musculotendinous junction tears.

**Preoperative Planning**

- A standard examination under anesthesia of the glenohumeral joint is performed to evaluate for instability.

**Positioning**

- The patient is placed in the 30-degree modified beach chair position. The shoulder and arm are prepared free. A shoulder positioning device is helpful, but not necessary, to position the arm during surgery (FIG 4).

**Approach**

- An anterior approach to the shoulder and proximal humerus is used—the internervous plane between the axillary nerve of the deltoid and the superior and inferior pectoral nerves of the pectoralis major.

---

**PECTORALIS MAJOR REPAIR USING DRILL HOLES**

- Our preferred technique for direct primary repair of the pectoralis major tendon is to attach the tendon directly to the humeral cortex using drill holes.
- A limited 4- to 5-cm deltopectoral incision is made (TECH FIG 1A). The cephalic vein is identified and retracted laterally with the deltoid.
- The biceps tendon is identified, gaining access to the insertion of the pectoralis major just lateral to the biceps tendon in the proximal humerus. In cases of musculotendinous junction tears or partial tears, the entire tendon or a portion of it will be intact.
- Medial dissection is then performed to identify the retracted tendon. The sternocostal and clavicular heads are identified as well as the location of the tendon or musculotendinous junction tear.
- In cases of complete tears, the tendon is typically retracted medially and folded upon itself, identifiable by palpation.
- A traction suture is placed in the tendon, and stepwise gentle blunt mobilization of the muscle and tendon is performed.
- The excursion of the tendon is then tested. Even in cases of chronic tears, the tendon can typically be mobilized to reach the humerus without difficulty.
- The tendon edge is freshened with a scalpel. A no. 5 braided, nonabsorbable suture is used in a Bunnell or modified Mason-Allen locking stitch in the end of the tendon (TECH FIG 1B). Two or three sutures are used, spaced about 1 cm apart, depending on the width of the tendon.
Chapter 27 PECTORALIS MAJOR REPAIR

The insertion site lateral to the biceps tendon is decorticated with a burr.

A commercially available drill can be used to drill the proximal and distal sets of holes. A bridge of 8 to 10 mm is adequate secondary to the thickness of the humerus. The holes usually need to be overdrilled with a 2-mm drill bit, as the humeral cortex is extremely strong and thick.

A needle with a matching radius of curvature is then used to pass a 2-0 looped Vicryl passing suture (TECH FIG 1C). Each corresponding suture is passed using the 2-0 Vicryl passing suture.

The central drill holes are shared by the upper and lower respective sutures in a horizontal mattress configuration for the Bunnell technique (TECH FIG 1D).

If a modified Mason-Allen stitch was used, the deep suture is passed through the drill hole and the knot tied on the upper surface of the tendon (TECH FIG 1E).

The sutures are then tied with the arm in adduction and internal rotation to ensure apposition of the tendon to the humerus (TECH FIG 1F).

Alternatively, the drill holes may be made freehand and the sutures passed with either a free needle or a loop of 24-gauge wire.

PECTORALIS MAJOR REPAIR USING SUTURE ANCHORS

The musculotendinous unit is mobilized in the same way as described for drill hole repair. The humeral cortex is decorticated with a burr.

Two or three suture anchors are then placed in the humeral insertion, spaced 1 cm apart. The sutures are passed in a Kessler mattress stitch through the distal pectoralis tendon (TECH FIG 2).

One limb is passed in a simple fashion. This is used as the post during tying so the knot slides and apposes the tendon to the humerus without the knot lying in the repair site.

Metallic anchors loaded with braided, nonabsorbable no. 5 sutures are used, as the humeral cortex in this region may be too thick to accept an absorbable anchor.

MUSCULOTENDINOUS JUNCTION REPAIRS

Multiple figure 8 or modified Kessler sutures of a no. 2 braided, nonabsorbable suture are used on both the superficial and deep layers.

The quality of the repair depends on the strength and the amount of tendon left on the muscular side.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications for repair</th>
<th>A discussion and risk–benefit analysis is necessary in patients with partial and musculotendinous junction ruptures.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tendon mobilization</td>
<td>Medial dissection is required to free the perimuscular adhesions in chronic ruptures. The neurovascular bundle is rarely at risk.</td>
</tr>
<tr>
<td>Suture passing</td>
<td>Using a commercially available matched drill and needle facilitates suture passage through the humerus (CurvTek). Because of the thickness of the humerus, overdrilling the holes makes needle passage easier.</td>
</tr>
<tr>
<td>Chronic tears</td>
<td>Repair of pectoralis major ruptures is feasible up to 5 years after the injury. The outcome of chronic repairs is not as good as that of acute repairs, with residual weakness as the most common complaint.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- The arm is kept in a sling for 6 weeks postoperatively. It is removed from the sling one or two times daily for gentle, progressive passive and active assisted range of motion of the shoulder, elbow, wrist, and hand.
- The extremes of abduction and external rotation are avoided for the first 6 weeks. At this time, the sling is removed and unrestricted movement is allowed. In addition, strengthening is begun.
- Return to full activities is generally achieved between 3 and 5 months.

OUTCOMES

- There are no large prospective or randomized studies in the literature comparing operative and nonoperative treatment. Results are universally good with acute repairs (within 8 weeks).
- Park and Espinilla7 in 1970 evaluated 30 patients with pectoralis major ruptures. The results were 90% good to excellent results with operative repair versus 75% with nonoperative treatment.
- McEntire and colleagues5 in 1972 compared operative and nonoperative treatment in 11 patients. Again, operative repair had a more favorable outcome at 88% versus 83%, with a higher ratio of excellent to good results.
- Zenman and coworkers10 in 1979 reviewed nine athletes with pectoralis major ruptures. Four patients were treated with surgical repair and had excellent results. All five of the patients treated nonoperatively had residual weakness, and two were dissatisfied with their outcome.
- Kretzler and Richardson3 in 1989 reported on their results after repair of 16 distal tendon tears. Eighty-one percent regained full motion and strength. Two repairs that occurred 5 years after repair of 16 distal tendon tears. Eighty-one percent regained full motion and strength. Two repairs that occurred 5 years after the injury had persistent weakness.
- Wolfe and colleagues9 in 1992 evaluated 14 patients with pectoralis major ruptures, half of whom were treated with operative repair. Cybex strength testing demonstrated normal strength in the repaired patients, with persistent weakness in the unrepair group.
- Jones and Matthews2 in 1988 reviewed the literature and concluded that acute repair within 7 days has 57% excellent and 30% good results. Repair in the setting of a chronic tear yielded 0% excellent and 60% good results. They concluded that although chronic repair is possible even up to 5 years after the injury, the outcome is not as good as an acute repair, with a high likelihood of persistent weakness and cosmetic deformity.
- Schepsis and colleagues8 in 2000 found that operatively repaired patients (both acute and chronic) had significantly better outcomes than conservatively treated patients.
- There are no studies to date documenting rerupture after repair.

COMPLICATIONS

- Complications are relatively infrequent after pectoralis major repair. One patient experienced loss of abduction.3 Another patient had ulnar-sided hand paresthesias of unknown etiology that spontaneously resolved.8
- There have been several reports of complications in the elderly after rupture and nonsurgical management. One patient needed a blood transfusion. Two died of sepsis from an infected hematoma. Myositis ossificans developed in one patient 4 months after rupture.

REFERENCES

DEFINITION
- The snapping scapula syndrome first was described by Boinet in 1867.14
- It is characterized by painful scapular motion with associated crepitus during scapulothoracic motion, with or without a clear history of injury or trauma.
- It has also been referred to as scapulothoracic bursitis, retroscapular creaking, superior scapular syndrome, and retroscapular pain.3,7,11,14
- The associated audible crepitus, which can be tactile in most instances, has been described by Milch and Burman11 as a tactile-acoustic phenomenon, possibly generated secondary to an abnormality in the scapulothoracic interval.
- This crepitus is divided into three classes, based on the volume of the sound produced.10
  - The first group is considered physiologic, with what is described as a “gentle friction” sound.
  - The second group, which includes most patients with the snapping scapular syndrome, features a louder grating sound.
  - The third group is defined by a loud snapping noise that is considered pathologic in most cases.

ANATOMY
- The scapulothoracic articulation consists of the interface between the anterior aspect of the scapula and the ribs in the posterior aspect of the convex thoracic chest wall (FIG 1).
- This articulation is cushioned by several muscles, specifically the subscapularis and the serratus anterior.
- In addition, two major and four minor bursae have been described in the scapulothoracic articulation6,7,23 (Fig 1).
  - The two major bursae are the infraserratus bursa, located between the serratus anterior muscle and the chest wall, and the supraserratus bursa, located between the serratus anterior and the subscapularis muscles.
  - The four minor bursae are distributed as follows: two at the superomedial angle of the scapula, one at the inferior angle of the scapula, and one at the medial base of spine of the scapula, underlying the trapezius muscle.
- While the major bursae have been found consistently in cadaveric and clinical studies, those of the minor bursae were not.3,19,20

PATHOGENESIS
- Incongruence of the scapulothoracic articulation has been postulated to be the main cause of the snapping scapular syndrome, which may or may not be associated with bony anomalies of this region.13,17
- Maltracking or dynamic compression of the scapulothoracic articulation has been postulated as a main etiology of this syndrome, because it leads to irritation of the bursa secondary to pathologic contact between the ribs and the superior angle of the scapula.4,22
  - This maltracking is considered to be a soft tissue cause of snapping scapula syndrome, which has been reported in cases of subscapularis atrophy secondary to glenohumeral fusion and long thoracic nerve palsy.11,24
- Clinical studies and histologic findings of muscle infrasacular fibrosis, bursitis, edema, and shoulder girdle muscle atrophy support this hypothesis.7,17
- Bony or skeletal causes of snapping scapula syndrome are rare. These include scapular osteochondromas and exostoses (FIG 2), anterior angulation of the scapula, scapula fracture, scapular tubercle of Luschka, skeletal abnormalities of the vertebrae (omovertebral bone), and abnormal angulations and tumors of the ribs.10,11,21

NATURAL HISTORY
- Patients with snapping scapula syndrome usually complain of pain around the shoulder girdle.
- This pain most often is secondary to bursitis in the scapulothoracic articulation. Constant motion irritates the soft tissues, leading to inflammation and a cycle of chronic bursitis and scarring.
The chronic inflammation of the bursae will lead to fibrotic, scarred, and tough bursal tissues that can lead to mechanical impingement and pain with motion, resulting in further inflammation.

Once the patient reaches this level of chronic bursal inflammation, the symptoms rarely subside by themselves without trial of rest and physical therapy.

In many cases, especially when the cause of snapping is skeletal, surgical intervention becomes essential to manage this problem.

PATIENT HISTORY AND PHYSICAL FINDINGS

Patients with scapulothoracic bursitis report a history of pain in the shoulder or neck with overhead activities for months or years and often have a history of repetitive overuse in work or recreation or a history of trauma.

A history of neck injury, shoulder injury or fracture, or previous shoulder surgery should be ruled out.

Audible or palpable crepitus may accompany the symptoms with scapulothoracic motion; this is another indication for the location of the symptomatic inflamed bursa.

Some patients report a family history of the disorder and have bilateral symptoms.

Localized tenderness is an indication for the site of scapulothoracic bursitis.

Improvement of symptoms by lifting the scapula off the chest wall helps localize the source of pathology to the scapulothoracic articulation.

Diagnosis is confirmed if significant relief or even elimination of the pain occurs when local anesthetic and corticosteroids are injected in the scapulothoracic bursa under the superomedial border of the scapula.

The examiner also must assess soft tissue tightness, muscle strength, and flexibility around the involved shoulder.

Special attention should be directed to rule out tight trapezius, pectoralis minor, or levator scapula muscles, as well as weakness of any of the scapular muscles, specifically the serratus anterior and the trapezius.

In patients with winging of the scapula, a careful neuromuscular examination should be performed to differentiate true winging from compensatory pseudo-winging that might originate from a painful scapulothoracic articulation.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiologic studies should include an anterior-posterior (AP) and tangential (Y) views of the shoulder, to identify bony abnormalities in the scapula and ribs (FIG 3A).
- A CT scan may be needed for more bony definition. Its role, with or without three-dimensional reconstruction, is still debated, but in patients with suspected bony skeletal abnormality, the CT scan might be helpful (FIG 3B).
- Fluoroscopy could be used to visualize the snapping during simulated shoulder motion.
- MRI can identify the location and size of the inflamed bursa, but its usefulness is debated. The senior author does not believe that the MRI is necessary and has never ordered it in any of his cases.
- Nerve conduction and electromyography studies are useful if a neurologic injury is suspected as the reason for scapula winging.

DIFFERENTIAL DIAGNOSIS

- Soft tissue lesions, such as atrophied muscle
- Fibrotic muscle
- Anomalous muscle insertion
- Subscapular elastofibroma. This tumor is nonneoplastic and appears to form in response to repetitive injury or microtrauma. Most patients who have this tumor complain of a palpable mass rather than pain.
- Cervical spondylosis and radiculopathy
- Periscapular muscle strain
- Glenohumeral pathology

NONOPERATIVE MANAGEMENT

- The initial management of snapping scapula syndrome, once the diagnosis has been made, is conservative.
- Rest, activity modification, and nonsteroidal anti-inflammatory medications should be started.
- Next, physical therapy should be initiated to restore the normal kinematics of the shoulder and prevent it from sloping.
- Weakness in the serratus anterior, even if subtle, may lead to tilting of the scapula forward, thus increasing the friction and rubbing of the upper medial pole of the scapula on the thoracic ribs. This will cause irritation and inflammation of the scapulothoracic bursae.
- Therapy should emphasize periscapular muscle strengthening, particularly the serratus anterior and subscapularis, which can elevate the scapula off the chest wall when they are hypertrophied.
- Taping, a figure-8 harness, scapulothoracic bracing, or postural training can serve to minimize shoulder sloping and thoracic kyphosis.
- Injection of corticosteroid and local anesthetic into the scapulothoracic bursa can be diagnostic and also may be therapeutic and helpful in the rehabilitation program.
- There is no consensus on how long the patient should be kept on trial of physical therapy. The underlying diagnosis is important. In general, a 3- to 6-month trial is a good estimate.
- If the diagnosis is certain, no structural anatomic lesion is present, and the patient has failed 3 to 6 months of appropriate conservative treatment, then surgical options should be considered.
- The threshold to proceed to surgical intervention also should be much lower if the patient has a real structural lesion such as a bony exostosis or an osteochondroma.
SURGICAL MANAGEMENT

Preoperative Planning
- All radiographs are reviewed before surgery.
- The decision to operate is made based on relief of pain with anesthetic injection into the scapulothoracic region in patients who failed conservative management, or in patients who have symptomatic snapping scapula syndrome secondary to structural lesion.
- The different surgical approaches, as well as the technique that the surgeon decides to perform, are discussed with the patient before surgery.

Positioning
- The patient is positioned in the prone position for both arthroscopic and open techniques (FIG 4).
- The involved arm is placed in internal rotation against the patient’s lower back (chicken-wing position). This will cause the scapula to wing out from the thorax and make the superomedial angle more prominent.
- The surgeon stands on the side opposite the scapula to be operated to get the best access to the surgical field.

Approach
- Multiple surgical approaches are available that can decompress the impingement in the superomedial region of the scapula.

These include open surgical decompression, arthroscopic surgical decompression, or a combination of the two approaches.
- Each of these approaches may include bursectomy alone, bony resection of the superomedial aspect of the scapula alone, or a combination.
OPEN DECOMPRESSION

- A longitudinal incision is made along the medial scapular edge (TECH FIG 1A).
- Subcutaneous undermining is performed to expose the superior portion of the scapula, from the level of the scapula spine to the superomedial angle of the scapula.
- Splitting and elevation of the trapezius in line with its fibers is performed at the level of the scapular spine, and the superomedial edge of the scapula is exposed (TECH FIG 1B).
- The levator scapulae and rhomboids are detached from the superior and medial edge of the scapula to expose the upper scapular border (TECH FIG 1C).
- Care is taken not to dissect into the rhomboids or fully detach them so as not to injure the dorsal scapular nerve.

TECH FIG 1 • A. Patient positioned prone with hand positioned behind back to lift the scapula off the chest wall. The surgical incision is placed over the medial border of the scapula, centered over the level of the scapula spine. B. The trapezius is split along its fibers, and the levator scapulae, the rhomboids, and the posterior surface of the scapula are exposed. C. The levator scapulae, rhomboid major, and rhomboid minor are detached from their insertion on the scapula and tagged with sutures. (continued)
which usually is located 2 cm medial to the medial scapular edge.

- The serratus anterior muscle is left intact.
- A retractor is placed underneath the scapula to lift it away from the thoracic ribs.
- The scapulothoracic bursa is identified against the ribs, underneath the serratus anterior muscle.
- A clamp is used to grasp the bursa, and sharp excision of it is performed from superior to inferior.
- Subperiosteal elevation of the muscles around the superomedial border of the scapula, including the supraspinatus, infraspinatus, subscapularis, and serratus anterior muscles, is performed with the use of electrocautery to expose 1 to 2 cm of bone (TECH FIG 1D).
- This exposed portion of the superomedial portion of the scapula is resected with use of an oscillating saw (TECH FIG 1E).
- Once the bony resection is accomplished, drill holes are placed into the upper-medial border of the scapula in order to reattach the muscles to their anatomic insertion (TECH FIG 1F) using a no. 2 nonabsorbable braided suture (TECH FIG 1G).
- The skin is closed with absorbable subcuticular suture.

TECH FIG 1 • (continued) D,E. Resection of the superomedial border of the scapula. F. The detached muscles are reattached to the scapula through drill holes. G. The final repair of the detached levator scapulae and rhomboids.
Positioning is the same as in open decompression.
Placement of the arm in the chicken-wing position results in scapula winging and protraction off the posterior thorax, which facilitates the entry of the arthroscopic instruments in the bursal space.
Standard arthroscopic portals are used.
The initial “safe” portal is placed at the level of the scapular spine, 2 cm medial to the scapular edge, to avoid injury to the dorsal scapular nerve and artery (TECH FIG 2A).
The scapulothoracic space is localized with a spinal needle and distended with approximately 30 mL of saline, and the portal is created.
A blunt obturator is inserted into the scapulothoracic (subserratus) bursa between the posterior thoracic wall and the serratus anterior muscle.
Care should be taken to avoid overpenetration through the serratus anterior into the subscapular space or through the chest wall.
A 30-degree arthroscope is inserted into the scapulothoracic space, which was distended with fluid infiltration.
Use of a fluid pump is optional. Our preference is to use an arthroscopy pump but keep the pressure low, at around 30 mm Hg, to minimize fluid extravasation.
A spinal needle is used to localize the second portal under direct visualization.
This portal is inserted, in most instances, in line with and approximately 4 cm distal to the first portal.
A bipolar radiofrequency device and a motorized shaver are introduced into a 6-mm cannula through the lower portal, and used to resect the bursal tissue. Because the inflamed scapulothoracic bursa is a potential source of bleeding during arthroscopic shaving, the radiofrequency device becomes particularly useful to minimize bleeding in these tissues (TECH FIG 2B).
A methodic approach to resection should be followed, because there are no real landmarks.
Ablation of tissues should be performed from medial to lateral and then from inferior to superior.
The surgeon should be ready to switch portals and should have a 70-degree arthroscope ready to facilitate visualization. A probe can be used to palpate the scapula and serratus muscle superiorly and the ribs and intercostal muscles inferiorly.
An additional superior portal may be placed as needed. We prefer not to use this portal, because it may place the accessory spinal nerve, transverse cervical artery, and dorsal scapular neurovascular structures at risk.
After complete bursectomy is performed, the arthroscopic instruments are withdrawn, and skin closure is performed with absorbable subcuticular sutures.

TECH FIG 2 • A. Locations of the arthroscopic portals. A proximal (safe) portal (black arrow) is placed 2 cm medial to the spine of the scapula. A distal portal (white arrow) is placed in line with and 4 cm distal to the proximal portal. B. Sites of portal placement. The shaver and the camera can be placed interchangeably in either portal for viewing and shaving.
**ARTHROSCOPIC BURSECTOMY AND PARTIAL SUPEROMEDIAL SCAPULECTOMY**

- First, all the steps for arthroscopic bursectomy are followed.
- After the bursa has been completely resected, the superomedial angle of the scapula is localized by palpation through the skin.
- Detachment of the conjoined insertion of the levator scapulae, supraspinatus, and rhomboids is performed with the use of the radiofrequency device.
- A motorized shaver and a burr are used to perform a partial scapulectomy. We do not attempt to repair the periosteal sleeve; it is allowed to heal through scarring.
- The rest of the steps are the same as those for arthroscopic bursectomy.

**ARTHROSCOPIC BURSECTOMY AND OPEN PARTIAL SUPEROMEDIAL SCAPULECTOMY**

- The decision to perform the superomedial scapular bony resection through a small skin incision rather than through the arthroscope may be made either before surgery or at the time of surgery.
- If full definition of the superomedial border of the scapula becomes difficult because of swelling from the arthroscopic fluid, then bony resection is performed through a small skin incision.
- A 4- to 6-cm incision is performed obliquely over the superomedial border of the scapula (see Tech Fig 1A).
- The trapezius muscle is split, and the levator scapulae and rhomboids are detached from the superomedial angle (see Tech Fig 1B-C).
- The superomedial angle of the scapula is resected. Then the levator scapulae and rhomboids are repaired to the superior scapula through drill holes (see Tech Fig 1D).
- Skin closure is performed with absorbable subcuticular sutures.

**PEARLS AND PITFALLS**

| Indications                                                                 | • Appropriate history, physical examination, and review of radiographs should be done. |
|                                                                             | • Diagnostic injection is very helpful to confirm the diagnosis and predict a good surgical outcome. |
| Contraindications to arthroscopic decompression                             | • Symptoms that originate from the trapezoid bursa. This bursa is superficial to the scapulothoracic space, and, therefore, removing it will not remove the pathologic tissue. |
| Positioning                                                                 | • Patient prone, with hand of the affected shoulder behind the back to elevate and protract the scapula. |
|                                                                             | • Surgeon should be standing by the opposite shoulder. |
| Open decompression                                                          | • Avoid suprascapular notch during bony resection. |
|                                                                             | • It is essential to reattach the detached muscles to the scapula through bony drill holes. |
| Arthroscopic decompression                                                   | • Use a spinal needle for localization of the scapulothoracic space. |
|                                                                             | • Care should be taken to avoid over-penetration through the serratus anterior into the subscapular space or through the chest wall. |
|                                                                             | • Use of a bipolar radiofrequency device is essential to avoid bleeding from the inflamed bursa. |
|                                                                             | • Complete bursectomy should be performed. |

**POSTOPERATIVE CARE**

- After open decompression and a combined arthroscopic and open approach:
  - The patient is kept in a sling, and gentle, passive range of motion is started early after surgery and continued for 4 weeks.
  - After 4 weeks, active range of motion is started.
  - Strengthening is allowed at 8 to 12 weeks.
  - After arthroscopic decompression:
    - The patient is kept in a sling and allowed passive and active assisted range-of-motion exercises immediately after surgery.
    - After 4 weeks, isometric exercises are started.
    - Strengthening of the periscapular muscles begins by 8 weeks.

**OUTCOMES**

- No published reports have compared the outcomes of different surgical techniques of scapulothoracic decompression.
The outcome of open decompression, as reported in the literature, has been good.\(^7,12,17,18\)

No large series have been published reporting the outcome of arthroscopic scapulothoracic decompression for symptomatic snapping scapular syndrome.

Early results from small series of patients who underwent arthroscopic decompression seem promising, with minimal morbidity and early return to work.\(^2,3,8,15,16\)

**COMPLICATIONS**

- Recurrence of symptoms secondary to incomplete resection
- Pneumothora
- Iatrogenic injury to the neurovascular structures around the superomedial border of the scapula
- Aggressive bony resection risking injury to the suprascapular nerve through the notch
- Insufficiency of the scapular muscles due to detachment after surgery

**REFERENCES**

DEFINITION
- Trapezius palsy results from a disruption of cranial nerve (CN) XI, also known as the spinal accessory nerve.
- Because the trapezius is innervated exclusively by CN XI, any disruption causes trapezius palsy.
- Spinal accessory nerve palsy is a rare but well-described complication of cervical lymph node biopsy.15,17
- The trapezius plays an integral part in stabilization of the scapula, and dysfunction leads to painful shoulder disability.
- Nonoperative treatment, including strengthening of the functioning thoracoscapular muscles, does not provide satisfactory clinical results.2,4
- Transfer of the levator scapulae, rhomboid major, and rhomboid minor (Eden-Lange procedure, or triple transfer) is an accepted technique for this difficult problem.16
- The procedure was first described by Eden5 in 1924 and then corroborated by Lange6 in 1951 and Francillon7 in 1955, all reporting satisfactory short-term results. Further modifications have improved on the initial procedure.1
- Lateral transfer of the insertions of the three muscles allows the scapula to be stabilized in a position of abduction and anterior flexion.15

ANATOMY
- The trapezius muscle is broad and superficial, taking its origin from the C7–T12 spinous processes and inserting on the acromion, clavicle, and spine of the scapula (FIG 1A).
- Its function is to elevate and rotate the scapula; absence of the trapezius leads to lateral winging of the scapula.
- In the posterior cervical triangle, CN XI is located in the subcutaneous tissue; this superficial location renders it susceptible to damage during procedures such as cervical lymph node biopsy.
- Functionally, the trapezius can be divided into three separate parts: upper, middle, and lower.
- The upper portion consists of descending fibers and functions as an aid to suspension of the shoulder girdle, allowing shrugging of the shoulder. The middle portion consists of transverse fibers and contributes to abduction and rotation of the inferior angle of the scapula. The ascending fibers of the lower portion (along with the serratus anterior) anchor the scapula to the chest wall.
- Scapular winging occurs in both spinal accessory and serratus anterior palsy. In serratus palsy, the inferior angle of the scapula is noted to rotate medially (FIG 1B), whereas in trapezius palsy, the scapula rotates laterally (FIG 1C, D).

PATHOGENESIS
- Paralysis of the trapezius most often results from injury to the spinal accessory nerve during cervical lymph node biopsy.13
- Other causes include trauma (including traction injuries) or injuries from other surgical procedures, such as radical neck dissection.1
- In one instance, a CN XI palsy was reported to have occurred after a viral infection.13
- Idiopathic CN XI paralysis also has been reported.6
- Patterson11 reported trapezius palsy after acromioclavicular and sternoclavicular dissociation.
- Even rarer causes include post-carotid endarterectomy and post-catheterization of the internal jugular vein.3
- In most cases, patients report pain and present with visible deformity and dysfunction of the shoulder girdle.

NATURAL HISTORY
- Trapezius palsy most often results from iatrogenic causes, as noted earlier, and, if left untreated, will lead to progressively worsening altered biomechanics and pain of the shoulder girdle.
- Radiating arm pain is thought to be the result of traction on the brachial plexus caused by drooping of the shoulder girdle.13

FIG 1 • A. Schematic of the three parts of the normal trapezius muscle: upper, middle, and lower. (continued)
Although nonoperative management can provide reduction of pain, it does not lead to return of function, and patients treated without surgery usually go on to progressive shoulder dysfunction.

Typically, the initial presentation is acute shoulder pain without palsy, with weakness of anterior elevation and abduction appearing after a few days (with slow diminution of pain). Atrophy of the trapezius becomes clinically apparent after a few weeks.16

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Altered mechanics of the entire shoulder girdle are possible with trapezius palsy.
- The classic winging of the scapula seen in CN XI palsy is characterized by downward and lateral translation of the scapula.
- The patient should be observed from behind so comparison can be made with the contralateral side.
- Signs unique to CN XI palsy include lateral winging of the scapula (FIG 2A), an asymmetric neckline, pain, weakness of shoulder abduction, and forward elevation.14 Visible atrophy of the trapezius muscle should be noted16 (FIG 2B).
- Symptoms include weakness made worse by prolonged use of the arm, a feeling of a heavy arm, and a dull pain radiating from the scapula to the forearm (and occasionally with radiation to the hand). The radiation of pain is described as mimicking thoracic outlet syndrome (medial aspect of the upper limb). Pain typically is made worse by abduction of the shoulder as well as forward elevation.16 Some patients also reported paresthesias in the distribution of the auricular nerve (posterolateral side of the neck).16
- Patients also often state that the arm feels difficult to control.13
- It should be noted, however, that occasionally patients are pain free and present only with winging and drooping of the scapula.
- Range of motion is decreased in elevation as well as abduction, and typically is limited to 90 degrees.13 Teboul et al16 report average active abduction of 78 degrees (range 30 to 140 degrees), and active forward flexion of 110 degrees (range 50 to 180 degrees). As a result, overhead activities are not possible, nor is shrugging of the shoulder.

![FIG 1](continued)

**FIG 1**

**B.** Schematic of trapezius palsy, demonstrating lateral scapular winging and shoulder drooping.

**C.** Schematic of serratus anterior palsy, demonstrating medial scapular winging.

**FIG 2**

**A.** Patient with a trapezius palsy demonstrating characteristic scapular winging.

**B.** Anterior sternocleidomastoid muscle wasting due to the spinal accessory nerve palsy.
- External rotation of the shoulder and elbow flexion are not affected by CN XI lesions.\textsuperscript{16}
- Reports of stiffness and passive range of motion are somewhat contradictory in the literature. Romero and Gerber\textsuperscript{13} state that patients did not always present with a stiff shoulder but passive range of motion typically was decreased. On the other hand, Teboul et al\textsuperscript{16} report that patients often presented with stiffness but with no deficit in passive range of motion.
- Often, the diagnosis of CN XI dysfunction is one of exclusion, and it is not until an unsuccessful trial of physical therapy that a patient is referred for an electrodiagnostic study and spinal accessory nerve palsy is confirmed.
- The necessity for electrodiagnostic testing is an issue of debate in the literature. Romero and Gerber\textsuperscript{13} state that this testing is not necessary to establish the diagnosis of CN XI palsy, but that it can be a valuable tool if other nerve lesions are suspected. Setter et al\textsuperscript{14} advocate electrodiagnostic testing as part of the initial workup.
- Evaluate the scapula for signs of lateral translation by asking patient to perform a wall push-up.
- Spinal accessory nerve (CN XI) palsy also affects the sternocleidomastoid muscle.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- A standard five-view shoulder series (including true AP views of the glenohumeral joint in neutral, external, and internal rotation; as well as a scapular Y and axillary view) is required for every patient, although osseous pathology typically is not associated with CN XI palsy.
- MRI is not necessary, although it could be useful to assess the degree of fatty atrophy of the trapezius muscle as well as to help rule out any associated pathology such as rotator cuff injury.
- Electrodiagnostic testing is recommended in every case, according to Setter et al.\textsuperscript{14} Not only will an EMG help confirm the diagnosis of spinal accessory nerve palsy, but it also will serve as confirmation that the muscles to be used in the transfer procedure are functioning normally.

**DIFFERENTIAL DIAGNOSIS**
- Missed diagnosis of spinal accessory nerve palsy is the rule,\textsuperscript{13} most likely owing to the rare nature of the condition.
- Other possible types of shoulder dysfunction that may confuse the issue include serratus palsy and rotator cuff pathology.
- It is crucial to be able to differentiate between spinal accessory nerve (trapezius) palsy and long thoracic nerve (serratus) palsy. In serratus palsy, the inferior angle of the scapula rotates medially, whereas in trapezius palsy, the inferior angle of the scapula rotates laterally.

**NONOPERATIVE MANAGEMENT**
- Typically, if the injury is not detected within 6 months (after which point nerve repair usually is not recommended), a 12-month trial of nonoperative treatment is recommended.\textsuperscript{14}
- Due to possible compensation by the levator scapulae, the impact of injury to the spinal accessory nerve must be determined individually for each patient.\textsuperscript{9}
- Maxillofacial surgeons have reported that 30\% to 49\% of patients do not exhibit any clinical symptoms after radical neck dissection where the spinal accessory nerve is sacrificed.\textsuperscript{10}
- If the CN XI palsy is symptomatic, pain sometimes can be relieved after a course of nonoperative treatment, but satisfactory return to function cannot be achieved.
- Strengthening of the remaining scapulothoracic muscles does not compensate for the trapezius deficit, and, in one study, patients who elected nonoperative management could not elevate their arms above the horizontal.\textsuperscript{13}
- One study has reported favorable results with nonoperative management in sedentary or elderly persons because discomfort was alleviated.\textsuperscript{12}

**SURGICAL MANAGEMENT**
- If trapezius palsy is detected early, microsurgical repair or reconstruction of the nerve can be considered. Timing of the repair attempt is controversial; some authors believe that repair should only be attempted if diagnosis is confirmed within 6 months of injury,\textsuperscript{14} whereas other surgeons advocate repair up to 20 months from the time of the nerve insult.\textsuperscript{16}
- In patients with spontaneous spinal accessory palsy for whom conservative treatment has not been helpful, some authors advocate proceeding directly to muscle transfer reconstruction, because nerve procedures have produced poor results.\textsuperscript{15}
- Patients who have failed nerve repair attempt or conservative therapy should be considered surgical candidates for the Eden-Lange procedure, the current procedure of choice for stabilization of the scapula after CN XI palsy.
- Timing of the Eden-Lange procedure also is controversial. Typically, however, reconstructive surgery is recommended if more than 12 months has elapsed since the injury.\textsuperscript{17}
- The goal of the Eden-Lange procedure is to reconstruct the three parts of the trapezius muscle. Because the rhomboid major and minor and levator scapulae have medial insertions, they are not capable of stabilizing the scapula unless they are transferred laterally.\textsuperscript{16}

**Preoperative Planning**
- It is imperative to have appropriate preoperative discussions with the patient so that he or she understands the procedure, the postoperative rehabilitation program, and the timeframe within which improvement should be expected.

**Positioning**
- The patient is placed in the lateral decubitus position with the entire extremity draped free (FIG 3).
EXPOSURE

- Teboul et al\textsuperscript{16} describe an incision starting from the spine of the scapula and progressing along its medial angle up to a point 2 cm above the inferior angle of the scapula (TECH FIG 1A).
- The trapezius is then divided and retracted, and the three muscles of interest (the levator scapulae, rhomboid major, and rhomboid minor) are identified and dissected and marked with vessel loops (TECH FIG 1B).
- The supraspinatus and infraspinatus must be elevated 3 to 5 cm to expose their respective fossae for transfer of the rhomboids\textsuperscript{16} (TECH FIG 1C).

Modification

- Bigliani et al\textsuperscript{1} proposed a modification of the procedure in which the rhomboid minor is transferred cephalad to the scapular spine, thereby closing the gap between the rhomboid minor and the levator scapulae (TECH FIG 3).
- In this modification, the new position of the rhomboid minor more efficiently substitutes for the middle part of the trapezius.

RHOMBOID TRANSFER

- A series of transosseous mattress sutures are placed in anticipation of transferring the rhomboids. At least four mattress sutures are used in the infraspinous fossa (TECH FIG 2A) and two in the supraspinous fossa.
- The rhomboids are advanced about 3 cm laterally and attached to the scapula with heavy, nonabsorbable transosseous sutures (TECH FIG 2B).

Modification

- Bigliani et al\textsuperscript{1} proposed a modification of the procedure in which the rhomboid minor is transferred cephalad to the scapular spine, thereby closing the gap between the rhomboid minor and the levator scapulae (TECH FIG 3).
- In this modification, the new position of the rhomboid minor more efficiently substitutes for the middle part of the trapezius.
A second incision is made about 5 to 7 cm from the posterolateral corner of the acromion for transfer of the levator scapulae (TECH FIG 4A).

Care must be taken to ensure that the levator has been dissected laterally enough to allow tension-free excursion to the scapular spine (TECH FIG 4B). The levator is then transferred subcutaneously and affixed with a series of heavy nonabsorbable sutures.

The infraspinatus muscle is then sutured over the new rhomboid muscle insertions and, finally, the wounds are closed in layers.

**LEVATOR TRANSFER AND WOUND CLOSURE**

- A second incision is made about 5 to 7 cm from the posterolateral corner of the acromion for transfer of the levator scapulae (TECH FIG 4A).
- Care must be taken to ensure that the levator has been dissected laterally enough to allow tension-free excursion to the scapular spine (TECH FIG 4B). The levator is then transferred subcutaneously and affixed with a series of heavy nonabsorbable sutures.

The infraspinatus muscle is then sutured over the new rhomboid muscle insertions and, finally, the wounds are closed in layers.

**TECH FIG 3** • A. Normal position of the levator scapula, rhomboid minor, and rhomboid major on the medial border of the scapula. B. Lateral transfer of the levator scapula, rhomboid minor, and rhomboid major. This modification includes transfer of the rhomboid minor to the supraspinatus fossa.

**TECH FIG 4** • A. The second incision is made 5 to 7 cm medial to the posterolateral corner of the acromion for transfer of the levator scapula muscle. B. Excursion of the levator is confirmed before the muscle is subcutaneously tunnelled to the planned transfer site.
### PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Rhomboid transfer</th>
<th>Levator transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separate the rhomboid minor from the rhomboid major so they can be transferred separately.</td>
<td>Dissect the levator scapula far enough laterally to allow tension-free transfer to the scapular spine.</td>
</tr>
<tr>
<td>The infraspinatus and supraspinatus are elevated from their respective fossae for approximately 5 cm. This modification of the original procedure permits the rhomboid minor to be transferred to a position that better substitutes for the action of the middle trapezius.</td>
<td>Avoid iatrogenic injury to the transverse cervical artery and the dorsal scapular nerve, which run superficial and deep, respectively, to the levator scapulae and then terminate into the deep surface of the rhomboids near their insertion onto the scapula.</td>
</tr>
<tr>
<td>Care should be taken to prevent injury to the suprascapular nerve, which lies on the deep surface of the supraspinatus muscle.</td>
<td>A tunnel is created through the atrophied trapezius, in line with its upper fibers, for passage of the tagged levator scapulae.</td>
</tr>
<tr>
<td>The infraspinatus and supraspinatus are elevated from their respective fossae for approximately 6 weeks after surgery is important to avoid pull-out of the transferred muscles, especially the rhomboids, which, unlike the levator scapulae, are not attached to their new scapular insertion with the tendo-osseous interface intact.</td>
<td></td>
</tr>
<tr>
<td>The levator should not be transferred too far laterally, because this can cause a web-like deformity in the neck. A good position is 5 to 7 cm from the posterior lateral corner of the acromion.</td>
<td></td>
</tr>
</tbody>
</table>

### POSTOPERATIVE CARE
- Most authors advocate immobilization for 6 weeks postoperatively, followed by initiation of physical therapy (passive and active).  
  13,14,16
- Romero and Gerber13 prefer an abduction splint, whereas Teboul et al16 suggest securing the arm to the chest with an elastic bandage.
- Our routine postoperative protocol is to use a foam wedge or orthosis for the first 4 weeks, keeping the arm in 60 to 70 degrees of abduction. We encourage early passive range of motion above the wedge or orthosis to prevent stiffness (forward elevation to 130 degrees and external rotation to 40 degrees in the first 4 weeks).
- At 4 weeks, the wedge is discontinued, and gentle strengthening exercises are added. We have designed a progressive strengthening program that uses rubber tubing, free weights, and medicine ball throws to achieve dynamic scapular stability. All of the exercises in the protocol are designed to strengthen the transferred levator scapula and rhomboids.

### OUTCOMES

- The Eden-Lange procedure produces satisfactory results for the difficult problem of trapezius palsy.
- In a study in which 16 patients were reviewed at a mean follow-up of 32 years, clinical outcomes were noted to be excellent in 9 patients, fair in 2 patients, and poor in 1 patient (as determined by Constant score).13 Some patients with outcomes that were less than satisfactory also had dorsal scapular and long thoracic lesions.
- Romero and Gerber13 describe a radiographic outcomes measure that uses an AP radiograph to measure the angle between a line drawn between the cranial and caudal ends of the glenoid with a vertical axial line. This measurement was compared to the contralateral side, and no statistical differences were found.
- Another recent study16 concluded that muscle transfer should be performed only after previous nerve repair surgery had failed or when more than 20 months has elapsed since the injury was incurred. In this series of 7 patients treated with the Eden-Lange procedure (the other 20 patients were treated with nerve surgery), results were excellent in 3 patients, good in 1 patient, and poor in 3 patients. Teboul et al16 state that two factors are most predictive of a poor result following reconstructive surgery: if the patient is older than 50 years or the lesion is caused by radical neck dissection, penetrating injury, or spontaneous palsy.

### COMPLICATIONS

- Complications associated with the Eden-Lange procedure, in addition to the usual surgical risks, include failed integration of the transferred muscles with resultant continued dysfunction. Such a complication is discussed rarely, and we were only able to find one report of a failure of muscle integration.16
- Patient compliance with strict immobilization for the first 6 weeks after surgery is important to avoid pull-out of the transferred muscles, especially the rhomboids, which, unlike the levator scapulae, are not attached to their new scapular insertion with the tendo-osseous interface intact.
- Initial complications do not seem to be the problem with the Eden-Lange procedure; rather, the primary complication appears to be later effects of functional outcome falling short of expectations.
- Iatrogenic dysfunction resulting from no longer having a physiologic levator scapula or rhomboids is not, to our knowledge, discussed in the literature. However, because the origin of these muscles is merely being transposed more laterally, it does not appear that the Eden-Lange procedure creates a new problem while fixing the old one.
- In cases of failure of the procedure, where pain and dysfunction continue, scapulothoracic arthrodesis can be performed as a salvage procedure.

### REFERENCES
DEFINITION
■ Long thoracic nerve palsy leads to classical scapular winging because of weakness of the serratus anterior muscle (FIG 1).
■ Other types of winging include trapezius winging and rhomboid winging.
■ Lesions of the long thoracic nerve can range from paresis to complete paralysis, leading to varying degrees of shoulder dysfunction.
■ The serratus anterior muscle functions to stabilize the scapula against the chest wall, thus providing a fulcrum for the humerus to push against while moving the arm in space.3,4
■ Without this fulcrum, shoulder elevation is weakened, which leads to inability to use the arm in forward activities.
■ Forward elevation of the shoulder is most severely affected, followed by shoulder abduction.

ANATOMY
■ The serratus anterior is a large broad muscle that covers the lateral aspect of the thorax. It has digitations that take origin from the upper nine ribs, pass deep to the scapula, and insert on the medial aspect of the scapula.15
■ The muscle has three divisions.5
■ The first division consists of one slip and takes origin from the first two ribs. This division runs slightly upward and inserts on the superior angle of the scapula.3,4
■ The second division is made up of three slips from the second, third, and fourth ribs, and inserts on the anterior surface of the medial border of the scapula.
■ The third division, which consists of the inferior five slips from ribs five through nine, inserts on the inferior angle of the scapula. Because this division has the longest course it has the longest lever-arm and the most power for scapular rotation.
■ The serratus anterior muscle stabilizes the scapula against the chest wall, creating a fulcrum for the proximal humerus to lever against while moving the arm in space.
■ The serratus anterior protracts and upwardly rotates the glenoid.
■ Its direction of pull brings the inferomedial border of the scapula anteriorly. The inferior border of the scapula is pulled forward with forward elevation of the arm. This causes the glenoid to tip posteriorly and allow full forward elevation without impingement.
■ With weakness of the serratus anterior muscle, the scapula translates superiorly and medially, and the inferior border rotates medially and dorsally (FIG 2A).
■ The serratus anterior muscle is innervated by the long thoracic nerve, which arises from the ventral rami of cervical roots C5–7.
■ The C5 and C6 roots pass through the scalenus medius muscle and merge before they receive a branch from C7.
■ The nerve enters the axillary sheath at the level of the first rib and travels posteriorly in the axilla.
■ It then passes over a prominence in the second rib and descends along the lateral chest wall, where it enters the serratus anterior fascia and then the muscle itself (FIG 2C).5,15
■ The total length of the nerve is about 24 cm, and there are several possible points of injury.
■ Proximally, as well as distally along the chest wall, the nerve is susceptible to injury because of its superficial location.
■ The nerve is tethered in the axillary sheath, which places it on stretch with forward elevation of the arm.

PATHOGENESIS
Scapular Winging
■ Scapular winging may be due to primary, secondary, or voluntary causes.8
■ Primary scapular winging can be divided into neurologic, bony, and soft tissue types.
■ Neurologic disorders, which are most common, include:
  - Long thoracic nerve palsy (serratus anterior weakness)
  - Spinal accessory nerve palsy (trapezius weakness)
  - Dorsal scapular nerve palsy (rhomboid weakness)
  - Trapezius weakness winging may be distinguished from serratus winging by the position and direction of scapular laxity (see Fig 2A, B).
■ Bony abnormalities include osteochondromas of the scapula or fracture malunion.
■ Soft tissue disorders include:
  - Soft tissue contractures, causing winging
  - Muscular disorders such as fascioscapulohumeral dystrophy

FIG 1 • Clinical photograph of serratus winging.
Congenital absence or traumatic rupture of the parascapular muscles
- Scapulothoracic bursitis
- Secondary winging may occur following disorders of the glenohumeral joint. The most common causes are multidirectional and posterior instability.
- The sequence of events leading to secondary scapular winging due to primary shoulder pathology is as follows:
  - Primary glenulohumeral or subacromial pathology, leading to
  - Limited glenulohumeral motion, leading to
  - Increased compensatory scapulothoracic motion, leading to
  - Increased demand on periscapular muscles, leading to
  - Fatigue of periscapular muscles—serratus, trapezius, and rhomboids—leading to
  - Secondary scapular winging
- Voluntary winging may occur in psychiatric patients or for secondary gain.

Long Thoracic Nerve Palsy
- Long thoracic nerve palsy is the most common cause of serratus dysfunction resulting in symptomatic scapular winging, especially in those patients who fail nonoperative management and are being considered for pectoralis tendon transfer.¹
- Long thoracic nerve palsy has been reported to result from idiopathic, iatrogenic, viral, compressive, or traumatic (blunt or penetrating) causes.¹³
- Most injuries are neurapraxic, due to blunt trauma.
- Lesions also may occur through entrapment of the fifth or sixth cervical roots at the level of the scalenus medius, during traction over the second rib, or with traction and compression at the inferior angle of the scapula with general anesthesia or prolonged abduction of the arm.
Iatrogenic injuries may occur during radical mastectomy, first rib resection, or transaxillary sympathectomy, or during surgical positioning.\(^6\)

Other less common causes include viral illnesses, Parsonage-Turner syndrome, isolated long thoracic neuritis, immunizations, or C7 nerve root lesions.\(^4\)

Often, the cause is idiopathic, with a questionable history of trauma or viral illness.

**Pathoanatomy**

A mechanical advantage is gained by stabilization of the scapula against the chest wall.

- With loss of this mechanical advantage, forward elevation against resistance is decreased owing to scapulothoracic motion.
- Additional types of shoulder pathology can result secondary to stabilization of the scapula:
  - Impingement due to relative anterior rotation of the acromion (FIG 3)
  - Weakness due to loss of mechanical advantage in forward elevation
  - Adhesive capsulitis from disuse
  - With complete paralysis of the serratus anterior, complete forward elevation and abduction greater than 110 degrees are not possible.\(^3,15\)

**Natural History**

- As mentioned previously, most injuries to the long thoracic nerve are neurapraxic from stretch of the nerve or blunt trauma.
- Most cases resolve spontaneously without operative intervention within 12 months, although maximal recovery may take up to 24 months.\(^2,7,9\)
- The exception to this rule is injury due to nerve laceration from penetrating trauma or iatrogenic injury.

**Patient History and Physical Findings**

A thorough history (including previous illnesses, procedures and interventions, hand dominance, and activity level) and complete examination of the shoulder and back are essential.

Treatment often is delayed, and diagnosis may become apparent only after failed treatment for other disorders.

Furthermore, patients may develop secondary stiffness from disuse, and this may be the primary complaint.

Patients often present with vague complaints of shoulder pain or weakness with overhead activities.

Because winging may be subtle, the patient must be undressed from the waist up, viewed from the back, and tested with provocative maneuvers such as resisted forward elevation and pushups against a wall.

Pain may come from several sources, making diagnosis of long thoracic nerve palsy based on pain distribution difficult.

Compensatory overuse of the remaining scapulothoracic musculature may cause pain localized posteriorly about the scapula.

Patients may present with impingement-type pain with forward elevation.

In secondary winging, pain may result from an underlying diagnosis such as glenohumeral instability.

With severe pain, long thoracic neuritis or Parsonage-Turner syndrome should be considered.

Physical examination usually reveals classic winging, with the scapula translated medially and the inferior border rotated toward the midline (see Fig 1).

Patients may present with varying degrees of weakness of forward elevation of the arm.

- Resisted testing may accentuate winging, as will having the patient do a pushup against a wall.
- Weakness of forward elevation may be decreased by manual scapular stabilization against the chest wall by an examiner, the so-called “scapular stabilization test.”\(^13\)

**Imaging and Other Diagnostic Studies**

- Plain radiographs of the shoulder, cervical spine, and chest should be part of the workup.
- Although radiographs rarely are diagnostic, bony abnormalities such as osteochondromas, cervical spondylosis, or scoliosis may be evident.
- CT or MRI scans may be helpful in these situations, but are often not necessary.
Electromyographic and nerve conduction velocity studies are useful in confirming the diagnosis as well as following patients clinically.

- Additionally, in idiopathic cases or where dystrophy is suspected, these tests may be helpful in ruling out other neuromuscular disorders (such as fascioscapulohumeral dystrophy) that may preclude muscle transfer as an option for scapular stabilization.
- Serial studies every 3 months are recommended.
- Studies should include cervical roots, brachial plexus, and the spinal accessory nerve.

DIFFERENTIAL DIAGNOSIS
- Rotator cuff tear
- Fracture malunion
- Glenohumeral instability
- Impingement
- Acromioclavicular joint disease
- Biceps tendinitis
- Neurologic disorders
- Suprascapular nerve entrapment
- Scoliosis
- Scapular osteochondroma

NONOPERATIVE MANAGEMENT
- Whether idiopathic, viral, or compressive, almost all cases of serratus winging from long thoracic palsy resolve spontaneously within 1 to 2 years.\(^2,7,9\)
  - Without a clear history of penetrating trauma, all patients initially should be treated conservatively (FIG 4).
  - Physical therapy should consist of range-of-motion exercises to avoid secondary glenohumeral stiffness.
  - Braces and orthotics that have been designed to stabilize the scapula to the chest wall may provide symptomatic relief. Their use is controversial, however, and many patients find them cumbersome.
  - Some authors have recommended bracing to decrease continued traction on the nerve.\(^14\)

SURGICAL MANAGEMENT
- Patients for whom nonoperative treatment has failed and who have persistent symptomatic scapular winging are candidates for surgical stabilization.
- Patients often are given up to 24 months to recover nerve and muscle function before surgical repair is considered.
- However, Fery\(^2\) has reported that up to 25% of patients with serratus anterior paralysis may fail nonoperative treatment.
- Patients who have penetrating trauma or iatrogenic injury, where a long thoracic nerve transection is suspected, may be indicated for acute nerve exploration and repair.
- Historically, three different procedures have been used to treat patients with symptomatic serratus anterior dysfunction: scapulothoracic fusion, static stabilization procedures, and dynamic muscle transfers.
  - Scapulothoracic fusion is mainly a salvage procedure, sometimes used in patients with previous failures or in patients with dystrophies, such as fascioscapulohumeral dystrophy, where multiple muscles may be affected.
  - Static stabilization uses fascial slings or tethers to help stabilize the scapula.
  - These procedures have fallen out of favor because the slings may gradually stretch out, with subsequent loss of scapular stability.
  - Dynamic muscle transfers, first described by Tubby\(^12\) in 1904, have been found to offer the optimal recovery and result in nearly normal scapulothoracic motion.

Numerous different transfers have been described, but most surgeons currently perform a transfer of the sternal head of the pectoralis major to the inferior angle of the scapula to reconstruct the function of the deficient serratus anterior.

- The sternal head of the pectoralis is preferred because it has good excursion and similar power to the serratus, and its fiber orientation is similar to that of the serratus.\(^1,2\)

Preoperative Planning

- Preoperative planning should include a discussion with the patient regarding allograft versus autograft augmentation of the pectoralis transfer.
  - Typical options include contralateral fascia lata or semitendinosus autograft, or semitendinosus allograft.
  - A tendon stripper is needed for autograft harvest if desired.
  - A 5-mm round trip burr or drill bit is needed to fashion a tunnel through the inferior angle of the scapula.
  - Heavy nonabsorbable suture (no. 2 or no. 5) is needed to attach the pectoralis transfer and prepare the graft augmentation.

Patient Positioning

- The patient is placed supine in the beach chair position, with care taken to leave access to the midline posteriorly and anteriorly.
  - A pad is placed behind the midline of the thorax to improve posterior exposure.
  - The forequarter is draped free with the entire scapula in the surgical field.
  - A pneumatic arm positioner (Spider Limb Positioner, Tenet Medical Engineering, distributed by Smith & Nephew Endoscopy, Andover, MA) is helpful during the procedure to maintain position of the extremity.
  - If fascia lata or semitendinosus autograft is to be harvested, the lower extremity must be prepped and draped free as well.

Approach

- The following section describes our preferred technique for transfer of the sternal head of the pectoralis major to the inferior angle of the scapula for serratus anterior dysfunction.

**EXPOSURE**

- A 10- to 15-cm incision is made in the axillary crease posterior to the lateral border of the scapula (**TECH FIG 1A**).
  - The deltopectoral interval is developed, and the cephalic vein is retracted laterally.
  - The pectoralis tendon is identified at its humeral insertion.
  - The sternal head, which lies deep to the clavicular head, is identified and isolated bluntly (**TECH FIG 1B, C**).
  - Often, abduction and external rotation of the extremity is helpful in exposing the sternal head.

- The sternal head insertion is released sharply from the humerus, taking care not to damage the underlying long head of the biceps tendon or the clavicular head of the pectoralis major (**TECH FIG 1D, E**).
  - Traction sutures are placed into the sternal head tendon, and the muscle belly is freed of adhesions medially.

**TECH FIG 1** • A. Axillary incision used for pectoralis major transfer. B.C. The sternal head, which lies deep to the clavicular head, is identified and isolated bluntly. (continued)
Chapter 30  PECTORALIS MAJOR TRANSFER FOR LONG THORACIC NERVE PALSY 3313

TECH FIG 1  (continued) D,E. The sternal head insertion is released sharply from the humerus, taking care not to damage the underlying long head of the biceps tendon or the clavicular head of the pectoralis major. (B–E: from Post M. Orthopaedic management of neuromuscular disorders. In: Post M, Flatow EL, Bigliani LU, Pollack RG, eds. The Shoulder: Operative Technique. Philadelphia: Lippincott Williams & Wilkins, 1998:201–234.)

GRAFT HARVESTING

- At this point, attention is turned to the fascia lata harvest, or preparation of the allograft tendon.
  - For fascia lata harvest, two small incisions (2 to 3 cm) are made on the lateral aspect of the thigh, about 20 cm apart.
  - After incision, the fascia lata is exposed and cleaned with an elevator between the two incisions.
  - Once the fascia lata is identified and isolated, a tendon stripper is used to harvest a graft approximately 6 cm × 20 cm.

- The graft is then folded over itself and tubularized using heavy, nonabsorbable suture.
- Once prepared, the graft is woven into the sternal head tendinous origin and secured with heavy, nonabsorbable suture (TECH FIG 2).

SCAPULAR EXPOSURE, PREPARATION, AND TENDON ATTACHMENT

- After the pectoralis tendon and graft are ready, the scapula is exposed.
- The inferior angle of the scapula is identified and exposed by blunt dissection along the chest wall.
- The latissimus dorsi and teres major tendons are retracted distally, and the lateral neurovascular structures are avoided by staying medial.
- Once the inferior angle of the scapula is identified, it is exposed subperiosteally, and a 6- to 8-mm burr hole is made 2 cm from the lateral and inferior border of the scapula.
- The graft is then passed through the bone hole from anterior to posterior, tensioning the graft while reducing the scapula on the chest wall, so that the native pectoralis tendon is flush with the bone tunnel.
- The graft is then looped through the hole in the inferior scapula and sutured to itself using heavy, nonabsorbable suture (TECH FIG 3).
  - It is necessary to ensure that native pectoralis tendon is brought to the scapula, because the tendon graft may stretch over time.


PEARLS AND PITFALLS

- Electromyography is helpful in identifying patients with dystrophy or other palsies, which may preclude the possibility of a sternal head transfer for serratus anterior dysfunction.
- Patients with blunt trauma or idiopathic etiologies initially should be managed nonoperatively, because most will recover serratus anterior function.
- The sternal head lies deep to the clavicular head, and positioning the arm in abduction and external rotation can help identify the insertion of the tendon.
- When approaching the inferior scapula, care is taken to stay medial while retracting the latissimus and teres major distally, because the neurovascular structures are lateral.
- The scapula should be reduced to the chest wall by an assistant before tensioning the pectoralis transfer.
- Avoid scapular fracture by keeping the osseous tunnel a minimum of 1 cm away from the scapular borders.
- The sternal head is lengthened by autograft or allograft, but it is critical to have native, living pectoralis tendon attached directly to the inferior scapula. The auto- or allograft is meant for augmentation.

POSTOPERATIVE CARE

- Patients are kept immobilized in the sling and orthosis for 6 weeks.
- After 6 weeks, range-of-motion exercises are begun, and the brace is discontinued.
- Strengthening exercises are begun as motion returns.
- Patients are restricted from heavy lifting or manual labor for 6 months.

OUTCOMES

- Most series of sternal head transfer for serratus anterior dysfunction and scapular winging report good to excellent results with improvement in function, relief of pain, and correction of winging.
- Post11 reported on eight patients treated with sternal head transfer with excellent results.
- Connor et al1 reported on 11 patients, 10 of whom (91%) had significant improvement in pain and function and relief of winging.
- Warner and Navarro13 reported that seven of eight patients had excellent results, with the only unsatisfactory outcome following a deep infection.
- Conversely, Noerdlinger et al10 reported that of 15 patients treated, only 7 (47%) had good to excellent results. They found that those patients who lacked external rotation at follow-up
had poorer results, and that more aggressive therapy regarding rotation may be needed.

**COMPLICATIONS**

- Seroma and infection\(^{13}\)
- Neurovascular injury
- Scapular fracture through bone tunnel
- Shoulder stiffness\(^{10}\)
- Graft loosening and loss of tension\(^{11}\)

**REFERENCES**

DEFINITION
- Refractory disorders of the scapulothoracic articulation have been reported to result in debilitating pain and dysfunction that may require surgical management.
- The most common clinical presentation, scapular winging, was first reported in the published literature in 1723, and several etiologies for scapular winging have been documented since then.
- Soft tissue operations (eg, pectoralis major tendon transfer) have had reported success in stabilizing the dyskinetic scapula in appropriate patients.
- Despite successful clinical outcomes, a population of patients experience recurrent symptomatic scapular winging even after pectoralis major transfer.
- Several authors report that arthrodesis is the treatment of choice for these failed muscle transfers. For failed pectoralis transfer or significant (ie, irreducible) fixed winging, scapulothoracic arthrodesis can be a successful salvage operation for these patients.

ANATOMY
- The scapula is positioned over the posterolateral aspect of the rib cage, overlying ribs 1 to 7. It is suspended from the sternum by the clavicle anteriorly and plays an important role in positioning the upper extremity for proper function.
- The lateral scapula includes the glenoid fossa for articulation with the humeral head.
- The scapula provides an attachment for 16 muscles, which help maintain it in functional positions. It articulates on the thoracic cavity, allowing rotation, protraction, and retraction.
- A thin bursal layer separates the scapula from the underlying ribs.

PATHOGENESIS
- Dysfunction of the scapulothoracic articulation has been well documented in the peer-reviewed literature.
- The most common manifestation of scapulothoracic dysfunction is symptomatic scapular winging (FIG 1).
- Traumatic injuries to the serratus anterior muscle or the long thoracic nerve have been reported to cause symptomatic winging.
- Atraumatic etiologies, such as neuralgic amyotrophy, polio, and the muscular dystrophies, also may produce disabling scapular winging.
- Intolerable winging also has been demonstrated in association with other bony abnormalities (eg, rib or scapular osteochondromas and malunited scapular fractures) or soft tissue lesions (eg, scapular-stabilizing muscle contractures, muscle avulsions, and scapulothoracic bursitis).
- Recent authors have reported a significant incidence of scapular winging secondary to glenohumeral joint lesions such as rotator cuff tears and glenohumeral instability (especially posterior and multidirectional instability).

The scapulothoracic articulation also is a potential source of debilitating pain in the shoulder girdle.
- Several authors have documented the incidence of painful scapulothoracic crepitus (“snapping scapula” syndrome) and scapulothoracic bursitis.
- Painful crepitus can be due to interposed muscle, fibrous and granulomatous lesions, or bony incongruity associated with osteochondromata, fractures, scoliosis, or kyphosis.

NATURAL HISTORY
- Most patients who present with symptomatic scapular winging, scapulothoracic pain, or crepitus respond to nonoperative measures.
- A subset of this patient population, however, experiences complex scapulothoracic dysfunction or pain refractory to conservative measures.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients presenting with scapulothoracic disorders typically complain of debilitating pain, shoulder dysfunction, or scapulothoracic crepitus.
- Physical findings commonly include scapular winging, crepitus, alterations in normal scapulohumeral rhythm, or neurologic deficits.
- Physical examination should focus on the resting posture of the scapula, as well as its dynamic position.
- Both scapulae should be observed and palpated while the arms are elevated or while the patient performs a wall push-up. These dynamic tests may make subtle winging more obvious.
- The pattern of winging distinguishes between serratus anterior dysfunction (long thoracic nerve) or trapezius palsy (spinal accessory nerve).

FIG 1 • A. Moderate dynamic scapular winging demonstrated with slow forward elevation of the arms in the frontal plane. B. The same patient demonstrating marked medial winging with the resisted elevation at 30 degrees.
• The more common medial winging is consistent with serratus anterior dysfunction, whereas lateral winging is observed in trapezius palsy.

• Further assessment includes the scapula stabilization test to assess for fixed or correctable winging. This test is crucial in determining fixed versus reducible winging. It demonstrates the amount of discomfort the patient has and indicates the extent to which reduction of the scapula will relieve that discomfort.

• Painful crepitus localized to the scapulothoracic region is verified by diagnostic injection, in which 1% lidocaine is injected beneath the medial border of the scapula into the scapulothoracic bursa. Improvement in pain may be noted in the examination room, further supporting the diagnosis.

IMAGING AND OTHER DIAGNOSTIC STUDIES

• Standard plain radiographs of the shoulder, including anteroposterior views in internal and external rotation, axillary lateral views, and scapula Y views are obtained to evaluate the status of the clavicle, acromioclavicular joint, glenohumeral joint, and bony contour of the scapula.

• CT scans, including axial images and reformatted coronal and sagittal images, provide further detail, and may be required to assess scapula morphology and the presence of exostoses or deformity.

• Electromyography and nerve conduction velocity are important to verify neurologic dysfunction of the long thoracic or spinal accessory nerves.

DIFFERENTIAL DIAGNOSIS

• Long thoracic nerve palsy

• Spinal accessory nerve palsy

• Glenohumeral joint derangement with secondary scapular winging

• Scapulothoracic bursitis

• Snapping scapula

• Scapular exostosis or osteochondroma

NONOPERATIVE MANAGEMENT

• Nonoperative treatment is the cornerstone of management of scapulothoracic dysfunction.

• Therapeutic modalities involve supervised scapular–stabilizer and glenohumeral stretching and strengthening, the judicious use of oral anti-inflammatory medications, and selective cortisone injections.

SURGICAL MANAGEMENT

• Patients who have failed an extensive nonoperative course are candidates for surgical treatment.

• Surgical options for scapulothoracic dysfunction include:

  • Arthroscopic or open decompression and bursectomy or medial border scapulectomy for painful crepitus

  • Split pectoralis major tendon transfer for dynamic winging

  • Scapulothoracic arthrodesis

• Surgical indications for scapulothoracic arthrodesis include the following clinical situations:

  • For patients with disabling pain associated with fixed scapular winging or failed pectoralis transfer, indications for fusion include:

    • Significant winging

    • Difficulty in reducing the scapula with the “scapular stabilization test”

    • Significant pain relief (>75%) that substantially improved function during a scapular stabilization test

Preoperative Planning

• Preoperative anesthesia consultation is recommended. We use general anesthesia with a double-lumen endotracheal tube to allow for selective deflation of the ipsilateral lung during wire passage.

Positioning

• Patients are placed in the prone position.

• Care is taken to pad all bony prominences.

• The entire involved arm, scapula, and ipsilateral posterior iliac crest are prepped and draped to the midline of the spine (FIG 2).

• It is essential that the entire arm be prepped and draped in the surgical field to allow for appropriate manipulation of the scapula and accurate placement of the scapula on the rib cage for fusion.

Approach

• A direct approach to the scapulothoracic articulation along the medial border of the scapula is used. This approach allows excellent exposure of the underlying ribs and undersurface of the scapula. The superficial location of the scapula makes this approach relatively straightforward.
**EXPOSURE**

- The incision is placed along the medial border of the scapula from just superior to the scapular spine to the inferior angle.
- The superficial fascia is incised, and the trapezius muscle is identified and retracted medially (TECH FIG 1A). The rhomboid muscles are incised off the medial edge of the scapula and are tagged for reattachment before closure (TECH FIG 1B).
- With the rhomboid muscles elevated, a rake retractor can be placed on the anterior surface of the medial scapular border to retract the medial scapula away from the rib cage (TECH FIG 1C).
- About one third of the musculature of the serratus anterior and subscapularis is resected from medial to lateral off the anterior surface of the scapula to allow for a wide fusion surface (TECH FIG 1D).
- Care must be taken to avoid resecting the subscapularis beyond the midline of the scapula to prevent denervation.

**BONY PREPARATION**

- The anterior surface of the scapula is now roughened slightly with a burr (TECH FIG 2A). Care must be taken during this maneuver to avoid thinning the medial border excessively, because that could lead to fracture during hardware fixation.
- Next, the scapula is reduced to the rib cage in approximately 20 to 25 degrees of external rotation from the midline to maximize subsequent shoulder range of motion (most notably elevation and external rotation).
- If patients demonstrated concomitant multidirectional glenohumeral instability with a symptomatic inferior component, the scapula is rotated externally 35 to 40 degrees from the midline to use the inferior glenoid rim to buttress against inferior translation.
- The ribs corresponding to the decorticated anterior surface of the scapula are identified, and the scapula is again retracted to allow for rib preparation.
- Depending on the size and configuration of the scapula, three or four ribs typically will be used in the fusion (usually the third to sixth ribs).
- The periosteum is incised carefully in a longitudinal direction and stripped off each rib (TECH FIG 2B,C).
- The ribs are minimally roughened with a burr down to bleeding bone.
- It is essential to remove all areas of soft tissue between the scapula and rib cage to permit maximum bony contact between the anterior surface of the scapula and the ribs (TECH FIG 2D).
TECH FIG 2 • A. The anterior surface of the scapula is lightly decorticated with a motorized oval burr. B. The first rib has been prepared with the periosteum incised and stripped off of the rib, ready for light decortication. C. Rib preparation continues, exposing the bony surface of the ribs corresponding to the undersurface of the scapula. This typically involves three to four ribs. D. Appearance of the rib surface after light decortication to a bleeding bony surface. Note that in this case, three ribs were prepared for the fusion surface.

WIRE PASSAGE AND PLACEMENT OF SEMITUBULAR PLATE

- At this time, the involved lung is deflated before cerclage wires are passed around the ribs, to minimize trauma to the lung fields.
- Using rib and periosteal dissectors, a cerclage wire with a minimum diameter of 1.5 mm is passed carefully around each of the exposed ribs at the level where the medial border of the scapula will be placed on the rib cage (TECH FIG 3A,B).
- After passage of the cerclage wires, a one-third semitubular large fragment plate (usually with 5 or 6 holes, depending on the size of the scapula) is lined up on the posterior aspect of the medial border of the scapula (the thickest part of the scapula; TECH FIG 3C).
- A 3-mm burr is used to make holes through the scapula corresponding to the holes in the semitubular plate (TECH FIG 3D).

TECH FIG 3 • A. A 1.5-mm wire is passed around the rib using rib and periosteal elevators. The lung is deflated by the anesthesia team before the wire is passed to minimize damage to the underlying pleura. B. Wires are passed around each of the ribs to be involved in the fusion construct. C. A one-third semitubular plate (typically with 5 or 6 holes) is positioned over the medial border of the scapula. D. Holes are drilled in the scapula, corresponding to the plate, with a 3-mm motorized burr. A skin retractor is placed beneath the scapula to protect the underlying thoracic cavity.
Cancellous bone is now harvested from the posterior iliac crest in routine fashion through a separate incision paralleling the path of the cluneal nerves.

- If more bone graft is desired, either allograft cancellous chips or a synthetic bone graft substitute can be added.

- The wires are now passed through the scapula and semitubular plate (TECH FIG 4A), and the bone graft is placed between the scapula and ribs.

- The scapula is reduced to the underlying ribs (TECH FIG 4B), and the wires are sequentially tightened with the scapula held in 20 to 25 degrees of external rotation from the midline (TECH FIG 4C,D).

- The semitubular plate allows uniform stress distribution once the wires are tightened (TECH FIG 4E,F).

- The wires are cut, and attention is turned to closure of the wound (TECH FIG 4G).

**TECH FIG 4 • A.** The previously placed wires are then passed through the scapula and plate in the appropriate position. **B.** The scapula is reduced into the predetermined position overlying the ribs and held in place before wire tightening. **C,D.** The wires are tightened sequentially, applying uniform tension on the plate and compressing the scapula against the ribs. **E.** The final position of the scapula after fixation with the wires. Note the autologous bone graft seen along the medial border. **F.** Illustration of the final construct. **G.** The wires are then cut, and attention is turned to wound closure.
POSTOPERATIVE CARE

- The patient is placed in a “gunslinger” brace, immobilizing the arm in neutral rotation (FIG 3), and a postoperative chest radiograph is obtained to document any hemo- or pneumothorax.
- If a chest tube has been placed, it is removed 1 or 2 days postoperatively, depending on chest tube outputs and pulmonary status.
- Patients are immobilized in the brace for 12 weeks.
- Rehabilitation is commenced at 12 weeks with a gentle passive range-of-motion program that emphasizes forward elevation and external rotation.
- Three weeks later, the patient is progressed to an active range-of-motion program.
- A strengthening program involving resisted exercises is begun 6 weeks after the gunslinger brace is removed.

OUTCOMES

- Despite the significant complication rate (nearly 50%) that accompanies scapulothoracic arthrodesis, this operation has been documented to provide improvements in both pain and functional disability.
- A high level of patient satisfaction when patients are chosen appropriately and expert surgical technique is used can make this operation rewarding for both patient and surgeon.
- In one series of 23 patients undergoing scapulothoracic fusion, mean ASES scores improved from 35.8 to 40.1. Postoperative pain scores decreased from mean 5.5 to 4.7. Mean patient satisfaction was 9.5 out of 10 for the surgical procedure, and 91% of patients reported that they would undergo the procedure again.14

COMPLICATIONS

- Complications are not uncommon with this procedure and have been reported to be as high as 50% in some series.14
The most commonly cited complications associated with this procedure include:

- Pneumothorax
- Hemothorax
- Hardware complications, including wire breakage, nonunion, and pseudoarthrosis
- Neurologic complications, including intercostal neuralgia
- Wound complications, including infection or wound dehiscence

REFERENCES

DEFINITION

- Suprascapular nerve (SSN) entrapment is an uncommon cause for shoulder pain and weakness. It was initially described by Koppel and Thompson.\(^{11}\)
- SSN entrapment typically occurs at the suprascapular or spinoglenoid notch and presents with symptoms ranging from diffuse shoulder pain to weakness and atrophy of the supraspinatus and infraspinatus muscles.

ANATOMY

- The SSN arises from the upper trunk of the brachial plexus, with contributions from C5 and C6 (rarely also C4), and provides branches to the supraspinatus and infraspinatus muscles. It also carries afferent fibers from the glenohumeral joint and rarely also cutaneous fibers from the lateral aspect of the shoulder.
- The nerve traverses two potential compression points, at the suprascapular notch and spinoglenoid notch (FIG 1), and is accompanied by the suprascapular artery and vein.
- At the suprascapular notch, the nerve runs in a fibro-osseous canal formed by the scapular notch and the transverse scapular ligament. Generally, the nerve runs under the ligament, but it is occasionally accompanied by a branch of the main vessels, which course over the ligament.
- The suprascapular notch is approximately 4.5 cm medial to the posterolateral corner of the acromion and 3 cm medial to the glenoid rim (supraglenoid tubercle). The spinoglenoid notch is approximately 1.8 cm medial to the glenoid rim and 2.5 cm inferomedial to the supraglenoid tubercle.\(^{3}\)
- Several anatomic studies have described the presence of a spinoglenoid ligament (inferior transverse scapular ligament) at the spinoglenoid notch in 3% to 60% of specimens,\(^{5,6}\) but its role in nerve entrapment at this level is controversial.

PATHOGENESIS

- The most common site of entrapment is at the suprascapular notch, where it can be compressed by a thickened or ossified transverse scapular ligament.
- The relative confinement of the nerve at the suprascapular notch also places it at risk for injury due to traction, such as seen either in acute trauma or repetitive overhead activities such as volleyball, tennis, or weightlifting.
- Compression from labral ganglions can also occur, typically at the spinoglenoid notch.\(^{1}\) These cysts can develop as the result of labral tears that allow fluid extravasation but block backflow, similar to a one-way valve.
- More recently, traction injury to the nerve has been described as the result of massive, retracted tears of the posterosuperior cuff.\(^{2}\)
- Direct or indirect trauma leading to SSN neuropathy has been described as the result of shoulder dislocation, proximal humerus fracture, or scapular fracture.
- Iatrogenic injury to the SSN can occur during distal clavicle resection, positioning during spine surgery, transglenoid drilling for instability repair, shoulder arthrodesis, or the posterior approach to the glenohumeral joint.

NATURAL HISTORY

- The natural history depends on the presence or absence of a space-occupying lesion as the cause of SSN neuropathy.
- Without compression by a mass, most patients will improve with time and supervised physical therapy.\(^{8}\)
- Conversely, the presence of a mass, such as a cyst or ganglion, usually results in failure of conservative management and will require decompressive surgery.
- The natural history of periarticular ganglion cysts in the shoulder is controversial, but they are thought to persist and enlarge with time.\(^{9}\) In rare instances, spontaneous resolution of ganglion cysts has been documented.

PATIENT HISTORY AND PHYSICAL FINDINGS

- SSN neuropathy secondary to compression at the suprascapular notch typically presents as a dull pain in the posterior...
and lateral shoulder, but the pain can also be referred to the anterior chest wall, lateral arm, and ipsilateral neck. Compression at the spinoglenoid notch is often comparatively pain-free and presents with isolated infraspinatus atrophy (FIG 2).

- The patient often provides a history of acute or repetitive trauma to the shoulder, such as a fall on the outstretched hand, or activities such as volleyball, tennis, or weightlifting.
- There appears to be an increased incidence of isolated infraspinatus atrophy in asymptomatic volleyball players. This typically responds well to conservative measures.
- Depending on the chronicity and degree of compression, varying amounts of weakness in abduction and external rotation can be detected on physical examination.
- In longstanding compression, atrophy of the supraspinatus and infraspinatus can be observed.
- Atrophy, if present, may assist in differentiating compression at the suprascapular notch from that at the spinoglenoid level, since supraspinatus atrophy occurs only with the former.
- Palpation of the spinoglenoid notch and cross-body adduction may reproduce the patient’s symptoms.
- It is important to exclude other potential sources of pain, such as the cervical spine, acromioclavicular joint, or rotator cuff.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- An anesthetic injection into the suprascapular notch can be diagnostic if it results in complete but transient pain relief.
- Stryker notch views, or anteroposterior radiographs of the scapula, with a 15- to 30-degrees caudally directed beam, provide visualization of the suprascapular notch. Alternatively, a CT scan can provide good osseous detail in cases of posttraumatic deformity or ossification of the transverse scapular ligament.
- MRI can reveal a superior or posterior labral tear and the presence of a ganglion in the area of the suprascapular or spinoglenoid notch (FIG 3). Ganglion cysts present as homogeneous masses with low signal intensity on T1-weighted images and high signal intensity on T2-weighted images.
- Electromyography and nerve conduction studies can often provide a conclusive diagnosis by showing denervation potentials, fibrillations, spontaneous activity, and prolonged motor latencies in the supraspinatus or infraspinatus, depending on the level of entrapment.

**DIFFERENTIAL DIAGNOSIS**

- Cervical radiculopathy
- Glenohumeral instability
- Rotator cuff pathology
- Acromioclavicular joint arthrosis

**NONOPERATIVE MANAGEMENT**

- Initial treatment for SSN neuropathy in the absence of a space-occupying lesion is conservative and will lead to near-complete resolution of symptoms in most cases.
- Complete resolution of pain and weakness can take more than 1 year.
- Supervised physical therapy, followed by a self-directed home exercise program, should consist of range-of-motion exercises, as well as strengthening of the rotator cuff muscles, the deltoid, and the periscapular musculature, including the trapezius, rhomboids, and serratus musculature. Restoring proper scapular function is beneficial in recovery and may prevent recurrence of the injury.
- Image-guided cyst aspiration has shown success in about half of patients, with persistence or recurrence in the other half.9,12
SURGICAL MANAGEMENT

- Surgical treatment is indicated in patients who have failed to respond to 6 to 12 months of nonoperative measures and continue to have significant pain and dysfunction. SSN neuropathy secondary to a mass is best treated with decompression, and evaluation and potential repair of the glenoid labrum.
- Other sources for shoulder pain and dysfunction should be ruled out if the mass is smaller than 1 cm in diameter or is not directly compressing the neurovascular bundle.

Preoperative Planning

- Oblique sagittal MR imaging allows visualization of the SSN in the supraspinatus fossa, the spinoglenoid notch, and the infraspinatus fossa.
- If a space-occupying lesion is present, this imaging will assist in preoperative planning by delineating the exact position of the mass and determining whether it is confined to the supraspinatus or the infraspinatus fossa or involves both areas.
- A paralabral ganglion or cyst that is confined to one area, especially when associated with a labral tear or other intra-articular pathology, is often amenable to arthroscopic decompression.
- We have found it useful first to perform a diagnostic shoulder arthroscopy and potential treatment of intra-articular pathology, followed by arthroscopic or open decompression of the SSN.

- Arthroscopic decompression has the potential advantages of treating associated intra-articular lesions, such as labral tears and avoiding the morbidity associated with open procedures.

Positioning

- Either the beach chair or the lateral decubitus position can be used.

OPEN DECOMPRESSION

Approach to the Suprascapular Notch

- Decompression of the suprascapular nerve at the suprascapular notch is best achieved through a trapezius-splitting approach.
- The anterior approach requires a more complex dissection and therefore carries a higher risk of neurovascular complications. It also offers incomplete visualization of the SSN posterior to the notch and is generally not recommended.
- A saber-type skin incision following the Langer lines is performed over the top of the shoulder. The incision begins posteriorly at the distal third of the scapular spine and extends anteriorly to a point 2 cm medially off the acromioclavicular joint (TECH FIG 1A).
- A transverse skin incision parallel to the scapular spine can be chosen instead but produces a less cosmetic scar.
- The trapezius fascia and muscle is divided in line with its fibers for a distance of 5 cm.
- Abduction of the arm decreases tension on the muscle, which if necessary can be elevated off the scapular spine for an extensile exposure.
- The supraspinatus muscle is bluntly dissected off the anterior aspect of the suprascapular fossa and retracted posteriorly to provide access to the suprascapular notch (TECH FIG 1B).

TECH FIG 1 • Schematic and intraoperative photograph demonstrating suprascapular nerve release at the suprascapular notch. A. The trapezius muscle is split in line with its fibers. B. The supraspinatus muscle is bluntly dissected off the suprascapular fossa and retracted to expose the suprascapular notch. C. The transverse scapular ligament has been released.
The overlying suprascapular artery and vein are gently retracted to expose the transverse scapular ligament.
- A small right-angle clamp can be used to bluntly dissect under the ligament and protect the underlying nerve while the ligament is transected with a scalpel.
- Occasionally the nerve is still tethered after release of the transverse ligament, requiring careful resection of the medial aspect of the suprascapular notch. The resected edge of the bone must be smooth at the completion of the procedure.
- If the trapezius was detached during the approach, it should be sutured back to the bone of the scapular spine. If the muscle was only split in line with its fibers, it is reaproximated with interrupted, absorbable sutures.

**Approach to the Spinoglenoid Notch**
- The posterior approach provides direct visualization of the suprascapular nerve at the spinoglenoid notch.
- A longitudinal skin incision is centered approximately 4 cm medial to the posterolateral corner of the acromion, approximately 5 cm in length. Following Langer lines provides a cosmetically acceptable scar.
- The underlying fascia and deltoid muscle is split in line with its fibers beginning at the level of the scapular spine and extending 5 cm distal from the posterior acromion (TECH FIG 2A). A stay suture placed at the distalmost extent of the incision protects against propagation of the split, which carries a risk of injury to the axillary nerve.
- The infraspinatus is identified, dissected off the scapular spine, and retracted inferiorly (TECH FIG 2B).
- Commonly, a small area of vascular fibrous tissue is encountered posterior to the site of the spinoglenoid notch, covering the suprascapular neurovascular structures.
- If a ganglion is present, the contents of the cyst should be removed along with the wall (TECH FIG 2C).
- A spinoglenoid ligament, if present, should be excised.
- Decompression is complete when the SSN can be followed along its entire length from the spinoglenoid notch until it arborizes into its infraspinatus branches (TECH FIG 2D).
- The infraspinatus muscle is allowed to return to its anatomic position.
- The deltoid muscle and fascia is reaproximated with interrupted, absorbable sutures.

**TECH FIG 2** • Schematics and intraoperative photographs showing suprascapular nerve release at the spinoglenoid notch. A. The deltoid muscle is split in line with its fibers, beginning about 4 cm medial to the posterolateral corner of the acromion. B. The spinoglenoid notch has been exposed. The retractors displace the infraspinatus muscles posteriorly and inferiorly. C. A multilobulated ganglion cyst. D. The suprascapular nerve is now visible after the soft tissue band has been divided.
**ARTHROSCOPIC DECOMPRESSION**

**Approach to the Suprascapular Notch**

- Routine glenohumeral arthroscopy is performed to assess concomitant pathology, especially tears of the superior-posterior labrum.
- The subacromial bursa is resected, extending more medially than what is usual for subacromial decompression.
- The bursectomy should allow adequate visualization from the acromioclavicular (AC) joint and coracoid anteriorly to the scapular spine posteriorly.
- The coracoid is palpated with a probe or switching stick, which can also be used to bluntly dissect the surrounding soft tissues to expose the coracoclavicular ligaments.
- Alternatively, the ligaments can be found approximately 15 mm medial to the AC joint and then followed inferiorly to their insertion on the coracoid.
- The conoid ligament attaches to the coracoid just laterally to the suprascapular notch. Fibers of the conoid ligament are in continuity with the transverse scapular ligament.

- The suprascapular notch is typically covered by the supraspinatus muscle and fat, complicating visualization of the neurovascular bundle (TECH FIG 3A).
- An accessory portal is created approximately 2 cm medial to the standard Neviser portal along a line that bisects the angle formed between the clavicle and spine of the scapula. An 18-gauge spinal needle helps with correct positioning of the portal (TECH FIG 3B).
- Use of a switching stick or smooth trocar through this accessory portal allows careful, blunt dissection of the fat to expose the suprascapular vessels coursing over the transverse scapular ligament, which presents as glistening white fibers.
- Once adequate visualization has been achieved, the nerve is protected with a probe or small trocar while the overlying ligament is cut with the arthroscopic scissors as far laterally as possible (TECH FIG 3C–E).
- The SSN is probed to ensure adequate decompression; any residual compression from the bony structures can be removed with the arthroscopic burr.

**TECH FIG 3** • Schematic and arthroscopic images showing arthroscopic suprascapular nerve release at the suprascapular notch. A. After soft tissue removal, the nerve (N) can be visualized underneath the superior transverse scapular ligament (STSL). A blunt trocar is retracting the overlying vessel. B. The arthroscope is positioned in the lateral portal and the instruments are introduced through a superior portal, medial to the standard Neviser portal. C. Arthroscopic scissors positioned to cut the STSL. D, E. The ligament has been released. A, artery. (A, C, E: Courtesy of Dr Laurence Higgins.)
Approach to the Spinoglenoid Notch

- Ganglion cysts associated with labral tears are most commonly located at the spinoglenoid notch. They often extend into the infraspinatus fossa.
- With an intact labrum, the joint capsule above the superior-posterior labrum is incised, beginning posterior to the biceps root and extending posteriorly for 2 to 3 cm.
- After incision of the capsule, the fibrous raphe between the supraspinatus and infraspinatus seen lateral to the spinoglenoid notch provides a useful landmark.
- The spinoglenoid notch can be palpated with an arthroscopic instrument, providing a bony landmark that can be correlated with the cyst position as seen on preoperative MR imaging.

POSTOPERATIVE CARE

- The arm is immobilized in a sling for 2 or 3 days for comfort.
- Pendulum exercises commence on postoperative day 1, and active motion is increased as tolerated.

OUTCOMES

- Nonoperative treatment is successful in 80% of patients without space-occupying lesions.8
- Open decompression with release of the transverse scapular ligament improved pain and weakness in 73% to 87% of patients.4,13

PEARLS AND PITFALLS

Arthroscopic decompression

- Hemostasis and visualization can be improved by increasing the fluid pressure to 50 mm Hg and using an electrothermal device to cauterize bleeders.
- The decompression should be performed before treatment of any concomitant pathology to avoid further complicating this procedure owing to fluid extravasation and swelling.
- A 70-degree scope is sometimes helpful to visualize the notch.
- Visualization should be performed through the lateral portal, with posterior and accessory medial working portals.

COMPLICATIONS

- Damage to the suprascapular nerve and vessels
- Damage to the spinal accessory nerve if mobilization of the trapezius muscle is carried out far medially
- Incomplete decompression, especially in rare cases of compression at both suprascapular and spinoglenoid notch

REFERENCES

PATIENT HISTORY AND PHYSICAL FINDINGS
- Distal humerus fractures occur in two age groups:
  - Younger patients who sustain high-energy trauma
  - Older patients with underlying osteopenia
- Comminution is the dominant feature of supracondylar and intercondylar fractures and complicates internal fixation.
- The goals of the initial evaluation are to:
  - Understand the fracture pattern.
  - Determine the existence of previous symptomatic elbow pathology.
  - Determine the extent of associated soft tissue (open fractures).
  - Identify associated musculoskeletal or neurovascular injuries.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Elbow radiographs in the anteroposterior and lateral planes are the first imaging studies obtained and should be carefully scrutinized to identify the fracture lines and fragments as well as the extent of comminution.
- A complete understanding of the fracture pattern is difficult to obtain based only on simple radiographs because of the complex geometry of the distal humerus and fragment overlapping (FIG 1A,B).
- CT with three-dimensional reconstruction is extremely helpful, especially in the more complex cases. It allows the surgeon to look for specific fractured fragments at the time of fixation, facilitating accurate fracture reduction (FIG 1C,D).
- Traction radiographs obtained in the operating room with the patient under anesthesia just before surgery also can be helpful, especially if a CT scan is not available.

SURGICAL MANAGEMENT
- Internal fixation is the treatment of choice for most fractures of the distal humerus.
- Modern fixation techniques seem to benefit from:
  - Fixation strategies designed to improve the mechanical stability of the construct
  - Use of precontoured periarticular plates
  - Use of screws locked to the plates
- Elbow arthroplasty should be considered in elderly patients with previous elbow pathology or in very low, comminuted fractures in patients with osteopenia.
- The goal of the internal fixation technique is to achieve a construct stable enough to allow immediate unprotected motion without fear of redisplacement. This can be attained in most distal humerus fractures—even the most complex—provided the following principles are adhered to (FIG 2):
  - Plates used for internal fixation are applied so that fixation in the distal fragments is maximized.
  - Distal screw fixation contributes to stability at the supracondylar level, where true interfragmentary compression is achieved.

Approaches
- Adequate exposure is necessary to achieve satisfactory reduction and fixation.
- Subcutaneous transposition of the ulnar nerve is associated with a decreased incidence of postoperative ulnar neuropathy.

FIG 1 • A,B. AP and lateral radiographs showing a comminuted intra-articular supracondylar fracture of the distal humerus. The complexity of the fracture is difficult to appreciate fully because of the geometry of the distal humerus, fracture comminution, and fragment overlapping. C,D. The use of CT with three-dimensional reconstruction and surface rendering helps understand the fracture configuration and anticipate the surgical findings.
Most fractures require mobilization of the extensor mechanism of the elbow through an olecranon osteotomy, triceps reflection, or triceps split.

Simple fractures occasionally may be addressed working on both sides of the triceps without mobilization of the extensor mechanism.

Olecranon osteotomy is the preferred surgical approach for internal fixation for most distal humerus fractures.\(^1\)

**Advantages**
- Provides excellent exposure
- Offers the potential of bone-to-bone healing, thereby limiting the risk of triceps dysfunction
- Complications: nonunion, intra-articular adhesions
- Hardware removal may be needed.
- Limits the ability for intraoperative conversion to elbow arthroplasty
- May devitalize the anconeus muscle
- The proximal ulna cannot be used as a template to judge reduction and motion.

Triceps reflection and triceps split\(^8\) allow preservation of the intact ulna.
- Avoids complications related to olecranon osteotomy
- Facilitates intraoperative conversion to total elbow arthroplasty
- Allows use of the proximal ulna as a template for reduction of the distal humerus articular surface
- Allows assessment of extension deficit after fracture fixation, which is especially useful in fractures requiring metaphyseal shortening
- Bilaterotricipital approach\(^1\)

**Goals and indications**
- The goal is to provide adequate exposure for fracture fixation without violating the extensor mechanism.
- This approach is used only for the more simple fracture patterns (eg, extra-articular or simple intra-articular distal humerus fractures [AO/OTA A, C1, C2]) or when elbow arthroplasty is being considered.

**Advantages**
- This approach avoids complications related to the extensor mechanism.
- No postoperative protection is needed.
- Surgical time is decreased.

**Disadvantage**
- The procedure provides limited exposure of the articular surface.

---

**SURGICAL APPROACH**

**Olecranon Osteotomy**
- Chevron osteotomy provides increased stability (TECH FIG 1A).
- The distal apex of the chevron osteotomy is centered with the bare area of the olecranon articular surface.
- The anconeus is divided with electrocautery in line with the lateral limb of the osteotomy.
  - Alternatively, the anconeus may be preserved by dissecting it free on its distal aspect and reflecting it proximally attached to the proximal ulnar fragment.\(^2\)
- Start the osteotomy with a thin oscillating saw.
- Complete the osteotomy with an osteotome.
  - Decreases risk of damage to the articular cartilage on ulna and humerus
  - Creates irregularities at the opposing cut surfaces, which may increase interdigitation
- Mobilize the fragment to facilitate exposure (TECH FIG 1B).
- Fixation (TECH FIG 1C)

---

**Triceps Reflection and Triceps Split**
- Bryan-Morrey triceps-sparing approach (TECH FIG 2)
  - The triceps is elevated from the medial intermuscular septum.
  - The forearm fascia and periosteum are incised just lateral to the flexor carpi ulnaris.
  - The triceps, forearm fascia, and anconeus are elevated in continuity from medial to lateral.
TECH FIG 1 • Olecranon osteotomy provides an excellent exposure for distal humerus fracture fixation. 
A. A chevron osteotomy is initiated with a microsagittal saw and completed with an osteotome. Drilling and tapping before performing the osteotomy facilitates fixation of the osteotomy if screw fixation is selected. 
B. Proximal mobilization of the osteotomized fragment and triceps allows ample exposure of the articular surface and columns. 
C. Fixation may be performed with a cancellous screw and tension band, wires and a tension band, or a plate.

- The anterior bundle of the medial collateral ligament and the lateral ulnar collateral ligament must be preserved to avoid postoperative instability.
- Mayo-modified extensile Köcher approach
  - The triceps is elevated from the lateral intermuscular septum.
  - The triceps and anconeus are elevated in continuity from lateral to medial.
- As noted earlier, the anterior bundle of the medial collateral ligament and the lateral ulnar collateral ligament must be preserved to avoid postoperative instability.

Bilaterotricipital Approach
- The triceps is elevated from the medial and lateral intermuscular septae.
- Lateral dissection can be extended anterior to the anconeus muscle (TECH FIG 3).
- Arthrotomy is performed posterior to the median collateral ligament and lateral collateral ligament complex.

TECH FIG 2 • The extensor mechanism (ie, triceps, anconeus, and forearm fascia) may be elevated off the ulna subperiosteally in continuity from medial to lateral (Bryan-Morrey approach) or from lateral to medial (Mayo-modified extensile Köcher approach).

TECH FIG 3 • Fractures with no or limited articular involvement may be fixed working on both sides of the triceps. As shown in this image, the extensor mechanism is left mostly undisturbed.
INTERNAL FIXATION

Technical Objectives

- Screws in the distal fragments (articular segment) should be placed according to the following principles:
  - Every screw should pass through a plate.
  - Each screw should engage a fragment on the opposite side that also is fixed to a plate.
  - As many screws as possible should be placed in the distal fragments.
  - Each screw should be as long as possible.
  - Each screw should engage as many articular fragments as possible.
  - The screws should lock together by interdigitation within the distal segment, thereby rigidly linking the medial and lateral columns together, creating an architectural structure similar to that of an arch or dome.

- Plates are used for fixation.
  - Plates should be applied such that compression is achieved at the supracondylar level for both columns.
  - Plates must be strong enough and stiff enough to resist breaking or bending before union occurs at the supracondylar level.

Provisional Assembly of the Articular Surface and Plate Placement

- Reduce the articular surface fragments anatomically.
  - The proximal ulna and radial head may be used as templates.
  - Rotational alignment should be carefully assessed.
  - Use smooth K-wires to maintain the reduction provisionally (TECH FIG 4A).
  - Two 2.0-mm smooth wires introduced at the medial and lateral epicondyles facilitate provisional placement of the plates and can be replaced by screws later.

- Fine-threaded wires or absorbable pins may be used for definitive fixation of small fracture fragments.
- Medial and lateral plates are placed so that one of the distal holes of each plate slides over the medial and lateral 2.0-mm smooth wires introduced at the medial and lateral epicondyles (TECH FIG 4B).
- One cortical screw is loosely introduced into a slotted hole of each plate to hold the plates in place; use of slotted holes for these screws facilitates later adjustments in plate positioning.

Articular and Distal Fixation

- Two or more distal screws are inserted through the plates medially and laterally. As noted, the screws should be as long as possible and engage the opposite column.
  - Before screw application, a large bone clamp is used to compress the articular fracture lines, unless there is comminution of the articular surface.
  - The two 2.0-mm smooth pins may be replaced with distal screws without previous drilling, to avoid accidental breakage of the drill when contacting the other screws. Usually, these last screws will interdigitate with the previously applied distal screws, thereby increasing the stability of the construct (TECH FIG 5).

Supracondylar Compression and Proximal Plate Fixation

- The proximal screw on one side is backed out, and a large bone clamp is applied distally on that side and proximally on the opposite side to apply maximum compression at the supracondylar level. Compression is maintained by application of one proximal screw in the compression mode (TECH FIG 6A,B).
  - The same steps are followed on the opposite side.

---

**TECH FIG 4** • A. Anatomic reduction of the articular surface is maintained provisionally with fine wires placed so that they will not interfere with plate and screw application. B. The medial and lateral plates are held in place provisionally with two distal 2.0-mm pins (which later will be replaced by screws) and two proximal screws through an oval hole to allow small adjustments in plate positioning. (Copyright Mayo.)
Chapter 33  ORIF OF SUPRACONDYLAR AND INTERCONDYLAR FRACTURES

The remaining diaphyseal screws are then introduced, providing additional compression as they push the undercontoured plates to gain intimate contact with the underlying bone (TECH FIG 6C,D).

Small posterior fragments can be fixed with threaded wires or absorbable pins.

Provisional wires are removed.

The elbow is put through range of motion. Motion should be smooth. If extension is limited, the tip of the olecranon may be removed.

**TECH FIG 5**  Maximal distal plate anchorage is then achieved by insertion of multiple long screws through the plates and into the distal fragments. Usually the screws from the medial and lateral directions will engage, creating an interlocked structure that increases fracture stability. (Copyright Mayo.)

**TECH FIG 6**  A,B. Supracondylar compression is achieved with the use of a large clamp, insertion of screws in the compression mode, and slight undercontouring of the plates. The same technique is applied laterally and medially. C. Internal fixation of a complex distal humerus fracture. (A,B: Copyright Mayo.)

**SUPRACONDYLAR SHORTENING**

- In cases with supracondylar comminution (ie, bone loss), compression at the supracondylar level cannot be achieved unless the humerus is shortened into a non-anatomic reduction that will provide adequate bone contact (TECH FIG 7A,B).
- The humerus may be shortened between a few millimeters and 2 cm with only minor losses in extension strength.\(^9\)
- Bone is trimmed from the diaphysis to ensure adequate bone contact with the distal fragments.
- The distal fragments are translated proximally and anteriorly. Anterior translation is necessary to create room for the radial head and the coronoid in flexion.
- The fracture is fixed in the desired position using the technique described previously.
- A new deep and wide olecranon fossa is created by removing bone from the distal and posterior aspect of the diaphysis (TECH FIG 7C). Otherwise, extension will be restricted.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pearls and Pitfalls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olecranon osteotomy</td>
<td>- Position the apex of the osteotomy distally.</td>
</tr>
<tr>
<td></td>
<td>- Use a thin oscillating saw to minimize bone loss.</td>
</tr>
<tr>
<td></td>
<td>- If plate fixation is preferred, consider drilling the holes for the plate before beginning the osteotomy. This facilitates plate fixation of the osteotomy at the conclusion of the surgery.</td>
</tr>
<tr>
<td></td>
<td>- Similarly, if tension band fixation with an intramedullary screw is preferred, predrill the screw hole.</td>
</tr>
<tr>
<td>Triceps reflection and triceps split</td>
<td>- Subperiosteal detachment of the extensor mechanism is critical to preserve its thickness and facilitate a strong reattachment.</td>
</tr>
<tr>
<td></td>
<td>- Reproduce anatomic reattachment of the extensor mechanism.</td>
</tr>
<tr>
<td></td>
<td>- Protect extension against resistance for 6 weeks.</td>
</tr>
<tr>
<td>Bilaterotricipital approach</td>
<td>- Separate the triceps from the underlying medial and lateral joint capsules.</td>
</tr>
<tr>
<td></td>
<td>- Resect the posterior capsule and fat pad to improve visualization.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE MANAGEMENT

- After closure, the elbow is placed in a bulky noncompressive dressing with an anterior plaster splint to maintain the elbow in extension, and the upper extremity is kept elevated.
- Motion is initiated according to the extent of soft tissue damage. Motion usually can be initiated on the first or second postoperative day, but it may be necessary to wait for several days in the case of open fractures or severe soft tissue damage.
- Most patients benefit from a program of continuous passive motion for the first week or two after fixation; some may benefit from a longer period of passive motion.
- When postoperative motion fails to progress as expected, a program of patient-adjusted static flexion and extension splints is implemented.
- Treatment with indomethacin or single-dose radiation to the soft tissues shielding the fracture site may be considered for patients with high risk of heterotopic ossification, such as those with associated head or spinal trauma as well as those who require several surgeries in a short period of time.

OUTCOMES

- The results of internal fixation for fractures of the distal humerus using modern techniques are summarized in Table 1.
- The results of the different studies are difficult to interpret, because the severity of the injuries included cannot be compared, and there may be variations in the accuracy of range-of-motion measurements.
- Improvements in fixation techniques have resulted in a decreased rate of hardware failure and nonunion, but range of motion is not reliably restored in every patient.

COMPLICATIONS

- Infection
- Nonunion
- Stiffness, with or without heterotopic ossification
- Need for removal of the hardware used for fixation of the olecranon osteotomy
- Posttraumatic osteoarthritis or avascular necrosis requiring interposition arthroplasty or elbow replacement
## Table 1

Results of Internal Fixation for Distal Humerus Fractures Affecting the Humeral Columns

<table>
<thead>
<tr>
<th>Study</th>
<th>No.</th>
<th>Mean Age (Range) (y)</th>
<th>Follow-up (mo)</th>
<th>Fracture Type (no.) (AO Classification)</th>
<th>Mean Degrees ROM (range)</th>
<th>Overall results</th>
<th>Complications (no.)</th>
<th>Reoperations (no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jupiter et al5</td>
<td>34</td>
<td>57 (17–79)</td>
<td>70 (25–139)</td>
<td>C1 (13) C2 (2) C3 (19)</td>
<td>14 (41%)</td>
<td>76% achieved at least 30–120</td>
<td>Nonunion (2)</td>
<td>Hardware removal (24)</td>
</tr>
<tr>
<td>Hansley et al4</td>
<td>33</td>
<td>32 (15–61)</td>
<td>18.3</td>
<td>C1 (23) C2 (8) C3 (2)</td>
<td>14 (42%)</td>
<td>Mean extension, 19; mean flexion 126</td>
<td>Refracture (1)</td>
<td>Capsulectomy (3)</td>
</tr>
<tr>
<td>Sanders et al14</td>
<td>17</td>
<td>51 (12–85)</td>
<td>&gt;24</td>
<td>C1 (4) C2 (3) C3 (10)</td>
<td>7 (41%)</td>
<td>108 (55–140)</td>
<td>Nonunion (2)</td>
<td>Repeat ORIF (2)</td>
</tr>
<tr>
<td>McKee et al (closed fractures)7</td>
<td>25</td>
<td>47 (19–85)</td>
<td>37 (18–75)</td>
<td>C (25)</td>
<td>None</td>
<td>108 (55–140)</td>
<td>Nonunion (1)</td>
<td>TBW removal (3)</td>
</tr>
<tr>
<td>McKee et al (open fractures)6</td>
<td>26</td>
<td>44 (17–78)</td>
<td>51 (10–141)</td>
<td>C1 (5) C2 (13) C3 (8)</td>
<td>100%</td>
<td>Mean DASH 23.7 (0–57.5)</td>
<td>Nonunion (1)</td>
<td>Repeat ORIF (1)</td>
</tr>
<tr>
<td>Gofton et al13</td>
<td>23</td>
<td>53 (16–80)</td>
<td>45 (14–89)</td>
<td>C1 (3) C2 (11) C3 (9)</td>
<td>7 (30%)</td>
<td>122 (extension loss 19 ±12, flexion 142 ± 6)</td>
<td>Nonunion (2)</td>
<td>Repeat ORIF (2)</td>
</tr>
<tr>
<td>Sanchez-Sotelo et al11</td>
<td>32</td>
<td>58 (16–99)</td>
<td>24 (12–60)</td>
<td>A3 (3) C2 (4) C3 (25)</td>
<td>13 (44%)</td>
<td>Mean extension: 26 (0–55); Mean flexion: 124 (80–150)</td>
<td>Osteotomy nonunion (1)</td>
<td>Repeat ORIF (3)</td>
</tr>
</tbody>
</table>

Class II HO, heterotopic ossification restricting motion; DASH, Disabilities of the Arm, Shoulder and Hand questionnaire; MEPS, Mayo Elbow Performance Score; ORIF, open reduction and internal fixation; OTA, Orthopedic Trauma Association rating; ROM, range of motion; TBW, tension band wiring.

* According to the Jupiter rating system.
REFERENCES

DEFINITION
- Capitellar fractures are uncommon, accounting for less than 1% of all elbow fractures and 6% of all distal humerus fractures.  
- They often are associated with radial head fractures and posterior elbow dislocations.
- A classification system for capitellar fractures has been proposed by Bryan and Morrey and modified by McKee:  
  - Type 1: complete fractures of the capitellum  
  - Type 2: superficial subchondral fractures of the capitellar articular surface  
  - Type 3: comminuted fractures  
  - Type 4: coronal shear fractures that include a portion of the trochlea as well as the capitellum as one piece (FIG 1)  
- Ring and Jupiter have proposed a new classification, expanding on the growing understanding that isolated capitellum fractures are rare and often are involved as part of articular shear fractures of the distal humerus. The classification includes five anatomic components:  
  - The capitellum and lateral aspect of the trochlea  
  - The lateral epicondyle  
  - The posterior aspect of the lateral column  
  - The posterior aspect of the trochlea  
  - The medial epicondyle

ANATOMY
- The two condyles of the distal humerus diverge from the humeral shaft to form the lateral and medial columns, which support the trochlea between them. The anterior aspect of the lateral column is covered with articular cartilage, forming the capitellum. Distally, these two condyles can be visualized as forming a triangle at the end of the humerus.
- The capitellum is the first epiphyseal center of the elbow to ossify.
- It is covered by articular surface anteriorly but devoid of it posteriorly.
- The capitellum is directed distally and anteriorly at an angle of 30 degrees to the long axis of the humerus.
- The radial head rotates on the anterior surface of the capitellum in elbow flexion and articulates with its inferior surface in elbow extension.
- The lateral collateral ligament inserts next to the lateral margin of the capitellum.
- The blood supply of the capitellum is derived posteriorly. It arises from the lateral arcade, which is the anastomosis of the radial collateral arteries of the profunda brachii and the radial recurrent artery.

PATHOGENESIS
- Capitellar fractures usually result from a fall on an outstretched hand or forearm as the radial head impacts the capitellum on impact.
- Capitellar–trochlear shear fractures involve impaction of the radial head against the lateral column of the distal humerus in a semi-extended position, resulting in a shearing mechanism of the distal humerus.
- Fracture fragments vary in size and displace superiorly and anteriorly into the radial fossa, resulting in impingement with elbow flexion.

NATURAL HISTORY
- Capitellar fractures occur almost exclusively in adults. These fractures do not occur in children, because in that age group the capitellum is largely cartilaginous, and a similar mechanism of injury would instead cause a supracondylar or lateral condyle fracture.
- Capitellar fractures are more common in females, a finding that has been attributed to the higher carrying angle of the elbow.
- Elderly patients of both genders are more susceptible to capitellum and complex capitellar–trochlear shear fractures because of the metabolic susceptibilities of osteoporosis.
- Displaced fractures that go untreated can have a poor outcome owing to progressive loss of motion and posttraumatic arthrosis.
PATIENT HISTORY AND PHYSICAL FINDINGS
- Symptoms of capitellar fractures are similar to those of radial head fractures, including pain and swelling along the lateral elbow and pain with elbow motion.
- Although there may be variable loss of forearm rotation, loss of flexion and extension is common, often accompanied by crepitus and pain.
- The association of concomitant radial head fractures and ligamentous injuries with capitellar fractures is high. 18
- The shoulder and wrist should be examined for concomitant injury.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standard radiography is inadequate for accurate assessment of capitellar fractures.
- Lateral radiographs are best for obtaining an initial evaluation of capitellar fractures.
- Anteroposterior views do not reliably show the fracture, because the outline of the distal humerus is not consistently affected.
- The radial head–capitellum view can help identify fractures of the capitellum. This view is a lateral oblique projection taken with the x-ray beam pointing 45 degrees dorsoventrally, thereby eliminating the ulno- and radiohumeral articulation shadows.10
  - A type 1 fracture appears as a semilunar fragment sitting superiorly with its articular surface pointing up and away from the radial head in most cases.
  - Type 2 fractures are more difficult to diagnose, depending on the amount of subchondral bone accompanying the articular fragment. They may appear as a loose body lying in the superior part of the joint.
  - Type 3 fractures display variable amounts of comminution.
  - Coronal shear fractures show a characteristic “double arc” sign on lateral radiographic views (FIG 2A).
- CT scans are necessary for delineating the fracture pattern and should be performed in all cases.
  - CT scanning of the elbow should be done at 1- to 2-mm intervals using axial or transverse cuts.
  - Three-dimensional (3D) CT reconstructions provide the best detail and ability to appreciate the anatomic orientation of the fracture patterns and should be ordered if 3D imaging is available (FIG 2B,C).

DIFFERENTIAL DIAGNOSIS
- Radial head fracture
- Distal humeral lateral condyle fracture
- Elbow dislocation

NONOPERATIVE MANAGEMENT
- Truly nondisplaced and isolated capitellum fractures can be splinted for 3 weeks, followed by protected motion. We do not advocate nonoperative management for any other type of capitellum fracture.
- Closed reduction techniques, which have been described in the literature, should be performed with caution, and only complete anatomic reduction should be accepted.4,19
- Capitellar–trochlear shear fractures should not be treated nonoperatively because of their inherent instability and articular incongruity.

SURGICAL MANAGEMENT
- The goal of surgery is anatomic reduction and fixation of the fracture to allow for early motion without mechanical block.
  - Long-term goals are pain-free and maximal motion with minimal stiffness.
- Capitellar fractures are uncommon, and the wide array of treatment options presented in the literature is based on relatively small series.
- Treatment options include closed reduction,4,19 open excision,1,8,16 open reduction and internal fixation (ORIF), and arthroplasty.5,9
- With the improvement in techniques for fixation of small fragments and management of articular surfaces, ORIF has become the mainstay of treatment.
  - Advantages of ORIF include restoration of anatomy and stability.
  - Disadvantages include stiffness and failed fixation.
- In elderly patients, we do consider total elbow arthroplasty for complex intra-articular distal humerus fractures.
  - Advantages include early return to function and motion.
  - Disadvantages include functional limitations.

Preoperative Planning
- Before proceeding with surgery, a thorough understanding of the fracture and its orientation should be obtained with the help of a CT scan, and, if possible, 3D reconstructions.

FIG 2 • A. Characteristic “double arc” sign on lateral radiographs of coronal shear fractures. B,C. 3D CT reconstructions of a coronal shear fracture of the distal humerus.
The timing of surgery is important. Fractures preferably should be approached within 2 weeks, before osseous healing sets in, but after swelling has gone down. Ensure that the necessary implants and hardware are available. Reduction and fixation of the fracture will require K-wires, articular or headless screws, and small-fragment AO screws. An image intensifier should be used during surgery to confirm reduction of the fracture and proper positioning of implanted hardware.

**Positioning**

- General anesthesia is recommended.
- The patient usually is positioned supine on the operating table, with a radiolucent hand table.
- Alternatively, a lateral or prone position can be considered, with the anterior surface of the elbow supported by a padded bolster to use the universal posterior approach.

**CAPITELLAR FRACTURES**

**Exposure**

- The incision should begin 2 cm proximal to the lateral epicondyle and extend 3 to 4 cm distal toward the radial neck.
- If no large soft tissue or capsular defect is present, a direct lateral Köcher approach between the anconeus and ECU interval is recommended.
- The common extensor origin is sharply raised off the lateral epicondyle and reflected anteriorly to expose the lateral elbow joint.
  - Care must be taken to avoid damage to the radial nerve traveling between the brachialis and brachioradialis.
- Often the lateral ligamentous complex will be avulsed from the distal aspect of the humerus, with or without some aspect of the lateral epicondyle.
  - This ligamentous violation can be exploited to improve exposure by hinging open the joint on the medial collateral ligament with a varus stress.

- The capitellar fracture usually is displaced proximally and rotated and has no soft tissue attachments.

**Reduction and Fixation**

- The fragment is reduced under direct visualization, held with reduction tenaculums, and provisionally fixed with 0.045-inch K-wires from an anterior-to-posterior direction.
- Internal fixation options include fixation from posterior to anterior with AO cancellous screws or from either direction with headless compression screws.
- Cancellous screws are best for fracture fragments with a large subchondral component, as in type 1 fracture fragments. However, extending the dissection posteriorly around the lateral column theoretically increases the risk of osteonecrosis (TECH FIG 1).
- Headless compression screws, such as the Herbert screw, are best for fragments with less subchondral

**Approach**

- Either a lateral or posterior midline incision should be used, depending on the nature of the fracture, followed by a lateral approach into the elbow joint.
- Multiple intervals that can be exploited in the lateral approach to the elbow.
  - We advocate the Köcher approach, which uses the interval between the extensor carpi ulnaris and the anconeus and affords greater protection of the posterior interosseous nerve.
  - To increase exposure, the origin of the extensor carpi ulnaris (ECU), extensor digitorum communis, and extensor carpi radialis longus can be raised off of the lateral epicondyle anterior to its interval with the triceps.
- In many cases, a capsular violation has occurred. This can be exploited and used as the interval to expose the fracture, thereby avoiding the need to cause an additional soft tissue defect.

**TECH FIG 1** Fixation of a type 1 capitellum fracture with a headless screw anteriorly and AO screws from posterior to anterior.
bone, such as type 2 and small type 1 fracture fragments. The head of the screw must be buried below the articular surface.

- Excision of fracture fragments is recommended in type 2 fractures with small, thin articular pieces and type 3 comminuted fractures where the fragments are not amenable to internal fixation.
- Fragment reduction and hardware position should be confirmed by image intensifier.

- Unrestricted forearm rotation and elbow flexion-extension without mechanical block or catching should be confirmed intraoperatively.
- If the lateral collateral ligament is found to be avulsed, it should be repaired back to the lateral epicondyle with drill holes and nonabsorbable no. 2 suture or suture anchors.
- The capsule should be closed.
- The retracted extensor origin should be relaxed and closed to the surrounding soft tissue.

**CAPITELLAR-TROCHLEAR SHEAR FRACTURES**

**Exposure**

- A posterior midline incision should be made, and full-thickness flaps should be raised medially and laterally off of the extensor mechanism.
  - This incision provides extensile exposure, access to both sides, and ease of osteotomy if necessary (TECH FIG 2A).
- Beginning medially, the ulnar nerve should be decompressed in situ behind the medial epicondyle (TECH FIG 2B).
- Returning laterally, the interval between the anconeus and the ECU should be developed. In many cases, a capsular violation can be exploited (TECH FIG 2C).
- The common extensor origin, including the ECU, extensor digitorum communis, and extensor carpi radialis longus, is then sharply raised off the lateral epicondyle and reflected anteriorly to expose the lateral elbow joint and improve visualization medially.

- Care must be taken to avoid injury to the radial nerve proximally as it travels between the brachialis and brachioradialis, and to the posterior interosseous nerve distally when raising the ECU anteriorly. This may be done by keeping the forearm pronated.
- In many cases, the lateral epicondyle will have avulsed off of the distal humerus, and this traumatic osteotomy can be exploited.
- Otherwise, a formal lateral epicondyle osteotomy can be performed to enhance visualization while maintaining the integrity of the lateral ligamentous complex.
- Additionally, an olecranon osteotomy may be performed to improve visualization and fixation of fractures extending medially and posteriorly.
- The fracture fragments should now be visualized and accounted for. They are most commonly displaced proximally and internally rotated (TECH FIG 2D).

**TECH FIG 2** • A. Posterior midline incision used to for capitellar-trochlear shear fractures. B. Ulnar nerve compression medially. C. Lateral approach to elbow taking advantage of violation of the capsule and extensor muscles at the level of the extensor carpi ulnaris (ECU) and anconeus. D. The fracture fragments tend to displace proximally and become internally rotated.
**Reduction and Fixation**

- The fragment is reduced under direct visualization, held with reduction tenaculums, and provisionally fixed with 0.045-inch K-wires from anterior to posterior (TECH FIG 3A).
- Inability to reduce the fracture anatomically may represent fracture impaction, requiring either disimpaction or bone grafting, or both.
- Options for internal fixation include fixation from posterior-to-anterior with AO screws or from either direction with headless compression screws.
- Cancellous screws are best when the fracture fragment has a large subchondral component, but they make it necessary to extend the dissection posteriorly around the lateral column, theoretically increasing the risk of osteonecrosis.

- Headless compression screws, such as the Herbert screw, are best for fragments with less subchondral bone and provide the added benefit that they can be used in either direction, anteriorly or posteriorly. Diligence must be maintained to confirm that the head of the screw is buried below the articular surface when placed anteriorly.
- Fragment reduction and hardware position should be confirmed by image intensifier.
- Unrestricted forearm rotation and elbow flexion–extension without mechanical block or catching should be confirmed intraoperatively.
- The lateral epicondyle, if avulsed or osteotomized, should be repaired with a tension band technique or plate and screws (TECH FIG 3A,B).
- The capsule should be closed.
- The interval and released extensor origin should be relaxed and closed to the surrounding soft tissue.

**PEARCALS AND PITFALLS**

<table>
<thead>
<tr>
<th>Category</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnosis</td>
<td>Diligence should be paid to identifying concomitant injuries such as dislocations, radial head fractures, and ligamentous instability.</td>
</tr>
<tr>
<td>Imaging</td>
<td>Plain radiographs are insufficient, and a CT scan should be performed routinely.</td>
</tr>
<tr>
<td></td>
<td>Order 3D reconstructions if possible.</td>
</tr>
<tr>
<td>Nonoperative management</td>
<td>Nonoperative management should be chosen cautiously. Anatomic and stable reduction of the fracture is necessary. Otherwise, a painful elbow with restricted motion may result. We do not recommend nonoperative management of any capitellar–trochlear shear fractures.</td>
</tr>
<tr>
<td>Surgical management</td>
<td>A straight posterior skin incision will allow ulnar nerve decompression and fracture fixation.</td>
</tr>
<tr>
<td></td>
<td>Lateral epicondyle osteotomy can enhance exposure.</td>
</tr>
<tr>
<td></td>
<td>Inability to reduce the fracture anatomically may represent impaction of the lateral column and require disimpaction or bone grafting.</td>
</tr>
<tr>
<td></td>
<td>Excision of comminuted fragments that cannot be fixed internally is preferred over nonanatomic reduction and malunion.</td>
</tr>
<tr>
<td></td>
<td>Concomitant fractures and ligamentous injuries should be treated simultaneously to optimize outcomes.</td>
</tr>
<tr>
<td>Postoperative management</td>
<td>Stable fixation should be sought to allow for early motion.</td>
</tr>
<tr>
<td></td>
<td>Heterotopic ossification is common after elbow fractures, and prophylaxis with nonsteroidal anti-inflammatory drugs should be considered.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- If secure fixation has been obtained, immediate mobilization can be initiated postoperatively.
- If fixation is tenuous, splint or cast the elbow for 3 to 4 weeks, followed by active and assisted range-of-motion exercises.

OUTCOMES

- Focusing initially on outcomes after ORIF of types 1 and 2 capitellar fractures, multiple small series have shown good results using Herbert screws in an anterior to posterior direction.6,13,14,20
- More recently, Mahirogullari et al15 reported on 11 cases of type 1 capitellum fractures treated with Herbert screws, which yielded 8 excellent and 3 good results. They recommended fixation in a posterior-to-anterior direction with at least two Herbert screws.
- Reported outcomes on type 4 capitellar–trochlear shear fractures are limited. McKee et al17 originally described this pattern and reported on 6 cases.
  - Each case involved an extended lateral Köcher approach and fixation with Herbert screws from an anterior to posterior direction. Good or excellent results were achieved in all cases, with average elbow motion of 15 to 141 degrees, and forearm rotation of 83 degrees pronation and 84 degrees supination.
- Ring and Jupiter examined 21 cases of articular fractures of the distal humerus treated with Herbert screw fixation and found 4 excellent results, 12 good results, and 5 fair results.
  - All of the fractures healed and had an average range of motion of 96 degrees. No ulnohumeral instability, arthrosis, or osteonecrosis was reported.
  - The authors stressed the importance of proper evaluation of these fractures and awareness that apparent capitellum fractures often are complex articular fractures of the distal humerus.21
- Dubberley et al7 further subclassified type 4 fractures in their series of 28 cases. They achieved an average range of motion of flexion-extension of 25 degrees less than the contralateral elbow and 4 degrees of supination-pronation less than the contralateral elbow.
  - Two comminuted cases required conversion to a total elbow arthroplasty.
  - Varied fixation methods were used, including Herbert screws, cancellous screws, absorbable pins, and supplementation with K-wires.

COMPLICATIONS

- The most common complication of capitellar fractures is loss of elbow motion and residual pain. The compromised motion most commonly is manifested in loss of flexion and extension.
- Ulnar neuropathy has been noted after ORIF, and some recommend routine ulnar nerve decompression.21
- Osteonecrosis may occur from the initial fracture displacement or surgical exposure. Blood is supplied to the capitellum from a posterior to anterior direction and may be compromised by surgical dissection.
  - In symptomatic cases in which revascularization after fixation has not occurred, delayed excision is indicated.
- Malunions may occur when the patient has delayed seeking treatment, when inadequate reduction or loss of closed reduction occurs, or after ORIF. Malunions result in loss of motion and may require excision of the fragment and soft tissue releases.
- Nonunions may occur, although this is uncommon. They most likely result secondary to inadequate reduction or lack of revascularization of the fragment.

REFERENCES

DEFINITION
• The radial head is distinctive in anatomy and function with unique considerations regarding the diagnostic and treatment options available to the surgeon.
• Radial head and neck fractures are the most common elbow fractures in adults, representing 33% of elbow fractures.
• The original Mason classification was modified by Johnson, then Morrey. Hotchkiss proposed that the classification system be used to provide guidance for treatment. It has poor intraobserver and interobserver reliability (FIG 1).9
  • Type I fractures are nondisplaced and offer no block to pronation and supination on examination.
  • Type II fractures have displaced marginal segments that block normal forearm rotation. We only include fractures with three or fewer articular fragments, which meet criteria for fractures that can be operatively reduced and fixed with reproducibly good results.
  • Type III fractures are comminuted or impacted articular fractures that are optimally managed with prosthetic replacement.
  • Type IV fractures are associated with elbow instability and should never be resected in the acute setting.

ANATOMY
• The radial head is entirely intra-articular. It has two articulations, one with the humerus, via the radiocapitellar joint, and another with the ulna, via the proximal radioulnar joint (PRUJ).
  • The radiocapitellar joint has a saddle-shaped articulation allowing both flexion and extension as well as rotation.
  • The PRUJ, constrained by the annular ligament, allows rotation of the radial head in the lesser sigmoid notch of the proximal ulna.
  • To avoid creating a mechanical block to pronation and supination, implants must be limited to a 90-degree arc (the “safe zone”) outside the PRUJ (FIG 2).4
• Blood supply to the radial head is tenuous, with a major contribution from a single branch of the radial recurrent artery in the safe zone and minor contributions from both the radial and interosseous recurrent arteries, which penetrate the capsule at its insertion into the neck (FIG 3).13
• There is considerable variability in the shape of the radial head, from nearly round to elliptical, as well as variability in the offset of the head from the neck.
• The anterior band of the medial collateral ligament (MCL) is the primary stabilizer to valgus stress. The radial head, a secondary stabilizer, maintains up to 30% of valgus resistance in the native elbow. Therefore, in cases where the MCL is ruptured:
  • A radial head that is not reparable should be replaced with a prosthesis and not excised given its biomechanical importance.
  • It may be prudent to protect a repaired radial head from high valgus stress during early range of motion by placing a hinged external fixator.
• The radial head also functions in the transmission of axial load, transmitting 60% of the load from the wrist to the elbow.10 This is a crucial consideration when the interosseous membrane is disrupted in the Essex-Lopresti lesion.5 Resection of the radial head in this setting results in devastating longitudinal radioulnar instability, proximal migration of the radius, and possible ulnar-carpal impingement.

PATHOGENESIS
• Radial head fractures result from trauma. A fall on an outstretched hand with the elbow in extension and the forearm in pronation produces an axial or valgus load (or both) driving the radial head into the capitellum, fracturing the relatively osteopenic radial head.
  • Loading at 0 to 35 degrees of extension causes coronoid fractures.
  • Loading at 0 to 80 degrees of extension produces radial head fractures.
Associated soft tissue injuries can lead to considerable complications, including pain, arthrosis, stiffness, and disability:
- MCL injury in 50%
- Lateral ligament disruption in about 80%
- Capitellar bone bruises in 90%
- Capitellar cartilage defects in about 50%

The axial loading may also rupture the interosseous membrane, causing longitudinal radioulnar instability with dislocation of the distal radioulnar joint (DRUJ) (FIG 4).

The “terrible triad” injury results from valgus loading of the elbow, disrupting the MCL or lateral ulnar collateral ligament and fracturing the radial head and coronoid process.

**NATURAL HISTORY**

Results are mixed regarding the efficacy of radial head excision for treatment of radial head fracture. Good or fair results may be possible, with a few caveats:

**FIG 2** The “safe zone” is a roughly 90-degree arc of the radial head that does not articulate with the ulna in the proximal radioulnar joint with full supination and pronation. With the wrist in neutral rotation, the safe zone is anterolateral.
There is a demonstrable increase in ulnar variance at the wrist and increased carrying angle.

10% to 20% loss of strength is expected.

It is contraindicated in the face of associated soft tissue injuries.

Radiographic, but usually clinically silent, degenerative changes such as cysts, sclerosis, and osteophytes occur radiographically in about 75% of elbows after radial head excision (FIG 5).

Results of excision are poor in patients with concomitant MCL, coronoid, or interosseous membrane injury.

Radial head resection should be reserved for patients with low functional demands or limited life expectancy, and when the surgeon has excluded elbow instability with a fluoroscopic examination.

Delayed excision of the radial head after failed nonoperative management may be considered with modest increase in function; it has shown 23% fair or poor results at 15 years of follow-up. Other studies suggest that there is no difference between delayed and primary excision.

Although open reduction and fixation of a comminuted fracture can be attempted, a large series by experienced elbow surgeons found that fixation of a radial head with more than three articular fragments is fraught with poor results.

Nonanatomic reduction of the shaft or joint may result in limited range of motion due to a cam effect in the PRUJ, but no literature or prospective studies indicate what parameters are “acceptable.”

PATIENT HISTORY AND PHYSICAL FINDINGS

The history typically involves a fall on an outstretched hand followed by pain and edema over the lateral elbow, accompanied by limited range of motion.

The examiner should note the patient’s activity level and profession.

Physical examination should include neurovascular status and examination of the skin to look for medial ecchymosis, which may suggest injury to the MCL.

A detailed examination of the elbow must include bony palpation of the medial and lateral epicondyles, olecranon process, DRUJ, and radial head, as well as the squeeze test of the interosseous membrane and DRUJ to screen for potential longitudinal instability.

Varus and valgus stress testing, with or without fluoroscopy, can indicate injury to the anterior band of the MCL or to the lateral ulnar collateral ligament, respectively.

Range-of-motion and stress examinations are vital to proper decision making and may obviate the need for advanced imaging if performed correctly with adequate anesthesia. If omitted, this will lead to undiagnosed associated injuries and may result in flawed decision making.

In the emergency department or office, adequate anesthesia may be obtained by aspirating hematoma, then injecting the elbow joint with 5 mL of local anesthetic and examining the elbow under fluoroscopy. This may be performed by the traditional lateral injection in the “soft spot” or posteriorly into the olecranon fossa (FIG 6).

If operative intervention is clearly indicated, this examination can be performed under a general anesthetic, provided the surgeon and patient are prepared for a change in operative plan as dictated by the examination.

Normal values are 0 to 145 degrees of flexion–extension, 85 degrees of supination, and 80 degrees of pronation. The examiner should check for a bony block to motion.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Radiography

Anteroposterior (AP), lateral, and oblique views are the standard of care, but they underestimate or overestimate joint impaction and degree of comminution (FIG 7A, B).

A radiocapitellar view with forearm in neutral and at 45 degrees cephalad gives an improved view of the articular surfaces.
If the examination reveals wrist or forearm tenderness, the examiner should have a low threshold for obtaining bilateral wrist posteroanterior (PA) views to rule out an Essex-Lopresti lesion.

**Magnetic Resonance Imaging**

- Magnetic resonance imaging (MRI) is a useful adjunct to physical examination for evaluating associated injuries such as collateral ligament tears, chondral defects, and loose bodies, but it is not routinely indicated (FIG 7C).

**DIFFERENTIAL DIAGNOSIS**

- Simple elbow dislocation
- Distal humerus fracture
- Olecranon fracture
- Septic elbow

**NONOPERATIVE MANAGEMENT**

- The standard protocol for treating radial head fractures is shown in FIGURE 8.

![FIG 7 • A,B. AP and lateral radiographs reveal a type 2 displaced radial head fracture. With standard radiography it is difficult to judge comminution and associated injuries. C. A T2-weighted MR image demonstrating a bony medial collateral ligament avulsion with surrounding edema associated with a radial head fracture. The ligament can be seen inserting distally to the sublime tubercle.](image)

![FIG 8 • Treatment algorithm for radial head fractures.](image)
Conservative management, with a week of sling immobilization followed by range of motion once the acute pain resolves, is the treatment of choice in nondisplaced radial head fractures, where universally good and excellent results have been reported.

Nonoperative management is also the treatment of choice in fractures with less than 2 mm of displacement, with minor head involvement, and without bony blockage to range of motion.

A 7-day period of cast or splint immobilization is followed by aggressive motion after the inflammatory phase.

Our current practice for fractures that are more than 2 mm displaced is to determine whether there is a blockage of motion on fluoroscopic examination.

If there is maintenance of at least 50 degrees of both pronation and supination, we recommend conservative treatment.

If there is a blockage or instability, excision, fixation, or arthroplasty is recommended based on patient factors and instability.

A recent report regarding the long-term results of nonoperative management (similar to that described) of 49 patients with radial head fractures encompassing over 30% of the joint surface and displaced 2 to 5 mm revealed that 81% of patients had no subjective complaints and minimal loss of motion versus the uninjured extremity. Only one patient had daily pain.1

**SURGICAL MANAGEMENT**

**Preoperative Planning**

- It is essential to review all radiographs and, most importantly, perform thorough history, physical, and fluoroscopic examinations before making an incision.
- The presence of instability or associated fractures warrants a more extensile approach (FIG 9).

**Positioning**

- Positioning depends on the planned approach and the surgeon’s preference.
- We prefer the patient supine with the affected extremity brought across the chest over a bump to allow access to the posterolateral elbow.
- A tourniquet is placed high on the arm.

**Approach**

- Two approaches, the extensile posterior (Boyd) and posterolateral (Köcher), will be presented (FIG 10).
- The extensile posterior (Boyd) approach2 with an interval between the ulna and anconeus allows for excellent visualization compared to traditional approaches. This versatile approach facilitates ORIF or arthroplasty of the radial head if the fracture proves to be more comminuted than preoperative imaging would predict. It can be easily accessed through a universal extensile incision that allows the surgeon to address ligamentous injuries in addition to the radial head fracture.

**BOYD APPROACH**

- An 8-cm straight longitudinal incision is made just lateral to the olecranon (TECH FIG 1A).
- Full-thickness skin flaps are developed bluntly over the fascia.
- The fascia is longitudinally incised in the interval between the anconeus and ulna (TECH FIG 1B).
- The anconeus is dissected off the ulna, elevating proximal to distal to preserve the distal vascular pedicle. Great care is taken not to violate the joint capsule or lateral ulnar collateral ligament by using blunt fashion (TECH FIG 1C).
- The lateral ulnar collateral ligament and annular ligament complex are sharply divided and tagged from their insertion on the crista supinatoris of the ulna. The radial head and its articulation with the capitellum are now evident (TECH FIG 1D).
- After repair or replacement, the ligaments are repaired to their insertion with suture anchors.
**KÖCHER APPROACH**

- The traditional posterolateral (Köcher) approach between the anconeus and extensor carpi ulnaris is cosmetic and spares the lateral ulnar collateral ligament.
- We recommend not using an Esmarch tourniquet to allow visualization of penetrating veins that help identify the interval.
- A 5-cm oblique incision is made from the posterolateral aspect of the lateral epicondyle obliquely to a point three fingerbreadths below the tip of the olecranon in line with the radial neck (TECH FIG 2A).
- The radial head and epicondyle are palpated and the fascia is divided in line with the skin incision.
- The Köcher interval is identified distally by small penetrating veins and bluntly developed, revealing the lateral ligament complex and joint capsule (TECH FIG 2B).
- The anconeus is reflected posteriorly and the extensor carpi ulnaris origin anteriorly. The capsule is incised obliquely anterior to the lateral ulnar collateral ligament (TECH FIG 2C,D).
- The proximal edge of the annular ligament may also be divided and tagged, with care taken not to proceed distally and damage the posterior interosseous nerve.

**TECH FIG 1** • Boyd approach. **A.** Make an 8-cm longitudinal incision at the junction of the ulna and anconeus starting about four fingerbreadths distal to the olecranon and extending 2 cm proximal to the olecranon. **B.** The interval between the ulna and anconeus is incised sharply, with care taken not to violate the periosteum or muscle to minimize the risk of proximal radioulnar synostosis. **C.** Blunt elevation of the anconeus is crucial to avoid damaging the capsule or lateral ligament complex. **D.** The capsule and lateral ligament complex are tagged during the approach to facilitate final repair with suture anchors.

**TECH FIG 2** • Köcher approach. **A.** The skin incision proceeds distally from the posterolateral aspect of the lateral epicondyle to the posterior aspect of the proximal radius. **B.** Full-thickness flaps are made and the fascial interval between the extensor carpi ulnaris and anconeus muscles is identified. (continued)
FRACTURE INSPECTION AND PREPARATION

- The fracture is now visible (TECH FIG 3).
- The wound is irrigated and loose bodies are removed.
- The forearm is rotated to obtain a circumferential view of the fracture and appreciate the safe zone for hardware placement.
- If comminution (more than three pieces) is evident at this step, we elect to replace the radial head.

TECH FIG 3 • Here the fractured radial head fragment has violated the lateral capsule, indicating a high-energy injury. The proximal radius is now exposed for fixation or prosthetic replacement.

REDUCTION AND PROVISIONAL FIXATION

- Any joint impaction is elevated and the void filed with local cancellous graft from the lateral epicondyle.
- The fragments are reduced provisionally with a tenaculum and held with small Kirschner wires placed out of the zone where definitive fixation is planned.
- It is acceptable to place this temporary fixation in the safe zone (TECH FIG 4).

TECH FIG 4 • We prefer to use 0.062-inch Kirschner wires placed outside the zone of planned definitive fixation to provisionally hold the reduction.
POSTOPERATIVE CARE

- The elbow is immobilized in a splint for 7 to 10 days.
- Active range of motion is allowed as soon as tolerable. Supervised therapy may be considered if the patient is not making adequate progress.
- Associated injuries may call for more protected range of motion.
- Light activities of daily living are allowed at 2 weeks, with increased weight bearing at 6 weeks.

RESULTS

- The results of open reduction and internal fixation depend both on host factors such as the type of fracture, smoking, compliance, demand, as well as surgical and rehabilitation protocols.
- In uncomplicated fractures, over 90% satisfactory results can be expected.
- Complications and resultant secondary procedures will be more likely in cases with undiagnosed instability and associated injury.
COMPLICATIONS

- Stiffness is the most common complication, with loss of terminal extension, supination, and pronation being most evident.
- Arthritis of the radiocapitellar joint or proximal radioulnar joint
- Heterotopic ossification
- Symptomatic hardware may require secondary removal (FIG 11A).
- Infection
- Early and late instability from missed or failed treatment of associated injuries
- The rate of avascular necrosis is about 10%, significantly higher in displaced fractures. This is expected given that the radial recurrent artery inserts in the safe zone where hardware is placed. This is generally clinically silent.
- Loss of reduction
- Nonunion (FIG 11B,C)

REFERENCES

DEFINITION
- Radial head fractures are the most common fracture of the elbow and usually can be managed either nonoperatively or with open reduction and internal fixation.
- Radial head arthroplasty is indicated for unreconstructable displaced radial head fractures with an associated elbow dislocation or a known or possible disruption of the medial collateral, lateral collateral, or interosseous ligaments.  
- Most comminuted radial head fractures have an associated ligament injury, so radial head excision without replacement is uncommonly indicated in the setting of an acute radial head fracture.
- Biomechanical studies have shown that the kinematics and stability of the elbow are altered by radial head excision, even in the setting of intact collateral ligaments, and are improved with a metallic radial head arthroplasty.
- Radial head replacement is also indicated to treat posttraumatic conditions such as radial head nonunion and malunion and to manage elbow or forearm instability after radial head excision.

ANATOMY
- The radial head has a circular concave dish that articulates with the spherical capitellum and an articular margin that articulates with the lesser sigmoid notch of the ulna.
- The articular dish has an elliptical shape that varies considerably in size and shape and is variably offset from the axis of the radial neck.
- There is a poor correlation between the size of the radial head and the medullary canal of the radial neck, making a modular implant desirable for an optimal fit.
- Elbow stability is maintained by joint congruity, capsuloligamentous integrity, and an intact balanced musculature.
- The radial head is an important valgus stabilizer of the elbow, particularly in the setting of an incompetent medial collateral ligament, which is the primary stabilizer against valgus force.
- The radial head is also important as an axial stabilizer of the forearm and resists varus and posterolateral rotatory instability by tensioning the lateral collateral ligament.
- The radial head accounts for up to 60% of the load transfer across the elbow.
- The lateral ulnar collateral ligament is an important stabilizer against varus and posterolateral rotational instability of the elbow and should be preserved or repaired after radial head arthroplasty (FIG 1).

PATHOGENESIS
- Displaced radial head fractures typically result from a fall on the outstretched arm.
- Axial, valgus, and posterolateral rotational patterns of loading are all thought to be potentially responsible for these fractures.
- Injuries of the medial collateral or lateral collateral ligament or the interosseous ligament are typically associated with comminuted displaced unreconstructable radial head fractures.
- In more severe injuries, dislocations of the elbow and forearm and fractures of the coronoid, olecranon, and capitellum can occur and further impair stability.

NATURAL HISTORY
- Long-term follow-up studies suggest a high incidence of radiographic arthritis with radial head excision, although the incidence of symptomatic arthritis varies widely between series.
- Biomechanical data have demonstrated an alteration in the kinematics, load transfer, and stability of the elbow after radial head excision that may lead to premature cartilage wear of the ulnohumeral joint and secondary pain due to arthritis.
- Metallic radial head replacement in elbows with intact ligaments restores the kinematics and stability similar to that of a native radial head and has been shown to provide good clinical and radiographic outcome in most patients at medium-term follow-up; however, long-term outcome studies are lacking.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The mechanism of injury is typically a fall on the outstretched hand.
- The patient will complain of pain and limitation of elbow or forearm motion.

FIG 1 • The ligaments on the lateral aspect of the elbow include the lateral ulnar collateral ligament, the radial collateral ligament, and the annular ligament. The lateral ulnar collateral ligament is an important stabilizer against varus and posterolateral rotational instability of the elbow and should be preserved or repaired after radial head arthroplasty.
■ A history of forearm or wrist pain should be sought.
■ Inspection may reveal ecchymosis along the forearm or medial aspect of the elbow. Deformity may be evident if there is an associated dislocation.
■ Careful palpation of the radial head, the medial and lateral collateral ligaments of the elbow, the interosseous ligament of the forearm, and the distal radioulnar joint should be performed. Local tenderness over one or all of these structures implies a possible derangement of the relevant structure.
■ Since associated injuries of the shoulder, forearm, wrist, and hand are common, these areas should be carefully examined.
■ Range of motion, including forearm rotation and elbow flexion-extension, should be evaluated. The presence of palpable and auditory crepitus should be noted.
■ Loss of terminal elbow flexion and extension is expected as a consequence of a hemarthrosis in acute fractures, while loss of forearm rotation typically is caused by a mechanical impingement.
■ A careful neurovascular assessment of all three major nerves that cross the elbow should be performed.
■ The examiner should observe for localized or diffuse swelling in the elbow. Effusion represents hemarthrosis due to intra-articular fracture.
■ The examiner should compare active and passive range of motion to the uninjured side. Reduced range of motion may be a result of hemarthrosis or mechanical block from a broken fragment. Intra-articular injection of a local anesthetic helps differentiate between reduced range of motion due to a mechanical block versus pain inhibition.
■ The examiner should look for varus-valgus instability. Any gapping on the medial or lateral side beneath the examiner’s hand is noted. Positive findings suggest mediolateral collateral ligament insufficiency. Typically, this test is positive only when performed under a general anesthetic.
■ The lateral pivot shift test is performed. Positive apprehension or a clunk that is seen or felt when the ulna and radius reduce on the humerus suggests posterolateral rotatory instability.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

■ Anteroposterior (AP), lateral, and oblique elbow radiographs, with the x-ray beam centered on the radiocapitellar joint, usually provide sufficient information for the diagnosis and treatment of radial head fractures.
■ Bilateral posteroanterior radiographs of both wrists in neutral rotation should be performed to evaluate ulnar variance in patients with wrist discomfort or a comminuted radial head fracture, since there is a higher incidence of an associated interosseous ligament injury in these patients.6
■ Computed tomography with sagittal, coronal, and 3D reconstructions may assist with preoperative planning and can help the surgeon predict whether a displaced radial head fracture can be repaired with open reduction and internal fixation or if an arthroplasty will likely be needed.

**DIFFERENTIAL DIAGNOSIS**

■ Acute radial head fractures
■ Other fractures or dislocations about the elbow (eg, supracondylar, capitellar, coronoid, osteochondral fractures)
■ Radial head nonunion or malunion, posttraumatic arthritis
■ Congenital dislocation of the radial head
■ Forearm or elbow instability
■ Lateral epicondylitis
■ Rheumatoid arthritis or osteoarthritis
■ Synovitis, inflammatory or infectious
■ Tumors

**NONOPERATIVE MANAGEMENT**

■ The indications for surgical management of radial head fractures are not well defined in the literature. Fragment size, number of fracture fragments, degree of displacement, and bone quality influence decision making regarding the optimal management.
■ Nondisplaced fractures or small (less than 33% of radial head) minimally displaced fractures (less than 2 mm) can be treated with early motion with an excellent outcome in the majority of patients.
■ Associated injuries and a block to motion are also important factors to consider when deciding between nonoperative and surgical management.

**SURGICAL MANAGEMENT**

■ Small displaced fractures that cause painful crepitus or limited motion are managed with fragment excision if they are too small (typically less than 25% of the diameter of the radial head) or osteopenic to be internally fixated.
■ Larger displaced fractures are typically managed with ORIF with good outcomes in most patients.
■ Radial head fractures that are displaced but too comminuted to be anatomically reduced and stably fixed and that are too large to consider fragment excision (involve more than a quarter to a third of the radial head) should be managed by radial head excision with or without arthroplasty.
■ Patients who are known to have, or are likely to have, an associated ligamentous injury of the elbow or forearm should have a radial head arthroplasty because radial head excision is contraindicated (FIG 2).
■ The decision as to what fracture is reconstructable depends on surgeon factors (eg, experience), patient factors (eg, osteoporosis), and fracture factors (eg, fragment number and size, comminution, associated soft tissue injuries). The final decision is often made only at the time of surgery.
■ Other indications for radial head arthroplasty include radial head nonunion or malunion, primary or secondary management of forearm or elbow instability (eg, Essex-Lopresti injury), rheumatoid arthritis or osteoarthritis, and tumors.

**Preoperative Planning**

■ Currently available devices include spacer implants, press-fit and ingrowth stems, and bipolar and ceramic articulations.
■ Silicone radial head implants offer little in the way of axial or valgus stability to the elbow and have been complicated by a high incidence of implant wear, fragmentation, and silicone synovitis leading to generalized joint damage. As a result, they have fallen out of favor and have been replaced by metallic implants.
■ Most metallic radial head implants that have been developed and used to date employ a monoblock design, making size matching suboptimal and implant insertion often difficult because of the need to subluxate the elbow to allow for insertion of these devices.10
■ Recently, modular metallic radial head prostheses have become available with separate heads and stems, allowing improved size matching of the native radial head and neck18 and easier placement in the setting of competent lateral ligaments.17
Precise implant sizing and placement are critical with these devices to ensure correct capitellar tracking and to avoid a cam effect with forearm rotation, which may cause premature capitellar wear due to shearing of the cartilage and stem loosening due to increased loading of the stem–bone interface. Preoperative radiographic templating of the contralateral normal radial head should be employed in the setting of a secondary radial head replacement but is not needed for acute fractures because the excised radial head is available for accurate implant sizing.

Positioning
- The patient is placed supine on the operating table and a sandbag is placed beneath the ipsilateral scapula to assist in positioning the arm across the chest.
- Alternatively, the patient can be positioned in a lateral position with the affected arm held over a bolster.
- Prophylactic intravenous antibiotics are administered.
- General or regional anesthesia is employed.
- A sterile tourniquet is applied.

**Surgical Approach**
- A midline posterior elbow incision is made just lateral to the tip of the olecranon (TECH FIG 1A).
- A full-thickness lateral fasciocutaneous flap is elevated on the deep fascia. This extensile incision decreases the risk of cutaneous nerve injury and provides access to the radial head, coronoid, and medial and lateral collateral ligaments for the management of more complex injuries (TECH FIG 1B).
- Alternatively, a lateral skin incision centered over the lateral epicondyle and passing obliquely over the radial head can be used (see Tech Fig 1A).
COMMON EXTENSOR SPLIT

- The extensor digitorum communis tendon is identified.
  - The landmarks for this plane are a line joining the lateral epicondyle and the tubercle of Lister.
  - The extensor digitorum communis tendon is split longitudinally at the middle aspect of the radial head, and the underlying radial collateral and annular ligaments are incised (TECH FIG 2A).
  - Dissection should stay anterior to the lateral ulnar collateral ligament to prevent the development of posterolateral rotatory instability (see Fig 1).
  - The forearm is maintained in pronation to move the posterior interosseous nerve more distal and medial during the surgical approach.7
- If further exposure is required:
  - The humeral origin of the radial collateral ligament and the overlying extensor muscles are elevated anteriorly off the lateral epicondyle to improve the exposure if needed (TECH FIG 2B).
  - Release of the posterior component of the lateral collateral ligament can be considered, but careful ligament repair is required at the end of the procedure in order to restore the varus and posterolateral rotatory stability of the elbow.9
TECH FIG 2 • (continued) B. The humeral origin of the radial collateral ligament and the overlying extensor muscles are elevated anteriorly off the lateral epicondyle to improve the exposure if needed.

PREPARATION OF THE RADIAL HEAD AND NECK

- All fragments of the radial head are removed, as well as a minimal amount of radial neck at a right angle to the medullary canal, to make a smooth surface for seating of the prosthetic radial head.
  - Complete fragment excision can be confirmed with the use of an image intensifier.
  - The capitellum is evaluated for chondral injuries or osteochondral fractures.
- The radial head prosthesis is sized in one of several ways:
  - The resected radial head is reassembled in the provided sizing template to assist in the accurate sizing of the prosthesis (TECH FIG 3A–C).
  - The diameter of radial head prosthesis should be based on the size of the articular dish. This is typically 2 mm smaller than the outer diameter of the excised radial head.
  - Alternatively, if the radial head has been previously excised, radiographic templating of the contralateral normal radial head may be used to determine the appropriate diameter and height of the radial head implant.
  - If the native radial head is in between available implant sizes, the implant diameter or thickness should be downsized.
- The radial neck is delivered laterally using a Hohmann retractor carefully placed around the posterior aspect of the proximal radial neck (TECH FIG 3D).
  - An anteriorly based retractor should be avoided because of the risk of injury from pressure on the posterior interosseous nerve.
  - The medullary canal of the radial neck is reamed using hand reamers until cortical contact is encountered.
  - A trial stem one size smaller than the rasp is inserted to achieve a nontight press-fit.
TECH FIG 3 • (continued) and height (C), and to ensure that all the fragments have been removed from the elbow. D. The radial neck is delivered laterally using a Hohmann retractor carefully placed around the posterior aspect of the proximal radial neck. An anteriorly based retractor should be avoided because of the risk of injury to the posterior interosseous nerve.

RADIAL HEAD REPLACEMENT

- A trial head is inserted onto the stem, and the diameter, height, tracking, and congruency of the prosthesis are evaluated both visually and with the aid of an image intensifier.
- The radial head prosthesis should articulate at the same height as the radial notch of the ulna and about 1 mm distal to the tip of the coronoid (TECH FIG 4A).
- The alignment of the distal radioulnar joint, ulnar variance, as well as the width of the lateral and medial portions of the ulnohumeral joint, are checked and compared to the contralateral wrist and elbow, respectively, under fluoroscopy.
- Overlengthening the radiocapitellar joint with a radial head implant that is too thick should be avoided to reduce the risk of cartilage wear on the capitellum from excessive pressure; a nonparallel medial ulnohumeral joint space that is wider laterally is suggestive of overstuffing.
- Some modular and bipolar implants allow insertion of the stem first, then placement of the head onto the stem with coupling in situ, which significantly reduces the surgical exposure needed (TECH FIG 4B).
- If the prosthesis is maltracking on the capitellum with forearm rotation, a smaller stem size should be trialed to ensure that the articulation of the radial head with the capitellum is controlled by the annular ligament and articular congruency and not dictated by the proximal radial shaft.

TECH FIG 4 • A. A trial stem is inserted. A trial head is inserted onto the stem and the diameter, height, tracking, and congruency of the prosthesis are evaluated both visually and with the aid of an image intensifier. B. Some modular and bipolar implants allow insertion of the stem first, then placement of the head onto the stem with coupling in situ, which significantly reduces the surgical exposure needed.
LATERAL SOFT TISSUE CLOSURE

- After radial head replacement, the lateral collateral ligament and extensor muscle origins are repaired back to the lateral condyle.
- If the posterior half of the lateral collateral ligament is still attached to the lateral epicondyle, then the anterior half of the lateral collateral ligament (the annular ligament and radial collateral ligament) and extensor muscles are repaired to the posterior half using interrupted absorbable sutures (TECH FIG 5A).
- If the lateral collateral ligament and extensor origin have been completely disrupted either by the injury or surgical exposure, they should be securely repaired less equalize to the lateral epicondyle using drill holes through bone and nonabsorbable sutures or suture anchors.
- A single drill hole is placed at the axis of motion (the center of the arc of curvature of the capitellum) and connected to two drill holes placed anterior and posterior to the lateral supracondylar ridge.
- A locking (Krackow) suture technique is employed to gain a secure hold of the lateral collateral ligament and common extensor muscle fascia (TECH FIG 5B–D).
- The ligament sutures are pulled into the holes drilled in the distal humerus using suture retrievers and the forearm is pronated, and varus forces are avoided, while tensioning the sutures before tying (TECH FIG 5E).
- The knots should be left anterior or posterior to the lateral supracondylar ridge to avoid prominence.

TECH FIG 5 • A. If the posterior half of the lateral collateral ligament is still attached to the lateral epicondyle, then the anterior half of it (the annular ligament and radial collateral ligament) and extensor muscles are repaired to the posterior half using interrupted absorbable sutures. ECU, extensor carpi ulnaris; EDC, extensor digitorum communis. B–D. If the lateral collateral ligament and extensor origin have been completely disrupted by the injury or detached by the surgical exposure, they should be securely repaired to the lateral epicondyle. A single drill hole is placed at the center of the arc of curvature of the capitellum and connected to two drill holes placed anterior and posterior to the lateral supracondylar ridge. A locking (Krackow) suture technique is employed to gain a secure hold of the lateral collateral ligament (B) as well as of the annular ligament (C). D. A second stitch is used in a similar manner to repair the common extensor muscle fascia. (continued)
The sutures are pulled into the holes drilled in the distal humerus using suture retrievers, tensioned while keeping the forearm pronated and while avoiding varus forces, and eventually tied over the lateral supracondylar ridge.

**COMPLETION**

- After replacement arthroplasty and lateral soft tissue closure, the elbow should be placed through an arc of flexion–extension while carefully evaluating for elbow stability in pronation, neutral, and supination.²
- Pronation is generally beneficial if the lateral ligaments are deficient,⁹ supination if the medial ligaments are deficient,¹ and neutral position if both sides have been injured.
- In patients who have an associated elbow dislocation, additional repair of the medial collateral ligament and flexor pronator origin should be performed if the elbow subluxates at 40 degrees or more of flexion.
- Tourniquet deflation and hemostasis should be secured before wound closure.

**KÖCHER APPROACH**

- Alternatively, the radial head may be approached by using the Köcher interval²⁰ between the extensor carpi ulnaris and anconeus.
- The fascial interval between these muscles is identified by noting the diverging direction of the muscle groups and small vascular perforators that exit at this interval (TECH FIG 6).
- Care should be taken to preserve the lateral ulnar collateral ligament, which is vulnerable as the dissection is carried deeper through the capsule.

**TECH FIG 5** • (continued) E. The sutures are pulled into the holes drilled in the distal humerus using suture retrievers, tensioned while keeping the forearm pronated and while avoiding varus forces, and eventually tied over the lateral supracondylar ridge.

**TECH FIG 6** • The extensor carpi ulnaris is elevated anteriorly and an arthrotomy is performed at the midportion of the radial head. Care should be taken to preserve the lateral ulnar collateral ligament, which is vulnerable as the dissection is carried deeper through the capsule.
The surgeon should avoid overstuffing the thickness or diameter of the radial head because of the risk of capitellar synovitis due to particulate debris.25 If the radial head does not track well on the capitellum, the stem should be downsized. The radial head implant is typically 2 mm smaller than the outer diameter of the radial head. Radial head articular surface height should be at the level of the proximal radioulnar joint. If the radial head does not track well on the capitellum, the stem should be downsized. If the native radial head is in between implant sizes, the implant should, in general, be downsized. Intraoperative fluoroscopy is used to assess the alignment of the radiocapitellar and distal radioulnar joints and to avoid overlengthening of the radius.

**PEARLS AND PITFALLS**

**Indications**
- Displaced unreconstructable fracture of the radial head with known or probable associated medial or lateral collateral or interosseous ligament injury

**Pearls**
- A preoperative radiographic template of the contralateral native radial head should be used in the setting of a secondary radial head replacement.
- Dissection should stay anterior to the lateral ulnar collateral ligament to prevent the development of posterolateral rotatory instability.
- The radial head should be sized based on the diameter of the articular disk and thickness of the excised radial head.
- The radial head implant is typically 2 mm smaller than the outer diameter of the radial head.
- Radial head articular surface height should be at the level of the proximal radioulnar joint.
- If the radial head does not track well on the capitellum, the stem should be downsized.
- If the native radial head is in between implant sizes, the implant should, in general, be downsized.
- Intraoperative fluoroscopy is used to assess the alignment of the radiocapitellar and distal radioulnar joints and to avoid overlengthening of the radius.

**Pitfalls**
- Hohmann retractors should not be used around the anterior aspect of the radial neck and the forearm should be kept pronated to avoid damage to the posterior interosseous nerve.
- The surgeon should avoid overstuffing the thickness or diameter of the radial head because of the risk of capitellar wear and pain. Filling the gap between the capitellum and radial neck is not a useful landmark for prosthesis thickness because lateral soft tissues are often deficient owing to the surgical exposure or initial injury.

**POSTOPERATIVE CARE**

- The elbow with stable ligaments should be splinted using anterior plaster slabs in extension and elevated for 24 to 48 hours to diminish swelling, decrease tension on the posterior wound, and minimize the tendency to develop a flexion contracture.
- In the setting of a more tenuous ligamentous repair or the presence of some residual instability at the end of the operative procedure, the elbow should initially be splinted in 60 to 90 degrees of flexion in the optimal position of forearm rotation to maintain stability.
- Perioperative antibiotics are continued for 24 hours postoperatively.
- Indomethacin 25 mg three times daily for 3 weeks may be considered in patients undergoing radial head arthroplasty to decrease postoperative pain, reduce swelling, and potentially lower the incidence of heterotopic ossification.
- Indomethacin should be avoided in elderly patients and those with a history of peptic ulcer disease, asthma, known allergy, or other contraindications to anti-inflammatory medications.
- For an isolated radial head replacement treated with a lateral ulnar collateral ligament-sparing approach, active range of motion should be initiated on the day after surgery.
- A collar and cuff with the elbow maintained at 90 degrees is employed for comfort between exercises.
- A static progressive extension splint is fabricated for nighttime use for patients without associated ligamentous disruptions and is employed for a period of 12 weeks. The splint is adjusted weekly as extension improves.
- In patients with associated elbow dislocations or residual instability, extension splinting is not implemented until 6 weeks after surgery.
- Patients with associated fractures, dislocations, or ligamentous injuries should commence active flexion and extension motion within a safe arc 1 day postoperatively.
- Active forearm rotation is performed with the elbow in flexion to minimize stress on the medial or lateral ligamentous injuries or repairs.
- Extension is performed with the forearm in the appropriate rotational position—that is, pronation if the lateral ligaments are deficient,9 supination if the medial ligaments are deficient,1 and neutral position if both sides have been injured.
- A resting splint with the elbow maintained at 90 degrees and the forearm in the appropriate position of forearm rotation is employed for 3 to 6 weeks.
- Passive stretching is not permitted for 6 weeks to reduce the incidence of heterotopic ossification.
- Strengthening exercises are initiated once the ligament injuries and any associated fractures have adequately healed, usually at 8 weeks postoperatively.

**OUTCOMES**

- Silicone radial head arthroplasty, while initially successful in many patients,5,24 has fallen out of favor because of problems with residual instability and arthritis, implant fracture, and silicone synovitis due to particulate debris.25
- While the short- and medium-term results of metallic radial head implants are encouraging, there is a paucity of literature demonstrating the long-term outcome with respect to loosening, capitellar wear, and arthritis.
- Metallic radial head replacement in elbows with intact ligaments restores the kinematics and stability similar to that measured with a native radial head. Moreover, when the fractured radial head occurs in combination with ligamentous and soft tissue disruption, a metallic prosthesis restores elbow stability, with only mild residual deficits in strength and motion.
- Moro et al.21 reported the functional outcome of 25 cases managed with a metallic radial head arthroplasty for unreconstructable fractures of the radial head at an average follow-up of 39 months. The results were rated as 17 good or excellent, 5 fair, and 3 poor.
- The radial head prosthesis restored elbow stability when the fractured radial head occurred in combination with a dislocation of the elbow, rupture of the medial collateral ligament, fracture of the coronoid, or fracture of the proximal ulna.
- There were mild residual deficits in strength and motion, and no patient required removal of the implant.
Harrington et al\(^\text{12}\) reported their experience with metallic radial head arthroplasty in 20 patients at an average follow-up of 12 years. The results were excellent or good in 16 and fair or poor in 4.

Improvements in radial head arthroplasty designs, sizing, and implantation techniques may lead to improved outcomes for unreconstructable radial head fractures.

COMPLICATIONS

- Posterior interosseous nerve injury can occur as a consequence of dissection distal to the radial tuberosity and placement of anterior retractors around the distal radial neck.
- Infection
- Loss of motion, mainly terminal extension due to capsular contracture, heterotopic ossification, or retained cartilaginous or osseous fragments
- Prosthetic loosening or polyethylene wear
- Capitellar wear and pain due to implant overstuffing
- Complex regional pain syndrome
- Instability or recurrent dislocations of the elbow due to an inadequate or failed ligament repair
- Osteoarthritis of the capitellum as a consequence of articular cartilage damage from the initial injury, from component insertion, from persistent instability, or due to loading from a radial head implant that is too thick.

REFERENCES

DEFINITION
- Fracture of the olecranon process is common, usually displaced, and nearly always treated operatively.
- Important injury characteristics include displacement, comminution, and subluxation or dislocation of the elbow, and all are accounted for in the Mayo classification (FIG 1). A
- Fracture-dislocations of the olecranon can be anterior (trans-olecranon) or posterior (the most proximal type of posterior Monteggia according to Jupiter and colleagues3) in direction.2,3,9,10
- Open injuries are unusual.

ANATOMY
- The greater sigmoid notch of the ulna is formed by the coronoid and olecranon processes and forms a nearly 180-degree arc capturing the trochlea.
- The region between the coronoid and olecranon articular facets is the nonarticular transverse groove of the olecranon, a common location of fracture and a place where precise articular reduction is not critical.
- The triceps has a broad and thick insertion from just superior to the point of the olecranon and the tip of the olecranon process that can be used to enhance fixation of small, osteoporotic, or fragmented fractures and can be split longitudinally, if needed, when applying a plate.

PATHOGENESIS
- Fractures of the olecranon are most often the result of a direct blow to the point of the elbow, but occasionally they result from indirect forces during a fall on the outstretched hand.

NATURAL HISTORY
- Stable nondisplaced or minimally displaced fractures are uncommon.
- The majority of olecranon fractures are displaced and benefit from operative treatment.
- The occasional untreated displaced simple olecranon fracture demonstrates a slight flexion contracture, some weakness of extension, no arthrosis, and little if any pain.
- In contrast, undertreated or poorly treated fracture-dislocations lead to severe arthrosis with or without instability.
- Even well-treated complex injuries are at risk for stiffness, heterotopic ossification, arthrosis, and occasionally nonunion.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Knowledge of the characteristics of the patient (age, gender, medical health) and the injury (mechanism, energy) will help the surgeon understand the injury and determine optimal treatment.
- First the patient is assessed for life-threatening injuries (ATLS protocol) and any medical problems that may have contributed to the injury.
- A secondary survey is performed to identify any other fractures, ipsilateral arm injuries in particular.
- The skin is carefully inspected for any wounds associated with the fracture.
- The pulses are palpated, capillary refill inspected, and an Allen test performed if necessary.
- Peripheral nerve function is assessed.
- Patients with high-energy injuries, particularly those with ipsilateral wrist or forearm injuries, are at risk for compartment syndrome. If the clinical examination is suggestive or unreliable (owing to problems with mental status), compartment pressure monitoring should be performed.

FIG 1 • The Mayo classification of olecranon fractures accounts for the factors that will influence treatment decisions: displacement, comminution, and dislocation or subluxation of the articulations.
IMAGING AND OTHER DIAGNOSTIC STUDIES
- Anteroposterior (AP) and lateral radiographs are used for initial characterization of the injury.
- Radiographs after reduction or splinting, or oblique views can be useful.
- Computed tomography (CT) is useful for characterization of fracture-dislocations. In particular, 3D CT reconstructions can be useful for assessment of the coronoid and radial head.

DIFFERENTIAL DIAGNOSIS
- Elbow dislocation
- Monteggia and Essex-Lopresti fracture-dislocations of the forearm
- Distal humerus fracture

NONOPERATIVE MANAGEMENT
- Nonoperative management is appropriate for the rare fracture of the olecranon that is less than 2 millimeters displaced with the elbow flexed 90 degrees.
- Four weeks of splint immobilization followed by active assisted mobilization of the elbow will usually result in a healed fracture and good elbow function.

SURGICAL MANAGEMENT
- The vast majority of olecranon fractures are displaced and merit operative treatment.

TENSION BAND WIRING
Reduction and Kirschner Wire Fixation
- Blood clot and periosteum are cleared from the fracture site to facilitate reduction.
- Limited periosteal elevation is performed at the fracture site to monitor reduction.
- A large tenaculum clamp is used to secure the fracture in a reduced position (TECH FIG 1A,B). A drill hole can be made in the dorsal cortex of the distal fragment to facilitate clamp application.

Preoperative Planning
- The fracture characteristics that determine treatment are defined on radiographs and CT.
- Templating the surgery with tracings of the radiographs is a useful way of running through the surgery in detail before performing it, familiarizing oneself with the anatomy, anticipating problems, and ensuring that all of the implants and equipment that might be necessary are available.

Positioning
- In most patients a lateral decubitus position with the arm over a bolster or support is best.
- Some patients with fracture-dislocations that require both medial and lateral access may be positioned supine with the arm supported on a hand table.
- A sterile pneumatic tourniquet is used.

Approach
- A dorsal longitudinal skin incision is used.

Two 1.0-mm smooth Kirschner wires are drilled across the fracture site (TECH FIG 1C).
- If these are drilled obliquely from dorsal proximal to volar distal, they will exit the anterior ulnar cortex distal to the coronoid process, providing an anchoring point of cortical bone to limit the potential for pin migration.
- In anticipation of later impaction of the proximal ends of the wires, the Kirschner wires should be retracted 5 to 10 mm after drilling through the anterior ulnar cortex.
**Wiring**

- The apex of the ulnar diaphysis just distal to the flat portion of the proximal ulna is drilled with a 2.0-mm drill, with or without prior subperiosteal dissection.
- When two wires are used, a second drill hole is made a centimeter more distal.
- If one wire is used, it should be 18 gauge. My preference is to use two 22-gauge stainless steel wires to limit the size of the knots, which may diminish implant prominence. The wires are passed through the drill holes. A large-bore needle can be used to facilitate passage of the wire through the drill hole (TECH FIG 2A).
- The two tension wires are each passed over the dorsal ulna in a figure 8 fashion, then around the Kirschner wires, and underneath the insertion of the triceps tendon using a large-bore needle (TECH FIG 2B).

**TECH FIG 1 • (continued)**

C. Two 1-mm Kirschner wires are drilled obliquely across the fracture site so that they exit the anterior ulnar cortex distal to the coronoid process. (A,B: Copyright David Ring, MD.)

- Each wire is tensioned both medially and laterally by twisting the wire with a needle holder (TECH FIG 2C,D).
- This should be done to take up slack only. These small wires will break if they are firmly tightened, which is not necessary.
- The tightening should be done in a place that will make the wire knots less prominent.
- After tightening the knots are trimmed and bent into the soft tissues to either side.
- The Kirschner wires are then bent 180 degrees and trimmed.
- These bent ends are then impacted into the proximal olecranon, beneath the triceps insertion, using an osteotome (TECH FIG 2E-H).

**TECH FIG 2 • A.** Two 22-gauge stainless steel tension wires are passed in a figure 8 fashion through drill holes in the ulnar shaft. **B.** They engage the triceps insertion proximally. **C,D.** The wires are tensioned on both sides. These do not need to be tight, but simply snug, with all slack taken up. Attempts to tighten these smaller 22-gauge wires will break them. (continued)
TECH FIG 2 • (continued) E. The proximal ends of the Kirschner wires are bent 180 degrees and impacted into the olecranon process, beneath the triceps insertion. F. The resulting fixation has a relatively low profile and is unlikely to migrate. G,H. Even these small wires are strong enough for active exercises to regain elbow motion. (A,B,D,F–H: Copyright David Ring, MD.)

PLATE AND SCREW FIXATION OF OLECRANON FRACTURES

- Contour the plate to wrap around the proximal aspect of the olecranon or use a precontoured plate (TECH FIG 3A–C).
- A straight plate will have only two or three screws in metaphyseal bone proximal to the fracture.
- Bending the plate around the proximal aspect of the olecranon provides additional screws in the proximal fragment. The most proximal screws can be very long, crossing the fracture line into the distal fragment. In some cases, these screws can be directed to engage one of the cortices of the distal fragment, such as the anterior ulnar cortex.
- A plate contoured to wrap around the proximal ulna can be placed on top of the triceps insertion. Alternatively, the triceps insertion can be incised longitudinally and partially elevated medially and laterally sufficiently to allow direct plate contact with bone.
- If the proximal (olecranon) fragment is small, fragmented, or osteoporotic, it can be useful to add a figure

TECH FIG 3 • A. A lateral radiograph illustrates a comminuted olecranon fracture with a small proximal olecranon fragment. B. An oblique view shows the fragmentation. C. A 3.5-mm limited-contact dynamic compression plate and screws contoured to wrap around the dorsal surface of the olecranon is used for fixation. (continued)
8 tension wire that engages the triceps insertion and passes over the top of the plate and around one of the screws at the metaphyseal level.

- Distally, a dorsal plate will lie directly on the apex of the ulnar diaphysis. The muscle need only be split sufficiently to gain access to this apex—there is no need to elevate the muscle or periosteum off either the medial or lateral flat aspect of the ulna.
- No attempt is made to precisely realign intervening fragmentation—once the relationship of the coronoid and olecranon facets is restored and the overall alignment is restored, the remaining fragments are bridged, leaving their soft tissue attachments intact.
- Bone grafts are rarely necessary if the soft tissue attachments are preserved.
- If the olecranon fragment is small, osteoporotic, or fragmented, a wire engaging the triceps insertion should be used to reinforce the fixation (TECH FIG 3D).
- The plate and screws will serve to hold the coronoid and olecranon facets in proper alignment and bridge fragmentation, and the wire will help ensure fixation even if screw purchase is lost.

Exposure

- In the setting of a fracture-dislocation of the olecranon (TECH FIG 4A), fractures of the radial head and coronoid process can be evaluated and often definitively treated through the exposure provided by the fracture of the olecranon process.
- With little additional dissection, the olecranon fragment can be mobilized proximally as one would do with an olecranon osteotomy, providing exposure of the coronoid through the ulnohumeral joint.
- If the exposure of the radial head through the posterior injury is inadequate, a separate muscle interval (eg, Köcher or Kaplan intervals) accessed by the elevation of a broad lateral skin flap can be used.
- If the exposure of the coronoid is inadequate through posterior injury and olecranon fracture, a separate medial or lateral exposure can be developed.
■ A medial exposure, between the two heads of the flexor carpi ulnaris, or by splitting the flexor-pronator mass more anteriorly, or by elevating the entire flexor–pronator mass from dorsal to volar, may be needed to address a complex fracture of the coronoid, particularly one that involves the anteromedial facet of the coronoid process.

■ When the lateral collateral ligament is injured, it is usually avulsed from the lateral epicondyle. This facilitates repair that can be performed using suture anchors or suture placed through drill holes in the bone.

■ The fracture of the coronoid can often be reduced directly through the elbow joint using the limited access provided by the olecranon fracture (TECH FIG 4B, C).

**Fixation**

■ Provisional fixation can be obtained using Kirschner wires to attach the fragments either to the metaphyseal or diaphyseal fragments of the ulna, or to the trochlea of the distal humerus when there is extensive fragmentation of the proximal ulna.

■ An alternative to keep in mind when there is extensive fragmentation of the proximal ulna is the use of a skeletal distractor (a temporary external fixator; TECH FIG 5A).

■ External fixation applied between a wire driven through the olecranon fragment and up into the trochlea and a second wire in the distal ulnar diaphysis can often obtain reduction indirectly when distraction is applied between the pins.

■ Definitive fixation can usually be obtained with screws applied under image intensifier guidance.

The screws are placed through the plate when there is extensive fragmentation of the proximal ulna.

■ A second, medial plate may be useful when the coronoid is fragmented.

■ If the coronoid fracture is very comminuted and cannot be securely repaired, the ulnohumeral joint should be protected with temporary hinged or static external fixation, or temporary pin fixation of the ulnohumeral joint, depending on the equipment and expertise available.

■ A long plate is contoured to wrap around the proximal olecranon (TECH FIG 5B).

■ A very long plate should be considered (between 12 and 16 holes), particularly when there is extensive fragmentation or the bone quality is poor.

■ When the olecranon is fragmented or osteoporotic, a plate and screws alone may not provide reliable fixation.

■ In this situation, it can be useful to use ancillary tension wire fixation to control the olecranon fragments through the triceps insertion (TECH FIG 5C).
**POSTOPERATIVE CARE**

- When good fixation is obtained (which occurs in most patients), active assisted and gravity-assisted elbow and forearm exercises can be initiated immediately after surgery. A delay of several days for comfort is reasonable.
- If the lateral collateral ligament was repaired, the patient must be instructed not to abduct the shoulder for the first month.
- If the fixation is tenuous, it is reasonable to immobilize the arm in a splint for a month or so before beginning exercises.

**OUTCOMES**

- Nonunion is nearly unheard of after simple olecranon fractures, and early implant failure is usually due to noncompliance.6
- The appeal of tension band wiring has been limited by prominence of the implants; however, if the techniques described herein are followed, few patients will request a second surgery specifically for implant removal.8
- Macko and Szabo pointed out that it was initial implant prominence and not migration that led to implant-related problems after tension band wiring of olecranon fractures.5
- In any case, a second surgery for implant removal is not unreasonable, and it may not be appropriate to consider this a complication.
- Some surgeons have considered plate-and-screw fixation of simple, noncomminated olecranon fractures.1 However, plates can also cause symptoms, and if only a few screws can be placed in the olecranon fragment, particularly in the setting of fragmentation or osteoporosis, it may be preferable to use the soft tissue attachments to enhance fixation rather than relying on implant–bone purchase alone.
- Medial and lateral plates have been associated with early failure, malunion, and nonunion in the treatment of complex proximal ulna fractures.10,11
- Dorsal plates perform better, but the elbow is often compromised in the setting of such complex injuries.

**COMPlications**

- Implant loosening
- Implant breakage
- Nonunion
- Malunion
- Instability
- Arthrosis

**REFERENCES**

DEFINITION

- Simple elbow dislocation is a dislocation of the ulnohumeral joint without concomitant fracture.
- Complex instability denotes the presence of a fracture associated with dislocation.
- The elbow is the second most commonly dislocated large joint (excluding phalanx dislocations and so forth).

PATHOANATOMY

- Elbow stability is conferred by both the osseous anatomy as well as the ligamentous anatomy.
- Primary stabilizers of the ulnohumeral joint include the osseous architecture of the joint, including the coronoid process and greater sigmoid notch of the ulna, and the trochlea of the humerus.
  - The anterior band of the medial collateral ligament (aMCL) and the lateral ulnar collateral ligament (LUCL) are the primary ligamentous stabilizers of the elbow.8,12
  - The aMCL originates on the anterior inferior face of the medial epicondyle and inserts on the sublime tubercle of the ulna.
  - The LUCL originates from an isometric point on the lateral supracondylar column and traverses across the inferior aspect of the radial head, inserting on the supinator crest of the ulna.8
- Secondary stabilizers include the radial head and dynamic constraints such as the flexor and extensor muscles of the forearm.
  - The anterior joint capsule is also felt to play a role in ulnohumeral stability.
- O’Driscoll12 has proposed the term “posterolateral rotatory instability” (PLRI) to describe the series of pathologic events that result in ulnohumeral dislocation.
- PLRI is felt to start with disruption of the LUCL and progresses medially with tearing of the anterior and posterior capsular tissue. This allows the ulna to “perch” on the distal humerus. Further soft tissue or osseous injury results in dislocation11 (FIG 1A).
  - Most traumatic injuries to the LUCL result in avulsion of the ligament from the lateral humerus (FIG 1B).
  - As forces continue from lateral to medial across the joint, the anterior and posterior capsular tissue and eventually the MCL may be disrupted.
  - It is possible to dislocate the ulnohumeral joint with disruption of the LUCL and preservation of the aMCL.12
- Common fractures that occur with elbow dislocation include radial head or neck and coronoid fractures, although any fracture about the elbow may be observed.
  - Radial head fractures are usually readily apparent on plain radiographs.
  - Coronoid fractures may be subtle, and even a “fleck” of coronoid is often a hallmark of a more significant injury (eg, “terrible triad” injury), and its importance should not be underestimated.
  - Recently, a variant of elbow instability termed posteromedial rotatory instability (PMRI) has been described, which is a consequence of LUCL injury and medial coronoid facet fracture. This injury pattern is most commonly observed without radial head fracture, making it potentially very subtle on plain radiographs. A computed tomography (CT) scan can delineate this injury in detail and should be obtained if any suspicion exists (FIG 1C–E).2,11

ETIOLOGY AND CLASSIFICATION

- Most elbow dislocations occur with a fall on an outstretched arm.
- Forces of valgus, extension, supination, and axial load across the joint can result in the ulna rotating away from the humerus, disrupting lateral–anterior soft tissues initially, and dislocating the elbow.
- Simple elbow dislocations are classified by the direction of displacement of the ulna in reference to the humerus, with posterolateral dislocation the most common.
  - Less common variants include anterior, medial, or lateral dislocations.

PATIENT HISTORY AND PHYSICAL FINDINGS

- History is aimed at determining the timeline and mechanism of injury, frequency of dislocations, and previous treatment.
  - Unlike the shoulder, recurrent instability of the elbow is rare after an initial simple dislocation that was treated expeditiously.
  - Recurrent instability is more common in association with fractures (eg, the “terrible triad” injury).
  - Chronic instability, although rare in the United States, does occasionally occur, and management often requires reconstructive surgery or elbow replacement. Closed treatment is rarely successful in these patients.
  - Iatrogenic injury of the LUCL (during procedures such as open tennis elbow release or radial head fracture management) is a known cause of recurrent PLRI. However, these patients often complain of subtle lateral elbow pain due to subluxation of the joint with activities, such as rising from a chair, but rarely have recurrent dislocation.
  - Examination at the time of injury requires attention to the neurovascular anatomy.
  - Nerve injury can occur after elbow dislocation, and a thorough neurologic examination of the extremity is mandatory before any treatment of the dislocation.
  - Most nerve injuries are neuropraxia that often resolve.
  - The ulnar nerve is most frequently involved, although median or radial nerve injury may also occur.14
  - The dislocated elbow has obvious deformity, with the elbow often held in a varus position and the forearm supinated.
After initial reduction, the neurovascular status of the limb is re-evaluated. Loss of neurologic function after closed reduction is rare but can be an indication for surgical exploration to rule out an entrapped nerve.

Stability of the joint is assessed based on the amount of extension obtainable and association of pronation or supination with instability (see the treatment algorithm section).

It is helpful to evaluate the stability throughout the elbow range of motion while the patient is still anesthetized, as this may guide treatment (examination under anesthesia).

Stressing of the lateral soft tissues is performed with the lateral pivot-shift maneuver, which can be performed under anesthesia and with fluoroscopic imaging. This test can be used to assess the degree of posterolateral rotatory instability, and may aid in determining treatment.

Medial ecchymosis may be a sign of an aMCL injury, and often is apparent 3 to 5 days after dislocation when the MCL has been injured.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standard orthogonal radiographs of the elbow are obtained before and after reduction to assess for fracture and confirm relocation of the joint.
- Congruency of the trochlea-ulna and radial head-capitellum is assessed.
- Valgus stress views, once the joint is reduced, may help demonstrate an aMCL injury.
- With the elbow flexed 30 degrees and the forearm in pronation, a valgus stress is placed under fluoroscopic evaluation to see if the medial ulnohumeral joint opens compared to the resting state.
- Varus stress views are often not helpful.
- CT scans with 3D reconstructions are obtained in any situation where a fracture may be suspected, as it is critical to identify PMRI variants or subtle coronoid fractures, which may be an indication for surgical management.
- Magnetic resonance imaging (MRI) is usually not necessary in the management of simple dislocation, although if questions regarding the integrity of the MCL exist, an MRI can delineate this structure well.

**NONOPERATIVE MANAGEMENT**

- Most simple dislocations may be managed nonoperatively with splinting or bracing, guided by the degree of instability determined during the examination under anesthesia after reduction. Once reduced, elbow stability is assessed during flexion-extension in neutral forearm rotation.
- If the elbow is stable throughout an arc of motion, it is immobilized in a sling or splint for 3 to 5 days for comfort and then range-of-motion exercises are begun.

---

**FIG 1** A. Posterolateral rotatory instability follows a typical progression of disruption, allowing the joint to become perched and then dislocate as soft tissue injury progresses. B. Intraoperative photograph demonstrating avulsion of the origin of the lateral ulnar collateral ligament (LUL) after traumatic dislocation of the elbow. The origin of the LUL and the extensor muscles are avulsed as one layer, held by the forceps. C–E. Posteromedial rotatory instability is a variant of elbow instability in which the elbow dislocates, rupturing the LUL, and the medial coronoid sustains an impaction fracture. In this injury pattern, the radial head remains intact, making appropriate diagnosis of the severity of the injury difficult on standard radiographs. CT scans help better delineate the injury pattern. Impaction fracture can be seen on the 3D CT reconstruction. (A: Adapted from O’Driscol SW, Morrey BF, Korinek S, et al. Elbow subluxation and dislocation: a spectrum of instability. Clin Orthop Relat Res 1982;280:194. C–E: Copyright the Mayo Foundation, Rochester, MN.)
If instability is present in less than 30 degrees of flexion, the forearm is pronated and stability is reassessed. If pronation confers stability, then a hinged orthosis that maintains forearm pronation is used, after 3 to 5 days of splinting, to allow protected range of motion.

Elbows that sublux (confirmed by fluoroscopic imaging) in less than 30 degrees of flexion and pronation of the forearm are managed with a brief period of splinting, followed by a hinged orthosis that controls rotation of the forearm and has an extension block.

Elbows that are unstable in more than 30 degrees of flexion and pronation often are managed surgically.

Hinged bracing is maintained for 6 weeks, with progressive advancement of extension and rotation, as allowed by stability of the joint.

Weekly radiographs are needed to ensure maintenance of a congruent joint during the first 4 to 6 weeks.

After 6 weeks bracing is discontinued and terminal stretching to regain motion is used if flexion contractures exist.

**SURGICAL MANAGEMENT**

**Indications**

Surgical management is indicated in elbows that are unstable, even when placed in flexion (more than 30 degrees) and pronation, elbows that recurrently sublux or dislocate during the treatment protocol, or those with associated fractures (“complex” instability).

Management of simple dislocation requires repair or reconstruction of those ligamentous injuries resulting in instability. By definition, simple dislocation occurs without fracture.

An algorithmic approach to ligament repair is used to stabilize the elbow. The LUCL is felt to be the primary lesion of dislocation, and therefore this ligament is addressed first, followed by assessment of stability.

The LUCL usually avulses from its origin during dislocation, and therefore most often can be repaired after acute injury.

Repair may be performed via bone tunnels in the humerus or with suture anchors, depending on the surgeon’s preference.

Reconstruction of the LUCL is rarely needed in acute management but is more commonly needed in chronic instability.

Reconstruction, when necessary, uses autograft (either palmaris or gracilis) or allograft.

Often, repair or reconstruction of the LUCL confers stability, even in the face of MCL injury, as the intact radial head is a secondary stabilizer to valgus instability.

Persistent instability after LUCL repair is rare and is more commonly observed with fracture-dislocations or chronic instability.

If persistent instability exists, the MCL is repaired or reconstructed, a hinged external fixator is placed, or both are performed.

This section will discuss the surgical technique of LUCL repair and reconstruction.

**Preoperative Planning**

Planning should include the possibility of reconstruction of the LUCL using autograft, which will be harvested at surgery, or by having allograft available.

If autograft is to be harvested, a tendon stripper is needed.

For allograft we routinely use semitendinosus tendon.

A hinged external fixator should be available in the rare case that the elbow remains unstable after ligamentous repair or reconstruction.

2.0- and 3.2-mm drill bits or burrs are used to make bone tunnels for LUCL repair or reconstruction.

Alternatively, some surgeons prefer suture anchor repair of ligament avulsions; if desired, these should be available.

Fluoroscopy is useful for confirming reduction and is required for placement of a hinged external fixator.

A sterile tourniquet is used if exposure of the proximal humerus is necessary for placement of proximal external fixator pins.

**Patient Positioning**

Patients are positioned supine with the arm on a radiolucent hand table.
A small bump is placed under the scapula to aid in arm positioning.
- The forequarter is draped free to ensure the entire brachium is kept in the surgical field.

If hamstring autograft is to be used for LUCL, the leg should be draped free and a bump is placed under the hemipelvis to aid in exposure.

**LATERAL ULNAR COLLATERAL LIGAMENT REPAIR**

**Surgical Approach and Arthrotomy**

- Tourniquet control is used during this procedure.
- Two different surgical approaches are used to manage elbow instability.
- Often, a posterior midline skin incision can be used to gain access to both the medial and lateral aspects of the joint; therefore, it is a very extensile approach to the elbow.
- Alternatively, a “column” incision, centered over the lateral epicondyle, may be used (TECH FIG 1A). If medial-sided exposure is needed, a similar “column” incision may be made over the medial epicondyle to gain access.
- There are benefits to both approaches, and currently no data exist delineating which approach is better.
- For simple dislocation we routinely use a lateral column approach.
- After skin incision, skin flaps are raised anteroposterior at the level of the deep fascia.
- Often the lateral soft tissues are avulsed off the epicondyle, exposing the joint. Occasionally, however, the extensor origin is intact with an underlying ligament injury.
- If the extensor muscles are intact, the interval between the extensor carpi ulnaris (ECU) and anconeus (the Köcher approach), which directly overlies the LUCL, is used. This interval is often readily identified by the presence of a “fat stripe” in the deep fascia (TECH FIG 1B).
- The elbow joint is then exposed by incising the proximal capsule along the lateral column of the humerus, continuing distally along the radial neck (through the supinator muscle and underling capsule) in line with the ECU–anconeus interval.
- The posterior interosseous nerve (PIN) is at risk with this exposure, and therefore the forearm is kept in pronation to protect the PIN.

**Ligament Repair**

- The radiocapitellar joint and coronoid are inspected to confirm no fractures are present and that no soft tissue is interposed in the joint, preventing reduction.
- Once the joint is clear of debris, the ability to obtain a concentric reduction is confirmed with fluoroscopy.

**TECH FIG 1 • A.** Lateral column skin incision. The lateral incision is centered over the epicondyle and radiocapitellar joint and is often the primary incision, as the lateral ulnar collateral ligament (LUCL) rupture is thought to be the primary injury in simple dislocations. **B.** The deep interval between the extensor carpi ulnaris and anconeus is used to gain exposure to the joint. This is often identified by a “fat stripe” in the fascia. Care should be taken not to violate the LUCL, which traverses in line with this interval deep to the fascia and supinator muscle.
with a 2.0-mm drill bit or burr, connected to the distal humeral tunnel at the isometric point.

- Once the humeral tunnels are completed, the limbs of the running suture are passed through the humeral tunnels.
- The joint is concentrically reduced with fluoroscopic confirmation and the LUCL repair sutures are then tied with the joint reduced and the elbow in 30 degrees of flexion and neutral rotation.

- The elbow is ranged through an arc of motion to assess stability, with careful attention placed on the radial head’s articulation with the capitellum, looking for posterior sag in extension, indicating either a lax LUCL or a nonisometric repair.
- If the elbow is stable through an arc of motion, the extensor origin is repaired with interrupted, heavy (no. 0) nonabsorbable suture and the skin is closed in layers.

**TECH FIG 2** - A. The origin of the lateral ulnar collateral ligament (LUCL), which often avulses during elbow dislocation, is identified by a “fold” of tissue on the deep surface of the capsule. The isometric point of the joint is in the center of rotation of the capitellum (B), and confirmation is made using the previously placed sutures in the ligament remnant to ensure that an isometric repair will be obtained (C). D. It is important to make the humeral tunnel so that the most anterior aspect of the tunnel is placed at the isometric point. Exit holes for the humeral tunnel are made anterior and posterior to the lateral supracondylar ridge (B).
**Lateral Ulnar Collateral Ligament Reconstruction**

- Occasionally, the native LUCL is damaged beyond repair (more often with iatrogenic PLRI than with primary instability) or attenuated after recurrent or chronic elbow instability, and reconstruction is necessary.
- Autograft palmaris or gracilis or allograft may be used.
- Autograft and allograft options should be discussed with the patient and decisions made preoperatively. We routinely use semitendinosus allograft unless the patient desires autograft.
- This section will cover the technique of ligament graft reconstruction once tendon graft has been harvested.

**Bone Tunnel Preparation**

- We use a “docking” technique, similar to those described for MCL reconstruction, for LUCL reconstruction.
- The insertion of the LUCL is at the supinator crest of the ulna, and reconstruction begins with creation of the ulnar tunnels at the supinator crest.
- Reflecting the supinator origin from the ulna posterior to the radial head exposes the supinator crest.
  - The forearm is held in pronation to protect the PIN.
- Once the crest is exposed, the ulnar tunnel is made at the level of the radial head using two 3.4-mm burr holes placed 1 cm apart. Care is taken to connect the holes using small curettes or awls without fracturing the roof of the tunnel (TECH FIG 3).
- Once the ulnar tunnel is made, a suture is placed in the tunnel to aid in graft passage and to help identify the isometric point on the humerus, similar to the technique described with ligament repair.
- Once the isometric origin on the humerus is confirmed, humeral bone tunnels are made as mentioned in the LUCL repair section.
  - With LUCL reconstruction the isometric tunnel is deepened to about 1 cm to allow graft docking.
  - Further, the docking tunnel is widened using a 3.4-mm burr to be able to accept both limbs of the graft.
  - It is important to widen the docking hole anterior and proximal to the isometric point, as the most posterior aspect of the tunnel needs to be at the isometric point.

**Graft Preparation**

- One end of the graft is freshened and tubularized using a no. 2 nonabsorbable suture in a running Krackow fashion.
- The graft is then passed through the ulnar bone tunnels using the passage suture previously placed.
- The limb of the graft with locking suture is then fully docked into the humeral origin, and the joint is reduced.
- The final length of the graft is determined by tensioning the graft and identifying the point at which the free limb of the graft meets the isometric origin. This point is marked on the graft.
  - Care should be taken to ensure appropriate graft tension and length by fully docking the first limb and then marking the free limb at the point of initial contact with the humerus, thereby allowing some overlap of graft limbs in the humeral tunnel but minimizing the likelihood of slack in the final construct.
- The marked graft end is then freshened and tubularized in an identical fashion as the other limb.

**Final Reconstruction**

- Once the graft is placed and ready for final tensioning and fixation, the capsule and remnant of the LUCL is repaired back to the humerus in an effort to make the ligament reconstruction extra-articular, if possible.
- Each limb of the graft is then placed into the isometric docking tunnel on the humerus with corresponding limbs from each locking suture exiting the proximal humeral tunnels.
  - Both limbs of locking suture from one end of the graft are passed through one proximal tunnel in the humerus, followed by the limbs from the other end of the graft through the second proximal tunnel.
- The joint is then reduced and the graft is finally tensioned to ensure there is no slack and neither graft end has “bottomed out” in the humeral docking tunnel.
- The locking sutures are then tied together over the lateral column of the distal humerus with the joint concentrically reduced in 30 degrees of flexion and neutral rotation.
- The joint is then ranged and stability assessed. If the joint is stable, no further reconstruction is necessary and the extensor muscles are repaired using a nonabsorbable interrupted stitch, followed by skin closure.
HINGED EXTERNAL FIXATION

- A hinged fixator may be necessary in chronic dislocations, some fracture-dislocations, or rarely in patients with persistent instability after LUCL repair or reconstruction for simple dislocation.\(^\text{4,16}\)
- Once any soft tissue blocking reduction is removed and a concentric reduction can be obtained, the fixator is placed.
- All hinged elbow fixators are constructed around the axis or rotation of the elbow to allow range of motion to occur while maintaining a concentric reduction.
  - Most implants are built around an axis pin, placed in this center of rotation.
  - The center of rotation is identified as the center of the capitellum on a lateral aspect of the elbow, and on the medial side it is just anteroinferior to the medial epicondyle, in the center of curvature of the trochlea (TECH FIG 4).
  - The axis pin is placed through both of these points, parallel to the joint surface, and the position is confirmed by fluoroscopy.
- After placement of the axis pin, the humeral and ulnar pins are placed after confirmation of concentric reduction of the elbow is made.
- Once the external fixator is fully constructed, the elbow is taken through an arc of motion and maintenance of reduction is confirmed.
- Fixators are kept on for 6 to 8 weeks.
- Meticulous pin care is necessary to minimize pin tract infections or loosening.

TECH FIG 4 • The center of rotation of the elbow, along which an axis pin for hinged fixators is placed, is identified by the center of the capitellum and just anteroinferior to the medial epicondyle.

PEARLS AND PITFALLS

- LUCL avulsion is the primary ligamentous injury in most simple dislocations of the elbow.
- If the radial head and coronoid are intact (as is the case in a simple dislocation), the MCL rarely needs to be repaired or reconstructed, as the radial head acts as a secondary stabilizer in the elbow with a repaired lateral ligament complex.
- The LUCL origin can be identified by a capsular fold of tissue. This is the point at which repair sutures should be placed, not at the origin of the more superficial extensor tendons.
- The isometric origin of the LUCL is in the center of the capitellum, as projected onto the lateral column, and repair or reconstruction needs to be brought to this point to have an isometric ligament.
- Bone tunnels in the humerus for repair or reconstruction are made so the anteroinferior aspect of the tunnel is at the isometric origin.
- A hinged external fixator may be necessary in management of elbow dislocation, especially chronic or recurrent situations, and should be available.
- All hinged fixators are constructed around the axis of rotation of the elbow, identified by a line between the isometric point on the lateral capitellum and the center of rotation of the trochlea on the medial aspect of the joint.
- Stiffness is the most common adverse sequela of elbow dislocation, and therefore range of motion should be started as soon as soft tissue and skin healing allows, with care taken to avoid varus or valgus stress.

POSTOPERATIVE CARE

- After operative stabilization without external fixation, the elbow is splinted in flexion for 3 to 5 days to allow wound healing.
- Range-of-motion exercises are then begun in flexion, extension, and rotation, with care taken to avoid varus or valgus stress.
  - A hinged orthosis can be helpful in protecting the ligament repair or reconstruction.
  - Active and passive motion is continued for 6 weeks, when strengthening is added.
- Residual contractures, often loss of extension, can be managed with static splinting and terminal stretching.

OUTCOMES

- Most series have reported the results of closed management of simple dislocation.
  - Mehlhoff and colleagues\(^\text{7}\) reported the results of 52 simple dislocations managed, with most patients having normal elbows. Length of immobilization, especially greater then 3 weeks, was found to be more likely to result in persistent loss of extension.
Part 7 SHOULDER AND ELBOW • Section VIII  ELBOW TRAUMA

- Similarly, Eygendaal and colleagues reported the long-term results of 50 patients after closed management of simple dislocations. Sixty-two percent of patients described their elbow function as good or excellent, and 24 of 50 (48%) patients had loss of extension of 5 to 10 degrees.

- Some series have examined the surgical management of PLRI, often as a result of recurrent instability after traumatic dislocation.

- Nestor and colleagues reported the results of 11 patients with recurrent PLRI managed with either repair or reconstruction of the LUCL. Ten of 11 (91%) remained stable and 7 of 11 (64%) had an excellent result.

- More recently, Sanchez-Sotelo and colleagues reported the results of 44 patients treated for recurrent PLRI (9 occurred after simple dislocation). Thirty-two (75%) of the patients had an excellent result by Mayo score.

- Lee and Teo found that in patients with chronic PLRI, reconstruction offered more predictable outcomes over repair.

COMPLICATIONS

- Stiffness
- Heterotopic ossification
- Neurovascular injury
- Recurrent instability
- Compartment syndrome
- Hematoma or infection

REFERENCES


DEFINITION

- Simple dislocations of the elbow can most often be treated successfully with closed means: reduction and short-term immobilization followed by early motion.
- Fracture-dislocations of the elbow are more troublesome in that they often require operative intervention.
- Fractures associated with elbow dislocations often involve the radial head and coronoid. When both are combined with dislocation, this is termed the “terrible triad.”
- The principle of treating fracture-dislocations of the elbow is to provide sufficient stability through reconstruction of bony and ligamentous restraints such that early motion can be instituted without recurrent instability.
- Failure to achieve this will result in either recurrent instability or severe stiffness after prolonged immobilization.

ANATOMY

- Posterolateral dislocations of the elbow are associated with disruption of the medial and lateral collateral ligaments.
- The medial collateral ligament (MCL) is the primary stabilizer to valgus stress (FIG 1).
- The lateral collateral ligament (LCL) is the primary stabilizer to posterolateral rotatory instability. Most often the disruption is from the lateral epicondyle, leaving a characteristic bare spot. Less commonly, the ligament may rupture mid-substance. Secondary restraints on the lateral side that may also be disrupted are the common extensor origin and the posterolateral capsule.
- Radial head fractures have been classified by Mason:
  - Type I: small or marginal fracture with minimal displacement
  - Type II: marginal fracture with displacement
  - Type III: comminuted fractures of the head and neck
- Coronoid fractures have been classified by Regan and Morrey (FIG 2):
  - Type I: tip fractures (not avulsions)
  - Type II: less than 50% of the coronoid
  - Type III: more than 50% of the coronoid
  - The insertion of the MCL is at the base of the coronoid and it may be involved in type III fractures.
PATHOGENESIS
- Fracture-dislocations of the elbow occur during falls onto an outstretched hand, falls from a height, motor vehicle accidents, or other high-energy trauma (FIG 3).
- Typically there is a hyperextension and valgus stress applied to the pronated arm.

NATURAL HISTORY
- Elbow dislocations with associated coronoid or radial head fractures have a poor natural history. Redislocation or subluxation is likely with closed treatment.
- Treatment of the radial head fracture by excision alone in the context of an elbow dislocation has a high rate of failure due to recurrent instability.
- Problems of recurrent instability, arthrosis, and severe stiffness lead to poor functional results.¹⁰

PATIENT HISTORY AND PHYSICAL FINDINGS
- Fracture-dislocations of the elbow are acute and traumatic, so the history should be straightforward.
- It is not unusual for these injuries to occur with high-energy trauma, so a diligent search for other musculoskeletal and systemic injuries must accompany evaluation of the elbow. The ipsilateral shoulder and wrist should be evaluated.
- The evaluation and documentation of peripheral nerve and vascular function in the injured extremity is critical.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- High-quality plain radiographs in the anteroposterior (AP) and lateral plane should be obtained before and after closed reduction.
- Cast material can obscure bony detail after closed reduction.
- If there is any evidence of forearm or wrist pain associated with the elbow injury, these should be imaged as well.
- Computed tomography (CT) scans with reformatted images and 3D reconstructions are helpful in understanding the configuration of bony injuries and are helpful in treatment planning (FIG 4).

DIFFERENTIAL DIAGNOSIS
- Radial head or neck fractures without associated dislocation
- Coronoid fracture associated with posteromedial instability. This results from a varus force and is associated with rupture of the LCL. The radial head is not fractured, making diagnosis more difficult.

NONOPERATIVE MANAGEMENT
- Initial treatment involves closed reduction and splinting with radiographs to confirm reduction (FIG 5).
- If reduction cannot be maintained because of bone or soft tissue injury, repeated attempts at closed reduction should not be attempted. This is thought to contribute to the formation of heterotopic ossification.
- The ability of nonoperative management to meet treatment goals in these situations is rare and surgery is indicated in almost all cases.
SURGICAL MANAGEMENT

- The goals of surgery are to obtain and maintain a concentric and stable reduction of the ulnohumeral and radiocapitellar joint such that early motion within a flexion–extension arc of 30 to 130 degrees can be initiated. Early motion is key to avoid elbow stiffness and resultant poor function.
- Management of elbow dislocations with associated radial head and coronoid fractures should follow an established protocol (Table 1) that has produced reliable results.8
- The radial head is an important secondary stabilizer of the elbow to valgus stress and posterior instability.7
- It is also a longitudinal stabilizer of the forearm to proximal translation.
- If fractured in this setting, it must be fixed or replaced, as excision leads to recurrent instability and unacceptable results.10

Preoperative Planning

- Before surgery, the surgeon must ensure that the proper equipment and implants are available.

## Table 1

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fix the coronoid fracture</td>
</tr>
<tr>
<td>2</td>
<td>Fix or replace the radial head</td>
</tr>
<tr>
<td>3</td>
<td>Repair the lateral collateral ligament</td>
</tr>
<tr>
<td>4</td>
<td>Assess elbow stability within 30 to 130 degrees of flexion–extension with the forearm in full pronation</td>
</tr>
<tr>
<td>5</td>
<td>If the elbow remains unstable, consider fixing the medial collateral ligament</td>
</tr>
<tr>
<td>6</td>
<td>Failing this, apply a hinged external fixator to maintain concentric reduction and allow for early motion</td>
</tr>
</tbody>
</table>

Positioning

- Most commonly, the patient is positioned supine on the operating table under general anesthesia.
- The operative limb is supported on a hand table and a tourniquet is applied to the upper arm before preparation and draping (FIG 6).
- Alternatively, the lateral decubitus position can be used with the operative limb supported by a padded bolster. This position is used if hinged fixation is deemed likely.

Approach

- The lateral approach is the workhorse for treatment of these injuries where the coronoid, radial head, and LCL can be addressed. A direct lateral incision with the patient supine and the arm on a hand table is used.
- Landmarks and skin incision are shown in FIGURE 7A.
- The surgeon should use the traumatic dissection that occurred at the time of injury to gain exposure of the elbow.
- Typically the LCL has been avulsed from the lateral distal humerus, leaving a bare spot (FIG 7B).8
- Some cases require a medial approach as well for either medial ligament reconstruction or plating of a coronoid fracture.
fracture. This can be accomplished through a second medial incision.
- The ulnar nerve is at risk in this approach and should be identified and protected. The common flexor origin is split distal to the medial epicondyle to expose the coronoid medially.
- Alternatively, a posterior skin incision can be used with elevation of full-thickness flaps at the fascial level to approach both laterally and medially.
- The patient can be placed in the lateral decubitus position or supine with the arm across the chest for this approach.

**TECHNIQUES**

**LATERAL EXPOSURE**
- Make an incision along the lateral supracondylar ridge of the humerus curving at the lateral epicondyle toward the radial head and neck.
- At the fascial level, elevate full-thickness flaps and insert a self-retaining retractor (TECH FIG 1).
- Split the common extensor origin in line with its fibers.
- Make use of the traumatic dissection that occurred at the time of injury.
  - Most commonly, the LCL will have avulsed from the distal humerus, leaving a bare spot. The common extensor origin is avulsed as well two thirds of the time.\(^7\)
  - Reconstruction occurs in an orderly fashion from deep to superficial.
  - If the radial head is to be replaced, its excision provides excellent exposure of the coronoid through the lateral approach.
  - If, on the other hand, it is to be fixed, set free fragments aside to allow access to the coronoid.

**ORIF OF CORONOID FRACTURE**

**Type I Coronoid Fractures**
- For type I fractures, we recommend fixation with a non-absorbable (no. 2 braided) suture passed through the anterior elbow capsule just above the bony fragment (TECH FIG 2).
- Two parallel drill holes are made from the dorsal surface of the ulna through a separate small incision and directed toward the coronoid tip. These are made with a small drill or Kirschner wire.
- Once the suture is passed through the capsule, its ends are brought out each of the drill holes and tied over the ulna to plicate the anterior elbow capsule.
- The suture ends can be retrieved through the drill holes using an eyeleted Kirschner wire, a Keith needle, or a suture retriever.
Radial head or neck fracture

Radial head fracture is addressed after treatment of the coronoid injury because once the head is fixed or replaced, access to the coronoid from the lateral approach is limited.

The decision to fix a radial head is largely based on the fracture configuration. If fracture comminution is limited such that the head is in two or three fragments, reduction and fixation is usually possible.

Fractures that are comminuted or with articular surface damage require replacement.

Expose the head and neck as necessary for fracture reduction and fixation by extending the Köcher interval.

The posterior interosseous nerve is at risk during more distal radial neck exposures. Its distance from the operative site can be maximized by keeping the forearm in full pronation.

ORIF of Radial Head Fractures

For radial head fragments, reduce and hold the fragment to the intact head with a pointed reduction clamp.

We secure the fragments with Herbert screws. The fragments can be held temporarily with a 2-mm Kirschner wire and then replaced with a Herbert screw.

If the screw is inserted through articular cartilage, its head must be countersunk.

Radial neck fractures, once reduced, can be held provisionally with a Kirschner wire.

Definitive fixation is with a small fragment T plate over the "safe zone" (TECH FIG 4).

Care is taken to not injure the posterior interosseous nerve while exposing the shaft or by trapping it under the plate distally.

If the radial head cannot be reconstructed, it is replaced.
TECH FIG 4 • The “safe zone” for plating radial neck fractures. The 90-degree arc outlined does not articulate with the proximal ulna throughout the full range of forearm rotation. Plating a radial neck fracture in this zone will not interfere with rotation.

Radial Head Replacement
- The replacement used must be metallic as silicone implants are inadequate both biomechanically and biologically.6
- We use a modular implant such that the stem diameter can be varied independent of the head diameter and thickness.

TECH FIG 5 • Radial head implant. An appropriately sized radial head implant has been inserted. It is held reduced with the forearm in full pronation. Note the anatomic alignment with the capitellum.
- If required, cut the proximal radius at the level of the neck with a micro-sagittal saw.
- Ream the canal of the proximal radius to cortical bone with sequentially larger reamers.
- Radial head size can be judged by assembling the fractured fragments that have been removed. In general, downsizing the head slightly is recommended such that the elbow joint is not overstuffed.
- A trial implant should be inserted to test stability and motion. Elbow range of motion, both flexion–extension and forearm rotation, should be checked. View the articulation between the proximal radius and ulna to see if the diameter of the implant seems appropriate.
- Once satisfied with sizing, the definitive implant is inserted (TECH FIG 5).

REPAIR OF THE LATERAL COLLATERAL LIGAMENT COMPLEX
- Repair of the LCL complex is critical to re-establish elbow stability (TECH FIG 6A).
- It is most often avulsed from the distal humerus. Its anatomic attachment point is slightly posterior to the lateral epicondyle at the center of the arc of the capitellum.
- The LCL is a discrete structure deep to the common extensor origin, which runs from the lateral epicondyle to the supinator crest of the ulna (TECH FIG 6B).
- Use a no. 2, braided, nonabsorbable suture for the repair.

TECH FIG 6 • A. Elbow instability associated with deficient lateral collateral ligament. Without repair of the lateral collateral ligament, the radial head subluxes into a posterolateral position with forearm supination. Note that the radial head and capitellum are no longer in normal alignment. B. The lateral collateral ligament is held by the forceps. It is a distinct structure easily identified in this acutely injured elbow. (continued)
PERSISTENT INSTABILITY

- On occasion, repair of the coronoid, radial head, and LCL from the lateral approach is insufficient to restore elbow stability such that early motion may be initiated.
- In these cases, further efforts must be made to obtain such stability.
- Repair of the MCL through a separate medial incision is one option if a lateral approach has been used for coronoid and radial head fracture fixation.
  - Alternatively, a posterior skin incision can be used with full-thickness flaps created to access both sides. Positioning the patient in the lateral decubitus position facilitates this approach.
- A deep approach to the medial aspect of the elbow puts the ulnar nerve at risk, and it must be identified and protected during the procedure.
- Usually the MCL is torn in its mid-substance. Suture repair of this is often unsatisfying. Using a graft to replace the MCL is not recommended in the acute injury setting.
- If elbow stability remains unsatisfying, applying a hinged fixator is the final option. If the hinge is not available or the surgeon is not familiar with its use, a static fixator can be applied to maintain elbow reduction.

Hinged External Fixation

- Application of the hinged fixator starts with the insertion of a guide pin through the center of elbow rotation.
  - The ligament can be reattached to the distal humerus through bone tunnels or using suture anchors. We prefer bony tunnels.
  - Using a drill, Kirschner wire, or pointed towel clip, make holes in the distal lateral humerus above the epicondyle.
  - Pass the suture through the holes and into the lateral ligament such that it will tighten on tying the sutures.
  - At least two, preferably three, sutures through bone are required. Pass, cut, and snap all of the sutures (TECH FIG 6C).
  - Ensure that the elbow is now held in 90 degrees of flexion and full forearm pronation.
  - Incorporate the more superficial common extensor origin in the repair.
  - Tie the sutures once they have all been passed and then close the lateral wound in layers.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Elbow dislocations with associated fractures of the coronoid or radial head must be recognized as complex dislocations. They usually require surgical treatment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals of treatment</td>
<td>The goals are to obtain a concentric reduction with sufficient elbow stability such that early range of motion is possible, and to avoid persistent instability, elbow stiffness, and arthritis.</td>
</tr>
<tr>
<td>Coronoid fractures</td>
<td>Repair of coronoid fractures is technically demanding but necessary for successful treatment.</td>
</tr>
<tr>
<td>Radial head</td>
<td>The surgeon should be prepared to replace the radial head if necessary with a metal, modular prosthesis. Excision alone is not an option.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- The injured elbow is placed in a well-padded plaster splint at 90 degrees of flexion and full pronation. The patient is given a sling for comfort.
- AP and lateral radiographs are obtained in the operating room to ensure congruent reduction and verify hardware placement.
- The patient typically stays in hospital one night to receive adequate analgesia and prophylactic antibiotics.
- We do not routinely give prophylaxis for heterotopic ossification unless the patient has a concomitant head injury: in this case, indomethacin 25 mg three times a day is prescribed with a cytoprotective agent for 3 weeks.
- The patient returns to our clinic at 7 to 10 days postoperatively for staple removal. The splint is typically removed at this point.
- Range-of-motion exercises are initiated at this time under the supervision of a physiotherapist.
- Active and active-assisted flexion–extension between 30 and 130 degrees and forearm rotation with the elbow at 90 degrees of flexion is initiated.
- A lightweight resting splint is made for the injured elbow that is removed for hygiene and physiotherapy.
- The patient returns at 4, 8, and 12 weeks after surgery for clinical review with plain radiographs. Thereafter the interval of clinic visits is widened, but we follow our patients out to 2 years.
- At 4 weeks we allow unrestricted range of motion and at 8 weeks unrestricted strengthening.
- Evidence of fracture union is usually present between 6 and 8 weeks.
- Progress with range of motion can be slow and frustrating for the patient but does not plateau until 1 year of follow-up.

OUTCOMES

- Following the protocol outlined for fracture-dislocations of the elbow should yield satisfactory functional results.
- Pugh et al.8 reported the results of this treatment protocol for 36 elbows at 34 months.
  - The flexion–extension arc averaged 112 degrees and rotation 136 degrees.
  - Fifteen patients had excellent results, 13 good, 7 fair, and 1 poor by the Mayo Elbow Performance Score.
  - Eight patients had a complication requiring reoperation.

COMPLICATIONS

- The most likely complication after treatment is unacceptable elbow stiffness with a resultant nonfunctional range of motion.
  - An acceptable range is 30 to 130 degrees of flexion.
  - At about 1 year after surgery, once motion has plateaued, patients are candidates for release with hardware removal if they are not happy with their range of motion and the flexion–extension arc is less than 100 degrees.
  - This is done through the lateral approach with an anterior and posterior capsulectomy plus manipulation under anesthesia.
  - A radial head implant in place can be downsized to improve motion, but it should not be simply removed. The lateral ligament complex is preserved.
  - In our series, this was necessary in 11% of cases.
  - Synostosis around the elbow is another possible cause of rotational forearm stiffness.
  - A resection can be planned to improve motion.
  - CT scanning preoperatively helps to define the extent of the lesion. Resection is technically demanding.
  - Superficial and deep wound infection is possible after repair. Immediate and aggressive treatment is recommended with antibiotics initially and irrigation with débridement if rapid improvement is not seen.
  - Persistent instability is rare but may occur despite best efforts at repair.
  - Posttraumatic arthritis may be a long-term problem.

REFERENCES

DEFINITION

- This injury was initially reported by Giovanni Monteggia in 1814 as a fracture of the ulna associated with an anterior dislocation of the radial head.\(^6\)
- The term “Monteggia lesions” was coined by Bado to describe any fracture of the ulna associated with a dislocation of the radiocapitellar joint.\(^1\)
- The Bado classification of Monteggia lesions,\(^1\) with the Jupiter subclassification of type II fractures,\(^4\) is shown in Table 1.
- Equivalent injuries in adults
  - Variable pathology that is thought to be equivalent to injuries classified by the Bado system
  - Equivalent injuries do not always fall within the traditional definition of a Monteggia fracture in that they do not always have a concomitant radiocapitellar dislocation. Therefore, it can be argued that these injuries are not necessarily equivalent to Monteggia fractures.
- Type I and II injuries are the only ones that have equivalent injury patterns.

PATHOGENESIS

- The exact mechanism of injury for Monteggia fractures is controversial.
- Proposed mechanisms of injury for type I injuries include the following:
  - Direct blow to the posterior aspect of the elbow
  - Fall on outstretched arm with hyperpronated hand (forearm pronation levers radial head anteriorly)
  - Fall on outstretched arm
  - Violent contraction of biceps pulling radial head anteriorly
- Proposed mechanism for type II injuries: hypothesized to occur when a supination force tensions the ligaments that are stronger than bone
- Proposed mechanism for type III injuries: direct blow to the inside of the elbow with or without rotation

PATIENT HISTORY AND PHYSICAL FINDINGS

- The initial examination should systematically evaluate:
  - Skin integrity
  - Neurovascular status of the extremity
  - Bony injury
- Ulna fracture
  - Injury pattern
    - Noncomminuted
    - Comminution
    - Associated injury to key structural elements of the ulna (coronoid, olecranon)
- Radial head injury
  - Isolated dislocation without fracture
  - Radial head or neck fracture

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs (FIG 1): Orthogonal radiographs of the elbow, forearm, and wrist are required.
  - Ulna fracture is easily identified.
  - Radial head fracture or dislocation can be subtle, especially if radial head dislocation reduces.
- Computed tomography (CT) scans can be helpful to determine the extent of the bony injury and the location of fracture fragments. They are particularly helpful in fractures involving the coronoid, olecranon, and radial head.
- 3D CT reconstructions provide information on the spatial relationship of fracture fragments in comminuted fractures.

DIFFERENTIAL DIAGNOSIS

- Isolated ulna fracture
- Nightstick fracture
- Olecranon fracture
- Fracture-dislocation of the elbow ("terrible triad" injury)
- Transolecranon fracture-dislocation

NONOPERATIVE MANAGEMENT

- Monteggia fracture-dislocations in the adult population are generally treated surgically.
- Improved fixation methods and surgical technique have remarkably improved the results of surgery, making it a more reliable treatment option.

SURGICAL MANAGEMENT

Preoperative Planning

- The timing of surgery depends on the condition of the soft tissues and the availability of necessary equipment and personnel.
  - The surgeon should define all injuries that need to be addressed.
  - Equipment requirements:
    - Small fragment plates and screws or anatomic plating system
    - Minifragment system
    - Threaded Kirchner wires
    - Radial head replacement
    - Bone graft (allograft or autograft)

Patient Positioning

- Lateral decubitus position with the arm over a padded arm support (FIG 2)
- Supine positioning is an alternative approach (although it is not preferred because of difficulty in maintaining the arm across the chest). If this approach is used, a saline bag under the ipsilateral shoulder will help keep the arm across the chest.
**Table 1** Bado Classification of Monteggia Lesions, With Jupiter Subclassification of Type II Fractures

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Anterior dislocation of the radial head with fracture of the diaphysis of the ulna with anterior angulation of the ulna fracture (most common type of lesion)</td>
<td><img src="image1" alt="Illustration" /></td>
</tr>
<tr>
<td>II</td>
<td>Posterior or posterolateral dislocation of the radial head with fracture of the ulnar diaphysis with posterior angulation of the ulna fracture</td>
<td><img src="image2" alt="Illustration" /></td>
</tr>
<tr>
<td>IIA</td>
<td>Fracture at the level of the trochlear notch (ulna fracture involves the distal part of the olecranon and coronoid)</td>
<td><img src="image3" alt="Illustration" /></td>
</tr>
<tr>
<td>IIB</td>
<td>Ulna fracture is at the metaphyseal-diaphyseal junction, distal to the coronoid</td>
<td><img src="image4" alt="Illustration" /></td>
</tr>
<tr>
<td>IIC</td>
<td>Ulna fracture is diaphyseal</td>
<td><img src="image5" alt="Illustration" /></td>
</tr>
<tr>
<td>IID</td>
<td>Comminuted fractures involving more than one region</td>
<td><img src="image6" alt="Illustration" /></td>
</tr>
</tbody>
</table>
### Table 1 (continued)

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>III</td>
<td>Lateral or anterolateral dislocation of the radial head with fracture of the ulnar metaphysis</td>
<td><img src="image1.png" alt="Illustration" /></td>
</tr>
<tr>
<td>IV</td>
<td>Anterior dislocation of the radial head with a fracture of the proximal third of the radius and ulna at the same level</td>
<td><img src="image2.png" alt="Illustration" /></td>
</tr>
</tbody>
</table>


**FIG 1** - Plain AP and lateral radiographs typically demonstrate fracture pattern.

**FIG 2** - Lateral decubitus positioning is preferred.
**SURGICAL APPROACH**

- A midline posterior skin incision is placed lateral to the tip of the olecranon (TECH FIG 1A).
- Subcutaneous flaps are elevated on the fascia of the forearm. The medial antebial cutaneous nerve does not need to be identified if dissection is performed on the fascia of the flexor–pronator muscles since it is mobilized with the medial skin flap.
- The interval between the flexor carpi ulnaris (FCU) and anconeus is developed along the subcutaneous border of the ulna to expose the fracture site. The amount of dissection required for exposure is dictated by the fracture pattern and the type of fixation to be used (TECH FIG 1B).
- If the radial head needs to be addressed surgically, the anconeus can be mobilized more extensively through a Boyd approach (TECH FIG 1C). If the ulna fracture permits, the radial head can be fixed through the fracture bed of the ulna before definitive fixation of the ulna. Once the ulna is fixed, access to the radial head is not possible.

**TECH FIG 1 • A.** Posterior midline incision positioned just off the lateral aspect of the olecranon. **B.** Deep surgical interval uses the internervous plane between the anconeus and flexor carpi ulnaris. **C.** Exposure of the radial head can be accomplished by releasing the anconeus from the humerus and reflecting it proximally to expose the radial head.

**RADIAL HEAD MANAGEMENT**

- Radial head fractures are typically fixed before the ulna fracture is addressed. If the lesser sigmoid notch of the ulna is involved, determining radial length if radial head replacement is required can be difficult. Therefore, fractures are generally fixed before the ulna while replacement may need to be performed after ulnar fixation is completed in order to establish appropriate radial head sizing.
- Reconstructable fractures of the radial head are fixed (TECH FIG 2A,B).
- Unreconstructable fractures of the radial head are replaced (TECH FIG 2C).

**TECH FIG 2 • A,B.** Preoperative and postoperative radiographs demonstrating open reduction and internal fixation of the radial head component of the Monteggia fracture. (continued)
ULNA FRACTURE FIXATION

No Articular Involvement of the Ulnohumeral Joint
- Ulna fractures distal to the coronoid can be plated laterally or on the subcutaneous border of the ulna.
- Lateral plate placement is preferred by some to prevent hardware prominence.

Articular Involvement of the Ulnohumeral Joint
- Fractures extending proximal to the coronoid require the plate be placed on the subcutaneous border of the ulna to accommodate the complex geometry of this region.
- In general, the ulna fracture is reconstructed from distal to proximal. Ensure that any associated injury to the coronoid is identified and addressed.
- The fracture is reconstructed by fixing the distal fragments; this may require interfragmentary fixation or subarticular Kirschner wires (TECH FIG 3A). As fixation progresses proximally, reconstruction of the coronoid and greater sigmoid notch is performed. Particular attention is directed at anatomic reconstruction of the articular surface.
- Coronoid involvement with a Monteggia fracture-dislocation often extends distally into the volar cortex of the ulna, as opposed to the axial-plane fracture patterns characterized by Regan and Morrey\(^9\) (TECH FIG 3B).
- Larger fragments can be definitively fixed with antegrade lag screws from the dorsal aspect of the ulnar or can be provisionally fixed with threaded wires and ultimately definitively fixed once the plate is applied to the dorsal aspect of the ulna.
- Coronoid fracture exposure can typically be obtained through the olecranon fracture. If this does not provide sufficient exposure, the FCU can be elevated from the dorsal aspect of the ulna.
- The final fragment to be fixed is the olecranon fragment. The attached triceps will obscure fracture reduction if reduced before distal reconstruction (TECH FIG 3C).

Definitive fixation is performed with a dorsal plate. The triceps is partially split to allow the proximal aspect of the plate to oppose the olecranon (TECH FIG 3D).
The olecranon fragment with attached triceps is reduced and provisionally held with medial and lateral Kirschner wires pending definitive fixation. Final fixation for most Monteggia fractures is with a rigid plate applied to the dorsal cortex.

WOUND CLOSURE

- The tourniquet is deflated and hemostasis is obtained.
- The fascia between the FCU and anconeus is closed with interrupted absorbable 0 or 1 suture.
- Subcutaneous tissues are closed with 3-0 absorbable suture and skin is closed with staples.
- I prefer to close the wound over a drain placed in the subcutaneous tissues to avoid hematoma.
- A well-padded dressing is applied and an anterior splint is placed with the elbow in full extension.

PEARLS AND PITFALLS

Indications
- Monteggia fracture-dislocations in adults require surgical intervention.

Goals of treatment
- The first goal is to restore ulnar length and location of the radial head. When the articulation is involved, the goal is to obtain a concentric reduction with sufficient elbow stability that early range of motion is possible.
- The second goal is to avoid complications that compromise function.

Ulna fractures
- Fractures distal to the coronoid need only to be fixed such that ulnar length is re-established.
- When plating these fractures, avoiding malreduction of the ulna is critical to reduction of the radial head. Failure to re-establish ulnar geometry can result in persistent subluxation or dislocation of the radial head (FIG 3).
- Fractures involving the articulation require stable fixation to re-establish a competent joint.

Radial head
- Radial head fractures are fixed or replaced.

Physical therapy
- Early range of motion is the goal of treatment but may be delayed if fixation is questionable.

FIG 3 • Malunion of the ulna with resulting apex dorsal angulation results in dislocation of the radial head.
POSTOPERATIVE CARE
- The arm is splinted in full extension to take pressure off the posterior soft tissues.
- If a drain is used, the splint and dressing are removed when the drain output is less than 30 mL in 8 hours. If no drain is used, the dressing is removed on postoperative day 1.
- Active or active-assisted flexion and gravity-assisted extension is begun once the surgical dressings are removed.
- If fixation is tenuous because of poor-quality bone or comminution, mobilization is delayed.

OUTCOMES
- Historically, the results of operative treatment of Monteggia fracture-dislocations have been unpredictable.\(^3,7,8,11\)
- The advent of rigid internal fixation has improved the results of operative treatment.\(^2,4,7\)
- Certain factors have been associated with a poor clinical result:\(^5\):
  - Bado type II injury
  - Jupiter type Ila injury
  - Fracture of the radial head
  - Coronoïd fracture
  - Complications requiring further surgery

COMPLICATIONS
- Complications associated with Monteggia fracture-dislocations occur with frequency. A multicenter study evaluating Monteggia fracture-dislocations in adults demonstrated complications in 43% of the patients treated, with an unsatisfactory outcome in 46% of the patients treated.\(^10\)
- Radial nerve palsy
  - Most commonly posterior interosseous nerve
  - Causes of injury include:
    - Compression at the arcade of Frosche
    - Direct trauma
    - Traction with lateral displacement of the radial head
- Most common with type III fractures
- Complete resolution typically occurs.
- Malunion
  - Most common in type II fractures with volar comminution that is not appreciated or addressed
  - If radial head subluxation persists, malunion must be considered.
- Nonunion
  - Causes of nonunion include:
    - Infection
    - Inadequate internal fixation
    - Compression plate fixation required, particularly if fracture is comminuted
    - Semitubular and reconstruction plates are not structurally strong enough.
- Radioulnar synostosis
  - Seen with high-energy injuries with associated comminution
  - Higher incidence if radial head fracture associated with ulna fracture at the same level
  - Boyd approach implicated since the radius and ulna are exposed through the same incision

REFERENCES
DEFINITION
- Lateral collateral ligament (LCL) injuries most often occur after significant elbow trauma, most commonly dislocation.
- Attenuation of the LCL can also occur after multiple surgeries to the lateral side of the elbow and after multiple corticosteroid injections and has recently been reported to occur in patients who have residual cubitus varus after malunion of supracondylar humerus fractures.
- Significant injury to the LCL complex can result in posterolateral rotatory instability (PLRI).

ANATOMY
- The LCL is made up of four major components: the lateral ulnar collateral ligament (LUCL), also called the radial ulnohumeral ligament (RUHL); the radial collateral ligament proper (RCL); the annular ligament; and the accessory collateral ligament (FIG 1).
- The ligaments originate from a broad band over the lateral epicondyle, deep to the extensor muscle mass, and separate distally into more discrete structures.
- The RUHL is the most important stabilizer against PLRI, and it attaches distally on the supinator crest of the ulna.
- The RCL is more anterior and primarily resists varus stress.
- The annular ligament sweeps around the radial head and stabilizes the proximal radioulnar joint.
- The capsule acts as a static stabilizer, especially at the anterior portion, while the arm is extended.
- The anconeus and extensor muscle groups act as dynamic stabilizers.

PATHOGENESIS
- Multiple studies have shown that injury to the LCL can lead to PLRI, which is the first stage in elbow instability that can lead to frank elbow dislocation.
- It is controversial whether injury to the RUHL alone can lead to PLRI or whether further injury to the LCL complex is necessary.
- When the forearm is supinated and slightly flexed, a valgus stress with an attenuated LCL causes the ulnohumeral joint to rotate, compresses the radiocapitellar joint, and ultimately causes the radial head to subluxate or dislocate posteriorly.

NATURAL HISTORY
- PLRI is not a new condition, but it has only recently been described and studied.
- The prevalence and natural history of this condition are currently not known.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients typically report trauma but may have had recurrent lateral epicondyliitis or previous surgery.
- Elderly patients may not have frank dislocation of the elbow, but 75% of patients younger than 20 years report elbow dislocation.
- Patients report mechanical-type symptoms (clicking, popping, and slipping) during elbow supination and extension and rarely report recurrent dislocations.
- Physical examination can be difficult; provocative tests are described below. It is often necessary to conduct these tests with the patient under anesthesia or with the aid of fluoroscopy.
- Inspection for effusion: With acute injuries, effusion is likely to be present, but in more chronic situations, it may be absent.
- Range of motion (ROM): Locking of the elbow could represent loose bodies; stiffness may indicate intrinsic capsular contracture.

FIG 1 • A. The lateral collateral ligament complex is made up of four major components: the lateral ulnar collateral ligament, also called the radial ulnohumeral ligament; the radial collateral ligament proper; the annular ligament; and the accessory collateral ligament. B. Osseous anatomy of the lateral collateral ligament insertion.
Supine lateral pivot-shift test: When the elbow is slightly flexed, the radial head can be palpated to subluxate or frankly dislocate, and as the elbow flexes past 40 degrees, it relocates, often with a palpable clunk. This test is difficult to perform on an awake patient because often apprehension is felt and the patient does not allow the test to continue.

Prone pivot-shift test: Radial head or ulnohumeral subluxation constitutes a positive test, same as the supine lateral pivot-shift test. Examination under anesthesia may be required.

Push-up test: Reproduction of the patient’s symptoms of apprehension during supination and not pronation constitutes a positive test. Inability to complete the push-up also constitutes a positive test.

Chair push-up: Elicited pain constitutes a positive test.

Table-top relocation test: Elicited pain or apprehension as the elbow reaches 40 degrees constitutes a positive test.

Elbow drawer test: Ulnohumeral subluxation constitutes a positive test.

A thorough examination of the elbow should also be completed to rule out other injuries.

Valgus instability with the forearm in pronation and 30 degrees of flexion suggests medial collateral ligament (MCL) injury.

Lateral epicondylitis or radial tunnel syndrome can present with tenderness over the proximal extensor mass and with resisted extension of the wrist (Thompson test) and long finger.

Loose bodies may present with crepitus or locking of the elbow during ROM.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standard anteroposterior (AP) and lateral view radiographs often indicate normal findings but may reveal small lateral epicondyle avulsion fractures and radiocapitellar wear.
- Stress AP and lateral view radiographs may reveal widening of the ulnohumeral joint and posterior subluxation of the radial head (**FIG 2A**).
- Magnetic resonance imaging (MRI), especially with intra-articular contrast enhancement, may reveal injuries to the LCL complex. The proximal extensor mass requires attention (**FIG 2B**).

Diagnostic arthroscopy of the elbow can be performed, although we do not recommend routine diagnostic arthroscopy for this injury.

The drive-through sign occurs when the scope can easily be “driven through” the lateral gutter into the ulnohumeral joint from the posterolateral portal.

The pivot-shift test also can be performed during arthroscopy, and the radial head will subluxate posteriorly.

**DIFFERENTIAL DIAGNOSIS**

- Lateral epicondylitis
- Loose bodies
- Elbow fracture-dislocation
- MCL injury
- Radial head dislocation

**NONOPERATIVE MANAGEMENT**

- If the injury is diagnosed early, immobilization in a hinged elbow brace in pronation for 4 to 6 weeks may prevent chronic instability.
- Removable neoprene sleeves may offer support.
- A trial of elbow extensor strengthening can be performed.

**SURGICAL MANAGEMENT**

**Indications**

- Recurrent symptomatic PLRI despite nonoperative treatment

**Preoperative Planning**

- All imaging studies should be reviewed and informed consent obtained.
- An examination of the elbow should be performed with the patient under anesthesia, especially the pivot-shift test.
- If there is any doubt regarding the diagnosis, a pivot-shift test should be performed under fluoroscopy.

**Positioning**

- The patient is placed supine on the operating room table.
- The arm can be placed on an arm board or across the patient’s chest with a sterile tourniquet applied to the upper arm and the entire arm draped free (**FIG 3**).
- During the approach, the forearm should be pronated to protect the posterior interosseous nerve.
Approach

- The main approach is the Köcher interval between the anconeus and extensor carpi ulnaris muscles.
- This can be accomplished through a lateral skin incision or through a utilitarian posterior incision.
- A posterior incision should be considered if a medial approach will also be needed to repair concomitant ligamentous or bony injury.

FIG 3 • The patient is placed supine on the operating room table. The arm is placed on an arm board with a sterile tourniquet applied to the upper arm and the entire arm draped free. During the approach, the forearm should be pronated to protect the posterior interosseous nerve.

FIGURE 8 YOKE TECHNIQUE

Surgical Approach

- A 10-cm incision is made over the Köcher interval.
- The interval between the anconeus and the extensor carpi ulnaris is developed, and the remainder of the LCL complex is identified along with the supinator crest and the lateral epicondyle.
- The lateral epicondyle and 2 cm of the supracondylar ridge are exposed.

Tunnel Placement

- Two drill holes for the graft insertion site are made in the ulna.
- One is drilled near the tubercle of the supinator crest (palpate in supination and varus stress), the other 1.25 cm proximal to that, near the insertion of the annular ligament (TECH FIG 1A).
- A suture is passed through the two holes and tied to itself. The suture is then held up against the lateral epicondyle as the elbow is ranged in flexion and extension to determine its isometric point.
- The isometric ligament insertion occurs at the point where the suture does NOT move.
- The isometric point is usually more anteroinferior than expected (TECH FIG 1B,C).
- A Y-shaped tunnel is made with the base exiting at the isometric point.
- The hole is widened to accept a three-ply graft. (Palmaris longus is usually harvested; if not present, gracilis or allograft is used.) A 16-cm graft is usually sufficient.

Graft Passage and Tensioning and Wound Closure

- The graft is passed through the ulnar tunnel with enough length to just reach the isometric point.
- The end is then sutured to the long end of the graft (the Yoke stitch).
- The long end is then passed through the isometric point and exits the superior humeral tunnel (TECH FIG 2A).
The long end is wrapped around the supracondylar ridge and passed through the distal tunnel, exiting back through the isometric point and into the ulnar tunnel.

The graft is then tensioned in 40 degrees of flexion, full pronation, and axial tension.

If the graft is not long enough to reach the ulnar tunnel, it can be sutured back to itself (TECH FIG 2B).

The reconstruction can be reinforced by weaving a no. 2 Fiberwire suture (Arthrex, Inc., Naples, FL) from distal to proximal through the course of the figure 8, thus sewing the graft to itself.

Plicate the anterior and posterior capsule as needed.

The extensor origin is repaired to the lateral epicondyle, and the extensor carpi ulnaris fascia is reapproximated to the anconeus muscle with absorbable sutures.

### TECH FIG 1
C. A suture is passed through the two holes and tied to itself. The suture is then held up with a hemostat against the lateral epicondyle as the elbow is ranged in flexion and extension to determine its isometric point. No movement occurs if the suture is at the isometric point.

### TECH FIG 2
A. A Y-shaped tunnel is made with the base exiting at the isometric point (3). The hole is widened to accept a three-ply graft. The tendon graft is passed through the ulnar tunnel (1→2) with enough length to just reach the isometric point. The end is then sutured to the long end of the graft (the Yoke stitch). The long end is then passed through the isometric point and exits the superior humeral tunnel (3→4).
B. The long end is then passed through the distal tunnel, exiting back through the isometric point (5→3) and into the ulnar tunnel (3→1→2). The graft is then tensioned in 40 degrees of flexion, full pronation, and axial tension. If the graft is not long enough to reach the ulnar tunnel, it can be sutured back to itself.

### SPLIT ANCONEOUS FASCIA TRANSFER
- We have developed a reproducible technique for LCL reconstruction that has proved biomechanical strength and reproducibility.
- Advantages include using only local autograft tissue and the minimal creation of bone tunnels.\(^1\)\(^2\)

### Surgical Approach
- A 6- to 8-cm skin incision is made over the Köcher interval, exposing the underlying Köcher interval between the extensor carpi ulnaris and anconeus (TECH FIG 3A,B).
- The interval between the anconeus and extensor carpi ulnaris muscles is developed, taking care to preserve the remainder of the underlying LCL complex.
- The annular ligament, lateral epicondyle, and 2 cm of supracondylar ridge are isolated (TECH FIG 3C).

### Graft Preparation
- The anconeus and distal triceps fascia are isolated in continuity. A 1.0-cm-wide by 8.0-cm-long band of fascia is mobilized off the underlying muscle, leaving the ulnar insertion intact (TECH FIG 4A,B).
A 6- to 8-cm skin incision is made over the Kocher interval. SR, supracondylar ridge; L, lateral epicondyle; RH, radial head; UC, ulnar crest. The underlying Kocher interval between the extensor carpi ulnaris (E) and anconeus (A) is exposed. The interval between the anconeus (A) and the extensor carpi ulnaris (E) is developed, taking care to preserve the remainder of the underlying lateral collateral ligament complex (held in forceps). The annular ligament (AL), lateral epicondyle (L), and 2 cm of the supracondylar ridge are isolated.

The band is then divided longitudinally into two bands of equal width (TECH FIG 4C).

The anterior band is passed through an incision just distal to the annular ligament while the posterior band is passed under the anconeus muscle (TECH FIG 4D).

The isometric point of the lateral epicondyle is then located by holding the two bands against the epicondyle while ranging the elbow (TECH FIG 4E).

The final lengths of the fascial bands are estimated by holding the bands along their respective paths. The bands are then trimmed appropriately to prevent them from “bottoming out” prematurely in the humeral docking tunnel.

Separate Krackow sutures are placed in each band with no. 0 FiberWire suture.

**Tunnel Preparation**

A 5-mm round burr is used to create a 1.5-cm-long (depth) docking tunnel into the humerus at the isometric point. A 1-mm side-cutting burr is then used to make anterior and posterior bone bridge holes. The holes are separated by 1.5 cm. Individual suture lassos are placed from proximal to distal into the docking tunnel from the separate humeral tunnels (TECH FIG 5).
Graft Passage and Tensioning and Wound Closure

- The anterior band sutures are brought out the anterior humeral exit hole by using suture passers. The posterior band passes superficial to the annular ligament, and its sutures are brought out the posterior humeral exit tunnel.
- The ends of the fascial bands are docked into the humeral tunnel, and the grafts are tensioned with the elbow in 40 degrees of flexion, in full pronation, and with a valgus stress.
- The sutures are then tied over the bony bridge on the supracondylar ridge (TECH FIG 6A).
- The extensor origin is then repaired to the lateral epicondyle and the extensor carpi ulnaris fascia is reapproximated to the anconeus muscle with absorbable sutures.
- The skin is closed with a running subcuticular suture (TECH FIG 6B).
TECH FIG 6 • A. The ends of the fascial bands are docked into the humeral tunnel, and the grafts are tensioned with the elbow in 40 degrees of flexion, full pronation, and valgus stress. Sutures are then tied over the bony bridge on the supracondylar ridge (clamp on posterior band). B. The incision is closed with subcuticular suture.

DOCKING TECHNIQUE

- As previously discussed, the Köcher approach is used for the docking technique.
- Preparation of the ulnar drill holes is described in the section on the figure 8 yoke technique elsewhere in this chapter.
- A 5-mm round burr is used to create a 1.5-cm-long (depth) docking tunnel into the humerus at the isometric point. A 1-mm side-cutting burr is then used to make anterior and posterior bone bridge holes. The holes are separated by 1.5 cm. Individual suture lassos are placed from proximal to distal into the docking tunnel from the separate humeral tunnels (see Tech Fig 5).
- After passage of the graft through the ulnar tunnels, the final lengths of the two graft strands are estimated by holding the strands against the docking tunnel with the arm in the “reduced” position of 40 degrees of flexion, full pronation, and axial tension.
- The strands are then trimmed appropriately to prevent the strands from “bottoming out” prematurely in the humeral docking tunnel.
- Separate Krackow sutures are placed in each graft strand with no. 0 FiberWire suture for 1 cm.
- The anterior graft strand sutures are brought out the anterior humeral exit hole by using suture passers. The posterior graft strand sutures are brought out the posterior humeral exit tunnel.
- The ends of the humeral graft portion are docked into the humeral tunnel, and the grafts are tensioned with the elbow in 40 degrees of flexion, in full pronation, and with a valgus stress.
- The sutures are then tied over the bony bridge on the supracondylar ridge.
- Standard incision closure is performed.

DIRECT REPAIR

- As previously discussed, the Köcher approach is used for direct repair.
- If the LCL complex is intact but avulsed from its ulnar or humeral attachments (or both), it can be directly repaired to its correct anatomic location with suture anchors or bone tunnels.
- A running locked no. 2 FiberWire suture is placed into the detached LCL complex and repaired back to its origin on the lateral epicondyle through the anterior and posterior drill holes (TECH FIG 7).
- A careful repair of the extensor origin and the interval between the anconeus and the extensor carpi ulnaris is performed.

TECH FIG 7 • Primary lateral ulnar collateral ligament repair. Running locked suture placed through detached lateral ulnar collateral ligament. A relaxing incision can be made at its attachment to the base of the annular ligament. Repair through drill holes in the lateral epicondyle.
PEARLS AND PITFALLS

Indications
- Iatrogenic causes (e.g., “tennis elbow” surgery) very common
- Careful history and physical examination to exclude other pathologic conditions
- History of numerous lateral elbow corticosteroid injections

Split anconeus fascia technique: exposure
- Isolate Köcher interval; fatty stripe within interval.
- Anconeus fibers oblique to extensor carpi ulnaris
- Identify LCL disruption.
- Isolate annular ligament; protect posterior interosseous nerve.

Split anconeus fascia preparation
- Be careful to harvest long enough fascial band (proximal to humeral bone tunnels).
- Be careful not to detach from ulnar insertion.
- Isolate LCL complex isometric point of origin.
- Harvest fascial band in line with old LUCL.

Figure 8 yoke technique
- Carefully isolate isometric point on lateral epicondyle, usually more anterior and inferior; err on inferior placement.
- Make ulnar tunnel perpendicular to direction of LUCL.
- Chamfer bone tunnels to prevent graft impingement and breakage.

Bone tunnel preparation
- Maintain sufficient bony bridge between tunnels.
- Smooth edges to prevent graft irritation.

Arm position for final graft tensioning
- 40 degrees of elbow flexion
- Full pronation
- Axial load, valgus stress

POSTOPERATIVE CARE

- Stage I (0 to 3 weeks)
  - Elbow immobilization in posterior splint or brace at 40 degrees of flexion
  - Wrist and hand isometrics as tolerated
  - Shoulder active and passive ROM
- Stage II (3 to 6 weeks)
  - Hinged elbow brace or orthoplast splint, with limits set by surgeon
  - Begin flexor–pronator isometrics
  - Continue with wrist and hand strengthening
  - Continue shoulder as above
  - Active-assisted ROM: 20 to 120 degrees of flexion; keep forearm pronated at all times
- Stage III (6 to 12 weeks)
  - Discontinue immobilization
  - Passive ROM and active-assisted ROM to full motion, including supination
  - Begin unrestricted strengthening of flexor–pronators and extensors
- Stage IV (3 to 6 months)
  - Avoid varus stress to elbow and ballistic movement in terminal elbow ranges
  - Begin shoulder strengthening with light resistance (emphasis on cuff)
  - Start total body conditioning
  - Terminal elbow stretching in flexion and extension
  - Resistive elbow exercises as tolerated

OUTCOMES

- Nestor et al. have shown successful functional outcomes in patients using the figure 8 reconstruction technique with reproducible results.

- Our early experience with the split anconeus fascia reconstruction technique has shown excellent results, with no failures to date in 22 patients at an average follow-up of 2 years. All elbows have achieved stability without loss of motion.

COMPLICATIONS

- Recurrent elbow instability
- Elbow stiffness
- Infection
- Graft harvest site morbidity (if remote autograft is used for reconstruction)
- Humerus stress fracture through bone tunnels
- Ulnar stress fracture through bone tunnels
- Bone bridge compromise

REFERENCES

2. Chebli CM, Murthi AM. Split anconeus fascia transfer for reconstruction of the elbow lateral collateral ligament complex: anatomic and biomechanical testing. 22nd Open Meeting of the American Shoulder and Elbow Surgeons. Chicago, IL, March 2006.
DEFINITION
- Primary osteoarthritis of the elbow is a relatively uncommon but limiting disorder that affects mostly middle-aged men who use the upper extremity in a repetitive fashion. Typically, patients are heavy manual workers or athletes. Osteoarthritis affects the elbow less frequently than other major joints.
- Early stages of arthritis of the elbow may be characterized primarily by pain at the extremes of motion, with some loss of terminal extension and flexion. Some patients present with pain carrying an object with the arm in extension. More advanced stages may present with pain and crepitus throughout the range of motion, stiffness, or locking. Rotation of the forearm may be spared, depending on radiohumeral involvement.
- Radiographs show osteophyte formation on the coronoid and olecranon but relatively preserved joint space at the early stages. More advanced stages may be associated with significant joint space narrowing.
- Multiple operative techniques have been described for treatment of primary osteoarthritis of the elbow: débridement arthroplasty, interposition arthroplasty, the Outerbridge-Kashiwagi procedure, arthroscopic débridement, and total elbow replacement.
- Ulnohumeral (Outerbridge-Kashiwagi) arthroplasty was first described in 1978 and became popular a few years later. It is based on a posterior approach to the elbow, removal of olecranon spur and bony overgrowth of the olecranon fossa, and drilling of a hole in this fossa with a trephine to expose the anterior capsule and excise the coronoid osteophyte.

ANATOMY
- The elbow joint consists of three separate articulations: the ulnohumeral, the radiocapitellar, and the proximal radioulnar joints.
- The elbow has two main functions: position the hand in space and stabilize the upper extremity for motor activities and power.
- The normal range of elbow flexion–extension is 0 to 150 degrees and normal forearm pronation–supination is 80 and 80 degrees.
- A 100-degree flexion–extension arc of motion, from 30 to 130 degrees, is quoted for normal activities of daily living. Functional forearm rotation is quoted as 100 degrees, with 50 degrees pronation and 50 degrees supination.
- The condyles articulate at the elbow joint, as the trochlea medially and the capitellum laterally. The articular surface is angled about 30 degrees anterior to the axis of the humeral shaft and has a slight valgus position, about 6 degrees, compared to the epicondylar axis.
- The coronoid fossa and the olecranon fossa, just proximal to the articular surface, accommodate the coronoid process and olecranon process of the ulna in the extremes of flexion and extension, respectively.
- The olecranon and coronoid process coalesce to form the greater sigmoid notch, the articulating portion of the proximal ulna. It is often not completely covered with articular cartilage centrally.

PATHOGENESIS
- Symptomatic osteoarthritis of the elbow has been found to affect about 2% of the general population and represents only 1% to 2% of all patients diagnosed with degenerative arthritis.
- It has a predilection for males, with a ratio of 4 or 5 to 1. It is most commonly seen in middle-aged and older patients.
- The majority of patients experience symptoms in their dominant extremity.
- The exact etiology of primary degenerative elbow arthritis is still unknown. It is generally attributed to overuse. About 60% of patients report employment or hobbies or sports requiring repetitive use of the limb. The few younger patients who present likely have a predisposing condition such as osteochondritis dissecans.
- There are characteristic pathologic changes that occur within the elbow joint: osteophyte formation on the olecranon, olecranon fossa, coronoid, and coronoid fossa.
- In early stages the joint space is relatively preserved. The periarticular bone is typically hard.
- Very often, loose bodies may be present into the joint and cause clicking or locking of the elbow, or both.
- Capsular contracture and fibrosis of the anterior capsule contribute to loss of extension.

NATURAL HISTORY
- Early stages of primary osteoarthritis of the elbow are characterized by pain at the extremes of motion and some loss of terminal extension and flexion. As the severity of the arthritis progresses, pain, stiffness, and loss of range of motion increase.
- When symptoms do not improve with nonoperative treatment, surgical intervention is indicated.
- Because osteoarthritis is a progressive disease, symptoms and pathologic condition may recur. The most common problem is recurrence of impingement pain and flexion contractures.
- Prognostic factors include the etiology of arthritis, the degree of motion loss, mid-arc versus end-range discomfort, the presence of loose bodies, mechanical symptoms, and the presence or absence of cubital tunnel syndrome.
PATIENT HISTORY AND PHYSICAL FINDINGS

- The typical patient with primary degenerative elbow arthritis is a man older than 45 years of age, exposed to repetitive manual labor, who presents with pain at the end ranges of motion, especially in extension.
- Younger patients also may provide a history of sports such as weightlifting, boxing, and other throwing-intensive activities. Arthritic elbows in athletes frequently will include a spectrum of pathologic changes, such as loose bodies and bone spurs.
- Some patients report a history of chronic use of crutches or wheelchairs.
- The chief complaint is pain, especially terminal extension pain, as a result of mechanical impingement.
- Patients usually feel pain while carrying objects with the elbow in full extension.
- The intensity of pain is mild to moderate and only occasionally is described as severe.
- Pain is not usually noted in the mid-range of motion until later stages of arthritis.
- Loss of motion is the most common presenting symptom.
- Loss of extension is often partially the result of posterior olecranon and humeral osteophytes or anterior capsule contracture.
- Loss of flexion is secondary to osteophytes on the coronoid or its fossa and to loose bodies.
- Supination–pronation is not restricted or is only minimally restricted, owing to limited involvement of the radiohumeral joint.
- Catching or locking may be present with articular incongruity, or when loose bodies are present.
- Crepitus may be present throughout the range of motion.
- Swelling may occur but is not typical.

- Ulnar nerve symptoms may also be present owing to excessive osteophyte formation. They should actively be sought out because they may influence treatment decisions and even direct the surgical approach.
- Physical examination may reveal a positive Tinel sign and a positive elbow flexion test, with decreased sensation and weakness in the ulnar nerve distribution. Cubital tunnel syndrome may be present in up to 20% of patients.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Anteroposterior (AP), lateral, and oblique radiographs (FIG 1) are diagnostic and illustrate characteristic features of the condition.
- The AP view should be taken with the beam perpendicular to the distal humerus for distal humerus pathology and perpendicular to the radial head for proximal forearm pathology. These views will show ossification and osteophyte formation of the olecranon and coronoid fossa.
- The lateral view should be taken in 90 degrees of flexion with the forearm in neutral rotation. This view will show an anterior osteophyte on the coronoid fossa and process and a posterior osteophyte on the olecranon fossa and process.
- The lateral oblique view provides better visualization of the radiocapitellar joint, medial epicondyle, and radioulnar joint.
- The medial oblique view provides better visualization of the trochlea, olecranon fossa, and coronoid tip.
- A cubital tunnel view may be useful if there is ulnar nerve symptomatology.
- A lateral tomogram and computed tomography are helpful for preoperative planning to assess the presence and location of loose bodies and subtle osteophyte formation (especially in earlier stages).

FIG 1 • A. Lateral radiograph of a 50-year-old heavy laborer’s elbow. The patient had severe pain at the extremes of motion. The radiograph reveals characteristic osteophytes of the olecranon and of the coronoid process. B. AP radiograph of the elbow (same patient). This view shows ossification and osteophytes of the olecranon and coronoid fossa. C. Lateral oblique radiograph. This view provides better visualization of the radiocapitellar and radioulnar joint. There is an osteophyte at the tip of the olecranon, which causes pain during full extension.
DIFFERENTIAL DIAGNOSIS
- Posttraumatic arthritis
- Rheumatoid (inflammatory) arthritis

NONOPERATIVE MANAGEMENT
- Nonoperative treatment may be helpful in the early stages.
- Patients should limit activities that require heavy elbow use.
- Physical therapy is used to maintain range of motion and strength. Modalities such as heat and cold may be effective.
- Nonsteroidal anti-inflammatory drugs can decrease pain and are of some value. Intra-articular corticosteroid injections may also improve symptoms, but their benefits are usually temporary.
- Avoidance of pressure on the cubital tunnel and avoidance of prolonged elbow flexion are recommended if ulnar nerve symptoms are present.

SURGICAL MANAGEMENT
- Surgical treatment is indicated when symptoms do not improve with appropriate nonoperative management.
- The procedure is indicated in patients with pain in terminal extension or flexion (or both), radiographic evidence of coronoid or olecranon osteophytes (or both), ulnar neuropathy, and functional limitations due to pain or loss of motion.
- The procedure is contraindicated in patients with pain throughout the entire arc of motion, marked limitation of motion with an arc of less than 40 degrees, or severe involvement of the radiohumeral or proximal radioulnar joints.

Preoperative Planning
- It is very important to carefully review all radiographs (AP, lateral, oblique) before surgery to assess the severity of arthritic changes and evaluate for the presence of loose bodies. A lateral tomogram or CT scan may assist in this evaluation. Care should be taken not to overlook any loose bodies, as these may lead to persistent mechanical symptoms postoperatively.
- Specific attention should be paid to the presence of ulnar nerve pathology. If present, this must be addressed at the time of the procedure.

Positioning
- There are two options for positioning:
  - The patient may be positioned in the lateral decubitus position with the elbow flexed at 90 degrees and resting on an armrest.

EXPOSURE
- After the skin incision is made, the subcutaneous tissue is reflected from the medial aspect of the triceps.
- The ulnar nerve is identified and decompressed at the cubital tunnel if there is evidence of ulnar nerve pathology.
- The triceps muscle-tendon unit is split longitudinally or reflected.
- The triceps is elevated from the posterior aspect of the distal humerus by blunt dissection using a periosteal elevator.
- A capsulotomy is then performed (TECH FIG 1).
Chapter 42  ULNOHUMERAL (OUTERBRIDGE-KASHIWAGI) ARTHROPLASTY

**OSTEOPHYTE REMOVAL AND OLECRANON RESECTION**

- To minimize impingement in extension, the posterior osteophyte and the tip of the olecranon are removed using an oscillating saw. An osteotome is then used to complete the resection. The orientation of the osteotomy should be parallel to each face of the trochlea.

- A rongeur is used to smooth the edges.

- A hole is drilled in the olecranon fossa to gain access to the anterior elbow compartment and the coronoid process. This requires removal of osteophytes around the olecranon fossa (TECH FIG 2).

**TECH FIG 1** • The triceps muscle has been split to expose the posterior joint. The prominent olecranon osteophyte and the tip of the olecranon process are then removed. The initial cut should be made with an oscillating saw to provide optimal orientation. The osteotomy of the olecranon is completed with an osteotome parallel to each face of the trochlea.

**FORAMINECTOMY**

- A 1.5-cm neurosurgical dowel is applied to a reaming drill bit, and a drill hole is developed. Proper placement of this foraminectomy is of great importance. The dowel should follow the curvature of the trochlea.

- Once the foraminectomy is complete, a core of bone is removed from the distal humerus. This may include osteophytes from the anterior aspect of the joint (TECH FIG 3A,B).
TECH FIG 3 • A,B. Once the foraminectomy is completed, the core of bone is removed from the distal humerus. This allows access to the anterior elbow compartment and to the coronoid. At this time, loose bodies of the anterior compartment may be identified and removed. C. With maximum elbow flexion, the anterior osteophyte from the coronoid process is removed, using a curved osteotome. D. An instrument is then introduced through the foramen and the osteophyte and a portion of the coronoid are removed.

This hole is used to clean debris and remove loose bodies from the anterior aspect of the elbow (TECH FIG 3C,D).

With maximum elbow flexion, the anterior osteophyte from the coronoid process is removed using a curved osteotome.

Occasionally it is necessary to strip the anterior capsule from the anterior humerus using a blunt periosteal elevator, to regain better extension.

Care must be taken to ensure that no osteophytes or loose bodies are overlooked.

Bone wax is used to cover the margins of the foramen, and Gelfoam is inserted into the defect to fill the dead space.

The wound is meticulously irrigated and closed in standard fashion.

The elbow is carefully manipulated to maximize the total arc of motion.

PEARLS AND PITFALLS

Indications

- Primary osteoarthritis of the elbow presenting with pain at the extremes of motion due to osteophyte formation on the olecranon or coronoid process (or both) and in the olecranon or coronoid fossa (or both)

Contraindications

- Severe involvement of the radiohumeral joint
- Pain throughout the entire arc of motion

Assessment

- Careful selection of patients is important.
- Appropriate imaging studies should be obtained to identify all loose bodies or osteophytes. A preoperative lateral tomogram may be indicated.
- The surgeon should always evaluate for coexisting ulnar nerve pathology, which should be addressed during surgery.

Operation

- Proper placement of foraminectomy
- Meticulous inspection of posterior and anterior aspects of the joint
- Removal of all loose bodies and osteophytes
POSTOPERATIVE CARE

- A splint is applied with the elbow in 15 degrees of extension for 1 week.
- Active range of motion is allowed 7 to 10 days after surgery.
- The patient is re-evaluated at 3 weeks, 6 weeks, and 3 months after surgery.
- Continuous passive motion can be initiated on the day of surgery and is discontinued after 3 weeks.

OUTCOMES

- A review of the literature shows satisfactory results in over 80% of patients.
- Satisfactory pain relief is achieved in about 90% of patients.
- Extension improves by about 10 to 15 degrees and flexion improves by about 10 degrees. Overall improvement in the motion arc is about 20 to 25 degrees (FIG 3).
- There have been no reports of postoperative instability.

COMPLICATIONS

- The complication rate for this procedure is very low, in contrast to most reconstructive procedures of the elbow.
- The recurrence rate is less than 10%.
- Iatrogenic ulnar nerve palsy is unusual, but can occur as a result of overzealous use of retractors intraoperatively.
- Improper placement of the foraminectomy may result in a column fracture.

REFERENCES

DEFINITION
- Extrinsic elbow contracture refers to elbow stiffness secondary to fibrosis, thickening, and, occasionally, ossification of the elbow capsule and periarticular soft tissues.
- In contrast to intrinsic contracture, the articular surface is either uninjured or minimally involved, without the presence of intra-articular adhesions or articular cartilage destruction.
- While a distinction is made between extrinsic and intrinsic causes of contracture, these entities often overlap.

ANATOMY
- The elbow is a compound uniaxial synovial joint comprising three highly congruous articulations.
- The ulnohumeral joint is a ginglymus, or hinge, joint. The radiocapitellar and proximal radioulnar joints are gliding joints.
- All three articulations exist within a single capsule and are further stabilized by the proximity of the articular surface and capsule to the intracapsular ligaments and overlying extracapsular musculature.

PATHOGENESIS
- The propensity for elbow stiffness after even trivial elbow trauma is well recognized. After even seemingly trivial injuries, the capsule can undergo structural and biochemical alterations leading to thickening, decreased compliance, and loss of motion.
- Causes of extrinsic elbow contracture include capsular contracture, damage to and fibrosis of the flexor–extensor muscular origins, collateral ligament scarring, heterotopic bone, and skin contracture.
- Prolonged immobilization after trauma may be a separate risk factor for the development of stiffness.

NATURAL HISTORY
- Little consensus exists regarding the natural history of capsular contracture. It is felt that appropriate recognition and treatment of acute elbow injuries, avoidance of prolonged immobilization, and early active range of motion may limit the severity of posttraumatic extrinsic contracture.
- Patients typically do not tolerate elbow stiffness well since adjacent joints do not provide adequate compensatory motion.
- Morrey\(^\text{10}\) showed that the performance of most activities of daily living requires a functional arc of motion from 30 to 130 degrees.
- Vasen and colleagues\(^\text{11}\) have demonstrated that volunteers with uninjured elbows may adapt to a functional arc of motion from 70 to 120 degrees to perform 12 tasks of daily living.
- Patients typically request treatment for elbow contracture when loss of extension approaches 40 degrees and flexion does not exceed 120 degrees.
- Patients who do not improve with a concerted effort at nonoperative treatment often require surgical release.
- Stiffness of the elbow typically is incited by soft tissue trauma, hematrhrosis, and the patient’s response to pain. Elbow trauma may cause tearing and contusion of the periarticular soft tissues. The patient typically holds the injured elbow in a flexed position to reduce pain. A fibrous tissue response then ensues within the hematoma and damaged muscular tissues. This fibrous tissue may ossify. In addition, overly aggressive therapy may further exacerbate these injuries, potentiating the cycle of pain, swelling, and limitation in motion that leads ultimately to frank contracture.
- Collateral ligament injury may contribute to contracture. Primary fibrosis may develop within the collateral ligaments because of the initial injury. Alternatively, secondary fibrosis may result from immobilization and scar formation.
- Significant injury to the anterior joint capsule and the overlying brachialis muscle may also result in capsular hypertrophy and fibrotic reaction contributing to ankylosis. This is particularly common in association with fracture-dislocations of the elbow.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The cause of contracture should generally be easily elucidated from the history. Particular notation should be made of concomitant injuries, including closed head injury or associated burn injury.
- The duration and possible progression of symptoms should be noted.
- The impact of the contracture on the patient’s upper extremity function and any limitations in activities of daily living should be noted.
- Any previous treatment for contracture should be elucidated. This should include the appropriateness, duration, and results of prior physical therapy, splinting, intra-articular injections, and surgeries.
- For patients with prior elbow surgery, the presence and type of any residual internal fixation devices should be noted. In addition, attention should be paid to any remote history of elbow infection.
- Physical examination should include a general physical examination as well as a detailed examination of the involved extremity.
- Attention must be paid to the examination of the skin and soft tissue envelope about the elbow, with notation made of prior incisions, skin grafts, flaps, or areas of wound breakdown.
- Elbow motion should be measured with a goniometer and active and passive motion should be compared.
- Notation should be made whether motion improves with the forearm in full pronation, which may suggest posterolateral rotatory instability. This effectively “spins” the forearm away from the humerus, causing gapping of the ulnohumeral joint and posterior subluxation of the radial head from the...
capitellum. While frank dislocation is not possible in the unanesthetized patient, guarding is effectively a positive sign.
- While rare, symptomatic incompetence of the ulnar collateral ligament may elucidated by examination.
- Strength of the involved limb should be assessed, as a joint without adequate strength is unlikely to maintain motion after release.
- Since many posttraumatic and inflammatory contractures about the elbow are associated with ulnar nerve symptoms, a careful neurologic examination should be performed. A positive Tinel test over the cubital tunnel as well as a positive elbow flexion test should increase the suspicion for concomitant ulnar nerve pathology.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Anteroposterior (AP) and lateral radiographs are often all that is needed for preoperative planning (FIG 1).
- Cross-sectional imaging with computed tomography is helpful in visualizing the articular surfaces, particularly after fracture.
  - We advocate the use of computed tomography for preoperative planning in cases of moderate to severe heterotopic ossification.
- Extracapsular contracture is typically not painful through the remaining arc of motion and is not painful at rest. If pain is a significant component of the patient’s symptoms, serologic workup for infection, including a complete blood count, erythrocyte sedimentation rate, and C-reactive protein, is indicated.

**DIFFERENTIAL DIAGNOSIS**
- Conversion disorder
- Infection
- Inflammatory arthropathy
- Intracapsular contracture

**NONOPERATIVE MANAGEMENT**
- Alternative measures to improve elbow stiffness include conservative modalities to decrease joint swelling and inflammation and relax or stretch contracted soft tissues. For protracted swelling, edema control sleeves, ice, elevation, active motion (including the forearm, wrist, and hand), and oral agents such as anti-inflammatory medication can be useful.
- A short-term oral prednisone taper can be very effective in difficult cases. In addition, one can consider an intra-articular cortisone injection to decrease inflammation and joint synovitis.
- Rarely, when patients exhibit guarding and involuntary co-contraction, biofeedback may be a helpful adjunct.
- Dynamic splints, which apply a constant tension to the soft tissues, may be helpful.
- Patient-adjusted static braces appear to be more effective. These braces use the principle of passive progressive stretch, allowing for stress relaxation of the soft tissues. They are applied for much shorter periods of time and are better tolerated by patients.

**SURGICAL MANAGEMENT**
- To improve elbow flexion, one must release any soft tissue structures posteriorly that might be tethering the joint. These include the posterior joint capsule and the triceps muscle and tendon, which can become adherent to the humerus.
  - Any bony or soft tissue impingement also must be removed anteriorly, including osteophytes off the coronoid process and any bony or soft tissue overgrowth in both the coronoid and radial fossae.
  - There must be a concavity above the humeral trochlea to accept both the coronoid centrally and the radial head laterally for full flexion to occur.
- Similarly, to improve elbow extension, posterior impingement must be removed between the olecranon tip and the olecranon fossa.
  - Anteriorly, any tethering soft tissues must be released, namely the anterior joint capsule and any adhesions between the brachialis and the humerus.

**Preoperative Planning**
- All radiographic studies should be reviewed.
- The presence and type of any retained implants is noted.
- Range-of-motion and pivot-shift testing is performed under anesthesia as well as under live fluoroscopy.

**Positioning**
- Patients are positioned supine with the arm on a hand table.
- The patient’s torso is brought to the edge of the operating table to ensure adequate elbow exposure for fluoroscopic imaging.
- A towel bump may be placed under the medial elbow.

**Approach**
- A direct posterior skin incision or a lateral incision is used.
- A direct posterior incision has been criticized for an increased propensity toward postoperative seroma formation.
- It has the advantage of being a utilitarian incision that allows access to the medial and lateral sides simultaneously.
- Advantages to the lateral exposure include its simplicity, less extensor and flexor–pronator disruption, and access to all three joint articulations.
- The main disadvantage of the lateral exposure is the inability to address the ulnar nerve when indicated.
- The deep interval for exposure of the anterior capsule lies between the extensor carpi radialis longus (ECRL) proximally and the extensor carpi radialis brevis (ECRB) distally. Posterior access is achieved between the triceps and the humerus.

**SURGICAL APPROACH**

- The procedure can be performed under general anesthesia or under regional anesthesia with a long-acting regional block.
- For the posterior incision, care is taken to avoid placing the line of incision directly over the prominence of the olecranon. Full-thickness fasciocutaneous flaps are elevated laterally to expose the extensor muscle mass.
- For a lateral incision, an extended Köcher approach is used, beginning along the lateral supracondylar ridge of the humerus and passing distally in the interval between the anconeus and the extensor carpi ulnaris (ECU).

**POSTERIOR RELEASE**

- The Köcher interval between the anconeus and ECU is developed.
- The anconeus is reflected posteriorly in continuity with the triceps. This exposes the posterior and posterolateral joint capsule (TECH FIG 1A,B).
- A triceps tenolysis is carried out with an elevator, releasing any adhesions between the muscle and the posterior humerus. The humeroulnar joint is identified posteriorly and the olecranon fossa is cleared of any fibrous tissue or scar that would restrict terminal extension. The tip of the olecranon is removed if there was evidence of overgrowth or impingement (TECH FIG 1C).
The posterior aspect of the radiocapitellar joint is inspected after excision of the elbow capsule just proximal to the conjoined lateral collateral and annular ligament complex through the “soft spot” on the lateral side of the elbow. The proximal edge of this complex lies along the proximal border of the radial head.

**ANTERIOR RELEASE**

- Once the posterior release is completed, dissection is carried anteriorly. The anterior interval proximally is between the lateral supracondylar column and the brachioradialis and ECRL. Distally the interval is between the ECRL and extensor digitorum communis (EDC) (TECH FIG 2A).
- The brachialis is then mobilized off the humerus and anterior capsule with an elevator, releasing any adhesions between the muscle and the anterior humerus (TECH FIG 2B).
- The brachioradialis and ECRL released from the lateral supracondylar ridge of the humerus (TECH FIG 2C).
- This dissection is continued distally between the ECRL and ECRB, allowing exposure of the anterior capsule with preservation of the lateral collateral ligament and the origins of the ECRB, the EDC and minimi, and the ECU from the lateral epicondyle.
- Dissection is then carried out beneath the elbow capsule between the joint and the brachialis. The capsule is excised as far as the medial side of the joint.
- The radial and coronoid fossae are cleared of fibrous tissue and the tip of the coronoid is removed if overgrowth or impingement was noted in flexion. Loose bodies are removed (TECH FIG 2D,E).
- After release of the anterior capsule, gentle extension of the elbow with applied pressure usually brings the joint out to nearly full extension.
- In longstanding cases of contracture, the brachialis muscle can be tight, inhibiting full terminal elbow extension. This myostatic contracture can be stretched for several minutes during the procedure and requires attention at subsequent physiotherapy (TECH FIG 2F).

**TECH FIG 2 • A.** The lateral view of a dissected elbow. Blue lines mark the fascial intervals for access to the anterior and posterior aspect of the joint, which leaves the extensor carpi ulnaris (ECU), extensor digitorum communis (EDC), and extensor carpi radialis longus (ECRL) origins intact as well as the underlying lateral collateral ligament complex. The anterior elbow capsule is exposed by releasing the extensor carpi radialis longus from the lateral supracondylar ridge. Distally the exposure continues between the ECRL and ECRB. T, triceps; BR, brachioradialis. B,C. The anterior exposure for release. The anterior capsule is exposed by detaching the humeral origin of the ECRL proximally and the interval between the ECRL and ECRB distally. The brachialis is released from the anterior capsule. The capsule should be visualized all the way over to the medial joint with all muscle reflected anteriorly. (continued)
Indications
- The importance of prolonged postoperative rehabilitation cannot be stressed enough. A program of active and passive range of motion, weighted elbow stretches with wrist weights, formal therapy, and patient-adjusted elbow bracing is common for 3 to 6 months after surgery.
- Postoperative gains may easily be lost in the patient who is not fully committed to rehabilitation or who does not have access to regular supervised therapy.

Ulnar nerve
- Patients with preoperative signs and symptoms of ulnar nerve irritability should undergo neurolysis and transposition of the ulnar nerve. Although no strict guidelines exist, patients with preoperative flexion less than 100 degrees generally undergo concurrent ulnar nerve release even in the absence of preoperative symptoms.

Median nerve and brachial artery
- These structures are generally well protected by the brachialis muscle. Their safety is increased if dissection proceeds in the interval between the elbow capsule and the brachialis.

Radial nerve injury
- The posterior interosseous nerve may be encountered as extracapsular dissection proceeds distal to the radiocapitellar joint. Care must be taken with more distal dissection, and a firm understanding of neural anatomy is mandatory before attempting capsular release. Except in cases of significant anterolateral heterotopic ossification, we do not routinely dissect and isolate the radial nerve from proximal to distal.

Iatrogenic posterolateral rotatory instability
- Instability may be induced with overly aggressive dissection about the lateral condyle. Care should be taken to stay anterior to the origin of the extensor carpi radialis brevis.

POSTOPERATIVE CARE
- Although several rehabilitation programs may be effective, we have found continuous passive motion, begun immediately in the recovery room and used continuously until the following morning, to be helpful in maintaining the motion gained at surgery (FIG 2A).
- Formal therapy is begun on postoperative day 1.
  - The dressing is removed and edema control modalities (eg, an edema sleeve or Ace wrap, ice) are used to limit swelling.
- Active and gentle passive elbow motion is combined with intermittent continuous passive motion.
- To help maintain extension, weighted passive stretches using a two-pound wrist weight with the arm extended over a bolster are performed several times daily for 10 to 15 minutes as tolerated.
- Because the collateral ligaments are not released at surgery, no restrictions are typically placed on therapy.
- Static progressive elbow bracing is begun early in the postoperative period. The brace is worn for about 30 minutes, two
or three times a day. Flexion and extension are alternated based on the preoperative deficit and the early progress of the elbow (FIG 2B).

- A nonsteroidal anti-inflammatory agent (Indocin) is commonly prescribed as a prophylaxis against heterotopic ossification for several weeks postoperatively. This also helps to limit inflammation of the joint and soft tissues during rehabilitation.
- Patients are typically discharged home on postoperative day 1. Home therapy is performed daily thereafter, including active and passive exercises, continuous passive motion, weighted stretches, and patient-adjusted bracing.
- Progress should be closely monitored by a therapist who is familiar with the protocol. The physician must also follow these patients closely.
- Although the bulk of ultimate elbow motion is gained during the first 6 to 8 weeks, patients can continue to make gains in terminal flexion and extension for several months postoperatively. This is especially true for elbow flexion.
- Continuous passive motion is typically discontinued at 3 to 4 weeks, but bracing is continued for several months as required. As long as the patient is able to obtain full elbow flexion and extension once per day (eg, in the brace), a favorable prognosis exists with respect to the ultimate outcome if vigilance is maintained.

OUTCOMES

- In appropriate patients, release of the contracted elbow can be a reliable and satisfying procedure with predictable results.
- We reviewed our results for 22 patents treated for posttraumatic elbow stiffness using a soft tissue release of the elbow through a lateral approach. The average length of follow-up was 29 months.

- Total elbow motion improved in all subjects. Extension increased from an average of 39 ± 10 degrees preoperatively to 8 ± 6 degrees at follow-up. Elbow flexion increased from 113 ± 18 degrees preoperatively to 137 ± 9 degrees at follow-up. Thus, total ulnohumeral joint motion increased an average of 55 degrees (P < 0.001).
- Elbow pain, as determined by visual analogue scales, decreased in all patients. Elbow function, as determined by standardized scales, also significantly improved.
- Radiographic analysis revealed no patients with regrowth of excised osteophytes or loose bodies at follow-up.

COMPLICATIONS

- Ulnar nerve
  - The most common complication after elbow release surgery involves the ulnar nerve. This may be related in part to improved elbow flexion after surgery, as ulnar nerve tension increases with flexion. This may precipitate symptoms in a nerve that is already subclinically compromised.
  - Patients with preoperative signs and symptoms of ulnar nerve irritability should undergo neurolysis and transposition of the ulnar nerve.
  - Although no strict guidelines exist, patients with preoperative flexion less than 100 degrees generally undergo concurrent ulnar nerve release even in the absence of preoperative symptoms.
- Median nerve and brachial artery
  - Although generally well protected by the brachialis muscle, these structures are at risk with anterior dissection. Their safety is increased if dissection proceeds in the interval between the elbow capsule and the brachialis.
  - In addition, transient median neuritis is known to occur in our practices after release. This is likely due to stretch of the median nerve with extension of the severely contracted elbow.
- Radial nerve injury
  - The posterior interosseous nerve may be encountered as extracapsular dissection proceeds distal to the radiocapitellar joint.
  - Except in cases of significant anterolateral heterotopic ossification, the radial nerve does not typically require identification.
- Persistent stiffness
  - The importance of prolonged postoperative rehabilitation cannot be stressed enough. A program of active and passive range of motion, weighted elbow stretches with wrist weights, formal therapy, and patient-adjusted elbow bracing is common for 3 to 6 months after surgery. All of our patients meet preoperatively both with the therapists at our home institutions as well as with their local therapists.

REFERENCES


DEFINITION

- Multiple techniques have been described for the release of elbow contractures. The medial approach has the advantages of direct access to both the anterior and posterior aspects of the ulnohumeral joint, and direct visualization of the ulnar nerve.
- Medial-based releases were initially proposed by Wilner, whose technique involved medial epicondylectomy and wide dissection.
- Weiss subsequently has described splitting the flexor pronator mass rather than complete release of the flexor pronator mass.
- Hotchkiss popularized this approach to deal with extrinsic contracture of the elbow and ulnar nerve involvement.
- Itoh et al and Wada et al underlined the importance of the posterior oblique band of the medial collateral ligament as a critical structure to identify and release if an extension contracture exists.

ANATOMY

- The medial compartment of the elbow includes the medial side of the ulnohumeral joint, the medial collateral ligament, the flexor–pronator mass, the ulnar nerve, and the median antebrachial cutaneous nerve (FIG 1A).
- The medial ulnohumeral joint is composed of the medial column, the medial epicondyle, the medial side of the proximal aspect of the ulna, and the coronoid process.
- The medial collateral ligament consists of three parts: anterior, posterior, and transverse segments (FIG 1B).
- The anterior bundle is the most discrete component, the posterior portion being a thickening of the posterior capsule, and is well defined only in about 90 degrees of flexion.
- The transverse component appears to contribute little or nothing to elbow stability.
- The medial collateral ligament originates from a broad anteroinferior surface of the epicondyle but not from the condylar elements of the trochlea just inferior to the axis of rotation. The ulnar nerve rests on the posterior aspect of the medial epicondyle, but it is not intimately related to the fibers of the anterior bundle of the medial collateral ligament itself.
- The flexor–pronator mass includes the pronator teres, the most proximal of the flexor pronator group; the flexor carpi radialis, which originates just inferior to the origin of the pronator teres at the anteroinferior aspect of the medial epicondyle; the palmaris longus muscle, which arises from the medial epicondyle and from the septa it shares with the flexor carpi radialis and flexor carpi ulnaris; the flexor carpi ulnaris, which is the most posterior of the common flexor tendons originating from the medial epicondyle and from the medial border of the coronoid and the proximal medial aspect of the ulna; and the flexor digitorum superficialis, which is the deepest from the common flexor tendon but superficial to the flexor digitorum profundus.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Diagnosis of the contracture is usually made by identifying a characteristic history and performing a physical examination.
- Joint involvement is confirmed by plain radiographs. The anteroposterior (AP) view gives good visualization of the joint line, but the lateral view demonstrates osteophytes on the coronoid and at the tip of the olecranon, even when the joint space is preserved.
- The details of the extent of the involvement are best observed on computed tomography.
- Transverse imaging by magnetic resonance imaging (MRI) has little utility in our practice.

NONOPERATIVE MANAGEMENT

- Several options have been proposed for the treatment of elbow contracture.
- Nonoperative treatment with mobilization of the elbow through the use of alternating flexion and extension splints sometimes provides a good result if it is begun soon after the contracture develops.
- Manipulation with the patient under anesthesia has also been recommended, but loss of motion and ulnar nerve injury have been reported.
- Recently, botulinum toxin has been used to release muscle contracture in order to improve elbow rehabilitation.
- Nonoperative treatment usually is successful only for extrinsic stiffness that has been present for 6 months or less, however, and the results are unpredictable. With failure of nonoperative treatment, surgical release may be indicated. Some reports of this being done through an arthroscopic procedure recently appeared. Most surgeons employ an open procedure, and several have been described.

SURGICAL MANAGEMENT

Indications

- Contracture release
- Stiff elbow
- Degenerative arthritis with anterior and posteromedial osteophytes
- Ulnar nerve symptoms

Advantages

- Allows exposure, protection, and transposition of the ulnar nerve
- Preserves the anterior band of the medial collateral ligament
- Affords access to the coronoid with intact radial head
Disadvantages
- Difficulty in removing heterotopic bone on the lateral side of the joint
- Affords poor access to radial head

Preoperative Planning
- Before surgery, the decision must be made to approach the capsule from the lateral or medial aspect.
- If the ulnar nerve is to be addressed or there is extensive medial or coronoid arthrosis, the medial approach is of value.
- If the radiohumeral joint is involved or if a simple release is all that is required, the lateral “column” procedure is carried out.

Positioning
- The patient is usually positioned supine, supported by an elbow or a hand table.
- Two folded towels should be placed under the scapula.
- A sterile tourniquet is positioned.
To expose the posterior joint, the patient’s shoulder should have fairly free external rotation; otherwise, the arm should be positioned over the chest.

**Approach**

- The skin incision may be a posterior skin incision or a midline medial one (FIG 2).
- The key to this exposure is identification of the medial supracondylar ridge of the humerus.
- At this level, the surgeon can locate the medial intermuscular septum, the origin of the flexor–pronator muscle mass, and the ulnar nerve.
- This site also serves as the starting point of the anterior and posterior subperiosteal extracapsular dissection of the joint.

---

**EXPOSING THE ULNAR NERVE AND THE MEDIAL FASCIA**

- Once the medial intermuscular septum is identified, the medial antebrachial cutaneous nerve is identified, traced distally, and protected.
  - The branching pattern varies, however, so it is occasionally necessary to divide the nerve to gain full exposure and to adequately mobilize the ulnar nerve, especially in revision surgery.
  - If this is necessary, the nerve is divided as proximally as the skin incision will allow, ensuring that the cut end lies in the subcutaneous fat (TECH FIG 1).
- If previously anterior transposition was performed, the ulnar nerve should be fully identified and mobilized before proceeding.
- The surgeon must be prepared to extend the previous incision proximally, as necessary.
- In this setting, the nerve is often flattened over the medial flexor–pronator muscle mass, or it can “subluxate” to a posterior position.
- This dissection requires patience and may take considerable time. Dissection of the nerve needs to be carried distally far enough to allow the nerve to sit in the anterior position without being kinked distal to the epicondyle.
- The septum is excised from the insertion on the supracondylar ridge to the proximal extent of the wound, usually about 5 to 8 cm.
- Many of the veins and perforating arteries at the most distal portion of the septum require cauterization.

**EXPOSING THE ANTERIOR CAPSULE FOR EXCISION AND INCISION**

- Once the septum has been excised, the flexor–pronator muscle mass should be divided parallel to the fibers, leaving roughly a 1.5-cm span of flexor carpi ulnaris tendon attached to the epicondyle (TECH FIG 2A,B).
- The surgeon then returns the supracondylar ridge and begins elevating the anterior muscle with a Cobb elevator.
Subperiosteally, the anterior structures of the distal humeral region proximal to the capsule are elevated to allow placement of a wide Bennett retractor. As the elevator moves from medial to lateral, the handle of the elevator is lifted carefully, keeping the blade of the elevator along the surface of the bone.

- When heterotopic ossification along the lateral distal humerus is profuse, the radial nerve is at risk if it is entrapped in the scar on the surface of the bone.
- A separate approach to the lateral side is sometimes needed.
- The median nerve, brachial vein, and artery are superficial to the brachialis muscle.

A small cuff of tissue of the flexor–pronator origin can be left on the supracondylar ridge as the muscle is elevated. This facilitates reattachment during closing.

- A proximal, transverse incision in the lacertus fibrosus may also be needed to adequately mobilize this layer of muscle.

Once the Bennett retractor is in place and the medial portion of the flexor–pronator has been incised, the plane between muscle and capsule should be carefully elevated.

As this plane is developed, the brachialis muscle is encountered from the underside. This muscle should be kept anterior and elevated from the capsule and anterior surface of the distal humerus.

TECH FIG 2 • A,B. Exposure of the anterior capsule. C–E. After excision of the anterior capsule, visualization of the ulnohumeral joint down to the radiocapitellar joint.
Chapter 44  EXTRINSIC CONTRACTURE RELEASE: MEDIAL OVER-THE-TOP APPROACH

TECHNIQUES

EXPOSING AND EXCISING THE POSTERIOR CAPSULE AND BONE SPURS

- The posterior capsule of the joint is exposed. The supracondylar ridge is again identified (TECH FIG 3).
- Using the Cobb elevator, the triceps is elevated from the posterior distal surface of the humerus.
- The exposure should extend far enough proximal to permit use of a Bennett retractor.
- The posterior capsule can be separated from the triceps as the elevator sweeps from proximal to distal. The posterior medial joint line should also be identified, as it is often involved by osteophytes or heterotopic bone.
- In contracture release, the posterior capsule and posterior band of the medial collateral ligament should be excised.
- Once this edge of the capsule is incised, it can be lifted and excised as far distally as is safe. From this vantage, and after capsule excision, the radial head and capitellum can be visualized and freed of scar, as needed.
- In cases of primary osteoarthritis of the elbow, removing the large spur from the coronoid is crucial.
- Using the Cobb elevator, the brachialis muscle can be elevated anteriorly for 2 cm from the coronoid process.
- With the elevator held in position, protecting the brachialis but anterior to the coronoid, the large osteophyte can be removed with an osteotome.
- The brachialis insertion is well distal to the tip of the coronoid.

ULNAR NERVE TRANSPOSITION

- After being reattached to the medial supracondylar region, the ulnar nerve should be transposed and secured with a fascial sling to prevent posterior subluxation.
- The sling can be fashioned by elevating two overlapping rectangular flaps of fascia or by using a medially based flap attached to the underlying subcutaneous tissue.
- Once this maneuver is completed, the nerve must not be compressed or kinked.
- The joint should be flexed and extended to ensure that the nerve is free to move.
**CLOSURE**

- The flexor–pronator mass should be reattached to the supracondylar ridge with nonabsorbable braided 1-0 or 0 suture.
  - If a large enough cuff of tissue was left on the medial epicondyle, no holes need be drilled in bone.
  - Otherwise, drill holes in the edge of the supracondylar ridge can be made to secure the flexor–pronator mass (TECH FIG 4).

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Wrong incision</th>
<th>Identification of the medial supracondylar ridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury to the medial antebrachial cutaneous nerve</td>
<td>Identification of the medial antebrachial cutaneous nerve</td>
</tr>
<tr>
<td>Injury to the ulnar nerve</td>
<td>Identification, mobilization, and protection of the ulnar nerve</td>
</tr>
<tr>
<td>Disinsertion of the flexor–pronator mass from the medial epicondyle</td>
<td>The flexor–pronator muscle mass should be divided parallel to the fibers.</td>
</tr>
<tr>
<td>Injury to the anterior vessels and nerves</td>
<td>A Bennett retractor is placed between the anterior muscle and the capsule.</td>
</tr>
<tr>
<td>Section of the anterior band of the medial collateral ligament</td>
<td>A small, narrow retractor is inserted to retract the medial collateral ligament, pulling it medially and posteriorly.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- If the neurologic examination findings in the recovery room are normal, a brachial plexus block is established and maintained with a continuous pump through a percutaneous catheter.
  - The arm is elevated as much as possible, and mechanical continuous passive motion exercise is begun the day of surgery and adjusted to provide as much motion as pain or the machine itself allows.
  - After 2 days the plexus block is discontinued, and, at day 3, the continuous passive motion machine is stopped.
  - Physical therapy is not used, but a detailed program of splint therapy is prescribed.
  - Adjustable splints are prescribed, depending on the motion before and after the procedure. The splints include a hyperextension or a hyperflexion brace, or both.
  - A detailed discussion regarding heat, ice, and anti-inflammatory medication, along with a visual schedule for bracing, is provided.
  - During the first 3 months, the patient sleeps with the splint adjusted to maximize flexion or extension, whichever is more needed; it should not be so uncomfortable as to prevent sleeping for at least 6 hours.
  - Because the principal objective is to gain motion but to avoid pain, swelling, and inflammation, routine use of an anti-inflammatory medication is prescribed.
  - Therapy with splints is continued for about 3 months, during which time the patient is seen at 2- to 4-week intervals, if possible.
  - After 4 weeks, an arc of about 80 degrees of motion is obtained, and the amount of time that each splint is worn is gradually decreased.
  - Splinting at night is continued for as long as 6 months if flexion contracture tends to recur when the splint is not used.
  - Patients are advised that it may take a year to realize full correction.

**OUTCOMES**

- Recent reports on the results of surgical arthrolysis reveal an absolute gain in the flexion–extension arc between 30 and 60 degrees, \(1,3,5,7,9-11,14-16,19,21\)
  - A functional arc of motion between 30 and 130 degrees is obtained in more than 50% of cases, and some improvement in motion in more than 90% of the cases has been reported in the literature. \(1,3,5,7,9-11,14-16,19,21\)
  - In Europe, a combined lateral and medial approach has been used for many years, and gains in flexion arc have averaged between 40 and 72 degrees (in about 400 procedures). \(1,3,7,14\) Some preferred a posterior extensile approach if medial and lateral exposures are anticipated.
  - The importance of sequential release of tissues has been emphasized, based on an experience with 44 of 46 patients
Antuna et al.\(^\text{2}\) recommended that elbows with preoperative presence or absence of ulnar nerve symptoms. Patients who have stiff elbows must be evaluated for the preoperative period to decompress the ulnar nerve when ulnar nerve symptoms exist preoperatively.\(^\text{13}\)

Using a medial approach, Wada et al.\(^\text{12}\) obtained improvement of the mean arc of movement of 64 degrees. A functional arc of flexion–extension (30 to 130 degrees) was obtained in 7 of the 14 elbows. None of the patients developed symptoms related to the ulnar nerve. According to those authors, the medial approach has several advantages over both the anterior and lateral approaches:

- Pathologic changes in the posterior oblique bundle of the medial collateral ligament can be observed and excised under direct vision.
- Anterior and posterior exposure is possible through one medial incision, through which a complete soft tissue release and excision of part of the olecranon and coronoid process can be undertaken if necessary. Additional lateral exposure is indicated only if the medial approach has proved to be inadequate.
- In the medial approach, the ulnar nerve is routinely released and protected under direct vision, which decreases the risk of damage.

**COMPLICATIONS**

- A most important emerging consideration of the proper treatment of elbow stiffness is the vulnerability of the ulnar nerve.
- The most common cause of failure of treatment has been in patients whose preoperative ulnar nerve symptoms were not appreciated or addressed, or patients in whom ulnar nerve symptoms developed postoperatively without adequate treatment. This is attributable to traction neuritis caused by the abrupt increase in elbow flexion or extension during the operation.
- Even in the absence of preoperative neurologic symptoms, the nerve may be compromised subclinically and become symptomatic as elbow motion increases after surgery. Therefore, all patients who have stiff elbows must be evaluated for the presence or absence of ulnar nerve symptoms.
- Antuna et al.\(^\text{2}\) recommended that elbows with preoperative flexion limited to 90 to 100 degrees in which we expect to improve the motion by 30 or 40 degrees must be treated with inspection and often prophylactic decompression or translocation of the nerve, depending on the appearance of the nerve once the surgical procedure is finished.
- Furthermore, all patients with preoperative ulnar nerve symptoms, even if they are mild, are treated with mobilization of the nerve.
- These authors stated that manipulation of the elbow in the early postoperative period must be avoided if the nerve has not been decompressed or translocated.

**REFERENCES**

DEFINITION
- Rheumatoid arthritis (RA) is a chronic, systemic, inflammatory condition of unknown etiology affecting 1% to 2% of the population.
  - It affects females two to three times as frequently as males, and the incidence increases with age, typically peaking between 35 and 50 years of age.
  - Peripheral joints are often affected in a symmetric pattern.
  - The elbow is affected in about 20% to 70% of patients with RA, with a wide spectrum of severity.
- Ninety percent of these patients also have hand and wrist involvement, and 80% also have shoulder involvement.
- Juvenile rheumatoid arthritis (JRA) is diagnosed based on the presence of arthritis, synovitis, or both in at least one joint lasting for more than 6 weeks in an individual less than 16 years old.
  - Compared with adult-onset RA, JRA is complicated by severe osseous destruction, deformity, and soft tissue contractures.

PATHOGENESIS
- The cause of RA is unknown.
  - Infectious etiologies have been proposed, but no microorganism has been proven to be causative.
  - Genetic and twin studies have demonstrated that a genetic predisposition clearly exists, and the disease is also associated with autoimmune phenomena.
  - In patients with RA, numerous cell types, including B lymphocytes, CD4 T cells, mononuclear phagocytes, neutrophils, fibroblasts, and osteoclasts, have been shown to produce abnormally high levels of various cytokines, chemokines, and other inflammatory mediators.
  - The result is inflammatory-mediated proliferation of synovial tissue, leading to soft tissue and finally bony destruction.

NATURAL HISTORY
- Overall, the disease progresses from predominantly soft tissue (synovial) inflammation to articular cartilage damage and ultimately subchondral and periarticular bone destruction.
- Manifestations of RA are initiated by synovitis and synovial hyperplasia resulting in pannus formation. This correlates with a boggy, inflamed elbow that is painful and with limited range of motion.
- Synovial proliferation coupled with joint capsule distention may produce a compressive neuropathy with pain, paresthesias, or weakness in the ulnar or radial nerve distributions, or both.
- Degeneration may progress to ligamentous erosion or disruption, or both. Clinically, the patient experiences progressive instability as ligamentous integrity is compromised.
  - It may affect the annular ligament and produce radial head instability with anterior displacement.
  - Eventually the medial and lateral collateral ligament complexes may be disrupted, thus causing further instability.
  - Prolonged synovitis leads to erosion of the cartilage followed by subchondral cyst and marginal osteophyte formation; the result is end-stage arthritis.
  - End-stage disease is marked by severe damage to subchondral bone and gross joint instability. At this stage, patients typically have a painful, weak, and functionally unstable elbow.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients typically describe a history of a swollen, tender, and warm elbow with diminished and painful range of motion.
  - This may be accompanied by a report of progressively declining function, constitutional complaints, and often polylarticular involvement.
  - In early stages of the disease, the elbow may appear more boggy, with impressive soft tissue swelling and erythema about the elbow.
  - As the disease progresses to later stages, soft tissue swelling may become less prominent, and the elbow becomes more stiff and painful.

Differences in Examination Findings Between Rheumatoid Arthritis and Juvenile Rheumatoid Arthritis
- Elbows affected by JRA obviously occur in younger patients as compared with elbows affected by RA.
- Patients with JRA also have stiffer elbows and therefore typically do not have instability.
- Often JRA patients have more joints affected by the rheumatoid process, but they also demonstrate a greater tolerance for pain.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Anteroposterior (AP) and lateral radiographs of the elbow are obtained to assess the degree of rheumatoid involvement and for preoperative planning (FIG 1). No further studies are typically required.

Classification
- Although several classification systems have been proposed, the most commonly used is the Mayo Radiographic Classification System (Table 1). It allows monitoring of disease progression and often correlates well with clinical examination findings and patients’ functional limitations.
  - The grading system is based on bone quality, joint space, and bony architecture and delineates four grades of progression in order of increasing severity.
to optimize range of motion, as preoperative range of motion is often predictive of postoperative total arc of motion after arthroscopic synovectomy as well as total elbow arthroplasty.

**SURGICAL MANAGEMENT**

- Surgical management of the rheumatoid elbow primarily consists of synovectomy and total elbow arthroplasty.

**Surgical Management of the Elbow Before Total Elbow Arthroplasty**

- For early disease states, excellent clinical results may be achieved with synovectomy performed using open or arthroscopic techniques.
- The goal of synovectomy is to relieve pain and swelling. Although this procedure has not necessarily been shown to alter the natural history of the disease, it reliably produces symptomatic relief for 5 or more years in the majority of cases performed on elbows in the early stages of the disease process.³
- The arthroscopic approach is advantageous over the more traditional open approach in that it is less invasive, is associated with less perioperative morbidity, and also allows predictable access to the sacciform recess. When open synovectomy is performed, the radial head must be excised to access and completely débride the diseased synovial tissue that exists in this region.
- Open synovectomy has traditionally been accompanied by radial head excision due to (1) ubiquitous radiocapitellar and proximal radioulnar joint articular destruction and (2) the need to surgically expose the sacciform recess for the requisite complete synovectomy.
- It has been shown that routine radial head excision may predispose some patients with RA to increasing valgus elbow instability due to the loss of the stabilizing effect of the radial head (particularly if the medial collateral ligament is adversely affected by the rheumatoid process).⁷
- Now that the entire synovial proliferation around the radial neck can be accessed arthroscopically, a combined arthroscopic radial head excision is performed only in patients with stable elbows and preoperative elbow symptoms with forearm rotation. Otherwise, a complete arthroscopic synovectomy is performed without excising the radial head.
- In addition, the minimally invasive nature of an arthroscopic approach yields the potential advantages of less pain, faster recovery with earlier range of motion, and a lower rate of infection compared with an open procedure.
- An arthroscopic anterior capsular release may be performed at the time of the arthroscopic synovectomy to improve elbow extension. A posterior olecranon-plasty may also be performed to re-establish normal concavity of the olecranon fossa.
- Posteromedial capsule release should be avoided to prevent the risk of iatrogenic ulnar nerve injury. If an elbow requires a release of the posterior capsule to regain elbow flexion (typically those with 100 degrees or less of preoperative flexion), then the surgeon should consider performing an open ulnar nerve decompression and subcutaneous transposition followed by complete posterior capsule release (including the posteromedial band of the medial collateral ligament).
### Table 1: Mayo Radiographic Classification System

<table>
<thead>
<tr>
<th>Grade</th>
<th>Radiographic Appearance</th>
<th>Description</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td><img src="image1" alt="Image" /></td>
<td>Synovitis in a normal-appearing joint with mild to moderate osteopenia</td>
<td>Often correlates with impressive soft tissue swelling on clinical examination</td>
</tr>
<tr>
<td>II</td>
<td><img src="image2" alt="Image" /></td>
<td>Loss of joint space, but maintenance of the subchondral architecture</td>
<td>Varying degrees of soft tissue swelling are present</td>
</tr>
<tr>
<td>III</td>
<td><img src="image3" alt="Image" /></td>
<td>Marked by complete loss of joint space</td>
<td>The synovitis has “burned out” and the elbow is typically more stiff</td>
</tr>
<tr>
<td>IIIA</td>
<td><img src="image4" alt="Image" /></td>
<td>Bony architecture is maintained</td>
<td></td>
</tr>
<tr>
<td>IIIIB</td>
<td><img src="image5" alt="Image" /></td>
<td>Associated bone loss</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td><img src="image6" alt="Image" /></td>
<td>Severe bony destruction</td>
<td>Patients often have severe pain and functional limitations; functional instability may also be present if the joint’s bony architecture is destroyed.</td>
</tr>
<tr>
<td>V</td>
<td><img src="image7" alt="Image" /></td>
<td>Presence of bony ankylosis of the ulnohumeral joint</td>
<td>Most commonly seen with juvenile rheumatoid arthritis</td>
</tr>
</tbody>
</table>

Total Elbow Arthroplasty

- This procedure is indicated primarily for advanced (grade III or IV) RA of the elbow in patients with significant pain and limitations in activities of daily living.
- Absolute contraindications include active infection, upper extremity paralysis, and a patient’s refusal or inability to abide by postoperative activity restrictions.
- Relative contraindications include presence of infection at a remote site and a history of infected elbow or elbow prosthesis.

Preoperative Planning

- AP and lateral radiographs of the elbow are reviewed to assess humeral bow and medullary canal diameter as well as angulation and diameter of the ulnar medullary canal.
- Preoperative radiographic templates may be helpful to assess preoperative radiographic magnification.
- In particular for JRA patients, the canal width may be very small, and therefore the surgeon must ensure that appropriately sized implants as well as intramedullary guidewires and reamers are available.
- If an ipsilateral total shoulder arthroplasty has been performed or is anticipated, use of a 4-inch humeral implant and a humeral cement restrictor should be considered.
- Preoperative limitations in forearm rotation may be due in part to ipsilateral distal radioulnar joint pathology. Thus, radiographs should also be obtained on the ipsilateral shoulder and wrist.

Implant Selection for Total Elbow Arthroplasty

- Implant options have traditionally been classified as linked (semiconstrained) or unlinked.
  - These terms are being used with decreasing frequency, however, as unlinked implant designs have been developed that have precisely contoured components that create a degree of constraint.
  - Linked, semiconstrained implants have about 7 degrees of varus–valgus “play” and 7 degrees of axial rotation, while unconstrained implants consist of unlinked, resurfacing components.
  - The stability of unconstrained implants depends on soft tissue and ligamentous integrity, while such tissues may be destroyed by the rheumatoid inflammatory process or surgically released with semiconstrained implants without compromising stability.
  - Although no prospective comparisons between linked (semiconstrained) and unlinked implants have yet been performed, both appear to have similar survivorship records.
  - The semiconstrained design is preferred because it is equally effective in pain relief and in improving range of motion and function, while preserving stability without an observed increase in aseptic loosening.
  - The Techniques section below focuses on implantation of a linked (semiconstrained) implant.

Sequence and Timing of Total Elbow Arthroplasty in the Patient with Polyarticular Involvement

- Because RA typically affects multiple joint articulations, the timing of elbow arthroplasty should be considered with regard to the need for arthroplasties of other joints.
- In general, the most disabling articulation should be addressed first. In the case of equivocal involvement in the elbow and a lower extremity joint in which arthroplasty is planned, the surgeon must consider the postoperative effects of surgery and plan accordingly.
- If total elbow arthroplasty is performed first, at least 3 to 6 months should pass before lower extremity reconstruction is performed to allow adequate healing in the elbow. If the lower extremity will be addressed first, total elbow arthroplasty should be delayed until assistive ambulatory devices, which may put strain on the elbow, are no longer required.
- Patients with total elbow arthroplasty should not weight bear with crutches. A walker may be used, provided it does not increase strain on the elbow. This may be achieved by raising the walker’s arm rests to an appropriate height such that when the forearms are placed on the arm rests, the elbow may not be extended beyond 90 degrees of flexion.

Assessment of the Cervical Spine

- Because nearly 90% of patients with RA have cervical spine involvement, about 30% of whom have significant subluxation, the cervical spine must be evaluated before any surgery in which intubation is likely.
- Cervical spine radiographs should be routinely obtained.
- If patients have neck pain, decreased range of motion, myelopathic symptoms, or radiographic evidence of instability, a magnetic resonance imaging (MRI) study should be ordered with concomitant referral to a spine surgeon to consider addressing the cervical spine pathology before elbow surgery.

Temporary Cessation of Medications Before Total Elbow Arthroplasty

- Tumor necrosis factor (TNF) inhibitors affect the immune system and have been found to increase the risk of developing a prosthetic joint infection.
  - In general, anti-TNF agents are typically stopped for a short period before surgery and for about 2 weeks after surgery to reduce the risk of perioperative morbidity.
  - Patients on chronic NSAIDs should stop taking those medications about 2 weeks before surgery to reduce the risk of increased bleeding.
  - For patients on chronic steroids, stress-dose steroids may be required perioperatively.
  - Communications with the patient’s rheumatologist and the anesthesiologist are imperative to coordinate these efforts.

Positioning

- Intravenous antibiotics are administered 30 to 60 minutes before the incision.
  - The patient is placed in a supine position on the operating table with a rolled towel under the ipsilateral scapula.
  - The entire operative extremity and shoulder girdle is prepared and draped; a sterile tourniquet is placed.
  - The arm is exsanguinated and the tourniquet inflated.

Approach

- Although multiple approaches may be used, the Bryan-Morrey approach (triceps–anconeus “slide”) is preferred.
INCISION AND EXPOSURE

- A straight incision, measuring about 15 cm, is made centered between the lateral epicondyle and the tip of the olecranon.
- The ulnar nerve is carefully identified and isolated along the medial aspect of the triceps.
- Proximal neurolysis of the nerve is achieved by incising the fascia from the medial head of the triceps to the medial intermuscular septum and then mobilized to beyond its first motor branch distally by splitting the cubital tunnel retinaculum, which includes the band of Osborne (the fascia between the two heads of the flexor carpi ulnaris [FCU]) and the FCU fascia (TECH FIG 1A,B).
- The intermuscular septum is excised and a deep pocket of subcutaneous tissue over the flexor pronator group distally and anterior to the triceps proximally is created.
  - The nerve is then anteriorly transposed into this subcutaneous tissue pocket; it must be protected throughout the operation.
- An incision is then made over the medial aspect of the ulna between the anconeus and FCU. The anconeus is subperiosteally elevated off the ulna.
- The medial aspect of the triceps is then retracted along with the fibers of the posterior capsule to tension the Sharpey fibers at their ulnar insertion (TECH FIG 1C,D).

These fibers are then sharply dissected, and the triceps in continuity with the anconeus is reflected from medial to lateral (TECH FIG 1E).
- The lateral ulnar collateral ligament complex is released from its humeral attachment, thus allowing the extensor mechanism to be completely reflected to the lateral aspect of the humerus (TECH FIG 1F).
- If ulnohumeral ankylosis is present, as is sometimes the case in JRA patients, a saw or osteotome may be necessary to re-establish the joint line and to create the osteotomy at the appropriate center of rotation of the ulnohumeral joint.
- The elbow is then progressively flexed, exposing the medial collateral ligament, which is then released subperiosteally from its humeral attachment (TECH FIG 1G).
- The tip of the olecranon is removed with a rongeur or oscillating saw, depending on the quality of the bone, and the humerus is then externally rotated and the elbow fully flexed to adequately expose the articulating surfaces of the humerus, ulna, and radial head.
The midportion of the trochlea is then removed, with an oscillating saw if the bone is dense or with a rongeur if the bone is soft, up to the roof of the olecranon fossa. The removed bone should be preserved for the anterior, distal humeral bone graft needed later in the procedure (TECH FIG 2A). The roof of the olecranon is entered with a rongeur or burr, and a small twist reamer is then used to identify the humeral medullary canal (TECH FIG 2B,C). For patients with severe stiffness, the effect of humeral shortening should be considered. Hughes et al developed a biomechanical model that demonstrated that resecting 1 cm or less of humeral bone has little effect on triceps strength. With the elbow in 30 degrees of flexion, resecting 1 to 2 cm reduced triceps strength by 17% to 40%, while shortening of 3 cm reduced extension strength by 63%. Therefore, the humerus should not be shortened by greater than 2 cm.

An alignment stem is then placed down the canal. The handle of the alignment stem is then replaced by the humeral cutting jig (TECH FIG 2D,E). An oscillating saw is used to make oblique cuts along the edges of the jig, with the tip of the saw pointing away from the midline of the humerus to avoid cross-hatching at the junction of the column and the olecranon fossa (TECH FIG 2F). Care must be taken as this area may be very thin in patients with RA, and thus susceptible to fracture. With the midportion of the trochlea removed, a thin rasp or intramedullary guide is used to again identify the humeral canal. Progressive 6-inch rasps are typically used unless an ipsilateral shoulder arthroplasty has been performed or is planned (TECH FIG 2G). In these cases, consider using a 4-inch humeral component. The anterior capsule is completely subperiosteally released from the anterior aspect of the humerus to accommodate the flange of the humeral component and to allow unencumbered postoperative elbow extension.
TECH FIG 2 • A. For soft bone, a rongeur is used to remove the midportion of the trochlea. B. A burr is used to enter the roof of the olecranon. C. Then a twist reamer is used to identify the medullary canal. D,E. The humeral cutting jig is aligned as a template for removal of the distal humeral articulation. F. An oscillating saw is placed at an oblique angle to the jig to accurately remove the articulating surface of the distal humerus while avoiding cross-hatching of the supracondylar columns. G. An appropriately sized rasp is used for the humeral canal.
ULNAR PREPARATION

- It is important to fully expose the greater sigmoid notch.
- A high-speed burr is angled 45 degrees relative to the axis of the ulnar shaft at the junction of the sigmoid fossa and coronoid to identify the ulnar medullary canal (TECH FIG 3A,B).
- Again, a twist reamer is used to further identify the canal, and an appropriately sized ulnar rasp is then inserted.
- The ulnar bow should be acknowledged and palpated while inserting the ulnar rasps to avoid ulnar perforation.
  - During advancement of the rasp, it is important to maintain proper rotation of the rasp so that the handle is perpendicular to the flat, dorsal aspect of the proximal ulna (TECH FIG 3C,D).
- Alternatively, reaming should be considered if the canal is very small, as may be the case in JRA patients.
- The ulnar canal is thus prepared, and the ulnar component is inserted to the depth such that the center of the ulnar component is midway between the tips of the olecranon and coronoid to reproduce the elbow’s axis of rotation (TECH FIG 3E).
- A rongeur is then used to remove the tip of the coronoid.
- Because proximal radioulnar arthritis is ubiquitous in patients with RA and JRA, and the Conrad-Morrey total elbow arthroplasty does not require proximal radioulnar and radiocapitellar reconstruction, a radial head excision is performed.
  - This may be performed by rotating the forearm and using a rongeur to progressively excise the radial head from an axial orientation, while holding the elbow in full flexion.

TECH FIG 3 • A,B. A high-speed burr is used to identify the ulnar medullary canal. C,D. A small twist reamer is used to identify the ulnar canal (C), which is then rasped to the appropriate size while maintaining proper rotation (D). E. The ulnar component is seated to ensure the proper depth and axis of rotation.
TRIAL REDUCTION

- The humeral component is then inserted and a trial reduction is performed.
- Range of motion is tested and should be full without limitation in the flexion–extension plane.
  - If range of motion is limited owing to inadequate soft tissue release, this should be addressed at this time.
- The components should also be evaluated for bony impingement, which may commonly occur posteriorly (olecranon impingement on the humerus) or anteriorly (coronoid tip on the anterior flange of the humeral component; TECH FIG 4).
  - Any impinging bone should be removed with a rongeur.
- After satisfactory trial reduction, the provisional components are removed.

CEMENTING

- Both medullary canals are then pulse lavaged and dried.
- Based on the trial components used, the length of the cement applicator is measured to equal that of the humeral component.
  - The tip of the applicator is cut at this level to ensure appropriate depth of the cement down the humeral canal (TECH FIG 5).
- It is recommended that cementing of the components be performed simultaneously.
  - Two packs of cement with antibiotics are mixed and injected with a runny consistency.
  - The humeral cement is placed first, followed by the ulnar cement and then the ulnar component.
  - Remove excess cement.
HUMERAL COMPONENT AND BONE GRAFT

- A small (about 2 cm × 2 cm and 2- to 4-mm thick) piece of the removed trochlea is used for the anterior bone graft.
- This bone graft is wedged between the anterior aspect of the humerus and the flange as the humeral component is placed (TECH FIG 6).
- This provides the humeral component with rotational stability as well as additional stability in the AP plane.
- Once again, excess cement is removed at this time.

ASSEMBLY AND IMPACTION

- The components are then linked with the use of two interlocking cross-pins, which are placed from opposite directions (TECH FIG 7A).
- If humeral bowing or a small canal exists, a slight bow can be placed in the proximal aspect of the humeral component to ensure proper fit (TECH FIG 7B, C).
- After coupling the prosthesis, the components must be seated; the elbow is flexed to 90 degrees and the humeral component is then impacted such that the distal aspect of the humeral component is roughly at or slightly proximal to the contour of the distal capitellum (TECH FIG 7D, E).
- Range of motion is checked and a full arc of motion is confirmed.
- The elbow is taken through several arcs of flexion—extension to “normalize” the rotational version of components to one another.
- Hold the elbow in full extension until the cement cures.

(continued)
TRICEPS REATTACHMENT

- Small cruciate and transverse drill holes are placed through the olecranon at the site of triceps reattachment, and a heavy, nonabsorbable suture is placed on a Keith needle and then brought through the distal medial cruciate drill hole and out the proximal lateral hole (TECH FIG 8A–C).
- The elbow is flexed to about 60 degrees and the extensor mechanism is reduced over the tip of the olecranon; consider slightly overreducing the extensor mechanism medially to minimize the potential for postoperative lateral subluxation.
- The suture is woven through the triceps tendon in a locking, crisscross pattern such that the suture emerges at the proximal medial hole (TECH FIG 8D).
- The suture is then passed through this hole and out the distal medial hole such that it is located directly across from the initial suture end.
- These suture ends are then passed again through the forearm extensor fascia and tied together.
- Two reinforcing sutures are then passed through the transverse holes and extensor fascia before being tied together.
- Avoid knots directly over the subcutaneous border of the proximal ulna.
- The tourniquet is then deflated and hemostasis is achieved.
- The medial soft tissue extensor mechanism is then reaproximated.

TECH FIG 7 • (continued) D,E. The elbow is flexed to 90 degrees and the humeral component is then impacted.

TECH FIG 8 • Cruciate (A,B) and transverse (C) drill holes are placed in the ulna for triceps reattachment. (continued)
TECH FIG 8 • (continued) **D.** Suture is passed through the proximal ulna and then woven through the triceps tendon before being tied together.

**ULNAR NERVE TRANSPOSITION AND WOUND CLOSURE**

- The protected nerve is in the subcutaneous tissue pocket previously created, and dermal sutures are placed to protect and secure the nerve (TECH FIG 9).
- Wounds are closed in layers, and a drain is placed. Staples are used to close the skin.
- A volar splint is placed with the elbow in full extension, making sure to adequately pad the anterior aspect of the splint both proximally and distally to prevent skin breakdown.

TECH FIG 9 • The ulnar nerve is transposed into the subcutaneous tissue of the medial epicondylar region and secured with sutures in the dermal layer.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Approach and exposure</th>
<th>Take your time with the Bryan-Morrey approach; maintaining subperiosteal elevation of the extensor mechanism will make for a better postoperative extensor mechanism repair.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Obtain complete ulnohumeral dissociation before bony preparation. This includes complete releases of the lateral ulnar collateral ligament and medial collateral ligament complexes, and a complete anterior capsule release.</td>
</tr>
<tr>
<td></td>
<td>Consider reflection of common flexors or extensors if severe deformities or arthrofibrosis is present.</td>
</tr>
<tr>
<td>Humeral preparation</td>
<td>Shorten the humerus by 1 cm or less to augment postoperative range of motion without compromising strength.</td>
</tr>
<tr>
<td></td>
<td>Use a burr distally to open up the humeral canal if needed, rather than forcing with rasps.</td>
</tr>
<tr>
<td>Radial and ulnar preparation</td>
<td>Excise the radial head and the tip of the coronoid.</td>
</tr>
<tr>
<td></td>
<td>Always palpate the ulna and consider the ulnar bow before ulnar preparation to avoid perforation.</td>
</tr>
<tr>
<td></td>
<td>Have guidewires and reamers (5.0, 5.5, 6.0, 6.5) available if needed.</td>
</tr>
<tr>
<td>Cementing</td>
<td>Review the cement technique and order mentally before proceeding; use cement that does not rapidly set.</td>
</tr>
<tr>
<td>Triceps reattachment</td>
<td>Overreduce the triceps–anconeus repair medially.</td>
</tr>
<tr>
<td>Postoperative care</td>
<td>Use a postoperative extension splint for 24 to 36 hours.</td>
</tr>
<tr>
<td></td>
<td>Make all efforts to reduce postoperative swelling.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE
- Postoperatively, the anteriorly placed splint maintains the elbow in full extension for about 24 to 36 hours.
- The elbow is elevated overnight and on postoperative day 1.
- The drain is removed on postoperative day 1 or when output is less than 30 mL in an 8-hour period.
- After splint removal, open-chain active-assisted range of motion is allowed. A formal physical therapy consultation is not usually required.
- The patient is restricted to no pushing and no overhead activities for 3 months to protect the triceps. In addition, no repetitive lifting of objects heavier than 5 pounds and no lifting greater than 10 pounds in a single event is allowed for life.
- A collar and cuff are provided for comfort.

OUTCOMES
- Successful outcomes for total elbow arthroplasty are judged based on relief of pain and improved range of motion, stability, and function.
  - The Mayo Elbow Performance Score assigns numeric values to each of these categories to produce scores for each of these criteria as well as an overall score. Outcomes are often compared using this system.
- Total elbow arthroplasty for RA
  - In the largest study with the longest follow-up in the literature, Gill and Morrey reported 86% good or excellent results with a 13% reoperation rate on 69 patients with RA treated with a semiconstrained total elbow arthroplasty. Forty-four of these patients were followed for more than 10 years.
  - The prosthetic survival rate was 92.4% at 10 years of follow-up, thus approaching the success of lower extremity arthroplasty.
- Total elbow arthroplasty for JRA
  - Connor and Morrey reported 87% good or excellent results on 19 patients (24 elbows) followed for a mean of 7.4 years.
  - The mean improvement in the Mayo Elbow Performance Score was 59 points, 96% had little or no pain, and there was no evidence of loosening in any prostheses at the latest follow-up.
- The mean flexion-extension arc of motion improved by only 27 degrees (from 67 to 90 degrees) in this study, but these outcomes were reported before shortening of the humerus for severely contracted elbows was routinely performed.

COMPLICATIONS
- Infection
- Aseptic loosening
- Mechanical failure
- Short term
- Long term
- Ulnar nerve injury
- Triceps weakness or avulsion
- Ulnar component fracture
- Ulnar fracture
- Wound healing problems

REFERENCES
DEFINITION
- Most comminuted elbow fractures have significant associated soft tissue injuries, which are often of equal or greater importance to the bony element.
- The key point in determining how to treat acute elbow fractures is to assume that all fractures will be anatomically reduced and fixed.
- An acute elbow replacement should be considered only if it is felt that open reduction and internal fixation is unlikely to achieve a predictably good functional outcome.
- In the vast majority of cases, elbow replacements for the treatment of acute fractures should be limited to the physiologically elderly patient with low demands and osteoporotic bone stock.

ANATOMY
- The bony anatomy of the elbow consists of the distal humerus, proximal ulna, and proximal radius.
- Important soft tissue stabilizers include the medial and lateral ligamentous complexes and surrounding musculature, especially the brachialis, common flexor and common extensor masses, and triceps.
- The ulnar nerve is tethered to the medial condylar–epicondylar fragment by the cubital tunnel retinaculum distally and the arcade of Struthers proximally.

PATHOGENESIS
- Elbow injuries are often the result of direct impact—for example, a direct blow on the elbow during a fall.
- Knowing the energy of the fracture is important to gauge the likelihood of associated injuries.
- Less energy is required to create a comminuted fracture in elderly and osteoporotic individuals, but muscular injuries of the triceps and brachialis are common, with a subsequent influence on the functional outcome.
- The ulnar nerve displaces with the medial fragment. As a consequence, the nerve may kink, leading to a local nerve injury. Nerve lacerations are an uncommon consequence of comminuted distal humeral fractures.

NATURAL HISTORY
- Most distal humeral fractures are treatable with either open reduction and internal fixation (ORIF) or nonoperative management. The challenging fracture subgroups are those that involve the articular surfaces and are comminuted.
- Many direct and indirect soft tissue complications may ensue, including neurovascular entrapment, muscle tears leading to myositis ossificans and soft tissue contracture with joint stiffness.
- There is some evidence to suggest that congruently reducing and fixing a comminuted intra-articular distal humeral fracture does not eliminate the risk of posttraumatic arthritis, although, where possible, ORIF should remain the primary goal.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The physical examination (FIG 1) should be performed gently in the presence of fractures, especially when comminution suggests the possibility of neurovascular injury if the examination is too vigorous.
- A complete examination of the elbow should also include evaluation of associated injuries. It should begin away from the elbow, progressing toward it.
- The following associated injuries should be ruled out:
  - Distal radial and scaphoid fractures: Since the most common mechanism of injury is a fall onto an outstretched hand, the energy transfer of the fall begins in the extended wrist, through the distal radius and scaphoid. Direct palpation of the distal radius should be done and anatomic snuff-box tenderness should be elicited. Palpation of the scaphoid tubercle and ulnar and radial deviation of the wrist may also identify a scaphoid injury.
  - Distal radioulnar joint disruption: Ballottement of the ulnar head should be done in the volar and dorsal directions, in pronation and supination. A disrupted joint is often painful with such ballottement, and the ulnar head may be prominent with the forearm in pronation.
  - Fracture extension beyond the elbow: The examiner should palpate the ulna shaft, along its subcutaneous border, from the wrist to the olecranon.
  - Interosseous membrane injury: Palpating the interval between the bones of the forearm is not a sensitive examination but can raise suspicion for an Essex-Lopresti injury.

FIG 1 • Typical appearance of an elbow with an underlying fracture with extensive swelling and bruising.
leading to further imaging. If an interosseous membrane disruption is present, this will influence the type of implant used for elbow replacement (one with a radial head replacement), but the pathology is not commonly described.

**IMAGING AND DIAGNOSTIC STUDIES**
- Plain radiographs, including anteroposterior (AP) and lateral views (FIG 2) of the elbow and both wrists, should be obtained. The elbow view may have to be taken in a protective splint or plaster back-slab for patient comfort.
- Elbow radiographs will allow initial assessment of the degree of commination and may indicate the presence of decreased bone mineral density.
- Bilateral wrist views will indicate the presence of an axial (interosseous membrane) injury if the ulnar head is in positive variance compared to the contralateral uninjured wrist.
- Plain tomograms are of use in improving the understanding of the fracture configuration, but an alternative would be a computed tomography (CT) scan. With the latter the surgeon can view a three-dimensional reconstruction, which is a useful surgical planning tool.
- If there is evidence on physical examination of a neurologic injury, it is prudent to document its extent with a carefully performed neurologic examination.

**DIFFERENTIAL DIAGNOSIS**
- Nonunion
- Ligamentous disruption
- Fracture-dislocation

**NONOPERATIVE MANAGEMENT**
- The “bag-of-bones” technique is a nonoperative method of treatment described by Eastwood that encourages the compressive molding of the comminuted distal humeral fracture fragments.
- Subsequent rehabilitation with collar and cuff support achieves substandard but acceptable results only in the elderly and debilitated group of patients who have almost no demand on elbow function.
- This type of treatment does not achieve acceptable results with respect to stability and strength in younger patients.

**SURGICAL MANAGEMENT**

**Open Reduction and Internal Fixation**
- ORIF has been widely documented for comminuted fractures of the distal humerus.
- Some reported series demonstrate good results with fixation of such challenging fractures, with better results predominantly in the younger age groups. Rarely are good results achieved in the elderly, osteoporotic group. Many series report less-than-satisfactory outcomes in the elderly treated by operative fixation. A direct comparison of internal fixation to primary total elbow replacement in the elderly osteoporotic group revealed that replacement produced no poor results and no need for revision surgery at 2 years of follow-up. The internal fixation group produced three poor results requiring revision to a total elbow replacement.

**Elbow Arthroplasty**
- When a distal humerus fracture is not reconstructable, arthroplasty becomes a valid treatment option.
- Elbow replacement following a failed attempt at fixation has proven to have a significantly worse outcome than if the arthroplasty was performed initially. There are a number of studies that support the concept of an acute total elbow arthroplasty in select patients with comminuted fractures of the distal humerus.
- The more traditional form of replacement for the elderly and low-demand population with an unreconstructable distal humerus fracture is the total elbow arthroplasty.
- A more recent innovation has been the replacement of the distal humerus (hemiarthroplasty) to preserve an intact ulna and radial head. This procedure is not FDA approved and so should be considered experimental and not for general consideration, especially since the elbow joint is variable and highly congruent in its topography, which differs from many of the standard implants used for acute fractures.

**Indications and Contraindications**
- Indications for acute total elbow arthroplasty
  - Comminuted, unreconstructable distal humerus fracture
  - Physiologically elderly patient
  - Low-demand patient
- Indications for acute elbow hemiarthroplasty
  - Unreconstructable distal humeral fracture (C3)
  - Unreconstructable combined fractures of capitellum and trochlea
  - Very low bicondylar T fracture of distal humerus
    - Young patient
    - Active patient
  - Repairable or intact collateral ligaments (may require reconstruction of the medial and lateral supracondylar columns)
    - Repairable or intact radial head
  - Absolute contraindications for acute joint replacement
    - Infection (overt)
    - Lack of soft tissue coverage (skin, muscle)
  - Relative contraindications for acute joint replacement
    - Infection in distant body part
    - Contaminated wound
    - Neurologic injury involving the elbow flexors
Preoperative Planning

- Standard radiographs should be obtained (AP and lateral).
- If doubt exists regarding the ability to anatomically repair the fracture, then a CT scan should be requested to assess the degree of comminution and the fracture line orientation.
- An assessment of humeral shaft bone loss is important in planning the implant design that might be considered. If the degree of loss is greater than the articular condylar fragments, an implant that has the ability to restore humeral length will be more appropriate. If an unreconstructable fracture of the humeral articular surfaces without humeral shaft bone loss is encountered, an implant with the ability to resurface the articular surfaces as a hemiarthroplasty or a resurfacing ulnotrochlear replacement can be considered, but the former implantation technique should be regarded as an off-label and experimental procedure.
- Humeral shaft length loss of 2 cm can be tolerated and standard implants used.
- Humeral shaft length loss of greater than 2 cm can be restored with implant designs with anterior flanges, especially those with extended flanges that allow restoration of humeral length.
- The surgeon should assess the intramedullary canal dimensions of the humerus and ulna. This will help to plan the requirement of extra-small diameter.
- Neurovascular status of the limb should be fully assessed and documented in the clinical notes.

Patient Positioning

- Two methods of patient positioning can be used, depending on surgeon comfort and the access required:
  - Supine: The arm is draped for maximum maneuverability. During the procedure the arm is supported on a large rolled towel placed on the patient’s upper thorax, carefully avoiding the endotracheal tube, stabilized by an assistant. In this position the surgeon stands on the side of the patient’s injured limb (FIG 3A).
  - Lateral decubitus: The arm is positioned on an arm support, thereby minimizing the need for an assistant, but this set-up is less maneuverable. In this position the surgeon stands on the opposite side of the patient’s injured limb (FIG 3B).

Surgical Approach

- Two main surgical approaches are useful for acute total elbow arthroplasty:
  - Triceps-splitting approach
  - Bryan-Morrey approach
- The triceps should be carefully managed in either approach, and it often has a thin tendon, especially in older patients and those with rheumatoid arthritis. The triceps tendon should be dissected from the olecranon with a small curved scalpel blade, maintained perpendicular to the interface between the tendon and bone.

INCISION AND DISSECTION

- Make a midline longitudinal skin incision (TECH FIG 1A), with a gentle curve to avoid the olecranon weight-bearing prominence. Extend the incision 5 cm distal to and proximal to the prominence of the olecranon tip.
- Develop the full-thickness medial and lateral skin flaps (TECH FIG 1B) and define the medial and lateral borders of the triceps (TECH FIG 1C,D).
- At the medial border, define and partially neurolyse the ulnar nerve, and mark and handle it with a tied vessel loop (without an attached hemostat, since its constant weight may cause inadvertent nerve injury) (TECH FIG 1E).
- With the nerve visualized and handled to safety, remain in the medial gutter to extend the dissection distally to define the medial fracture fragment. Transect the medial collateral ligament in its entirety, and remove all soft tissue from this bony fragment and remove the latter (TECH FIG 1F).
TECH FIG 1 • A. Skin incision is posterior longitudinal, with or without a small diversion to avoid the “point” of the olecranon. B. Raising the skin should aim to maintain the full thickness of the flaps by using the “flat knife” technique. C. The medial and lateral borders of the triceps are defined (arrows). D. This patient had an anconeus epitrochlearis (star) in relation to the ulna nerve (UN). E. A vessel loop is used to maneuver the nerve without an attached clip. F. The medial fragment of the fracture is removed once all the soft tissues are released from it, and the nerve is gently retracted to ensure tension-free removal.

TRICEPS MANAGEMENT

Triceps Preserving

- With the ulnar nerve gently medially retracted, use a periosteal elevator to define the plane between the triceps and the posterior humerus, from the medial to the lateral border, exiting posterior to the lateral intermuscular septum. Use this elevator to lift the triceps, with blunt dissection, by sliding the shaft of the elevator proximal and distal in the interface (TECH FIG 2A).
- Develop the lateral triceps–lateral intermuscular septum margin and resect the lateral fracture fragments, having firstly cleared them of soft tissue attachments (TECH FIG 2B).
  - While in the lateral corridor, visualize the radial head and resect sufficient head to prevent abutment on the prosthesis.
  - From the lateral margin of the humeral shaft, raise the brachialis from 2 to 3 cm of the anterior surface.

Modified Bryan-Morrey Approach

- Preserving the integrity of the triceps insertion makes component insertion more difficult. An alternative approach for managing the triceps is to reflect it from the tip of the olecranon from medial to lateral, thereby improving exposure (TECH FIG 3).
- Define the medial triceps border and dissect the ulna nerve free from its connections, while protecting it in a vessel loop. The nerve is transposed into a subcutaneous pocket.
- The medial triceps is dissected to its ulna attachment. Release the triceps from the medial condylar fragments and transect the medial collateral ligament. Free the medial fragments from soft tissue attachments and remove the medial fragments between the triceps and a gently anteriorly retracted ulnar nerve.
TECH FIG 2 • A. A periosteal elevator is introduced between the triceps and the humeral shaft and the two structures are separated by sliding the elevator proximally and then distally to the level of the triceps insertion. B. The lateral corridor is defined and lateral fragments are removed.

- Develop the interval between the anconeus and flexor carpi ulnaris along the subcutaneous border of the ulna.
- The triceps tendon is sharply elevated from the olecranon, in continuity with the anconeus, and subluxed laterally. Take care to release the Sharpey fibers adjacent to the bone in order to retain the flap thickness. Further access is afforded by raising the anconeus from its ulnar attachment while maintaining its attachment distally.
- As the triceps is reflected laterally, the lateral condylar fragments are identified and removed by releasing the lateral collateral ligament and common extensor tendon.

TECH FIG 3 • A. The triceps is split through its central tendon, in line with the fibers. The tendinous portion is dissected from the olecranon to gain access to the ulna. B,C. To dissect the Sharpey fibers off the ulna, the surgeon uses the scalpel parallel to the ulna surface and maintains the release directly adjacent to the bone. D. Comminuted distal humeral fracture in an osteoporotic elderly woman, with CT imaging confirming significant articular comminution. This is the view through the triceps split.
BONE PREPARATION

- Identify the olecranon fossa (if any part of it still exists). This landmark is the seating point for the base of the anterior flange of the Coonrad-Morrey humeral component (TECH FIG 4A). If the olecranon fossa is not present owing to a greater degree of comminution, an extended-flange humeral component can be used.
- Release the anterior capsule and any soft tissue from the anterior surface of the distal humerus. This provides a site for the anterior humeral bone graft.
- The posterior flat surface of the humerus is identified since this plane approximates the axis of rotation of the distal humerus (TECH FIG 4B). Humeral canal preparation is completed with the canal broaches provided with the implant system being used.
- The ulnar canal preparation commences with removal of the tip of the olecranon. The intramedullary canal is entered at the base of the coronoid (TECH FIG 4C,D).
- The entry point is enlarged up toward the coronoid with a burr to allow easier component insertion without cortical abutment, which leads to malalignment (TECH FIG 4E).

TECH FIG 4 • A. The humeral component entry point, the apex of the olecranon fossa, is identified and humeral canal preparation is commenced by opening the canal with a bone nibbler or burr. B. The posterior flat surface of the humeral shaft is identified and the component is aligned. C,D. Ulnar canal preparation is commenced by opening the canal at the base of the coronoid process with a drill or burr. (continued)
During intramedullary preparation, the broaches must parallel the subcutaneous border of the ulna. This ensures that the track of insertion of the ulna parallels the intramedullary canal.

The tip of the coronoid is removed to avoid impingement during terminal flexion (TECH FIG 4F,G).

The radial head does not need to be resected if there is no disease of the proximal radioulnar joint (TECH FIG 4H).

### IMPLANT INSERTION AND TENSIONING

- With the canal preparation completed (TECH FIG 5A), including pulse lavage of the medullary canals and cement restrictor placement, implant insertion can commence (TECH FIG 5B,C).
- Humeral insertion
  - When bone loss is at or below the level of the olecranon fossa, standard humeral insertion can occur. If bone loss occurs above the olecranon fossa (greater than 2 cm), then humeral length must be restored.
  - Prepare a wedge-shaped bone “cookie” for placement behind the humeral flange.
  - Inject antibiotic cement into the humerus.
  - When inserting the humeral component, place the bone graft behind the anterior flange. Because the humeral condyles have been resected, the implant can

TECH FIG 4 • (continued) E. The trajectory of the ulnar component (black ring) is prepared by rasping the entry track posteriorly into the ulna with a rasp or bone nibbler (gray crescent). F,G. The tip of the coronoid should be resected sufficiently to prevent abutment on the humeral flange during full flexion. Also shown are the resections of the olecranon and the entry point for the ulnar stem insertion. H. The partially resected radial head is used as a bone graft for incorporation behind the humeral flange.
be completely seated and coupled once the cement has hardened.
- Maintain the component orientation relative to the posterior flat surface of the distal humerus.
- Seat the component and flange until the flange is completely engaged with the anterior cortex.
- Ulnar component insertion
  - Inject antibiotic cement into the ulnar canal.
  - The ulnar component is inserted such that the axis of rotation is recreated and the implant is perpendicular to the dorsal flat surface of the olecranon.

**TRICEPS REATTACHMENT**

- The triceps is reattached using a nonabsorbable suture in a running locking mode (eg, running Krakow stitch) to achieve predictable purchase (**TECH FIG 6A,B**).
- Avoid capturing large amounts of triceps muscle fibers within the locking loops.
- The triceps tendon should be reattached to the flat of the olecranon process, not to the tip (**TECH FIG 6C,D**). Pass the sutures through bone tunnels (oblique crossing) that begin on the periphery of the flat reattachment area of the olecranon (**TECH FIG 6E**).
- Avoid tying the sutures directly over the midline of the proximal ulna, which is a source of painful symptoms and may require knot removal. Place the knot under the anconeus.
- When tensioning the triceps at reattachment, place the elbow at 30 to 45 degrees of flexion while tying the knot.
- Use a separate absorbable suture to “cinch” the triceps footprint onto the reattachment area (**TECH FIG 6F**).

**TECH FIG 6 • A,B.** A running locking stitch is used to improve triceps purchase when reattaching the muscle to the ulna. A. An example of a running locking stitch on either side of the split tendon. B. A locking stitch that locks both sides of the split together with one continuous locking suture. It is then reinforced with a reversed across-split locking suture. (continued)
TECH FIG 6 • (continued) C,D. The triceps footprint to which reattachment should be attempted is predominantly on the flat part of the ulna or olecranon process, and not the tip, which is resected to prevent posterior abutment. E. Drill holes (1.5 to 2 mm) are oriented in a crossing fashion to secure the triceps to the footprint area. F. A separate “cinch” suture is used to increase the security and the area of contact between the triceps and the ulna, thereby improving healing potential.

WOUND CLOSURE

- The ulnar nerve is transposed into an anterior subcutaneous location.
- Reapproximate the triceps to the flexor and extensor masses with absorbable suture. Do not overtighten this repair, as it will restrict motion.
- The use of a subcutaneous drain is a matter of surgeon preference. However, there is no literature demonstrating the efficacy of a postoperative drain in preventing hematoma.
PEARLS AND PITFALLS

| Indications | ■ A complete history and physical examination should be performed, with specific questions about any bone mineral density problems and healing tendency.  
■ Care must be taken to address associated pathology at the elbow, wrist, and shoulder. |
| Planning | ■ The surgeon should attempt fracture osteosynthesis when physiologically the patient has adequate bone stock and demand on the elbow.  
■ Arthroplasty should be available in the physiologically older and lower-demand patient, with a view to converting the decision to an acute arthroplasty if the osteosynthesis potential is tenuous. |
| Exposure | ■ Initial definition and protection of the ulnar nerve are important. Careful dissection of the nerve from the cubital tunnel restraints will allow freedom to move the nerve without risking traction injury during the remainder of the procedure.  
■ If the exposure involves removing the triceps from its ulnar attachment (Bryan-Morrey or TRAP approach), the site of Sharpey fiber attachment should be marked and reattached anatomically.  
■ During a tendon-splitting approach, the distal triceps tendon should be split within the structure of the tendon and should not involve the muscular belly. |
| Inspection | ■ A thorough inspection of the ulna and radial articular surface should be performed to investigate the possibility of a hemiarthroplasty replacement in the appropriately selected younger patient.  
■ The surgeon should observe the state of the ulnar nerve and muscles around the elbow (especially triceps and brachialis); this will help to explain altered nerve function in the former, and weakness and possible myositis ossificans and stiffness in the latter. |
| Bone preparation | ■ If the humeral columns are intact, then an attempt at preservation should be made, with their extensor and flexor mass attachments, during a total elbow replacement. |
| Implantation | ■ When planning length and implantation, the surgeon should pay careful attention to the tension and lever arms of the main motor drivers; the brachialis and triceps need some tension to function well, but if over-tensioned the elbow will be stiff and if under-tensioned the elbow will be weak. |
| Wound closure | ■ Drains should not be used because of the superficial nature of the elbow and the risk of deep infection. However, the surgeon should pay close attention to hemostasis, and for the first 12 hours a moderately tight bandage should be used to avoid hematoma formation. The dressing is reduced the next day. |
| Rehabilitation | ■ With triceps reattachment, the surgeon should be cautious to avoid overzealous rehabilitation for fear of compromising triceps healing, with subsequent avulsions or extension weakness. |

### POSTOPERATIVE CARE

■ A volar plaster or thermoplastic splint is used to maintain the elbow in full extension for the first several days. This avoids tension on the incision and on the triceps reattachment.  
■ The arm is elevated on pillows or with a Bradford sling overnight to prevent edema.  
■ Nonsteroidal anti-inflammatories are avoided because of their detrimental effects on tissue healing (bone to tendon and bone to bone).  
■ On the second day after surgery the dressing is removed and the compliant patient should commence gentle active antigravity flexion, with passive gravity-assisted extension.  
■ Graduated and targeted motion is prescribed, with greater than 90 degrees of elbow flexion attempted after 5 weeks. This allows sufficient time for the triceps to adhere and heal (incompletely) to the ulna. Aggressive flexion too early may result in triceps avulsion or pull-out. Triceps antigravity exercises can commence after 5 weeks.  
■ Always, at each patient interaction, the surgeon should reiterate the restrictions of use with an elbow arthroplasty: limited internal (varus) and external (valgus) rotatory torques, 2-pound repetitive and 10-pound single-event lifting.

### COMPLICATIONS

■ Triceps avulsion  
■ Stiffness  
■ Overlengthened implantation  
■ Overtensioned triceps reattachment  
■ Overzealous closure of triceps to flexor–extensor compartments  
■ Inadequate soft tissue release  
■ Impingement  
■ Radial head on humeral component (distal yolk)  
■ Coronoid on humeral component (anterior yolk)  
■ Olecranon process on posterior humerus  
■ Deep venous thrombosis  
■ Infection  
■ Periprosthetic fracture  
■ Osteoporotic bone  
■ Stem–canal mismatched sizes  
■ Stem–canal mismatched curvature  
■ Inadequate opening for ulna component at coronoid base  
■ Ulna nerve neuropathy or injury

### OUTCOMES

■ Cobb and Morrey\(^1\) reported 15 excellent and 5 good results, with one patient with inadequate data, in a cohort of patients with acute distal humeral fractures (average age 72 years) at 3.3 years of follow-up.  
■ Ray et al\(^3\) reported 5 excellent and 2 good functional results in a group of patients with an average age of 81 years at 2 to 4 years of follow-up.  
■ Gambirasio et al\(^5\) reported excellent functional results in a cohort of 10 elderly patients with osteoporotic intra-articular fractures.
Frankle et al. compared the outcomes of patients over age 65 with comminuted intra-articular distal humeral fractures treated with ORIF versus total elbow replacements. The ORIF group had 8 excellent results, 12 good results, 1 fair result, and 3 poor results, with 3 patients requiring conversion to elbow replacement. All 12 acute primary elbow replacements achieved excellent (n = 11) or good (n = 1) results.

Kamineni and Morrey reported an average Mayo Elbow Performance Score (MEPS) of 93/100 in a series of 49 acute distal humeral fractures (average patient age 67 years) at 7 years of follow-up. The average arc of motion was 107 degrees.

Lee et al. reported seven acute elbow replacements for distal humeral fractures in patients with an average age of 73 years. The average arc of motion was 89 degrees and the average MEPS was 94/100 at an average follow-up of 25 months.

REFERENCES

DEFINITION

- Primary degenerative arthritis of the elbow is an uncommon problem.\(^1\)
- It occurs in less than 2% of the population\(^29\) and principally affects the dominant extremity in middle-aged manual laborers.\(^1,3,17,23,29\)
- The disorder predominates in men and is rarely seen in women, with an incidence of 4 to 5:1.\(^8\)
- The dominant extremity is involved in 80% to 90% of symptomatic patients. Bilateral involvement of the elbow is noted in 25% to 60% of patients.\(^6\)
- It has also been reported in people who require continuous use of a wheelchair or crutches, in athletes, and in patients with a history of osteochondritis dissecans of the elbow.\(^21,25\)
- The pattern of pathologic changes in primary degenerative arthritis is different than the age-related changes of the distal humerus and the radiohumeral joint.\(^6,26\)
- The current understanding of the disease process in primary degenerative arthritis has led to treatment algorithms designed to address the pathologic process short of joint replacement.
- The role of total elbow arthroplasty (TEA) for patients with primary degenerative arthritis of the elbow is limited, in large part because of the younger age and increased activity levels of patients with this condition.

PATHOGENESIS

- The exact pathogenesis of primary osteoarthritis of the elbow is still unknown. It is generally believed that overuse plays a key role in the onset of the disease process. However, younger patients with this disease often have predisposing conditions such as osteochondritis dissecans.\(^11\)
- The degenerative changes of the elbow joint are usually more advanced in the radiohumeral joint, where bare bone is often in wide contact, and the capitellum appears to have been shaved obliquely (FIG 1).\(^6\)
- This is due to the high axial, shearing, and rotational stresses at this articulation, which result in marked erosion of the capitellum and hypertrophic callus formation in a skirt-like pattern on the radial neck.\(^32\)
- The ulnohumeral joint is usually less involved in the beginning of the disease process, but involvement becomes more pronounced with more advanced disease.\(^21\)
- The central aspect of the ulnohumeral joint is characteristically spared. The anterior and posterior involvement of this joint is usually manifested by fibrosis of the anterior capsule in the form of a cord-like band and hypertrophy of the olecranon.
- Osteophytes are seen over the olecranon, especially medially, the coronoid process, and the coronoid fossa.
- These changes in the radiohumeral and ulnohumeral joints lead to the loss and fragmentation of the cartilaginous joint surfaces with distortion, cyst formation, and bone sclerosis.\(^2\)
- Kashiwagi\(^9\) noted that the early stage of the disease is characterized by small, round bony protuberances; the early stage progresses into various shapes of osteophytes and bony sclerosis with more advanced cases.
- Suvarna and Stanley\(^30\) reported on the progressive fibrosis of the local marrow, increased thickness of all the bony components of the olecranon fossa, and increases in anterior and posterior fibrous tissues.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Despite considerable radiographic severity, many patients with osteoarthritis of the elbow report minimal symptoms.\(^11\)
- Trauma rarely underlies the onset of degenerative arthritis. However, trivial injury often brings the problem to the patient’s attention.
- Characteristic manifestations of primary degenerative arthritis of the elbow are well described.\(^22,24\) These include:
  - Progressive loss of motion
Mechanical symptoms of locking and catching caused by intra-articular loose bodies (occurs in about 10% of patients)9
- Pain at the extremes of motion due to mechanical impingement of osteophytes (pain occurs most frequently at terminal extension, although about 50% of patients also have pain during terminal flexion)
- Pain throughout the arc of motion indicates significant involvement of the ulnohumeral joint; this typically occurs late in the disease process.
- Ulnar neuropathy
  - Medial joint pain in patients with advanced osteoarthritis of the elbow might be the first manifestation of ulnar neuropathy.
  - Up to 20% of patients with primary osteoarthritis of the elbow have some degree of ulnar neuropathy.1
  - The proximity of the ulnar nerve to the arthritic posteromedial aspect of the ulnohumeral joint makes it susceptible to impingement.
  - The expansion of the capsule as a result of synovitis and the presence of osteophytes in that area of the joint result in direct compression and ischemia of the ulnar nerve.
  - Acute onset of cubital tunnel syndrome in patients with osteoarthritis of the elbow might be also the first manifestation of a medial elbow ganglion.10
- Radiocapitellar symptoms: With more progressive disease, the patients may have pain with forearm rotation and throughout the range of elbow motion. This could lead to disability in this patient population as well in the older laborers who extensively use their upper extremity.6,16,33

PHYSICAL FINDINGS
- Physical examination findings depend on the extent of the patient’s disease.
- Range of motion
  - The flexion-extension arc will demonstrate loss of extension greater than flexion and will average about 30 to 120 degrees.
  - The midrange of the flexion–extension arc is typically pain-free in the early stages of the disease.
- A painful midrange of motion and crepitus indicate more extensive involvement of the ulnohumeral joint.
- The arc of pronation–supination is rarely affected early in the disease process. Involvement of the proximal radioulnar and radiohumeral joint later in the disease process may limit forearm rotation.
- Forced motion at the extremes of flexion and extension will often cause pain, particularly in extension.
- Ulnar nerve symptoms need to be thoroughly evaluated. Symptoms of ulnar neuropathy associated with primary degenerative arthritis of the elbow include:
  - Decreased sensation and weakness
  - Positive Tinel sign at the cubital tunnel
  - Positive elbow hyperflexion test

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Some characteristic radiographic features are seen on the anteroposterior and lateral radiographs of the elbow:
  - Radiocapitellar narrowing (noted in 25% to 50% of patients)
  - Ossification and osteophyte formation in the olecranon fossa in almost all patients with osteoarthritis of the elbow15,21
  - Osteophyte formation of the coronoid and olecranon processes
  - Loose bodies and fluffy densities might be observed filling the coronoid and olecranon fossae (FIG 2A,B).
- Radiographs do not allow for accurate visualization of all osteophytes.
- A cubital tunnel view is obtained if there is ulnar nerve irritation to look for impinging osteophytes or loose bodies.4,6,7
- Computed tomography (CT) helps in delineating the detailed structural anatomy of the articular surface of the elbow with an accurate determination of the locations of the osteophytes and loose bodies (FIG 2C).
- When contemplating surgical treatment of the osteoarthritic elbow, a CT is quite helpful for determining which osteophytes need to be removed.

FIG 2 • A,B. Anteroposterior and lateral views of a right osteoarthritic elbow show narrowing of the joint line and subchondral sclerosis, with formation of osteophytes in the coronoid, capitellar, and olecranon fossae. (continued)
Three-dimensional reconstructions provide additional detail on osteophytic deformity and facilitate preoperative planning of removal.

MRI does not provide any useful information in primary osteoarthritis of the elbow and is rarely indicated.

NONOPERATIVE MANAGEMENT

Because of their young age, most patients with primary osteoarthritis of the elbow tend to be active and involved in manual labor, which will place a great demand on any kind of prosthetic replacement.

Early in the course of the disease, treatment by nonsurgical measures should be followed.21 This consists of activity modification, physical therapy, anti-inflammatory medications, and possibly steroid injection or visco-supplementation.13

SURGICAL MANAGEMENT

Indications

If nonoperative treatment fails to improve symptoms, surgery may be indicated.

Several surgical options exist for the management of primary degenerative arthritis of the elbow. Surgery is directed toward addressing the pathology contributing to the predominant complaints of the patient.

The surgical techniques depend on:

- Degree of osteophyte formation
- Degree and direction of motion loss
- Associated loose bodies
- Associated ulnar nerve symptoms
- Degree of ulnohumeral involvement resulting in pain through the midrange of motion

Arthroscopic Débridement

Arthroscopic management of degenerative arthritis of the elbow is discussed in detail in Chapter SM-22.

In general, arthroscopic débridement for degenerative arthritis of the elbow can be performed for moderate to severe disease when there are no midrange symptoms, indicating limited involvement of the ulnohumeral joint.

Advantages of arthroscopy include the ability to visualize the entire joint and limited morbidity from surgery.

Savoie et al reported good results with extensive arthroscopic débridement involving capsular release, fenestration of the distal part of the humerus, and removal of osteophytes.28

Disadvantages of arthroscopy include potential neurovascular injury and difficulty assessing the normal anatomic relationships, resulting in inadequate débridement, compared with open débridement and release.

Contraindications to arthroscopic treatment include altered neurovascular anatomy, limited surgical expertise, and advanced involvement of the ulnohumeral joint.

Open Débridement

- Open débridement can be performed for all patients with primary degenerative arthritis of the elbow.
- Open joint débridement should be considered in patients with advanced disease or when the treating surgeon has limited experience with arthroscopic techniques.
- Options for open débridement of the elbow include:
  - Outerbridge-Kashiwagi arthroplasty (see Chap. SE-42)
  - Lateral column approach for débridement (see Chap. SE-43)
  - Medial over-the-top approach for débridement (see Chap. SE-44)

Total Elbow Arthroplasty

- TEA for the treatment of primary osteoarthritis of the elbow is performed sparingly in carefully selected patients. In general, the patient population with primary degenerative arthritis of the elbow includes relatively young men who are physically active in their occupation and want to remain so. TEA is contraindicated in high-demand patients.
- The indications for TEA for primary degenerative arthritis of the elbow include patients older than 65 years with low physical demands and a painful arc of motion. These patients should have attempted and failed all other appropriate treatment options.

Implant Choices

- Unlinked (resurfacing) and linked (semiconstrained) designs may be appropriate in patients with primary degenerative arthritis of the elbow.
- The current literature supports the use of linked implant designs for primary degenerative arthritis. However, osteoarthritis may be the best indication for the use of an unlinked implant.
- Linked implants
  - Current linked designs with a semiconstrained, loose-hinged articulation allow varying degrees of varus–valgus motion and rotational laxity (FIG 3A).
  - Muscle activation about the elbow protects against excessive loading, thereby reducing aseptic loosening.

![Computed tomography of the elbow demonstrating marginal osteophytes on the ulna and olecranon fossa.](FIG 2 • (continued) C)
Unlinked implants
- Anatomic requirements for the use of unlinked implants include:
  - Competence of the medial and lateral collateral ligaments
  - Minimal deformity of the subchondral architecture
  - Integrity of the medial and lateral supracondylar columns
- Maintenance of the collateral ligaments and surrounding muscles helps absorb forces across the elbow, thereby reducing stress on the bone–cement interface. This has the theoretical, but unproven, advantage of offloading stresses on the implant.
- Some authors believe that this potential advantage may allow this implant type to be used in a higher-demand patient population. However, this potential advantage is yet unproven. Therefore, the indications for total elbow replacement are still limited in this patient population to patients willing to adopt low physical demands.
- The major complication of unlinked implants is instability.
- If an unlinked implant is considered in this patient population, the ability to convert to a linked replacement (linkable) has obvious advantages.

Linkable implants
- These devices permit implantation in an unlinked fashion, taking advantage of the benefits of an unlinked design (FIG 3B).
- The ulnohumeral articulation can be captured, thereby converting the unlinked implant to a linked implant by placing an ulnar cap on the ulnar component (FIG 3C). This can be performed at the time of implantation of the unlinked implant if stability cannot be established or at a point distant to the initial implantation if instability becomes an issue.

Patient Positioning
- The patient is positioned supine on the operating room table with a bump under the ipsilateral scapula. The arm is positioned across the chest and supported on a bolster (FIG 4).
- A tourniquet is applied to the arm. The use of a sterile tourniquet increases the “zone of sterility” and allows removal for more proximal exposure if needed.

Approach
- The surgical technique for linked arthroplasty is discussed in other chapters. Please refer to these chapters for the specific technical details of implantation of a linked, semiconstrained implant. This chapter will discuss an unlinked total elbow system, which can be converted to a linked implant if required for stability.
SURGICAL EXPOSURE

- A straight posterior, midline incision placed just off the medial tip of the olecranon is used (TECH FIG 1).
- Full-thickness flaps are elevated. The extent of flap elevation is based on how the triceps is to be managed surgically.
- The ulnar nerve is identified, protected with help of a Penrose drain, and transposed anteriorly.

TECH FIG 1 • Straight posterior midline skin incision is placed off the medial aspect of the olecranon. (Courtesy of Tornier, Inc., Edina, MN.)

TRICEPS MANAGEMENT

- Surgical management of the triceps is a matter of surgeon preference. The general methods of triceps management are triceps-sparing, triceps-reflecting, and triceps-splitting approaches.
  - Triceps-sparing approaches leave the triceps attached to the tip of the olecranon. The advantage of this type of approach is that it prevents triceps weakness postoperatively, but it sacrifices surgical exposure.
  - Triceps-reflecting approaches subperiosteally elevate the triceps from its attachment on the ulna; it must be carefully reattached and protected postoperatively. However, surgical exposure is facilitated with these approaches.
  - Triceps-splitting approaches violate the attachment of the triceps to the ulna yet provide the advantages of improved visualization of the joint.

A triceps-splitting approach is performed by completing a midline split in the triceps muscle and tendon, which is carried distally onto the ulna along the subcutaneous border of the ulna between the anconeus and the flexor carpi ulnaris (TECH FIG 2A).

- The medial triceps is elevated in continuity with the flexor carpi ulnaris while the lateral triceps is elevated in continuity with the anconeus. Care must be taken when elevating the medial triceps flap. The medial triceps attachment to the triceps is tenuous in comparison to the lateral triceps flap, which is much more robust.
- The medial collateral ligament (anterior bundle) and lateral collateral ligament complex are tagged and released from their humeral attachment (TECH FIG 2B).
- The shoulder is externally rotated and the elbow is flexed, allowing the ulna to separate from the humerus (TECH FIG 2C).

TECH FIG 2 • A. Triceps-splitting approach carried from the subcutaneous border of the ulna proximally into the triceps tendon. The medial and lateral triceps are subperiosteally elevated from the olecranon. B. The medial and lateral collateral ligaments are released from their humeral attachment and tagged for later repair. C. The elbow is dislocated with flexion of the joint, allowing the ulna to separate from the humerus. This separation provides exposure for component insertion. (Courtesy of Tornier, Inc., Edina, MN.)
IMPLANTATION

Humeral Preparation
- Sizing of the implant to the patient’s native anatomy is critical. Trial spools should be compared to the distal humerus and the proximal radioulnar joint for appropriate sizing (TECH FIG 3A,B). If the native joint size is between spool sizes, the smaller spool is selected.
- The medial and lateral points of the axis of rotation through the distal humerus are determined and an axis pin is placed through these two points, thereby replicating the axis. A drill guide aids in reproducing these points (TECH FIG 3C).
- The central portion of the distal humerus articulation is removed, the intramedullary canal is opened, and a rod is placed in the intramedullary canal. The axis pin is replaced to determine the offset of the intramedullary canal relative to the flexion–extension axis (TECH FIG 3D,E).
- A distal humeral cutting block is used to precisely prepare the distal humerus relative to the intramedullary canal and the flexion–extension axis (TECH FIG 3F,G).
- The humeral canal is sequentially broached to the size selected for the articular spool.

Ulnar Preparation
- Preparation of the ulna is based on the flexion–extension axis of the proximal radius and ulna. The selected size spool is attached to the cutting guide, and the guide is tightened with set screws (TECH FIG 4A). Care must be taken to maintain the relationship of the trochlea and capitellar portions of the spool with the native greater sigmoid notch and radial head.
- A bell saw is used to resect a small portion of the articular surface and subchondral bone of the ulna (TECH FIG 4B).
- If the radial head is going to be replaced, a sagittal saw is used to resect the radial head through the cutting guide. The canal is broached and a trial radial head component is inserted.
- The ulnar canal is opened and sequentially broached to the same size as the selected humeral component.

Component Placement
- If the replacement is going to be unlinked, a short ulnar component can be used. If the implant is going to be linked, a standard (longer) stem is selected. If a standard ulnar component is going to be used, flexible reamers may be required to prepare the ulna.
- Trial reduction is performed to assess the alignment, stability, and tracking of the components.
- If the components are going to be inserted unlinked, the collateral ligaments are reattached to the anatomic origin through the humeral implant. An accessory box stitch could be placed through the ulna and humeral component to support the collateral ligament repair.
- The canals are lavaged and cement restrictors are placed in the humerus and ulna.
- Antibiotic-impregnated cement is injected into the canals. Methylene blue is added to the cement to facilitate cement removal if required in the future.
A locking stitch is used to repair the collateral ligaments through the cannulated humeral bolt (TECH FIG 5A).

Further support is achieved using a cerclage stitch passed through the humeral bolt and a transverse drill hole in the ulna (TECH FIG 5B).

The selected anatomic spool is attached to the ulnar cutting jig. The set screws are tightened, taking care to ensure the anatomic spool stays firmly opposed to the native radius and ulna. With the ulnar cutting guide properly aligned, a bell saw is used to prepare the proximal ulna. The radial head can also be removed using the same cutting jig. (Courtesy of Tornier, Inc., Edina, MN.)

The medial and lateral collateral ligaments are reattached to the epicondyles using a locking stitch that is passed through the cannulated humeral screw. The collateral ligament repair is reinforced with a box stitch passed through the cannulated humeral screw and a transverse hole placed through the proximal ulna. (Courtesy of Tornier, Inc., Edina, MN.)
TRICEPS REPAIR

- Triceps repair is crucial for the stability of unlinked devices.
- The triceps is reattached through two crossing drill holes and one transverse drill hole in the olecranon.
- A grasping suture (Krackow stitch) is used and passed through the crossing drill holes.
- A cerclage stitch is passed through the transverse drill hole around the triceps attachment (TECH FIG 6).

TECH FIG 6 • The triceps is repaired to the ulna through drill holes. The split in the triceps and between the anconeus and flexor carpi ulnaris is closed side to side with interrupted or running suture. (Courtesy of Tornier, Inc., Edina, MN.)

WOUND CLOSURE

- The ulnar nerve is transposed into an anterior subcutaneous pouch.
- The wound is closed over a drain placed in the subcutaneous position.

POSTOPERATIVE CARE

- The arm is placed in a well-padded postoperative dressing and the arm is immobilized in about 90 degrees of flexion for the first several days.
- A resting elbow splint at 90 degrees with the wrist included is fabricated before discharge to protect the soft tissue repair while it heals.

OUTCOMES

- Most studies in the literature reporting on TEA involve large numbers of patients, mostly with rheumatoid arthritis or other inflammatory pathologies but very few patients with primary osteoarthritis.
- This makes it difficult to make accurate conclusions on the value of this treatment option for this population of patients.\(^{5,14,20,27}\)
- There are few studies in the English literature reporting specifically on the outcome and complications of TEA as a treatment option for patients with primary osteoarthritis of the elbow.\(^{4,13}\)
- Kozak\(^{13}\) reported on the Mayo clinic experience.
- Over a 13-year period, only 5 of 493 patients (<1%) who underwent TEA had the procedure performed for primary osteoarthritis of the elbow.
- A linked Coonrad-Morrey implant (Zimmer, Warsaw, IN) was used in three patients and an unlinked Pritchard elbow resurfacing system (ERS) (DePuy, Warsaw, IN) was used in the other two patients.
  - The average age of the patients was 67 and follow-up ranged from 37 to 121 months.
  - Two minor and four major complications were reported in four elbows, two of which required revision.

- This rate of complications, according to the authors, is much higher than the rate of complications reported in TEA performed for other reasons in the same institution during the same period of time, including revision TEA, posttraumatic arthritis, nonunion of distal humerus, and rheumatoid arthritis.\(^{12,18,19}\)
- Espag et al\(^{4}\) reported on 11 Souter-Strathclyde cemented unlinked primary TEAs in 10 patients with osteoarthritis of the elbow.
  - The diagnosis was primary osteoarthritis of the elbow in nine patients and posttraumatic osteoarthritis in two patients.
  - The average age of the patients was 66 years; mean follow-up was 68 months.
  - Only one patient required revision after 97 months for ulnar component loosening.
  - All patients reported good symptomatic relief of pain and a significant increase in range of motion, and all patients considered the procedure to be successful.
  - The authors compared these results with the result of Souter-Strathclyde TEA used in patients with rheumatoid arthritis.\(^{27,31}\)
  - The revision rate in their series (9%) performed for ulnar component loosening compares favorably with the revision rate with the rheumatoid patients (5% to 21%), in which the main indications for revision included dislocation, and perioperative fracture.
  - The authors attributed the decrease in the incidence of peri- and postoperative fracture to the good amount of bone stock in patients with primary osteoarthritis of the elbow, which makes the risk of fracture very minimal.
  - As evident from this review, the outcome studies of TEA in patients with primary osteoarthritis of the elbow are very limited. The above-mentioned studies included a
small number of patients, and no final recommendation could be drawn at this time.

- It is hoped that a greater understanding of elbow anatomy and kinematics will lead to advances in prosthetic design and surgical technique.
- The newer anatomic unlinked implants may improve the outcome of elbow replacement in younger patients.  
- More outcome studies are needed on these implants or any other modern implants before openly recommending elbow replacement in younger active patients with primary osteoarthritis of the elbow.

REFERENCES


DEFINITION AND PATHOGENESIS

- Posttraumatic conditions of the elbow represent a variety of disorders involving the elbow as a result of previous injury. Included among the posttraumatic conditions are:
  - Posttraumatic arthritis
    - Primary pathology involves posttraumatic degeneration of the articular surface.
    - Secondary pathologies can include contracture, loose bodies, and heterotopic bone.
  - Nonunion of the distal humerus
    - Total elbow arthroplasty (TEA) is considered when reconstruction of the nonunion is deemed impossible or undesirable.
  - Dysfunctional instability of the elbow
    - This is a special clinical situation where the fulcrum for stable elbow function is lost. The forearm may be dissociated from the brachium (FIG 1).
  - Chronic instability (dislocation)
    - Chronic ligamentous instability of the elbow can lead to articular degeneration, particularly in the elderly, osteopenic patient.
- Treatment for posttraumatic conditions is individualized depending on the underlying pathology as well as the functional demands and age of the patient.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient history is directed at gaining information about the initial injury, treatments undertaken, complications of treatment, presenting complaints, and patient expectations.
- Detailed investigation of the patient’s symptoms should include questions regarding the degree of pain, presence of instability or stiffness, and mechanical symptoms of catching, or locking.
- The physical examination of the elbow should follow a systematic approach:
  - Inspection of the elbow
    - Presence and location of previous skin incisions or persistent wounds
    - Alignment of the extremity at rest
    - Prominent hardware
  - Range of motion (ROM)
    - Active ROM is assessed and compared to the opposite side. The degree of motion, smoothness of motion, and feel of the endpoint are established.
    - Normal active ROM varies, but it should be symmetrical with the opposite unaffected side. Range of motion should be from near full extension (may have hyperextension) to 130 to 140 degrees of flexion. Normal forearm rotation is an arc of 170 degrees, with slightly more supination than pronation.
    - Functional ROM has been defined as a flexion–extension arc from 30 degrees to 130 degrees and a pronation–supination arc from 50 degrees of pronation and 50 degrees of supination.10
    - Passive range of motion (PROM) is then assessed and compared to the active motion arc.
    - Palpation of the elbow should systematically review all of the bony and soft tissue structures of the elbow.
    - The ulnar nerve needs to be carefully assessed. If previously surgically manipulated, its location should be identified if possible.
    - Motor function of the elbow should be assessed, in particular the flexor (biceps and brachialis) and extensor (triceps) function.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Orthogonal radiographic views of the elbow are mandatory (FIG 2).
  - A good lateral radiograph can typically be obtained.
  - A useful anteroposterior (AP) radiograph can be difficult, particularly if the patient has significant flexion contracture. A poor AP radiograph can make assessment of the joint space difficult, typically resulting in overestimating the amount of joint destruction.
  - Oblique radiographs can be helpful in obtaining more detail.
  - CT scans are particularly helpful in assessing the integrity of the bone and establishing whether the joint space is reasonably preserved.
  - Three-dimensional reconstructions provide a better understanding of any deformity.
  - Magnetic resonance imaging is rarely needed in the assessment of a posttraumatic joint and is therefore used sparingly.

FIG 1 Radiograph demonstrating dissociation of the forearm from the brachium in a patient with an inadequately treated fracture of the distal humerus with resultant nonunion.
DIFFERENTIAL DIAGNOSIS
- Nonunion or malunion of the distal humerus
- Posttraumatic stiffness of the elbow
- Chronic dislocation of the elbow

NONOPERATIVE MANAGEMENT
- The success of nonoperative management depends on specific features of the pathology and the motivation and goals of the patient.
- Activity modification is used to reduce the forces across the elbow.
- Range of motion of the elbow should be maintained. Aggressive efforts to regain lost motion can aggravate the joint.
- External bracing is occasionally used to support an unstable extremity. However, in general, bracing is poorly tolerated and functionally limiting.

SURGICAL MANAGEMENT
- Surgical management of traumatic conditions of the elbow is directed at addressing the underlying cause of disability and should take into consideration the patient’s age, physical requirements, and expectations.

Surgical Options
**Interposition Arthroplasty**
- **Indications**
  - Patients with pain or loss of range of motion who have failed to respond to nonoperative management
  - Posttraumatic arthritis in patients who are either too young for TEA or who are unwilling to accept the functional restrictions with TEA
  - The patients who do best following interposition are those with painful loss of motion when there is no requirement for aggressive, heavy use of the extremity.
- **Contraindications**
  - Active infection (septic arthritis with persistent infection)
  - Grossly unstable elbow
  - Marked angular deformity
  - Pain without associated functional loss

- **Total Elbow Replacement**
  - Patients with posttraumatic conditions of the elbow tend to be younger than other patients undergoing TEA.
  - In this group of patients, TEA should be considered in patients who:
    - Have failed to respond to appropriate nonoperative management
    - Are not appropriate candidates for other surgical options
    - Are willing to adopt a more sedentary lifestyle
    - Have no absolute contraindications to the procedure

Preoperative Planning
**Interposition Arthroplasty**
- **Graft options**
  - Achilles tendon allograft has the advantage of no donor site morbidity. It can also be used to reconstruct the collateral ligaments if necessary.
  - Dermal or fascia lata autogenous graft
  - Dermal tissue allograft
- **Revision**
  - The salvage for a failed interposition arthroplasty is a TEA.¹
  - Interposition arthroplasty should not be undertaken unless the surgeon is comfortable performing a total elbow replacement in the face of failure.

**Total Elbow Replacement**
- Implants are described in terms of their physical linkage (linked, unlinked, or linkable) and based on their constraint (constrained, semiconstrained, minimally constrained).
- **Linkage** is determined by whether the components are physically linked.
- **Constraint** is a more poorly defined quality of the implant. It depends on the geometry of the implant and its interaction with stabilizing soft tissues about the elbow.⁶
- **Implant selection in posttraumatic arthritis**
  - Linked (semiconstrained) designs: Linked implants have the advantage of being universally applicable to all posttraumatic conditions of the elbow.
  - Unlinked designs: The requirement for the use of unlinked designs in posttraumatic conditions of the elbow is integrity of the collateral ligaments and limited deformity such that normal anatomic relationships can be re-established.
  - **Linkable designs**: Linkable designs have been developed to take advantage of the features of an unlinked implant while capturing the universal applicability of the linked implants. They can be converted from unlinked to linked either at the time of an initial surgery if stability cannot be conferred or remotely if instability becomes an issue postoperatively.

Positioning
- **Interposition arthroplasty**
  - Supine with the arm across the chest and a bump under the ipsilateral shoulder
  - Alternatively, the lateral decubitus position with the arm over an arm holder
  - Total elbow replacement

**FIG 2** • AP and lateral radiographs of the elbow in a patient with posttraumatic arthritis of the elbow.
Patients are placed supine on the operating table with a bump under the ipsilateral shoulder. The arm should be freely mobile through the shoulder to allow manipulation of the joint throughout surgery. The arm can then be placed across the body on a bump or externally rotated through the shoulder and flexed at the elbow (FIG 3).

**FIG 3** • Patient positioning for total elbow arthroplasty with the arm across the body supported on a bolster.

**INTERPOSITION ARTHROPLASTY**

- Posterior skin incision: Develop medial and lateral subcutaneous flaps.
- Isolate and transpose the ulnar nerve.
- Perform deep exposure to the elbow through an extensile Köcher approach. The triceps can be partially released from the ulna to allow the triceps–anconeus composite to be mobilized (TECH FIG 1A).
- Mobilize the common extensor group from the anterior capsule and release it proximally with the extensor carpi radialis longus.
- Isolate the lateral ulnar collateral ligament and release it from its humeral origin (TECH FIG 1B). Perform an anterior and posterior capsular release. Supination of the forearm allows the ulna to be rotated away from the humerus. Attempt to leave the medial collateral ligament intact as it will improve postoperative stability.
- Inspect the cartilage surfaces. If more than 50% of the articular surface is involved, surgery proceeds to interposition.
- If extensile exposure is required, the extensile Köcher approach can be expanded to a triceps-reflecting anconeus pedicle (TRAP) approach (TECH FIG 1C,D). Reshape the distal humerus to conform to the olecranon. Remove the cartilage from the distal humerus and smooth the bone, but avoid aggressive resection of bone (TECH FIG 1E).
- Prepare the interposition tissue. The graft of choice is up to the surgeon, but there is a growing experience with allograft Achilles tendon. In addition to being a robust graft source, it allows for reconstruction of one or both collateral ligaments (TECH FIG 2A).
- Place drill holes across the supracondylar region from anterior to posterior (TECH FIG 2B). These drill holes are placed at the medial aspect of the trochlea, above the trochlear sulcus, at the lateral margin of the trochlea, and at the lateral aspect of the capitellum.
- Drape the interposition tissue over the distal humerus and secure it with sutures placed through the graft from front to back. If there is collateral ligament insufficiency, the tails of the graft (especially when using Achilles tendon) can be fashioned to reconstruct the collateral ligaments (TECH FIG 2C).
- Leave the radial head intact, especially if medial collateral ligament reconstruction is performed, to contribute to the valgus stability of the elbow.
- Repair the lateral collateral ligament through drill holes at the center of rotation laterally. Do not tie the ligament until the external fixator is securely applied.

**TECH FIG 1** • A. Extensile Köcher approach to the lateral elbow. The anconeus and triceps are elevated off the posterolateral capsule while the common extensor group is elevated off the anterior capsule. Exposure can be extended posteriorly with partial release of the triceps from the lateral aspect of the olecranon. B. Deep extensile exposure requires release of the lateral collateral ligament and anterior and posterior capsule. (continued)
TECH FIG 1 • (continued) C,D. The triceps-reflecting anconeus pedicle (TRAP) approach is an alternative approach that allows extensile exposure. C. The medial interval is along the medial triceps proximally and between the anconeus and flexor carpi ulnaris. The triceps is reflected from medial to lateral (Bryan-Morrey approach) off the olecranon in continuity with the anconeus. D. The lateral interval is an extensile Köcher approach between the anconeus and the extensor carpi ulnaris, which is extended proximally along the lateral supracondylar column. The triceps–anconeus composite maintains the neurovascular pedicle to the anconeus from above while allowing extensile exposure to the joint. E. The remaining cartilage on the distal humerus is removed and the subchondral bone is reshaped. Care should be taken to retain as much subchondral bone as possible for structural support of the interposition membrane.

**Hinged Elbow External Fixator**

- Apply a hinged external fixator to protect the interposed graft and to stabilize the joint while soft tissue healing occurs.
- The axis of rotation of the elbow is defined by bony landmarks about the lateral and medial joint (TECH FIG 3A).
  - The center of rotation at the lateral elbow is the center point of an arc defined by the articular surface of the capitellum.
  - The center of rotation at the medial elbow is defined by tightly distributed instantaneous centers of rotation approximated by a point at the anterior inferior aspect of the medial epicondyle.
- Establish an axis pin coincident with the lateral and medial centers of rotation. This is the foundation for construction of the fixator.
- The type of fixator used dictates the method of pin insertion relative to the axis pin. Fixator systems that allow the humeral and ulnar pins to be placed independently and then assembled to the axis pin are easiest for the surgeon with limited experience (TECH FIG 3B).
- When placing the humeral pin, take care to avoid injury to the neurovascular structures.
  - Pins in the proximal humerus are placed through the anterolateral aspect of the deltid distal to the axillary nerve.
  - Pins in the midshaft of the humerus are placed in the anterolateral humerus to avoid the radial nerve, which lies posteriorly.
- Ulnar pins are placed along the posterolateral aspect of the ulna.
TECH FIG 2 • A. The interposition membrane is prepared with mattress sutures placed distally. The Achilles tendon allograft also permits reconstruction of the collateral ligaments if necessary. B. Drill holes are placed from posterior to anterior across the supracondylar region to secure the interposition graft. C. The interposition membrane is secured to the distal humerus. If necessary, the graft can be fashioned to reconstruct the collateral ligaments. (From Morrey BF, Larson AN. Interposition arthroplasty of the elbow. In: Morrey BF, Sanchez-Sotelo J, eds. The Elbow and Its Disorders, 4th ed. Philadelphia: Elsevier; 2009: Figure 69–6.)

TECH FIG 3 • A. Drawing demonstrating the center of rotation on the lateral and medial side of the elbow. B. Photograph demonstrating a hinged external fixator. The humeral and ulnar pins are independently attached to the hinge.
A bar is fixed to the humeral and another bar is fixed to the ulnar pins.

The hinge is loosely attached to the humeral and ulnar bars.

The joint is reduced and ligament reconstruction, if necessary, is completed.

With the joint reduced, the fixator is tightened. If desired, distraction can be applied.

### TOTAL ELBOW REPLACEMENT

#### Surgical Approach

- A straight posterior skin incision placed off the medial aspect of the olecranon is preferred. Previous incisions may modify the location of the incision. Regardless of the incision used, deep access to the medial and lateral aspect of the joint is essential.

- Identify the ulnar nerve. If not previously handled surgically, the nerve is transposed anteriorly. If the nerve was previously transposed, it only needs to be identified, but not formally dissected unless the position of the nerve places it at risk during surgery.

#### Triceps Management

- Triceps-reflecting approaches are preferred over triceps-sparing approaches for posttraumatic conditions. Posttraumatic scarring and deformity can make a triceps-sparing approach difficult unless a nonunited distal humeral segment is to be resected.

- A Bryan-Morrey approach is typically performed (**TECH FIG 4A,B**). The medial aspect of the triceps is developed proximally while the interval between the anconeus and flexor carpi ulnaris (FCU) is developed distal to the olecranon. The triceps is reflected from medially to laterally in continuity with the anconeus. Release of the lateral and medial collateral ligaments completes the exposure and allows separation of the ulna from the humerus.

- A modification of the Bryan-Morrey approach involves release of the triceps insertion onto the ulna through an extra-articular osteotomy of the dorsal tip of the ulna (**TECH FIG 4C,D**). The rationale for this modification relates to the recognized complication of triceps insufficiency that occurs with soft tissue release of the triceps. The osteotomy affords several advantages:
  - Bone-to-bone healing of the osteotomy is more reliable than soft tissue healing of the triceps to the ulna.
  - Failure of the osteotomy to heal can be identified radiographically and addressed early.

#### Deep Dissection

- Release the collateral ligaments and capsule (**TECH FIG 5**). This permits the ulna to be separated from the humerus. If ligamentous integrity is necessary (ie, unlinked arthroplasty) then the lateral ulnar collateral ligament and medial collateral should be tagged with plans at reattachment via bone tunnels in the humerus during closure.

- Release contracted muscles (flexor–pronator and common extensor) to correct deformity, which can result in maltracking of the TEA. Release the scarring about the elbow sufficiently to gain unencumbered access to the humerus and ulna for component implantation.

- The tip of the olecranon can be removed to better visualize the trochlea.
Component Insertion and Completion

- Insertion of total elbow implants is performed in standard fashion and is described in Chapter SE-45.
- After component insertion, the triceps mechanism is repaired through bone tunnels in the ulna. When a sliver of bone is taken with the triceps insertion, transverse tunnels are made. Each limb of nonabsorbable suture is tied over the top of the triceps and bone fragment. An additional cerclage suture is brought through one of the two transverse tunnels and is brought around the tip of the olecranon, incorporating the triceps insertion. This suture counters the pull of the triceps.
- The anconeus is repaired to the flexor carpi ulnaris fascia. Similarly, the medial triceps is repaired to the flexor–pronator group.
- Subcutaneous ulnar nerve transposition is routinely performed.
- A subcutaneous drain is placed and wound closure is performed.
PEAKS AND PITFALLS

**Indications**
- Interposition arthroplasty is considered in patients with a stable elbow and limited, painful ROM.
- TEA is considered in carefully selected patients if other nonoperative and operative measures have been exhausted.

**Goals of treatment**
- Regardless of the treatment undertaken, the goal of treatment is a pain-free, functional arc of motion.

**Interposition arthroplasty**
- Predictors of poor outcome:
  - Painful, mobile elbow
  - Preoperative instability
  - Need to reconstruct both the medial and lateral ulnar collateral ligaments at the time of interposition
  - Maintain the fixator for at least 4 weeks (preferably 6 weeks).
  - Meticulous pin care is required.

**TEA**
- Ulnar nerve transposition in all cases
- Triceps-reflecting approach, especially when the joint is very stiff
- Release both the medial and lateral collateral ligaments.
- Release the flexor-pronator and common extensor, particularly if there is significant preoperative deformity.

**POSTOPERATIVE MANAGEMENT**

**Interposition Arthroplasty**
- ROM is started as quickly as allowed by the condition of the soft tissues. In general, immediate motion is preferred. However, the prerequisite is a quiet soft tissue envelope. ROM may be assisted with a continuous passive motion machine if desired.
- Patients are taught pin care, which is performed daily at home.
- Patients are seen at 10 to 14 days postoperatively for staple removal and wound check and every 2 weeks thereafter until pin removal.
- The external fixator is left in place for about 4 to 6 weeks and then removed in the operating room with assessment of elbow stability and motion under anesthesia.
- I prefer to wait 6 weeks to allow collateral ligament healing since instability is the most common complication after fixator removal.
- Rehabilitation is continued, focusing on obtaining a functional ROM.

**Total Elbow Replacement**
- The elbow is immobilized in full extension in a well-padded anterior splint.
- The arm is elevated on pillows or suspended from an IV pole to reduce swelling.
- The splint is removed 24 to 48 hours after surgery.
- Gentle active ROM is begun in flexion, pronation, and supination. Active extension is avoided for 6 weeks to protect the triceps repair. However, gravity-assisted extension or passive extension is permitted.
- In general, formal physical therapy is rarely required to regain ROM. However, it may be beneficial in patients who struggle to regain their ROM. The general timeline of therapy is:
  - Phase I (0 to 6 weeks): Protect the soft tissue and begin protected active-assistive ROM.
  - Phase II (6 to 12 weeks): Continue to improve ROM. Begin strengthening exercises and encourage functional use of the arm.
  - Phase III (12 to 16 weeks): Return to normal functional activities within the restrictions for TEA.
  - Postoperative stiffness may be helped with splinting. Static splinting is preferred over dynamic splinting.
  - Restrictions: Lifetime limitations of the operated extremity include 2- to 5-pound repetitive lifting and 10-lb single-event restriction.

**OUTCOMES**

**Interposition Arthroplasty**
- The most predictable results for interposition occur in patients presenting with:
  - Stiffness and pain preoperatively
  - Stable elbow
  - One or no ligament reconstruction required at surgery
- Poor results are noted when:
  - Pain is the only presenting complaint
  - Elbow is unstable
  - Reconstruction of both the medial and lateral collateral ligaments is needed at the time of interposition
- Most studies report a 70% satisfaction rate among patients with respect to pain relief; 80% of patients regain a functional ROM.
- Cheng and Morrey 2 found that 67% of patients treated for rheumatoid arthritis had satisfactory relief of pain, and 75% of patients treated for osteoarthritis were satisfied at 5-year follow-up.

**Total Elbow Arthroplasty**
- Patients undergoing TEA for posttraumatic conditions of the elbow tend to be younger and have higher demand.
- TEA for posttraumatic conditions of the elbow is associated with improved clinical outcomes.
- A higher complication rate is noted for posttraumatic conditions compared to other indications for TEA.
- Mechanical complications such as component fracture and increased polyethylene bushing wear are more common.
Causes of increased complications include:

- Multiple previous surgeries
- Deformity of the elbow requiring realignment of the extremity through the implant

**COMPLICATIONS**

**Interposition Arthroplasty**

- Complications of interposition arthroplasty include:
  - Instability
  - Infection
  - Ulnar neuropathy
  - Resorptive bone loss
  - Heterotopic bone formation
- Complications related to the external fixator include:
  - Superficial pin tract infections
  - Deep infection (osteomyelitis)
  - Pin breakage
- In the literature, complications have been reported to occur in up to 25% of patients.

**Total Elbow Replacement**

- TEA for traumatic conditions is associated with a high complication rate. Major complications include:
  - Infection
    - Current reports indicate an infection rate of 2% to 5% for primary TEA.
    - Higher infection rates are noted with posttraumatic arthritis and a history of prior surgery.
  - Loosening
  - Triceps insufficiency (an underrecognized problem)
  - Neurologic injury (incidence of transient ulnar neuropathy as high as 26% and permanent nerve injury up to 10%)
  - Wound complications
    - Associated with prior surgery
    - Manage wound by immobilizing in extension postoperatively; use a subcutaneous drain to avoid hematoma formation. A significant postoperative hematoma should be evacuated.
    - Periprosthetic fracture (can occur intraoperatively or postoperatively; incidence ranges from 1% to 23%)

**REFERENCES**

Elbow arthrodesis is a rarely performed orthopaedic procedure. It is mainly performed for severe joint destruction due to:
- Posttraumatic arthrosis
- Instability
- Infection
Historically, it is performed for a tuberculous infection of the elbow.1
- Early fusion rates are about 50%.1
- With modern techniques, fusion rates approach 50% to 100%.3,9
- Arthrodesis of the elbow results in greater functional disability than arthrodesis of the ankle, hip, or knee joints.
- Satisfactory shoulder function is a prerequisite, even though it does not compensate for loss of motion in the elbow.2
- Compensatory motion is seen more in the spinal column and wrist.
- A functional hand is also desirable when performing arthrodesis of the elbow.
- No optimal position for arthrodesis exists.
- The position of fusion is dictated by the needs of the patient.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Skin and soft tissue defects are evaluated.
- The surgeon should evaluate the need for bone graft or soft tissue coverage before arthrodesis.
- If soft tissue coverage is necessary, a plastic surgery consultation is recommended.
- Shoulder, wrist, and spinal column motion is evaluated.
- Neurologic and motor deficits are documented.
- Blood flow to the hand is determined.
- The quality and quantity of bone available for fusion are assessed.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standard radiographs of the elbow are obtained.
- Computed tomography (CT) scans of the elbow are obtained for more detailed bony anatomy.
- If infection is suspected:
  - Blood work is obtained for complete blood count, sedimentation rate, and C-reactive protein.
  - The joint is aspirated or an indium scan is performed.

SURGICAL MANAGEMENT
- The elbow is one of the most difficult joints to fuse because of the long lever arm and strong bending forces across the fusion site.
- Arthrodesis should be considered a salvage procedure when no other satisfactory surgical option exists.

Indications
- Septic and tuberculous arthritis
- Sequela of septic arthritis
- Complex war injuries (with large bone and soft tissue defects)
- Young healthy laborers with posttraumatic arthritis who are too young for total elbow arthroplasty
- Posttraumatic arthrosis or severe instability
- Pseudarthrosis
- Severely comminuted intra-articular fractures of the distal humerus with joint destruction
- Chronic osteomyelitis
- Failed elbow arthroplasty
- Failed internal fixation for nonunions

Contraindications
- Massive bone loss preventing successful arthrodesis
- Massive soft tissue loss not amenable to flap reconstruction
- Compromised function of the ipsilateral shoulder, wrist, and spinal column

Preoperative Planning
- The best elbow position is controversial, although the literature suggests between 45 and 110 degrees.
- Historically, 90 degrees is accepted as the best position.
- Factors for choosing the best position include:
  - Gender
  - Occupation
  - Hand dominance
  - Functional requirements
  - Associated joint involvement
  - Unilateral versus bilateral arthrodesis
  - Patient preference
- One to 3 weeks before surgery, the elbow to be fused is braced or casted in various angles.
- Generally acceptable angles include:
  - Male: dominant arm at 90 degrees
  - Females seem to prefer lower angles of 40 to 70 degrees.
  - Ninety to 110 degrees is better for personal hygiene.
  - Forty to 70 degrees is better for extrapersonal needs and activities.
  - Bilateral elbow arthrodesis: dominant arm at 110 degrees, nondominant arm at 65 degrees
- Soft tissue coverage is evaluated.
- Flap coverage or skin grafts are performed before arthrodesis.
- If soft tissue coverage is required, the joint is stabilized with an external fixator.
- The surgeon should consider bulk graft with demineralized bone matrix and cancellous allograft or autograft.
For large bone defects, autograft cancellous bone is preferable.
Antibiotics are given 30 minutes before the incision.
General anesthesia is used.
An axillary or interscalene block can be used.

Special Instruments
- Large fragment locking set (4.5-mm locked narrow plate)
- A 3.5-mm locked plate may be substituted in smaller patients.
- Sterile goniometer
- Plate press
- High-speed burr
- Power drill
- Osteotomes
- Oscillating saw
- Kirschner wire set

Patient Positioning
- A tourniquet is placed as high on the arm as possible. A sterile tourniquet is required to increase the zone of sterility.
- The patient is placed in the lateral decubitus position with the operative arm resting on a padded arm rest.

SURGICAL APPROACH
- Mark existing surgical scars and use prior incisions.
- Use a direct posterior approach for the elbow.
  - An anterior approach may be needed if the tissue is compromised posteriorly.
- If flap coverage is present, a plastic surgeon may be required for exposure.
  - Flaps with vascular pedicles can be located with Doppler.
- Create full-thickness flaps right down to the bone.
- Split the triceps tendon longitudinally.
- Carry the triceps split distally in the interval between the flexor carpi ulnaris (FCU) and the anconeus.
- Identify the ulnar nerve and make sure it remains protected.
- Identify neurovascular structures in known areas before following structures through areas of heavy scar tissue.

ARTHRODESIS

Osteotomy and Fracture Reduction
- Expose the dorsal surface of the distal humerus and proximal ulna.
- Use osteotomes to “fish-scale” the exposed bone.
- Open the medullary canal of the humerus and ulna.
- Perform a step-cut osteotomy of the proximal ulna and distal humerus to increase the surface area for fusion (TECH FIG 1A).
- Contour the bone so that it can be reduced at the appropriate angle chosen for arthrodesis.
  - It is often necessary to excise the radial head to allow for adequate reduction of the humerus and ulna.
- Reduce the distal humerus to the proximal ulna.
  - Confirm the fusion angle with a sterile goniometer (TECH FIG 1B).
  - Provisionally hold the reduction at the desired angle with 1.6-mm Kirschner wires.
- Apply the 4.5-mm locking plate posteriorly, prebent at the chosen angle of arthrodesis (TECH FIG 2B).
  - A long plate should be selected with a minimum of 10 to 14 holes.
  - A plate press is easier to use than bending irons.
- The plate functions as a neutralization device.
- All compression is achieved with the lag technique employed for screw placement.
- The plate is pulled down to the bone and secured with cortical screws before adding locked screws.
- Use at least one locked screw proximal and distal to the fusion site to increase the torsional strength of the construct (TECH FIG 2C).

Screw and Plate Fixation
- Drill from distal to proximal for lag screw insertion (TECH FIG 2A).
  - Use two or three lag screws whenever possible.
- Check the position and fixation of the construct intraoperatively with fluoroscopy.
- The final construct should compress well at the fracture site.
- The plate should conform securely to the bone at the desired angle of fusion (TECH FIG 3A).
- Irrigate and close the wound.
- Place one or two deep flat drains.
- Final radiographs should be taken intraoperatively (TECH FIG 3B,C).
TECH FIG 1 • A. Step-cut in distal humerus and proximal ulna. This is a multiplanar cut and should accommodate for the elbow position in both the coronal and sagittal planes. The step-cut provides a larger surface area for primary bone healing. B. Intraoperative use of a goniometer to confirm the fusion angle before definitive fixation.

TECH FIG 2 • A. Placement of lag screw. Screws are placed from distal to proximal in a crossed configuration. Two or three lag screws are placed before plate application. Provisional fixation is obtained with Kirschner wires and the fusion position is measured with a goniometer. B. Plate placement after the fusion angle has been confirmed. (continued)
PEARLS AND PITFALLS

- Step-cut bone to increase the surface area for healing.
- Place lag screws in both vertical and horizontal planes to increase compression.
- Keep dorsal tissue flaps at full thickness, including the periosteum.
- Use lag technique to compress the bone ends.
- Never identify neurovascular structures in areas of extensive surgical scarring. Work from known to unknown surgical fields.
- Open the medullary canal to facilitate blood flow.
- Select a plate of sufficient length to span the fusion site. Longer plates are desirable.
- Never place locking screws before reduction and compression of the bone ends.
- Keep patients in a cast for at least 4 months, until fusion occurs, depending on radiographs.

TECH FIG 2 • (continued) C. A guide for locking the screw through the plate and across the step-cut osteotomy. Compression must be achieved before locking screws are placed. A, distal humerus; B, proximal ulna.

TECH FIG 3 • A. Completed elbow arthrodesis using step-cut osteotomy and 3.5-mm locking plate and lag screw technique. A, distal humerus; B, proximal ulna. B,C. AP and lateral postoperative radiographs of left elbow fusion using step-cut osteotomy and locked plating technique.
POSTOPERATIVE CARE

- Drains are removed before hospital discharge.
- Intravenous antibiotics are continued for 48 hours or longer, depending on intraoperative cultures.
- Sutures or staples are removed at 2 weeks.
- The arm is placed in a long-arm cast at the 2-week visit.
- The patient is placed in serial casts for at least 4 months.
- Cast application is continued until there is radiographic evidence of union.

REFERENCES

Chapter 28
Surgical Management of Turf Toe Injuries 3665

Chapter 29
Internal Fixation of Sesamoid Fractures 3674

Chapter 30
Tibial Sesamoidectomy 3681

Chapter 31
Flexor-to-Extensor Tendon Transfer for Flexible Hammer Toe Deformity 3688

Chapter 32
Hammer Toe Correction 3696

Chapter 33
Weil Lesser Metatarsal Shortening Osteotomy 3707

Chapter 34
Angular Deformity of the Lesser Toes 3714

Chapter 35
Surgical Correction of Bunionette Deformity 3730

Chapter 36
Rheumatoid Forefoot Reconstruction 3736
Chapter 37
Morton’s Neuroma and Revision Morton’s Neuroma Excision 3743

Chapter 38
Uniportal Endoscopic Decompression of the Interdigital Nerve for Morton’s Neuroma 3751

Chapter 39
Plantarflexion Opening Wedge Medial Cuneiform Osteotomy 3755

Chapter 40
Tarsometatarsal Arthrodesis 3761

Chapter 41
Midfoot Arthrodesis 3766

Chapter 42
Percutaneous Midfoot Osteotomy With External Fixation 3788

Chapter 43
Surgical Stabilization of Nonplantigrade Charcot Arthropathy of the Midfoot 3794

Chapter 44
Axial Screw Technique for Midfoot Arthrodesis in Charcot Foot Deformities 3802

Chapter 45
Minimally Invasive Realignment Surgery of the Charcot Foot 3809
Chapter 46
Flexor Digitorum Longus Transfer and Medial Displacement Calcaneal Osteotomy 3814

Chapter 47
Lateral Column Lengthening 3823

Chapter 48
Spring Ligament Reconstruction 3832

Chapter 49
Calcaneonavicular Coalition Resection in the Adult Patient 3839

Chapter 50
Isolated Subtalar Arthrodesis 3843

Chapter 51
Surgical Management of Calcaneal Malunions 3849

Chapter 52
Calcaneal Osteotomy and Subtalar Arthrodesis for Calcaneal Malunions 3859

Chapter 53
Traditional Triple Arthrodesis 3868

Chapter 54
Single-Incision Medial Approach for Triple Arthrodesis 3879
Chapter 55
Comprehensive Correction of Cavovarus Foot Deformity 3885

Chapter 56
Management of Equinocavovarus Foot Deformity 3891

Chapter 57
Plantar Fascia Release in Combination With Proximal and Distal Tarsal Tunnel Release 3911

Chapter 58
Endoscopic Plantar Fasciotomy 3920

Chapter 59
Transsection and Burial of Neuromas of the Foot and Ankle 3925

Chapter 60
Barrier Procedures for Adhesive Neuralgia 3933

Chapter 61
Distraction Arthroplasty for Ankle Arthritis 3941

Chapter 62
Supramalleolar Osteotomy With Internal Fixation: Perspective 1 3953

Chapter 63
Supramalleolar Osteotomy With Internal Fixation: Perspective 2 3961
Chapter 64
Supramalleolar Osteotomy With Internal Fixation: Perspective 3 3967

Chapter 65
Supramalleolar Osteotomy With External Fixation: Perspective 1 3976

Chapter 66
Supramalleolar Osteotomy With External Fixation: Perspective 2 3995

Chapter 67
Total Ankle Shell Allograft Reconstruction 4000

Chapter 68
The STAR (Scandinavian Total Ankle Replacement) Total Ankle Arthroplasty 4007

Chapter 69
The HINTEGRA Total Ankle Arthroplasty 4022

Chapter 70
The BOX Total Ankle Arthroplasty 4032

Chapter 71
The Salto and Salto-Talaris Total Ankle Arthroplasty 4042

Chapter 72
Mobility Total Ankle Arthroplasty 4056
Chapter 73
INBONE Total Ankle Arthroplasty 4072

Chapter 74
TNK Total Ankle Arthroplasty 4085

Chapter 75
The Agility Total Ankle Arthroplasty 4093

Chapter 76
Revision Agility Total Ankle Arthroplasty 4102

Chapter 77
Ankle Arthrodesis 4123

Chapter 78
Transfibular Approach for Ankle Arthrodesis 4140

Chapter 79
The Miniarthrotomy Technique for Ankle Arthrodesis 4146

Chapter 80
Arthroscopic Ankle Arthrodesis 4154

Chapter 81
Tibiotalocalcaneal Arthrodesis Using a Medullary Nail 4161
Chapter 82
**Tibiotalocalcaneal Arthrodesis Using Lateral Blade Plate Fixation** 4173

Chapter 83
**Tibiocalcaneal Arthrodesis Using Blade Plate Fixation** 4179

Chapter 84
**Treatment of Bone Loss, Avascular Necrosis, and Infection of the Talus With Circular Tensioned Wire Fixators** 4192

Chapter 85
**Femoral Head Allograft for Large Talar Defects** 4203

Chapter 86
**Posterior Blade Plate for Salvage of Failed Total Ankle Arthroplasty** 4208

Chapter 87
**Arthroscopy of the Ankle** 4216

Chapter 88
**Microfracture for Osteochondral Lesions of the Talus** 4222

Chapter 89
**Posterior Ankle Impingement Syndrome** 4229

Chapter 90
**Posterior Ankle Arthroscopy and Hindfoot Endoscopy** 4234
Chapter 100
Hamstring Autografting/Augmentation for Lateral Ankle Instability 4322

Chapter 101
Lateral Ankle Ligament Reconstruction Using Allograft and Interference Screw Fixation 4331

Chapter 102
Chronic Lateral Ankle Instability 4340

Chapter 103
Deltoid Ligament Reconstruction 4347

Chapter 104
Medial Ankle/Deltoid Ligament Reconstruction 4354

Chapter 105
Open Achilles Tendon Repair 4367

Chapter 106
Limited Open Repair of Achilles Tendon Ruptures: Perspective 1 4374

Chapter 107
Mini-Open Achilles Tendon Repair: Perspective 2 4380

Chapter 108
Percutaneous Achilles Tendon Repair: Perspective 1 4387
Chapter 118
Open Management of Achilles Tendinopathy 4443

Chapter 119
Flexor Hallucis Longus Transfer for Achilles Tendinosis 4447

Chapter 120
Proximal Mini-Invasive Grafting of Plantaris Tendon 4454

Chapter 121
Repair of Peroneal Tendon Tears 4458

Chapter 122
Reconstruction of Chronic Peroneal Tendon Tears 4462

Chapter 123
Repair of Dislocating Peroneal Tendons: Perspective 1 4468

Chapter 124
Repair of Dislocating Peroneal Tendons: Perspective 2 4477

Chapter 125
Reconstruction of Tibialis Anterior Tendon Ruptures 4484

Chapter 126
Tendon Transfer for Foot Drop 4488
DEFINITION

The first reports of a distal metatarsal osteotomy date back to Reverdin, who described in 1881 a subcapital closing-wedge osteotomy for the correction of hallux valgus deformity.

The chevron osteotomy has become widely accepted for correction of mild and moderate hallux valgus deformities. In the initial reports by Austin and Leventen and Miller and Croce, no fixation was mentioned. They suggested that the shape of the osteotomy and impaction of the cancellous capital fragment upon the shaft of the first metatarsal provided sufficient stability to forego fixation.

To increase the indication for this technically simple osteotomy, internal fixation and a lateral soft tissue release have been added.

ANATOMY

The special situation distinguishing the first metatarsophalangeal (MTP) joint from the lesser MTP joints is the sesamoid mechanism.

On the plantar surface of the metatarsal head are two longitudinal cartilage-covered grooves separated by a rounded ridge. The sesamoids run in these grooves.

The sesamoid bone is contained in each tendon of the flexor hallucis brevis; they are distally attached by the fibrous plantar plate to the base of the proximal phalanx.

The head of the first metatarsal is rounded and cartilage-covered and articulates with the smaller concave elliptic base of the proximal phalanx.

Fan-shaped ligamentous bands originate from the medial and lateral condyles of the metatarsal head and run to the base of the proximal phalanx and the margins of the sesamoids and the plantar plate.

Tendons and muscles that move the great toe are arranged in four groups:

- Long and short extensor tendons
- Long and short flexor tendons
- Abductor hallucis
- Adductor hallucis

Blood supply to the metatarsal head

- First dorsal metatarsal artery
- Branches from the first plantar metatarsal artery

PATHOGENESIS

Extrinsic causes

- Hallux valgus occurs predominantly in shoe-wearing populations and only occasionally in the unshod individual.

Although shoes are an essential factor in the cause of hallux valgus, not all individuals wearing fashionable shoes develop this deformity.

Intrinsic causes

- Hardy and Clapham found in a series of 91 patients a positive family history in 63%.
- Coughlin reported that a bunion was identified in 94% of 31 mothers whose children inherited a hallux valgus deformity.
- Association of pes planus with the development of a hallux valgus deformity has been controversial.
- Hohmann was the most definitive that hallux valgus is always combined with pes planus.
- Coughlin and Kilmartin noted no incidence of pes planus in the juvenile patient.
- Pronation of the foot imposes a longitudinal rotation of the first ray, which places the axis of the MTP joint in an oblique plane relative to the floor. In this position the foot appears to be less able to withstand the deformity pressures exerted on it by either shoes or weight bearing.

The simultaneous occurrence of hallux valgus and metatarsus primus varus has been frequently described. The question of cause and effect continues to be debated.

PATIENT HISTORY AND PHYSICAL FINDINGS

Patient history often includes:

- Pain in narrow shoes
- Symptomatic intractable keratoses beneath the second metatarsal head (in 40% of patients)
- Lateral deviation of the great toe
- Pronation of the great toe
- Keratosis medial plantar underneath the interphalangeal joint
- Bursitis over the medial aspect of the medial condyle of the first metatarsal head
- Hypermobility of the first metatarsal-cuneiform joint

Physical examination for hallux valgus deformity includes the following:

- Hallux valgus angle: Normal is 15 degrees or less.
- Intermetatarsal angle: Normal is 9 degrees or less.
- Measurement of the position of the medial sesamoid relative to a longitudinal line bisecting the first metatarsal shaft
  - Grade 0: no displacement of sesamoid relative to the reference line
  - Grade I: overlap of less than 50% of sesamoid relative to the reference line
  - Grade II: overlap of greater than 50% of sesamoid relative to the reference line
  - Grade III: sesamoid completely displaced beyond the reference line
- Joint congruency: measuring the lateral displacement of the articular surface of the proximal phalanx with respect to the corresponding articular surface of the metatarsal head, as seen on a dorsoplantar roentgenogram
IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographs of the foot should always be obtained with the patient in the weight-bearing position with AP, lateral, and oblique views. The following criteria are examined:
  - Hallux valgus angle
  - Intermetatarsal angle
  - Sesamoid position
  - Joint congruency
  - Distal metatarsal articular angle: the relationship between the articular surface of the first metatarsal head and a line bisecting the first metatarsal shaft (normal is 10 degrees or less)
  - Arthrosis of the first MTP joint

DIFFERENTIAL DIAGNOSIS
- Ganglion
- Hallux rigidus

NONOPERATIVE MANAGEMENT
- Comfortable wider shoes
- Orthotics?
- Spiral dynamics physiotherapy in adolescents

SURGICAL MANAGEMENT
Indications
- Symptomatic hallux valgus deformity with a first intermetatarsal angle of up to 16 degrees
- Stable first metatarso-cuneiform joint

Contraindications
- Narrow metatarsal head so that adequate translation is not possible
- Intermetatarsal angle of more than 16 degrees
- Impaired vascular status
- Skeletally immature patient
- Severe osteoarthritic changes

Preoperative Planning
- Standard weight-bearing AP and lateral radiographs are mandatory.
- The hallux valgus and intermetatarsal angles and tibial sesamoid position are measured.
- A preoperative drawing is helpful.
- Clinical examination includes measurement of active and passive range of motion of the first MTP joint as well as inspection of the foot for plantar callus formation indicative of transfer metatarsalgia and stability of the first tarsometatarsal joint.

Positioning
- The foot is prepared in the standard manner.
- The patient is positioned supine.
- An ankle tourniquet is optional.

Approach
- The lateral soft tissue release is performed through a dorsal approach.
- The chevron osteotomy is performed through a straight midline incision.

LATERAL SOFT TISSUE RELEASE
- The procedure is typically performed under a peripheral nerve block.
- Make a dorsal 3-cm longitudinal incision over the first web space (TECH FIG 1A).
- Continue deep dissection bluntly.
- Insert a lamina spreader and a Langenbeck retractor to expose the first web space.
- Divide the lateral joint capsule (metatarso-sesamoid... (continued)
Chapter 1 DISTAL CHEVRON OSTEOTOMY: PERSPECTIVE

### TECHNIQUES

- Externally rotate the leg. Make a second skin incision at the medial aspect of the first MTP joint (TECH FIG 2A). Perform careful dissection to avoid any damage to the dorsomedial nerve. Open the medial MTP joint capsule with an inverted L-type incision (TECH FIG 2B,C). Inspect the joint for degenerative changes.
- Minimally shave the medial eminence to achieve a plane surface but also to preserve as much metatarsal head width as possible (TECH FIG 2D). This is one of the most important principles if a chevron osteotomy is carried out in a moderate to severe deformity.

### CHEVRON OSTEOTOMY

- Externally rotate the leg. Make a second skin incision at the medial aspect of the first MTP joint (TECH FIG 2A).
- Perform careful dissection to avoid any damage to the dorsomedial nerve. Open the medial MTP joint capsule with an inverted L-type incision (TECH FIG 2B,C). Inspect the joint for degenerative changes.
- Expose the metatarsal head and place Hohmann retractors dorsal and plantar just extra-articular of the first MTP joint. The plantar Hohmann retractor protects the plantar artery to the metatarsal head, and the dorsal retractor protects the dorsal intra-articular blood supply originating from the capsule.

**TECH FIG 1** • (continued) D. The great toe is brought into 20 degrees varus to demonstrate the release of the lateral structures.

**TECH FIG 2** • A. Medial skin incision for the osteotomy. B, C. Inverted L-type capsular incision. D. The medial eminence is minimally resected.
Drill a 1.0-mm Kirschner wire slightly dorsal to the center of the exposed medial eminence. This wire is generally inclined 20 degrees from medial to lateral, aiming at the head of the fourth metatarsal (TECH FIG 3A–C). In the situation of an elevated position of the first metatarsal, the inclination may be increased. If shortening or lengthening of the first metatarsal is needed, the wire may be aimed to the fifth or third metatarsal head.

Using a saw guide (TECH FIG 3D), make two cuts with an oscillating power saw so that they form an angle of 60 degrees proximal to the drill hole.

Once the capital fragment is freely mobile, pull the metatarsal shaft medially by using a towel clip while pushing the metatarsal head laterally with the help of the thumb of the other hand (TECH FIG 4A,B).

If the distal metatarsal articular angle is increased, a wedge from the distal dorsal cut may be excised to place the metatarsal head in a more varus position. If there is only a minor increase of the distal metatarsal articular angle, this may also be achieved by impacting the metatarsal head onto the shaft.

Insert a guidewire for a cannulated Charlotte multiuse compression screw (Wright Medical Technology) from the distal dorsal metatarsal shaft obliquely to lateral plantar of the metatarsal head (TECH FIG 4C,D).
Check the position of the osteotomy and the guidewire with a C-arm or a FluoroScan.
Measure the length of the screw with the cannulated depth gauge (TECH FIG 5A). The multiuse compression screws are designed to be totally self-tapping and self-drilling. However, to avoid dislocation of the head, use the cannulated drill (TECH FIG 5B) and cannulated head drill (TECH FIG 5C).

Insert the screw (TECH FIG 5D).
Excise the medial eminence in line with the metatarsal shaft, taking care not to excise too much bone off the metatarsal head (TECH FIG 5E).
While an assistant holds the great toe in a slightly overcorrected position, repair the medial joint capsule with U-type sutures, and tighten the first web space sutures (TECH FIG 5F).

**TECH FIG 5** • A. Length determination using the depth gauge. B. Predrilling with the Charlotte cannulated drill. C. Preparing a countersunk area with the Charlotte cannulated head drill. D. The screw is inserted until the head is completely countersunk within the bone. E. The medial eminence is resected. F. Closing of the medial capsule with U-type sutures.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Lateral tilt of the metatarsal head</th>
<th>Lateral release to avoid lateral tilting of the head, intraoperative FluoroScan control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avascular necrosis</td>
<td>Careful soft tissue dissection</td>
</tr>
<tr>
<td>Intraoperative fracture of the metatarsal head</td>
<td>A guidewire at the apex of the osteotomy will prevent overpenetration of the distal fragment with the saw blade.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- Starting immediately postoperatively, ice application to the foot is helpful to reduce swelling.
- Provided that the bone quality was intraoperatively sufficient, patients are allowed to walk with a postsurgical type shoe (OFA Rathgeber) (FIG 1) on the same day (limited for 4 weeks).
- Weekly changes of the tape dressing are necessary.
- An alternative to weekly dressing changes is the postoperative hallux valgus sock, which also reduces postoperative edema (FIG 2).
- Radiographs are taken intraoperatively and at 4 weeks of follow-up.
- After radiographic union is achieved, normal dress shoes with a more rigid sole are allowed.
- After 4 weeks physiotherapy to achieve normal forefoot function is recommended (FIG 3).

OUTCOMES

- In the early years of this technique it was limited to patients 50 years and younger. This was represented by the study of Johnson et al, which established a contraindication for using a chevron osteotomy in patients older than 50 years. However, Trnka and Schneider have proven that age is not a limiting factor for the chevron osteotomy.
- Another important issue that was stretched out over the years was the combination of a lateral soft tissue release and a distal chevron osteotomy. Earlier reports have expressed concern about an increased risk of avascular necrosis if a lateral release is performed in addition to a chevron osteotomy. Jahss, Mann, and Meier and Kenzora have all suggested that avascular necrosis frequently accompanies distal Chevron with lateral soft tissue release, citing an incidence of up to 40%. Pochatko and Trnka could not support this in their publications and found no increased risk of avascular necrosis.
- Chevron osteotomy was for many years limited to mild hallux valgus deformities. Designed primarily without fixation, the concern was stability and loss of fixation. As it became more obvious that a lateral soft tissue release is important for correction of more severe deformities, this concern gained weight. According to papers by Harper and Sarrafian, lateral displacement is limited to 50% of metatarsal width.
- Over a period of 14 years we have modified and developed the chevron osteotomy. By reviewing each step of the development with clinical studies, we now perform a chevron osteotomy with lateral soft tissue release and single screw fixation.
■ Trnka et al22 reported in 2000 a series of 43 patients (57 feet) with 2-year and 5-year follow-up. Radiographic evaluation revealed a preoperative average hallux valgus angle of 29 degrees and a preoperative average intermetatarsal angle of 13 degrees. At the 2-year follow-up, those angles averaged 15 and 8 degrees, respectively, and at the 5-year follow-up, they averaged 16 and 9 degrees. The results at these two follow-up periods proved that the chevron osteotomy is a reliable procedure for mild and moderate hallux valgus deformity and that there are no differences in outcome based on age.

■ Schneider et al19 reported in 2004 a series of 112 feet (73 patients) with a minimum follow-up of 10 years. For 47 feet (30 patients), the results were compared with those from an interim follow-up of 5.6 years. The AOFAS score improved from a preoperative mean of 46.5 points to a mean of 88.8 points after a mean of 12.7 years. The first MTP angle showed a mean preoperative value of 27.6 degrees and was improved to 14.0 degrees. The first intermetatarsal angle improved from a preoperative mean of 13.8 degrees to 8.7 degrees. The mean preoperative grade of sesamoid subluxation was 1.7 on a scale of 0 to 3 and improved to 1.2. Measured on a scale of 0 to 3, arthritis of the first MTP joint progressed from a mean of 0.8 to 1.7. The progression of arthritis of the first MTP joint between 5.6 and 12.7 years postoperatively was statistically significant. Excellent clinical results after chevron osteotomy not only proved to be consistent but also showed further improvement over a longer follow-up period. The mean radiographic angles were constant, without recurrence of the deformity. So far, the statistically significant progression of first MTP joint arthritis has not affected the clinical result, but this needs further observation.

■ Sanhudo17 retrospectively reviewed 50 feet with moderate to severe hallux valgus deformity in 34 patients with a mean follow-up of 30 months. There was a mean AOFAS score improvement of 39.6 (44.5 to 84.1) points. The hallux valgus angle and intermetatarsal angle improved a mean of 22.7 degrees and 10.4 degrees, respectively. He concluded that the chevron osteotomy is also indicated for moderate to severe hallux valgus deformity.

COMPLICATIONS

- Avascular necrosis of the metatarsal head
- A lateral release does not increase the incidence.16
- Hallux valgus
- Malpositioning
- Loss of fixation

REFERENCES

SURGICAL MANAGEMENT
- The primary indication for a chevron osteotomy is symptomatic hallux valgus deformity with a moderate deformity with an intermetatarsal angle of less than 15 degrees. The first metatarsocuneiform joint should be stable. The osteotomy can also be used to correct an abnormal distal metatarsal articular angle. It is used as a sole procedure in those presenting with minimal transfer symptoms.

Preoperative Planning
- AP and lateral weight-bearing radiographs of the foot are evaluated for metatarsal length, intermetatarsal angle, hallux valgus angle, distal metatarsal articular angle, and interphalangeal angle for cases that may require a proximal phalangeal osteotomy to obtain complete correction. Congruency of the joint, presence of osteophytes, the size of the bony medial eminence, and the position and condition of the sesamoids are noted.

Positioning
- Surgery is performed on an outpatient basis.
- Prophylactic antibiotics are administered.
- A thigh tourniquet is applied.
- The patient is positioned supine with a sandbag under the ipsilateral buttock so the big toe points to the ceiling.

CHEVRON OSTEOTOMY
- Perform the distal soft tissue release through a first web space incision. Take care to avoid stripping the lateral metatarsal head soft tissues. We then perform the osteotomy in a step manner as described below.
- Approach the metatarsal through a medial longitudinal incision extending from a point 1 cm proximal to the medial eminence to the medial flare of the proximal phalanx. This can be extended distally if a phalangeal osteotomy is required. Identify the dorsal medial cutaneous nerve and incise the medial capsule sharply in a single longitudinal direction (TECH FIG 1A). Expose the medial eminence and resect it 1 mm medial to the sagittal sulcus (TECH FIG 1B). The most important part of the exposure is the identification of the plantar vascular supply (TECH FIG 1C). The osteotomy must be extracapsular. This plantar vascular supply must remain attached to the capital fragment to minimize any risk of avascular necrosis (AVN).
- The apex of the osteotomy is defined as the center of an imaginary ellipse or circle started by the articular surface of the metatarsal. Mark the apex with ink (TECH FIG 2A).
- Create the transverse limb of the osteotomy from the apex to the plantar surface of the metatarsal. The obliquity of this cut varies, the most important factor being that the osteotomy must remain extra-articular and the plantar vascular supply must be maintained to the metatarsal head (TECH FIG 2B). Complete the osteotomy through to the lateral side.
- Perform the vertical osteotomy by measuring a 90-degree angle to the plantar cut and then angling the saw blade to reduce this angle by 10 to 20 degrees. The exact angle is not crucial; we find aiming for the angle to be between 60 and 80 degrees produces a stable osteotomy (TECH FIG 2C). Complete this osteotomy to the lateral side to allow displacement of the head fragment. Take care to protect the extensor hallucis longus tendon while performing the vertical osteotomy.
- Use a sharp towel clip to grasp the proximal fragment and use the thumb to apply lateral displacement to the capital fragment (TECH FIG 3A). We allow a maximum of 50% displacement. A McDonald dissector can be used to tease the capital fragment over if required.
• Use in-line force to compress the head fragment onto the shaft, allowing cancellous impaction (TECH FIG 3B). This aids in the immediate stability of the osteotomy while fixation is achieved.

• We prefer fixation using a 1.6-mm Kirschner wire, although a compression screw can also be used. We pass the Kirschner wire in a retrograde fashion under direct vision from the plantar head obliquely across to the proximal fragment and through an appropriately placed small skin incision (TECH FIG 3C). Back the wire out to leave it a few millimeters deep to cartilage, thus maintaining excellent fixation without penetrating the joint.

Shave the redundant neck cortex, approximating to 50% of the protruding portion.

• Imbricate the medial capsule with a strong absorbable suture while holding the hallux in a neutral or slightly abducted position with the aid of a swab.

• Confirm the reduction in the intermetatarsal angle, screws, and relocation of the sesamoids with image intensification with the foot flat on the image intensifier. Assess the need for a proximal phalangeal osteotomy.

• Close the wound in layers with continuous Monocryl to the skin and apply a forefoot bandage to maintain the correction.

**TECH FIG 2**

A. An imaginary ellipse based on the articular surface is made and the center is marked with ink. This is used as the apex of the osteotomy.  
B. The longitudinal cut is performed, ensuring that the proximal limb is extra-articular and the vascular bundle is maintained to the head.  
C. The saw blade is placed at 90 degrees to the longitudinal cut and then angled to produce a chevron osteotomy of between 60 and 80 degrees.

**TECH FIG 3**

A. The osteotomy is displaced and held with a clip.  
B. In-line compression is performed to impact the cancellous fragments together to increase stability.  
C. A 1.6-mm Kirschner wire is passed in a retrograde fashion across the osteotomy site.
PEARLS AND PITFALLS

**Exposure**
- The most important part of the exposure is that of the plantar vascular bundle. Failure to do so may compromise the blood supply to the metatarsal head.

**Osteotomy**
- If displacement of the osteotomy is difficult, check that all cuts have been completed. A limited lateral capsulotomy may be performed if needed, restricting the knife cuts to the lateral soft tissues distal to the metatarsal head.

**Distal metatarsal articular angle correction**
- To correct an abnormal distal metatarsal articular angle, a small medial wedge from the vertical limb of the osteotomy can be performed. This will make the osteotomy more unstable, and care must be taken to achieve good fixation.

POSTOPERATIVE CARE
- If safe, patients are discharged home on the day of surgery with strict advice to elevate the foot whenever resting for the first 2 weeks.
- In most cases they are allowed to bear weight on their heel and lateral forefoot in a hard-soled postoperative shoe.
- Cast immobilization is not required.
- The wound is inspected at 2 weeks, at which time the hallux is restrapped and patients are taught simple passive and active toe flexion–extension exercises.
- At 4 weeks postoperatively the osteotomy is assessed. The Kirschner wire is removed in the outpatient setting.
- At 6 weeks the osteotomy is checked radiologically, and if there is consolidation at the line of the osteotomy, the patient is instructed to wear a wide shoe or sneaker and to progress to full weight bearing as tolerated. Strapping of the hallux is discontinued at this time.

OUTCOMES
- The chevron osteotomy is the most commonly performed distal chevron osteotomy for mild hallux valgus in the United States, and outcomes are excellent. AVN with the use of a lateral release remains a concern. Recent reports suggest very low rates of AVN when correcting moderate deformities with the chevron osteotomy with a lateral release. The improved correction that we see with a lateral release means that we perform it in every case.
- Evidence also now suggests that concern that the osteotomy should be reserved for patients under 50 years old may not be true, with equivalent results in differing age groups.

COMPLICATIONS
- Complications include AVN, stiffness, wound problems, infection, undertreatment, overtreatment, fractures, chronic regional pain disorder, and deep vein thrombosis. Delayed union and nonunion are rare complications with the use of fixation.

REFERENCES
DEFINITION
- Hallux valgus is a common condition that can affect both adults and adolescents. Patients complain of pain and restriction with activities of daily living because of the lateral deviation of the great toe, the medial deviation of the first metatarsal, and the onset of inflammation at the progressively worsening medial eminence of the first metatarsal head.

ANATOMY
- The first metatarsophalangeal (MTP) joint’s complex anatomy is directly related to its complex physiology. The concave articular surface of the great toe’s proximal phalanx articulates with the convex first metatarsal head. Its physiologic relationship is maintained by the surrounding articular capsule and collateral ligaments. At the plantar aspect of the first MTP joint, the sesamoid complex acts as a rail on which the first metatarsal head glides congruently with the intrinsic and extrinsic tendons, providing power and stability to the joint.

PATHOGENESIS
- Congruent first MTP joint (physiologic distal metatarsal articular angle [DMAA])
  - The literature suggests that that lateral deviation of the great toe is the primary event leading to hallux valgus deformity. This primary deforming force has a reciprocal relationship with metatarsus primus varus; the first and second intermetatarsal angle (IMA) worsens with an increase in the hallux valgus angle (HVA), and vice versa. The valgus of the proximal phalanx produces forces whose vectors determine the lateral deviation of the head of the first metatarsal.
  - Congruent first MTP joint (increased DMAA)
    - With an increased DMAA, hallux valgus is present despite congruency of the first MTP joint. The articular surface of the first metatarsal head is in a valgus position relative to the first metatarsal shaft axis; therefore, hallux valgus is present even without an imbalance of the muscle forces on the first MTP joint. However, this imbalance leads to a worsening of the deformity. Hallux valgus with an increased DMAA is less common than the incongruent type and typically occurs in men and younger patients.

NATURAL HISTORY
- Shoe wear may contribute to the development of hallux valgus deformity. A narrow and triangular toe box combined with high heels may force lateral deviation of the great toe, leading to a mechanical disadvantage of the abductor hallucis muscle. Persistence of these deforming forces may create a relative lateral displacement of the extensor hallucis longus and flexor hallucis longus tendons, which in turn may increase valgus deviation of the great toe. Eventually, the first MTP joint’s medial capsule and collateral ligament become attenuated, while its lateral soft tissues become contracted.
- The laterally deviated hallux proximal phalanx exerts a varus-producing force to the first metatarsal head, thereby worsening the metatarsus primus varus deformity. Since the sesamoid complex is attached to the proximal phalanx, the sesamoid position typically remains anatomic as the first metatarsal head subluxates medially. Progression of this displacement often produces the functional deficits and pronation of the great toe.
- Because the first MTP joint is stable and congruent but malaligned with respect to the first metatarsal axis (increased DMAA), juvenile and adolescent hallux valgus deformity should prompt evaluation for potential associated pathology, such as metatarsus adductus, hypermobility, or ligamentous laxity.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients typically complain of pain over the first metatarsal head’s medial eminence, especially while standing and walking in a narrow toe box shoe. Occasionally, patients develop a symptomatic bursitis over the medial eminence.
- Pain plantar to the first metatarsal head suggests a symptomatic and incongruent articulation of the sesamoids with the first metatarsal head. Compensation for this discomfort may lead to transfer metatarsalgia.
- An imbalance of forefoot pressures created by the malalignment of the first ray secondary to hallux valgus may also lead to transfer metatarsalgia.
- We routinely review the patient’s general health, activity level, and family history of hallux valgus. We always check for comorbidities that may have a direct impact on the success of corrective bunion surgery, particularly diabetes, arthritis, and neurovascular diseases.
- To fully appreciate the degree of hallux valgus deformity, the involved foot must be examined with the patient standing.
- We evaluate the range of motion and alignment of the ankle, hindfoot, midfoot, and forefoot with the patient standing.
- Pronation of the hallux is also best assessed with the patient standing.
- The lesser toes are carefully examined for deformities, which can be rigid or supple, requiring different types of treatment.
- Pronation of the great toe must be assessed as well as the presence of callosities under the toes and forefoot associated with metatarsalgia.
- Passive correction of hallux valgus is attempted. With the patient standing, pressure is applied over the lateral face of the great toe, trying to correct its valgus deviation. Patients with passive correctable lateral deviation of the great toe will need less invasive or hazardous procedures for the treatment of their hallux valgus deformity, particularly the adductor hallucis release.
Hypermobility of the first ray can have an influence on the onset of the hallux valgus deformity as well as on its treatment.

It is easy to differentiate the flexible and rigid forms of hammer or claw toes by applying thumb pressure in the forefoot sole and elevating the metatarsal heads; in the flexible forms, the deformities reduces or disappears completely; in the rigid forms, the maneuver does not change the hammer or claw toes.

A positive MTP joint drawer sign indicates the presence of a capsulitis and instability of the joint due to the lesion of the plantar capsule or collateral ligaments, more commonly the lateral portion of the plantar plate.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Hallux valgus must be assessed with a minimum of AP and lateral weight-bearing radiographs of the foot.

  - The HVA is determined by the intersection of the diaphyseal axes of the first metatarsal and the proximal phalanx. Arbitrarily, a normal HVA does not exceed 15 degrees (Fig. 1A).

  - The IMA is the angle between the diaphyseal axes of the first and second metatarsals. Arbitrarily, a normal IMA does not exceed 9 degrees (Fig. 1B).

  - The sesamoid position is determined by its relationship with the first metatarsal diaphyseal axis. Typically the sesamoids remain in their anatomic position; with progressive hallux valgus deformity, the first metatarsal head progressively subluxates medially in relation to the sesamoids.

- Normal (grade 0) sesamoid position: The tibial and fibular sesamoids are equidistant from the bisecting line of the first metatarsal.

- Sesamoid position grades 1 to 3: Grades 1 through 3 signify an increasingly greater lateral position of the tibial sesamoid relative to the bisecting line of the first metatarsal shaft axis, with grade 3 indicating that the tibial sesamoid is positioned completely laterally relative to the reference line (Fig. 1C and 2).

- The interphalangeal angle (IPA) is measured between the articular edges of the head and the line bisecting the first metatarsal. The IPA normal value is up to 10 degrees.

- The proximal phalanx articular angle is measured between the tangent to the proximal articular surface of the proximal phalanx of the great toe and the line bisecting the diaphyseal axis of the same phalanx. It is considered normal up to 8 degrees (Fig. 3). Inter-and intra-observer reliability for measuring the DMAA is poor.

- The DMAA is obtained by the intersection of the line that connects the articular edges of the head and the line bisecting the first metatarsal shaft. The DMAA normal value is up to 8 degrees (Fig. 3). Inter-and intra-observer reliability for measuring the DMAA is poor.

- Relative length of the first and second rays is measured pre- and postoperatively. Most osteotomies lead to shortening of the first metatarsal. In our experience, greater than 5 mm of first metatarsal shortening frequently results in transfer metatarsalgia (Fig. 1D).

**DIFFERENTIAL DIAGNOSIS**

- Hallux valgus interphalangeus
- Hallux rigidus
- Sesamoiditis

**NONOPERATIVE MANAGEMENT**

- Patient education

  - While there is no concrete evidence that shoe wear causes hallux valgus, we believe that wearing shoes with tight toe boxes and high heels contributes to the worsening of deformity.

  - Patients with intrinsic factors contributing to hallux valgus, such as an increased DMAA, should be educated that they are particularly prone to external forces worsening their hallux valgus deformity.

- Orthotic devices and insoles may relieve symptoms but generally do not correct deformity. Moreover, patients already in need of wider toe boxes may need to find shoes with extra depth to accommodate both their foot deformity and the orthotic device. In juvenile hallux valgus (skeletally immature patients), the use of a custom-made night splint could limit the progression but cannot reverse the deformity.

**FIG 1** AP radiograph of a patient with hallux valgus. **Left,** Hallux valgus angle (**HVA**; up to 15 degrees). **Second from left,** First intermetatarsal angle (**IMA**; up to 9 degrees). **Second from right,** Sesamoid position. In this patient, the tibial sesamoid is divided into two halves by the diaphyseal axis of the first metatarsal, which means the beginning of a grade 2 sesamoid subluxation (normal is grade 0). **Right,** Relative length of the first and second metatarsals; normal is up to 5 mm.

**FIG 2** Evaluation of hallucal sesamoid position. Grade 0, no displacement of sesamoids relative to the middle diaphyseal axis of the first metatarsal (normal). Grade 1, overlap of less than 50% of the tibial (medial) sesamoid to the reference line. Grade 2, overlap of more than 50% of the tibial sesamoid to the reference line. Grade 3, tibial sesamoid completely displaced beyond the reference line.

**FIG 3** G0, G1, G2, G3.
In skeletally mature patients, intermittent use of a corrective splint does not adequately counterbalance many hours of shoe wear with a narrow toe box and a high heel.

SURGICAL MANAGEMENT

- The primary indication for the biplanar distal chevron osteotomy is moderate hallux valgus deformity with a 1–2 IMA of 14 degrees or less associated with a DMAA greater than 8 degrees.15
- Reports of the traditional distal chevron technique over the past two decades suggest that comparable outcomes are achieved for younger and older patients.9
- In our hands, contraindications to any distal first metatarsal osteotomy for hallux valgus correction include asymptomatic deformity; a 1–2 IMA exceeding 15 degrees; first MTP joint stiffness or degenerative arthritis; and osteoporosis or osteopenia.

Preoperative Planning

- Satisfactory neurovascular status
- Is the hallux valgus passively correctible? The surgeon should assess associated lesser toes deformities, including fixed versus flexible deformity, impingement or overlap on the first toe, and presence of plantar calluses.
- Using radiographic measurements from preoperative weight-bearing radiographs of the foot, we always have a preoperative estimation of the required lateral translation of the first metatarsal head and wedge resection to correct the increased DMAA.

Positioning

- The patient is positioned supine, with the plantar aspect of the operated foot in line with the end of the operating table.
- We stand on the side of the table immediately adjacent to the operated foot; our assistant stands at the end of the table.
- We routinely use a tourniquet.

Approach

- A 5-cm longitudinal midaxial medial incision is made, centered over the medial eminence (FIG 4).
- Careful subcutaneous dissection is performed to protect the dorsal and plantar medial sensory nerves to the hallux.
- While the distal metatarsal metaphysis must be exposed, periosteal stripping is kept to a minimum and the lateral vascular supply to the first metatarsal head remains protected.
- In our experience, with the proper indications outlined above, we rarely need to perform a risky lateral dissection of the adductor hallucis tendon at the joint line.
- A routine portion of the exposure, lateral dislocation of the metatarsal head, serves as a physiologic release of the adductor hallucis by bringing its phalangeal insertion closer to its origin.9,10,15

CAPSULOTOMY

- I use a Y-shaped incision over the medial face of the MTP joint capsule, creating three distinct flaps that I reapproximate at the completion of the procedure to achieve optimal tensioning (TECH FIG 1A,B).
- A short V capsular flap attached to the base of the hallux proximal phalanx may be used as an anchor to correct the deformity. I always preserve the relatively thin dorsal capsular flap continuous with the lateral capsule to maintain the blood supply to the first metatarsal head. The stout plantar capsular flap attached to the sesamoids serves to re-establish the optimal first metatarsal head-sesamoid position when tensioned after completion of the osteotomy.
MEDIAL AND DORSAL METATARSAL HEAD EXPOSURE

- After capsulotomy the first metatarsal head’s medial eminence and sagittal groove are exposed.
- Starting at the medial aspect of the sagittal groove, I resect the medial eminence with a small oscillating saw from dorsal to plantar, in line with the medial edge of the foot (TECH FIG 2A,B).
- I make sure to preserve the integrity of the metatarsal head and medial cortex of the metatarsal shaft (TECH FIG 2C,D).

- Occasionally, a “dorsal bunion” is present in the absence of degenerative change. I routinely resect this dorsal eminence in line with the dorsal cortex of the metatarsal shaft to eliminate any chance for impingement and potentially improve cosmesis (TECH FIG 2E).
OSTEOTOMY

As a point of reference, I mark the geometric center of the first metatarsal head with a sharp instrument on the prepared medial surface (TECH FIG 3A). From this point I draw the segments (arms) of the planned osteotomy.

I cut the plantar arm of the osteotomy parallel to the inferior surface of the foot (TECH FIG 3B), thereby creating a broad and stable surface area to promote healing between the two osteotomy fragments.

According to the preoperative radiographic DMAA estimate, I plan a medially based wedge resection as part of the dorsal limb osteotomy to rotate the capital fragment into a more physiologic relationship with the first metatarsal shaft. Three methods exist to determine the correct size for the medial wedge to be removed:

- A trigonometric formula (wedge width = tan DMAA × first metatarsal head width [in millimeters])
- Drawing the wedge corresponding to the measured DMAA over the AP radiographic image of the first metatarsal
- By direct vision during the operation, make the distal cut parallel to the distal metatarsal articular surface and the proximal cut perpendicular to the long axis of the first metatarsal (TECH FIG 3C-E).

The saw blade must not violate the inferior portion of the metatarsal head fragment.

In my experience, each millimeter of lateral metatarsal head translation corresponds to one degree of 1–2 IMA correction. Using average physiologic dimensions, the metatarsal head may be translated laterally up to 6 mm to create a 9-degree 1–2 IMA without forfeiting osteotomy stability.

After dorsal wedge resection and simultaneous to lateral translation, rotate the metatarsal head to create a physiologic DMAA and achieve optimal bony apposition at the dorsal aspect of the osteotomy.9,12

Gentle longitudinal traction on the hallux and concomitant pressure with the thumb over the medial capital fragment facilitates lateral displacement (TECH FIG 3F).

By driving the great toe as a joystick, the capital fragment is rotated under direct vision to correct the DMAA.
Once the proper positioning of the fragments is obtained, apply gentle pressure on the great toe to coapt the osteotomy site (TECH FIG 3G).

In our experience, it is not necessary to check the position of the fragments and the amount of correction with fluoroscopy but, for those who think that it is advisable, this is the right moment to do that. You can use a 1.2-mm Kirschner wire to maintain the fragments temporarily during the fluoroscopic checking.

I routinely secure the osteotomy with a single screw, either a solid screw placed in lag fashion or a headless cannulated or noncannulated dual-pitch compression screw, while maintaining manual reduction of the osteotomy.

- Screw position: 5 mm proximal to the dorsal arm of the biplanar chevron osteotomy, on the first metatarsal shaft (TECH FIG 3H)

- Screw trajectory: I aim the screw 10 degrees distally and 15 degrees laterally to target the optimal portion of the laterally translated distal fragment, compress the fragments, and limit the risk of penetrating the plantar articular surface.

- Using a 2.7-mm solid screw
- Initial 2.0-mm drill hole, followed by overdrill of the near cortex with a 2.7-mm drill to create a lag effect
- Because of the screw trajectory and relatively thin overlying capsule and skin, consider using a countersink.
- Insertion of the 2.7-mm screw to carefully compress the osteotomy and maintain reduction (TECH FIG 3I)
- Using a headless cannulated or noncannulated dual-pitch screw
- Guide pin (if cannulated)
I judiciously resect redundant medial capsule. Holding the proximal phalanx in optimal alignment relative to the long axis of the first metatarsal in both the sagittal and transverse planes facilitates determining the overlap of residual medial capsule.

In anticipation of some tendency toward recurrence of deformity, I typically hold the hallux in a slight varus and plantarflexion position.

In my experience, this optimal position is best maintained by the assistant holding the first metatarsal, the MTP joint, and hallux between the thumb and the second finger of the assistant’s hand so that the hallux rests in the space between the assistant’s first and second metacarpals (TECH FIG 4A,B).

With the assistant maintaining the optimal position, I resect the redundant capsular flaps. Next, I check the relationship of the medial sesamoid and first metatarsal head, applying greater tension to the plantar flap to reduce the head on the sesamoids if necessary. I place a 2-0 nonabsorbable buried suture at the central corners of both the dorsal and plantar capsular flaps and systematically close the capsulotomy from distal to proximal (TECH FIG 4C).

I appose the residual V-shaped flap attached to the medial aspect of the proximal phalanx to the previously sutured dorsal and plantar flaps. In my experience, removing greater capsular redundancy from the dorsal portion of the phalangeal flap facilitates correction of hallux pronation (TECH FIG 4D-F).

I use a single suture, which is placed at the center of the Y, where the capsular flaps meet (TECH FIG 4G).

Once the medial capsulorrhaphy is complete, the assistant releases the toe. Ideally, the hallux should maintain its corrected alignment without external support.

Occasionally I augment the capsulorrhaphy with complementary tensioning sutures to obtain the desired position. Again the hallux must be held in the corrected position, or even slight varus as noted above (TECH FIG 4H).

Carefully resect the residual medial prominence of the proximal fragment with an oscillating saw, directing the saw blade from dorsal to plantar while avoiding any violation of the first metatarsal diaphysis (TECH FIG 3K).

I routinely irrigate the first MTP joint with saline solution to remove undesirable detritus.

CAPSULORRHAPHY

I judiciously resect redundant medial capsule. Holding the proximal phalanx in optimal alignment relative to the long axis of the first metatarsal in both the sagittal and transverse planes facilitates determining the overlap of residual medial capsule.

In anticipation of some tendency toward recurrence of deformity, I typically hold the hallux in a slight varus and plantarflexion position.

In my experience, this optimal position is best maintained by the assistant holding the first metatarsal, the MTP joint, and hallux between the thumb and the second finger of the assistant’s hand so that the hallux rests in the space between the assistant’s first and second metacarpals (TECH FIG 4A,B).

With the assistant maintaining the optimal position, I resect the redundant capsular flaps. Next, I check the relationship of the medial sesamoid and first metatarsal head, applying greater tension to the plantar flap to reduce the head on the sesamoids if necessary. I place a 2-0 nonabsorbable buried suture at the central corners of both the dorsal and plantar capsular flaps and systematically close the capsulotomy from distal to proximal (TECH FIG 4C).

I appose the residual V-shaped flap attached to the medial aspect of the proximal phalanx to the previously sutured dorsal and plantar flaps. In my experience, removing greater capsular redundancy from the dorsal portion of the phalangeal flap facilitates correction of hallux pronation (TECH FIG 4D-F).

I use a single suture, which is placed at the center of the Y, where the capsular flaps meet (TECH FIG 4G).

Once the medial capsulorrhaphy is complete, the assistant releases the toe. Ideally, the hallux should maintain its corrected alignment without external support.

Occasionally I augment the capsulorrhaphy with complementary tensioning sutures to obtain the desired position. Again the hallux must be held in the corrected position, or even slight varus as noted above (TECH FIG 4H).

Carefully resect the residual medial prominence of the proximal fragment with an oscillating saw, directing the saw blade from dorsal to plantar while avoiding any violation of the first metatarsal diaphysis (TECH FIG 3K).

I routinely irrigate the first MTP joint with saline solution to remove undesirable detritus.

Dual-diameter drill corresponding to the particular screw system

Insertion of the screw after proper screw length has been determined, with compression of the fragments and stability created at the osteotomy (TECH FIG 3J)

Carefully resect the residual medial prominence of the proximal fragment with an oscillating saw, directing the saw blade from dorsal to plantar while avoiding any violation of the first metatarsal diaphysis (TECH FIG 3K).

I routinely irrigate the first MTP joint with saline solution to remove undesirable detritus.

CAPSULORRHAPHY

I judiciously resect redundant medial capsule. Holding the proximal phalanx in optimal alignment relative to the long axis of the first metatarsal in both the sagittal and transverse planes facilitates determining the overlap of residual medial capsule.

In anticipation of some tendency toward recurrence of deformity, I typically hold the hallux in a slight varus and plantarflexion position.

In my experience, this optimal position is best maintained by the assistant holding the first metatarsal, the MTP joint, and hallux between the thumb and the second finger of the assistant’s hand so that the hallux rests in the space between the assistant’s first and second metacarpals (TECH FIG 4A,B).

With the assistant maintaining the optimal position, I resect the redundant capsular flaps. Next, I check the relationship of the medial sesamoid and first metatarsal head, applying greater tension to the plantar flap to reduce the head on the sesamoids if necessary. I place a 2-0 nonabsorbable buried suture at the central corners of both the dorsal and plantar capsular flaps and systematically close the capsulotomy from distal to proximal (TECH FIG 4C).

I appose the residual V-shaped flap attached to the medial aspect of the proximal phalanx to the previously sutured dorsal and plantar flaps. In my experience, removing greater capsular redundancy from the dorsal portion of the phalangeal flap facilitates correction of hallux pronation (TECH FIG 4D-F).

I use a single suture, which is placed at the center of the Y, where the capsular flaps meet (TECH FIG 4G).

Once the medial capsulorrhaphy is complete, the assistant releases the toe. Ideally, the hallux should maintain its corrected alignment without external support.

Occasionally I augment the capsulorrhaphy with complementary tensioning sutures to obtain the desired position. Again the hallux must be held in the corrected position, or even slight varus as noted above (TECH FIG 4H).

Carefully resect the residual medial prominence of the proximal fragment with an oscillating saw, directing the saw blade from dorsal to plantar while avoiding any violation of the first metatarsal diaphysis (TECH FIG 3K).

I routinely irrigate the first MTP joint with saline solution to remove undesirable detritus.

Dual-diameter drill corresponding to the particular screw system

Insertion of the screw after proper screw length has been determined, with compression of the fragments and stability created at the osteotomy (TECH FIG 3J)
Close the subcutaneous tissue with interrupted absorbable sutures.
- I favor using absorbable subcuticular sutures and interrupted fine nylon suture in young patients (more favorable skin) and older patients (less favorable skin), respectively.

I routinely use a bunion dressing, or H dressing, in the first web space to relieve tension on the medial capsulorrhaphy. I wrap the forefoot with a sterile cotton bandage followed by an adhesive bandage that maintains slight compression on the first metatarsal.

**PEARLS AND PITFALLS**

Indications
- I favor a proximal first metatarsal osteotomy with a 1–2 IMA greater than 15 degrees.
- In my experience, the power of 1–2 IMA correction is limited by the width of the metatarsal head.
- In general, 1 mm of lateral translation equals 1 degree of 1–2 IMA correction.
- A biplanar osteotomy is not required unless the DMAA exceeds 8 degrees.

Approach
- I routinely perform the skin incision 2 mm dorsal to the medial midaxial line to identify and protect the dorsomedial sensory nerve to the hallux.

Capsular flaps
- Develop the capsular flaps carefully to allow optimal soft tissue balancing during capsulorrhaphy.

Medial eminence resection
- Perform the medial eminence resection in line with the medial foot, not the medial aspect of the first metatarsal.
- Less resection is better (limits potential for varus)!

Osteotomy
- The plantar arm should be parallel to the plantar plane of the foot.
- The apex of the wedge to be resected dorsally should coincide with the lateral cortex of the head to avoid shortening of the metatarsal.

Screw fixation
- Direct the drill and screw laterally to capture the plantar “tongue” of the distal fragment.
- Avoid placing a screw that penetrates the plantar cortex at the metatarsal head-sesamoid complex.
- Remember to countersink the dorsal metaphyseal cortex when using a 2.7-mm screw.

Capsulorrhaphy
- Be sure that your assistant maintains the great toe at the right position during capsulorrhaphy.

Dressing
- Should maintain the great toe in the optimal position for 3 weeks.
the fragment fixation. In a general view, we can see the size and position of the screw used in its fixation, and the alignment of the cephalic fragment with the metatarsal diaphysis resulting from the dorsal fragment resection.

**POSTOPERATIVE CARE**

- Anticipated dried blood may harden the bandage and create pressure-related symptoms postoperatively. This occurs often enough that we routinely change the patient’s bandage on postoperative day 3 or 4. We allow my patients to bear weight in a Barouk postoperative shoe after the first dressing change. This orthosis concentrates the patient’s weight on the rear of the foot while protecting the forefoot. Our patients do not routinely require crutches or assistive devices, but the occasional elderly patient with comorbidities may benefit from temporary use of a walker.

- We routinely change the bandage for my bunion patients at 10-day intervals to confirm that proper great toe alignment is maintained. To confirm that the alignment and reduction are maintained, we obtain a radiograph of the operated foot at 3 weeks after surgery. In our experience, at 1 month postoperatively patients may transfer to a pair of soft and wide lace-up shoes and initiate hallux range-of-motion exercises.

- In our practice, it takes an average of 3 to 4 months for patients to reach the maximum range of motion and return to regular shoe wear and full activity.

**OUTCOMES**

- Patient satisfaction rates after distal biplanar chevron osteotomy for moderate hallux valgus deformity approach 90%, depending on appropriate patient expectations and selection.

- In our experience, the procedure reliably and reproducibly corrects the 1–2 IMA, HVA, and increased DMAA (**FIG 5**).

**COMPLICATIONS**

- Complications are similar to other distal first metatarsal osteotomies for correction of hallux valgus.

- Recurrence or undercorrection

- Inappropriate preoperative planning

- Stretching the indications

- Usually due to inadequate:
  - Lateral translation
  - Rotation of the first metatarsal head
  - Soft tissue balancing during the capsulorrhaphy
  - Lack of proper postoperative bunion dressing

- Avascular necrosis of the head of the first metatarsal

- Overzealous lateral soft tissue stripping

- Overpenetration of the saw blade into the lateral capsule

- Although radiographic first metatarsal head changes are frequently observed after distal metatarsal osteotomies, they rarely progress to symptomatic necrosis and collapse of the metatarsal head.

- First MTP joint stiffness

- In our experience, joint stiffness responds to physical therapy and advancing the weight-bearing status. We maintain that slight overcorrection and some MTP joint stiffness is preferable to undercorrection and full MTP joint motion.

- Hallux varus

- Overresection of the medial capsule

- Unnecessary overrelease of the lateral capsule and adductor hallucis tendon

**REFERENCES**


DEFINITION
- The distal chevron osteotomy has proven to be a reliable, reproducible method of bunion repair for mild to moderate deformity. By altering the location and displacement of the osteotomy, the indications can be expanded to more complex deformities while preserving the straightforward surgical exercise.
- The apex of the chevron osteotomy can be modified to a more proximal location along with a reduced angle to provide a stable healing surface that facilitates maximal lateral translation.
- The proximal location of the osteotomy also reduces the risk of avascular necrosis and permits safe lateral capsule release needed for larger corrections.
- This technique facilitates treatment for moderate to severe bunion deformity with a straightforward surgical method using limited, readily available internal fixation.

ANATOMY
- Factors contributing to a bunion deformity vary among individuals. The diverse anatomic features require scrutiny during surgical planning.
- Pertinent to the corrective factors of a translational osteotomy is the width of the distal metatarsal. The amount of correction may be limited in a small, narrow, or “hourglass” shaped bone.
- The distal metatarsal articular angle (DMAA) may be altered by varus or valgus rotation during a distal osteotomy. This additional corrective factor should be addressed during the surgical planning.
- The position of the sesamoids needs to be assessed for optimal correction. Station III subluxation usually requires a lateral capsule release to restore normal joint mechanics.
- Hypermobility of the first ray should be evaluated. Correction by lateral translation of the distal metatarsal may be compromised if the cuneiform–metatarsal joint is unstable.

IMAGING AND DIAGNOSTIC STUDIES
- Weight-bearing AP and lateral radiographs are used to determine bone morphology, associated disease, and deformity parameters used in decision making.

SOFT TISSUE PREPARATION
- When significant sesamoid subluxation is present (grade II or III), use a dorsal first web incision to expose the lateral capsule.
- A Freer elevator is helpful to probe and identify the dorsal margin of the subluxed lateral sesamoid. Then incise the capsule longitudinally from the phalanx to well proximal to the lateral sesamoid. The adductor tendon is plantar to this incision and is preserved. Leave the intermetatarsal ligament intact. The purpose of this longitudinal cut is to allow medialization of the plantar sesamoid complex at the time of capsule repair from the medial side.
- Expose the joint through a medial longitudinal incision. Identify and protect the superficial peroneal nerve. Mobilize the tissues to expose the capsule from the medial sesamoid inferiorly to the extensor hallucis longus tendon superiorly. The medial plantar digital nerve is also at risk and needs to be protected as the dissection nears the medial sesamoid.

SURGICAL MANAGEMENT
Positioning
- The patient is positioned supine. When regional ankle block anesthesia is used, an ankle tourniquet is applied. Otherwise, a thigh tourniquet can be used for general or spinal anesthesia.
Cut the capsule longitudinally and slightly plantar to the center of the metatarsal. Reflect the capsule to expose the medial metatarsal eminence and the joint, but pre-
serve it on the dorsal or plantar aspect to minimize risk of vascular insult.

**BONE PREPARATION**

- Remove the medial eminence with a power saw. The amount of bone is based on radiographic interpretation. Avoid excessive removal to prevent hallux varus. Usually the cut is 1 to 2 mm medial to the articular margin or the sagittal groove.
- Determine the apex of the osteotomy and mark it with a surgical pen (TECH FIG 1). It is typically 15 to 20 mm from the articular surface. Outline the proximal limbs at an angle of about 35 to 45 degrees. If the limbs are too short, there may be instability; if they are too long, there may be difficulty translating or rotating the distal head portion.

Next, use a Freer elevator to gently strip the periosteum and soft tissue over the area where the osteotomy is anticipated to cut the dorsal and plantar aspects of the metatarsal. Again, leave the tissues distal to the bone cut in place to minimize vascular compromise.
- The osteotomy can be affected by saw position with a dorsal, plantar, proximal, or distal angulation. Generally, a straight or neutral cut is best.
- After completing the osteotomy, the distal head fragment should be readily mobilized. Translation is facilitated by applying traction to the toe with one hand and using the other hand to pull with a towel clip on the apex of the proximal metatarsal. Thumb pressure against the head while maintaining traction will allow repositioning of the metatarsal with minimum force (TECH FIG 2A). If the head fragment is not readily mobilized, the osteotomy needs to be rechecked and cut.
- Since the osteotomy is usually proximal to the metaphyseal bone, the lateral cortex often appears as a spike. The distal head is then perched on this lateral process to maintain length (TECH FIG 2B). Up to 90% translation is possible and satisfactorily stabilized with Kirschner wires. Slight varus or valgus tilt can be applied as indicated by the DMAA.
- Using 0.054 smooth Kirschner wires, direct a pin from the proximal third of the metatarsal, medially exiting the lateral cortex and then entering the distal head fragment. These three points of fixation help maximize stability.

**TECH FIG 1 •** Usual location for the osteotomy.

**TECH FIG 2 •** A. The osteotomy is translated laterally with traction and thumb pressure on the distal end while counterpressure is applied with a towel clip to the medial spike of the proximal end. B. The lateral cortex of the proximal metatarsal provides a stable spike to perch the distal head fragment.
with large corrections (TECH FIG 3). Place a second similar pin and check the position with radiographic control. Pins are typically bent and left out percutaneously but can be cut adjacent to the bone and removed electively.

- Cut the large prominence of bone from the proximal, medial metatarsal and contour it in line with the distal head’s medial margin. It is important to cut this back proximal enough to avoid a residual bump at the mid-metatarsal area (TECH FIG 4).

TECH FIG 3 • Optimal pin placement. Note contact with the medial and lateral aspect of the proximal metatarsal before entering the distal head fragment.

TECH FIG 4 • The saw is used to remove the remaining medial “bump” of the first metatarsal. This needs to be contoured in line with the medial metatarsal head to avoid symptoms at this area postoperatively.

**SOFT TISSUE CLOSURE**

- Tighten the medial capsule by removing a U-shaped wedge of tissue from the plantar aspect near the medial sesamoid. The amount of tissue removed is judged to allow adequate correction of the hallux valgus. Next, repair the capsule defect in the plantar limb. Then perform a “pants-over-vest” closure between the plantar and dorsal capsule to improve sesamoid position. The goal is to bring the medial sesamoid to the medial margin of the metatarsal head (TECH FIG 5). Skin closure and bunion dressings are then applied.

TECH FIG 5 • A. The longitudinal capsule incision. B. A U-shaped wedge of capsule is removed and sutured to tighten the plantar limb of the capsule and correct the hallux valgus. C. Suture is placed in a “pants-over-vest” technique to advance the plantar limb of the capsule medial and dorsal. D. The remaining capsule is closed.
POSTOPERATIVE CARE

- Patients are instructed to keep the limb elevated the majority of the first 2 weeks postoperatively. They are allowed to “heel walk” in a postoperative shoe with crutches provided for longer distance or pain management.
- At 2 weeks, sutures are removed and another bunion dressing is applied. The patient is instructed to passively dorsiflex and plantarflex the toe.
- At 5 weeks the pins are removed and the patient is taught to use a compression wrap and toe spacer. Aggressive range-of-motion exercises are initiated.
- Patients are followed on a 3- to 4-week basis to monitor healing and alignment (FIG 2).
- With larger osteotomy translation and correction, radiographic healing can take 3 months or more. However, the osteotomy is usually stable for activities of daily living within 2 months. Sports and strenuous activities may require 3 to 5 months of healing.

OUTCOMES

- We assessed 72 procedures in 62 patients operated on between Jan. 1, 2002, and Dec. 30, 2003. AOFAS scores and radiographic assessments were obtained from 39 at an average of 27.6 months after surgery.5
- AOFAS scores averaged 93.3, with complete radiographic healing in all patients.
- Hallux valgus angle correction averaged 22.3 degrees and intermetatarsal angle correction averaged 7.7 degrees.

COMPLICATIONS

- Complications included three symptomatic hallux varus deformities that were felt to be due to routine adductor release. This has been revised to a limited lateral capsule release as described here with preservation of the adductor tendon in most cases.
- There were three symptomatic medial diaphyseal “bumps” due to inadequate resection of the medial metatarsal after translation. This is now being addressed with more aggressive medial contouring.
- There was one symptomatic dorsal malunion and one case of surgical neuritis of the peroneal nerve branches.
- Only three cases of new or increased transfer lesions were identified.
- No cases of avascular necrosis were identified.

REFERENCES


PEARLS AND PITFALLS

- Avoid routine lateral adductor release to reduce the risk of hallux varus unless specifically indicated by the clinical situation. The increased lateral translation of the osteotomy usually decompresses the lateral structures. The main focus is to realign the sesamoids under the metatarsal head.
- An aggressive contouring of the proximal portion of the metatarsal is necessary to reduce the risk of a residual bony bump near the osteotomy site. This often goes into the medullary canal. The Kirschner wires need to be placed proximal enough to avoid being cut out during this maneuver.
- Two Kirschner wires are recommended to reduce the risk of head migration until healing callus has developed.

FIG 2 • A. Intraoperative radiographic appearance of the osteotomy. The “medial bump” still needs removal from the metatarsal. Office radiographs at 2 weeks (B), 8 weeks (C), and 12 months (D).
DEFINITION

- Hallux valgus is a deformity of the forefoot characterized by progressive lateral subluxation of the proximal phalanx of the first toe on the first metatarsal head. It is considered pathologic when the patient experiences symptoms associated with a valgus deviation (hallux valgus angle [HVA]) greater than 15 degrees (FIG 1).<sup>7,8</sup>
- Hallux valgus is more common in adult women. It is often bilateral, and in many cases it is associated with other foot deformities, such as lesser toe or hindfoot or midfoot deformities that may exacerbate the pathology.<sup>14</sup>
- Hallux valgus is often a progressive disease that compromises the physiologic function of the first metatarsophalangeal (MTP) joint and potentially the entire forefoot.

ANATOMY

- The first metatarsal is the broadest and shortest of the five metatarsals, and the distal condyle of the first metatarsal head articulates with the proximal phalanx of the great toe. In addition, the plantar aspect of the first metatarsal head articulates with the sesamoids, which are contained in the flexor brevis hallucis tendon.
- The relationship of the medial and lateral sesamoids is maintained by the intersesamoid ligament. In association with the ligaments of and muscle balance about the first MTP joint, the sesamoid complex contributes to stabilizing the first MTP joint.
- When functioning properly, the first MTP joint optimizes push-off of the hallux during gait.<sup>4</sup>
- While physiologically the first MTP joint has a wide motion arc in the sagittal plane, it exhibits very little flexibility in the coronal plane. Hallux valgus occurs with greater than physiologic coronal plane motion of the first MTP joint.
- The first metatarsal head receives its main dorsal blood supply from the first dorsal metatarsal artery, a major contributor to an extracapsular anastomosis at the first MTP joint. On the plantar aspect of the first metatarsal head, the blood supply is from a combination of capsular arteries, branches of the first plantar metatarsal artery, and the first dorsal metatarsal artery.<sup>15,17</sup>

PATHOGENESIS

- The pathogenesis of hallux valgus is not fully understood.
- In some patients, hallux valgus deformity may be due to congenital malalignment, neurologic conditions, systemic disease (such as rheumatoid arthritis), connective tissue disorders (with greater than physiologic ligamentous laxity), valgus deviation of the lesser toes, or trauma.<sup>3,4,12,13</sup>
- Several factors that may compromise the normal biomechanics of the foot have been implicated in the development of hallux valgus, including hereditary factors, shape of the first MTP joint, shoe wear, pes planus, and metatarsus adductus.<sup>1–3,10,18,19</sup>
- Controversy remains over the greatest primary cause leading to hallux valgus: valgus deviation of the hallux or metatarsus primus varus.<sup>5,7–11</sup>

PATIENT HISTORY AND PHYSICAL FINDINGS

- With loss of the physiologic balance of the first MTP joint, dynamic muscle function leads to progression of hallux valgus deformity in the majority of cases.
- Progressive hallux valgus may create other forefoot problems, including bursitis of the first MTP joint (FIG 2), callosities, and onychocryptosis (between the first and the second toe).
- Advanced hallux valgus may diminish first MTP joint function to the point that it leads to lesser toe deformity (claw and hammer toes) and associated transfer metatarsalgia (FIG 3).
- For ideal decision making in the management of hallux valgus, the following factors must be considered: pain, mobility and stability of the first MTP joint, and associated deformity.
- The site of the pain should be evaluated. The pain is often localized at the prominent medial eminence. At times, an inflamed...
bursa, a site of tenderness, overlies the prominent medial eminence. In advanced hallux valgus the pain should be referred to the lateral metatarsal head.

- Hallux mobility at the first MTP joint should be evaluated. Range of motion of the first MTP joint should be checked both in its resting valgus position and its correct neutral position. Any limitation may be a sign of first MTP joint incongruency or arthritis and should be evaluated radiographically.

- Stability of the first MTP joint should be assessed. Severe instability of the first MTP is a contraindication for use of the SERI technique.

- Associated lesser toe deformities, such as clawtoes, result in metatarsal overload and callus formation, often creating symptoms that exceed those directly related to the hallux.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- A standard radiographic examination, including AP and lateral weight-bearing views of the forefoot, allows the assessment of arthritis and congruency of the joint; measurement of the HVA, intermetatarsal angle (IMA), and distal metatarsal articular angle (DMAA); and calculation of the metatarsal formula, especially the relation between the length of the first and the second metatarsal.

- Preoperative planning is performed using the preoperative weight-bearing radiographs of the foot. In particular, we assess the radiographs to determine the desired obliquity of the bone cut and the amount of mediolateral and dorsoplantar shift of the metatarsal head required to reduce the metatarsal head over the sesamoid complex and correct an increased DMAA (FIG 4).

NONOPERATIVE MANAGEMENT

- Comfortable shoes with a wide toe box and sole may reduce the pressure on the first metatarsal head’s medial prominence. In severe deformity, custom-made shoes or insoles with a metatarsal support may relieve symptoms attributable to transfer metatarsalgia and associated plantar callus formation.

- Nonoperative treatment of hallux fails to correct the deformity; it only accommodates to it. Given that hallux valgus deformity tends to progressively worsen, probably due to muscle imbalance about the first MTP joint, symptoms may abate only with surgical correction when conservative treatment proves inadequate.

SURGICAL MANAGEMENT

Indications for SERI Technique

- In our experience, the SERI ("simple, effective, rapid, inexpensive") technique is effective in correcting mild to moderate hallux valgus, with HVA and IMA not exceeding 40 degrees and 20 degrees, respectively.

- The SERI technique may be applied to congruent and incongruent hallux valgus deformity. The operation is indicated in case of hallux valgus presenting with any degree of DMAA and a mild degenerative arthritis of the first MTP joint.

- Specific contraindications to the SERI technique are severe degenerative arthritis, stiffness, or severe instability of the first MTP joint.
Before surgery, the patient’s foot or feet (simultaneous bilateral procedures) are scrubbed using disinfectant soap solution.

Several anesthetic techniques can be used. We usually prefer a sciatic nerve block using ropivacaine hydrochloride monohydrate 7.5 mg/mL.

The patient is placed in a supine position, with the lower extremity externally rotated with the foot’s lateral border contacting the operating table.

After the foot is exsanguinated, an Esmarch elastic bandage is used as an ankle tourniquet with adequate padding.

The SERI technique does not require a lateral soft tissue release, particularly with a flexible hallux valgus deformity, because the lateral soft tissues relax with lateral translation of the first metatarsal head. Even with slight stiffness of the first MTP joint we do not perform a lateral release, instead applying an intraoperative manual stretch to the adductor hallucis by forcing the hallux in a varus position.

Make a 1-cm medial longitudinal incision midaxially just proximal to the medial eminence through the skin and subcutaneous tissue, directly to the medial aspect of the first metatarsal (TECH FIG 1A). The capsule of the joint is spared.

Retract the soft tissues dorsally and plantarly using two 5-mm retractors (TECH FIG 1B).

If performed as described, the medial aspect of the first metatarsal neck will be adequately exposed.

Perform a complete osteotomy using a standard pneumatic saw with a 9.5 × 25 × 0.4-mm blade (Hall Surgical, Linvatec Corp., Largo, FL) (TECH FIG 1C). In the sagittal plane, the osteotomy is performed with 15 degrees of inclination from dorsal to plantar and distal to proximal. The inclination of the osteotomy in the mediolateral direction is perpendicular to the foot axis (ie, to the long axis of the second metatarsal bone) if the length of the first metatarsal bone must be maintained. If shortening of the metatarsal bone or decompression of the MTP joint is necessary, as in the case of mild arthritis, the osteotomy is inclined in a distal to proximal direction up to 25 degrees. More rarely, if a lengthening of the first metatarsal bone is necessary (ie, if the first metatarsal bone is shorter than the second or if laxity of the MTP joint is present), the osteotomy is inclined in a proximal to distal direction as much as 15 degrees.

With a small osteotome, mobilize the head.

Using a standard wire driver, insert a single-tipped 2.0-mm Kirschner wire retrograde through the incision into the soft tissue immediately adjacent to the proximal and distal phalanges of the hallux, in the longitudinal axis of the great toe (TECH FIG 1D).

The Kirschner wire exits at the medial tip of the toe close to the toenail. Regrasp it with the wire driver (TECH FIG 1E) and retract it so that its proximal tip rests at the level of the osteotomy (TECH FIG 1F).

Using a small grooved lever to prize the osteotomy (TECH FIG 1G), obtain the correction by moving the metatarsal head depending on the pathoanatomy of the deformity (TECH FIG 1H,I).

If pronation of the first metatarsal bone is present, obtain the correction with a derotation of the hallux to the neutral position of the first metatarsal head.

After correcting the HVA, IMA, DMAA, and pronation, advance the Kirschner wire antegrade into the diaphysis of the first MTP joint so that its proximal tip reaches the metatarsal base (TECH FIG 1J).

Expose the medial prominence at the osteotomy site on the distal aspect of the metatarsal shaft by two retractors and remove it using a pneumatic saw or a rongeur (TECH FIG 1K).

The wound requires only a single 3-0 absorbable suture to reapproximate the skin.

Bend and cut the segment of the Kirschner wire that is protruding from the tip of the toe in routine fashion.

In our experience, the SERI technique may be performed as simultaneous bilateral procedures or combined with concomitant correction of associated foot deformities.
C. The osteotomy is performed with a pneumatic saw. D. Inserting the 2-mm Kirschner wire. E,F. The Kirschner wire is retaken by the drill and retracted at the osteotomy line. G. The grooved lever is used to prize the osteotomy. H,I. Metatarsal head dislocation. (continued)
PEARLS AND PITFALLS

- A 15-degree inclination in the osteotomy from dorsal to plantar and distal to proximal affords stability to the osteotomy to limit dorsal displacement of the metatarsal head with weight bearing.
- If shortening of the metatarsal or decompression of the MTP joint is necessary, the osteotomy should be inclined in a distal–proximal direction up to 25 degrees. More rarely, if lengthening of the metatarsal is necessary, the osteotomy should be inclined in a proximal–distal direction up to 15 degrees (FIG 5).
- An adjustment of the final intraoperative correction of the first metatarsal head in the mediolateral dislocation plane of the metatarsal head is dictated by the position of the K-wire in the metatarsal diaphysis. Greater correction warrants a more lateral placement of the wire within the metatarsal shaft. Greater plantar displacement of the metatarsal head necessitates placing the K-wire more dorsally into the soft tissue immediately adjacent the metatarsal head (FIG 6).
To correct the DMAA, the Kirschner wire must be introduced obliquely into the medial soft tissues in a mediolateral direction (FIG 7). Then, manual adduction of the hallux must be performed to rotate the metatarsal head, correcting the DMAA.

In our experience, an osteotomy performed proximal to the recommended position increases the risk of first metatarsal malunion and nonunion.

If the Kirschner wire is inserted into the phalanx rather than immediately adjacent to the phalanx, it has been our experience that the DMAA cannot be properly corrected.

Excessive shortening of the first metatarsal may lead to overload of the lesser toes.

Like most other corrective procedures for hallux valgus, the SERI technique is not indicated for hallux valgus associated with moderate to severe hallux rigidus.

POSTOPERATIVE CARE

After the completion of the surgery, a mildly compressive gauze dressing is applied to the wound and forefoot (FIG 8) and AP and oblique radiographs are obtained to confirm the placement of the osteotomy and the correction of any characteristics of the deformity.

Ambulation is allowed immediately using “talus” shoes. These shoes maintain the foot in the talus position of the ankle, allowing weight bearing on the hindfoot and discharging weight from the forefoot. Foot elevation is advised when the patient is at rest in the immediate postoperative period.

Kirschner wire fixation due to wire bending upon insertion produces a very stable and elastic stabilization, maintaining the same position obtained during surgery and favoring early healing of the osteotomy combined with early weight bearing.

After 1 month, the dressing, suture, and Kirschner wire are removed. Passive and active exercises with cycling and swimming are advised and comfortable normal shoes are worn, gradually returning to standard footwear.

As a rule, significant postoperative swelling does not last for more than 1 month.

OUTCOMES

With appropriate indications, the SERI technique of minimally invasive distal metatarsal osteotomy is simple, effective, rapid, and inexpensive, giving satisfactory results in more than 90% of cases.

This technique is easily repeated, without removal of the eminence and without open lateral release. It is minimally invasive but performed under direct line of vision and without radiations.

Normally, the osteotomies heal well, with callus evident after an average of 3 months.

The radiographic evaluation showed significant correction of the parameters over time (FIG 9).

No severe complications, such as avascular necrosis of the metatarsal head, nonunion of the osteotomy, or hallux varus, were observed.

All the metatarsal bones remodeled themselves over time, even in cases with significant offset at the osteotomy (few millimeters of bony contact). In our experience, the healing of the osteotomy and the remodeling capability of the metatarsal bone are not related to the offset at the osteotomy, but it is necessary to obtain a bony contact.

COMPLICATIONS

There was a 1.9% rate of delayed union of the osteotomy (over 4 months). In our experience, delayed union is not related to the amount of displacement or correction at the osteotomy.

There was a 2.1% rate of skin irritation or erythema about the Kirschner wire at the tip of the great toe.
There was a 12% rate of transfer metatarsalgia with plantar callosities under the second and third metatarsal heads, resolving by the use of insoles with metatarsal support.

There was a 0.5% rate of deep vein thrombosis.

REFERENCES

SURGICAL MANAGEMENT
- The primary indication for an Akin osteotomy is hallux valgus interphalangeus or in cases where residual hallux valgus causes pressure on the second toe on the load stimulation test. It is most commonly used to accompany a scarf or chevron osteotomy. An isolated Akin is contraindicated in the treatment of hallux valgus. We use a proximal medial closing wedge osteotomy that is fixed by a varisation screw (Depuy, Warsaw, IN).
- The osteotomy is fashioned within metaphyseal cancellous bone, ensuring excellent cancellous healing. The osteotomy, by being close to the apex of the deformity at the interphalangeal joint, allows for more powerful correction.

AKIN OSTEOTOMY
- We describe an eight-step method for performing the Akin osteotomy.
- The exposure is performed usually as an extension to the midline longitudinal incision from the metatarsal osteotomy. If performed as an isolated procedure, the exposure must allow visualization of the metatarsophalangeal joint proximally and the shaft of the proximal phalanx distally. The exposure of the shaft of the phalanx may require excision of overlying fatty tissue.
- After dissecting directly onto bone, complete the exposure by periosteal elevation above and below the phalanx.

Place two small pointed retractors above and below the phalanx to protect the extensor and flexor tendons (TECH FIG 1A).
- Position a 1-mm Kirschner wire in the midportion of the phalanx in the sagittal plane approximately 3 mm distal to the phalangeal flare (TECH FIG 1B).
- Traction on the big toe allows us to visualize the joint to ensure the wire is not intra-articular (TECH FIG 2A).
- Remove the Kirschner wire and mark the hole (TECH FIG 2B).

**TECH FIG 1** • A. Incision is made directly to bone with subperiosteal dissection above and below the proximal phalanx. B. Kirschner wire position on proximal phalanx parallel to phalangeal base.

**TECH FIG 2** • A. The joint is checked to confirm the Kirschner wire has not penetrated the articular surface. B. The Kirschner wire position is marked.
Make the proximal cut parallel to the phalangeal base (TECH FIG 3A). To maintain control of the osteotomy, score the lateral cortex but do not penetrate it with the saw blade, thus allowing it to act as a hinge. Perform the second osteotomy to produce a wafer of bone with the apex laterally (TECH FIG 3B). When removed it should look like a fine slice of lemon. Use direct pressure to close the wedge. This “greensticks” the intact but weakened lateral cortex.

Select the varisation staple (usually 8 mm; 10 mm in larger feet) and mark the tip of the distal end with a pen (TECH FIG 4).

Place the staple in position with the osteotomy compressed. Check that it is on the midportion of the phalanx in the sagittal plane (TECH FIG 5A). The distal staple leaves an ink mark; drill this mark with a 1-mm Kirschner wire (TECH FIG 5B) and then mark the hole. The position for the staple can then be identified by the two bone marks.

While maintaining compression, insert the staple in the predrilled holes. Check for stability of the fixation (TECH FIG 5C), and again axial traction confirms the staple is not in the joint.

Close the wound in layers with continuous Monocryl to skin, and apply a forefoot bandage to maintain the correction.
PEARLS AND PITFALLS

| Exposure | ■ The orientation of the osteotomy can be difficult if performed in the absence of a metatarsal osteotomy. Avoid the temptation to use a small incision, instead taking care to expose the metatarsophalangeal joint and the shaft of the phalanx. |
| Staple insertion | ■ Resistance may be encountered when inserting the staple due to the hard subchondral bone. Avoid using excess force when inserting the staple, as this may fracture the lateral “greensticked” cortex. Either repeat the Kirschner wire drilling or accept the staple 2 to 3 mm proud if a good hold is achieved. |
| Inadvertent lateral cortex fracture | ■ If the lateral cortex if fractured, then a compression screw is inserted from medial to lateral spanning the osteotomy. |
| Overcorrection | ■ The osteotomy is very powerful as it is at the apex of the deformity. Aim for a very fine segment of bone; it can be cut again if required. |
| Unable to greenstick the lateral cortex | ■ Often a rectangle of bone as opposed to a wedge has been removed. Forcing it to close will crack the lateral cortex. Instead use a gentle to-and-fro motion with the running saw while applying gentle compressive force. This thins the lateral cortex until the osteotomy closes without “bouncing back” once pressure is removed. |

POSTOPERATIVE CARE

■ See Chapter FA-7 on scarf osteotomy.

OUTCOMES

■ The most common indication for an Akin osteotomy is in combination with a metatarsal osteotomy for hallux valgus. Outcomes are therefore reported together with satisfaction rates at between 85% and 95%.1,2,4 Very few studies have concentrated solely on the Akin.

COMPLICATIONS

■ Complications of this osteotomy are rare3 but can include nonunion, nerve damage, infection, displacement of the osteotomy, and overcorrection or undercorrection. Failure to recognize propagation of the lateral cortex may increase the risk of subsequent displacement.

REFERENCES

SURGICAL MANAGEMENT

- The primary indication for a Scarf osteotomy is symptomatic hallux valgus deformity with an intermetatarsal angle of less than 20 degrees. The first metatarsocuneiform joint should be stable. It is a versatile osteotomy that can allow shortening, lengthening, rotation, displacement, or plantarization of the first metatarsal head. Thus, indications include symptomatic hallux valgus with or without mild transfer symptoms, juvenile hallux valgus with an abnormal distal metatarsal articular angle, arthritic hallux valgus not severe enough for a fusion, and revision surgery in suitable cases.

Preoperative Planning

- AP and lateral weight-bearing radiographs of the foot are evaluated for metatarsal length, intermetatarsal angle, hallux valgus angle, distal metatarsal articular angle, and interphalangeal angle for cases that may require a proximal phalangeal osteotomy to obtain complete correction. Congruency of the joint, presence of osteophytes, the size of the bony medial eminence, and position and condition of the sesamoids are noted.

Positioning

- Surgery is performed on an outpatient basis.
- Prophylactic antibiotics are administered.
- A thigh tourniquet is applied.
- The patient is positioned supine with a sandbag under the ipsilateral buttock so the big toe points to the ceiling.

SOFT TISSUE RELEASE AND BUNIONECTOMY

- Approach the metatarsal through a medial longitudinal incision extending from the first tarsometatarsal joint to the medial flare of the proximal phalanx (TECH FIG 1A). This can be extended distally if a phalangeal osteotomy is required. Identify the dorsal medial cutaneous nerve and incise the medial capsule sharply in a single longitudinal direction. Expose the medial eminence and resect it 1 mm medial to the sagittal sulcus (TECH FIG 1B). Overresection can lead to a postoperative varus deformity. Expose the metatarsal shaft using subperiosteal sharp dissection, taking care to protect the plantar neck vascular bundle to the metatarsal head (TECH FIG 1C). The proximal plantar exposure can be performed safely without any disruption to the plantar blood supply. Use a large Langenbeck retractor to protect and retract the plantar flap. The tarsometatarsal joint is identified but does not need to be exposed.
- Perform a lateral release of the first metatarsophalangeal joint by exposing the first web space with aid of a lamina spreader as an “over the top” technique. This does not compromise the plantar blood supply. Use a banana blade to perform the sharp dissection (TECH FIG 1D). Release the tendinous insertion of the adductor hallucis muscle onto the fibula sesamoid and proximal phalanx. Release the suspensory metatarsal–sesamoid ligaments and make multiple sharp perforations in the lateral capsule at the joint line if required. Apply a varus force to the hallux, completing the capsular release (TECH FIG 1E).
- This release can also be performed through a separate first web space incision if preferred.
SCARF OSTEOTOMY

- Make the cut starting with the medial longitudinal cut. This is begun distally 5 mm from the articular surface and 2 to 3 mm from the dorsal surface of the metatarsal and finished 5 mm from the tarsometatarsal joint, 2 to 3 mm from the proximal plantar surface of the metatarsal (TECH FIG 2A). Make the longitudinal cut in the same plane as the plantar orientation of the metatarsal (TECH FIG 2B). This allows a degree of plantarization of the metatarsal head. Using a large Langenbeck retractor helps to visualize the plantar metatarsal surface. Perform the transverse cuts at 60 degrees to the longitudinal cut as a chevron. Both cuts are directed proximally, avoiding convergence laterally, which would hinder translation (TECH FIG 2C). When performing the distal cut, elevate the hand to complete the lateral cut (TECH FIG 2D). Separate the two fragments, taking care not to lever the fragments. These steps may need to be repeated if there has been failure to complete all the cuts, but take care to avoid double cutting. Release of the capsule from the lateral side may be needed if it is preventing displacement (TECH FIG 2E).
Perform displacement or rotation with guidance from the preoperative radiographs by using a clamp on the distal lateral cortex (TECH FIG 3A). Use a compression clamp to hold the displacement (TECH FIG 3B). Up to two thirds of lateral displacement can be obtained while maintaining a strong lateral strut and good bone apposition.

Obtain screw fixation using Barouk screws (Depuy, Warsaw, IN). These are cannulated, self-tapping screws with a long distal thread and a threaded head to allow compression and burial of the head. Place the distal screw first. Pass the guidewire from the proximal fragment obliquely into the head (TECH FIG 4A). Directly visualize the guidewire in the joint, and withdraw it to be flush with the articular surface so that it can be measured (TECH FIG 4B). A screw at least 4 mm less than the measured amount is used to avoid intra-articular penetration. During the drilling over the guidewire, ensure that the drill countersink is seated fully to avoid inadvertent fracture of screw placement (TECH FIG 4C). Directly inspect the joint. Compress the osteotomy further with the clamp. Place the second guidewire for the proximal screw in the midline in an oblique direction to reach the plantar cortex of the distal fragment (TECH FIG 4D). Measure it by withdrawing the guidewire so as to be flush with the cortex. Retraction of the plantar tissue protects and allows direct visualization of the wire and the drill. This screw length equals the measurement from the wire. Directly visualize the screw to confirm compression and length (TECH FIG 4E).

TECH FIG 2 • (continued) C. Transverse cuts, avoiding convergence. D. The hand is elevated to complete the distal transverse cut. E. Release of the capsule from the proximal end.

TECH FIG 3 • A. Method of displacement of the fragment. B. Compression clamp applied after displacement.
Resect the medial distal aspect of the dorsal fragment (TECH FIG 5) and check the osteotomy for stability.

Imbricate the medial capsule with a strong absorbable suture while holding the hallux in a neutral or slightly abducted position with the aid of a swab (TECH FIG 6).

Confirm the reduction in the intermetatarsal angle, screws, and relocation of the sesamoids with image intensification with the foot flat on the image intensifier (TECH FIG 7). Assess the need for a proximal phalangeal osteotomy.

Close the wound in layers with continuous Monocryl to skin and apply a forefoot bandage to maintain the correction.
PEARLS AND PITFALLS

| Ensure adequate soft tissue release on the dorsal fragment. | After completing the cuts successfully, if displacement is still difficult, then check that the periosteum is not tethering the distal lateral corner of the proximal fragment. |
| Divergent transverse cuts | Avoid convergent transverse cuts, as this will make displacement difficult. |
| Rotational osteotomy to correct distal metatarsal articular angle | If using the Scarf osteotomy to correct the distal metatarsal articular angle, then excise a wedge of bone from the proximal, lateral, plantar fragment to allow for displacement and to avoid impingement onto the second metatarsal. A shorter Scarf can also be used. |
| Longitudinal cut | The direction of the longitudinal cut can depress the metatarsal head, depending on the requirement. |
| Transverse cut | Double cutting the transverse cuts can shorten the osteotomy in cases where the joint is very stiff or there is very severe hallux valgus deformity. |
| Screws | Direct visualization of the metatarsophalangeal joint is made to avoid joint penetration. Take care to avoid seating the proximal screw too deep into the very thin dorsal cortex, as this may reduce screw hold. |
| Proximal plantar exposure | This is a safe exposure and does not compromise the blood supply to the metatarsal. It is a vital step: once completed, it allows orientation of the longitudinal cut parallel to the plantar surface; identification of the flare of the first tarsometatarsal joint ensures the transverse cut is not intra-articular; and a clear view of the lateral plantar surface allows the surgeon to pass the guidewire under direct vision and check the screw length. |

POSTOPERATIVE CARE

- If safe, patients are discharged home on the day of surgery with strict advice to elevate the foot whenever resting for the first 2 weeks.
- In most cases they are allowed to bear weight on their heel and lateral forefoot in a hard-soled postoperative shoe.
- Cast immobilization is not required.

- The wound is inspected at 2 weeks, at which time the hallux is restrapped and patients are taught simple passive and active toe flexion-extension exercises.
- At 5 weeks postoperatively the osteotomy is assessed with radiographs. If there is some consolidation at the line of the osteotomy the patient is instructed to wear a wide shoe or sneaker and to progress to full weight bearing as tolerated.
Strapping of the hallux is discontinued at this time. Delayed union or nonunion is rare with this osteotomy.

OUTCOMES

- The Scarf osteotomy is now a widely used method of correction for hallux valgus; it is particularly popular in Europe. Satisfaction rates range from 88% to 92%,2,3,8,9 equivalent to those of the chevron osteotomy,4,5 including patients defined as having severe hallux valgus. In a review of five recent publications4,6,8–10 the hallux valgus angle was improved on average by 16 degrees (range 11 to 21), the intermetatarsal angle by 6.4 (range 3 to 10), and the AOFAS score by 45 (range 37 to 55).
- A learning curve for performing the Scarf osteotomy has also been noted, with higher complication rates seen in early series.1

COMPLICATIONS

- The main complication seen is stiffness, which occurs in up to 5% of cases.7 Other complications include wound problems, infection, undercorrection, overcorrection, fractures, chronic regional pain disorder, and deep vein thrombosis. Delayed union and osteonecrosis are rare complications. Fracture risk can be reduced by preserving the lateral strut when placing the proximal screw and by using a long longitudinal cut.

REFERENCES

**SURGICAL MANAGEMENT**

- The distal soft tissue procedure and proximal metatarsal osteotomy has been widely used for bunion corrections for more than 30 years. It is a reliable, reproducible procedure that can be used to treat a wide range of bunion deformities.
- The procedure is indicated for a hallux valgus deformity with an incongruent metatarsophalangeal joint, an intermetatarsal angle of more than 10 to 12 degrees, and a distal metatarsal articular angle of less than 10 degrees.

- It is carried out in three main steps:
  - Release of the contracted lateral capsular structures: the adductor hallucis tendon, the transverse metatarsal ligament, and the lateral joint capsule
  - By freeing up these three structures the sesamoid sling can be replaced beneath the first metatarsal head.
  - Preparation of the medial joint structures
  - Exposure and plication of the medial joint capsule
  - Excision of the medial eminence
  - Exposure of the base of the first metatarsal and proximal crescentic metatarsal osteotomy

**RELEASE OF THE LATERAL JOINT STRUCTURES**

- Make a 2.5-cm incision on the dorsal aspect of the first web space between the first and second metatarsal heads.
  - Deepen this incision through the subcutaneous tissue.
  - Place a Weitlander retractor to expose the web space.
  - On the floor of the web space lies the adductor hallucis, which passes obliquely to insert into the lateral sesamoid and the base of the proximal phalanx (TECH FIGS 1 AND 2).
- Identify the capsule between the subluxated fibular sesamoid and the lateral base of the first metatarsal head.
- Use a scalpel to release the capsule. By extending the incision distally in this interval, detach the adductor hallucis tendon from its insertion into the base of the proximal phalanx.
- Detach the adductor tendon from the lateral aspect of the fibular sesamoid, dissecting proximally until the flexor hallucis brevis muscle tissue is noted (TECH FIG 3).
- Place a Weitlander retractor between the first and second metatarsal heads, placing the transverse metatarsal ligament under tension (TECH FIGS 2 AND 4).
- Transect this ligament.
- While carrying out this step, it is important that only ligamentous tissue is cut because directly beneath the
ligament lies the common nerve to the first web space and the accompanying vessels.

- Release the lateral joint capsule.
- Make an incision through the dorsal aspect of the joint capsule at the level of the joint line, and pass the knife blade to the plantar aspect of the metatarsal (TECH FIGS 5 AND 6).
- With the blade well seated against the bone, pass the scalpel proximally, stripping the origin of the capsule off the metatarsal head over a distance of about 1.5 cm.
- This creates a flap of the lateral joint capsule to be used later in the repair (TECH FIG 7).
- Bring the hallux into about 25 degrees of varus, which ensures that no lateral contracture remains.

TECH FIG 3 • The adductor tendon has been detached from the lateral aspect of the fibular sesamoid and is being held in the forceps.

TECH FIG 4 • The transverse metatarsal ligament is placed under tension using a Weitlander retractor.

TECH FIG 5 • The scalpel has been placed through the dorsal aspect of the lateral joint capsule of the first metatarsophalangeal joint.

TECH FIG 6 • Diagram of Techniques Figure 5, illustrating the lateral joint capsule of the first metatarsophalangeal joint.

TECH FIG 7 • The origin if the lateral joint capsule has been stripped off the metatarsal head, creating the flap of tissue held in the forceps.

PREPARATION OF THE MEDIAL JOINT CAPSULE

- Approach the medial joint capsule through a longitudinal incision in the midline starting at the middle of the proximal phalanx and proceeding proximally just past the medial eminence.
- Identify the plane between the subcutaneous tissue and the joint capsule; take care to work along this plane.
- Dissecting dorsally at first, pull the skin flap away from the capsule to expose the dorsal medial cutaneous nerve, which is then carefully retracted.
Next, dissect the skin flap off the plantar half of the capsule until the abductor hallucis muscle and tendon are identified.

- Take care in this area, because the plantar medial cutaneous nerve lies just plantar to the abductor tendon.

- The capsulotomy that we prefer starts with a vertical cut in the medial joint capsule, made 2 to 3 mm proximal to the base of the proximal phalanx.

- Make a second, parallel cut 3 to 8 mm proximal to the first cut, depending on the severity of the hallux valgus deformity. A more severe deformity requires more resection of tissue from the medial joint capsule (TECH FIG 8).

- Bring together these two parallel capsular cuts dorsally through an inverted V-shaped incision.

- On the plantar side, make an upright V-shaped incision through the abductor hallucis tendon that ends at the tibial sesamoid (TECH FIG 9).

- Remove this capsular tissue (TECH FIG 10).

- While making the cut through the abductor hallucis tendon, keep the tip of the knife blade inside the joint to avoid damaging the plantar medial cutaneous nerve.

- Make an incision through the joint capsule on the dorsal aspect of the medial eminence.

- Peel the capsular flap proximally and plantarward until the medial eminence is completely exposed (TECH FIGS 11, 12, AND 13).
The medial eminence can be removed with a 16-mm osteotome or with a saw blade. This is strictly the choice of the operating surgeon.

After performing the osteotomy, inspect the metatarsal to be sure there are no rough edges of bone. Rongeur off any bony prominence.

The osteotomy to remove the medial eminence is started 1 to 2 mm medial to the sagittal sulcus and is performed in line with the medial aspect of the metatarsal shaft (TECH FIG 14).

The medial eminence can be removed with a 16-mm osteotome or with a saw blade. This is strictly the choice of the operating surgeon.

After performing the osteotomy, inspect the metatarsal to be sure there are no rough edges of bone. Rongeur off any bony prominence.

**APPROACH TO THE PROXIMAL CRESCENTIC OSTEOTOMY**

- Perform an osteotomy to remove the medial eminence.
  - Start the osteotomy 1 to 2 mm medial to the sagittal sulcus; the osteotomy is in line with the medial aspect of the metatarsal shaft (TECH FIG 14).

- The medial eminence can be removed with a 16-mm osteotome or with a saw blade. This is strictly the choice of the operating surgeon.

- After performing the osteotomy, inspect the metatarsal to be sure there are no rough edges of bone. Rongeur off any bony prominence.

- Make an incision directly over the extensor hallucis longus tendon, from just proximal to the metatarsal cuneiform joint distally about 2.5 to 3 cm.
  - Usually a large vessel crosses this plane; cut or cauterize it when the approach is made.
  - Mobilize the extensor tendon and retract it either medially or laterally to expose the metatarsal shaft.
  - As the metatarsal shaft is exposed, it is not necessary to be subperiosteal.
  - Working just above the periosteal plane allows the tissues to move easily.

- Identify the metatarsal cuneiform joint.
  - Make a mark on the metatarsal 1 cm distal to the joint; this is where the crescentic osteotomy will be created.
  - Make a second mark on the metatarsal 1 cm distal to the osteotomy site; this is where the screw will be placed that stabilizes the osteotomy (TECH FIGS 15 AND 16).
  - To confirm that the osteotomy site is correct, note the flare on the lateral aspect of the metatarsal that marks the junction of the diaphyseal and metaphyseal bone.
  - This is located about 1 cm distal to the metatarsal cuneiform joint.

- Advance a guide pin for the 4.0-mm cannulated screw a short distance into the metatarsal, beginning at the marked site.
  - The pin should be angled at about 50 degrees to the long axis of the metatarsal in the sagittal plane (TECH FIG 16). At this angle the pin and subsequent screw will pass into the plantar aspect of the proximal metatarsal fragment and will not violate the joint.

- Carry out the osteotomy using a crescent-shaped saw blade.
  - This blade comes in two lengths. It is easier to start with a shorter blade and then use the longer blade if necessary to complete the osteotomy (TECH FIGS 16 AND 17).
Positioning of the foot in preparation for the osteotomy is a critical part of this procedure. Sit at the side of the table holding the foot in one hand. Hold the foot in a neutral position in regard to dorsiflexion–plantarflexion and inversion–eversion. Place the saw with the concavity facing proximally, toward the heel. The angle of the saw blade should be neither perpendicular to the bottom of the foot nor perpendicular to the metatarsal, but about halfway between those positions (TECH FIG 16).

Start the osteotomy cut by applying firm pressure to the blade. After making the initial cut into the bone, carefully evaluate the position of the saw blade to be sure that it will cut through the lateral cortex of the metatarsal shaft. Sometimes in a wide metatarsal the blade will not penetrate both cortices. If the medial cortex is not completely cut, it is safe and simple to complete the osteotomy in this area. However, it is difficult and potentially dangerous to complete an osteotomy laterally, as there is a major artery in the space between the first and second metatarsals that could be harmed.

Make the cut by moving the saw in a medial–lateral direction along the arc of the saw blade. While cutting, apply a little bit of pressure to the blade toward the heel, as this helps to stabilize the blade in the plane of its cut. Once the cut is established, moving the saw blade back and forth without a lot of pressure plantarward will produce a nice smooth cut.

It is important that the cut passes all the way through the metatarsal so that the distal portion of the bone is totally free and has no bony attachments to the proximal fragment. If a medial piece of bone is still present, use a 4- to 6-mm osteotome to cut through the bone. Pass a knife blade along the medial side of the cut to be sure that the cut is completely free of any bony or periosteal attachment.

CORRECTION OF THE OSTEOTOMY

Correcting the osteotomy is the most technically demanding part of the bunion procedure. The objective is to stabilize the base of the metatarsal while rotating the distal portion of the metatarsal around the osteotomy site.

The first step is to push the proximal portion of the cut metatarsal in a medial direction so that it is at the medial excursion of the metatarsal cuneiform joint. This can be accomplished with a Freer elevator (TECH FIGS 18 AND 19).
Grasp the metatarsal head firmly with your other hand and rotate the distal aspect of the metatarsal in a lateral direction around the osteotomy site.

Examining the osteotomy site demonstrates that the distal fragment rotates no more than 2 to 3 mm around the “crescent” (Tech Figs 18 and 19).

Hold the osteotomy site in this alignment and drill the previously placed guide pin across the osteotomy site until the plantar cortex is engaged.

Once this occurs, the osteotomy site is reasonably stable.

Measure the guide pin to determine the screw length, which is usually 28 to 30 mm.

When learning to perform this procedure, or if there is a question as to the alignment of the osteotomy, at this point obtaining a radiograph is warranted.

If the guide pin is not providing adequate stability, a second pin or Kirschner wire can be used for supplemental fixation while evaluating the radiograph.

If the radiograph shows that the intermetatarsal angle is not sufficiently closed down, remove the guide pin and remanipulate the osteotomy site until the intermetatarsal angle is adequately corrected.

While holding the osteotomy site corrected, overdryll the guide pin with the appropriate-sized drill for the cannulated screw set (TECH FIG 20).

Usually it is adequate to advance the drill to a position just past the osteotomy site, so that the guide pin does not back out when the drill is removed.

Use a countersink, mainly on the distal side of the screw hole, to make the screw head less prominent. However, excessive countersinking can cause the screw head to be pulled through the screw hole site and produce instability of the osteotomy site.

Place a partially threaded 4.0-mm cannulated screw across the osteotomy site and carefully tighten it (TECH FIG 21).

Be cautious as the screw is tightened because the island of bone is only about 5 or 6 mm and can be cracked if the screw is tightened too firmly.

Check the stability of the osteotomy site by moving the distal fragment in the sagittal plane, looking for any motion at the osteotomy site.

Mild instability of the osteotomy can be addressed by carefully tightening the screw or by adding a small-diameter Kirschner wire for supplemental fixation.

Occasionally a small plate may need to be added to the first metatarsal to secure the osteotomy if there is gross instability.
RECONSTRUCTION OF THE MEDIAL JOINT CAPSULE

The first step in reconstructing the medial joint capsule is to hold the great toe in correct alignment:
- Neutral dorsiflexion–plantarflexion
- 0 to 5 degrees of varus
- Rotate the toe to correct pronation, which brings the sesamoids back underneath the metatarsal head.
- Reduction of the sesamoids has been achieved if they are visible along the plantar aspect of the medial eminence.
- Pull the proximal joint capsule distally to see whether the proximal and distal flaps of the capsule juxtapose one another (TECH FIG 22).
- If they do, then the capsular flaps are approximated.
- If insufficient capsule has been removed, then more capsular tissue needs to be removed before it is plicated.
- The capsular flaps should not be overlapped in a “pants over vest” fashion, as this creates too much bulk over the medial eminence.
- To repair the medial capsule, place four to six sutures of 2-0 chromic into the joint capsule with the toe held in correct alignment.

The first suture is placed as plantar as possible and incorporates the abductor hallucis tendon (TECH FIG 23).
- The suture line progresses dorsally (TECH FIG 24).
- Once the sutures are placed and tied, check the alignment of the toe.
- The toe should be in neutral position as far as varus and valgus is concerned, or possibly in a little bit of varus.
- In general, if the final alignment of the toe is in more than 5 degrees of valgus, extra capsular tissue should be removed.
- Return your attention to the first web space.
- Sew the adductor hallucis tendon (already tagged with a suture) to the flap of capsule that was stripped off the metatarsal head.
- If the toe had been positioned in a little too much varus when plicating the medial capsule, tension can be placed on this web space repair to prevent a hallux varus from occurring.
- Thoroughly irrigate the wounds with antibiotic solution and then close them with interrupted silk.
- Apply a sterile compression dressing and then release the tourniquet.

TECH FIG 22 • With the toe held in neutral position, the medial capsular flaps are checked for proper alignment.

TECH FIG 23 • The first suture for repairing the medial joint capsule is placed as plantar as possible; it incorporates the abductor hallucis tendon.

TECH FIG 24 • A total of four to six sutures are used to repair the medial joint capsule.
POSTOPERATIVE CARE

- The initial postoperative dressing is changed 1 to 2 days after surgery.
  - A dressing incorporating firm gauze and adhesive tape is used to hold the toe in correct alignment.
  - The patient is permitted to ambulate in a postoperative shoe.

- The patient is seen about 8 to 10 days after surgery, at which point the sutures are removed and a radiograph is obtained.
  - Based on the alignment of the toe in this radiograph, it is determined how the toe is dressed—namely, into a little more varus or valgus, or held in a neutral position.

- The dressings are changed on a weekly basis to ensure that the alignment of the toe remains correct.
  - At 3 to 5 weeks after surgery another radiograph is obtained to confirm the alignment of the toe.
    - If the alignment is not correct, it can still be corrected by pulling the toe into more varus or valgus, depending on what the radiograph dictates.

- After 8 weeks the dressings are removed and the patient is started on range-of-motion exercises.

OUTCOMES

- Proximal metatarsal osteotomy and distal soft tissue release decreases the bunion deformity to an average of 10 degrees and decreases the intermetatarsal angle to an average of 5 degrees.
  - A 90% to 95% rate of patient satisfaction has been reported, as well as improvements in pain level and improvements in overall function.

COMPLICATIONS

- Recurrence of hallux valgus deformity
- Hallux varus
- Dorsiflexion of metatarsal osteotomy
- Nonunion of osteotomy site
- Delayed union of osteotomy site

REFERENCES

DEFINITION

- Symptomatic hallux valgus associated with a first intermetatarsal angle greater than 15 degrees is typically corrected with a proximal first metatarsal osteotomy and distal soft tissue procedure when nonoperative treatment fails.
- Multiple techniques for the hallux valgus deformity correction have been described.\(^5\)
- In 1918 Ludloff\(^4\) described an oblique osteotomy from the dorsal–proximal to distal–plantar aspects of the first metatarsal, and the procedure was performed without internal fixation.
- The procedure recently gained renewed attention when Myerson\(^1,6\) recommended adding internal fixation and modified several parts of the technique.
- The modified Ludloff osteotomy has been extensively studied with biomechanical and mathematical investigations.

ANATOMY

- The special situation distinguishing the first metatarsophalangeal (MTP) joint from the lesser MTP joints is the sesamoid mechanism.
  - On the plantar surface of the metatarsal head are two longitudinal cartilage-covered grooves separated by a rounded ridge. The sesamoids run in these grooves.
  - The sesamoid bone is contained in each tendon of the flexor hallucis brevis; they are distally attached by the fibrous plantar plate to the base of the proximal phalanx.
  - The head of the first metatarsal is rounded and cartilage-covered and articulates with the smaller concave elliptical base of the proximal phalanx.
  - Fan-shaped ligamentous bands originate from the medial and lateral condyles of the metatarsal head and run to the base of the proximal phalanx and the margins of the sesamoids and the plantar plate.
  - Tendons and muscles that move the great toe are arranged in four groups:
    - Long and short extensor tendons
    - Long and short flexor tendons
    - Abductor hallucis
    - Adductor hallucis
  - Blood supply to the metatarsal head
    - First dorsal metatarsal artery
    - Branches from the first plantar metatarsal artery

PATHOGENESIS

- Extrinsic causes
  - Hallux valgus occurs almost exclusively in shoe-wearing populations, but only occasionally in the unshod individual.
  - Although shoes are an essential factor in the cause of hallux valgus, not all individuals wearing fashionable shoes develop this deformity.
- Intrinsic causes
  - Hardy and Clapham\(^2\) found, in a series of 91 patients, a positive family history in 63%.
  - Coughlin\(^5\) reported that a bunion was identified in 94% of 31 mothers whose children inherited a hallux valgus deformity.
  - The association of pes planus with the development of a hallux valgus deformity has been controversial.
  - Hohmann was the most definitive proponent that hallux valgus is always combined with pes planus.
  - Coughlin\(^5\) and Kilmartin noted no incidence of pes planus in the juvenile patient.
  - Pronation of the foot imposes a longitudinal rotation of the first ray that places the axis of the MTP joint in an oblique plane relative to the floor. In this position the foot appears to be less able to withstand the deformity pressures exerted on it by either shoes or weight bearing.\(^11\)
  - The simultaneous occurrence of hallux valgus and metatarsus primus varus has been frequently described.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Physical findings associated with hallux valgus deformity include the following:
  - Pain in narrow shoes
  - Symptomatic intractable keratoses beneath the second metatarsal head (in 40% of patients)
  - Lateral deviation of the great toe
  - Pronation of the great toe
  - Keratosis medial plantar underneath the interphalangeal joint
  - Bursitis over the medial aspect of the medial condyle of the first metatarsal head
  - Hypermobility of the first metatarsocuneiform joint
- Physical examination for hallux valgus deformity should include the following:
  - Hallux valgus angle measurement: Normal is 15 degrees or less.
  - Intermetatarsal angle measurement: Normal is 9 degrees or less.
  - Sesamoid position measurements
  - Joint congruency

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiographs of the foot should always be obtained with the patient in the weight-bearing position, with AP, lateral, and oblique views. The following criteria are examined:
  - Hallux valgus angle
  - Intermetatarsal angle
  - Sesamoid position
  - Joint congruency
  - Distal metatarsal articular angle: the relationship between the articular surface of the first metatarsal head and a line bisecting the first metatarsal shaft (normal is 10 degrees or less)
  - Arthrosis of the first MTP joint
DIFFERENTIAL DIAGNOSIS
■ Ganglion
■ Hallux rigidus

NONOPERATIVE MANAGEMENT
■ Comfortable wider shoes
  ▪ Orthotics?
  ▪ Spiral dynamics physiotherapy in adolescents

SURGICAL MANAGEMENT
■ Indications
  ■ Symptomatic hallux valgus deformity with a first intermetatarsal angle of more than 15 degrees
  ■ Stable first metatarsal-cuneiform joint
■ Contraindications
  ■ Narrow metatarsal so that adequate rotation of the dorsal fragment is not possible
  ■ Severe osteoporosis
  ■ Skeletally immature patient
  ■ Severe osteoarthritic changes

Preoperative Planning
■ Standard weight-bearing AP and lateral radiographs are mandatory.
■ The hallux valgus and intermetatarsal angles and tibial sesamoid position are measured.
■ A preoperative drawing is helpful.
■ Clinical examination includes measurement of active and passive range of motion of the first MTP joint as well as inspection of the foot for plantar callus formation indicative of transfer metatarsalgia and stability of the first tarsometatarsal joint.

Positioning
■ The foot is prepared in the standard manner.
■ The patient is positioned supine.
■ An ankle tourniquet is optional.

Approach
■ The lateral soft tissue release is performed through a dorsal approach.
■ The Ludloff osteotomy is performed through a straight midline incision.

LATERAL SOFT TISSUE RELEASE
■ The procedure is typically performed under the peripheral nerve.
■ Make a dorsal 3-cm longitudinal incision over the first web space (TECH FIG 1A,B).
■ Continue deep dissection bluntly.
■ Insert a lamina spreader and a Langenbeck retractor to expose the first web space.
■ Divide the lateral joint capsule (metatarsal-sesamoid ligament) immediately superior to the lateral sesamoid.
■ Fenestrate the lateral capsule at the first MTP joint (TECH FIG 1C,D).
■ Apply a varus stress to the hallux to complete the lateral release (TECH FIG 1E).
■ Place one or two sutures between the lateral capsule of the first MTP joint and the periosteum of the second metatarsal.

TECH FIG 1 • A. A dorsal 3-cm longitudinal incision is made over the first web space. B. A lamina spreader and a Langenbeck retractor are inserted to expose the first web space. C, D. Release of the metatarsal-sesamoid ligament. (continued)
LUDLOFF OSTEOTOMY

Incision and Exposure

- Make a midaxial skin incision over the medial first MTP joint, extending to the first tarsometatarsal joint (TECH FIG 2A,B).
- After careful subcutaneous dissection to avoid damage to the dorsomedial nerve bundle, expose the periosteum of the first metatarsal and insert dorsal–proximal and distal–plantar Hohmann retractors (TECH FIG 2C).
- Perform an L-shaped medial capsulotomy and split the periosteum up to the first tarsometatarsal joint level. Minimize periosteal dissection (TECH FIG 2D,E).

Beginning the Osteotomy

- Plan an oblique first metatarsal osteotomy from the dorsal–proximal first metatarsal (immediately distal to the first tarsometatarsal joint) to the plantar–distal first metatarsal (immediately proximal to the sesamoid complex). First mark the osteotomy with the electrocautery (TECH FIG 3A).
- The osteotomy is inclined from medial to lateral plantar at an angle of 10 degrees (TECH FIG 3B).
- Perform only the dorsal two thirds of the osteotomy initially to guarantee a stable situation (TECH FIG 3C,D).
Osteotomy Completion and Internal Fixation

- Insert a guidewire for a 3.0-mm or 4.0-mm cannulated screw (Synthes, Paoli, PA) or a Charlotte multiuse compression screw (Wright Medical Technology) in the proximal aspect of the dorsal fragment perpendicular to the osteotomy (TECH FIG 3E,F).
- Insert the first screw without full compression and complete the osteotomy (TECH FIG 3G).

TECH FIG 3 • A. The metatarsal is exposed. B. The osteotomy should be 10 degrees inclined from medial to lateral. C, D. The proximal two thirds of the osteotomy is performed first. E–G. The proximal 3.0 AO cannulated titanium screw is inserted but not tightened.
gentle thumb pressure on the first metatarsal head’s medial aspect (TECH FIG 4C,D).

- After confirming the desired correction fluoroscopically, tighten the first screw to secure the osteotomy.
- Insert a second Charlotte multiuse compression screw from plantar to dorsal across the distal aspect of the osteotomy (TECH FIG 4E).

Completion and Closure

- Resect the medial eminence (TECH FIG 5A). This is not done before the osteotomy because otherwise too much of the metatarsal head might be resected.
- Shave the slight medial bone prominence at the osteotomy smooth with the edge of the saw blade (TECH FIG 5B).

TECH FIG 4 • A, B. Osteotomy of the plantar third. C, D. With the use of a towel clip, the dorsal fragment is rotated laterally around the proximal screw. E. On the plantar side, a 3.0 Charlotte multiuse compression screw is inserted.

TECH FIG 5 • A, B. The medial eminence is resected. (continued)
POSTOPERATIVE CARE

- While an assistant holds the great toe in a slightly overcorrected position, repair the medial joint capsule with U-type sutures, and tighten the first web space sutures (TECH FIG 5C).
- Wrap the foot in a traditional, mildly compressive wet-and-dry bunion dressing.

PEARLS AND PITFALLS
- Avoid short osteotomy because it would create too small of a contact area.
- There should be a long enough distance between the two screws; otherwise, the rotational control is not guaranteed.
- When the screws do not have enough bite, use a cast for postoperative treatment.

POSTOPERATIVE CARE

- Starting immediately postoperatively, ice application to the foot is helpful to reduce swelling.
- Provided that the bone quality was intraoperatively sufficient, patients are allowed to walk with a postsurgical cork-soled shoe (OFA Rathgeber Health Shoes) or an OrthoWedge-type shoe (Darco) on the same day.
- If the bone quality was not sufficient, the patient is put in a walker boot or a short-leg cast.
- Weekly changes of the tape dressing are necessary.
- An alternative to weekly dressing changes is the postoperative hallux valgus compression stocking, which also reduces postoperative edema (FIG 1).
- Radiographs are taken intraoperatively and at 6 weeks of follow-up.
- After radiographic union is achieved, normal dress shoes with a more rigid sole are allowed.
- After 6 weeks, physiotherapy to achieve normal forefoot function is recommended (FIG 2).

FIG 1 • Postoperative hallux valgus compression stocking, for use after suture removal.

FIG 2 • 50-year-old woman (A) before surgery and (B) 2 years after the Ludloff osteotomy and Weil osteotomy 2 to 4.
OUTCOMES
- Chiodo et al\(^1\) presented their results on 82 consecutive Ludloff cases. Follow-up was possible in 70 cases (85%) at an average of 30 months (range 18 to 42 months). In their series, no symptomatic transfer lesions were found on the second metatarsal. The mean AOFAS forefoot score improved from 54 to 91 points. The mean hallux valgus and first intermetatarsal angles before surgery were 31 degrees and 16 degrees, respectively; postoperatively they averaged 11 degrees and 7 degrees. Complications included prominent hardware requiring removal (7%, 5/70), hallux varus deformity (6%, 4/70), delayed union (4%, 3/70), superficial infection (4%, 3/70), and neuralgia (4%, 3/70). The average patient age was not mentioned in the study.
- Saxena and McCammon\(^9\) reported the results of 14 procedures in 12 patients with the original technique. The mean hallux valgus angle was corrected from 30.1 to 13.4 degrees and the intermetatarsal angle from 15.9 to 10.8 degrees.
- Weinfeld\(^14\) reported in 2001 a series of 31 patients. The mean hallux valgus angle was corrected from 36.7 to 10.8 degrees and the mean first intermetatarsal angle from 14.8 to 3.9 degrees.
- Trnka et al\(^12\) reviewed the results of 99 patients (111 feet), with an average age of 56 years (range 20 to 78 years), in a multicenter study. The average AOFAS score improved significantly from 46 ± 11 points before surgery to 88 ± 13 points at follow-up. Patients under 60 years of age had a significantly higher AOFAS score (90 ± 12 points) than patients over 60 years of age (82 ± 17). The average preoperative hallux valgus angle of 35 ± 7 degrees decreased significantly to 8 ± 9 degrees, and the average intermetatarsal angle decreased significantly from 17 ± 2 degrees to 8 ± 3 degrees. All osteotomies united without dorsiflexion malunion. In the early postoperative period, 17% (18/111) had bony callus formation at the osteotomy site.

COMPLICATIONS
- Potential complications are similar to other proximal osteotomies.
- Hallux varus in 8% and 6%
- Delayed union
- Loss of fixation
- Iatrogenic fracture

REFERENCES
DEFINITION
Hallux valgus is a static subluxation of the first metatarso-sophalangeal (MTP) joint with medial deviation of the first metatarsal and lateral or valgus rotation of the hallux. A medial or dorsomedial prominence is present and usually called a bunion.

The development of hallux valgus is debated but occurs almost exclusively in shod populations. Other causes that may contribute to a hallux valgus deformity include heredity, pes planus, metatarsus primus varus, systemic arthritis, neuromuscular disorders, excessive roundness of the metatarsal head, and abnormal obliquity of the first metatarsal joint. Hypermobility may also be another causative factor in the formation of a bunion, and a first metatarsal–cuneiform joint fusion may be an appropriate alternative procedure.

Hallux valgus can lead to painful motion of the joint or difficulty with footwear.

Surgical correction of bunion deformity is a common procedure. For larger deformities a proximal osteotomy of the first metatarsal is required. The Mau proximal osteotomy technique is an accepted and proven technique. This osteotomy has the advantage over other proximal osteotomies of being inherently stable, having a reproducible surgical technique, and minimizing the common complications of other proximal osteotomies.

ANATOMY
The first MTP joint is two joints with a ball-and-socket type of joint between the first metatarsal and proximal phalanx. The second portion is a groove on the plantar first metatarsal that articulates with the dorsal surface of two sesamoids. These joints share a common capsule and interrelated muscles.

Collateral ligaments are fan-shaped ligaments that originate from the medial and lateral epicondyles of the first metatarsal head. These ligaments run vertical, horizontal, and oblique from the first metatarsal head, proximal phalanx, and sesamoids.

The sesamoids (medial and lateral) are separated by a rounded ridge (crista) and are connected by the intersesamoidal ligament. The lateral sesamoid is also connected to the plantar plate of the second metatarsal head by the transverse intermetatarsal ligament. In addition to collateral ligament attachments, each sesamoid is contained by a separated tendon of the flexor hallucis brevis muscle.

Intrinsic muscles that insert on the proximal phalanx are the abductor hallucis (plantar medial) and the oblique–transverse head of the adductor hallucis (plantar lateral phalanx). Both of these tendons also blend in with the flexor hallucis brevis to invest each corresponding sesamoid. These intrinsic muscles act to maintain alignment of the hallux and balance the forces of each other.

Extrinsic muscles include the flexor hallucis longus (FHL) and extensor hallucis longus (EHL). The FHL lies within a groove plantar to the intersesamoidal ligament. It proceeds distally to insert into the base of the distal phalanx. The EHL runs over the dorsal surface of the proximal phalanx and inserts into the base of the distal phalanx. Over the first MTP the EHL is anchored to the sesamoids by the extensor sling.

PATHOGENESIS
The development of hallux valgus varies depending on the causative factor.

The function of the abductor hallucis muscle is to plan tarflex, adduct, and invert the proximal phalanx. The reverse is true for the adductor hallucis muscle. When these muscles act together, a straight plantarflexion force is produced and the transverse–frontal plane forces are neutralized.

When the adductor hallucis muscle gains the mechanical advantage, such as in removing the tibial sesamoid or pronation, a hallux valgus deformity may ensue. The sesamoids are pulled laterally, thus eroding the crista. The metatarsal head is pushed medially, stretching the medial ligaments, and the abductor hallucis slides beneath the metatarsal head, pronating the hallux.

As the deformity progresses, the EHL and FHL have been shown to become a dynamic deforming force.

NATURAL HISTORY
The progression of a hallux valgus deformity is usually gradual, but when multiple causative factors are present, progression can be more rapid. As the deformity progresses, the hallux drifts laterally and either over or under a stable second digit. Over time the second MTP joint can dislocate. As the hallux drifts laterally, it assumes less weight bearing and a diffuse callus may occur underneath the second metatarsal head.

PATIENT HISTORY AND PHYSICAL FINDINGS
The chief compliant of a bunion deformity is usually pain. Pain can be located over several areas in a bunion deformity: median eminence, dorsal first MTP joint, medial or lateral sesamoids, or impingement on the second digit.

A thorough general medical history may include gout, osteoarthritis, rheumatoid arthritis, diabetes, or peripheral vascular disease.

Other important factors include style of shoes and if any shoe gear modification has been attempted, physical activity of the patient, and occupational demands.

Patient expectations are also very important. Goals of surgery should include increasing activity and decreasing pain. Forewarning the patient of limitations after surgery is necessary, such as the possibility of not returning to tight fashionable shoes.

The physical examination should start with the patient weight bearing to assess the bunion and lesser toe deformities and compare them to the other foot.
Evaluation of the vascular status is important. The perfusion is determined by palpating the posterior tibial and dorsal pedis arteries. Perfusion of a digit can be assessed by the capillary refill. Appropriate vascular studies such as transcutaneous oxygen, ankle-brachial index, digital pressures, and segmental pressures are useful when perfusion to the foot is in doubt.

The first MTP joint range of motion is assessed for crepitus, pain, or impingement if a dorsal spur is present. Motion is also assessed with the hallux in a corrected position to determine the degree of associated contracture of the soft tissues. Normal range of motion is 70 to 90 degrees of dorsiflexion. Joint range of motion is compared to that of the opposite foot.

Transverse plane mobility is assessed by distracting the hallux while the metatarsal head is pushed laterally to see clinical reduction of the intermetatarsal angle.

The median eminence is assessed for its prominence and underlying bursa. Neuritic pain can be elicited from the nearby dorsal or plantar cutaneous nerves.

The tibial and fibular sesamoids are directly palpated while putting the joint through a range of motion to indicate intraarticular derangement.

The first tarsometatarsal joint excursion is assessed by grasping proximal to this joint and moving the first metatarsal and comparing it to the opposite foot. Normal range of motion is 10 mm of excursion. A hypermobile first ray is more than 15 mm of excursion.

Range of motion of the hallux interphalangeal joint is evaluated in the transverse and sagittal plane, as well as joint quality.

Pain may also occur from lesser toe deformities or transfer lesions that may accompany the bunion deformity. A symptomatic intractable plantar keratoma beneath the second metatarsal head is present in the majority of patients. Other associated problems include neuromas, corns, and tailor’s bunion.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

The radiologic examination should include weight-bearing lateral, AP, and oblique views.

Several measurements are obtained using these radiographs to determine the severity of the bunion deformity, including the intermetatarsal 1–2 angle (IM1–2), hallux valgus angle (HVA), tibial sesamoid position, distal metatarsal articular angle (DMAA), and congruency of the first MTP joint.

The IM1–2 angle is determined by measuring the angle subtended by the lines bisecting the longitudinal axis of the first and second metatarsals.

Normal is less than 9 degrees (FIG 1).

The HVA is determined by measuring the angle subtended by the lines bisecting the first metatarsal and proximal phalanx of the hallux.

Normal is 15 degrees or less (FIG 2).

Tibial sesamoid position describes the relationship of the tibial sesamoid to the bisection of the first metatarsal.

The position of the sesamoid is determined by a numerical sequence of one to seven with increasing deformity.

Normal is a position of 1 to 3 (FIG 3).

The DMAA is the angle subtended by a line representing the articular cartilage of the first metatarsal head and a perpendicular line to the bisection of the shaft of the first metatarsal.

Normal measures less than 8 degrees (FIG 4).

An increase in the DMAA may demonstrate a structural deformity in the head of the metatarsal.

The first MTP joint may be described as congruent, deviated, or subluxed.

A congruent joint is one in which the cartilage surfaces of the first metatarsal head and proximal phalanx are parallel.

A deviated joint is one in which the cartilage lines intersect at a point outside of the joint.
Part 8  FOOT AND ANKLE • Section I  FOREFOOT

NONOPERATIVE MANAGEMENT

- Conservative treatment options for hallux valgus deformities are limited.
- Shoe wear modifications such as an extra-wide and deep toebox can help accommodate the deformity. Also a soft upper leather can be stretched over the bunion to provide accommodation.
- Custom-made shoes may help individuals reluctant or unable to undergo a surgical procedure.
- Bunion pads, night splints, and toe spacers tend to be of little use.
- A custom-made orthosis may be beneficial if an associated flatfoot deformity is present. The use of an orthosis has not been demonstrated to prevent a hallux valgus deformity or slow its progression. Others have proposed using orthoses post-operatively to prevent recurrence.

SURGICAL MANAGEMENT

- Bunions can be classified by their severity. This classification is used to facilitate the decision-making process of how to treat the deformity.
  - Mild bunion: HVA less than 20 degrees, congruent joint, IM angle less than 11 degrees. Pain is usually due to a medial eminence.
  - Moderate bunion: HVA 20 to 40 degrees, incongruent joint, IM angle 11 to 18 degrees. The hallux is usually pronated and presses against the second digit.
  - Severe bunion: HVA more than 40 degrees, subluxed joint, IM angle more than 18 degrees. Hallux is often overriding or underlapping the second digit; painful transfer lesion underneath the second metatarsal head; possible arthritic changes to the first MTP joint.
- The indications for hallux valgus surgery using the Mau osteotomy include:
  - Painful moderate to severe bunion deformity
  - Deformity unresponsive to conservative treatment
Preoperative Planning
- Routine preoperative clearance is obtained via history and physical. This may include an electrocardiogram, chest radiograph, and laboratory workup.
- A prophylactic antibiotic of choice is given 30 minutes before the procedure. Also, one tablet of 200 mg celecoxib (Celebrex) is given.

Positioning
- The patient is placed supine on the operating table with a bump placed under the contralateral hip.
- A well-padded pneumatic thigh tourniquet is used and set to 300 mm Hg (FIG 6).

Approach
- Typically two incisions are used to provide adequate exposure.
  - The first incision is placed over the first web space and the second is placed on the medial aspect of the first metatarsal.
  - The second incision starts at the first tarsometatarsal joint and courses distal and medially over the first MTP joint for the distal soft tissue procedure (FIGS 7 AND 8).

LATERAL RELEASE OF THE FIRST METATARSOPHALANGEAL JOINT
- Using an incision in the first web space (TECH FIG 1), perform the lateral release first. Carry dissection through the subcutaneous layer.
  - Typically the first structure incised is the superficial portion of the transverse ligament.
  - Use blunt dissection to view the lateral first MTP joint and fibular sesamoid.
- Release the adductor tendon from the plantar–lateral base of the proximal phalanx and fibular sesamoid (TECH FIG 2).
  - Incise the deep portion of the transverse ligament. The lateral capsule of the first MTP joint is “pie crusted” and a varus stress is placed on the joint.
MEDIAL CAPSULORRHAPHY

- Using a standard medial approach, perform an inverted-L capsulotomy. The alternative dorsal–medial skin incision, which is placed over the first dorsal metatarsal artery and nerve, can cause nerve irritation and entrapment.
- This allows exposure of the enlarged medial eminence and release of the stretched medial sesamoid suspensory ligament (TECH FIG 3). Remove the periosteum from the metatarsal head medially and dorsally but keep it intact at the neck plantarly to preserve the nutrient artery.
- Resect the medial eminence using a sagittal saw (TECH FIG 4).
- Take the eminence from dorsolateral to plantar–medial. Remove the eminence in this orientation to prevent staking of the metatarsal head and loss of the sagittal groove, which can lead to medial subluxation of the tibial sesamoid and promote hallux varus.

MAU OSTEOTOMY

- Carry the dissection deep to the first metatarsal shaft. The skin incision can be placed slightly plantar to the first metatarsal to avoid surrounding neurovascular structures such as the first dorsal metatarsal artery and nerve. With this incision, a potentially nonpainful scar results as the incision is not placed directly over bone. The extensor hallucis longus tendon is not encountered with this incision and is retracted safely.
- Identify the first tarsometatarsal joint but do not disturb the capsule. An 18-gauge needle can be placed in the joint for reference.
- Starting 1 cm from the first tarsometatarsal joint, reflect the periosteum plantar-proximal to dorsal-distal only in line with the osteotomy, thereby preserving the rest of the periosteum (TECH FIG 5). Much of the periosteum is retained to promote adequate bone healing.
- The osteotomy does not incorporate the entire metatarsal shaft as does the traditional Mau osteotomy. The osteotomy ends in the midshaft of the first metatarsal.
- Complete the osteotomy with a sagittal saw parallel to the weight-bearing surface to prevent unwanted dorsal angulation of the first metatarsal. The Mau is started proximal-plantar and ends distal-dorsal (TECH FIG 6). A self-retaining retractor is useful to protect the surrounding neurovascular and tendinous structures. Using the straight medial incision avoids tendinous structures and allows excellent visualization of the medial metatarsal shaft to complete the osteotomy. To maintain complete control while completing the osteotomy, a smooth guide pin for the selected cannulated screw can be placed perpendicular across the completed proximal portion of the osteotomy. Then the osteotomy can be completed without fear of losing the orientation.
- After completing the osteotomy, rotate the distal fragment. Optimal rotation of the osteotomy may be facilitated by placing a large reduction bone clamp on the first metatarsal head and neck of the second metatarsal to help reduce the IM1–2 angle (TECH FIG 7).
Redundant capsular tissue is excised and optimal correction is obtained with a tibial sesamoid position less than 2 and an IM1–2 angle less than 9 degrees. About 4 mm of redundant capsule is removed from the inverted-L portion of the capsulotomy to help reduce and advance the sesamoids upon closure. With larger deformities, more capsule may need to be removed to reduce the tibial sesamoid position adequately. To correct pronation of the hallux, the towel clip can be rotated to correct the deformity, and a double simple suture is placed to maintain the correction.

- We use two 2.5- or 3.0-mm headless cannulated screws for final fixation.

- Place two temporary Kirschner wires (0.025 inch) from dorsal to plantar perpendicular to the osteotomy site (TECH FIG 8).

- Reduction of the IM1–2 angle is mostly obtained by rotation of the distal fragment. It is acceptable to allow slight lateral translation of the distal fragment relative to the proximal fragment to further correct the IM angle.

- We recommend using intraoperative fluoroscopy to confirm proper position of the first metatarsal head over the tibial sesamoids, congruent joint alignment, and satisfactory orientation of the osteotomy. We use a towel clip to provisionally advance the capsule into the desired position to assess sesamoid alignment (TECH FIG 9). Redundant capsular tissue is excised and optimal correction is obtained with a tibial sesamoid position less than 2 and an IM1–2 angle less than 9 degrees. About 4 mm of redundant capsule is removed from the inverted-L portion of the capsulotomy to help reduce and advance the sesamoids upon closure. With larger deformities, more capsule may need to be removed to reduce the tibial sesamoid position adequately. To correct pronation of the hallux, the towel clip can be rotated to correct the deformity, and a double simple suture is placed to maintain the correction.

- We use two 2.5- or 3.0-mm headless cannulated screws for final fixation.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Incision</th>
<th>Incision is placed medial to the first metatarsal and slightly plantar to avoid the surrounding neurovascular structures. This allows fast deep dissection.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial capsulorrhaphy</td>
<td>Placing a varus stress on the hallux will expose redundant capsular tissue that can be incorporated within the L portion of the capsulotomy and can be adequately removed.</td>
</tr>
<tr>
<td>Osteotomy</td>
<td>The periosteum is elevated only in line with the osteotomy. The proximal portion of the osteotomy should be at least 1 cm distal from the first tarsometatarsal joint. This will also prevent placement of the osteotomy within the first tarsometatarsal joint.</td>
</tr>
<tr>
<td></td>
<td>The saw blade is kept parallel to the weight-bearing surface of the foot to prevent unwanted dorsal angulation of the first metatarsal head after completion of the osteotomy.</td>
</tr>
<tr>
<td></td>
<td>To maintain complete control of the osteotomy, a guidewire for the cannulated screw can be placed perpendicular in the completed proximal portion of the osteotomy. The osteotomy can be completed dorsal-distally without fear of losing the orientation.</td>
</tr>
<tr>
<td>IM1–2 reduction</td>
<td>Reduction can be achieved with large reduction clamps or by using a Freer elevator on the lateral portion of the proximal fragment and placing counterpressure on the first metatarsal head. Intraoperative fluoroscopy is recommended after placing temporary fixation to achieve an IM angle less than 9 degrees.</td>
</tr>
<tr>
<td>Screw placement</td>
<td>Placing a screw too distal may cause fracture of the dorsal portion of the osteotomy site. Allow adequate space between the screws and the distal aspect of the osteotomy to prevent fracture.</td>
</tr>
<tr>
<td>Unrecognized hypermobility of the first tarsometatarsal joint</td>
<td>This may result in the inability to effectively reduce the IM1–2 angle after temporary fixation. If encountered, the first tarsometatarsal joint may be temporarily pinned and permanent fixation placed. The pin across the first tarsometatarsal joint can be removed 4 to 6 weeks postoperatively.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- The patient is placed in a soft toe spica dressing after surgery and instructed to remain partially weight bearing on the heel in a surgical shoe.
- Two weeks after surgery the sutures are removed and the patient is fully weight bearing in a surgical shoe.
- Three weight-bearing radiographs (AP, lateral, oblique) are obtained at each visit until bony healing of the osteotomy site is seen.

OUTCOMES

- After a proximal osteotomy and distal soft tissue release, 90% to 95% patient satisfaction rates have been reported.3,5,17
- One study reviewed retrospective results of the Mau osteotomy and found excellent correction of a moderate to severe bunion deformity in 24 patients.8
- Biomechanical studies using sawbones and fresh frozen cadaver models showed superior stability with the Mau...
osteotomy in terms of fatigue, strength, and stiffness compared to other proximal osteotomies. The Mau osteotomy is an inherently stable osteotomy that allows early postoperative weight bearing without the need for cast immobilization as required for other proximal osteotomies due to complications such as dorsal malunion and nonunion. The Mau is a stable osteotomy due to the dorsal shelf to help reduce dorsal displacement forces and broad bony apposition to facilitate two-screw fixation.

The authors performed a follow-up study comparing the Mau and crescentic osteotomies. Both osteotomies showed comparable correction of the moderate to severe bunion deformity, but significantly more complications were associated with the crescentic osteotomy. Complications included dorsal malunion, placement of screws within the tarsometatarsal joint, and nonunion.

The Mau osteotomy is technically easier to perform than other proximal osteotomies with fewer complications, as seen in two studies, and excellent correction of a bunion deformity (FIGS 9–12).

COMPLICATIONS

One of the most common complications after bunion surgery is recurrence. This may be due to selection of the inappropriate procedure to correct the moderate to severe bunion deformity or intraoperative failure to obtain an adequate alignment to correct the deformity.

Hallux varus is a complication that occurs less often than recurrence. It occurs as a result of overcorrection of the deformity and is much more difficult to correct.

Other complications include shortening, dorsal malunion, and transfer lesions, which can occur with all proximal osteotomies.
REFERENCES

DEFINITION
- Correction of major bunion deformities through the proximal portion of the first metatarsal is widely recognized as the established method of reducing the angle between the first and second metatarsal.1–4
- More than 138 techniques have been described for bunion correction, with widely varied methods of fixation of these osteotomies including pins or screws.
  - Pins provide little inherent stability and have been associated with postoperative infections.
  - Getting excellent fixation of screws can be a problem in cases in which there is poor bone quality.
- Plates, although widely used in all other osteotomies, have not been employed in bunion surgery because of the fear of prominence and irritation of the patient’s foot.
- Recently, the use of locking plates and locking screws has been increasing in the orthopaedic world. The locking plates provide a fixed-angle device, which allows for a potentially stronger method of fixation.2

SURGICAL MANAGEMENT
Approach
- The procedure is performed through a single midmedial approach to the first metatarsal with the use of an Esmarch tourniquet (FIG 1).

SKIN AND CAPSULAR INCISION
- The skin and subcutaneous tissues are incised sharply to expose the first metatarsophalangeal (MTP) joint capsule. Care is taken to protect the medial dorsal and plantar cutaneous nerves.
- A vertical capsular resection is performed to remove about 3 to 5 mm of capsule just proximal to the base of the proximal phalanx (TECH FIG 1).
- A dorsomedial incision is made in the capsule parallel to the first metatarsal, creating a plantarly based capsular flap with exposure of the medial eminence.

The advantages of plate fixation for the patient include no external pins, potentially no second procedure to remove hardware, less pain because the osteotomy is stable, and early full or at least partial weight bearing.
- Advantages for the surgeon are that it is possible to do any osteotomy for the first metatarsal and that excellent and secure fixation is obtained.
- Although many different configurations of the osteotomy can be used, the proximal chevron osteotomy permits a greater degree of correction compared with distal osteotomies. It does this through both an angular and translational displacement of the distal portion of the first metatarsal.2

FIG 1 • A. Simulated weight-bearing view of foot. B. A mid-medial approach to the first metatarsal is used. The first metatarsophalangeal and first tarsometatarsal joints are identified.

TECH FIG 1 • Thick skin flaps are preserved, and a vertical segment of redundant capsule is excised.
RELEASE OF LATERAL JOINT STRUCTURES

- The lateral soft tissues are released from within the metatarsophalangeal joint after distraction of the sesamoids from the first metatarsal with a lamina spreader. First use a blunt Freer elevator to develop some room and then cut the capsular tissue with a sharp no. 15 blade (TECH FIG 2).

- Complete release can be confirmed when the toe can be brought into about 15 degrees of varus through the MTP joint.

- The proximal first metatarsal is subsequently exposed both dorsally and plantarly.

METATARSAL OSTEOTOMY

- The location of the tarsometatarsal (TMT) joint is confirmed, and a point is marked about 20 mm distally from the first TMT joint for the apex of the osteotomy and at the midpoint in the dorsal plantar direction.

- A proximally based chevron osteotomy is created at an angle of about 60 degrees using a microsagittal saw.

- Complete release, both plantarly and dorsally, is confirmed, and care is taken not to fracture either limb of the chevron osteotomy (TECH FIG 3).

- The proximal fragment is grasped with a towel clamp, and the distal fragment angulated laterally.

- It also is translated 3 to 5 mm laterally and plantarly enough to coapt the superior portion of the chevron, leaving an opening in the plantar portion of the osteotomy (TECH FIG 4).

- A pointed towel clip is used to hold the proximal metatarsal while the shaft is angulated and translated laterally to decrease the 1–2 intermetatarsal angle and narrow the foot. A K-wire is advanced from the TMT joint into the shaft to hold the correction temporarily.
**OSTEOTOMY FIXATION**

- The translated position is secured temporarily with a 0.062-inch K-wire.
- The prominent proximal fragment is cleaned of periosteum and removed flush with the distal fragment.
- The largest removed portion is then placed as bone graft between the fragments at the opening created in the chevron osteotomy from the plantar translation (TECH FIG 5A,B).

- A four-hole hole locking plate is used to bridge the osteotomy medially (TECH FIG 5C).
- Care is exercised to avoid penetrating the TMT articulation with screws.
- The medial eminence is removed 1 mm medial to the sagittal sulcus (TECH FIG 5D).
- The K-wire is removed, stability is confirmed, and correction and alignment are confirmed with fluoroscopy (TECH FIG 6).

**TECH FIG 5** • **A,B.** The prominent proximal bone is removed with a saw. The opening created by plantar flexing the metatarsal creates a gap into which the removed bone may be impacted. **C.** A four-hole locking plate is applied at the osteotomy site. **D.** The prominent medial eminence is removed 1 mm medial to the sagittal sulcus.

**TECH FIG 6** • **A,B.** Correction of the hallux valgus angle and the 1–2 intermetatarsal angle is confirmed with fluoroscopy.
POSTOPERATIVE CARE

- Bunion dressings are applied at the time of surgery, and sutures are removed 2 to 3 weeks from the date of surgery.
- Heel weight bearing can be allowed immediately postoperatively, with advancement to weight bearing as tolerated in a regular shoe at 6 weeks postoperatively.
- Radiographs are obtained at 6 weeks and 3 months.

REFERENCES

SURGICAL MANAGEMENT

- The primary indication for a proximal closing wedge osteotomy is a symptomatic hallux valgus deformity with a first intermetatarsal angle (IMA) of 14 degrees or greater.
- The first metatarsocuneiform (MC) joint should be stable. We evaluate stability of this joint both by physical examination and radiographs. On physical examination, the cuneiform is stabilized in one hand while the first metatarsal is translated superiorly and inferiorly with the other hand. On weight-bearing radiographs, the MC joint is inspected for incongruency on the AP view and plantar widening on the lateral view. We favor a Lapidus-type procedure for hallux valgus associated with first MC joint instability.
- Relative contraindications to this osteotomy include mild osteoarthritic changes in the first metatarsophalangeal (MTP) joint and the presence of an inflammatory arthropathy. In the presence of mild osteoarthritic changes, an active individual who understands the possible future need for a fusion may remain a candidate for a corrective osteotomy. Similarly, given the improved medical management of inflammatory arthropathy, an informed patient with well-managed rheumatoid arthritis may also be a candidate for reconstructive hallux valgus surgery rather than fusion.
- Absolute contraindications to this osteotomy are advanced osteoarthritis of the first MTP joint or the skeletally immature patient, in whom the very proximal nature of this osteotomy can jeopardize the growth plate.

Preoperative Planning

- AP and lateral weight-bearing radiographs of the foot are evaluated for metatarsal length, IMA, and hallux valgus angle. Congruency of the joint, the size of the bony medial eminence, and the position of the sesamoids are noted. We routinely mark the proposed osteotomy on the radiograph (FIG 1).

Positioning

- We perform this procedure on an outpatient basis. Prophylactic antibiotics are administered. A thigh tourniquet is applied. The patient is positioned supine with a small sandbag placed under the ipsilateral buttock to ensure the foot points up, allowing for easier osteotomy orientation.

Approach

- We perform the proximal closing wedge osteotomy with a distal soft tissue procedure through two incisions. The first is a dorsal first web space incision extended proximally in a lazy-S curve to the dorsal first MC joint. This incision allows access for lateral release and proximal osteotomy. The second medial midaxial incision over the first MTP joint is the traditional approach for medial capsulotomy, medial eminence resection, and medial capsular plication.

SOFT TISSUE RELEASE AND BUNIONECTOMY

- Perform a standard lateral release of the first MTP joint through a dorsal incision centered over the first web space.
- After incising the skin, continue deep dissection bluntly.
- Using sharp dissection, release the tendinous insertion of the adductor hallucis muscle onto the fibular sesamoid and proximal phalanx; we have not found it necessary to reattach this structure proximally (TECH FIG 1A).
- Release the suspensory metatarsal–sesamoid ligaments and make multiple sharp perforations in the lateral capsule at the joint line. Apply a varus force to the hallux, completing the capsular release.
- Approach the medial eminence through a midline longitudinal incision extending from just proximal to the medial eminence to the base of the proximal phalanx. Identify the dorsal medial cutaneous nerve and incise the medial capsule sharply in a longitudinal direction (TECH FIG 1B). Expose the medial eminence and resect it 1 mm medial to the sagittal sulcus. Overresection can lead to a postoperative varus deformity.
CLOSING WEDGE OSTEOTOMY

- Extend the first web space incision in an S shape to the first MC joint (TECH FIG 2A). Approach the dorsal metatarsal shaft through the interval between the extensor hallucis brevis and extensor hallucis longus. Retraction with two small pointed retractors facilitates exposure of the metatarsal base.

- The proposed wedge for resection has its apex on the medial cortex about 3 mm from the MC joint. The proposed long oblique osteotomy should leave a large residual proximal fragment for maximal contact area and solid fixation. The first cut, the proximal of the two, is perpendicular to the weight-bearing axis of the foot. This is demonstrated during surgery by the simulated weight-bearing test. To maintain control of the osteotomy, the medial cortex is scored but not penetrated with the saw blade (TECH FIG 2B).

- After making the second distal cut, excise a lateral wedge-shaped wafer of bone; this leaves a defect, which is compressed with a towel clip. This “greensticks” the intact but weakened medial cortex and the IMA is reduced (TECH FIG 2C–E).

- Insert two 2.7-mm cortical screws (Synthes, Paoli, PA) from the lateral to medial cortex in a lag screw fashion (TECH FIG 3AB). The small size of the proximal fragment leaves a wedge-shaped segment of bone, which is removed.
does not allow both screws to be parallel to the osteotomy, but this is not vital, as compression has already been obtained with the reduction forcep.

■ Confirm the reduction in the IMA, screws, and relocation of the sesamoids with image intensification.

■ Imbricate the medial capsule with a strong absorbable suture while holding the hallux in a neutral or slightly abducted position (TECH FIG 3C).

■ Close the wounds in layers with interrupted nylon sutures to the skin and apply a forefoot bandage to maintain the correction (TECH FIG 3D).

**PEARLS AND PITFALLS**

| Keep the center of correction proximal. | The apex of the deformity is the MC joint. To maximize the power of the osteotomy, the center of correction should be as close to the joint as possible, leaving a safe bridge of medial cortex. |
| Beware the short osteotomy! | If the osteotomy is too short it will exit the lateral cortex too proximally, leaving a small proximal fragment. This compromises the contact area and stability of the osteotomy, precludes adequate fixation, and decreases the corrective power of the osteotomy. |
| Maintain continuous control of the osteotomy. | By only scoring the medial cortex, complete control of the osteotomy segments is maintained at all times. |
| Avoid early full weight bearing. | The excessive sagittal loading can lead to a dorsiflexion malunion. |

**POSTOPERATIVE CARE**

■ If safe, patients are discharged home on the day of surgery with strict advice to elevate the foot whenever resting for the first 2 weeks.

■ In most cases patients are allowed to bear weight on their heel and lateral forefoot in a hard-soled postoperative shoe.

■ In noncompliant patients or those with poor bone quality and fixation, we do not hesitate to use cast immobilization from the outset.

■ The wound is inspected and sutures are removed at 2 weeks, at which time the hallux is restrapped and patients are taught simple passive and active toe flexion–extension exercises.
At 6 weeks postoperatively the osteotomy is assessed with radiographs (FIG 2A–D). If there is some consolidation at the line of the osteotomy, the patient is instructed to wear a wide shoe or sneaker and to progress weight bearing as tolerated. Strapping of the hallux is discontinued at this time. If there is evidence of a delayed union, the patient is kept non-weight-bearing in a hard-soled postoperative shoe.

OUTCOMES
- A review of our first 40 cases with an average age at surgery of 51 years identified one case of transfer metatarsalgia in a patient who had not had it before surgery, one malunion due to loss of fixation, one delayed union requiring prolonged immobilization, and one asymptomatic nonunion. Shortening of the first metatarsal was minimal with this technique, with an average of 0.98 mm (−1 to 3 mm). In the subset of 11 patients with a severe deformity and an IMA exceeding 18 degrees (range 18 to 22 degrees) the average postoperative IMA was 7.8 degrees, with an average 1.8 mm of shortening.
- Some studies have reported more shortening (average of 5 mm) with similar osteotomies, but this may be due to two factors: (1) a transverse rather than long oblique closing wedge osteotomy and (2) dorsiflexion malunion (which may make the metatarsal appear shorter on radiographic evaluation).
- The stability of this osteotomy is not compromised even when correcting hallux valgus with a large intermetatarsal deformity. This is in contrast to the Scarf, Ludloff, or proximal crescentic osteotomies, where bone contact area is substantially reduced.

COMPLICATIONS
- Those of any hallux valgus surgery: iatrogenic fracture, injury to the dorsal medial cutaneous nerve, superficial infection, loss of fixation, and delayed union
- The risk of iatrogenic fracture can be minimized by using appropriate-diameter screws, leaving a bridge of at least 3 mm between screws, and both drilling and tapping the near cortex (even when using a self-tapping screw).

REFERENCES
DEFINITION
- Symptomatic hallux valgus, or bunion deformity, is a common problem seen in foot and ankle and general practice clinics.
  - Historically, it is seen almost exclusively in persons who wear shoes.
  - It is characterized by a painful prominence at the medial aspect of the great toe.
- The deformity is exemplified by lateral deviation (valgus) of the great toe proximal phalanx and medial (varus) deviation of the first metatarsal.
- Juvenile hallux valgus deformity usually is a combination of valgus inclination of the metatarsal articular surface (i.e., increased distal metatarsal articular angle [DMAA]) and varus deformity of the first metatarsal.
- Deformity may be classified as mild, moderate, or severe, evaluated on weight-bearing radiographs of the foot and based on the following criteria:
  - The degree of valgus at the metatarsophalangeal (MTP) joint or hallux valgus angle (HVA)
  - The degree of varus deformity of the first metatarsal or 1–2 intermetatarsal angle (IMA)
- Advanced deformity is more complex, and the hallux exhibits the following:
  - Toe pronation noted clinically by medial rotation of the toenail
  - Sesamoid subluxation noted on the anteroposterior (AP) radiograph and sesamoid view
  - Medial capsular laxity and lateral capsular contracture

ANATOMY
- The great toe MTP joint is unique when compared to the lesser MTP joints because of the sesamoid complex, unique tendon insertions, and ligamentous support about the joint (FIG 1).
  - The sesamoid ligaments mesh with the collateral ligaments both medially and laterally.
  - The tendons of the flexor hallucis brevis, abductor and adductor hallucis, plantar aponeurosis, and joint capsule coalesce to form the plantar plate, surrounding and stabilizing the first metatarsal head (FIG 2).
  - Because there are no true tendon insertions on the first metatarsal head, it is vulnerable to varus deviation.
  - An intermetatarsal facet occasionally is present between the first and second metatarsal bases, sometimes creating a rigid metatarsus primus varus.
  - The first metatarsal blood supply is derived from arterial supply primarily through the lateral midshaft, and its flow is distal.
  - Intraosseous flow is variable with respect to proximal and distal branches.
  - The primary arterial sources are the first dorsal and plantar metatarsal arteries and the superficial branch of the medial plantar artery.
  - The DMAA is defined by the relationship between the metatarsal long axis and the distal metatarsal articular surface lateral inclination (FIG 3).
PATHOGENESIS
- The concept of a hallux valgus deformity with a congruent or subluxated MTP joint is important (FIG 4).
- Whereas hallux valgus with a subluxated joint usually is progressive, congruent joints tend to be static deformities.
- Congruent joint hallux valgus deformity is associated with an increased DMAA and juvenile hallux valgus.
- A flat metatarsal head, with little convexity, is associated with hallux rigidus.  
- A rounded metatarsal head is associated with greater MTP instability and hallux valgus. As the proximal phalanx deforms laterally, the metatarsal head shifts medially, increasing both the HVA and 1–2 IMA.  
- The sesamoid complex remains in its physiologic position as the metatarsal head shifts medially. The weak link is thought to be the medial capsule immediately superior to the insertion of the abductor hallucis.  
- Ultimately, the abductor hallucis slides plantar to the metatarsal head, leading to a lack of intrinsic muscle stability to the first MTP joint, with resultant pronation of the phalanx (FIG 5).

NATURAL HISTORY
- Hallux valgus with a subluxated joint usually is progressive, and the pathogenesis described in previous sections commonly is observed over time.
- Hallux valgus associated with a congruent joint tends to be more static in terms of deformity.
- Subluxated and congruent deformities may become symptomatic over time due to shoe pressure, cutaneous nerve irritation, bursitis, callus formation and a painful medial eminence.
- With progressive or painful deformities, other lesions may develop, such as associated lesser toe deformities, Morton’s neuroma, lesser MTP joint capsular instability, stress fractures, skin ulceration, and hallux or lesser MTP joint dislocation.

PHYSICAL FINDINGS
- A reddened prominence over the medial aspect of the great toe MTP joint, or “bunion,” often develops with pressure from shoe wear (Table 1).
- Many patients exhibit callus formation under the second or third metatarsal heads because the displaced first metatarsal is not bearing weight in a balanced manner with the lesser metatarsal heads.
- On palpation of the foot, most patients are tender over the medial eminence or show irritability in the cutaneous nerve.
- A large dorsal metatarsal prominence is more commonly associated with hallux rigidus and is not typical of symptomatic hallux valgus.
Joint range of motion in hallux valgus, even with severe deformity, usually is well preserved, without crepitance, and with minimal pain.

Range of motion also is checked while gently reducing the deformity out of valgus.

Chronic deformities or congruent joints with increased DMAA may exhibit less dorsiflexion at the MTP joint.

Palpation of the first MTC joint, if present, should be noted.

Prominence, swelling, and pain with cantilever stress of the first MTC joint, if present, should be noted.

Mobility of the first MTC joint and gastrocnemius tightness are assessed.

Other painful areas are sought out, including those with callosus formation, the lesser MTP joints, intermetatarsal spaces, bunionette deformities, and hammer toes.

We routinely also analyze the patient’s gait, with particular attention focused on the stance phase and evaluation of hindfoot position and status of the longitudinal arch.

Hindfoot joints are examined, tendon strength is checked, and general alignment about the foot and ankle are noted. In select patients, correction of concomitant pes planovalgus deformity, either simultaneously or in a staged fashion, may be warranted, because a valgus hindfoot may predispose to progression or recurrence of hallux valgus.

Pulses are palpated, sensation is assessed, and the skin is inspected. Poor circulation should prompt a vascular evaluation, and loss of protective sensation may indicate neuropathy and should be noted.

Pain, activity related pain is common when in shoes.

Neuromuscular disorders are associated with hallux valgus.

Tarsal coalition or symptomatic accessory navicular with hallux valgus may occur.

Adult or congenital flatfoot, posterior tibial tendon deficiency, generalized hyperlaxity, and first MTC instability can exacerbate hallux valgus.

Differential diagnosis

Inflammatory arthritis of many varieties can result in hallux valgus.

Traumatic hallux valgus or hallux varus can occur.

Adult or congenital flatfoot, posterior tibial tendon deficiency, generalized hyperlaxity, and first MTC instability can exacerbate hallux valgus.

Tarsal coalition or symptomatic accessory navicular with hallux valgus may occur.

Neuromuscular disorders are associated with hallux valgus.

Nonoperative management

Shoe wear modification, the mainstay of nonoperative management, includes shoe stretching, wider toe box shoes, and, occasionally, accommodative orthotics.

Toe spacers, night splints, bunion pads or posts, and other inventive devices may help reduce symptoms.

Surgical management

More than 120 procedures have been described to surgically correct hallux valgus, including a variety of proximal first metatarsal base, shaft, and distal osteotomies.

The goals of an ideal proximal base osteotomy are reliable, powerful, predictable correction with stable fixation to allow for early weight bearing.

Proximal metatarsal opening wedge osteotomy (PMOW) with a newer low-profile plate fixation system (Arthrex, Inc., Naples, FL) is, in our opinion, nearly ideal for addressing those goals.

Table 1

Table 1 Key History and Physical Findings of Hallux Valgus

<table>
<thead>
<tr>
<th>Chief Complaint</th>
<th>Painful cherry-red prominence over medial aspect of MTP joint: atypical pain is plantar MTP joint (seamoiditis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>Worsening pain and deformity the last 6 months to 1 year</td>
</tr>
<tr>
<td>Inspection</td>
<td>Swollen, reddened medial eminence with lateral deviation of the toe, often pronated with severe deformity</td>
</tr>
<tr>
<td>Palpation</td>
<td>Slight crepitus, bursitis, tender to touch over prominence, slight warmth, smooth and nearly full range of motion without pain</td>
</tr>
<tr>
<td>Deformity</td>
<td>Valgus (lateral) toe deviation varus metatarsal deviation and with severe deformity: pronation of the toe (the nail is rotated medially)</td>
</tr>
<tr>
<td>Key Differential</td>
<td>Rigidus; extreme pain, swelling (boggy) and warmth with gout or inflammatory condition</td>
</tr>
<tr>
<td>Aggravating Factors</td>
<td>Constrictive or unsupportive shoe wear worsens the pain, activity related pain is common when in shoes</td>
</tr>
</tbody>
</table>

- Standardized mid-diaphyseal reference points are used to measure the HVA and IMA.
- The IP angle is measured by a line bisecting the base of the proximal phalanx and the long axis of the phalanx.
- Although precise measurement of the DMAA has been controversial, it is critical that it be considered, because subtotal correction and persistent deformity will result if it is not addressed at the time of surgery.
- A DMAA of more than 15 degrees is considered increased. It is measured based on the AP weight-bearing radiograph (Fig. 3).
- Hallux valgus interphalangeus (HVI) is measured by the IP angle. HVI has been associated primarily with hallux rigidus, but occasionally it occurs with hallux valgus.
- Proximal first metatarsal osteotomies and distal soft tissue procedures do not correct an increased HVI; phalangeal osteotomies are required to correct HVI.
- MTC instability may be indicated by a first MTC angle of more than 10 degrees or excess joint obliquity on the weight-bearing AP radiograph, plantar gapping of more than 2 mm on the lateral weight-bearing view, or an intermetatarsal os.
- Although first ray hypermobility is controversial, in select patients, an increased 1–2 angle may be best corrected with a first MTC arthrodesis in lieu of a proximal first metatarsal osteotomy.
- An intermetatarsal facet at the base of the first and second metatarsals may directly impede correction of the 1–2 IMA.
- Hallux valgus associated with advanced arthrosis of the first MTP joint may preclude joint-preserving operations, and typically is best managed with a first MTP joint arthrodesis.

Imaging and diagnostic studies

Weight-bearing AP and lateral radiographs are routinely obtained.

MRI, CT, and bone scans are rarely indicated. The reported normal radiographic values of the hallux MTP joint are a hallux valgus angle (HVA) no greater than 15 degrees, a 1–2 IMA of no more than 9 degrees, and an IP angle of less than 10 degrees.6
The osteotomy is gently opened with three successive osteotomes (largest blade first) from the PMOW set, and care is taken to preserve the lateral hinge of bone and soft tissue, if possible. “Stacking” osteotomes diminishes the risk of breaking the lateral cortex, which is more likely to occur when a single osteotome is used to lever the osteotomy open.

Once the osteotomy is opened, manual pressure over the medial eminence and a mini lamina spreader (supplied in the set) are used to obtain the desired correction and verified fluoroscopically.

Alternatively, a measuring wedge (also provided in the set) may be utilized.

If the lateral cortical hinge should fail, the mini lamina spreader is quite useful.

The osteotomy site is held open and the plate applied as described, which typically reduces the lateral cortex.

To gain further support to the lateral cortex, one of the proximal screws may be placed not only through the plate but also across the osteotomy to capture the distal lateral cortex. Alternatively, an additional oblique screw may be added outside the plate.

About 5% of our cases have resulted in lateral cortex fracture with no delay in healing or modification in the postoperative protocol.

**TECHNIQUES**

**PROXIMAL METATARSAL OPENING WEDGE OSTEOTOMY**

- PMOW combined with a distal soft tissue procedure (i.e., lateral capsular release and medial capsular placement) is considered for moderate to severe hallux valgus, hallux valgus associated with a short first ray, a 1–2 IMA of more than 12 degrees, and recurrent hallux valgus, either after a distal procedure alone or as an adjunct to a distal procedure if subtotal correction is achieved.
- Two or three 3-cm incisions are used, depending on which distal procedure is being performed.
  - The first longitudinal incision is centered over the medial eminence, and a simple bunionectomy is performed in a routine fashion.
  - We prefer to use an inverted L-shaped capsulotomy and save bone resected from the medial eminence to use as autograft in the PMOW.
  - Alternatively, cancellous graft may be harvested from the lateral calcaneus through a 1- to 2-cm lateral heel incision.
  - We make the longitudinal incision for the PMOW dorsomedially, beginning just distal to the first MTC joint.
- The superficial peroneal nerve branch to the hallux and the extensor hallucis longus tendon must be identified and protected.
- The osteotomy is initiated medially about 1.5 cm distal to the joint, slightly oblique (about 20–30 degrees) toward the lateral aspect of the first metatarsal base, without violating the lateral cortex (**TECH FIG 1A**). Minimal periosteal stripping is required.
- The osteotomy is gently opened with three successive osteotomes (largest blade first) from the PMOW set, and care is taken to preserve the lateral hinge of bone and soft tissue, if possible. “Stacking” osteotomes diminishes the risk of breaking the lateral cortex, which is more likely to occur when a single osteotome is used to lever the osteotomy open.
- Once the osteotomy is opened, manual pressure over the medial eminence and a mini lamina spreader (supplied in the set) are used to obtain the desired correction and verified fluoroscopically.
- Alternatively, a measuring wedge (also provided in the set) may be utilized.
- If the lateral cortical hinge should fail, the mini lamina spreader is quite useful.
- The osteotomy site is held open and the plate applied as described, which typically reduces the lateral cortex.

**TECH FIG 1**

**A.** Site and position of first metatarsal opening wedge osteotomy. The proximal metatarsal opening wedge osteotomy is initiated about 1.5 cm distal medial to the first metatarsal cuneiform (MTC) joint. **B.** Site of osteotomy 1.5 cm distal to the first MTC joint. **C.** The plate has been set into position by insertion of the first screw. **D.** Screw placement with opening wedge plate.
Based on the authors' clinical data utilizing the oblique osteotomy, a general rule for preoperative planning is approximately 3 degrees of correction per millimeter of opening wedge.

The desired wedge is selected and the first screw is placed in the distal hole closest to the osteotomy to set the plate (TECH FIG 1B,C).

The next screw placed is in one of the proximal holes. We prefer to place both of these screws obliquely across the apex of the osteotomy (TECH FIG 1D).

If there is any concern about stability, an additional screw can be placed obliquely outside the plate to enhance the construct.

The final screw is placed distally.

With the plate securely fixed, fluoroscopy is used with the foot flat on the table to verify a congruent joint and increased DMAA or to determine whether any further correction is required.

With subluxated deformities, the PMWO is combined with a modified McBride bunionectomy using two or three incisions.

The third incision, if used, is for the first web space. However, with this technique an aggressive lateral release typically is not required.

If the joint is congruent with an increased DMAA or if still more correction is desired, a biplanar chevron incision with a long dorsal limb is used (TECH FIG 2A–C).

Any IP deformity or residual pronation can be treated with an Akin osteotomy.

The capsule is repaired through a drill hole at the metadiaphyseal junction or with mattress suture technique proximally if the tissue quality is satisfactory. The soft tissues over the osteotomy site are closed in a layered fashion, after autologous graft is impacted.

Nylon sutures are used for the skin.

TECH FIG 2 • A. Preoperative weight-bearing AP radiograph shows a severe hallux valgus deformity with a bipartite tibial sesamoid and mild degenerative changes. B. Intraoperative radiograph shows good correction of the 1–2 IMA to less than 9 degrees but an increased DMAA of 25 degrees. C. Six week postoperative weight-bearing AP radiograph shows good alignment post-PMOW first metatarsal and distal biplanar chevron bunionectomy.

PEARLS AND PITFALLS

- Start slightly oblique (10–15 degrees) osteotomy at least 1.5 cm distal to the first tarsometatarsal joint.
- A small lamina spreader is useful to obtain desired correction.
- The opposite side plate may fit better on the base of the first metatarsal in some people.
- Avoid an aggressive lateral release; pie-crusting release through the joint is usually enough.
- Distal biplanar chevron osteotomy or similar correction for the DMAA is often needed.
- Careful not to enter the joint with the oblique osteotomy; verify cut with radiology.
- Lateral cortex disruption can occur; temporary Kirschner wire fixation will stabilize.
- Plate removal is lower in clinical studies.7
- Varus overcorrection is reduced.10
- Although the DMAA is not increased because of PMOW, it becomes more easily recognized and should be treated to optimize the results.
POSTOPERATIVE CARE
- We prefer to use a carefully wrapped Coban dressing with a figure 8 toe cradle in the operating room and for the first 3 weeks postoperatively.
- A soft Velcro bunion splint is used thereafter for 6 weeks.
- The last 2 weeks are nighttime use only.
- Patients are seen 5 days after surgery and every 10 to 14 days, depending on the amount of swelling they experience.
- Sutures are removed 2 to 3 weeks postoperatively.
- We routinely place the patient’s operated foot in a short controlled ankle motion (CAM) walker immediately after surgery and allow heel weight bearing in the boot as tolerated.
- Patients are allowed full weight bearing on the foot at 6 weeks, first in the boot and then with a relatively rapid transition out of the boot into a comfortable shoe.
- Range of motion is initiated to the MTP joint 10 to 14 days postoperatively.
- Our routine is to assess healing with weight-bearing radiographs at 3, 6, and 14 weeks postoperatively.

OUTCOMES
- Wukich et al11 reported on 14 patients using PMOW with modified McBride bunionectomy for moderate and severe deformities during 1 year of follow-up. They found no instances of malunion or nonunion, and experienced excellent and reliable correction with complete patient satisfaction.
- Cooper et al4 reported on 25 patients using the same technique during their first year of experience and noted excellent correction and healing and no adverse outcomes with complete patient satisfaction.
- The authors reported about 2 degrees correction of 1–2 IMA per mm of opening wedge using a flat cut at the base of the metatarsal.
- Sargas7 reported greater than 90% good and excellent results in a retrospective review of patients treated by proximal opening wedge osteotomy of the first metatarsal and distal procedure with a low incidence of complications and plate and screw removal.
- The opposite side plate was used with excellent correction and minimal or no need for removal.
- Shurnas9 reported cadaveric biomechanical results comparing proximal chevron osteotomy and PMOW, finding no difference in load to failure, ultimate strength, or stiffness.
- Shurnas9 also reported the initial experience on 50 patients: 25 with at least 1 year of follow-up and 25 with 6 months to 1 year of follow-up.
- The author reported about 3 degrees correction of 1–2 IMA per mm of opening wedge using an oblique osteotomy.
- The mean postoperative IMA and HVA were 3 degrees and 11 degrees, respectively, with a mean change in IMA and HVA of 12 degrees and 20 degrees, respectively.
- Mean time to radiographic and clinical healing was 5.8 weeks, with no instances of nonunion, malunion, or delayed union.
- All patients were satisfied with their outcome, and mean range of motion was not significantly different comparing preoperative and postoperative values.
- There was an insignificant increase in the mean first metatarsal protrusion distance of 1.9 mm but no instances of shortening, elevatus, or hardware failure.
- A prospective study of patients who have undergone PMOW and various distal procedures for subluxed, congruent, and juvenile deformities is ongoing.
- Shurnas9 reported on a retrospective review of more than 90 patients with moderate and severe hallux valgus treated by proximal opening wedge osteotomy and distal procedure with a minimum of 2 years follow-up.
- The authors reported better than 90% good and excellent results.
- Plate and screw removal was required in about 15%.
- There were two varus deformities that required arthrodesis.
- There was one nonunion in a patient with true metal allergy.

COMPLICATIONS
- Five screws broken during insertion that were stabilized with an additional screw outside the plate without requiring healing delay or regimen change.
- Five hardware removals for symptomatic hardware.
- The primary author had five varus overcorrections:
  - Four of less than 8 degrees; the patients are completely satisfied and asymptomatic.
  - One of 15 degree varus, which has been revised with follow-up pending.
- The primary author had two cases of recurrence:
  - One due to capsule repair laxity, but the patient is satisfied with a 15-degree HVA.
  - The other recurrence was due to technical error. The first MTC joint was penetrated, leading to instability that required a Lapidus procedure.

REFERENCES
DEFINITION
- Paul W. Lapidus originally described a procedure for the correction of hallux valgus in 1934.
- This procedure was founded on the premise that hallux valgus was a secondary phenomenon to metatarsus primus varus arising from first tarsometatarsal (TMT) hypermobility and a medially oriented first TMT joint.
- The original Lapidus procedure entailed excision of the lateral aspect of the medial cuneiform and first TMT arthrodesis coupled with a distal first metatarsophalangeal (MTP) capsulorrhaphy.
- Many modifications of the original Lapidus procedure have been made, primarily advocating rigid internal fixation as a means for maintenance of reduction, lower nonunion rates, and earlier healing and mobilization.

ANATOMY
- The goal of foot surgery is to obtain a plantigrade position with normal underlying mechanical alignment to allow for weight bearing, shock absorption, accommodation, and power for efficient painless gait.
- Weight should be evenly distributed across the six weight-bearing surfaces, consisting of the paired sesamoids underlying the first metatarsal head, the lesser metatarsals, and the calcaneus.
- The lateral column of the foot is designed for mobility to accommodate to uneven surfaces while the medial column, including the first TMT joint, is more rigid to allow efficient power for push-off.
- The first TMT joint is typically 30 mm deep.

PATHOGENESIS
- Equinus is often an underlying pathologic feature predisposing the midfoot to increased repetitive tension and subsequent longitudinal collapse and instability.
- In particular, patients develop first TMT hypermobility potentially in both the axial and sagittal planes.
- Axial instability presents as metatarsus primus varus and resultant hallux valgus.
- Sagittal instability presents as a dorsiflexed first metatarsal with predisposition to dorsolateral peritalar subluxation.
- Furthermore, many patients have a medially oriented first TMT joint and tendency toward metatarsus primus varus.

NATURAL HISTORY
- Symptomatic hallux valgus associated with metatarsus primus varus with underlying first TMT hypermobility and equinus presents with progressive deformity and pain.
- In the face of underlying pathologic first TMT hypermobility or equinus, the hallux valgus deformity will inevitably progress over time in both symptomatology and degree of deformity.
- Consequently, it is imperative to treat any underlying pathology concomitantly with treatment of the hallux valgus deformity.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Physical examination methods include:
  - First TMT hypermobility. The examiner rests the index and middle finger of one hand over the dorsal aspect of the first TMT joint to monitor motion. The thumb of that hand rests under the lesser metatarsals. The other hand grasps the first metatarsal between the thumb and fingers and moves it up and down and side to side. Minimal motion should be palpated at this joint. Excessive motion or translation is pathologic and indicative of first TMT hypermobility and instability. Occasionally intercuneiform instability is noted.
  - Equinus/Silfverskiöld test. The examiner corrects the hindfoot to neutral subtalar position and checks dorsiflexion range of motion both with the knee in straight extension and flexed 30 degrees. The forefoot appears wide and splayed with a narrow hindfoot. An inability to obtain neutral dorsiflexion with the knee in straight extension that corrects with flexion is indicative of isolated gastrocnemius equinus. An inability to obtain neutral dorsiflexion in both knee extension and flexion is indicative of soleus and gastrocnemius equinus.
  - First MTP range of motion. The examiner assesses flexion and extension of the first MTP and repeats the test with the first metatarsal held in a corrected position out of varus. Loss of significant range of motion in a corrected position is indicative of loss of congruency at the MTP joint. Consideration may be needed for additional distal metatarsal osteotomy.
  - Lesser metatarsalgia. With hypermobility of the first TMT joint, the first metatarsal is relatively elevated compared to the adjacent lesser metatarsals, resulting in pain and callosities. Callosities are seen beneath the lesser metatarsals, and the skin under the first metatarsal head is often soft from lack of weight bearing. Claw toes and extensor recruitment can result in distal migration of the plantar forefoot fat pad, exacerbating lesser metatarsalgia.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain weight-bearing radiographs including AP, lateral, and oblique views of the foot should be obtained. Every effort should be made to obtain a true lateral radiograph with talar dome overlap.
- Features of first TMT hypermobility
  - Signs of second and third metatarsal overload (hypertrophied cortical thickening, stress fracture)
  - Dorsal translation or dorsiflexion of first metatarsal
  - Plantar widening at the first TMT joint
First, second, third TMT arthrosis
First MTP dorsal osteophytes
Occasionally plain radiographs of the ankle are needed to rule out adjacent involvement.
Axial sesamoid view can be helpful to assess the extent of metatarsosesamoid arthrosis and degree of sesamoid subluxation.
Full-length hip-to-ankle radiographs are obtained if there is suspicion of an underlying lower extremity malalignment.
Seldom is a CT scan, MRI, or other imaging modality needed.

DIFFERENTIAL DIAGNOSIS
- Hallux rigidus
- Metatarsosesamoid arthrosis
- Lesser metatarsalgia
- Interdigital neuroma
- Gout or other inflammatory arthropathy

NONOPERATIVE MANAGEMENT
- Many patients with hallux valgus and hypermobility of the first TMT joint are asymptomatic.
- However, once symptoms develop, progression is inevitable, in particular in patients with underlying equinus contractures.
- Initially management can be directed at resolving local symptoms, including nonsteroidal anti-inflammatories, activity modification, rest, weight loss, shoe modifications, and orthotics.
- In patients with equinus, a well-directed physiotherapy stretching protocol can be helpful.

SURGICAL MANAGEMENT
- Indications
  - Hallux valgus with associated metatarsus primus varus and first TMT hypermobility
  - Hallux valgus with first TMT arthrosis
  - Revision of failed hallux valgus surgery
  - Contraindication
  - Open physeal growth plates

Preoperative Planning
- AP foot plain radiographs are reviewed for:
  - Hallux valgus angle (normal less than 15 degrees)
  - Intermetatarsal angle (normal less than 9 degrees)
  - Angle of first TMT joint
  - Proximal phalangeal articular angle (normal less than 10 degrees)
  - Degree of sesamoid subluxation
  - Relative lengths of metatarsal heads
- Lateral foot plain radiographs are reviewed for:
  - Talar first metatarsal angle
- Based on the above, the surgeon formulates an operative plan, including:
  - Degree of correction
  - Need to excise lateral wedge from medial cuneiform
  - Need for concomitant second or third metatarsal shortening
- Intraoperatively the surgeon assesses for equinus and the need for percutaneous Achilles tendon lengthening or gastrocnemius slide.

Positioning
- The patient is placed supine on a radiolucent table with a padded wedge or bump under the ipsilateral hip to correct external rotation.
- The arm is placed across the chest and the ulnar nerve is padded.
- A tourniquet is applied to the thigh proximal enough to allow access to the proximal tibia for possible bone graft.
- Once the limb is prepared and draped, a towel bump is placed beneath the knee to allow access to the dorsum of the foot.

CORRECTION OF METATARSUS PRIMUS VARUS AND PREPARATION OF FIRST TARSOMETATARSAL JOINT
- Make an incision about 8 cm long between the extensor hallucis longus and brevis, roughly in line with the lateral aspect of the first metatarsal and medial cuneiform (TECH FIG 1A, B).
- Protect the deep peroneal nerve, dorsalis pedis artery, and dorsal cutaneous nerves.
- Identify the first TMT joint by moving the first metatarsal, and reflect the capsule sharply off bone using the Henry angle of dissection.
- Using a quarter-inch osteotome, remove the dorsal osteophytes over the first TMT joint and save them for bone graft.
- At this point, the joint is prepared in one of two ways:
  - If there is a need to correct a medially angled first TMT joint, use an oscillating saw. First insert an elevator to determine the slope of the joint. Resect a lateral wedge of bone from the medial cuneiform.
  - Remove the piece and check it to ensure that adequate plantar bone was removed. Resect a minimal amount of bone from the first metatarsal base, again ensuring that enough plantar bone is removed. Avoid excessive metatarsal shortening.
- If there is no medially angled first TMT joint or if there is an excessively short first metatarsal, then prepare the joint using a series of curved osteotomes and curettes. This will give two congruent opposing surfaces for arthrodesis.
- Use an oblong curette to ensure there is no residual plantar lip resulting in excessive dorsiflexion. The first TMT joint is 28 to 30 mm deep.
- Drill each side of the joint with a 2.0-mm drill (TECH FIG 1C).
- This should leave a lateral gap in the first TMT joint.
DISTAL SOFT TISSUE PROCEDURE

- Extend the dorsal incision down to the first web space, taking care to avoid the digital nerves.
- Deep to the attenuated intermetatarsal ligament is the fibular sesamoid and adductor hallucis tendon; leave it intact.
- Protect the fibular sesamoid, identify the first MTP capsule, and incise it longitudinally (TECH FIG 2).
- Make a separate medial incision over the first MTP joint, again watching for the crossing dorsal cutaneous nerves.
- Develop a flap superficial to the first MTP capsule, taking care to avoid thinning the capsule itself.
- Sharply incise the capsule full thickness longitudinally and reflect it plantar and dorsal.
- Tease back the capsular reflections to the first metatarsal head proximally to release the scarred synchiae and allow the sesamoid to move independently.
- Grasp the plantar capsule with a Kocher. With gentle pressure, the metatarsal head should be easily reducible over the sesamoids while simultaneously correcting the intermetatarsal angle and closing the gap at the first TMT joint.
- Resect a minimal amount of medial eminence with a rongeur to allow shaping of the medial metatarsal head into a rounded surface.

STABILIZATION

- Before stabilization, hold the foot in a reduced position and palpate the forefoot to ensure it is plantigrade.
- Temporary Kirschner wires may be helpful if assistance is unavailable.
- Burr a bone trough in the mid-dorsal aspect of the first metatarsal about 2 cm away from the joint and tapering out distally.
- Place a 4.0-mm screw after drilling in a lag screw fashion with a 4.0-mm and then a 2.9-mm drill (TECH FIG 3).
- Place a second 4.0-mm lag screw from the dorsal medial cuneiform to the plantar aspect of the first metatarsal base.
- Stabilize this construct by placing a last 4.0-mm screw from the first metatarsal into the base of the second metatarsal.
- Drill this last screw in a lag manner but avoid excessive tightening to prevent overcorrection of the intermetatarsal angle.
BONE GRAFTING

- Use a 5.0-mm burr to create two small troughs on the dorsomedial and dorsolateral aspects of the first TMT joint to serve as sites for shear-strain-relieving bone graft (TECH FIG 4A, B).
- Also place bone graft in any gaps at the arthrodesis site.
- Bone graft is obtained from the local procedure or proximal tibial bone graft.

INTRAOPERATIVE RADIOGRAPHS

- Obtain AP, lateral, and oblique films to ensure appropriate positioning and correction, which is often not seen in detail under C-arm fluoroscopy (TECH FIG 5A, B).
POSTOPERATIVE CARE
- A well-molded below-knee plaster cast is applied with a single anterior univalve to accommodate postoperative swelling.
- The cast is overwrapped with fiberglass before discharge.
- Analgesia is best managed with a popliteal peripheral nerve catheter.
- Six weeks of heel weight bearing in static stance phase only is prescribed.
- The patient is mobilized on a knee scooter.
- Progressive weight bearing is allowed between 6 to 12 weeks in a removable boot.
- The patient is weaned out of the removable boot into standard shoes at 12 weeks.

OUTCOMES
- With appropriate surgical indications, surgical technique, and patient compliance, the patient satisfaction rate is greater than 90%.
- Recurrence of hallux valgus is rare.

COMPLICATIONS
- See the Pitfalls section.

REFERENCES
DEFINITION
- Recurrent hallux valgus is a partial or complete return of valgus deformity at the first metatarsophalangeal (MTP) joint after surgical correction.
- Metatarsus primus varus is an increase in the first–second intermetatarsal angle due to obliquity or hypermobility of the first tarsometatarsal joint.

ANATOMY
- The first tarsometatarsal joint is 27 to 30 mm deep and irregularly shaped (FIG 1).
- The dorsalis pedis artery and deep peroneal nerve are just lateral to the extensor hallucis longus tendon (FIG 2).
- The two heads of the adductor hallucis muscle converge to a single tendon and insert on the lateral sesamoid at the first MTP joint.
- The sesamoids are contained in the capsuloligamentous complex of the MTP joint.
- The dorsal medial cutaneous branch of the superficial peroneal nerve runs along the dorsal medial aspect of the first MTP joint.
- The plantar medial cutaneous branches of the medial plantar nerve run along the plantar aspect of the first MTP joint near the articulations of the sesamoids.

PATHOGENESIS
- Recurrence of hallux valgus is most often due to an improperly chosen initial procedure or improper surgical technique.
- Less frequently, factors such as poor bone or tissue quality, infection, patient noncompliance, and instrumentation failure can lead to recurrent hallux valgus.
- A major cause of recurrent hallux valgus is unrecognized metatarsus primus varus.
- If uncorrected, metatarsus primus varus creates a valgus moment at the first MTP joint.
- An intact adductor hallucis or a tight lateral joint capsule will exacerbate the valgus moment.

NATURAL HISTORY
- Some partial recurrences of hallux valgus may be tolerable with nonoperative treatment.
- If there is an uncorrected metatarsus primus varus, the deformity will most likely progress over time.
- The medial prominence can result in pain, tenderness, and an overlying bursitis.
- Progressive deformity often leads to second toe overload and, ultimately, to arthritis at both the first and second tarsometatarsal joints.
- Lesser metatarsal overload, whether due to shortening of the first metatarsal or subluxation of the sesamoids, is a common reason for secondary surgery.
- Arthritis can develop at the sesamoid–first metatarsal articulations.
- Prolonged hallux valgus, especially with an incongruent joint, can lead to degenerative changes at the first MTP joint.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients report valgus deformity at the first MTP joint that either is recurrent or was never fully corrected (FIG 3).
- The examiner should evaluate for symptoms associated with metatarsus primus varus:
  - Hypermobility of the first tarsometatarsal joint
  - Mobility of the first tarsometatarsal joint is tested by holding the lesser metatarsal heads stable with one hand while passively dorsiflexing the first metatarsal head.
Hypermobility has been defined as elevation of the first metatarsal head more than 5 to 8 mm above the level of the second metatarsal head (FIG 4).

Hypermobility at the tarsometatarsal joint creates a valgus moment at the MTP joint, which may contribute to failure of distal hallux valgus correction.

Degenerative changes at the first tarsometatarsal joint
- Tenderness at the joint line
- Osteophytes at the dorsal aspect of the joint

Second metatarsal overload
- Patients may report feeling as if there is a rock in their shoe.
- Tenderness under the second MTP joint
- Callosity or ulceration under the second MTP joint
- Claw toe deformity (FIG 5)
- Passive correction of the metatarsus primus varus may reduce the hallux valgus deformity.
- The examiner should check for lesser toe overload.
  - The medial lesser toes should be inspected for claw toe or hammer toe deformity, overlap, large plantar callus, or plantar ulcers. The plantar surface of the MTP joints is palpated for tenderness. The proximal phalanx is translated to evaluate for instability of the MTP joint.
- Lesser toe overload is often associated with hypermobility of the first tarsometatarsal joint or a dorsiflexion deformity of the first ray.
- Range of motion of the first MTP joint with the hallux valgus deformity corrected is an indication of expected motion after surgical correction. Severely limited motion may be an indication for a fusion of the MTP joint.
- In general, the more severe the deformity, the greater the pronation of first MTP joint on weight bearing.
- Patients are evaluated for other potential causes of the recurrent deformity:
  - Infection
  - Failure of fixation
  - Generalized ligamentous laxity
  - Osteoporosis
IMAGING AND OTHER DIAGNOSTIC STUDIES
- AP, lateral, and oblique weight-bearing radiographs of the foot should be obtained and evaluated for the following:
  - Surgical changes from the initial surgery, including any retained instrumentation
  - Congruency of first MTP joint
  - Plantarflexion of the first ray
  - Hallux valgus angle
    - Angle between long axes of first metatarsal and proximal phalanx
    - Normal is less than 15 degrees
  - First–second intermetatarsal angle
  - Angle between long axes of first and second metatarsals
    - Normal angle is less than 9 degrees.
  - Distal metatarsal articular angle
    - Angle between long axis of metatarsal shaft and base of distal metatarsal joint surface
    - Normal is less than 15 degrees.
  - Radiologic signs of metatarsus primus varus
  - Increased first–second intermetatarsal angle
  - Plantar gap at first tarsometatarsal joint on weight-bearing lateral image (FIG 6).
  - Claw toe deformity

DIFFERENTIAL DIAGNOSIS
- Loss of fixation
- Generalized tissue laxity
- Infection

NONOPERATIVE MANAGEMENT
- Shoe wear modification
  - Wide toe box
  - Low heels
- Orthotics
  - Medial arch support for associated pes planus
  - Metatarsal pad for associated second toe overload
  - Activity modification

SURGICAL MANAGEMENT
- It is important to determine what the previous procedure entailed.
- Seldom can a failed distal or shaft procedure be revised with another such procedure.
- Most salvage procedures rely on stabilizing the base of the first metatarsal. It is also possible to get more angular correction at the base of the metatarsal.

Preoperative Planning
- Retained instrumentation may need to be removed.
- The age and position of previous incisions must be taken into account.
- The surgeon must take into account the need for shortening of the lesser metatarsals, correction of claw toes, and the addition of an Akin phalangeal osteotomy to correct concurrent deformities.

Positioning
- The patient is positioned supine.
- A tourniquet is placed on the proximal thigh.
- The foot should be positioned to allow access for intraoperative imaging.

Approach
- The approach depends on the procedure to be performed.

EXAMPLE CASE

Background
- Thirty-three year old woman post distal bunion correction (details unknown).
  - Persistent symptomatic hallux valgus deformity (TECH FIG 1A)
  - Has failed nonoperative management of this problem
  - Motion well preserved in first MTP joint
  - Overload phenomenon second metatarsal head but no deformity in second toe
- Radiographs (TECH FIG 1B,C)
  - Prior distal procedure to first metatarsal head
  - Increased 1–2 intermetatarsal angle
  - Increased hallux valgus angle
  - Questionable increase in the distal metatarsal articular angle
- Relatively short first metatarsal compared to second metatarsal
- No obvious second toe deformity

Distal Soft Tissue Procedure
- Dorsomedial approach, because that is what was used previously, but extended more proximally to perform the proximal osteotomy.
- Lateral release also performed through a separate first webspace incision
  - This puts the blood supply to the metatarsal head at risk if a simultaneous distal osteotomy is performed
  - Medial and lateral soft tissues released
  - Complete disruption of the intraosseous blood supply to the head
Therefore, lateral release must be performed judiciously:
- Distal to the lateral capsule that contains vessels to the metatarsal head
- With the exposure, the actual (not radiographic) distal metatarsal articular angle (DMAA) can be evaluated (TECH FIG 2)

**Proximal Osteotomy**

- In this case, a proximal medial opening wedge osteotomy was performed
- It may not lengthen the first metatarsal but the risk of shortening is diminished
- All traditional osteotomies, when they heal, shorten slightly, however, an opening wedged osteotomy may not have that tendency.
- The goal was to preserve length given that the patient was experiencing a second metatarsal head overload.

Given the osteotomy is performed from the medial side and the lateral cortex is left intact, it also has less of a tendency to develop a dorsiflexion malunion.

- Fluoroscopy is used to determine the trajectory of the osteotomy and the depth of the saw cut (TECH FIG 3A)
- We make the osteotomy in the oblique plane to increase the surface area and target the more proximal aspect of the lateral metatarsal base where the cortex is wider and the soft tissue support is greater (TECH FIG 3B)
- The saw cut approaches the lateral cortex without violating it
- The osteotomy is gently opened with a three osteotome technique (TECH FIG 3C-E)
- The medial plate with spacer is placed and secured with screws. (TECH FIG 3F)
- One of the proximal screws may be placed across the osteotomy to lend further support to the construct (TECH FIG 3G)
- We typically bone graft the osteotomy with bone graft harvested from the lateral calcaneus

**Distal Biplanar Chevron Osteotomy**

- The proximal osteotomy increases the already greater-than-physiologic DMAA.
- Furthermore, greater correction is warranted in this revision case with considerable hallux valgus deformity
- We check a pin under fluoroscopic guidance to determine the orientation of the osteotomy. (see Tech Fig 3G)
- A distal biplanar chevron osteotomy (Reverdin-Green osteotomy) affords greater correction, satisfactory stability, and a simple means of correcting the increased DMAA (TECH FIG 4A).
**Akin Osteotomy**

- We typically employ an oblique Akin osteotomy (TECH FIG 5A–H)
- Abundant surface area for healing
- Screw can be placed from proximal to distal perpendicular to the osteotomy
- Some rotation is still possible to correct the pronation deformity
TECH FIG 5 • Akin osteotomy (medially based wedge resection of proximal phalanx. 
Closure

- The capsule is reapproximated (TECH FIG 6A)
- The correction of the axial deformity is achieved with the bony realignment, not the capsular closure (TECH FIG 6B)
- However, we attempt to correct pronation by suturing the distal plantar capsule to proximal dorsal capsule.
- Motion should be maintained after the capsule is closed (TECH FIG 6C,D).
- Final fluoroscopic images to confirm alignment is appropriate (see Tech Fig 6B)
- We strive for a slight overcorrection since the tendency is for recurrence, particularly in a revision procedure (TECH FIG 6E; see Tech Fig 6B).
- Postoperative management is the same as for other bunion procedures (TECH FIG 7A-D).
LAPIDUS PROCEDURE (FIRST TARSOMETATARSAL FUSION)

First Tarsometatarsal Joint Preparation
- Make a 6-cm incision over the dorsum of the first tarsometatarsal joint.
- Identify the interval between the extensor hallucis longus and the extensor hallucis brevis.
- Incise the capsule over the first and second tarsometatarsal joints and expose the joints. Release the capsule all around the medial and lateral borders of the joint to allow adequate exposure (TECH FIG 8A,B).
- Remove the cartilage from the first tarsometatarsal joint using small osteotomes and small curettes.
  - If the first metatarsal is shortened, only cartilage should be removed.
  - If the first metatarsal is long, a small laterally based wedge can be removed from the medial cuneiform.
- A small plantarly based osteotomy can be performed to plantarflex the first metatarsal if necessary.
- Use a 2.0-mm drill to perforate the subchondral surfaces of the joint.
- Expose and decorticate the medial aspect of the base of the second metatarsal and the lateral aspect of the base of the first metatarsal (TECH FIG 8C).

Lateral Soft Tissue Release
- Make a 2-cm incision in the first web space.
- Use blunt dissection to identify the adductor hallucis tendon.
  - Identify and protect the terminal branch of the deep peroneal nerve.
- Incise the adductor hallucis tendon at the lateral aspect of the fibular sesamoid.
- Incise the lateral capsule longitudinally to allow reduction of the sesamoids.

Medial Exostectomy
- Make a direct medial incision over the first MTP joint.
- Incise the capsule in line with the incision.
  - A wedge of capsule can be removed to facilitate reduction of the sesamoids.
- Remove any residual prominence. Most of this was probably done with the primary procedure.

Fixation of the First Tarsometatarsal Joint
- Reduce the first metatarsal parallel to the second.
  - Confirm that the first metatarsal is parallel and properly rotated.
- Place a 3.5-mm cortical screw across the first tarsometatarsal joint from proximal to distal using a compression technique.
- Place a second 3.5-mm cortical screw from the medial aspect of the base of the first metatarsal into the base of the second metatarsal.
- Bone graft obtained from removal of the medial prominence can be placed in the first-second intermetatarsal space to augment the fusion.
- Use intraoperative imaging to confirm the position of the screws and reduction of the deformity (TECH FIG 9).

Capsular Repair and Wound Closure
- Repair the medial capsulectomy with absorbable suture.
  - It should not be necessary to overtighten the capsule to maintain the alignment of the MTP joint.
- Close the wounds in layers.

**TECH FIG 8 • A,B.** With the initial exposure, only the dorsal 10 to 15 mm of the tarsometatarsal joint is visualized. A small lamina spreader or distractor is required to expose the plantar half of the joint. This is a requirement of the procedure to avoid fusing the joint in dorsiflexion. With the distractor in place, the medial aspect of the base of the second metatarsal can be debrided of soft tissue to prepare for intermetatarsal fusion. **C.** Decortication of the lateral aspect of the base of the first metatarsal and the medial aspect of the second metatarsal to allow fusion.
Chapter 15  REVISION HALLUX VALGUS CORRECTION

Section: LUDLOFF METATARSAL OSTEOTOMY

- This procedure could be used instead of a Lapidus procedure (TECH FIG 10).

Indications

- Smokers or patients with other medical issues that would delay a tarsometatarsal fusion
- Patients unable to be non-weight-bearing for an extended period (e.g., obesity, rheumatoid arthritis, contralateral joint problems, shoulder problems)
- Patients with less severe deformities: correction achieved will be 8 to 16 degrees

Technique

- Make an incision over the medial aspect of the first metatarsal.
- The optimal osteotomy starts on the dorsum, 1 cm from the tarsometatarsal joint, and extends distal and plantar to a point just proximal to the sesamoid articulation.
- The osteotomy should be angled 10 degrees plantarly in the coronal plane.
- The axis of rotation should be within 5 mm from the proximal end of the osteotomy.
- Insert the proximal screw first. It is usually done from dorsal to plantar. This serves as the axis of rotation of the distal (capital fragment).
- Once the desired reduction is obtained, a second screw is inserted (TECH FIG 11).

TECH FIG 9 • Screw placement for a salvage of a failed distal procedure. A. The first metatarsal length was well preserved with the initial procedure. B. The first metatarsal length was such that a second metatarsal shortening was indicated to limit second metatarsal overload.

TECH FIG 10 • Ludloff osteotomy: long oblique from dorsal-proximal to plantar-distal.

TECH FIG 11 • Ludloff osteotomy. The proximal screw is placed first, from dorsal to plantar. The distal (capital) portion of the metatarsal is now rotated laterally to correct the intermetatarsal angle. This is followed by the second screw, usually from plantar to dorsal. (continued)
DORSAL OPENING-WEDGE OSTEOTOMY

Indications

- Dorsal malunion of a proximal metatarsal osteotomy
- Dorsal malunion or nonunion of a Lapidus procedure (TECH FIG 12A)

Technique

- Make a 6-cm incision over the dorsum of the first metatarsal base.
- Identify the interval between the extensor hallucis longus and the extensor hallucis brevis.
- Perform an osteotomy 1.5 cm distal to the first tarsometatarsal joint, leaving the plantar cortex intact.
- For a failed Lapidus procedure, the osteotomy is done through the previous fusion site.
- Place a triangular, tricortical bone graft with the wide surface placed dorsally to plantarflex the first metatarsal.
- Either an allograft or an iliac crest autograft can be used.
- A small distractor is helpful in distracting and keeping the osteotomy open.
- Fix the osteotomy with a small fragment screw from distal to proximal across the bone graft or with a dorsal plate that spans the bone graft (TECH FIG 12B).

TECH FIG 11 • (continued)

TECH FIG 12 • A. Dorsiflexion malunion of a proximal metatarsal osteotomy. B. Dorsal open-wedge osteotomy and bone grafting of a malunion of a Lapidus procedure.
Wound Closure and Postoperative Care
- Close the wound in layers.
- Apply a well-padded short-leg cast in the operating room.
- The patient may be partial weight bearing on the heel only for 6 to 8 weeks.

PEARLS AND PITFALLS

Lapidus procedure: Indications
- Depending on the pathology, there are simpler treatment options for primary bunion surgery.
- A modified Lapidus procedure is not indicated in the absence of metatarsus primus varus or first ray hypermobility.
- The modified Lapidus procedure does not correct an increased distal metatarsal articular angle. If there is a significant increase in the distal metatarsal articular angle, a distal medial closing-wedge osteotomy or an Akin procedure is also required.
- If there is a dorsiflexion malunion from a previous proximal osteotomy, a corrective osteotomy may be necessary instead of a Lapidus procedure.

First tarsometatarsal joint preparation
- Take care not to inadvertently shorten the first metatarsal. Use a saw very sparingly, if ever.
- The first tarsometatarsal joint is about 25 to 30 mm deep, and take care to expose and prepare the entire joint surface to avoid fusing the joint in dorsiflexion.
- A small Inge retractor or a smooth lamina spreader is invaluable in exposing the joint.

Lateral soft tissue release
- The terminal branch of the deep peroneal nerve is vulnerable to injury in the first web space.
- Excessive lateral release can lead to a hallux varus deformity.

Medial exostectomy
- Only a minimal medial exostectomy may be needed.
- Avoid dorsiflexion and pronation of the first metatarsal.
- Failure to appropriately expose and denude the plantar aspect of the joint can lead to a dorsiflexion malunion.
- To ensure appropriate position, it is helpful to hold the metatarsals in one hand while the screws are placed.
- Careful preparation of the first-second intermetatarsal joint is mandatory to minimize the incidence of nonunion.

Shortening of the first metatarsal
- It is not uncommon to find the first metatarsal shortened with the initial bunion procedure.
- If that is the case, and if there are signs of significant second metatarsal overload, a second and sometimes third metatarsal shortening osteotomy should be done.

POSTOPERATIVE CARE
- The wounds are dressed.
- A slipper great toe spica fiberglass cast is placed in the operating room.
- At 2 weeks, the cast is removed to allow wound check and suture removal.
- A new slipper cast or a postoperative bunion shoe is applied for an additional 4 weeks.
- At 2 weeks the cast is removed to allow suture removal and a wound check.
- A new short-leg cast or a cast boot is applied for another 4 to 6 weeks until bony healing is seen on radiographs.
- Avascular necrosis of the metatarsal head
- Severe recurrence of a hallux valgus in a rheumatoid patient

GREAT TOE FUSION

Indications
- Severe degenerative changes of the first MTP joint secondary to previous bunion surgery
- Avascular necrosis of the metatarsal head
- Severe recurrence of a hallux valgus in a rheumatoid patient

TECHNIQUES
OUTCOMES
- In appropriately chosen patients, the Lapidus procedure is a reliable option for recurrent hallux valgus.
- A prospective cohort study reported an 80% satisfaction rate after the Lapidus procedure for recurrent hallux valgus in carefully selected patients.
- The same prospective cohort study suggested an increased risk of nonunion in smokers.²

COMPLICATIONS
- Nonunion of the first tarsometatarsal fusion is the most common complication (6% to 10%).
- Transfer metatarsalgia due to dorsiflexion malunion of the first metatarsal or lesser metatarsal length discrepancy
- Failure to reduce the sesamoids due to rotational malunion of the first metatarsal or inadequate lateral release
- Hallux varus due to excessive lateral release
- Painful instrumentation
- Nerve injury
- Infection

REFERENCES
DEFINITION
- Shortening of the first metatarsal may occur after first metatarsal osteotomies for hallux valgus correction.
- If the first metatarsal is considerably shortened, the patient may develop painful transfer metatarsalgia of the lesser toes.

ANATOMY
- The physiologically normal first metatarsal is generally of similar length to or slightly shorter than the neighboring second metatarsal.
- This length relationship between the first metatarsal and the lesser metatarsals allows for a smooth, progressive weight transfer and optimizes the windlass mechanism during gait.
- The relative plantar position of the first metatarsal head (and sesamoids) also makes the windlass mechanism more effective in transferring weight to the lesser toes and may compensate for a physiologically shorter first metatarsal.

PATHOGENESIS
- Some metatarsal shortening occurs with the majority of all first metatarsal osteotomies performed during hallux valgus correction.
- An iatrogenically shortened first metatarsal can disrupt the normal forefoot weight transfer mechanism and cause a pathologic overload of the adjacent metatarsals.
- Relative dorsiflexion of the metatarsal head can also occur after hallux valgus correction with metatarsal osteotomy, exacerbating the mechanical disadvantage of the shortened metatarsal and further contributing to transfer metatarsalgia.

NATURAL HISTORY
- Transfer metatarsalgia generally does not resolve spontaneously, particularly if coupled with a concomitant forefoot fat-pad atrophy.
- Mild transfer metatarsalgia is generally well tolerated as the patient is able to modify gait, stance, and activity to compensate.
- However, the problem may progress, with painful callus formation developing under the lesser metatarsals. Severe, recalcitrant transfer metatarsalgia may cause debilitating forefoot pain that often persists until normal forefoot biomechanics are restored or reasonable footwear accommodation is used.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The great toe usually but not always appears shorter than the adjacent metatarsal, especially when compared to the contralateral foot (FIG 1).
- The plantar surface of the forefoot usually but not always has calluses under the lesser metatarsal heads.
- The lesser metatarsal heads are tender.
- When examined simultaneously, the first metatarsal head (and sesamoids) may appear elevated and more proximal relative to the second metatarsal head, particularly when compared to the contralateral foot.
- The medial forefoot incisions from prior forefoot surgery must be noted in anticipation of potential revision surgery.
- Hallux metatarsophalangeal (MTP) joint alignment must be examined. A recurrence of hallux valgus deformity after prior surgery will need to be corrected in conjunction with metatarsal lengthening.
- Hallux MTP joint motion must be determined. Stiffness and crepitance may suggest arthrosis that may favor first MTP joint arthrodesis over first metatarsal lengthening (FIG 2).
IMAGING AND OTHER DIAGNOSTIC STUDIES
- Weight-bearing plain radiographs are mandatory; we recommend bilateral radiographs to include the contralateral foot for comparison.
- AP radiographs of the symptomatic foot indicate the amount of first metatarsal shortening, the presence of residual deformity (particularly the first metatarsal head–sesamoid relationship), the nature of the prior hallux valgus surgery, and the integrity of the first MTP joint (FIG 3A).
- Lateral radiographs suggest the degree of concomitant elevation of the first metatarsal.
- Contralateral foot radiographs provide some indication of the required lengthening, which is useful in surgical planning (FIG 3B).

DIFFERENTIAL DIAGNOSIS
- Recurrence of hallux valgus
- First metatarsal head avascular necrosis
- Dorsiflexed malunion of first metatarsal

NONOPERATIVE MANAGEMENT
- Oral anti-inflammatory medication
- Shoe wear modification (ie, greater stiffness in combination with a rocker sole to unload the forefoot)
- Orthotics with medial posting for the first metatarsal and metatarsal support for the lesser metatarsals

SURGICAL MANAGEMENT
- Surgical management is indicated when nonoperative treatments have failed and other causes are not responsible for the forefoot pain and transfer metatarsalgia.
- Two broad categories may be considered in the surgical management of transfer metatarsalgia secondary to a short first metatarsal: (a) shortening of the lesser metatarsals and (b) lengthening of the first metatarsal. With severe first metatarsal shortening, a combination of these two approaches may need to be considered. First metatarsal lengthening affords the advantage of correcting the problem at its source in lieu of performing surgery on lesser metatarsals that are physiologically normal but subject to an overload phenomenon.

Preoperative Planning
- Weight-bearing plain radiographs are essential to plan the desired lengthening and potential realignment of the metatarsal and MTP joint, determine the need for hardware removal from previous surgery, and identify potential arthritis in the MTP joint (Fig 3). The contralateral first metatarsal, if not previously operated, serves as an ideal template to determine how a more physiologic first metatarsal anatomy may be restored. To account for magnification, relative lengths of the first and second metatarsals may be used as a reference.
- Once the patient is deemed appropriate for metatarsal lengthening, the appropriate position for the external fixator half-pins and corticotomy should be planned radiographically.

Positioning
- The patient should be placed in the supine position on the operating table.
- A bump should not be placed under the ipsilateral hip to allow external rotation of the leg and better access to the medial side of the foot.

Approach
- A four-pin single-plane external fixator will be placed along the medial border of the first metatarsal and a short, longitudinal dorsal approach to the metatarsal is needed to perform the metatarsal osteotomy (FIGS 4, 5). The incision may need to incorporate or be within previous surgical scars to minimize the risk of soft tissue complications.
- The four drill holes for the external fixator pins are created percutaneously, under fluoroscopic guidance, using a 1.5-mm Kirschner wire or the small-diameter drill corresponding to the particular external fixator set.
- After percutaneous placement of the four external fixator pins, a longitudinal dorsal approach to the metatarsal is used to perform the metatarsal corticotomy.
- Occasionally, a distal soft tissue procedure is necessary and surgical incisions must be planned carefully. In our experience, this procedure is most effective for a shortened first metatarsal and satisfactory alignment of the first MTP joint.
Chapter 16 METATARSAL LENGTHENING IN REVISION HALLUX VALGUS SURGERY

PLACEMENT OF THE EXTERNAL FIXATOR PINS

- Using a surgical marker, plan the incision for the corticotomy by drawing a 2-cm line along the middle third of the dorsal border of the first metatarsal (Fig 4).
- Using the closed external fixator as a drill guide, create four drill holes (two proximal and two distal) percutaneously along the medial side of the metatarsal using a 1.5-mm Kirschner wire. The external fixator must not be fully distracted when using it as a drill guide; however, it should be slightly distracted in order to apply initial compression after performing the corticotomy.
- With respect to sequence of drill holes, we recommend creating the most distal drill hole first and the most proximal one second, after which these half-pins are secured and the external fixator is attached. This sequence ensures that a monorail external fixator is parallel to the first metatarsal. Alternatively, a hinged external fixator may be employed that can be adjusted to accommodate the pins while still creating longitudinal distraction (TECH FIGS 1–4). Place all four pins into the drill holes in a similar percutaneous fashion, and check their position using fluoroscopy (TECH FIG 5).
- Some external fixator half-pins are tapered (eg, 2.5-mm tapered threads with 3.0-mm shafts) and thus should not be advanced beyond the lateral cortex of the first metatarsal and then reversed, as they will then lose their stability.

TECH FIG 1 • Determining proper location for external fixator, using a needle as a reference. A. Clinical view. B. Fluoroscopic view.

TECH FIG 2 • First pin placed in distal first metatarsal. A. Clinical view. B. AP fluoroscopic view. C. Lateral fluoroscopic view.
TECH FIG 3 • Determining optimal proximal pin position. A. Clinical view. B. Fluoroscopic view.

TECH FIG 4 • Placing second pin in proximal first metatarsal. A. Clinical view. B. AP fluoroscopic view. C. Lateral fluoroscopic view.

TECH FIG 5 • Final two pins placed. A. Second most proximal pin being placed. B. External fixator tightened. C. Fluoroscopic view of all four pins secured. (Note that external fixator was removed; no further adjustments are made, so that the external fixator may be repositioned on the pins so that the metatarsal maintains its anatomic alignment.)
CREATING THE CORTICOTOMY

- Make a 2-cm incision along the dorsal border of the metatarsal between the central two fixator pins (Fig 5).
- Dissect sharply to bone and incise the periosteum transversely at the site of the planned corticotomy. Avoid unnecessary periosteal stripping; the periosteum only needs to be elevated directly at the corticotomy site.
- Make a transverse osteotomy using a mini-sagittal saw while simultaneously cooling the blade with iced saline irrigation (TECH FIG 6).

![TECH FIG 6 • A. Corticotomy being performed (irrigation is being performed to diminish the risk of bone necrosis from the saw). B. Before making the corticotomy, the ideal location is confirmed fluoroscopically (the external fixator has been removed to allow for better access during corticotomy).](image)

APPLYING THE EXTERNAL FIXATOR

- After creating the corticotomy, confirm adequacy and distractibility of the distal and proximal first metatarsal segments with careful distraction through the external fixator and fluoroscopic confirmation (TECH FIG 7).
- Compress the corticotomy using the external fixator; little compression is required—essentially the width of the saw blade. Using fluoroscopic imaging, verify adequate bone-on-bone contact of the two first metatarsal segments and secure the fixator set screws (TECH FIGS 8, 9). Occasionally, there is slight subluxation of the two first metatarsal segments, and this should be adjusted so that the bony apposition is anatomic.

![TECH FIG 7 • The external fixator is replaced with the metatarsal in its preoperative position and the corticotomy is distracted to confirm that it is complete.](image)
PEARLS AND PITFALLS

| Placement of the external fixator pins | Use the external fixator as a drill guide.  
Be sure to place the distal two pins in the plantar half of the distal fragment. This helps impart relative plantarflexion of the distal fragment and metatarsal head, thus limiting the potential for first metatarsal elevation. |
| Creating the corticotomy | Cool the saw blade to limit thermal necrosis of the bone edges. |
| Applying the external fixator | The wound may be reapproximated before placing the fixator, but be sure to verify good bony contact clinically and using fluoroscopic imaging. |
| Sequence of external fixator pins | Placing the distal- and proximal-most pins first ensures that the external fixator is parallel to the first metatarsal and that no pin will violate the MTP or tarsometatarsal joints. |
| Stiffness of the first MTP joint | In our experience, with gradual distraction, preoperative motion of the first MTP joint is not compromised. |
| Formation of bone (“regenerate”) | Bone or callus does not form immediately with distraction at the corticotomy site; it may lag several weeks behind. |
| Failure of the regenerate to form | Occasionally, the regenerate will not form despite appropriate distraction technique. Once the full desired distraction has been achieved, alternating quarter-turn distraction and compression may stimulate formation of the regenerate. Use of an external bone stimulator may be considered. As a last resort, the intercalary segment may be bone grafted and internal fixation may be substituted for the external fixator, albeit only with a history of clean and healthy pin sites (the risk of infection with internal fixation is increased after previous external fixation in close proximity). |
| Duration of the external fixator | Generally, the regenerate becomes adequately stable for external fixator removal by 8 to 10 weeks, but occasionally 12 to 14 weeks is required. We routinely remove the external fixator in the office setting. |

WOUND CLOSURE

- We approximate the periosteum with 4–0 absorbable polyglactin suture and close the skin with 4-0 nylon suture.
- Apply a soft dressing. The patient can be discharged to home non–weight-bearing the same day of the procedure.

TECH FIG 8 • Additional “dummy” pins are added to the external fixator to afford greater fixator stability. A. Adding the pin. B. Trimming the pin.

TECH FIG 9 • The corticotomy is compressed to its anatomic, preoperative position, and the external fixator is tightened.
POSTOPERATIVE CARE

▪ The patient is kept non-weight-bearing. The first metatarsal needs to be protected until the regenerate has formed at the lengthening site. Weight bearing may compromise the stability of the corticotomy and the external fixator; moreover, weight bearing is not axial at the corticotomy site.
▪ We routinely see the patient in the clinic about 7 days postoperatively for wound inspection, patient education on distraction, and initiation of first metatarsal lengthening.
▪ We typically set the distraction rate for 1 mm per day (a quarter-turn of the external fixator every 6 hours).
▪ The patient should be given instructions in pin care and the number of days to distract the device to yield the desired length.
▪ We encourage daily first MTP joint range of motion to prevent joint contracture.
▪ The patient should return to the clinic regularly for radiographs to verify adequate distraction, appropriate position of the distal segment, and passive range of motion of the first MTP joint (FIG 6).
▪ The lengthening phase is complete once the first metatarsal has reached the desired length, typically the physiologic length based on the first–second metatarsal length ratio from the physiologically normal contralateral foot.
▪ Partial weight bearing is allowed when there is radiographic evidence of consolidation within the distracted segment, so long as it does not impinge on the external fixator. Boot or brace modifications typically allow for weight bearing even with the external fixator in place (FIG 7).
▪ The fixator is removed once there is satisfactory radiographic consolidation of the regenerate. The patient can resume full weight bearing once the fixator is removed, but we recommend several weeks of protected weight bearing in a surgical shoe or boot to avoid fracture through the half-pin holes, which are potential stress risers (FIG 8).

OUTCOMES

▪ See the 2007 study by Hurst and Nunley.2

COMPLICATIONS

▪ Pin tract infection (inadequate pin care)
▪ First MTP joint stiffness (failure to perform intermittent first MTP joint range of motion)
▪ Early consolidation of distracted segment (distraction schedule too slow)
▪ Loss of hallux valgus correction (rare, with routine distraction schedule)
▪ Dorsiflexion of the metatarsal head (poor pin placement or premature removal of external fixator)
▪ Nonunion (poor fixation or stability of external fixator or premature removal of external fixator)

FIG 6 • Distraction at 3 weeks (regenerate is not yet evident).

FIG 7 • Distraction at 10 weeks, regenerate present, but not mature.

FIG 8 • Radiographic appearance at final 12-month follow-up. First metatarsal consolidation is complete and adequate lengthening has been obtained.
REFERENCES

DEFINITION

- Hallux rigidus is a degenerative condition of the first metatarsophalangeal (MTP) joint.
- This leads to a functional limitation of motion of this joint, especially with respect to dorsiflexion.
- Other terms, such as hallux limitus and dorsal bunion, have also been used to describe this condition.
- Hallux rigidus affects about 3% of the adult population.5
- This chapter pertains to the surgical procedure of a dorsal closing wedge osteotomy of the proximal phalanx, popularized by Moberg. Although it was initially recommended for young patients (under 18 years of age), Moberg extended the indications to include adults.8
- It is usually performed in conjunction with a cheilectomy.

ANATOMY

- Usually dorsiflexion is blocked by a dorsal osteophyte on the metatarsal head. In some cases there is an osteophyte or ossicle on the dorsum of the base of the proximal phalanx. Dorsiflexion is also limited by contracture of the plantar portion of the MTP joint capsule.
- Articular erosion is characteristically seen on the dorsum of the articular surface of the first metatarsal head and, to a lesser extent, on the dorsum of the base of the proximal phalanx.
- The medial and plantar aspect of the MTP joint is usually spared until later in the disease process (FIG 1).

PATHOGENESIS

- The primary etiology of the hallux rigidus is not known.
- A common cause is trauma, and hallux rigidus may occur after a fracture, sprain, or crush injury. Furthermore, it is thought that microtrauma may injure the articular cartilage over time, leading to degeneration.4
- Systemic conditions such as gout and rheumatoid arthritis can also cause degeneration of the first MTP joint, simulating the idiopathic form.

NATURAL HISTORY

- Hallux rigidus is more common in adults than adolescents.
- Generalized degenerative changes tend to progress with increasing age, but this has not been linked with symptoms.9
- Women are affected more often than men and boys, and the condition is often bilateral.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients usually describe an insidious onset of activity-related pain at the first MTP joint.
- Swelling and stiffness are common complaints.
- On physical examination in the characteristic case, dorsiflexion motion is measurably limited and plantarflexion motion with force is painful. In some cases, forceful dorsiflexion is also painful, but not as painful as forceful plantarflexion.
- Limitation of dorsiflexion usually leads to problems with running, walking on inclines, and wearing high-heeled shoes.
- The increasing dorsal prominence can lead to problems with shoe wear.
- Paresthesias may rarely occur distal to the MTP joint with the compression of the dorsal cutaneous nerves by the dorsal osteophyte and tight-fitting shoes.
- Adaptive gait measures such as a supinated forefoot to unload the painful medial forefoot may lead to lateral foot pain and calluses.6
- There is usually generalized enlargement of the joint due to a combination of osteophytes and soft tissue swelling.
- In severe cases with full loss of cartilage and motion, there is sometimes no irritability even with forced flexion. These patients often just have pain because of the osteophytic enlargement causing impingement in the shoe. In these cases, a simple cheilectomy with limited dissection often leads to satisfactory results. These are patients often in their 70s and 80s.
- Interphalangeal joint hyperextension may develop to compensate for restricted MTP joint dorsiflexion, but this is very uncommon.2
- Axial loading of the great toe is usually not painful unless severe degeneration or a large osteochondral defect is present.
- Passive plantarflexion of the hallux can also produce pain, as this is thought to bring the inflamed synovium and MTP capsule over the dorsal osteophyte.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Three weight-bearing views (AP, lateral, and oblique) of the foot are usually sufficient.
NONOPERATIVE MANAGEMENT

- The decision to pursue nonoperative treatment depends on the patient’s symptoms and the extent of the degenerative changes. Patients with mild synovitis and minimal complaints can be treated with rest and anti-inflammatory medications.
- The hallux can be taped or braced to limit dorsiflexion, thus resting the joint.
- There are many devices available to increase the rigidity of the medial forefoot. This limits the motion of the MTP joint, thus minimizing the dorsiflexion impingement pain.
- A Morton extension is an example (FIG 4).
- Steroid injections can be given in the MTP joint. This will help with pain relief but does not slow the degenerative process.
- Standard shoes with a high toe box are helpful for cases of hallux rigidus. This increases the space for the dorsal osteophytes and reduces pressure on the irritable joint.
- A shoe with a stiff-soled rocker bottom is also helpful and helps with gait smoothness.
- These shoe-wear modifications can be effective, but patient compliance and acceptance vary from case to case.
- A study by the senior author with a minimum follow-up of 14 years showed that the pain associated with hallux rigidus remained the same in 22 of 24 feet.9

SURGICAL MANAGEMENT

- We routinely perform a cheilectomy with a proximal phalanx osteotomy. The osteotomy is not a stand-alone procedure but is used to augment the effect of the cheilectomy.10
- If the osteotomy is to be combined with a cheilectomy, stable internal fixation is important to secure the osteotomy so that early motion of the MTP joint can be started within 1 to 2 weeks after the surgery.

Preoperative Planning

- All radiographs and other imaging studies should be closely reviewed.
- Special attention should be directed to the lateral radiograph. This study will show the dorsal osteophytes from the distal metatarsal head and proximal phalanx.
- No specific physical examinations need to be done under anesthesia, but it is important to document the passive range of motion (both dorsiflexion and plantarflexion) before the onset of the procedure.
- The surgeon should alert the patient that we are “stealing” motion from plantarflexion and giving it to dorsiflexion.
Positioning
- The patient is placed supine on the operating table. A Martin-type tourniquet is applied to the supramalleolar region of the ankle.
- The procedure is usually done under ankle block anesthesia.
- A mini C-arm is also used during the procedure and should be available.
- Antibiotics are given before the procedure.
- Positioning is not as important for this procedure as for other operations (FIGS 5 AND 6).

Approach
- Usually a dorsomedial approach is used and the extensor hallucis longus (EHL) is retracted laterally. This will provide good access to both the medial and lateral sides of the MTP joint.
- A directly medial approach to the first MTP joint can be used as well, but this approach can limit access to the lateral side of the joint.

**FIG 5** • Operative photograph of foot; note dorsal prominence at metatarsophalangeal joint. Small areas of hemorrhage are from prior ankle block.

**FIG 6** • Lateral operative photograph of foot; note dorsal prominence at metatarsophalangeal joint. Small areas of hemorrhage are from prior ankle block.

**TECH FIG 1** • Operative photograph showing typical line of incision; note tourniquet at supramalleolar region.

**TECH FIG 2** • Operative photograph showing the metatarsophalangeal joint widely exposed. The extensor hallucis longus tendon is retracted laterally. Note exuberant osteophytes on metatarsal head and also osteophytes overhanging from proximal phalanx.
PROXIMAL PHALANX OSTEOTOMY

- We now shift our attention to the proximal phalanx. For the plantar osteotomy, expose the plantar aspect of the proximal phalanx sufficiently to protect the flexor hallucis longus (FHL) tendon.
- During the creation of the osteotomy, be careful to ensure you have enough lateral joint exposure to protect the EHL tendon.
- Place a 0.062-inch smooth Kirschner wire transversely from medial to lateral as a guidewire.
  - It is placed parallel and as close to the articular surface of the proximal phalanx as possible without entering the joint.
  - Use a mini C-arm to verify the proper extra-articular placement of the Kirschner wire. Place the guidewire such that the osteotomy is made just distal to the guide pin.
  - Once the placement of the Kirschner wire has been verified, the osteotomy can begin.
- To maximize the amount of dorsiflexion of the tip of the toe, make the osteotomy as close to the articular surface as feasible. However, if the proximal fragment is too small, sometimes it will fragment postoperatively.
- Use an oscillating saw with a 0.5-cm blade width to make the first cut in the phalanx just distal to the surface of the Kirschner wire.
  - The initial cut is incomplete, leaving the plantar cortex intact.
  - This protects the FHL and maintains stability in the phalanx in preparation for the second cut.
- Make a second, oblique cut measured 5 mm distal to the first cut.
  - In very mild cases of hallux rigidus, a 3–4 mm wedge is used.
- Keep this cut as parallel as possible to the first cut, looking at the dorsal surface.
  - This width is measured with a sterile ruler.
  - If the two cuts are not parallel, an angular deformity (hallux valgus or varus) can ensue.
  - If there is significant preoperative abductus (lateral angulation), it may help the appearance of the toe to make the medial part of the wedge bigger than the lateral side.
  - As with the first cut, it is important not to finish the osteotomy completely.
- Weaken the remaining plantar cortex with multiple 1.5-mm drill holes. The osteotomy is then completed or “greensticked” (dorsiflexion) manually (TECH FIGS 5–7).
Fix the osteotomy with 28-gauge wire.
The wire is placed through 1.5-mm drill holes.
Make one drill hole at the proximal dorsomedial aspect of the basal fragment.
   - Start this hole just adjacent to the articular cartilage at the base of the proximal phalanx and angle it about 45 degrees toward the intramedullary cavity.
   - This starting point is about 4 mm from the osteotomy and helps to avoid breakage of a rather fragile tunnel.
   - It is helpful to pass the wire from proximal to distal; this places most of the tension on the distal side of the osteotomy when the wire is pulled through the distal segment.
   - Start the distal drill hole 3 to 4 mm from the osteotomy and angle it about 45 degrees to the plane of the proximal phalanx.
   - A wire pass instrument can be used to retrieve the 28-gauge wire passed through the proximal aspect of the osteotomy.
   - As an alternative, a wire passer can be fashioned from the terminal 6 inches of the 28-gauge fixation wire.
   - The other 28-gauge wire is modified in the following ways:
     - A 6-inch piece of 28-gauge wire is folded onto itself to form a small loop.
     - The loop is compressed with a small hemostat to fit through the 1.5-mm hole. We usually fold the wire onto itself and form a small loop with the aid of a small hemostat, or mosquito.
     - This loop is then passed into the distal drill hole and into the osteotomy site.
     - Once located within the osteotomy, usually with the assistance of a small hemostat, the created loop is expanded and made larger.
     - This loop is made large enough so the wire from the proximal osteotomy site can be placed through it.
     - Once the proximal wire is placed through the loop, the wire with the loop is pulled distally, pulling the proximal wire with it.

The assistant places dorsiflexion pressure on the plantar tip of the hallux, closing the wedge osteotomy site as the wire is tightened and twisted.
   - While the surgeon applies finger tension on the wire, maintaining a closed osteotomy, the wire is twisted about five revolutions.
   - The wire is cut, leaving about 5 mm of residual wire to be bent and placed against the bone.
   - Close the capsule with nonabsorbable suture, usually 2-0 in diameter.
   - Try to completely cover the osteotomy site with soft tissue. Sometimes this is not possible, given the limited amount of distal capsule and thin periosteum.
   - Close the skin with nylon type suture in an interrupted fashion.
   - Apply a soft dressing consisting of a nonadherent dressing, 4 × 4 gauze, and 4-inch Kling.
   - Apply a 2- or 3-inch elastic bandage over this, and the patient is placed in a hard-soled postoperative shoe (TECH FIGS 8–15).
   - Alternatively, 0.045-inch K-wires or mini fragment screw fixation may be used to secure the osteotomy site.
Techniques

**TECH FIG 9** • Operative photograph of 28-gauge wire going into wire loop from proximal to distal.

**TECH FIG 10** • Operative photograph showing close-up of wire going into loop.

**TECH FIG 11** • Operative photograph of wire tied and placed into soft tissue over osteotomy.

**TECH FIG 12** • Creation of proximal and distal drill holes with 1.5-mm drill. Note that the plantar cortex is intact.

**TECH FIG 13** • Dorsal pressure is used to close the osteotomy; the wire is tied; the osteotomy is closed.

**TECH FIG 14** • Lateral radiograph showing healed osteotomy and area of resection from cheilectomy.

**TECH FIG 15** • AP radiographs displaying healed osteotomy of proximal phalanx.
PEARLS AND PITFALLS

**Indications**
- If the MTP joint has end-stage degeneration, the patient may have residual postoperative pain and be better served with an arthrodesis.

**Intra-articular osteotomy**
- Use of Kirschner wire and a mini C-arm can decrease the incidence of an intra-articular placement of the proximal limb of the osteotomy.

**Angular deformity after surgery**
- Extreme care should be taken to make the second cut of the osteotomy as parallel as possible to the first. “Parallel” is from the perspective of looking at the dorsal surface of the proximal phalanx.
- It is important to visualize the medial and lateral aspect of the joint and the proximal phalanx.

**FHL injury**
- Careful exposure of the proximal phalanx is essential.
- Incomplete plantar osteotomy and “greensticking” the osteotomy after multiple drill holes

**Nonunion**
- Rare, but bony apposition is important, as is solid fixation with the wire technique described.
- Greensticking of the plantar cortex is also helpful.

**Proximal fragment fracture**
- Creation of a 1.5-mm drill hole as close to the proximal articular cartilage as possible.
- Avoid making the osteotomy too close to the articular surface, let alone cutting into the articular surface.
- Pull wire from proximal to distal.

POSTOPERATIVE CARE

- Postoperatively, patients are placed in a hard-soled shoe for 6 weeks.
- Weight bearing as tolerated is allowed the day after surgery when blood coagulation is complete.
- Patients are initially seen 7 to 10 days after surgery. The patient is instructed to massage the operative site to desensitize the wound beginning 1 week postoperatively.
- Passive dorsiflexion exercises of the MTP joint are begun 2 weeks after surgery.
- Plantarflexion-type exercises are not started until 4 weeks postoperatively to avoid early tension on the wire fixation of the osteotomy site.
- Less emphasis is placed on plantarflexion unless the resting posture of the hallux is above ground.

OUTCOMES

- The use of a dorsal closing wedge osteotomy increases the space at the dorsal MTP joint. In effect, the osteotomy draws the dorsal aspect of the phalanx away from the dorsal aspect of the first metatarsal head. The osteotomy may reduce the joint compression force on the dorsum of the first MTP joint during the toe-off phase of gait.
- In one long-term study, eight women who had 10 toes treated for hallux rigidus by dorsal wedge osteotomy of the proximal phalanx were reviewed after an average follow-up of 22 years (no cheilectomies were done in this study). Five toes were symptom-free, four others did not restrict walking, and only one had required metatarsophalangeal fusion. The authors concluded that dorsal wedge osteotomy afforded long-lasting benefits for hallux rigidus.

COMPLICATIONS

- Intra-articular osteotomy
- FHL injury and laceration
- Angular deformity after surgery
- Fragmentation of the proximal fragment of the proximal phalanx
- Nonunion
- Malunion, including rotational malunion
- Failure to improve
- EHL injury and laceration

REFERENCES

DEFINITION
- Hallux rigidus refers to limited dorsiflexion of the first metatarsophalangeal (MTP) joint as a result of dorsal osteophyte impingement.
- Plantarflexion is typically not limited, but may be restricted if a large dorsal osteophyte is present.
- In advanced stages, global arthrosis of the first MTP joint is present.

ANATOMY
- The first MTP joint is supported medially and laterally by collateral ligaments that provide medial–lateral stability (FIG 1).
- The plantar aspect of the joint consists of (1) the sesamoid complex, including attachments of two slips of the flexor hallucis brevis, which invest the sesamoids (FIG 2), and (2) the plantar plate, a thick fibrous band of tissue that additionally invests and supports the sesamoids. The flexor hallucis longus runs between the sesamoids (FIG 3).
- The dorsal aspect of the joint includes the capsule, the attachment of the extensor hallucis brevis to the base of the proximal phalanx, and the extensor hallucis longus within the extensor hood.

PATHOGENESIS
- Congenital hallux rigidus (tends to be bilateral)
- Concomitant hallux interphalangus
- A flat, or chevron-shaped MTP joint. This tends to concentrate stresses more centrally.
- Abnormal joint biomechanics
- Trauma to the dorsal articular cartilage, either by a direct blow, or repetitive microtrauma
- Cartilage damage secondary to inflammatory reactions from gout or inflammatory arthritis

NATURAL HISTORY
- Abnormal stresses across the MTP joint—through alterations of biomechanics, increased concentration of dorsal cartilage stresses and wear, inflammatory reaction, or direct cartilage injury—result in reactive dorsal osteophyte and marginal osteophytes. If those stresses are not alleviated or corrected, more global arthritic changes may evolve.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Sagittal range of motion is assessed (FIG 4). Pain is typically elicited with extremes of motion, secondary to dorsal impingement, and with plantar motion traction on the dorsal osteophyte.
- A positive grind test indicates more global arthritis, a relative contraindication for cheilectomy.
- Note presence or absence of tenderness with the sesamoid complex exam.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standing anteroposterior (AP), lateral, and oblique radiographs are required (FIG 5).
- The joint space may be obliterated by osteophytes on the AP radiograph, so the oblique radiograph may provide a better view of the retained joint surface.
- The AP radiograph is useful to evaluate medial and lateral osteophytes, and the lateral radiograph will reveal the...
presence of metatarsus elevatus, and the extent of the dorsal osteophyte.

- Axial sesamoid view will provide additional information about the sesamoid complex.
- Magnetic resonance imaging is helpful if osteochondral defect of the metatarsal head is suspected (FIG 6).

DIFFERENTIAL DIAGNOSIS

- Arthrosis (advanced hallux rigidus)
- Osteochondral defect
- “Turf toe,” sesamoid complex injury
- Gout

FIG 3 • Detail of first MTP joint anatomy with detail of sesamoid complex.

FIG 4 • Assessing first MTP joint motion in patient with hallux rigidus. A. Dorsiflexion produces symptomatic impingement. B. Often, plantarflexion is also painful, with traction of the dorsal soft tissue structures over the dorsal osteophyte. C. Neutral position demonstrating dorsal osteophyte.

FIG 5 • Radiographs of patient with hallux rigidus. A. AP view demonstrating joint space narrowing. B. Lateral view with dorsal osteophyte on first metatarsal head.
NONOPERATIVE MANAGEMENT

- Nonoperative treatment consists of the institution of NSAIDs, accommodative orthotics, and, rarely, physical therapy if gait abnormality is present.
- Accommodative orthotics are designed to restrict sagittal range of motion of the hallux and to redistribute weightbearing stresses across the first MTP joint with the use of a Morton’s extension.
- If sesamoid inflammation is present, protective padding is added around the sesamoids and the orthotic is welled out under the sesamoids to provide stress relief.

SURGICAL MANAGEMENT

Preoperative Planning

- Preoperatively, patients are assessed for whether they are appropriate candidates for cheilectomy, or for fusion if there are symptoms of more global arthritis of the first MTP joint.
- Cheilectomy is performed for predominantly dorsal arthritic symptoms and for failure to respond to nonoperative means of treatment, as outlined in the previous section.

Positioning

- Preoperatively, patients receive a regional ankle block consisting of a 1:1 mixture of 0.5% bupivacaine and 1% lidocaine, without epinephrine.
- Intravenous antibiotics are administered in the holding area, 30 to 45 minutes before the procedure.
- The patient is placed supine on the operating room table, with the foot at the distal edge of the table to allow for easier fluoroscopic access.
- The foot, ankle, and lower leg are prepped and draped to the lower calf with the use of a leg holder.

Approach

- The first MTP joint is approached dorsally, starting distally from the midportion of the proximal phalanx, and extending proximally 3 cm proximal to the joint.
RESECTION (TECH FIG 2A–I)

- The dorsal 25% to 30% of the metatarsal head articular surface is resected with a flexible chisel, beginning distally and angled proximally to exit at the metaphyseal–diaphyseal junction of the metatarsal. The extent of articular surface resection frequently corresponds to the wear pattern of the cartilage. Avoid exiting too far proximal in the diaphyseal bone, which might weaken the metatarsal.

- Alternatively, a microsagittal saw can be used to resect bone from a proximal to distal direction, but care must be taken to avoid excessive articular cartilage resection. I prefer to start the cartilage resection from the metatarsal head distally.

- Medial and lateral osteophytes are resected, taking care to avoid destabilization of the collateral ligaments.

**TECH FIG 2 • A–F.** Resection. A. Removing dorsal osteophyte on proximal phalanx. B. Joint exposed, demonstrating typical degenerative wear pattern. Note medial and lateral osteophytes. C. Dorsal view of dorsal osteophyte. D. Sagittal view of large dorsal osteophyte and chisel positioned for resection. E. Chisel to resect osteophyte and dorsal ⅓ to 1/3 of residual articular surface. F. After osteophyte resection. (continued)
TECH FIG 2 • (continued) G–I. Checking first MTP joint range-of-motion after resection.
G. Passive dorsiflexion of the toe relative to the metatarsal shaft axis should approach 90 degrees.
H. Fluoroscopy prior to osteophyte resection.
I. Fluoroscopy after osteophyte resection.

- The hallux is maximally dorsiflexed and inspected for any residual impingement. If necessary, additional bone is resected and motion re-evaluated.
- Fluoroscopy can be used to verify adequacy of bone resection, in both the AP and sagittal planes.
- If discrete osteochondral defect is noted, the base of the defect is drilled in multiple directions with a 0.045-inch Kirschner wire to facilitate bleeding into the defect and formation of fibrocartilage.

COMPLETION
- The wound is irrigated, and a thin film of bone wax is applied to the cancellous bone of the dorsal metatarsal.
- Closure of the capsule is performed with a 2-0 absorbable suture. If necessary, the extensor mechanism is centralized to prevent valgus drift of the hallux postoperatively.
- Subcutaneous closure is performed with either 2-0 or 3-0 absorbable suture, and the skin is closed with simple 4-0 nylon suture. A sterile compressive dressing is applied.

PEARLS AND PITFALLS

| Indications | ■ Verify that the patient is experiencing symptoms of mechanical dorsal impingement.  
■ Global arthitis with a positive grind test and pain at rest is a contraindication for cheilectomy. |
| Approach | ■ Avoid destabilization of the extensor hallucis longus. Medial and lateral exposure should preserve the collateral ligaments.  
■ Avoid injury to the dorsomedial cutaneous branch of the superficial peroneal nerve. |
| Bone resection | ■ To protect the articular surface of the metatarsal, maximally dorsiflex the hallux while performing resection of the dorsal base of the proximal phalanx.  
■ Twenty-five to 30% of the articular surface of the metatarsal head needs to be resected to avoid residual impingement. Inadequate bone resection is responsible for most failures. |

POSTOPERATIVE CARE
- Patients are instructed to elevate the operative leg for the first 10 days, with heel weight bearing in a postoperative shoe (FIG 7A,B).
- At 10 days, sutures are removed and Steri-Strips applied. Postoperative radiographs are obtained at this visit.
- At this point, weight bearing as tolerated is permitted in a postoperative shoe. The patient weans to a sneaker or comfortable shoe over the successive 10 to 14 days.
- Physical therapy is also instituted at 10 days, concentrating on re-establishing range of motion, diminishing edema, and performing scar massage.

- Physical activity such as biking, swimming, and elliptical trainer and stairmaster usage is instituted shortly thereafter. Running activities are typically withheld until approximately 3 months after surgery.
- The use of an accommodative orthotic with a Morton’s extension is occasionally prescribed for a period of time if patients complain of discomfort after activities, or continued weight bearing on the lateral aspect of the foot is necessary.

OUTCOMES
- Good to excellent outcomes after cheilectomy range from 72% to 92%.
- Better results are noted with grades I and II.
- Poorer outcomes are reported if there is over 50% loss of articular cartilage at time of surgery.
- No correlation is noted between postoperative radiographic deterioration of joint space and clinical outcome.
- Results do not tend to diminish with time.
- Less than 8% of patients subsequently require fusion.

COMPLICATIONS
- Inadequate bone resection
- Destabilization of the collateral ligaments
- Dorsomedial cutaneous nerve damage
- Progression of arthritis

REFERENCES
DEFINITION

- Hallux rigidus, osteoarthrosis of the first metatarsophalangeal joint (MTP), was first described by Cotterill and Davies-Colley in 1887.
- Pain and restriction in range of motion (ROM) in the first MTP joint are the major characteristics of hallux rigidus. After hallux valgus, hallux rigidus is the second most common deformity of the first MTP joint. The big toe is the location in the foot with the highest incidence of osteoarthritis; estimates suggest that nearly 10% of the adult population is affected by hallux rigidus. The incidence of hallux rigidus is higher in women than in men.

ANATOMY

- The first MTP joint is a stable joint formed by the rounded head of the first metatarsal bone fitting into the concave proximal facet of the proximal phalanx. The joint is enhanced by the plantar and collateral ligaments. The deep transverse metatarsal ligament is connected to the second ray.
- The sesamoid bones are embedded in the flexor hallucis brevis tendon. They are accommodated at the underside of the first metatarsal in two longitudinally oriented grooves. In a normal relationship, the sesamoids glide distally and proximally within the grooves by a combination of active and passive forces.
- The extensor hallucis longus tendon covers the dorsal side of the first MTP joint and inserts into the base of the distal phalanx.
- The dorsomedial cutaneous nerve is in danger when using a dorsomedial approach to the joint. It is the most medial branch of the superficial peroneal nerve. An anatomic study has shown that the minimum distance from the medial edge of the extensor hallucis longus tendon is 6 mm.

PATHOGENESIS

- The mechanism responsible for developing hallux rigidus remains unclear.
- In theory, damage to the cartilage surface of the first MTP joint, ie, osteochondral fractures or chondral defects, may lead gradually to posttraumatic arthritis.
- Alternatively, repetitive microtrauma to the first MTP joint, with eccentric overload and stresses that exceed physiologic stresses, may result in hallux rigidus, as seen in football players and ballet dancers.
- The contact distribution shifts dorsally with increasing degrees of extension. This is consistent with the observation that chondral erosions often initially affect the dorsal aspect of the articular surface of the first metatarsal.

NATURAL HISTORY

- Various factors, in isolation or in combination, have been suggested as contributing to the development of first MTP joint arthrosis: (1) hyperextension injury (ie, turf toe injury) to the hallux; (2) metatarsus primus elevatus; (3) osteochondral lesions; (4) a long first metatarsal; or even (5) wearing inappropriate shoes.
- In 2003, Coughlin et al evaluated 114 patients treated operatively for hallux rigidus over a 19-year period in a single surgeon’s practice for demographics, etiology, and radiographic findings associated with hallux rigidus.
- The disease was not associated with metatarsus primus elevatus, first ray hypermobility, increased first metatarsal length, Achilles or gastrocnemius tendon tightness, abnormal foot posture, symptomatic hallux valgus, adolescent onset, footwear, or occupation.
- Hallux rigidus was associated with hallux valgus interphalangeus, female gender, and a positive family history in bilateral cases.
- In most cases the problem was bilateral, except when trauma was involved—if trauma had occurred, then the problem was unilateral.
- Metatarsus adductus was more common in patients with hallux rigidus than in the general population, but no significant correlation was found.
- A flat or chevron-shaped MTP joint was more common in patients with hallux rigidus.

MICROFRACTURE TECHNIQUE

- Pain and restriction in range of motion (ROM) in the first MTP joint are the major characteristics of hallux rigidus. After hallux valgus, hallux rigidus is the second most common deformity of the first MTP joint. The big toe is the location in the foot with the highest incidence of osteoarthritis; estimates suggest that nearly 10% of the adult population is affected by hallux rigidus. The incidence of hallux rigidus is higher in women than in men.

- The mechanism responsible for developing hallux rigidus remains unclear.
- In theory, damage to the cartilage surface of the first MTP joint, ie, osteochondral fractures or chondral defects, may lead gradually to posttraumatic arthritis.
- Alternatively, repetitive microtrauma to the first MTP joint, with eccentric overload and stresses that exceed physiologic stresses, may result in hallux rigidus, as seen in football players and ballet dancers.
- The contact distribution shifts dorsally with increasing degrees of extension. This is consistent with the observation that chondral erosions often initially affect the dorsal aspect of the articular surface of the first metatarsal.

- Various factors, in isolation or in combination, have been suggested as contributing to the development of first MTP joint arthrosis: (1) hyperextension injury (ie, turf toe injury) to the hallux; (2) metatarsus primus elevatus; (3) osteochondral lesions; (4) a long first metatarsal; or even (5) wearing inappropriate shoes.
- In 2003, Coughlin et al evaluated 114 patients treated operatively for hallux rigidus over a 19-year period in a single surgeon’s practice for demographics, etiology, and radiographic findings associated with hallux rigidus.
- The disease was not associated with metatarsus primus elevatus, first ray hypermobility, increased first metatarsal length, Achilles or gastrocnemius tendon tightness, abnormal foot posture, symptomatic hallux valgus, adolescent onset, footwear, or occupation.
- Hallux rigidus was associated with hallux valgus interphalangeus, female gender, and a positive family history in bilateral cases.
- In most cases the problem was bilateral, except when trauma was involved—if trauma had occurred, then the problem was unilateral.
- Metatarsus adductus was more common in patients with hallux rigidus than in the general population, but no significant correlation was found.
- A flat or chevron-shaped MTP joint was more common in patients with hallux rigidus.
radiographically over time in 16 of 24 feet, and in 8 of the 16 feet, the loss of cartilage space was dramatic.\textsuperscript{16}

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Hallux rigidus is associated with a positive family history of great toe problems in almost two thirds of patients.\textsuperscript{9}
- The standard history is a trauma at the MTP joint several years earlier, but more often we find active persons—mostly former athletes—who are performing high-impact sports such as tennis, golf, or basketball. Starting with “feeling the joint” after exercising, it becomes a progressively limiting factor that prevents them from performing their sport at their normal level.
- The true etiology of hallux rigidus is often not known.
- In the early stages, the patient complains of pain only on dorsiflexion of the great toe; the ROM is unaffected or only moderately restricted. In the mid-stage of hallux rigidus, the patient complains of motion-dependent pain. Dorsiflexion of the great toe is restricted. Osteophytes may occur dorsal to the first metatarsal head and may be palpable, the plantar structures become tight, plantarflexion becomes painful at the sesamoid–metatarsal joint (mostly medial), and the ROM also is restricted. A dynamic stress test in dorsiflexion (ie, pressure with the thumb on the medial or lateral sesamoid) can distinguish between sesamoid–MT head pain and MTP pain. Unfortunately, this test is not clear in the presence of ongoing stiffness and arthritic changes of the MTP joint. The late stages present with reduced to complete inhibited dorsiflexion and plantarflexion of the toe, with palpable osteophytes dorsal (medial and lateral) to the metatarsal head and especially around the entire phalangeal base.
- The most striking physical manifestation of hallux rigidus noticed by patients is the bony prominence at the dorsum of the metatarsal head, which is disturbing and painful, especially in firm leather shoes.
- Methods for examining the first MTP joint are as follows:
  - ROM, dorsiflexion, and plantarflexion are checked. In the early stages, restriction of dorsiflexion (“dorsal impingement”) is found. In later stages, restriction of plantarflexion and pain at the midrange of the motion arc (indicative of global first MTP joint degenerative joint disease) also are found.
  - Palpation of the first MTP joint. In later stages, palpable and painful osteophytes are present as a symptom of ongoing osteoarthritis.
  - Inspection for clinical changes in form or color of the first MTP joint

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standard weight-bearing AP (FIGS 1 and 2) and lateral radiographs of the foot as well as weight-bearing radiographs of the metatarsals and, in cases of sesamoid pathologies, a sesamoid special radiograph, should be performed.
- Coughlin and Shurnas\textsuperscript{10} proposed a classification system based on the radiographic system of Hattrup and Johnson\textsuperscript{20} that is representative of the natural history. It includes ROM, as well as radiographic and examination findings, as follows:
  - Grade 0: Dorsiflexion (DF) of 40 to 60 degrees (ie, 20% loss of normal motion), normal radiographic results, and no pain
  - Grade 1: DF of 30 to 40 degrees, dorsal osteophytes, and minimal to no other joint changes
  - Grade 2: DF of 10 to 30 degrees, mild flattening of the MTP joint, mild to moderate joint narrowing or sclerosis, and dorsal, lateral, or medial osteophytes
  - Grade 3: DF of less than 10 degrees, often less than 10 degrees plantarflexion, severe radiographic changes with hypertrophied cysts or erosions or with irregular sesamoids, constant moderate to severe pain, and pain at the extremes of the ROM
  - Grade 4: Stiff joint, radiographs showing loose bodies or osteochondritis dissecans, and pain throughout the entire ROM
- Indications for MRI in MTP–sesamoid pathology include:
  - Severe pain in the MTP complex unrelated to radiographic results
  - Absence of visible joint space narrowing on radiography
  - Suspected osteochondral lesion in the MT head on radiography
  - Suspected sesamoid arthritis or necrosis on radiography
- The MRI examination should include sagittal, axial, and coronal views with T1-weighted (TR 35 ms, TE 16 ms) and
high-resolution gradient echo (TR 1060 ms, TE 16 ms) images (FIG 3).

**DIFFERENTIAL DIAGNOSIS**
- Gout
- Rheumatoid arthritis
- Psoriatic arthritis
- Reiter’s syndrome
- Infectious arthritis
- Sesamoid osteonecrosis

**NONOPERATIVE MANAGEMENT**
- The primary nonoperative treatments of hallux rigidus are anti-inflammatory therapy and pain relief by orthotic devices.
  - Anti-inflammatory drugs (eg, diclofenac) may be used systemically and locally.
  - Injections in the joint should be restricted to single cases. A single shot of corticosteroids may lead to pain relief.
  - Cooling devices also inhibit the inflammation process.
  - Orthotic devices such as stiff inserts for shoes or rocker bottom soles take pressure from the MTP joint by facilitating the scrolling process. To further alleviate pressure on the joint, a shoe with a roomy toe box should be worn, and high heels should be avoided.
  - Physical therapy helps keep the joint mobile.
- The question is whether immobilizing the joint by orthotics or stiff insoles in early arthritis is a reasonable approach, because doing so results in the functional breakdown of the MTP joint. In our practice, we prefer to keep the joint mobile by physical therapy and manual therapy and by having the patient perform exercises for dorsiflexion and plantarflexion daily (eg, aqua jogging on tiptoes).
- We have found that chondroitin and glucosamine sulfate, slow-acting drugs for the treatment of osteoarthritis, have comparable success in improving the pain and symptoms of osteoarthritis.
- Additional nonsteroidal anti-inflammatory drugs and icing can be applied to support progress at the beginning of the physical therapy program.

**SURGICAL MANAGEMENT**
- The goal of surgical treatment is to achieve a pain-free joint.
- Several surgical approaches have been proposed in the literature, including resection arthroplasty, interpositional arthroplasty, MTP replacement (implant arthroplasty), and cheilectomy. After its first description by DuVries in 1959, cheilectomy emerged as the most popular choice for surgical intervention. Indications for performing a cheilectomy are controversial. Some authors recommend cheilectomy as a treatment for lower grades only, whereas others have reported successful results even for higher grades of the disease.

  - Cheilectomy ressects the dorsal obstacle, but does not address the plantar pathology, which includes tremendous shortening of the plantar capsular, as well as the short flexors and plantar osteophytes of the phalangeal base.
  - Cheilectomy alone without plantar release, in our opinion, cannot be successful.
  - A remaining cartilage lesion also may be responsible for persistent symptoms. This observation led to our idea of stimulating fibrocartilage regeneration by microfracturing the subchondral bone with a specially designed awl to open the zone of vascularization.
  - Steadman has developed a microfracture technique for the knee that creates fibrocartilage in chondral lesions.
  - It has been shown to be effective in comparison to untreated lesions in experimental studies in horses and in clinical studies of the knee.
  - Coughlin and Shurnas type 2 and 3 lesions are indications for the microfracture technique.
  - In type 3 lesions, the patient must be informed that the surgery has only limited success.

  - A contraindication for cheilectomy with microfracture is the stiff joint of types 3 and 4 osteoarthritis. In this case, in patients with a low activity level who want good range of motion, a resurfacing-type prosthesis (not a “head resection” type) is a good alternative and is being used with increasing frequency (FIG 4).
  - Patients with isolated, painful osteochondral lesions without degenerative joint disease may be considered in rare cases for microfracture alone (for a small, contained lesion) or for an osteochondral transplantation from the plantar medial talus (FIGS 5 AND 6).
Preoperative Planning

- Standard weight-bearing AP and lateral radiographs as well as, in some cases, MRI evaluation should be performed for grading the patient according to the Coughlin and Shurnas classification, and the cartilage damage should be assessed.
- The clinical examination should include measurement of active and passive ROM and determination of power in extension and plantarflexion, along with a dynamic stress test for evaluation of sesamoid pathology.

Positioning

- The patient is placed supine on the operating table.
- General or local anesthesia may be used, according to the setup and the surgeon’s preference.
- A pneumatic tourniquet or Esmarch bandage should be used.

Approach

- A 4- to 5-cm incision is made anteromedially (Fig 7), being careful to protect the dorsal nerve above the first metatarsal head.
- The fatty tissue and the subcutaneous tissue are dissected, and the joint capsule is prepared.
- The extensor hallucis longus tendon is retracted and the joint exposed (Fig 8).
- The joint is then inspected by flexing the great toe in the plantar direction.
**CHEILECTOMY**

- After inspection of the joint, the dorsal osteophytes on the base of the proximal phalanx are removed.
- Cheilectomy is performed with an oscillating saw.
- The cut is performed in line with the dorsal metatarsal shaft.
  - The resection must not exceed about 15% to 20% of the metatarsal head (*TECH FIG 1*), because this leads to a jerking motion of the toe.

- Osteophytes remaining on the medial and lateral facet of the joint are removed with a sharp rongeur, plantar-flexing the proximal phalanx (*TECH FIG 2*).
  - The rims are smoothed with a rasp.

**EXTENSIVE PLANTAR RELEASE**

- Release of the plantar structures is very important for improving the ROM.
  - Because of the inhibition of dorsiflexion in the first MTP joint, contracture of the plantar structures (joint capsule, short toe flexors) has taken place.
  - The joint capsule and the short flexors with the sesamoid bones are released subperiosteally using a McGlamry elevator (*TECH FIGS 3 AND 4*).
  - The phalangeal attachment of the plantar capsule and the insertion of the short flexor muscles are released (*TECH FIG 5*).
  - This maneuver must be performed cautiously so as not to detach the tendons from their insertion.

- The joint is inspected again for plantar osteophytes of the phalangeal base and unstable cartilage parts, which will be resected.
  - Further resection to the metatarsal head must be avoided to prevent joint instability.
  - The rims are smoothed again with a rasp.
  - Osteophytes at the proximal sesamoid site must be resected, because this also is a source for plantar pain and restricted dorsiflexion. (*TECH FIG 6*)
The remaining cartilage lesions at the first MTP joint or the proximal phalanx must be débrided of all remaining unstable cartilage and fibrous tissue.

- The calcified cartilage layer must be completely removed.
- Using an awl, the microfractures are placed approximately 1 to 2 mm apart and about 2 to 4 mm deep (TECH FIG 7).

The joint capsule is closed with interrupted absorbable sutures, and a 0.8-mm drain is placed between the capsule and the continuous subcutaneous suture.

- The skin is sutured intracutaneously.
- Infiltration of the skin with bupivacaine and morphine decreases pain and need for pain killers after surgery.
- A small splint, which fixes the joint in dorsiflexion, is important to stretch the released shortened plantar structures (TECH FIG 8).
PEARLS AND PITFALLS

Resection of the metatarsal head

- Do not exceed 20% of the metatarsal head circumference.
- Too much resection may lead to instability of the joint.

Plantar release of flexor tendons

- Rough detachment of the short flexors may result in weak plantarflexion.
- Using the McGlamry raspatory, a distinct sound must be heard and felt.

POSTOPERATIVE CARE

- After surgery a gauze-and-tape compression dressing is applied to the wound, and the hallux is fixed in 30 to 40 degrees dorsiflexion with a plantar cast for 2 days to support plantar release and to improve immediate ROM after surgery.
- A second-generation cephalosporin is prescribed for 5 days. Dexamethasone is given for 4 days, according to this schedule: day 1, 4 mg; day 2, 8 mg; day 3, 4 mg; and day 4, 2 mg.
- This regimen provides protection from infection, and the dexamethasone provides significant reduction of pain and swelling, which helps to restore range of motion.
- It also prevents excessive scar formation, which may result in recurrent loss of motion.
- The first dressing change, with removal of the drain, occurs on the second postoperative day.
- In our practice, from the second day, patients wear a postsurgical shoe with full weight bearing for 2 weeks to reduce loading and its accompanying pain and swelling. This allows the patient to become pain-free more quickly and makes it possible to regain dorsiflexion earlier (FIG 9).
- The shoe permits good mobility and excellent conditions for decreased swelling and improved wound healing.
- “Aggressive” treatment of pain and swelling is crucial for the success of the surgical procedure, because regaining and stabilizing the intraoperatively attained ROM is the postsurgical goal.
- Passive and active ROM exercises are started from the second day if wound conditions and pain permit.
- After removal of skin sutures, aggressive stretching is necessary to maintain ROM.
- At this point, the patient should walk without the postsurgical shoe, focusing on a normal gait.
- The rehabilitation program also includes isometric and proprioceptive training.
- Cooling, nonsteroidal anti-inflammatory drugs and physical therapy with joint distraction support the daily self-guided dorsiflexion exercises.
- At 3 to 4 months, the maximum ROM usually has been achieved. The patient must be aware that there is only a limited time frame for achieving good motion.

OUTCOMES

- In a prospective study, 36 patients (26 women and 10 men) with 37 cases of hallux rigidus were operated by the senior author (HT) using the described technique.
- Patients were examined and interviewed preoperatively as well as 1 year (mean 12m; 28 cases) and 2 years (mean 23m; 22 cases) postoperatively and rated using the American Orthopaedic Foot and Ankle Society (AOFAS) Hallux Metatarsophalangeal-Interphalangeal Score and by a visual analog scale (VAS, not scaled 10 cm, where 0 is very poor and 10 is excellent).
- The average age of the 36 patients at the time of surgery was 50 years (range 31 to 64 years).
- Preoperative radiographs following Hattrup and Johnson’s classification revealed 25 cases of grade 2 and 12 of grade 3. No patient was classified as grade 1.
- Two patients, both grade 3, refused the follow-up examination.
- According to the AOFAS score, the results revealed a significant improvement: from 43 points preoperatively to an average of 78 points (range 35–100 points) after both 1 and 2 years postoperatively.
- The average outcome on the VAS after 2 years was 7.1 for pain (preoperatively: 2.2; after 1 year: 7.0); 7.1 for function (preoperatively: 2.8; after 1 year: 6.7); and 7.4 for satisfaction (preoperatively: 1.1; after 1 year: 6.6).
- Clinical examination showed an average improvement in ROM of 22 degrees.
- Patients classified as grade 3 were found to have significantly poorer results on average than grade 2.
- Retrospectively, several of our patients would have been classified as grade 4 and, now believe, should not have been considered for cheilectomy. We believe grade 3 is an indication if microfracturing and plantar release are added for treatment and the joint was not stiff before surgery.

COMPLICATIONS

- In patients with coexisting hallux valgus deformity, correction of the axis with a soft tissue release is essential for a successful result. However, the obligatory immobilization of the osteotomy reduces the options for postoperative management, and results sometimes are less successful in regaining ROM.
- If too much metatarsal head is resected with the cheilectomy, first MTP joint instability may ensue.
- Rough detachment of the short flexors may result in weak plantarflexion.

REFERENCES


DEFINITION
- Hallux rigidus refers to degenerative arthritis of the first metatarsophalangeal (MTP) joint that is characterized by pain, decreased range of motion (ROM), and proliferative osteophyte formation.

ANATOMY
- The first MTP joint is composed of the dorsal joint capsule, the medial and lateral collateral ligaments, the plantar plate–sesamoid–flexor hallucis brevis (FHB) tendon complex, the first metatarsal head, and the proximal articulating end of the proximal phalanx.
- Pathology is limited primarily to the first MTP joint, with prominent dorsal osteophyte on the metatarsal head.

PATHOGENESIS
- The origin of progressive first MTP joint cartilage degeneration is uncertain. Most attribute hallux rigidus to biomechanical disturbance or local pathology that leads to repetitive stress on articular cartilage and subsequent deterioration of the cartilage surface.
- Trauma
- Inflammatory arthritides (eg, rheumatoid arthritis, gout)
- Primary osteoarthritis
- Associated factors such as long first metatarsal, flat metatarsal head, metatarsus primus elevatus, pronated feet, or hallux valgus interphalangeus are often found in patients with arthritis of the first MTP joint.
- Long first metatarsal may be correlated with development of hallux rigidus.

NATURAL HISTORY
- Initially pain is localized to the dorsal aspect of the great toe MTP joint. Loss of motion is minimal but can be seen with activities that require maximum dorsiflexion. Over time, generally several years, the degree of involvement and loss of motion increase. Eventually, in the end stage of the process, the first MTP joint will lose nearly all motion. A varus or valgus deformity is usually not associated with this process.
- Pain may or may not progress as osteophytes form to stabilize the joint.
- Progression of osteophytes and joint space narrowing on radiographs may or may not correlate with symptoms.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Typical history is swelling around the first MTP joint. Patients will complain frequently of a progressive increase in the size of the MTP joint and attribute this to a bunion type deformity.
- Occasionally, avoidance gait can result and cause an increased weight-bearing load on the lateral aspect of the foot.
- Initially, a tender dorsal osteophyte will be noted with MTP joint flexion retrograde elevation and uncovering of the dorsal portion of the articulation. Pain may be associated with local dorsal cutaneous nerve irritation caused by the osteophyte.
- Limited dorsiflexion with abutment of articular surfaces of the phalanx onto the metatarsal head can be seen. Periarticular osteophytes can be noted, particularly laterally.
- Compensatory hyperextension of the hallucal interphalangeal joint can be seen with longstanding disease.
- Axial compression of the MTP joint with pain can often differentiate the level of involvement of the degenerative process.
- Pain is felt with dorsiflexion activities (wearing high-heeled shoes, running, yoga).
- Progressive proliferation of osteophytes about the joint occurs and pain is felt with small-toe box shoes.
- Decreased dorsiflexion and plantarflexion motion of the joint is seen and pain is elicited with attempting these motions.
- Physical examination includes the following:
  - Visualize the dorsal osteophyte to check for swelling.
  - For lesser toe evaluation, examine for hammer toe formation or evidence of a more systemic process: Presence of multiple hammer toe formation with hallux rigidus suggests rheumatoid arthritis.
  - Evaluate ROM for dorsal based blocking of dorsiflexion.
  - Check axial compression by stabilizing the first metatarsal while compressing the proximal phalanx against the metatarsal head. Increasing levels of pain are associated with more complete joint involvement.
  - Tomassen’s sign: With the ankle held in neutral, dorsiflexion of the MTP joint is measured. A positive result is suggestive of a stenosing flexor hallucis longus (FHL) tenosynovitis and not a static dorsal osteophyte.
  - Pain at the mid range of the motion arc implies a global first MTP joint arthritis that may not be amenable to dorsal cheilectomy alone but instead is better treated with interpositional arthroplasty or arthrodesis.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standard weight-bearing anteroposterior (AP), oblique, and lateral radiographs of the foot
- Grade 1: small lateral spurs with joint space preservation
- Grade 2: metatarsal and phalangeal osteophytes with dorsal joint space narrowing and subchondral sclerosis
- Grade 3: marked osteophyte formation with loss of joint space and subchondral cyst formation (FIG 1).
- Laboratory studies if serologic etiology suspected

DIFFERENTIAL DIAGNOSIS
- Trauma
- Primary osteoarthritis
- Degenerative arthritis
Chapter 20  CAPSULAR INTERPOSITIONAL ARTHROPLASTY

Rheumatoid arthritis
Seronegative arthropathy
Gout
Stenosing FHL tendon

NONOPERATIVE MANAGEMENT

- Low-heeled shoes
- Steel shanks
- Stiff Morton’s extension orthoses
- Nonsteroidal anti-inflammatory drugs
- Cortisone injection
- Rocker-sole shoe or over-the-counter rocker shoe

SURGICAL MANAGEMENT

- Grade I: cheilectomy to address mild osteophyte formation, joint space intact, minimal dorsal spur formation
- Grade II: cheilectomy with Moberg dorsal phalangeal osteotomy to address moderate osteophyte formation, joint space narrowing, subchondral sclerosis, bony proliferation on metatarsal head and phalanx on radiograph or significant intraoperative joint involvement
- Grade III: interposition arthroplasty or fusion to address marked osteophyte formation, loss of visible joint space, extensive bony proliferation

Preoperative Planning

- Standing AP and lateral foot radiographs to anticipate level of intervention
- Consider consent for cheilectomy, Moberg dorsal osteotomy, and interposition arthroplasty. While arthrodesis could be considered as well, the goal of interpositional arthroplasty is to preserve motion in end-stage first MTP joint arthritis.
- Patients who do well with interpositional arthroplasty typically are moderately but not extremely active athletes who wish for retention of dorsiflexion of the toe for activities of daily living such as sports or use of certain shoe wear.
- Relative contraindications to interpositional arthroplasty include cases in which first MTP joint arthrodesis may be favored:
  - Long second metatarsal (potential risk for development of transfer metatarsalgia) (see FIG 1A)
  - Hallux valgus
  - Sesamoid arthritis
  - First tarsometatarsal instability: inflammatory arthritides
  - High-demand patients (athletes, dancers) present a challenge as we believe that they should be discouraged from this procedure yet are also not ideal candidates for first MTP joint arthrodesis.
  - Poor vascular status, neuropathy, and infection are absolute contraindications to this procedure.

Positioning

- The patient is placed supine with a bump under the contralateral lumbar region if needed to evert the foot for better exposure.
- The foot is placed at the bottom corner of the bed.
- A bolster is placed under the greater trochanter of the ipsilateral hip to avoid external rotation of the operated extremity.
- A mini C-arm is placed on the ipsilateral side of the bed, about 6 feet past the corner of the operating room table and at a 45-degree angle. In our experience, this positioning affords the best access to the foot and simplifies intraoperative imaging. Blankets or sheets are used to elevate the operated extremity to facilitate lateral fluoroscopic imaging unobstructed by the contralateral lower extremity.

Approach

- Two approaches are commonly used, dorsal and medial.
  - The dorsal approach allows for easier access to the lateral osteophyte. This approach makes suturing the interposition tissue to plantar surface of the joint difficult, however.
  - In contrast, the medial incision allows for easier access to the plantar surface and is the approach used by the senior author (W.G.H.). The capsule is carefully protected, with particular attention given to protecting the plantar nerve (Joplin’s nerve) as well as the dorsal cutaneous branch.
  - Protect the extensor hallucis longus (EHL) tendon and the dorsal and plantar digital nerves. Identify the extensor hallucis brevis (EHB) and the joint capsule.
  - Ankle block anesthesia is used, plus an Esmarch ankle tourniquet with three wraps approximating 300 mg Hg, incorporating a full roll of Webril wrapped around the ankle to protect the skin overlying the Achilles tendon.
EXPOSURE AND CAPSULOTOMY

- A longitudinal midaxial medial approach to the first MTP joint is performed (TECH FIG 1A).
- The dorsomedial sensory cutaneous nerve to the hallux is identified and protected throughout the procedure.
- A thin layer of adventitial tissue may be mobilized to later be closed over the interpositional arthroplasty to further support the toe.
- The EHL tendon is identified (TECH FIG 1B), and the interval between the EHL and the underlying EHB is developed (TECH FIG 1C).
- The EHL and FHL tendons are identified and must remain protected throughout the procedure, not only from being transected but from being tethered by suture.
- A longitudinal medial capsulotomy is performed to expose the arthritic joint.
- The capsule is reflected from the proximal phalanx (TECH FIG 1D,E).
- We often use a towel clamp to carefully mobilize the base of the proximal phalanx (TECH FIG 3F,G).

TECH FIG 1 • A. Midaxial incision centered over the medial first MTP joint. B. Cadaveric specimen demonstrating medial approach with the adventitial tissue over the medial joint capsule exposed and the EHL tendon and dorsomedial sensory cutaneous nerve identified. C. First MTP joint capsule being defined while elevating the EHL tendon. D,E. Dorsal capsule being reflected off the proximal phalanx. F,G. Use of a towel clip to mobilize the proximal phalanx.
CHEILOTOMY AND PHALANGEAL OSTEOTOMY

- Inspect joint and if over 50% of joint cartilage remains, consider proceeding with cheilectomy with or without dorsal (Moberg) closing wedge osteotomy of the phalanx.\textsuperscript{2,3}
- If less than 50% of joint cartilage remains, perform cheilectomy of the dorsal third of the metatarsal head.
- Subperiosteally release the dorsal capsule, the EHB tendon insertion, and the plantar plate–FHB from the proximal phalanx base (TECH FIG 2A).
- Resect 25% (roughly 8 mm) of the proximal phalanx with a sagittal saw, protecting the EHL and FHL (TECH FIG 2B,C).
- We recommend that no more than this is resected from the proximal phalanx to avoid potential postoperative instability of the residual first MTP joint (TECH FIG 2D,E).

INTERPOSITION ARTHROPLASTY

- Transect EHB tendon approximately 3 cm proximal to the joint. This prevents the capsular tissue from being retracted during gait. Moreover, the EHB tendon may then be used to augment the soft tissue interposition. Mobilize the EHB into the joint space (TECH FIG 3A,B).
- Suture capsular tissue to stumps of the FHB tendon with 0-0 nonabsorbable suture.
- The dorsal capsule is mobilized into the joint and approximated with the FHB tendon in a balanced fashion.
- Should the capsule not mobilize adequately, the dorsal cheilectomy may need to be increased.
- Protect the FHL tendon and the plantar nerves during suturing.
Typically, there remains a thin layer of adventitial tissue that is superficial to the capsule that can be carefully approximated to further support the toe.

Evaluate balance and motion of the toe. Dorsiflexion should be uninhibited throughout the motion arc (TECH FIG 3C,D).

Although originally described, we rarely use a K-wire to support the reconstruction.

In our experience, the EHL tendon needs to be lengthened in less than 5% of these surgeries, or almost never. However, when necessary, we prefer to perform the lengthening through a horizontal Z pattern.

The capsule is cut proximally such that it can be rotated down over the top of the metatarsal head. The capsule is mobilized and secured with 2-0 nonabsorbable suture. Repair is done via 2-0 or 3-0 Vicryl.

Typically, there remains a thin layer of adventitial tissue that is superficial to the capsule that can be carefully approximated to further support the toe.

Evaluate balance and motion of the toe. Dorsiflexion should be uninhibited throughout the motion arc (TECH FIG 3C,D).

Although originally described, we rarely use a K-wire to support the reconstruction.

Insufficient capsular tissue
- Allograft (gracilis or hamstring) or autograft (plantaris or hamstring) may be used for insufficient capsule. These can be placed into a cavity prepared by use of MTP joint fusion reamers or a burr instead of proximal phalanx resection.

Push-off weakness
- Perform oblique osteotomy of the proximal phalanx to decompress the MTP joint but leave the FHB–sesamoid complex attachment intact.

"Floppy" toe
- Take care not to resect too much proximal phalanx.
- Place a K-wire at resection site, confirm with fluoroscopy, and cut along the wire.

Toe sits in dorsiflexion
- Lengthen the EHL if the toe sits in an extended position after reconstruction.
- Consider pinning with 0.062-inch K-wire for 3 weeks.

Anatomic considerations
- Avoid tethering the FHL tendon with the permanent sutures.
- Avoid injury to the plantar or dorsal medial digital nerves.

Relative lengths of the first and second metatarsals
- A long second metatarsal may be subject to transfer metatarsalgia with a capsular interpositional arthroplasty. We view a long second metatarsal as a relative contraindication to first MTP joint interpositional arthroplasty. Consider second metatarsal shortening osteotomy for patients with long second metatarsal to prevent transfer metatarsalgia.

Achieving optimal soft tissue balancing of the first MTP joint
- Balance the capsule when attaching it to the plantar plate. Then balance the toe relative to the first metatarsal by reapproximating the residual adventitial tissue. Although originally described, pinning should not be necessary.

Suture placement
- Use of a Hintermann retractor or lamina spreader with a K-wire hole attachment allows for excellent distraction of the joint to facilitate suture placement.
POSTOPERATIVE CARE

- Weight bearing as tolerated in postoperative shoe for 4 to 6 weeks. Begin gentle passive ROM at home.
- Sutures are removed at 10 to 14 days.
- If a pin is used temporarily, it is removed at 3 to 4 weeks.
- Patients should be made aware before surgery that they will have a “floppy” toe for several months until the joint tissues and tendons stabilize with time.

OUTCOMES

- Between 73% and 94% of patients report good to excellent results.\(^1,4,6–8,10,11\)
- In our experience, transfer metatarsalgia develops to some degree in 30% of patients.\(^6\) These patients can be successfully managed with orthoses, lesser metatarsal shortening osteotomy, or lesser metatarsal plantar condylectomy.

COMPLICATIONS

- Transfer metatarsalgia, particularly with a long second metatarsal
- Resecting too little bone, leading to impingement and pain
- Hallux valgus or varus
- Floppy toe or stiffness
- Weakness of push-off with the first toe
- Injury to the dorsal and plantar digital nerves
- Tethering of the FHL tendon by the capsular sutures
- Floating great toe (rare and observed when EHL contracture is present and EHL is not lengthened)

REFERENCES

DEFINITION

- Hallux rigidus is an arthritic condition of the first metatarsophalangeal (MTP) joint. It is the most common form of arthritis affecting the foot.
- An estimated 2% to 10% of the general population displays varying grades of hallux rigidus.\(^1,7,9\)

ANATOMY

- Hallux rigidus involves the first MTP joint, which comprises the articulation between the first metatarsal head, the proximal phalangeal base, and the sesamoid complex.
- Although the proximal phalanx is often involved, the predominant disease involves the dorsal aspect of the metatarsal head with articular cartilage loss and dorsal osteophyte formation (FIG 1).

PATHOGENESIS

- The cause of hallux rigidus is controversial and is likely multifactorial.
- Predisposing or associated factors cited in the literature include flat, square-shaped metatarsal head morphology; metatarsus adductus; hallux valgus interphalangeus; positive family history with bilateral condition; and trauma.\(^1,9\)
- Isolated or repetitive injury may cause damage to the dorsal aspect of the joint, which leads to altered mechanics (compressive and shear forces increased dorsally). Progressive deterioration of the articular surface, osteophyte formation, and joint contracture ensue.

NATURAL HISTORY

- In its early stages, articular cartilage loss is present along the dorsal aspect of the first metatarsal head. As the condition progresses, articular cartilage loss extends to the central aspects of the metatarsal head and lastly the plantar aspect (FIG 2).
- Although less involved, the proximal phalanx will exhibit varying degrees of articular cartilage loss and dorsal osteophyte formation.
- The natural history of hallux rigidus is one of gradual, progressive worsening.\(^9\)

FIG 1 • A. Lateral diagram depicting articular cartilage loss and osteophyte along the dorsal aspect of the first metatarsophalangeal joint. B. Frontal view showing dorsal articular cartilage loss extending into the central aspect.

FIG 2 • Varying degrees of articular cartilage loss of the first metatarsal head in hallux rigidus. Radiographic findings often underestimate the extent of disease seen intraoperatively.
PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients present with complaints of dull, aching, and at times sharp pain along the dorsal aspect of the joint associated with weight-bearing activities.
- Complaints of stiffness and development of a painful dorsal bony prominence are characteristic of the condition.
- The physical examination reveals tenderness overlying the first MT head with a notable dorsal bony prominence, along with limited range of motion of the first MTP joint, particularly dorsiflexion (FIG 3).
- The examiner should assess for pain on midmotion, crepitus, positive first MTP grind test, and plantar tenderness overlying the sesamoids, which represents more extensive disease.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Weight-bearing AP, lateral, and oblique views are obtained. The examiner should assess for joint space narrowing, presence of dorsal osteophytes, and joint congruity.
- In a radiographic grading system often used in the literature, grades 1, 2, and 3 signify the percentage of joint space narrowing, the presence or absence of subchondral sclerosis or subchondral cyst, and the degree of osteophyte formation (Table 1, FIG 4).4

CT and MRI advanced imaging studies are generally not obtained. Evaluation with MRI may occasionally be indicated if the radiographs appear normal but suspicion remains for a central osteochondral defect of the metatarsal head. CT scan is occasionally obtained to assess or confirm the presence of severe metatarsosesamoid involvement, signifying advanced disease.

DIFFERENTIAL DIAGNOSIS
- Gout
- Other systemic arthritides (rheumatoid arthritis, psoriatic arthritis, seronegative arthropathy)
- Posttraumatic arthritis
- Arthritis associated with severe hallux valgus or sequelae status post hallux valgus surgery
- Central osteochondral defect, first metatarsal head
- Avascular necrosis of the metatarsal head
- Sesamoiditis or sesamoid-related pathology
- Septic arthritis
- Soft tissue or bone neoplasm

NONOPERATIVE MANAGEMENT
- Nonoperative management of hallux rigidus includes shoe wear modifications, use of anti-inflammatories, orthotics with a Morton extension or carbon fiber plate orthotic, and rarely intra-articular cortisone injections.

SURGICAL MANAGEMENT
- When nonoperative management fails to provide adequate symptom relief, the patient and surgeon are faced with choosing from an array of surgical procedures.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Radiographic Grading System for Hallux Rigidus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>Dorsal osteophyte</td>
</tr>
<tr>
<td>1</td>
<td>Mild to moderate</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
</tr>
<tr>
<td>3</td>
<td>Marked</td>
</tr>
</tbody>
</table>

The most common performed procedure for hallux rigidus is a cheilectomy.

Simple cheilectomy has been proven successful for early stages of hallux rigidus, although cheilectomy outcomes are less promising with advanced disease, particularly grade 3. As articular cartilage loss extends to the central and plantar aspects of the joint, the joint deterioration progresses beyond that which a cheilectomy would be expected to adequately treat.

Alternative or adjunctive procedures to cheilectomy include:
- Moberg dorsal closing wedge phalange osteotomy
- Various first metatarsal decompression osteotomies
- Soft tissue interpositional arthroplasties and modified oblique Keller resection
- Proximal phalangeal base hemiarthroplasty
- Metatarsal head resurfacing hemiarthroplasty
- Total great toe arthroplasty
- First MTP arthrodesis

Historically, a first MTP arthrodesis has proven to be the most reliable procedure for providing pain relief in advanced stages (grade 3). However, many patients find the thought of complete motion loss in exchange for pain relief unacceptable and prefer not to undergo a fusion procedure for this reason alone.

Alternative surgical solutions that maintain some degree of motion and provide pain relief have been sought in an effort to address this patient subset with advanced disease who refuse to undergo fusion. This has led to the development of various arthroplasty techniques, including soft tissue interposition or implant arthroplasty.

One such implant is the Arthrosurface HemiCAP with the technique described below.

Preoperative Planning

- History and physical examination are performed with particular attention to the location of pain, mid-range motion pain, or significant symptomatic sesamoid involvement.
- Range of motion and active and passive dorsiflexion and plantarflexion are recorded preoperatively.
- Routine weight-bearing radiographs are assessed for the presence of dorsal osteophytes, the degree of joint space narrowing, joint alignment and congruency, metatarsal length, and sesamoid pathology.
- Careful preoperative discussion regarding the patient’s goals and expectations are paramount in determining whether individual goals will be met by the procedure. A discussion of the risks and alternative procedures, in particular discussion regarding arthrodesis, is important.

Positioning

- The patient is positioned supine with a bump under the ipsilateral hip to rotate the foot to neutral.
- A tourniquet is applied; however, we prefer not to use a tourniquet during the case if possible. Excellent hemostasis is achieved on the approach and leads to a drier wound on closure. We believe that postoperative swelling from hemarthrosis or hematoma formation contributes to the early motion loss seen during the early postoperative period.

Approach

- A dorsal longitudinal incision is made centered over the first MTP joint.

  - The extensor hallucis longus tendon is identified and retracted laterally (FIG 5).
  - Sharp dissection is carried down just medial to the extensor hallucis longus tendon and a dorsal longitudinal capsulotomy is performed with soft tissue dissection performed subperiosteally along the medial and lateral aspects of the first metatarsal head.
  - If a large proximal phalangeal base dorsal osteophyte is encountered upon approach, the phalangeal osteophyte is excised at this time. The metatarsal head osteophyte may be left until the implant is placed for excision at the end of the procedure.
  - Plantarflexion of the hallux exposes the metatarsal head, and extensive articular cartilage loss is assessed.
  - To release the plantar capsular joint contracture, a curved (McGlamry or similar) elevator can be passed between the sesamoids and plantar metatarsal head as long as this can be performed carefully without causing iatrogenic injury.
GUIDE PIN PLACEMENT FOR HEMICAP

- Obtain complete visualization of the metatarsal head with hallux plantarflexion.
- Place the centering spherical guide for the 15-mm HemiCAP on the metatarsal head with the feet of the guide in a superior–inferior position. A 15-mm guide is used typically; only on rare occasions is a 12-mm guide used as an alternative with an anatomically small head.
- The perimeter of the guide should not violate the metatarsal–sesamoid complex, and its inferior border is generally seated just above the crista. Avoid malplacement of the guide pin by plantarflexing the guide as necessary to adjust for normal inclination of the metatarsal shaft.
- Place the centering guide pin on the metatarsal head in line with the long axis of the metatarsal shaft and verify its position on AP and lateral fluoroscopic views. Adjust the guide pin as necessary to obtain correct placement (TECH FIG 1A–C). Pay particular attention to the guide pin lateral view, for there is a tendency to underestimate the degree of inclination of the metatarsal shaft; parallel to the long axis of the shaft is the desired position. Adjust the pin before proceeding.
- Use a cannulated drill over the guide pin and drill to depth so that the proximal shoulder of the drill bit is flush with the articular surface (TECH FIG 1D–G).

**TECH FIG 1** Guide pin placement. A. Intraoperative picture of spherical guide placement just above the crista of the first metatarsal. B. AP view of pin placed in line with the long axis of the first metatarsophalangeal shaft. C. Lateral image of pin placed parallel to the long axis of the metatarsophalangeal shaft. The surgeon can drop his or her hand as necessary to match the inclination of metatarsal and midline within the shaft. D. A cannulated drill is used over the guide pin. E. The proximal end of the drill bit should stop flush with the remaining articular surface. (continued)
Tap the drill hole to the etched line.
- Place the tapered screw of the HemiCAP implant, gaining purchase within the distal metatarsal bone. Bring the line indicator on the screwdriver just flush with the depth of the remaining articular surface level (TECH FIG 2).

Remove the guide pin and place the trial button cap to confirm the correct depth of the screw. Place the peak height of the trial cap flush or slightly countersunk to the level of the existing articular cartilage surface. The depth can be adjusted simply by either advancing or backing out the screw, with each quarter-turn accounting for 1 mm.
- Place the centering shaft pin through the cannulated portion of the screw to act as a centering point for measuring the radii of curvature of the metatarsal head at...
four index points. This measures the geometric shape of
the metatarsal head, assessing superior, inferior, medial,
and lateral dimensions.
- Slide the contact probe device through the centering
pin; this measures the distance at these four points piv-
oving at 90-degree intervals (TECH FIG 3). Record the
numbers and choose the closest match to the provided
implant size. Note: Choose the largest number mea-
sured in the superior and inferior and medial and lat-
eral directions.
- Remove the centering shaft pin and place a standard
guide pin back within the cannulated portion of the
screw.

### TECHNIQUES

**TECH FIG 3** • The guide pin is replaced with a wider center-
ing shaft pin. A contact probe is then used to measure the
dimensions of the metatarsal head so the proper implant
size can be chosen.

---

### SURFACE PREPARATION OF METATARSAL HEAD

- A circular surface reamer is then used (TECH FIG 4). The
proper size is the largest size measured in either the su-
perior–inferior or mediolateral directions. For example, if
superior–inferior measures 3.0 mm and mediolateral
2.0 mm, then use a 3.0-mm circular reamer. Note: It is im-
portant to start the reamer before contacting the bone
to avoid the remote chance of uncontrolled metatarsal
bone blowout if poor bone quality is noted. The depth of
the reamer is controlled, for it will stop on its own when
contacting the screw.

**TECH FIG 4** • A. A circular reamer is used over the guide pin. There is a built-in stop when it reaches
the edge of the screw. B. View after reaming for bone preparation for the HemiCAP. The screw is seen
within the metatarsal head, for which the cap will mate with the Morse taper interlock.

---

### PLACEMENT OF FORMAL CAP COMPONENT

- Confirm the trial size component so that it is congruent
with the edge of the surrounding articular cartilage or
slightly recessed.
- Place the formal HemiCAP component to resurface the
arthritic metatarsal head by tamping the cap into position
as it forms a Morse taper interlock with the neck of the
seated screw (TECH FIG 5).

**TECH FIG 5** • A. The HemiCAP implant is placed in the suction delivery device. B. Formal HemiCAP
implant is tamped into place, forming a Morse taper interlock with the previously seated screw.
BONE EXCISION AND MOTION ASSESSMENT

- Remove dorsal osteophytes at this time with a microsagittal saw blade, osteotome, or rongeur. Any prominent bone along the dorsal, dorsomedial, and dorsolateral aspects is removed in an effort to eliminate any source of bony impingement as the hallux is brought into dorsiflexion (TECH FIG 6).

- Assess dorsiflexion of the hallux with passive motion. If motion still appears restricted, where the hallux cannot be dorsiflexed to 70 degrees relative to long axis of the first metatarsal, then consider performing an additional soft tissue or bony procedure.

- Consider a soft tissue procedure with release of plantar joint contracture (TECH FIG 7). This must be performed carefully so as not to cause any iatrogenic injury to the flexor hallucis brevis tendon or sesamoids. This may be performed with a Freer or McGlamry elevator or a small Beaver blade along the plantar capsule to elevate a few millimeters off the proximal phalangeal base or the plantar aspect of the first metatarsal.

- After soft tissue release, perform a slow, gentle dorsiflexion stretch of the hallux in a controlled manner in an effort to stretch the joint contracture.

- If after the soft tissue procedure more dorsiflexion is required, perform a simple Moberg closing wedge osteotomy of the proximal phalanx to improve dorsiflexion. Fixation of the Moberg phalangeal osteotomy may be achieved per the surgeon’s preference. An Akin or biplanar (Mo-Akin) osteotomy may be performed in certain cases to address any concomitant mild hallux valgus (TECH FIG 8). Note: Avoid the Moberg procedure if there is no preoperative passive plantarflexion beyond neutral.

- Obtain final AP and lateral fluoroscopic images to confirm alignment of the HemiCAP device (TECH FIG 9).
PEARLS AND PITFALLS

Indications
- Evaluate for advanced arthritis of the metatarsal–sesamoid articulation. Failure to recognize this may lead to a poor result with persistent plantar joint pain. This patient would be a better candidate for arthrodesis.
- Carefully review the patient’s expectations preoperatively. If the patient cannot accept the possibility of reduced yet residual pain, he or she may be a better candidate for arthrodesis.

Guide pin placement
- Avoid malposition of the implant by verifying that the guide pin placement is in line and parallel to the first metatarsal shaft axis on AP and lateral fluoroscopic views before drilling and placing the taper post screw. A common tendency is to underestimate the metatarsal inclination on the lateral view.

Intraoperative motion
- Soft tissue contracture: Release a plantar joint contracture with a curve elevator between the sesamoid and metatarsal region. Avoid iatrogenic injury to the sesamoid articular surface. Consider subperiosteal release along plantar base of proximal phalanx with beaver blade and/or small elevator.
- Peri-implant bone excision: After placement of the HemiCAP, carefully excise all surrounding bone around the dorsal, medial, and lateral aspects of the implant for thorough bony decompression in an effort to lessen the chances of residual bony impingement against the proximal phalanx. Leave a small rim of bone along the implant perimeter for cap stability.
- Consider decompression of extremely tight joints with a concave conical reamer from an arthrodesis set (FIG 6). At the very start of the procedure, slightly decompress the joint by removing 2 to 3 mm of the metatarsal head (using either an 18- or 20-mm reamer). This tends to create joint space and a spherical head morphology. Some degree of joint decompression is beneficial. Avoid an overly aggressive decompression, which may create too much shortening, leading to altered sesamoid mechanics or lateral transfer metatarsalgia.
- Consider adding a Moberg phalangeal osteotomy if additional dorsiflexion is desired (if unable to obtain at least 70 degrees intraoperatively after placement of the implant and soft tissue releases or decompression). Avoid the Moberg procedure if the patient preoperatively had no passive plantarflexion beyond neutral.
POSTOPERATIVE CARE

- A compressive dressing is placed intraoperatively.
- The dressing is changed at 2 to 3 days postoperatively for a light dressing along the dorsal incision only with a waterproof Op-Site (FIG 7). This allows for less restriction due to the bandage and encourages early range of motion.
- Early range-of-motion exercises are emphasized in an effort to preserve the motion gained intraoperatively. Some degree of motion loss is anticipated postoperatively from its intraoperative measurements, although every effort is made to minimize this amount.
- We have found the first 2 to 3 weeks to be a critical period for maintaining motion. Swelling, hematoma, or hemarthrosis that occurs within the joint postoperatively contributes to the loss of motion seen after surgery. Recent attempts to minimize this with strict hemostasis and an early motion protocol are encouraged. Patients are instructed to begin toe motion

---

FIG 6 • A. Use of a conical reamer at the start of the case for a severely tight joint. Only 2 to 3 mm is decompressed in an effort to add space without adversely affecting the sesamoid mechanism. B. After decompression. C. Decompression with HemiCAP.

FIG 7 • The initial dressing is changed to a light dorsal postoperative dressing so as not to restrict early motion. A waterproof sealed Op-Site is used.
exercises early at home several times per day, in addition to formal physical therapy. The only restriction is that no passive plantarflexion be performed beyond neutral for the first 4 weeks if a Moberg proximal phalangeal osteotomy was performed. Physical therapy and rehabilitation continue until the patient reaches a normal gait pattern and range of motion is maximized.

- Patients are allowed to bear weight immediately on the heel of a rigid postoperative shoe or sandal. Between 3 and 4 weeks, the patient is transitioned to a running or jogging type of sneaker with a solid supportive sole.
- Radiographs are obtained at 1 week, 6 weeks, and 12 weeks postoperatively. Subsequent radiographs are obtained at 6 months, 1 year, and 2 years postoperatively.
- The patient should avoid placing high-impact stress on the joint, such as running, jogging, or sports involving pivoting and cutting, for at least the first 3 to 4 months postoperatively.

OUTCOMES

- A study by Hasselman and Shields reported on 25 of their first 30 patients. At 20 months follow-up the patients showed a postoperative motion increase of 42 degrees (from 23 degrees preoperatively to 65 degrees postoperatively). Significant improvement in visual analog, AOFAS, and SF-36 scores were noted. All patients in this series claimed to be very satisfied with their results. Of note, an unspecified number of patients in this HemiCAP series underwent concomitant interpositional soft tissue grafting of the phalangeal side.
- The results of our follow-up study on 36 patients at an average of 45 months were less favorable than those of the previously cited study, although fair satisfaction rates were achieved in this patient population that had refused to consider fusion. Good to excellent results were noted in 76% of patients, 12% fair, and 12% poor. We found a modest increase in dorsiflexion motion averaging 26 degrees (from 20 degrees preoperatively to 46 degrees postoperatively), along with improvement in visual analog scores from an average before surgery of 6.3 to an average of 2.2 after surgery. Although complete pain relief was not noted in most patients, the reduction of pain in the majority of the patients led to an overall satisfaction rate of 80% for the procedure at a follow-up of nearly 4 years. Intermediate-term radiographic evaluation of the HemiCAP prosthesis in 56 patients demonstrated no significant evidence of loosening; it appeared to show superior radiographic results compared to those of other metallic implants using a stemmed design.

- Occasional evidence of regrowth of bony osteophytes along the dorsal perimeter of the implant was noted, whereas several patients displayed some degree of progressive chondral surface loss on the apposing proximal phalangeal base. These two issues may be factors associated with significant persistent pain and less-than-satisfactory results.

- When pain relief is the foremost goal of the patient, first MTP joint arthrodesis is the most predictable procedure for complete pain relief in advanced stages of hallux rigidus.

- When pain relief and preservation of some degree of joint motion are the desired goals, metatarsal head HemiCAP resurfacing can provide a reduction in pain and satisfactory outcome when patients understand the modest expectations—namely that complete pain relief may not be achieved with this procedure, rather a reduction in pain and maintenance of motion.

- It is critical to clearly explain this to the patient preoperatively so that the proper procedure can be chosen. As with all arthroplasty procedures (whether soft tissue interposition or implant), if the patient is unwilling to accept less-than-complete pain relief as a risk, then continued nonoperative treatment should be considered until a more predictable option becomes available or the patient accepts a fusion.

- Unlike other metallic prosthetic implants or Silastic implants, the HemiCAP did not display evidence of loosening. Rather, the mode of failure in cases in which patients were not satisfied proved to be secondary to persistence of pain or lack of adequate pain relief. Reformation of dorsal osteophytes and crepitus of the joint around the prosthetic implant or progressive chondral wear of the apposing phalangeal base may account for the residual pain seen in some patients.

- Given the lack of loosening seen in this implant, future design changes addressing dorsal periprosthetic bone formation and progressive arthritic changes of the proximal phalanx may provide a more predictable procedure with higher satisfaction rates. Design changes have been made for a second-generation HemiCAP with a dorsal flange and a more gradual dorsal curvature to the implant [FIG 8]. These design modifications have been made in an effort to avoid recurrent periprosthetic dorsal osteophytes and improve the passive dorsiflexion gliding mechanism of the proximal phalanx on the metatarsal head during gait.

- The lack of radiographic loosening is encouraging with this design, and it may serve as a model for future development. Design improvements are under way to address specific issues in an effort to improve the predictability of pain relief and satisfaction rates.

COMPlications

- Joint stiffness
- Periprosthetic dorsal osteophyte formation
- Progressive arthritic changes, proximal phalangeal base
- Sesamoiditis
- Hallux valgus deformity
- Lateral transfer metatarsalgia
- Deep infection
- Metallosis

REFERENCES

DEFINITION

- Hallux rigidus is arthritis of the first metatarsophalangeal (MTP) joint.
- The amount of arthritis can range from focal areas of cartilage injury or osteophyte formation without joint space narrowing to ankylosis with complete loss of the joint space. In one classification system proposed by Hattrup and Johnson, grade I is osteophyte formation without joint space narrowing, grade II is narrowing of the joint space, and grade III is loss of visible joint space.

ANATOMY

- The joint consists of the articulation of the first metatarsal head with the hallux proximal phalanx and the medial and lateral sesamoids (FIG 1).
- The flexor hallucis brevis contains the two sesamoids within its medial and lateral heads and inserts on the plantar base of the hallux proximal phalanx.
- The flexor hallucis longus runs between the medial and lateral sesamoids and inserts on the plantar base of the hallux distal phalanx.
- The extensor hallucis longus and the more lateral extensor hallucis brevis insert into the extensor mechanism of the great toe.
- The abductor hallucis and adductor hallucis insert on the medial and lateral sesamoids respectively, along with the plantar base of the hallux proximal phalanx.

PATHOGENESIS

- Hallux rigidus may be secondary to primary osteoarthritis, systemic inflammatory arthritis, or less commonly septic arthritis.
- It may also be posttraumatic in nature, developing after a previous intra-articular fracture or significant turf toe injury to the ligamentous structures of the first MTP joint.
- Biomechanical factors such as a long, hypermobile, or dorsally elevated first metatarsal may lead to dorsal impingement of the proximal phalangeal base on the first metatarsal head with first MTP dorsiflexion.

NATURAL HISTORY

- The extent of arthritis often progresses with time, leading to increased osteophyte formation and joint space narrowing. This may occur with or without joint-sparing surgical intervention.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients often complain of pain and stiffness in their first MTP joint. Symptoms may be exacerbated by shoes with a restrictive toe box and by walking barefoot or in shoes with a flexible forefoot.
- On examination there may be a prominent first metatarsal head, a swollen first MTP joint, and tender osteophytes of the metatarsal head and phalangeal base. First MTP joint motion may be limited and painful. Dorsiflexion range of motion should also be assessed with the patient bearing weight or with dorsal translation applied to the first metatarsal head to simulate weight bearing to assess for “functional hallux rigidus.” In mild to moderate hallux rigidus (Hattrup and Johnson grade I and II), pain is principally with maximum joint dorsiflexion or plantarflexion secondary to dorsal osteophytes causing bone impingement or soft tissue tenting, respectively. With severe arthritis (Hattrup and Johnson grade III), there is usually pain throughout the entire arc of motion and a positive “grind test,” in which mid-range of motion with axial compression applied to the first MTP joint is painful.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- AP, lateral, oblique, and sesamoid views of the foot should be obtained to assess the extent of arthritis in the first MTP and in the adjacent first tarsometatarsal and hallux interphalangeal joints. An assessment is also made for any concurrent hallux valgus or hallux varus deformity, osteopenia, avascular necrosis, or occult sesamoid fracture.
- If needed, MRI and CT scan can provide more detailed information on the above, particularly sesamoid pathology, which is important as this procedure leaves the metatarsosesamoid joint intact.
DIFFERENTIAL DIAGNOSIS
- Osteochondral lesion
- Avascular necrosis
- Occult fracture

NONOPERATIVE MANAGEMENT
- Conservative treatment should always be offered before performing first MTP joint arthroplasty.
- The principal goal is to limit painful motion of the first MTP joint and pressure on prominent osteophytes. An accommodative shoe with a soft upper and a rigid forefoot rocker may be worn. A rigid turf-toe plate may be placed under a removable soft insole or an orthotic with a Morton’s extension may be worn. Doughnut pads may be placed over tender osteophytes.
- Medications such as nonsteroidal anti-inflammatories, glucosamine and chondroitin sulfate, and acetaminophen may be taken.
- Corticosteroid and possibly hyaluronic acid injections may be performed.

SURGICAL MANAGEMENT
- There are many surgical options for hallux rigidus, including cheilectomy, metatarsal osteotomy, proximal phalangeal osteotomy, distraction arthroplasty, tissue interposition arthroplasty, implant arthroplasty, and arthrodesis.
- Of the many implants available, our preference is a cobalt chrome proximal phalangeal hemiarthroplasty made by BioPro (FIG 2). The material does not break down with associated extensive bone destruction like the silicone total and hemi implants, there are good long-term results published in the literature, and the amount of bone removed is small, making salvage of a failed prosthesis less challenging.
- Our potential indications for performing a first MTP hemiarthroplasty are symptomatic grade II arthritis with loss of greater than 50% of the metatarsal head articular cartilage and grade III arthritis without severe involvement of the articulation between the metatarsal head and the sesamoids.

FIG 2 • BioPro first metatarsophalangeal hemiarthroplasty implant.

Preoperative Planning
- History, physical examination, and radiographs are reviewed to confirm the appropriate indications for the procedure and determine if there are any concurrent deformities or biomechanical abnormalities that also need to be addressed.
- The patient needs to be told that based on the intraoperative findings a decision may be made that hemiarthroplasty is not the best option and that a simple cheilectomy, arthrodesis, or tissue interposition arthroplasty may be preferable.
- The equipment to perform the hemiarthroplasty and the above alternatives should be readily available in the operating room.

Positioning
- The patient is placed in the supine position with a leg or thigh tourniquet.

Approach
- A dorsomedial approach is preferable, although a medial longitudinal approach can also be used in the presence of a previous incision there.

FIRST MTP JOINT HEMIARTHROPLASTY USING THE BIOPRO PROSTHESIS
- Perioperative antibiotics and a regional anesthetic block are given.
- Make a longitudinal dorsomedial incision over the first MTP joint.
- Protecting the dorsomedial sensory nerve, expose the extensor digitorum longus tendon and dorsomedial joint capsule.
- Leaving a sufficient cuff of capsular tissue for subsequent repair, make a longitudinal capsulotomy medial to the extensor digitorum longus tendon.
- Using subperiosteal dissection and preserving the collateral ligaments, expose the dorsal aspect of the proximal phalanx and the dorsal, medial, and, if prominent, lateral aspect of the metatarsal head (TECH FIG 1).
  - Release any adhesions between the sesamoids and the metatarsal head.
  - Inspect the joint to determine the extent of articular cartilage damage.
  - If there is severe ankylosis and arthritis of the metatarsosesamoid joints, then a first MTP joint arthrodesis or tissue interposition arthroplasty is probably a better option.
- If the cartilage of the proximal phalanx and the plantar half of the metatarsal head is in good condition, then a cheilectomy with or without a metatarsal or phalangeal osteotomy is usually sufficient.
- Using a rongeur or sagittal saw, remove osteophytes from the metatarsal head, proximal phalangeal base, and also circumferentially about the sesamoids.
- Make an adequate dorsal cheilectomy of the metatarsal head.
- With dorsal stress applied to the metatarsal head, there should be at least 70 degrees and preferably 90 degrees of first MTP dorsiflexion relative to the axis of the first metatarsal shaft.
- Make an initial cut parallel to the dorsal cortex of the first metatarsal head. However, after the trial and final prostheses have been inserted, range of motion...
TECH FIG 1 • Exposure of dorsal osteophytes after capsular incision.

is reassessed and usually additional dorsal bone resection (up to 25% to 40% of the normal metatarsal head) is required. My experience with this procedure and with isolated cheilectomy is that there is a higher rate of recurrent symptoms if less than 30% of the dorsal metatarsal head is removed.

- Débride loose chondral flaps and drill or microfracture areas of visible subchondral bone on the remaining metatarsal head to promote fibrocartilage ingrowth.
- Remove the base of the proximal phalanx using a sagittal saw, with the cut perpendicular to the axis of the proximal phalanx.
- Take care to avoid injuring the flexor hallucis brevis insertion, which may occur with resection of too much bone (>6 mm or 20% of the total proximal phalangeal length) or overpenetration of the saw blade.
- The implant sizer is the same thickness as the prosthesis (2 mm) and can be used to guide the amount of bone resection.
  - If only 2 mm of bone is removed, then the joint is usually too tight and postoperative motion is restricted.
  - Usually 3 to 4 mm of bone resection is required for adequate motion; this can be assessed by the amount of “shuck” with the trial implant inserted.
  - Ideally, the space between the trial or final implant and the metatarsal head should distract at least 3 mm with applied force.
  - Visualization of the plantar aspect of the joint may be easier after this cut has been made.
- Available BioPro implant diameters are 17 mm (small), 20 mm (medium), 21.5 mm (medium/large), and 23 mm (large); these implants are either porous coated and non-porous coated.
- With the toe plantarflexed 90 degrees to improve exposure, use the sizer guide to determine the largest size implant that does not extend beyond the margins of the proximal phalangeal cut.
- With respect to orientation, the prosthesis is slightly wider in the mediolateral dimension than the dorsal–plantar dimension.
- There is a hole in the center of the sizer that is drilled to accommodate the stem of the trial prosthesis.
- Insert the trial stem and evaluate the extent of phalangeal base coverage and joint range of motion and stability. If as noted above there is insufficient joint distraction or dorsiflexion, more bone can be removed from the phalangeal base or dorsal metatarsal head, respectively.
- Once you are satisfied with the implant size and bone cuts, center the chisel with its longer end in the mediolateral dimension on the trial hole and use it to create a channel for the stem of the final prosthesis.
- Impact the prosthesis into position.
  - It should be flush with the phalangeal base and should not extend beyond its margins (TECH FIG 2).
  - Joint motion should be smooth with dorsiflexion and there should be at least 3 mm of “shuck,” as noted above.
- Use AP and lateral fluoroscopy or plain radiographs to confirm acceptable prosthesis position (TECH FIG 3).
  - If the patient is not allergic, place bone wax on the cut dorsal surface of the metatarsal head and irrigate the joint.
  - Close the joint capsule with absorbable suture.
  - If a large dorsal and medial eminence has been resected, then sometimes the capsule needs to be imbricated or partially removed. However, take care not to make the closure too tight, which may restrict postoperative motion.
  - Close the subcutaneous tissue and skin in layers and apply a sterile compressive dressing.

TECH FIG 2 • Cheilectomy has been performed and implant inserted.

TECH FIG 3 • Postoperative lateral radiograph showing component in place.
PEARLS AND PITFALLS

- Failure to recognize and address concurrent deformity or potential causative biomechanical abnormalities may lead to progressive arthritis of the remaining metatarsal head and sesamoids, component loosening, and postoperative pain and stiffness.
- An adequate cheilectomy must be performed, particularly if there is residual elevation of the metatarsal head or hypermobility of the first tarsometatarsal joint. If not, there is more likely to be recurrent dorsal osteophyte formation and decreased postoperative range of motion.
- Sufficient bone must be removed from the proximal phalangeal base to decompress the joint without damaging the flexor hallucis brevis insertion.
- The stem of the prosthesis needs to press-fit tightly and be centered within the proximal phalangeal canal. An attempt to remove more dorsal than plantar phalangeal bone to “increase relative toe dorsiflexion” or protect the flexor hallucis brevis insertion risks having the tip of the stem abut or penetrate the plantar cortex and may lead to poorer results.

POSTOPERATIVE CARE

- Postoperatively, the patient may be weight bearing as tolerated in an orthopaedic or regular shoe.
- Aggressive early first MTP joint range-of-motion and strengthening exercises should be initiated within the first few days after surgery.
- Sutures are removed at 10 to 15 days postoperatively.

OUTCOMES

- The developer of the prosthesis reported his results for 279 procedures with follow-up of 8 months to 33 years as 93.1% excellent, 2.2% good, and 4.7% unsatisfactory results.⁷
  - Twelve of the 13 unsatisfactory results underwent revision, including prosthesis removal.
  - A subsequent update on 468 procedures with follow-up of 2 months to 38 years noted no additional revisions and one case of radiographic loosening.²
- In another study, seven patients (nine feet) underwent a BioPro resurfacing endoprosthesis and at 1-year follow-up noted an average increase on a modified American Orthopaedic Foot and Ankle Society Hallux Metatarsophalangeal-Interphalangeal 100-point scale from 51.1 to 77.8, an average increase in first MTP joint dorsiflexion range of motion from 11.9 to 17.9 degrees, and no change in first MTP joint plantarflexion range of motion.⁵
- In a different study, 23 patients completed 1-year follow-up after BioPro hemiarthroplasty with an average ACFAS score increase from 41.2 to 80, average first MTP joint dorsiflexion increase from 12.6 to 50 degrees, and an average first MTP joint plantarflexion increase from 8 to 17.5 degrees.³
  - Another study evaluated 32 procedures in 28 patients with an average follow-up of 33 months.⁶
  - Foot Function Index Pain, Disability, and Activity Scores improved; 82% of patients were completely satisfied and 11% were satisfied with reservations.
  - There were three cases of radiographic loosening or subsidence.
- In a retrospective comparison study, 21 BioPro hemiarthroplasties and 27 first MTP arthrodeses were evaluated at mean final follow-up of 79.4 and 30 months, respectively. Five (24%) of the hemiarthroplasties failed; one of them was revised, and four were converted to an arthrodesis. Eight of the feet in which the hemiprosthesis had survived had evidence of plantar cutout of the prosthetic stem on the final follow-up radiographs. The satisfaction ratings in the hemiarthroplasty group were good or excellent for 12 feet, fair for 2, and poor or failure for 7, with a mean pain score of 2.4 out of 10.⁴
- In the 16 procedures in 15 patients that we performed (average follow-up of 49 months), there was a 92% satisfaction rate and an 83% incidence of no or mild, occasional pain for index procedures and a 50% satisfaction rate and 25% incidence of no or mild, occasional pain for patients having had a previous failed first MTP joint cheilectomy or tissue interposition arthroplasty.¹
  - There were three revision procedures—one implant removal for postoperative infection and two revision cheilectomies for recurrent osteophytes, possibly secondary to inadequate initial cheilectomy.

COMPLICATIONS

- Infection
- Nerve injury
- Component loosening
- Recurrent pain and loss of motion

REFERENCES

DEFINITION
- Arthrosis of the first metatarsophalangeal (MTP) joint is commonly seen in osteoarthritis (hallux rigidus), rheumatoid disease, and gout.
- The indication for surgical treatment of the first MTP joint is pain where conservative treatment has failed.
- Arthrodesis of the first MTP joint is the surgical treatment of choice in rheumatoid disease and is indicated in hallux rigidus when the disease is advanced.
- Many techniques in preparation of the joint exist to provide good cancellous apposition:
  - Flat cuts: these make accurate positioning of the toe difficult
  - Cone or peg socket: this leads to excessive shortening
  - Ball and socket: this results in minimal shortening and has the additional benefit of ease of adjustment in positioning the toe
- Various methods of fixation have been described. The most biomechanically advantageous method of fixation has been shown to be a dorsal plate and compression screw.\(^2,3\)

ANATOMY
- The first MTP joint is a ball-and-socket joint.
- The normal hallux valgus angle is less than 15 degrees.
- The metatarsal inclination angle relative to weight bearing is usually 25 to 30 degrees but varies with foot type (greater for cavus, less for planus) (FIG 1).
- The final position of the arthrodesed first MTP joint must allow for heel rise during the late stance phase of gait.
- The position can be checked by applying a flat surface to the sole of the foot. The tip of the toe should clear the surface with the interphalangeal joint in full extension and should touch the surface with the interphalangeal joint in 45 to 60 degrees of flexion.

PATHOGENESIS
- Primary osteoarthritis (hallux rigidus) and the inflammatory arthritides (rheumatoid, gout, psoriatic arthritis) account for the majority of causative factors.
- Secondary osteoarthritis arises from mechanical abnormalities (hallux valgus and varus) and trauma resulting in joint incongruity and excessive cartilage wear.

NATURAL HISTORY
- The natural history of first MTP joint arthrosis is related to its cause.
- Hallux rigidus is a progressive disease process and the joint will deteriorate with time, but the patient’s symptoms may not show the same deterioration.
- Progression of arthrosis secondary to the inflammatory arthritides will be related to the activity of the disease.

PATIENT HISTORY AND PHYSICAL FINDINGS
- In true hallux rigidus, patients experience an insidious onset of pain, swelling, and stiffness in the first MTP joint that is aggravated by activity (eg, walking, running).
- Lateral forefoot pain due to overload may develop as the foot supinates to avoid dorsiflexion of the first ray just before and immediately after heel rise.
- A comprehensive physical examination is required to enable diagnosis and selection of correct surgical procedure.
- The physician should palpate the MTP joint for tenderness; dorsal or dorsolateral osteophytes (cheilus) may be palpable and tender.
- The physician should examine the range of motion of the MTP and interphalangeal joints. Restriction in dorsiflexion but full plantarflexion may indicate that dorsiflexion osteotomy of proximal phalanx may improve the dorsiflexion arc.
- The grind test is not normally painful unless an osteochondral defect is present or degeneration is advanced. If painful, then arthrodesis is indicated.
- The physician should observe the patient’s walking gait. Avoidance of weight bearing on the hallux implies pain. Callus may be present under the lesser metatarsals.
- The physician should palpate for posterior tibial and dorsalis pedis pulses. Peripheral vascular disease is a contraindication to surgery. If suspected, vascular assessment and treatment is required first.
- The physician should palpate and move the tarsometatarsal joint. Arthrodesis of the tarsometatarsal joint is a relative contraindication to arthrodesis of the first MTP joint. The examiner should also palpate and move the interphalangeal joint. Arthrodesis of the interphalangeal joint is a contraindication to arthrodesis of the first MTP joint.

FIG 1 • Metatarsal inclination angle.
IMAGING AND OTHER DIAGNOSTIC STUDIES

- Weight-bearing anteroposterior and lateral radiographs should be obtained before surgery.
- The severity of the arthrosis can be assessed and any co-existing forefoot pathology identified and addressed at the time of surgery.
- The hallux valgus angle and the metatarsal inclination angle should be measured accurately.
- The lateral radiograph shows the cheilus and any narrowing of the joint space (either dorsally or through).
- Hallux rigidus can be graded using the clinical and radiologic information obtained.
- We have created a seven-point clinicoradiologic grading system (adapted from Coughlin and Shurnas) that correlates the severity of the disease (symptoms, clinical examination, and radiologic findings) with the appropriate surgical procedure (Table 1).

NONOPERATIVE MANAGEMENT

- Nonoperative management encompasses activity modification, weight loss, analgesic and anti-inflammatory medication (oral and intra-articular), physiotherapy (tendo Achilles and hamstring stretching), and shoe modification.
- Shoe modification can involve a carbon fiber extended insole with cutouts for the lesser toes, metal stiffeners in the last, and a forefoot rocker sole.

SURGICAL MANAGEMENT

- Arthrodesis of the first MTP joint does not restore normal anatomy or gait pattern. The patient should be counseled as to the surgical goals and optimal outcome in order to have realistic expectations of the surgery.
- Absolute contraindications to first MTP joint fusion include active infection, peripheral vascular disease, and arthrosis of the interphalangeal joint.
- Relative contraindications to first MTP joint fusion include degeneration of the first tarsometatarsal joint and peripheral neuropathy.

Preoperative Planning

- Initial assessment should include examination of circulation, sensation, the first tarsometatarsal joint, the interphalangeal joint, and any previous surgical incisions about the foot.
- It may be necessary to consult with the patient’s rheumatologist to reduce or stop immunosuppressant drugs before surgery.
- Preoperative weight-bearing AP and lateral radiographs should be obtained.

Positioning

- We prefer to position the patient supine with the heels at the end of the operating table. A thigh tourniquet is inflated to 350 mm Hg after prophylactic intravenous antibiotics have been given and the limb has been exsanguinated. The foot and leg are then prepared and draped above the knee in a routine manner.
- The end of the table is dropped 20 to 30 degrees. The surgeon sits at the end of the table.

Approach

- A dorsal approach is recommended regardless of previous scars. Care should be taken to avoid the dorsal cutaneous nerve and extensor hallucis longus. The former is retracted medially and the latter laterally, so they are protected.
Exposure
- Make a dorsal slightly curved incision just medial to the extensor hallucis longus tendon and lateral to the dorsal cutaneous nerve, extending from the middle of the shaft of the first metatarsal to the interphalangeal joint.
- Retract the extensor hallucis longus tendon laterally.
- Make a capsulotomy in the same plane and expose the joint.
- Perform a synovectomy.
- Release the medial and lateral soft tissues to allow maximum plantarflexion of the proximal phalanx, exposing both articular surfaces.

Joint Preparation
- Excise any large medial eminence or osteophyte with an oscillating saw.
- Excise osteophytes on the proximal phalanx to find the true center and size of the articular surface.
- Size the articular surface of the proximal phalanx to determine the correct convex reamer required.
- Insert a 1.6-mm Kirschner wire through the center of the articular surface of the proximal phalanx and pass it in line with its long axis. In osteoporotic bone the wire should cross the interphalangeal joint into the distal phalanx to prevent toggling of the wire, leading to eccentric reaming.
- Guide the sized convex reamer over the Kirschner wire and ream the surface sparingly to expose subchondral cancellous bone (TECH FIG 1).
- Remove the Kirschner wire. Remove any fine collar of cartilage remaining around the wire entry hole. Insert the wire into the center of the articular surface of the first metatarsal and advance it along its long axis. If the bone is osteoporotic then the wire should cross the tarsometatarsal joint.
- Use the matched-sized concave reamer in a similar fashion to expose the subchondral cancellous bone of the metatarsal head (TECH FIG 2). Remove the wire and retain all fragments of bone in the reamer.

Positioning
- Approximate the position of the hallux in relation to the first metatarsal and fix the position temporarily with an obliquely directed Kirschner wire. The ideal position is 20 to 25 degrees of dorsiflexion of the proximal phalanx in relation to the first metatarsal axis. The valgus angle should be 10 to 15 degrees. However, a gap of 3 to 5 mm must be left between the hallux and the second toe. The rotation of the hallux should be neutral so that the arc of rotation of the interphalangeal joint is at 90 degrees to the weight-bearing surface.
- Confirm the correct position of the hallux by placing a flat surface against the sole of the foot and bringing the ankle to 90 degrees. In this position, with the interphalangeal joint in full extension, the tip of the hallux lies about 1 cm from the flat surface. When the interphalangeal joint is flexed to 45 to 60 degrees, its tip comes in contact with the plantar surface. This enables the foot to rock at the MTP joint on heel rise (TECH FIG 3).
Fixation
- Insert an oblique 2.7-mm compression screw of appropriate length from distal medial to proximal lateral across the MTP joint.
- Size and secure the plate on the dorsal aspect of the joint with a Kirschner wire and fix it with six 2.7-mm self-tapping screws (TECH FIGS 4 AND 5). The plate is available in three side-specific (left and right) sizes (small for a small hallux, medium for a larger hallux, large for revision arthrodesis).
- Close the wound in layers over a drain.
- Apply a compression dressing.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Clinical examination</th>
<th>Coexisting arthritis of the tarsometatarsal and interphalangeal joints should be excluded.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plantarflexion of the first MTP joint is functionless in bipedal gait. When painless, a Moberg osteotomy is helpful in patients with a good plantarflexion arc, especially in athletes.</td>
</tr>
</tbody>
</table>

Most problems arise from the final arthrodesis position.
- Too dorsiflexed | A painful corn develops on the dorsum of the interphalangeal joint. |
- Too plantarflexed | Callosities may form under the condyles of the proximal phalanx. With time, a hyperextension deformity can arise in the interphalangeal joint (recurvatum). |
- Too varus | Not a major concern but can cause problems with footwear |
- Too valgus | This can be a major problem and cause great irritation of the second toe due to impingement and the inability to cleanse the web space. |

POSTOPERATIVE CARE
- If this technique is performed as an isolated procedure we do not use a cast but a compressive dressing and a postoperative stiff-soled shoe to allow early mobilization.
- Patients are kept non-weight-bearing for 2 weeks and then encouraged to bear weight by heel walking for 2 weeks.
- Four weeks after surgery a radiograph is taken (FIG 2). If there is evidence of consolidation, forefoot weight bearing is commenced in the postoperative shoe. Progression to full forefoot loading, assisted by crutches, follows over the next 4 weeks.
- Radiographs taken 8 weeks after surgery usually confirm consolidation. At this stage flat shoes with cushioned, shock-absorbing soles are worn.

OUTCOMES
- Union rates for arthrodesis are quoted in the literature ranging from 80% upward. Using this technique, we have achieved 100% union. The average time for union to be visible radiologically is 6 weeks. All patients experienced significant increases in their outcome scores.²
COMPLICATIONS

- Potential complications of first MTP joint arthrodesis include malunion, infection, delayed union, interphalangeal joint stiffness, extensor hallucis longus tenodesis (secondary to scarring), dorsal cutaneous nerve damage, and hardware problems.
- The incision described in this technique minimizes the risk to the extensor hallucis longus and dorsal cutaneous nerve while facilitating maximal plantarflexion to allow reaming.
- The ball-and-socket bone-end preparation minimizes shortening and provides a large congruent cancellous area of contact, enabling easy positioning of the hallux and reducing consolidation time. Temporary Kirschner wire fixation facilitates correct alignment.
- Use of the compression screw and dorsal plate ensures maximum stability.
- The low-profile precontoured titanium plate has inbuilt dorsiflexion and hallux valgus angles and is contoured to the specific shapes of the proximal phalanx and the first metatarsal. It acts as a neutralization plate and facilitates correct positioning. The differing screw axes increase pullout strength.
- These mechanical factors significantly reduce the risk of delayed union and nonunion.

REFERENCES

DEFINITION

- The term *hallux rigidus* refers to a painful condition of the first metatarsophalangeal (MTP) joint of the great toe that is characterized by restricted motion (mainly dorsiflexion) and periarticular bone formation.
- The basic pathologic entity is that of degenerative arthritis.
- Initially, hallux rigidus is characterized by pain, swelling, and MTP joint synovitis.
- As the degenerative process proceeds, proliferation of bony osteophytes on the dorsal and dorsolateral aspect of the first metatarsal head develop.
- With advanced disease, near-complete bony ankylosis may occur.

ANATOMY

- The round, cartilage-covered first metatarsal head articulates with the somewhat smaller, concave base of the proximal phalanx.
- Articulating on the plantar surface of the metatarsal head are the two sesamoids, which are contained in the tendon of the flexor hallucis brevis.
- Distally, the two sesamoids are attached by the plantar plate to the base of the proximal phalanx.
- The sesamoids are connected by the intersesamoidal ligament and protect, on their plantar surface, the tendon of the flexor hallucis longus within its tendon sheath.
- Dorsally, the extensor hallucis longus is anchored medially and laterally by the dorsal capsule and MTP joint hood ligaments.
- The tendons of the abductor and adductor hallucis pass medially and laterally, but much closer to the plantar surface of the MTP joint (FIG 1 and 2).

PATHOGENESIS

- The cause of hallux rigidus has not been determined, but joint trauma often is cited as a predisposing factor.
- This may occur as a single episode, such as an intraarticular fracture, as a crush injury, or with repetitive microtrauma.
- In a patient who sustains an acute injury to the MTP joint, forced hyperextension or plantarflexion may lead to an acute chondral or osteochondral injury.
- The only documented factors associated with the cause of hallux rigidus are a flat or chevron-shaped metatarsal articular surface, bilaterality in those with a positive family history, and female gender.
- Metatarsus primus elevatus typically is a secondary phenomenon related to the severity of the disease and restricted MTP joint motion, and is not a primary cause of hallux rigidus (FIG 3).

NATURAL HISTORY

- A patient with hallux rigidus typically complains of stiffness with ambulation and pain localized to the dorsal aspect of the first MTP joint that is aggravated by walking, especially during toe-off.
- Patients tend to ambulate with an inverted foot posture to prevent stress on the first MTP joint.
- With time and further osteophyte formation, increased bulk around the MTP joint periphery can lead to substantial discomfort with contracting footwear.
- More than 80% of patients, if followed long enough, will develop bilateral symptoms.
- Ninety-five percent of patients with bilateral symptoms have a positive family history.

FIG 1 • Axial drawing of the first metatarsophalangeal (MTP) joint.
Chapter 24  FIRST METATARSOPHALANGEAL JOINT ARTHRODESIS: PERSPECTIVE 2  3633

PATIENT HISTORY AND PHYSICAL FINDINGS

- A complete examination to evaluate for associated forefoot pathology should include the following.

Interdigital Neuroma
- The interdigital spaces should be palpated for any tenderness.
- A Mulder’s test should also be performed.
- The second and third interspaces are the most common locations for an interdigital neuroma.

Hammer Toe or Mallet Toe
- The patient should be examined while standing to evaluate for the presence of a hammer or mallet toe deformity.

Crossover Toe
- Inspection may reveal either medial or lateral deviation of the lesser toes. The MTP joints of the lesser toes should be palpated for plantar tenderness as well as thickening of the joint capsule. A drawer test of the lesser MTP joints also should be performed. Crossover toes usually affect the second and third digits.

Gastrocnemius Contracture
- A Silfverskiöld test should be performed to assess for a gastrocnemius contracture. This is rarely of clinical significance in patients with hallux rigidus.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Weight-bearing radiographs (AP, lateral, and seaming views) are obtained to evaluate the first MTP joint.
- The Coughlin/Shurnas classification of hallux rigidus (Table 1) is used to grade the severity of joint arthrosis.
- The AP radiograph often demonstrates nonuniform joint space narrowing with widening and flattening of the first metatarsal head.
- An oblique radiograph may demonstrate a well-preserved joint space, which is obscured on the AP radiograph by overlying osteophytes.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Characteristics</th>
<th>Radiograph</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Loss of 10%–20% dorsiflexion compared to the normal side. Normal or minimal radiographic findings.</td>
<td></td>
</tr>
<tr>
<td>Grade</td>
<td>Characteristics</td>
<td>Radiograph</td>
</tr>
<tr>
<td>-------</td>
<td>---------------------------------------------------------------------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Loss of 20%–50% dorsiflexion. Dorsal spur present with minimal joint space narrowing.</td>
<td><img src="image" alt="Arrow points to early osteophyte formation" /></td>
</tr>
<tr>
<td>2</td>
<td>Loss of 50%–75% dorsiflexion. Dorsal and lateral osteophytes present with less than 25% loss of joint space.</td>
<td><img src="image" alt="Arrow indicates dorsolateral osteophyte" /></td>
</tr>
<tr>
<td>3</td>
<td>Loss of 75%–100% dorsiflexion. Large dorsal and lateral osteophytes with substantial joint space narrowing.</td>
<td><img src="image" alt="Image" /></td>
</tr>
</tbody>
</table>
■ On the lateral radiograph, with more severe disease, the dorsal metatarsal osteophyte resembles “dripping candle wax” as it courses proximally along the first metatarsal (FIG 4).

■ The lateral radiograph also may be used to evaluate for the presence of an elevated first metatarsal in relation to the lesser metatarsals. Up to 5 mm of elevation is considered normal (see Fig 3).

■ Dorsal proximal phalangeal osteophytes and loose bodies also may be seen.

■ Subchondral cysts and sclerosis in the first metatarsal head, widening of the base of the proximal phalanx, and hypertrophy of the sesamoids are characteristic findings in more advanced stages of hallux rigidus.

■ Rarely, an MRI scan may be necessary to identify an occult chondral or osteochondral injury in a younger patient with a history of an acute injury.

**DIFFERENTIAL DIAGNOSIS**

■ MTP joint synovitis
■ Osteochondral injury or loose body
■ Gouty arthropathy
■ Hallux rigidus

■ Rheumatoid arthritis
■ Turf toe or capsular ligamentous injury

**NONOPERATIVE MANAGEMENT**

■ Conservative management of symptomatic hallux rigidus depends on a patient’s symptoms and the magnitude of the articular degenerative process (see Table 1).

■ NSAIDs and a graphite insole or Morton’s extension to reduce MTP motion are the mainstays of conservative treatment (FIG 5).

■ Several commercially prefabricated orthoses provide rigidity to the forepart of the shoe and can be moved from shoe to shoe.

■ The addition of an extended steel or fiberglass shank placed between the inner and outer sole may be effective in reducing MTP joint motion as well.

■ Custom-made orthoses may be fabricated to reduce midfoot pronation, which also may help to reduce symptoms.

■ Unfortunately, orthoses also diminish available room in the toe box of the shoe, which may, in turn, increase pressure on the dorsal exostosis.

■ Occasionally, judicious use of an intra-articular corticosteroid injection may provide temporary relief of pain.

---

**Table 1**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Characteristics</th>
<th>Radiograph</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>As in grade 3, but with advanced degenerative joint disease</td>
<td></td>
</tr>
</tbody>
</table>

---

**FIG 4** • Lateral radiograph of a patient with hallux rigidus. The arrow points to a large dorsal metatarsal osteophyte.

**FIG 5** • Morton’s extension used to restrict first MTP joint motion.
Repeted injections, however, may accelerate the degenerative process and are discouraged.

- Synovitis and limited MTP joint motion without radiographic changes should be evaluated by ruling out an inflammatory or erosive joint process with the following laboratory tests: serum CBC, ESR, CRP, ANA, RF, HLA-B27, and uric acid tests.

**SURGICAL MANAGEMENT**

- Indications and contraindications for surgery are presented in Table 2.

### Preoperative Planning

- All imaging studies must be carefully evaluated.
- An arthrodesis provides stability to the first MTP joint, maintains length of the first ray, relieves pain, achieves permanent correction of any deformity of the hallux, and allows the use of ordinary shoes.
- For grade 4 hallux rigidus, salvage procedures in addition to MTP joint arthrodesis include excisional arthroplasty, soft tissue interpositional arthroplasty, and prosthetic replacement.
- The Keller procedure may be considered in more sedentary patients or the household ambulator with a grade 3 or 4 hallux rigidus. However, Coughlin and Mann reported significant postoperative metatarsalgia after excisional arthroplasty.

### Positioning

- The patient is placed supine on the operating table with a bump beneath the ipsilateral buttock to align the foot in a neutral position (**FIG 6**).
- A popliteal, sciatic, or ankle block is used for anesthesia.
- An Esmarch bandage is used to exsanguinate the foot and ankle. It is applied as an ankle tourniquet and wrapped just above the malleoli with a thin layer of padding beneath the bandage (**FIG 7**).

### Approach

- Numerous surgical techniques have been proposed describing various approaches, techniques of joint preparation, and methods of internal fixation to improve both the alignment and the success rate of arthrodesis.
While the use of flat surfaces for MTP joint arthrodesis has been popular because of the simplicity of creating horizontal osteotomies of the proximal phalanx and metatarsal articular surfaces, this technique requires utter precision to obtain the desired alignment.

The joint is prepared with a power reaming system coupled with internal fixation with a dorsal plate, providing a strong construct that actually “brings the bones to the plate,” usually ensuring correct alignment (FIG 8).

The convex male reamer excavates the proximal phalanx to a concave congruous surface, while the concave female portion of the reamer shapes the metatarsal surface to a matching uniform, curved hemisphere (FIG 9).

The cup-shaped surfaces tend to resect less bone, reducing shortening of the first ray.

The curved nature of the cup-shaped surfaces allows preparation without predetermination of the dorsiflexion or plantarflexion, rotation, and varus and valgus alignment.

After the joint preparation is completed, the surgeon can then select the appropriate alignment for the MTP joint arthrodesis.

JOINT EXPOSURE

A dorsal longitudinal incision is centered directly over the MTP joint in an interval between the medial and lateral common digital nerves.

The incision is extended from a point just proximal to the interphangeal joint of the hallux to a point 3 to 4 cm proximal to the MTP joint.

The dissection is deepened along the medial aspect of the extensor hallucis longus tendon through the extensor hood and the joint capsule (TECH FIG 1A).

A thorough synovectomy is performed, and the MTP joint is inspected to locate osteophytes or loose bodies and to assess the extent of the articular cartilage damage (TECH FIG 1B).
**JOINT RESECTION AND DECOMPRESSION**

- A thin section of the articular surfaces of the distal first metatarsal and proximal phalanx is removed using a sagittal saw (TECH FIG 2A,B).
- If further shortening of the first ray is desired, more bone may be resected from the metatarsal head.

- By decompressing the MTP joint, increased exposure is achieved for the MTP joint surface preparation.
- A sagittal saw is also used to resect the medial eminence if the fusion is performed for a hallux valgus deformity (TECH FIG 2C).

**METATARSAL HEAD PREPARATION**

- A 0.062-Kirschner wire (K-wire) is driven in a proximal direction at the center of the metatarsal head (TECH FIG 3A).
- The appropriate size of the reamer is chosen by comparing the diaphyseal width of the metatarsal to the inner size of the metatarsal reamer.
- The power reamer engages the K-wire and is then driven in a proximal direction, shaving the metatarsal subchondral surface and metaphysis to a cup-shaped convex surface (TECH FIG 3B).
- Any debris or excess bone along the periphery is removed with a rongeur.
- The K-wire is then removed and used to perforate the prepared metatarsal head in multiple places to increase the surface area for arthrodesis (TECH FIG 3C).
PROXIMAL PHALANGEAL PREPARATION

- A 0.062-inch K-wire is centered on the base of the proximal phalanx and driven distally (TECH FIG 4A).
- The smallest of the convex cannulated phalangeal reamers is then chosen to prepare the phalangeal surface.
- Each successively larger reamer is used to enlarge the phalangeal surface until it matches the size of the prepared metatarsal surface (TECH FIG 4B).
- The K-wire is then removed and used to perforate the prepared phalangeal surface in multiple places to increase the surface area for arthrodesis (TECH FIG 4C).
- Cancellous bone shavings are collected throughout the joint preparation process and saved in a small cup to form a slurry for use as an autograft as the surfaces are coapted.

JOINT ALIGNMENT

- The bone slurry saved from the reamings is placed between the joint surfaces (TECH FIG 5).
- The congruous cancellous joint surfaces are coapted in the desired amount of varus and valgus, dorsiflexion and plantarflexion, and rotation.
- The desired position is 20 to 25 degrees of dorsiflexion, 10 to 15 degrees of valgus, and neutral rotation. For women who prefer high-heeled shoes, increased dorsiflexion at the fusion site may be desirable.
- All angular measurements relate to the axis of the first metatarsal shaft.
- An advantage of using the cup-shaped surface preparation technique is that any dimension may be adjusted without disturbing the other alignment variables.

TECH FIG 4 • A. A K-wire is placed in the center of the base of the proximal phalanx. B. Power reamers prepare the proximal phalangeal joint surface. C. Multiple perforations in the prepared base of the proximal phalanx.

TECH FIG 5 • Cancellous autograft bone reamings are placed between the prepared joint surfaces before fixation.
INTERNAL FIXATION

TECH FIG 6 • Temporary fixation with a 0.062-inch K-wire.

- After obtaining proper alignment, the arthrodesis site is temporarily stabilized with one or two crossed 0.062-inch K-wires (TECH FIG 6).
- A rongeur is used to smooth the dorsal aspect of the first metatarsal and proximal phalanx to allow the plate to sit flush against the bone.
- The primary arthrodesis plate comes pre-bent to the desired dorsiflexion and valgus angles and is placed over the dorsal aspect of the prepared metatarsal and proximal phalanx (TECH FIG 7).
- If more or less dorsiflexion is desired, the plate may be bent further to the desired dorsiflexion.
- If more or less valgus is desired, the plate may be offset slightly to accommodate MTP joint angulation.
- Bicortical self-tapping screws are used first to fix the plate to the metatarsal. Locking screws may be used in the presence of osteopenic bone.
- The plate is then affixed to the proximal phalanx, with the first screw placed in compression.
- The K-wire is then removed, and a cross-compression screw is placed to augment the fixation construct (TECH FIG 8A).
- The general philosophy is that in most cases, the plate can be trusted for appropriate alignment of the arthrodesis.
- Using the flat surface of an instrument cover is helpful to ensure the hallux is in appropriate and acceptable dorsiflexion alignment.
- The capsule and skin are then closed in a routine manner (TECH FIG 8B).

TECH FIG 7 • Precontoured primary arthrodesis plates.

TECH FIG 8 • A. Dorsal plate in place. The compression screw will augment the fixation construct. B. Final wound closure with interrupted mattress sutures.
### POSTOPERATIVE CARE
- The foot is wrapped in a gauze-and-tape compression dressing following the surgery, and the dressing is changed weekly.
- The patient is allowed to ambulate in a wooden-soled postoperative shoe or short walking boot.
- Weight initially is borne on the heel and lateral aspect of the foot.
- If the patient is considered unreliable, a below-knee cast is applied.
- Dressings or casts are discontinued at 12 weeks after surgery with radiographic evidence of a successful MTP joint arthrodesis (FIG 11).

### OUTCOMES
- In seven published series on the use of conical joint preparation and dorsal plate fixation for MTP joint arthrodesis, we have achieved a 95% fusion rate (268/281 first MTP joint arthrodeses).\(^2,3,4,5,8,10,11\)
- The preoperative diagnoses of this multiseries cohort included patients with hallux rigidus (28%); hallux valgus, as a primary, recurrent, or postoperative complication (41%); and rheumatoid arthritis (31%).
- Of the 13 nonunions in this multiseries analysis, only five were symptomatic.
- While the concept of cup-shaped preparation of joint surfaces has changed little over the last two decades except for refinement of power reamer design,\(^1,2,4,9,10,13\) the techniques and design of the dorsal plate fixation have changed dramatically.
- Our initial use of a stainless steel mini-fragment plate witnessed a 34% hardware removal rate (12/35) after fusion, and occasional hardware failure.\(^2\)

### PEARLS AND PITFALLS

| **Joint preparation** | - Results vary depending on the selected method of joint preparation.  
- An enlarged surface area is created by using the cup-shaped reamers.  
- Coupled with this, multiple perforations of the prepared surfaces and the use of a bony slurry aid in increasing the rate of successful joint fusion. |
| **Alignment** | - If the MTP joint is fixed in a straight position (minimal valgus or slight varus), the medial border of the hallux may impact the toe box of the shoe.  
- Dorsiflexion of less than 10 degrees may cause a complaint of pressure at the tip of the toe.  
- Malrotation in either pronation or supination is poorly tolerated (FIG 10).  
- The use of precontoured plates helps to minimize this type of complication. |
| **Internal fixation** | - A variety of methods can be used to stabilize the arthrodesis, including K-wires, single or cross screws, staples, wire sutures, and plates.  
- We have demonstrated a high rate of successful fusion with dorsal plates and a cross-compression screw. |
| **Radiographic parameters** | - Although preoperative radiographs may demonstrate an abnormally widened 1–2 intermetatarsal angle, a first metatarsal osteotomy is rarely if ever indicated in combination with a first MTP joint arthrodesis.  
- Typically, following decompression and arthrodesis of the first MTP joint, the 1–2 intermetatarsal angle will reduce substantially. |

---

**FIG 10** • Neutral rotation of the final arthrodesis. Note that the toenail is parallel to the plantar surface of the foot.

**FIG 11** • AP radiograph of a healed first MTP joint fusion.
More recently, the use of a precontoured low-profile titanium plate has demonstrated a significant reduction in the incidence of hardware removal, to 4% (2/53 cases). Subjective good and excellent results were noted in 92% of cases (260/281 feet). Overall, 48 patients were noted to have slight progression of interphalangeal joint arthritis, but only six were symptomatic.

COMPLICATIONS
- Nonunion
- Malunion
- Hardware failure
- Interphalangeal joint arthritis

REFERENCES
DEFINITION
- Disorders of the first ray are a common cause of foot and ankle problems. Arthrodesis of the hallux metatarsophalangeal (MTP) joint is a utilitarian technique in contemporary foot and ankle surgery.
- Arthrodesis can effectively address a variety of conditions affecting the hallux, including deformity, inflammatory and degenerative arthritides, spasticity and neuromuscular disorders, and salvage of failed surgeries.
- The most important aspect of this procedure is optimal positioning of the toe during first MTP joint arthrodesis.

ANATOMY
- The bony anatomy of the first MTP joint includes the rounded first metatarsal head, which articulates with the concave, elliptically shaped base of the proximal phalanx.
- Two longitudinal grooves separated by the crista, a central prominence, are located on the plantar surface of the metatarsal head. The two sesamoid bones contained in the medial and lateral tendon slips of the flexor hallucis brevis articulate with their corresponding longitudinal grooves on the inferior surface of the first metatarsal head. The flexor hallucis longus tendon runs between the two sesamoids, bypassing the MTP joint to insert distally onto the distal phalangeal base.
- The extensor hallucis brevis tendon inserts into the dorsal MTP capsule and the extensor hallucis longus runs distally to insert onto the distal phalanx.
- The strong, fan-shaped collateral ligaments of the MTP joint originate medially and laterally from the metatarsal head and run distally and plantarward to the base of the proximal phalanx. The metatarsosesamoid ligaments fan out in a plantar direction to the margin of the sesamoid and the plantar pad.
- Distally, the two sesamoids are attached by the fibrous plantar plate to the base of the proximal phalanx, stabilizing the joint plantarly (FIG 1).

PATHOGENESIS
- Common forms of degenerative arthritis that affect the hallux MTP joint include hallux rigidus and posttraumatic arthritis. Hallux rigidus may be the result of isolated trauma, with forced hyperextension and resultant chondral injury, or the result of repetitive microtrauma of the articular cartilage. Pathologic alteration in the kinematics of the first MTP joint also may lead to degenerative changes.
- Chondral erosion or loss is seen dorsally on the metatarsal head and phalangeal base.
- Inflammatory arthropathies can affect the hallux MTP joint, necessitating fusion. Common causes include rheumatoid arthritis, psoriatic arthritis, and gout.
arthritis, gouty arthropathy, lupus, and seronegative spondyloarthropathies. Repetitive episodes of synovitis lead to chondral loss and joint narrowing.

- Progressive hallux valgus or hallux varus with severe deformity, spasticity (secondary to neurologic conditions), soft tissue contracture, or arthritis, or that occurring in elderly patients, also may benefit from MTP arthrodesis.

**NATURAL HISTORY**

- Hallux rigidus and degenerative arthritis present with progressive pain, stiffness, and osteophyte formation of the MTP joint.
- Initial symptoms of inflammatory arthritides include pain and swelling from MTP synovitis; progressive disease is marked by worsening stiffness, pain, and deformity.
- Hallux valgus or hallux varus deformities typically are flexible in the early stage, but over time these deformities tend to become progressively more rigid secondary to joint contracture.
- All of these conditions can produce pain, difficulty with ambulation, and transfer metatarsalgia to the lesser toes.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Patient history
  - Pain and mechanical symptoms on ambulation in hallux rigidus and degenerative arthritis
  - Pain at rest or in the morning with inflammatory arthritis
  - Pain with shoe wear over the hallux or medial eminence (bunion)
  - Some patients complain of the prominence over the first MTP joint.
- Physical findings
  - Careful interview of the patient to identify contributing medical conditions, shoe wear history, previous treatment methods, and previous surgical procedures
  - Standing examination of the foot to assess for malalignment of the toe, including varus, valgus, or claw deformity
  - Gait examination to identify dynamic deformity of the foot, including forefoot supination or generalized pes planovalgus
  - Visible shortening of the hallux, failure of the toe to engage the ground, and lesser toe metatarsalgia or keratosis (callus) indicate mechanical unloading of the first ray.
  - Examination of the seated patient allows observation for callus, skin irritation, or presence of dorsal or medial bunion.
  - Palpation elicits tenderness about the joint. Hallux rigidus typically is tender dorsally, whereas the pain with hallux valgus is located medially over the bunion. Generalized degenerative or inflammatory arthritides exhibit diffuse tenderness about the MTP joint, and axial grinding of the phalanx against the metatarsal elicits pain.
  - Manipulation of the joint is performed to assess stability of the collateral ligaments and the relative flexibility or rigidity of varus or valgus toe deformity.
  - Range-of-motion examination often shows limited passive MTP dorsiflexion, with normal or reduced plantarflexion.
  - Skin irritation may be present over the dorsal exostosis or medial bunion.
  - Tingling, hypesthesias, or a positive Tinel (percussion) sign over the dorsal hallucal nerve may indicate nerve compression from synovitis or dorsal osteophytes.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standing AP, lateral, and oblique radiographs are the standard views for evaluation. Additional views, such as an oblique or sesamoid view, sometimes are indicated.
- The weight-bearing AP view is obtained to determine the overall alignment of the MTP joint. It also can be assessed for the extent of arthritic involvement, including joint narrowing, flattening of the metatarsal head, and the presence of subchondral sclerosis, erosions or cystic changes within the metatarsal head, osteopenia, or bone loss (FIG 2). This view can also facilitate evaluation of shortening of the first ray relative to the lesser metatarsals. The oblique view also can illuminate these findings.
- The lateral weight-bearing view can show dorsal metatarsal or phalangeal osteophytes and can be used to evaluate the degree of joint narrowing (particularly plantarly) and the presence of an elevated first metatarsal (FIG 3). However, the plantar two thirds of the joint can be obscured by overlapping shadows of the lesser metatarsals.
- An axial sesamoid view can be an adjunctive radiograph for evaluating the metatarsal–sesamoidal articulation for...
narrowing or cystic changes, although involvement of the metatarsosesamoid joint occurs infrequently, except with severe arthrosis.

- Additional imaging studies, such as CT or MRI, rarely are necessary. However, such scans may be useful for defining the degree of cyst involvement or avascular necrosis of the metatarsal head, which indicates the need for intraoperative bone grafting.

DIFFERENTIAL DIAGNOSIS

- Arthrodesis is appropriate for surgical correction of the following conditions:
  - Osteoarthritis or posttraumatic arthritis
  - Hallux rigidus
  - Severe hallux valgus, particularly in elderly patients
  - Hallux varus caused by inflammatory disorders, iatrogenic deformity after previous surgery, or idiopathic involvement
  - Inflammatory arthropathies, including rheumatoid arthritis, lupus, gout, and seronegative spondyloarthropathies
  - Soft tissue contracture, as in scleroderma
  - Deformity secondary to neurologic conditions or spasticity, such as that occurring in patients with diabetes or those who have experienced a stroke

NONOPERATIVE MANAGEMENT

- Nonoperative measures to be attempted before MTP arthrodesis include:
  - Nonsteroidal anti-inflammatory drugs to decrease joint pain and inflammation
  - Judicious use of corticosteroid injections into the hallux MTP joint to relieve synovitis, although repeated injections are not advised
  - The use of silicone gel, cotton wool, or felt pads to relieve pressure from calluses or impingement against the shoe or adjacent toe
  - Strapping or taping of the hallux may be useful for flexible deformities.
  - Comfortable shoe wear with low heels and wide toe box; extra-depth shoes may allow use of an orthotic device. Shoe modifications, such as a stiff sole or metatarsal bar, may unload the forefoot during push-off.
  - A full-length orthotic insole with a carbon fiber or stainless steel extension may limit the motion of a painful MTP joint in hallux rigidus.
  - Custom accommodative orthotic insole with a build-up under the hallux may improve weight bearing of a shortened or dorsiflexed first ray to diminish transfer metatarsalgia.

SURGICAL MANAGEMENT

- In situ hallux MTP arthrodesis is a utilitarian technique with a wide range of indications.1–8,13,15–19,22
  - Absolute contraindications include active infection of the MTP joint, severe peripheral vascular disease, and poor soft tissue envelope secondary to systemic disease or scar tissue. In such patients, a joint-sparing procedure would be more appropriate.
  - A relative contraindication to MTP arthrodesis is symptomatic interphalangeal joint arthritis; however, concurrent arthrodesis of both joints has been described.20

Preoperative Planning

- Radiographs are assessed for extensive bony lysis, erosions, or cysts that may require bone grafting.
  - Severe bone loss, shortening, or failed implant arthroplasty may require distraction MTP arthrodesis with bulk bone graft, discussed elsewhere.
  - Standard arthrodesis can be performed under general, spinal, or regional anesthesia, such as a popliteal or ankle block.
  - We prefer to administer an ankle block in conjunction with sedation, using a 1:1 mixture of 2% lidocaine and 0.5% ropivacaine, via a 26-gauge needle.

Positioning

- The patient is positioned supine with a roll under the ipsilateral hip.
- The procedure can be performed without a tourniquet or with a pneumatic calf or thigh tourniquet. Alternatively, an Esmarch tourniquet can be applied at the supramalleolar ankle over cotton padding, which is our preferred technique.

Approach

- Our preferred approach is a dorsal incision centered over the MTP joint.
  - An alternate approach is the medial midline incision, based on the surgeon’s preference or whether a previous surgical scar exists.

IN SITU ARTHRODESIS OF THE HALLUX MTP JOINT WITH CROSSED-SCREW FIXATION

Incision and Exposure

- Make a dorsal incision over the MTP joint just medial to the extensor hallucis longus tendon.1,4,8,10,17,18
  - Release the collateral ligaments and the plantar portion of the joint by releasing the plantar plate with a Freer elevator.
  - Remove large osteophytes and loose ossicles with a rongeur.
  - Resect the medial eminence from a dorsal approach with a microsagittal saw or chisel.4,7,17,18

- Carry the dissection down to the joint capsule, avoiding the dorsomedial cutaneous nerve, a terminal branch of the superficial peroneal nerve.3
  - Retract the extensor hallucis longus tendon laterally and perform an arthroscopy directly over the MTP joint.
  - Perform subperiosteal dissection to raise medial and lateral flaps off the metatarsal head and base of the proximal phalanx, exposing the joint (TECH FIG 1).3,5–7,16–18

- Esmarch tourniquet can be applied at the supramalleolar ankle.
  - The procedure can be performed without a tourniquet or with a pneumatic calf or thigh tourniquet. Alternatively, an Esmarch tourniquet can be applied at the supramalleolar ankle over cotton padding, which is our preferred technique.

Joint Preparation

- Prepare the joint surfaces for arthrodesis with a power burr or specialized reamers.
Biomechanically, spherical surfaces provide for improved stability compared with flat cuts. Hemispherical surfaces also provide more freedom for positioning the arthrodesis compared with flat saw cuts.

Using a power burr, prepare the joint surfaces in a ball-and-cup fashion by removing the chondral surfaces.

Shape the subchondral surface hemispherically, with the metatarsal head convex and the phalangeal base concave (TECH FIG 2). Carefully avoid excessive bony resection, particularly in osteopenic or rheumatoid patients, to prevent additional shortening of the toe.

An alternative method of joint preparation is to use specialized reamers that produce similar hemispheric surfaces (TECH FIG 3).

Using concentric reamers, plantarflex the proximal phalanx and insert a Kirschner wire axially in the center of the metatarsal head.

Use a cannulated, concave-shaped reamer to prepare the metatarsal head.

Remove the wire and then insert it in the proximal phalanx, and use a cannulated convex reamer.

A final method of joint preparation is with flat cuts using a saw blade.

Resect the ends of the metatarsal head and base of the phalanx, incorporating the chondral surfaces, with the cuts angled appropriately to produce the proper angles for subsequent positioning.

Create multiple drill holes in the metatarsal head and phalangeal base with a Kirschner wire or small drill bit to augment bleeding and bony ingrowth.

Arthrodesis Positioning and Fixation

After preparing the joint surfaces, position the arthrodesis in 10 to 15 degrees of valgus, 15 degrees of dorsiflexion relative to the sole of the foot, and neutral pronation–supination.

Because it can be difficult to determine the plane of the sole with the patient on the table, a more predictable method of positioning the toe is to determine dorsiflexion relative to the first metatarsal axis. In most cases, the appropriate angle is about 25 to 30 degrees of dorsiflexion.

The hallux is held provisionally with Kirschner wires or partially threaded guidewires from a cannulated screw set.

Confirm the positioning radiographically with a mini-fluoroscopy unit and clinically with use of a flat surface to simulate weight bearing (the cover of the screw set tray works nicely).

The hallux should be slightly off the surface with the heel on the cover (TECH FIG 4).

Placing a screwdriver handle under the heel simulates a shoe with a small heel; in this case, the pulp

---

** TECH FIG 1 •** Exposure of metatarsal head through dorsal approach. The extensor hallucis longus tendon is retracted laterally with the exposed metatarsal head, showing a large dorsal osteophyte and loss of articular cartilage.

** TECH FIG 2 •** Joint preparation with power burr. The metatarsal head is shaped hemispherically in a convex manner to fuse with the concave base of the proximal phalanx.

** TECH FIG 3 •** Alternative technique for joint preparation with specialized reamers. The Kirschner wire is placed in the center of the head to ensure concentric joint preparation.

** TECH FIG 4 •** Positioning of the first metatarsophalangeal joint. A flat surface is used to position the toe properly. Note the positioning of the toe to allow for adequate clearance during gait.
of the distal hallux should just barely engage the surface.

- Cannulated or solid screws can be used per the surgeon’s preference. We use 4.0-mm cannulated screws in most patients; however, in some situations, such as for very large individuals, 4.5-mm screws can be used. Solid 3.5-mm cortical screws are an alternative (TECH FIG 5).

- Insert one guidewire from the medial aspect of the phalangeal base just distal to the metaphyseal flare and advance it across the arthrodesis site through the dorsolateral cortex of the metatarsal neck.

- Place the second wire from the medial aspect of the metatarsal neck, just proximal to the flare of the medial eminence; advance this wire distally and slightly plantarly across the arthrodesis site to engage the plantar–lateral cortex of the phalanx.

- Check wire position and length with fluoroscopy.

- Measure the wires percutaneously with the cannulated depth gauge and overdrip them with the cannulated drill bit. Then, countersink the cortex carefully to prevent subsequent cracking with screw placement.3

- Place the partially threaded cannulated screws over the guidewires while compressing the hallux manually.
- Alternatively, insert solid lag screws under fluoroscopic guidance.

- In the event of suboptimal fixation or in patients with osteopenic bone (eg, secondary to rheumatoid arthritis or chronic oral corticosteroid usage), a dorsal plate can be used for augmented fixation.

- This plate can be a precontoured, commercially available hallux MTP fusion plate or a standard mini-fragment plate that is cut and contoured to fit, and then affixed to the dorsal surface of the metatarsal and phalanx with small-diameter screws (eg, 2.7 mm) (TECH FIG 6).

- Close the incision in layers with absorbable suture for the arthrotomy and subcutaneous layers and nonabsorbable monofilament for the skin.

**ALTERNATIVE TECHNIQUE**

- A medial incision over the hallux MTP joint can be used in the presence of a previous surgical scar or at the surgeon’s preference.
- Carry out dissection at the level of the joint capsule, taking care to avoid the dorsomedial branch of the superficial peroneal nerve with elevation of the flap.
- Perform a midline arthrotomy to expose the metatarsal head and base of the proximal phalanx.21
- Prepare the joint surfaces with a saw blade.21

- To allow for correct positioning, make the cut on the metatarsal head perpendicular to the sole of the foot, and avoid resecting excessive bone when making the cut on the proximal phalanx. Then, position the hallux, with attention to all three planes as described above.
- Perform fixation with the crossed-lag-screw technique as described above, with supplemental dorsal plate fixation as needed.
PEARLS AND PITFALLS

| Arthrodesis preparation | ▪ To prevent shortening, avoid excessive bone resection. |
| Hallux positioning | ▪ Intraoperatively, the position of the hallux is assessed fluoroscopically and clinically with a flat surface to simulate weight bearing. Proper positioning includes valgus of 10 to 15 degrees, dorsiflexion of 25 to 30 degrees relative to the metatarsal shaft (or 15 degrees relative to the sole of the foot), and neutral rotation. Clinically, the hallux should not impinge on the second toe and the nail plate should be aligned with the same plane as the lesser toes. |
| Guide pin breakage | ▪ Maintain correct positioning of the hallux during insertion of the guide pin. Avoid bending and shearing of the wire during cannulated drilling. |
| Fixation problems | ▪ When arthrodesis is performed on osteopenic bone, requiring additional fixation with a dorsal plate, additional Kirschner wires or threaded pins may be necessary to supplement standard crossed screws. Before the patient leaves the operating room, intraoperative fluoroscopy must be used in a biplanar fashion to identify fixation problems. |

POSTOPERATIVE CARE

▪ In patients with an isolated arthrodesis that has good bone quality and solid fixation, weight bearing as tolerated on the heel and lateral border of the foot is allowed in a postoperative hard-soled shoe or fracture boot, restricting weight bearing on the forefoot.
▪ If there are concerns about bone quality, suboptimal fixation, or potential noncompliance by the patient, strict non–weight-bearing in a below-the-knee cast is maintained for 6 to 8 weeks.
▪ After 6 to 8 weeks, partial weight bearing is advanced, based on evidence of clinical and radiographic healing.
▪ Full weight bearing usually is achieved by 10 to 12 weeks, at which time the patient transitions from the postoperative shoe or boot into sneakers or comfortable, low-heeled walking shoes.
▪ At 14 to 16 weeks, with additional reduction in swelling, most patients can transition into unrestricted shoe wear; however, some individuals have permanent difficulty wearing fashion shoes or high heels.
▪ Prolonged walking and athletic activities usually resumes at 4 to 5 months.
▪ Custom-made orthotics with a build-up under the hallux to improve weight bearing of the first ray may dissipate forefoot stresses.

OUTCOMES

▪ The clinical results after hallux MTP arthrodesis usually are excellent, with high rates of bony union, patient satisfaction, and pain relief.
▪ Union rates for in situ arthrodesis range from 77% to 100%. Patient satisfaction rates also are high, regardless of the indications.
▪ MTP arthrodesis causes a rigid lever arm, resulting in an earlier toe-off in the gait cycle and decreasing the stress on the lesser metatarsals. This stiffness may result in increased stress across the hallux interphalangeal joint.
▪ After arthrodesis, the first ray shows improved weight-bearing capacity, with the foot compensating for the relative stiffness during stance phase.

COMPlications

▪ Nonunion rates range from 5% to 10%. Nonunion may not be symptomatic and may not require revision surgery.
▪ Malunion after MTP arthrodesis can result in mild malalignment that is tolerated, but more severe malposition may be symptomatic.
▪ Excessive dorsiflexion leads to unloading of the hallux and lesser toe transfer metatarsalgia.
▪ Positioning the hallux in relative plantarflexion may lead to interphalangeal joint irritation, callus formation, and later interphalangeal arthritis.
▪ Valgus positioning can lead to painful impingement on the second toe, whereas varus positioning causes impingement of the hallux against the toe box of the shoe.
▪ Subsequent arthritis of the interphalangeal joint may occur in one third of cases.
▪ Arthritis in the interphalangeal joint is more common than that of the first tarsometatarsal or other midfoot joints.
▪ However, symptoms may be mild despite radiographic involvement and may take 10 years to develop.
▪ Severe symptoms may require secondary interphalangeal arthrodesis, which leads to extreme stiffness of the hallux.
▪ Iatrogenic nerve injuries of the dorsomedial cutaneous nerve are more common than injuries to the plantar nerves.
▪ These may result in neuroma formation, mild numbness, or persistent dysesthesias that compromise an otherwise successful arthrodesis.
▪ Prevention by proper incision placement and meticulous surgical dissection remains the best strategy.

REFERENCES

DEFINITION

- Revision first metatarsophalangeal joint (MTPJ) arthrodesis is performed for pain or deformity following failed hallux valgus surgery, excisional arthroplasty, or prosthetic arthroplasty, and for nonunion or malunion following primary first MTPJ arthrodesis, when a trial of conservative treatment has been unsuccessful.

- As is the case for a primary arthrodesis, many techniques for preparation of the joint exist, all designed to provide good cancellous apposition. If possible, in revision surgery, it is better not to shorten and reduce the remaining bone stock.

- Ball-and-socket preparation with reamers should be considered for failed hallux valgus surgery and nonunion of the first MTPJ as a way to achieve cancellous congruency with a large contact surface area. However, this may not be possible: e.g., in the case of malunions, flat cuts should be performed.

- In cases of failed Silastic (Dow Corning, Midland, MI) arthroplasty, the defect should be curettaged until normal bone is reached. This creates a defect that will require a ball-shaped interposition cancellous graft.

- After a previous excisional arthroplasty with a large resection of the proximal phalanx, a tricortical interposition graft can be used to try to regain length.

- Many techniques exist for achieving fixation of the MTPJ. The use of a low-profile precontoured titanium plate and, when possible, a compression screw achieves a very stable construct, without the need to traverse the interphalangeal (IP) joint with threaded pins,1–3 which can produce postoperative stiffness in that joint. Such a plate must have the facility to give strong stable fixation to the remaining short proximal phalanx and allow fixation of an interposition graft.

ANATOMY

- In revision surgery, normal anatomy may be severely disrupted. The first metatarsal length may be lost, the metatarsal head may be avascular, and the proximal phalanx may be short or have poor bone stock.

- The aim in revision arthrodesis is to create a painless and solid medial column, of a length that is appropriate to the foot, that provides a stable medial arch and a plantigrade foot that prevents load transfer to the lesser rays.

- Complex foot deformities may have additional problems with the alignment of the lesser toes. These should be corrected first, before the final hallux valgus arthrodesis angle is set.

- As in primary arthrodesis, the final position of the arthrodesed first MTPJ must allow for heel rise during the late stance phase of gait. Therefore, the tip of the toe should be clear of the weight-bearing surface with the IP joint in full extension. The tip of the hallux also should be able to touch the ground in midstance, simulated at surgery with the ankle at 90 degrees and a flat surface applied to the sole of the foot. In this position, the tip of the toe should be able to touch the flat surface with the IP joint in 45 to 60 degrees of flexion. In addition, a gap of 3 to 5 mm should be left between the first and second toes.

PATHOGENESIS

- Failed hallux valgus surgery may result in recurrent deformity, avascular necrosis of the metatarsal head, or pain and stiffness secondary to accelerated degeneration of the first MTPJ.

- Failed resection arthroplasty may result in recurrent valgus deformity, a cock-up deformity, or a flail toe4 (FIGS 1 AND 2).

- Failed Silastic arthroplasty may result in an aggressive foreign body reaction with bone loss on one or both sides of the joint, depending on whether a single- or double-stemmed implant was used.

- Failed primary arthrodesis can lead to a painful deformity and hardware impingement. A fusion that is too straight leads to a painful callus under the condyles of the proximal phalanx; one that is too dorsiflexed leads to a painful callus on the dorsum of the IP joint.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough physical examination of the foot and ankle is necessary before a first MTPJ revision arthrodesis is begun.

- Any history of cigarette smoking should be documented and the patient cautioned about nonunion.

- Peripheral circulation and sensation must be tested.

- The age and site of previous scars should be noted so the safest approach may be planned.

- The IP joint, MTP joint, and first tarsometatarsal (TMT) joint should be examined as for primary arthrodesis.
IMAGING AND OTHER DIAGNOSTIC STUDIES

- If infection is suspected, it should be ruled out before surgery. A differential white cell count, C-reactive protein level, and erythrocyte sedimentation rate should be obtained. An isotope bone scan may be helpful, but it can be hot for nonunion or infection.
- Weight-bearing anteroposterior (AP) and lateral radiographs should be obtained for preoperative planning. Particular attention should be paid to the extent of bone loss from the proximal phalanx and metatarsal head, where an oblique radiograph may give more information. The severity of any deformity should be noted and any coexisting forefoot pathology identified and addressed at the time of surgery.
- If avascular necrosis is suspected, an MRI may be useful as long as the patient has no metallic implants.

NONOPERATIVE MANAGEMENT

- Nonoperative management encompasses activity modification, weight reduction, analgesic and anti-inflammatory medication (oral and intra-articular), physical therapy (e.g., tendo Achilles and hamstring stretching), functional foot orthoses, and customized shoes.
- Functional foot orthoses may include a stiffened insole with a Morton’s extension to limit dorsiflexion of the hallux, a medial arch support, and a metatarsal dome.
- Customized shoes may include an extra-deep toe box, bunion pockets, or a stiffened sole with a metatarsal rocker.

SURGICAL MANAGEMENT

- Revision arthrodesis of the first MTPJ does not restore normal anatomy or gait pattern. The risks of nonunion, infection, neuroma formation, and vascular complications are greater than for primary arthrodesis. Time to union increases in proportion to the size of interposition graft required (i.e., a larger graft takes longer to become incorporated). The patient should be counseled toward realistic outcomes.
- Absolute contraindications to revision first MTPJ fusion include active infection and peripheral vascular disease.
- Relative contraindications to first MTPJ fusion include degeneration of the first TMT and IP joints or peripheral neuropathy.

Preoperative Planning

- Following a thorough examination to assess circulation, sensation, the first TMTJ, the IP joint, the lesser toes, and the skin (for previous surgical incisions or callus under the metatarsal heads), weight-bearing AP and lateral radiographs of the forefoot should be obtained.
- The extent of bone loss should be noted and the patient prepared and draped for harvesting iliac crest bone graft. We prefer to use the ipsilateral crest to limit postoperative disability to one side only.
- Any lesser toe deformity should be addressed before performing the arthrodesis so that the hallux may be set at the correct valgus angle to the neighboring toes and painful transfer lesions alleviated. The lesser toes may be clawed or hammered with subluxation or dislocation of the MTPJs. Provision should be made to perform proximal interphalangeal joint arthrodesis, MTPJ capsulotomy, extensor digitorum longus lengthening, plantar condylectomy, or Weil’s osteotomies, as required. A Weil’s osteotomy of the second metatarsal head should never be performed in isolation: an osteotomy of the third metatarsal head must accompany it to prevent transfer metatarsalgia to the third metatarsal head.
- A rheumatology consultation or preoperative anesthetic assessment should be done if necessary.

Positioning

- We prefer to position the patient supine with the heels at the end of the operating table. If bone graft is required, a sandbag is placed under the ipsilateral buttock.
- Prophylactic intravenous antibiotics are administered at induction of anesthesia. A thigh tourniquet is put in place after the limb has been exsanguinated. The iliac crest and leg are then prepared and draped in a routine manner.
- The end of the table is dropped 20 to 30 degrees, and the surgeon sits at the end of the table.

Approach

- A dorsal approach incorporating previous dorsal scars is recommended. The tissues should be handled carefully. Self-retaining retractors should be positioned under low tension for short periods of time only, particularly if the hallux is then held in forced plantarflexion. Excessive retraction with bone levers must be avoided.
- Because previous surgery may have caused intense scarring of the tissues, when possible, full-thickness flaps are raised off the metatarsus and proximal phalanx. Care should be taken to protect the dorsal cutaneous nerve and extensor hallucis longus and the terminal branch of the deep peroneal nerve in the first web space.
REVISION ARTHRODESIS OF THE FIRST METATARSOPHALANGEAL JOINT USING A DORSAL TITANIUM CONTOURED PLATE (HALLU-S PLATE; NEWDEAL, SAINT PRIEST, FRANCE)

- Ideally, a dorsal, slightly curved incision is made just medial to the extensor hallucis longus tendon and lateral to the dorsal cutaneous nerve, extending from the middle of the shaft of the first metatarsal to the interphalangeal joint.
- The extensor hallucis longus tendon is retracted laterally.
- A capsulotomy is made in the same plane, and the joint exposed.
- Any previous metalwork or implants are removed.
- A synovectomy is performed, along with excision of any avascular bone.
- The medial and lateral soft tissues are released to allow maximum plantarflexion of the proximal phalanx so as to fully expose both surfaces to be arthrodesed.

PREPARATION OF THE DISTAL FIRST METATARSAL AND PROXIMAL PHALANX

- Preparation of the surfaces and graft techniques vary according to the nature of revision.
- Revision of nonunion of a primary arthrodesis, failed hallux valgus surgery, or failed excision arthroplasty (where there has been minimal resection of the proximal phalanx)
- In these cases, where bone graft is not required, the arthrodesis site can be prepared with ball-and-socket reamers in a fashion similar to that for a primary arthrodesis. Osteophytes are excised, and the proximal phalanx is sized to determine the correct convex reamer. The proximal phalanx is reamed over a 1.6-mm guidewire. A size-matched concave reamer is used to prepare the metatarsal head in a similar manner (TECH FIG 1).
- Revision of malunion of primary arthrodesis
  - These cases are revised because the hallux is either too dorsiflexed or too plantarflexed. A simple closing wedge with flat cuts can be performed with the apex at the original arthrodesis site (TECH FIG 2).

TECH FIG 1 • A. Reaming the articular surface of the proximal phalanx. B. Reaming the articular surface of the metatarsal head.

TECH FIG 2 • Revision of malunion.
Chapter 26  REVISION FIRST METATARSPHALANGEAL JOINT ARTHRODESIS 3653

**COMPLEX REVISION CASES**

- When the residual deficit in bone stock is such that the first ray is short and defunctioned, then either a tricortical iliac crest bone graft or a ball-shaped cancellous graft is required.
- The aim is to arthrodese the hallux in the best functional position. This position is determined as follows.
  - The geometry of the hallux is assessed by placing a flat surface against the sole of the foot and bringing the ankle to 90 degrees.
  - In this position, with the IP joint in full extension, the tip of the hallux should lie about 1 cm from the flat surface.
  - When the IP joint is flexed to 45 to 60 degrees, its tip comes in contact with the plantar surface. There should be a gap of 3 to 5 mm between the hallux and the second toe.
  - The rotation of the hallux should be neutral so that the arc of rotation of the IP joint is at 90 degrees to the weight-bearing surface.

- **Revision for failed excision arthroplasty**
  - Bone from the distal first metatarsal is resected back to vascular cancellous bone with an oscillating saw. A flat surface is placed on the sole of the foot. The osteotomy is performed in the coronal plane and in the sagittal plane, at 90 degrees to the flat surface.
  - Bone from the proximal phalanx is resected back to vascular cancellous bone with an oscillating saw, perpendicular to its long axis (TECH FIG 3).
  - The hallux is held in an estimated best position. The gap between the flat surfaces of the proximal phalanx and metatarsal head is measured. An appropriately sized tricortical iliac crest bone graft is harvested from the ipsilateral crest in a standard fashion.

- **Revision for avascular necrosis following hallux valgus surgery**
  - The distal first metatarsal and distal phalanx are prepared as previously described.
  - A retrograde 1.6-mm K-wire is passed through the proximal phalanx and retrieved distally. The hallux is held in the estimated correct position and the K-wire driven into the remaining metatarsal shaft.
  - A trough is cut out of the dorsum of each bone using the underlying K-wire as an alignment guide. The dimensions of the trough are measured, and the K-wire is then removed.

- **Revision of failed prosthetic arthroplasty**
  - Following curettage to normal bone, a considerable champagne-glass defect usually is present in each bone.
  - The defects are impaction grafted to create concave surfaces.
  - The hallux is again held in an estimated best position. A ball-shaped cancellous graft of sufficient size to fill the defect is prepared (TECH FIG 5).
POSITIONING OF THE HALLUX

- In simple revision cases, the hallux is positioned as for primary arthrodesis. The correct position of the hallux is confirmed by placing a flat surface against the sole of the foot and bringing the ankle to 90 degrees. In this position, with the IP joint in full extension, the tip of the hallux lies about 1 cm from the flat surface. When the IP joint is flexed to 45 to 60 degrees, its tip comes in contact with the plantar surface. This enables the foot to rock at the MTPJ on heel rise.

- If a graft is used, it is positioned in the arthrodesis site and the alignment of the hallux is reassessed using a flat surface against the sole of the foot, as described earlier. The interposition graft is trimmed as required to achieve the correct position of the hallux and the whole construct held with temporary K-wires.

FIXATION OF THE ARTHRODESIS

- When bone graft is not required, an oblique 2.7-mm compression screw of appropriate length is inserted from distal medial to proximal lateral across the MTPJ before a dorsal titanium precontoured low profile plate is secured.

- When an interposition graft is used, it may be necessary to reposition the temporary K-wire fixation to allow positioning of a trial plate. The plate is available in three size-specific sizes (small, medium, and large). In revision arthrodesis the large size usually is required for men, medium for women, and small if no interposition graft is used.

- The dorsum of the MTP joint may require feathering down with the oscillating saw to enable a flush fit, or the plate may need slight adjustment. If the hallux length has not been fully restored, then the plate needs to be straightened.

- The plate is now secured on the dorsal aspect of the joint with a K-wire and fixed with six to seven 2.7-mm–diameter self-tapping screws. The interposition graft is secured to the plate with one screw (see Fig 2).

- If the bone quality is poor and screw purchase is insufficient, 3-mm–diameter rescue screws can be used.

- The wound is closed in layers over a drain.

- A compression dressing is applied.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Silicone synovitis</th>
<th>The centers of the defects are packed with loose cancellous graft to create a shallow, saucer-like deficiency. The iliac crest graft should then be shaped to form a ball.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failed Keller-Brandes procedure</td>
<td>Tricortical graft is required.</td>
</tr>
<tr>
<td>Avascular necrosis</td>
<td>A trough is created and tricortical inlay graft is used.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- We prefer to use a compressive dressing and a postoperative stiff-soled shoe to allow early mobilization with careful heel weight bearing only.

- Early stretching of the tendo Achilles and range-of-motion exercises of the IP joint are encouraged.

- In revision cases, patients are kept non–weight-bearing for 4 weeks and then encouraged to bear weight by heel-walking for 4 weeks. Radiographs at this stage may show consolidation if bone graft has not been used.

- At 8 weeks post surgery, a radiograph is obtained. If there is evidence of consolidation, forefoot weight bearing is commenced in the postoperative shoe. Progression to full forefoot loading, assisted by crutches, follows over the next 4 weeks.

- Radiographs are taken 12 weeks post surgery. If these confirm consolidation, flat shoes with cushioned or shock-absorbing soles are worn.

- The time to union depends on the size of bone graft. Forefoot loading should commence only when there is some evidence of consolidation. Patients should be informed that the entire process can take up to 6 months, particularly if there has been a large defect filled with graft or there has been avascular necrosis.

OUTCOMES

- Time to union varies according to the patient’s underlying medical condition and smoking habits, and in direct relationship to the size of graft used.

- The precontoured low-profile titanium plate used was originally designed to obtain the maximum possible purchase in a shortened proximal phalanx, following a Keller’s procedure. In both the metatarsal and phalangeal ends, the three screws are on three different axes, to maximize pull-out strength. Additional holes are available to purchase the central graft. This fixation strength cannot be equalled with a single-axis dorsal plate.

COMPLICATIONS

- Infection

- IP joint stiffness
- Delayed union or nonunion
- Extensor hallucis longus tenodesis
- Dorsomedial sensory cutaneous nerve injury

REFERENCES


DEFINITION

■ First metatarsophalangeal arthrodesis is a reasonable alternative to a joint-sparing procedure in salvage of various great toe deformities.

■ These deformities comprise failed hallux valgus procedures, avascular necrosis of the metatarsal head, failed first metatarsophalangeal (MTP) joint arthroplasty, prior infection, rheumatoid arthritis, posttraumatic conditions, hallux rigidus, severe hallux valgus deformities, and neuromuscular disorders.

■ With minimal to moderate bone loss, we perform hallux MTP joint arthrodesis in situ, accepting slight shortening of the hallux. In our opinion, the slight shortening creates minimal cosmetic concerns and affords satisfactory functional improvement in a majority of cases.

■ With marked shortening of the hallux and associated lesser metatarsalgia, an in-situ hallux MTP joint arthrodesis may fail to restore satisfactory function.

■ We favor interposition structural bone graft to restore first ray length, which, in turn, should improve the weight bearing of the first metatarsal and hallux while alleviating lesser metatarsalgia.

■ Sources for structural interposition bone block arthrodesis include (a) structural allograft (usually contoured from a donor femoral head or iliac crest) or (b) structural autograft (typically obtained from the patient’s iliac crest). In our hands, ipsilateral anterior iliac crest harvesting is ideal for foot and ankle surgery because this site is readily accessible in the patient positioned supine on the operating table.

■ Several configurations have been described for contouring the interpositional graft. We prefer the ball-and-socket technique, which affords three advantages over flat cuts or a conical preparation: (a) minimal resection of residual host bone, (b) optimal surface area at both ends of the graft for healing, and (c) relative ease of positioning the toe after preparing the arthrodesis without forfeiting contact area for fusion.

PATHOGENESIS

■ In our referral practice, we most commonly use the ball-and-socket interpositional bone block distraction technique for severe bone loss after:
  - Keller-Brandes procedure (FIG 1A), resection of the base of the proximal phalanx (this generally creates bone loss isolated to the hallux and not globally in the first ray)
  - Mayo procedure (FIG 1B), resection of the first metatarsal head (creates a more global bone loss in the first ray)
  - The Keller-Brandes and Mayo procedures have for the most part been abandoned because of their detrimental effects on forefoot function and the introduction of modern procedures that preserve anatomy.

■ Avascular necrosis of the first metatarsal head (FIG 1C), a relatively rare complication of a distal chevron osteotomy

■ Bone destruction after first MTP joint arthroplasty, particularly silicone implants (FIG 1D)

NATURAL HISTORY

■ The natural history after failure of the aforementioned procedures is one of functional imbalance of the forefoot. The first ray fails to provide physiologic support, creating an overload phenomenon, or transfer metatarsalgia, to the lesser metatarsal heads. While the lesser metatarsals may be shortened to compensate for the loss of first ray length, this is often undesirable because there is no pathology at the lesser toes.
PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient typically complains of pain and deformity in the hallux MTP joint and pressure and pain under the lateral forefoot.
- Typical physical examination findings include:
  - Short hallux or first ray (bone loss at the hallux only is typical with bone loss on the phalangeal or metatarsal head side; more global first ray bone loss occurs after the Mayo procedure, avascular necrosis of the metatarsal head, or a failed great toe implant)
  - Cock-up deformity of the hallux
  - Residual hallux valgus deformity and occasional hallux varus deformity
  - Pain and crepitance with range of motion of hallux
  - Pain and tenderness (and occasionally plantar callus formation) under the lesser metatarsal heads
- The potential iliac crest harvest site should also be inspected for unanticipated soft tissue concerns or to confirm that no prior graft harvest has been performed.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Weight-bearing foot radiographs, including AP, lateral, and oblique views
- With avascular necrosis of the first metatarsal head, an MRI of the forefoot may prove useful in estimating the extent of necrotic bone and predicting the size of the interpositional graft.

NONOPERATIVE MANAGEMENT

- In our experience, nonoperative treatment of the painful, shortened, and cocked-up hallux is generally unsuccessful. The shoe’s toe box may be enlarged and an accommodative orthotic to post under the hallux may be considered, but this is generally of limited value.
- Metatarsal support, however, may relieve the symptoms related to transverse metatarsalgia by unloading the lesser metatarsal heads. If metatarsal pads are effective, then a custom orthotic with metatarsal support may prove beneficial as well.

SURGICAL MANAGEMENT

Preoperative Planning

- The decision to perform a structural femoral head or iliac crest allograft or an anterior iliac crest autograft must be made preoperatively. However, we recommend having the flexibility to use either method, with the patient’s consent, if one graft proves ineffective based on intraoperative assessment. The patient should be aware of the risks of iliac crest graft harvest and the use of allograft bone.
- Myerson et al in 2005 investigated the use of structural allografts in foot and ankle surgery and discussed the risks of using a structural allograft. One concern with the use of structural allograft is the possible transmission of disease and malignancy, but with the use of processed allografts the risk is practically zero. The risk of iliac crest bone harvest is donor-site morbidity, which includes local hematoma, local infection, and in rare cases local nerve irritation.
- We routinely draw a preoperative plan for the structural graft, determining the approximate amount of bone resection required and the length of graft that needs to be acquired.

Positioning

- The patient is positioned supine on the operating table, with a bump placed beneath the hip ipsilateral to the foot that will be operated on. This not only positions the foot in an ideal position (to allow improved assessment of proper hallux alignment) but also facilitates harvest of the iliac crest graft by making the anterior crest more accessible.

Approach

- First MTP joint: A standard dorsal approach is recommended, starting about 4 cm proximal to the MTP joint and extending to the interphalangeal joint. When possible, previous incisions should be incorporated into the approach, to avoid a skin bridge that may be at risk, particularly when the toe will be distracted with the interpositional graft.
- Iliac crest: An incision is made parallel and inferior to the anterior iliac crest, about 3 cm posterior to the anterior-superior iliac spine, to avoid injuring the lateral femoral cutaneous nerve.
PREPARATION OF THE MTP JOINT

- Start the dorsal skin incision about 4 cm proximal to the first MTP joint and extend it to the interphalangeal joint (TECH FIG 1).
- The extensor hallucis longus (EHL) tendon can be simply retracted if the first ray has minimal shortening. With moderate to severe shortening, particularly with associated cock-up toe deformity, the EHL tendon may need to be Z-lengthened to allow restoration of toe length and to avoid hyperextension at the hallux interphalangeal joint.
- Divide the first MTP joint capsule, scar tissue from prior surgery, and periostium of the proximal phalanx and distal first metatarsal longitudinally and reflect them. While we subscribe to the principle of minimal soft tissue stripping, we believe that subperiosteal preparation is mandatory to afford sufficient mobilization of the hallux. However, we leave the plantar soft tissues to maintain the blood vessels supplying the residual metatarsal head and proximal phalanx (TECH FIG 2).
- We routinely remove any osteophytes and additional soft tissue adhesions.

TECH FIG 1 • The joint capsule and the soft tissue coverage of the metatarsal and the phalanx are incised longitudinally straight down to the bone and then opened as an envelope. Subperiosteal preparation is mandatory to ensure sufficient release from the lateral soft tissue and scar adhesions.

TECH FIG 2 • After the articular surfaces of the first metatarsophalangeal joint have been adequately freed, the big toe is brought into maximal plantarflexion.

REAMING OF THE METATARSAL HEAD AND BASE OF THE PROXIMAL PHALANX

- After mobilizing the articular surfaces of the first MTP joint, maximally plantarflex the hallux (TECH FIG 3).
- Insert a guidewire for the reamer set into the center of the metatarsal head. Place the appropriately sized “female” reamer over the guidewire (TECH FIG 4). Remove the sclerotic bone surface with the reamer down to cancellous bleeding bone.
- Expose the base of the proximal phalanx (TECH FIG 5) and place a guidewire for the reamer set (TECH FIG 6).
- In a similar manner, prepare the proximal phalanx with the “male” reamer counterpart (TECH FIG 7). Distract the toe to the desired length and measure the gap (TECH FIG 8).

TECH FIG 3 • After the articular surfaces of the first metatarsophalangeal joint have been mobilized, the hallux is maximally plantarflexed.

TECH FIG 4 • The adequately sized female reamer is then used to remove the sclerotic bone surface of the metatarsal head down to the cancellous bleeding bone.
**TECHNIQUES**

- Make the incision for the tricortical iliac crest block 3 cm posterior to the anterior-superior iliac spine (TECH FIG 9). Carry dissection down to the intermuscular plane using electrocautery for hemostasis. Reflect the periosteum from the superior crest. Insert a Hohmann retractor on the inner and outer aspects of the iliac crest, deep to the periosteum (TECH FIG 10). Based on

**Harvest of the Iliac Crest Bone Block**

- Make the incision for the tricortical iliac crest block 3 cm posterior to the anterior-superior iliac spine (TECH FIG 9). Carry dissection down to the intermuscular plane using electrocautery for hemostasis. Reflect the periosteum from the superior crest. Insert a Hohmann retractor on the inner and outer aspects of the iliac crest, deep to the periosteum (TECH FIG 10). Based on
the desired length of the first ray and the gap created with first MTP joint preparation, mark the segment of iliac crest to be harvested. We use a microsagittal saw to cut the iliac crest and an osteotome to complete the separation of the structural graft (TECH FIG 11).

- Harvest the iliac crest structural graft (TECH FIG 12).
- The defect in the iliac crest may be backfilled with allograft bone chips. Close the periosteum after placing a drain. Reapproximate the subcutaneous tissues and close the skin.

CONTOURING OF THE GRAFT

- Secure the graft (either the harvested iliac crest graft or a femoral head graft) on the back table using a forceps, to be shaped into the desired length (TECH FIG 13).
- Place a guidewire for the reamer set in the center of the graft’s long axis. Use the same reamers that were used to prepare the first MTP joint to contour the ends of the graft. One end is prepared with the “female” reamer and the other using the “male” reamer to create optimal contact to the host bone (TECH FIG 14).

TECH FIG 10 • A Hohmann retractor is inserted on the inner and outer side of the iliac crest under the periosteum.

TECH FIG 11 • A saw is used to osteotomize the ends of the tricortical bone block.

TECH FIG 12 • The iliac crest bone block is retrieved.

TECH FIG 13 • A. The graft is held on the table with a forceps and shaped into the desired length. B. The graft margins are marked on an allograft femoral head.
**WARNING**

Insert the contoured graft *(TECH FIG 15)* into the prepared gap between metatarsal and phalanx. With a ball-and-socket shape on either end of the prepared gap, the alignment of the lengthened hallux may be seamlessly adjusted in any direction. Place either a standard plate or a special revision plate dorsally *(TECH FIG 16).* Place temporary pins to maintain the reduction, and confirm proper arthrodesis and plate positions fluoroscopically.

In our experience, optimal hallux position for arthrodesis is (a) neutral rotation (no pronation or supination), (b) about 15 degrees of dorsiflexion (relative to the plantar surface of the foot), and (c) 5 degrees of valgus with respect to the first metatarsal *(TECH FIG 17).*

To determine optimal sagittal plane position, a lid from an instrument tray may be used to simulate weight bearing. Ideally, the distal hallux tuft is 1 to 2 mm elevated from the plate when the ball of the foot and heel are contacting the instrument tray lid *(TECH FIG 18).*

Place a 3.0-mm or 3.5-mm screw from the medial aspect of the residual proximal phalanx across the graft to the lateral aspect of the residual metatarsal *(TECH FIG 19).*

Secure the plate to the construct, with screws in the proximal phalanx, graft, and metatarsal, while avoiding the initial screw *(TECH FIG 20).* Three or four absorbable deep sutures are generally adequate to cover the plate. We advocate the use of a small-diameter drain for 2 days postoperatively to reduce the risk of hematoma formation.

Reapproximate the subcutaneous layer and skin in a tension-free manner; perform the closure carefully since the soft tissues are already under some tension due to lengthening of the first ray.

After sterile dressings are placed on the wound, we routinely apply a well-padded short-leg cast that extends beyond the toes. We recommend univalving the cast.
TECH FIG 16 • The special revision plate is placed dorsally.

TECH FIG 17 • The hallux is positioned in neutral rotation, with special attention paid to the position of the toenail.

TECH FIG 18 • For the optimal extension, a lid of the instrument tray may be used to simulate floor contact.

TECH FIG 19 • To add additional stability, a 3.0 AO screw is inserted from the medial aspect of the proximal phalanx of the great toe across the graft to the lateral side of the metatarsal.

TECH FIG 20 • The plate is fixed with adequate screws.
POSTOPERATIVE CARE

- We recommend placing the patient in a short-leg cast that extends beyond the toes for a full 6 to 8 weeks. The patient should be touch-down weight bearing until suture removal and then weight bearing on the heel until 6 to 8 weeks.

OUTCOMES

- Myerson et al.4,5 treated 24 patients with hallux MTP joint arthrodesis using bone graft to restore first ray length (FIG 2).

PEARLS AND PITFALLS

- Avoid excessive dorsiflexion of the arthrodesis. Use the lid of an instrument tray to simulate the floor with weight bearing. Excessive elevation may lead to sesamoid overload, symptomatic irritation of the hallux in the shoe, and a poor cosmetic appearance.

- Avoid excessive plantarflexion of the arthrodesis. Use the lid of an instrument tray to simulate the floor with weight bearing. Excessive plantarflexed toe position will result in symptoms during push-off in the gait cycle and eventual interphalangeal arthrosis from excessive stress of the hallux interphalangeal joint.

- Avoid being overzealous in lengthening; the soft tissues may be put on excessive tension, resulting in vascular compromise. One trick is to distract the hallux with a laminar spreader and deflate the tourniquet while harvesting or preparing the graft. If after 5 to 10 minutes the toe is still not well perfused, then the distraction may be too great and a shorter graft should be used.

- While varus position makes shoe wear difficult, excessive valgus is also poorly tolerated since the hallux impinges on the second toe. Slight valgus relative to the metatarsal is acceptable, but a neutral position, in our hands, is usually ideal.

- Residual pronation is poorly tolerated after first metatarsal arthrodesis and leads to a symptomatic medial toe callus. Be sure to align the hallux nail with the same orientation as the second and third toenails.

- This procedure was performed after bone loss subsequent to previous surgeries for the correction of hallux valgus and hallux rigidus with Silastic arthroplasty (n = 11), bunionectomy and distal metatarsal osteotomy (n = 6), Keller resection arthroplasty (n = 5), and total joint replacement (n = 2).

- All patients were examined clinically and radiographically at a mean interval of 62.7 months after surgery (range 26 to 108 months).

- Successful fusion was observed in 19 of the 24 patients (79.1%) at a mean of 13.3 weeks (range 11 to 16 weeks),

FIG 2 • A. A 45-year-old woman after Keller-Brandes arthroplasty. B. Postoperative photograph of a first metatarsophalangeal bone block fusion. C. 2-year follow-up after hardware removal.
and the first ray was lengthened by a mean of 13 mm (range 0 to 29 mm).

- Of the five nonunions noted radiographically, two were asymptomatic and three were managed successfully with further surgery.
- Complications included one deep infection requiring intravenous antibiotics and irrigation and débridement of the graft repeat surgery for treatment of osteomyelitis and two minor superficial wound infections managed effectively with oral antibiotics and local wound care.
- The mean AOFAS score improved from 39 points (range 22 to 60 points) to 79 points (range 64 to 90 points).
- Brodsky et al reviewed 12 patients (12 feet) who underwent salvage first MTP arthrodesis with structural interposition autologous iliac crest bone graft.
- Eight patients had a bony defect secondary to failed first MTP joint implant arthroplasties, two had avascular necrosis after failed bunion surgery, one had a nonunion of an attempted arthrodesis for failed bunion surgery, and one had been treated for osteomyelitis after cheilectomy.
- Eleven cases had a single dorsal plate secured by screws and one case had two plates, one dorsal and one medial.
- A plate, crossed screw(s), or Kirschner wire combinations were used in four cases.
- Clinical arthrodesis was achieved after an average of 12 weeks (range 4 to 20).
- Radiographic arthrodesis was achieved in 11 of 12 feet at an average of 15 weeks (range 8 to 28), with one pseudarthrosis.

- The AOFAS forefoot clinical rating score averaged 70 points (maximum 90 after first MTP arthrodesis) at an average follow-up of 22 months (range 5 to 70).
- Sesamoiditis, prominent hardware, and scar sensitivity were complaints in four patients postoperatively. Two cases required flap coverage for skin necrosis. There was no symptomatic progression of interphalangeal degenerative change postoperatively.

**COMPlications**

- Pseudarthrosis
- Wound dehiscence or infection
- Nerve irritation
- Poor alignment

**REFERENCES**

DEFINITION

- Turf toe injuries involve the capsular–ligamentous–sesamoid complex of the hallux metatarsophalangeal (MP) joint.\(^1,2\) They fall within a spectrum ranging from stable capsular sprains to unstable disruptions of the complex.
- Turf toe injuries have become more prevalent with more rigid playing surfaces (ie, artificial turf) and less rigid shoe wear\(^7,10\) and may be considered more disabling than ankle sprains\(^5,9\).
- Turf toe can result in significant disability and loss of playing time in athletes, so it must be diagnosed early and evaluated properly to restore function.

ANATOMY

- The hallux MP joint is stabilized by adjacent capsular, ligamentous, tendinous, and osseous structures (FIG 1). Disruption of a part of this complex results in a turf toe injury.
- The plantar plate is composed of the joint capsule, with attachments to the transverse head of the abductor hallucis, to the flexor tendon sheaths, and to the deep transverse intermetatarsal ligament.
- The tibial and fibular sesamoids articulate with the metatarsal head. They are contained within the medial and lateral portions of the flexor hallucis brevis (FHB) tendons, respectively. Their relationship to one another is maintained by the intersesamoid ligament. Ligamentous attachments also run between the sesamoids and the metatarsal head and proximal phalanx. The sesamoids may be bipartite.
- The FHB is located within the third plantar layer of the foot. It originates from the lateral cuneiform and the cuboid. It inserts into the proximal phalanx of the hallux and is innervated by the medial plantar nerve.
- Medially, in the first plantar layer of the foot, the abductor hallucis muscle originates from the medial process of the os calcis tuberosity. It inserts with the medial tendon of the FHB into the medial aspect of the base of the hallux proximal phalanx. It also is innervated by the medial plantar nerve.
- Laterally, also in the third plantar layer of the foot, the abductor hallucis has two heads. The oblique head originates from the base of metatarsals two through four, while the transverse head takes origin from the lateral fourth MP joint. The two heads unite and insert through the fibular sesamoid into the lateral aspect of the base of the hallux proximal phalanx. Both heads are innervated by the lateral plantar nerve.

PATHOGENESIS

- The primary mechanism of injury involves a hyperextension force to the hallux MP joint. Most commonly, an axial load is applied to the heel of a foot fixed in equinus (FIG 2).
- The most common variation is that created by a valgus-directed force, resulting in an injury to the plantar medial complex or fibular sesamoid that, if left untreated, may lead to a traumatic bunion and hallux valgus. A varus-directed force is less common but can lead to a traumatic varus deformity.

- In our experience, limited ankle dorsiflexion places the hallux MP joint at greater risk for injury, although the literature is controversial on this mode of pathogenesis.

NATURAL HISTORY

- The natural history of turf toe depends on the degree of injury to the capsular–ligamentous–sesamoid complex. Simple, stable sprains usually heal uneventfully. Missed or untreated unstable injuries may lead to hallux limitus or rigidus and chronic pain and push-off weakness.

FIG 1 • Normal plantar anatomy of the hallux metatarsophalangeal joint. (From Agur AMR, Dalley AF. Grant’s Atlas of Anatomy, 11th ed. Baltimore: Lippincott Williams & Wilkins, 2005.)
The history of this injury is particularly important. Useful information includes the type of shoe the patient was wearing, the circumstances of the injury (i.e., the position of the foot at the time of injury, the direction of applied force, the type of athletic surface and shoe, any perceived “pop,” and any initial obvious deformity, such as a dislocation that may have reduced spontaneously or required manual manipulation).

In our experience, a regional anesthetic, such as a digital anesthetic block of the hallux, may be required to perform a satisfactory examination of the acute turf toe injury. However, significant swelling, as seen in the acute setting, will make this problematic.

Relevant clinical findings include plantar swelling and ecchymosis about the hallux MP joint. Alignment of the hallux MP joint is noted and compared to the contralateral side. Asymmetric hallux valgus suggests a traumatic bunion, and asymmetric hallux varus implies traumatic injury to the lateral sesamoid complex. Dorsal dislocation of the first MP joint is an obvious finding and may involve severe injury to the sesamoid complex.

The examination can include the following:

- Active and passive hallux MP range of motion. Hallux MP motion varies widely among individuals, with reported plantarflexion from 3 to 40 degrees and dorsiflexion from 40 to 100 degrees. The best method is to compare to the noninjured contralateral side.
- The examiner should observe the patient’s gait (specifically, the time between heel rise and toe-off). The patient will shorten time spent after heel rise since this concentrates pressure onto the injured hallux MP joint.
- Vertical Lachman test. A positive test is any laxity greater than the contralateral side.
- Turf toe classification
  - A. Hyperextension (turf toe)
    - Grade 1: Stretching of the plantar complex; localized tenderness, minimal swelling, no ecchymosis
    - Grade 2: Partial tear; diffuse tenderness, moderate swelling, ecchymosis, restricted movement with pain
    - Grade 3: Complete tear; severe tenderness to palpation, marked swelling and ecchymosis, limited movement with pain, positive vertical Lachman test; associated injuries possible (medial–lateral injury; sesamoid fracture/bipartite diastasis; articular cartilage–subchondral bone bruise)
  - B. Hyperflexion (sand toe)
  - C. Dislocation
    - Type I: Dislocation of the hallux with the sesamoids; no disruption of the intersesamoid ligament; usually irreducible
    - Type II: IIA (associated disruption of intersesamoid ligament; usually reducible); IIB (associated transverse fracture of one of the sesamoids; usually reducible); IIC (complete disruption of intersesamoid ligament with fracture of one of the sesamoids; usually reducible)

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

A thorough radiographic evaluation is mandatory (including weight-bearing views of the foot in the AP, lateral, and oblique planes) (**FIG 3**).
Bilateral standing AP views are recommended for comparison.

Forced (stress) dorsiflexion lateral views are helpful to diagnose diastasis of a bipartite sesamoid or a sesamoid fracture (FIG 4). It will also suggest distal disruption of the FHB if the sesamoid complex migrates proximally. Studies suggest that more than 10.4 mm from the tip of the tibial sesamoid to the phalanx or more than 13.3 mm from the fibular sesamoid equates to a 99.7% chance for plantar complex rupture.11

Fluoroscopic evaluation has proven invaluable and is highly recommended when available. The hallux is dorsiflexed and if the sesamoids do not migrate distally, a plantar plate disruption can be inferred.

MRI is recommended for any patient with radiographic abnormalities and for those with significant swelling, any ecchymosis or limitation of motion, or a positive vertical Lachman test (FIG 5). Osteochondral lesions and edema in the metatarsal head are often present and may be prognostic.

DIFFERENTIAL DIAGNOSIS

- Chondral or osteochondral lesion of the hallux metatarsal head
- Hyperflexion injury (sand toe)6
- Fracture of the proximal or distal phalanx of the hallux

NONOPERATIVE MANAGEMENT

- Rest, ice, elevation, and nonsteroidal anti-inflammatories4
- Immobilization with a boot or cast. A toe spica cast with the hallux in plantarflexion relieves tension on the injured plantar complex (FIG 6).

- Corticosteroid injections are avoided, especially in the athlete, to avoid rupture or further weakening of the capsular–ligamentous complex. Corticosteroids can mask unstable injuries that, if not addressed, can lead to hallux deformity and permanent loss of push-off strength.
- Taping of the hallux with a dorsal band to prevent excessive dorsiflexion
- Inserts, including off-the-shelf orthotics and custom devices that include the Morton extension to stiffen the first ray

SURGICAL MANAGEMENT

- Operative treatment should be considered for large capsular avulsions with an unstable joint; diastasis of a bipartite sesamoid or a sesamoid fracture; retraction of the sesamoids (single or both), traumatic bunion, or progressive hallux valgus; a positive vertical Lachman test; and the presence of a loose body or chondral injury.
- Serial examinations may be needed to document progressive varus–valgus or cock-up deformities, but ideally early diagno-
sis and appropriate surgical repair of the injury are performed before these late sequelae develop.

Preoperative Planning
- The degree and exact location of the injury are determined before surgery. MRI is a useful preoperative tool to ascertain the area of involvement but may exaggerate the true extent of the injury by revealing adjacent edema.

Positioning
- While the patient may be placed prone for direct access to the sesamoid complex, we routinely perform surgical repair of turf toe injuries with the patient in the supine position. It is ideal to have the operative extremity in slight external rotation since the approach is largely medial. If the patient’s natural tendency is not external rotation, then a bump can be placed under the contralateral hip or the table can be tilted toward the operative side.

Approach
- Described approaches include a plantar-medial, medial and plantar-lateral, and the J configuration. Over the past 3 years, we have employed the combined medial and plantar-lateral approach in patients suspected of having a complete plantar plate disruption. This approach allows for a more direct repair of the lateral structures without extensive skin and neurovascular dissection and retraction. Improved wound healing has been noted anecdotally (FIG 7).

INCISION
- In this example, the surgeon has elected to use the J incision, which extends plantar-medial and then crosses plantarly along the flexor crease at the base of the phalanx (TECH FIG 1).
- Take extreme care to identify and protect the plantar-medial digital nerve (TECH FIG 2).

Make a longitudinal incision at the level of the abductor hallucis tendon (TECH FIG 3). This allows both intra- and extra-articular examination of the plantar complex.
- Fully define the extent of the injury (TECH FIG 4).
- Once the defect has been fully defined, distally mobilize the plantar plate and sesamoid complex.
Chapter 28  SURGICAL MANAGEMENT OF TURF TOE INJURIES

In complete plantar ruptures, both sesamoids will be proximally retracted but will slide distally around the flexor hallucis longus (FHL) tendon.
- In chronic cases, this requires removal of fibrous scar tissue. Protect the FHL tendon while débriding scar tissue.
- Thoroughly examine the FHL tendon for longitudinal tears (TECH FIG 5). In our experience, longitudinal tears of the FHL tendon are most commonly associated with a late presentation of turf toe injury in which the FHL is subjected to frequent greater-than-physiologic stretching as a result of the lack of plantar restraint of the MP joint.

TECH FIG 3 • Longitudinal incision at the abductor hallucis and capsule allows visualization of the joint.

TECH FIG 6 • Turf toe variant with intact but redundant plantar complex.

TECH FIG 7 • Redundant tissue is transversely excised and the remaining defect is repaired primarily.

TECHNIQUES

REPAIR OF DISTAL RUPTURES

- Make the J incision and identify the plantar-medial digital nerve where it crosses obliquely immediately deep to the planned incision. Once the nerve is identified, carefully retract it throughout the surgery, but with intermittent relaxation to limit the risk of a traction neuralgia.
- Make an incision at the level of the abductor hallucis tendon to allow examination of the MP joint.
- Identify the components of the plantar complex, including FHB, FHL, sesamoids, interosseous ligament, transverse and oblique heads of adductor hallucis, and plantar capsule. This step may take some time, depending on the degree of disruption and the time from injury.
- In acute cases, a rim of stout capsule typically remains on the base of the proximal phalanx. In the chronic situation, the sesamoid complex may appear redundant, often due to intervening scar tissue or elongated, weakened soft tissues at the site of injury (TECH FIG 6). We recommend excising the redundant scar tissue sharply and advancing the proximal intact and healthy portion of the complex (TECH FIG 7).

TECH FIG 4 • After exposure, the extent of the injury must be defined. This involves identifying each element of the plantar complex to determine its integrity.

TECH FIG 5 • The flexor hallucis longus tendon is inspected for longitudinal tears and repaired primarily if necessary.
Distal ruptures require primary repair of remnants from lateral to medial, working around the FHL tendon (TECH FIG 8).

- If the soft tissue is contracted and cannot be advanced to allow a primary repair, the FHB and abductor hallucis may be fractionally lengthened.

- If soft tissues are inadequate, suture anchors or drill holes to the plantar aspect of the base of the proximal phalanx may be used (TECH FIG 9). A drill hole can also be created in the distal pole of the tibial sesamoid if there is an absence of soft tissue for repair on the proximal aspect.

- Close the wound using standard techniques.

**TECH FIG 8** • Repair proceeding from lateral to medial and working around the intact flexor hallucis longus tendon.

**TECH FIG 9** • A. In the absence of healthy tissue at the base of the proximal phalanx, suture anchors can be used to advance the plantar complex. B. Radiograph showing anchors in the proximal phalanx.

**TECH FIG 10** • Repair of injury involving a tibial sesamoid fracture. A. The fragments are excised. B. The remaining void is often significant. (continued)
TECH FIG 10 • (continued) C. An attempt is made to close the void primarily with approximation of adjacent tissue.

TECH FIG 11 • A. Advancement of the abductor hallucis tendon into the defect after sesamoid excision. The rerouted abductor tendon now serves as a flexor tendon. B. The abductor tendon has been advanced and secured.

**TECHNIQUES**

- Use the standard J incision and the aforementioned approach.
- Isolate each fragment of both the tibial and fibular sesamoids. Reduce the corresponding fragments with a pointed reduction forceps.
- Due to the small size of the sesamoids and because comminution is often present, internal fixation can be difficult, with resultant further fragmentation of the sesamoids.
- Therefore, Cerclage the proximal and distal poles of the sesamoids using nonabsorbable suture (TECH FIG 12). Then repair the adjacent soft tissue.
- If the articular surface of the sesamoid is damaged or demonstrates significant cystic change or fragmentation within the sesamoid body, excise it. The defect is managed with an abductor tendon transfer as described above.
- If at all possible, avoid excising both sesamoids, as it may lead to a cock-up hallux toe deformity. If both sesamoids are painful and pathologic, it is best to stage the sesamoidectomies to lessen the risk for this complication.
- We maintain a low threshold to transfer the abductor hallucis tendon to the resulting plantar defect (TECH FIG 11). The distal aspect of the abductor hallucis tendon is easily elevated from its attachment on the proximal phalanx and rotated plantarly into the defect created by tibial sesamoid excision, where it is secured to the FHB tendon. This transfer affords not only an improved soft tissue closure of the defect but also, we believe, a dynamic component to strengthen the repair.
- Perform routine closure.

**REPAIR OF BOTH FIBULAR AND TIBIAL SESAMOIDS**

- Use the standard J incision and the aforementioned approach.
- Isolate each fragment of both the tibial and fibular sesamoids. Reduce the corresponding fragments with a pointed reduction forceps.
- Due to the small size of the sesamoids and because comminution is often present, internal fixation can be difficult, with resultant further fragmentation of the sesamoids.
- Therefore, Cerclage the proximal and distal poles of the sesamoids using nonabsorbable suture (TECH FIG 12). Then repair the adjacent soft tissue.
- If the articular surface of the sesamoid is damaged or demonstrates significant cystic change or fragmentation within the sesamoid body, excise it. The defect is managed with an abductor tendon transfer as described above.
- If at all possible, avoid excising both sesamoids, as it may lead to a cock-up hallux toe deformity. If both sesamoids are painful and pathologic, it is best to stage the sesamoidectomies to lessen the risk for this complication.
- We maintain a low threshold to transfer the abductor hallucis tendon to the resulting plantar defect (TECH FIG 11). The distal aspect of the abductor hallucis tendon is easily elevated from its attachment on the proximal phalanx and rotated plantarly into the defect created by tibial sesamoid excision, where it is secured to the FHB tendon. This transfer affords not only an improved soft tissue closure of the defect but also, we believe, a dynamic component to strengthen the repair.
- Perform routine closure.

**TECH FIG 12 •** Standard cerclage technique used to repair a fractured or diastased sesamoid.
REPAIR OF TRAUMATIC BUNION

- In essence, this repair is a modified McBride bunionectomy or distal soft tissue procedure. Release the adductor hallucis tendon via a longitudinal incision in the dorsum of the first web space (TECH FIG 13). Transect it and elevate it off the lateral sesamoid.
- Make a medial incision and perform a longitudinal capsulotomy (TECH FIG 14).
- Perform a conservative excision of the bunion exostosis (TECH FIG 15). This assists with scarring of the medial structures.
- Identify the medial defects and repair them primarily as described above, followed by routine closure (TECH FIG 16).

CORRECTION OF LATE COCK-UP HALLUX DEFORMITY

- A sequela of untreated turf toe injury is the cock-up hallux deformity, or hyperextension of the hallux MP joint and flexion at the hallux IP joint.
- Perform a medial incision.
- Often, the dorsal capsule and extensor hallucis longus and brevis are contracted and must be released. The extensors may need to be Z-lengthened.
- Release the FHL as far distal as possible at its insertion into the distal phalanx. Make a dorsal-to-plantar drill hole in the proximal phalanx toward its base. Route the FHL tendon from plantar to dorsal through the osseous tunnel and secure it dorsally. A small interference screw may be used, or the tendon can simply be secured with a nonabsorbable suture.
**PEARLS AND PITFALLS**

| Proper diagnosis | • Attention to history and physical examination is paramount. An MRI is ordered if any concern for an unstable situation exists. |
| Progressive deformity | • With injuries managed nonsurgically, serial examinations allow the physician to appreciate a tendency for progressive deformity. Surgical repair is recommended before the deformity leads to late sequelae such as traumatic bunion or cock-up deformity. |
| Plantar-medial soft tissue defects | • These defects, typically noted after medial sesamoid excision, may be augmented with transfer of the abductor hallucis tendon into the defect. |

**POSTOPERATIVE CARE**

- Postoperative care is a delicate balance between soft tissue protection and early hallux MP range of motion, avoiding arthrofibrosis of the sesamoid-metatarsal articulation.
- Gentle passive range of motion (plantarflexion) is initiated under supervision at 7 to 10 days after surgery.
- The patient remains non-weight-bearing in a removable splint or boot with the hallux protected for 4 weeks.
- At 4 weeks the patient is allowed to initiate active motion of the joint and ambulate in a boot.
- Modified shoe wear consisting of a turf toe plate (aluminum, steel, or carbon fiber) is instituted at 2 months.
- Return to contact activity occurs at 3 to 4 months, with protection from excessive dorsiflexion. Return to play depends on the player’s position, level of discomfort, and healing potential.
- Full recovery is expected to take 6 to 12 months. Shoe modifications are generally needed for at least 6 months after return to play. In general, this correlates to the presence of 50 to 60 degrees of painless passive range of motion of the hallux MP joint.

**OUTCOMES**

- Clanton et al found that half of 20 athletes had persistent symptoms, including stiffness and pain, at 5-year follow-up.
- Anderson et al report that 17 of 19 college and professional athletes returned to full athletic activity with minimal residual discomfort after surgical repair of a turf toe injury.

**COMPLICATIONS**

- As with any surgery, infection and wound problems are potential complications. Athletes may be at increased risk if they attempt to initiate rehabilitation too early.
- Transient neuritis of the plantar-medial digital nerve at the level of the hallux MP joint is common due to retraction of the nerve during surgery. However, a transection and secondary neuroma may result in significant discomfort and difficulty with shoe wear and push-off.
- Disruption of the repair may result with excessive dorsiflexion during the early rehabilitation process.
- Inadequate rehabilitation or prolonged immobilization can cause significant hallux MP stiffness.

**REFERENCES**


**FIG 8** • Hallux claw toe after a missed turf toe injury.

- A missed or delayed diagnosis can lead to progressive hallux varus or valgus or cock-up deformity (FIG 8).
DEFINITION

- Hallux sesamoid bone fracture is a break through the sesamoid bone or cartilage. Medial sesamoid bone fractures are more common than lateral sesamoid bone fractures.\(^1,15\)
- Fractures usually occur about perpendicular to the long axis of the elliptically shaped bone. Longitudinal and comminuted fractures are less common.\(^5,17\)
- In partite or bipartite sesamoid bones, the fracture always occurs in the fibrocartilaginous junctional zone (most often perpendicular to the long axis), which can disguise the fracture.\(^15\)

ANATOMY

- The hallux sesamoid bones usually are 13.5 ± 3 mm long. The sesamoid bones are larger in men than in women, and the medial sesamoid is more elliptically shaped and larger compared to the more circularly shaped lateral sesamoid.\(^14\)
- The hallux sesamoid bones are invested in the tendon sheath of the flexor hallucis brevis. They connect with the intersesamoid ligament to form a solid pedestal to elevate the first ray and absorb stress during gait.\(^2,3,14\) (FIG 1A).
- The sesamoid complex acts as a fulcrum to the flexor hallucis brevis and longus tendons, increasing their lever arms and big toe push-off power, e.g., the patella to the quadriceps tendon.\(^2,3\) (FIG 1B).
- Failure of the bone to ossify completely during childhood results in a multi-part sesamoid bone. Bipartite sesamoids are much more common than those with three or more parts. Despite incomplete ossification, the sesamoid parts are firmly connected with fibrocartilaginous tissue to act as one bone. Spontaneous fusion can occur later in life.\(^10\)
- Partite sesamoid bones are bilateral in only about 25% of cases; therefore, unilaterality cannot be relied upon as a criterion of fracture.\(^10\)
- The main blood supply is provided over the posterior tibial to the medial plantar artery to the sesamoids. Considerable variation exists, however, such as the main blood supply from the lateral plantar artery or even the dorsal arterial arch.\(^7,14\)
- In general, only one major artery pierces the cortex of the sesamoid bone at the plantar aspect of the proximal pole. Small vessels also enter from the plantar nonarticular side and over the capsular attachments as a second source of vascularity.\(^7,14\)

FIG 1 • Anatomy and biomechanics of the hallux sesamoid complex. A. The sesamoids elevate the first metatarsal bone. Fifty percent or more of body weight is transferred over the first ray. With sesamoid excision, preloading of the metatarsal bone is decreased, transferring the load to the lesser toes. B. Sesamoid bones increase the lever arm of the hallucis brevis and hallucis longus flexor tendons. Sesamoid excision reduces this lever and subsequently reduces push-off power of the big toe. (A: From Aper RL, Saltzman CL, Brown TD. The effect of hallux sesamoid resection on the effective moment of the flexor hallucis brevis. Foot Ankle Int 1994;15:462–470; B: From Aper RL, Saltzman CL, Brown TD. The effect of hallux sesamoid excision on the flexor hallucis longus moment arm. Clin Orthop Relat Res 1996;325:209–217.)
Chapter 29  INTERNAL FIXATION OF SESAMOID FRACTURES

PATHOGENESIS
- Acute trauma or chronic overuse leads to acute or stress fractures, respectively, of the sesamoid bones.\(^1\,15\)
- In the acute setting, the typical mechanism is excessive hyperextension of the big toe, also referred to as the “turf toe” injury seen in American football players. Disruption of the plantar joint capsule occurs as a trans-sesamoidal fracture–dislocation of the first metatarsophalangeal (MTP) joint.\(^15\)
- Typically, in the chronic setting, no trauma is remembered. Pain and swelling increase insidiously over weeks, months, or years. Diagnosis is significantly delayed. Endurance sports such as running and dancing have shown to be associated with chronic stress fractures of the hallux sesamoid bones.\(^5\,12\)
- Foot deformities that concentrate pressure to the sesamoids increase the chance of suffering sesamoid stress fractures in both athletic and nonathletic persons. Cavus foot deformities with a steep plantar flexed first ray stress both sesamoid bones. Hallux valgus deformity with varus dislocation of the metatarsal head leads to pressure concentration at the medial sesamoid bone only\(^12\,13\) (FIG 2).

NATURAL HISTORY
- Acute fractures without mild dislocation heal normally with little or even no treatment.\(^15\)
- Chronic stress fractures usually do not heal without surgery, which is explained by the typical pathogenesis described earlier. During the prolonged time to diagnosis and the constant friction of fracture fragments, necrotic tissue accumulates at the fracture site and prevents healing. Brodsky et al,\(^6\) Van Hal et al,\(^17\) and Saxena and Krisdakumtorn\(^16\) independently reported on consecutive series of athletes with chronic sesamoid fractures. None of the sesamoid fractures in their series healed, even with prolonged nonsurgical regimens. Histologic examination after sesamoid excision revealed accumulation of necrotic tissue at the fracture site.\(^6\)
- Foot deformities can cause fragment separation and may prevent healing with immobilization.\(^12\)

PATIENT HISTORY AND PHYSICAL FINDINGS
- The patient history and physical examination must rule out the differential diagnoses.
  - The typical patient history is discussed in the section Pathogenesis.
  - The physical examination includes examination of areas of localized pain and swelling, and hyperextension testing of the big toe.
  - Patients have localized pain and swelling around the first MTP joint (FIG 3).

FIG 2 • Biomechanics of the sesamoid complex in hallux valgus deformity. A. Varus subluxation of the first metatarsal bone causes pressure concentration to the medial sesamoid bone. The intersesamoid crista enhances friction to the sesamoid joint surface. B. After stress fracture occurs, hallux deviation will cause constant fragment displacement. Therefore, immobilization may not suffice. Sesamoid excision will enhance hallux deviation if the deformity is not addressed. (A, B: From Pagenstert GI, Valderrabano V, Hintermann B. Medial sesamoid nonunion combined with hallux valgus in athletes. Foot Ankle Int 2006;27:135–140.)

FIG 3 • Clinical appearance of sesamoid stress fracture. A. Swelling of the MTP joint with localized tenderness at the medial sesamoid bone. B. Evaluate the hallux valgus deformity on the left. Progression of the deformity was noted by the patient within the preceding 3 months.
varus, and talo–first metatarsal angle are evaluated for stress concentration to the medial sesamoid bone. The talonavicular joint congruence is examined to identify excessive forefoot abduction with pes plano valgus or excessive adduction with neurogenic pes cavo varus.

DIFFERENTIAL DIAGNOSIS

- Hallux rigidus or sesamoid–first metatarsal bone osteoarthritis
- Hallux valgus
- First MTP joint capsuloligamentous disruptions (turf toe)
- Osteomyelitis and septic arthritis
- Podagra of gout and pseudogout
- Inflammatory arthritis
- Avascular necrosis of sesamoid or metatarsal head

NONOPERATIVE MANAGEMENT

- Acute fractures with up to 5 mm dislocation are treated with a forefoot immobilization shoe (stiff and convex sole) for 6 to 8 weeks.15
- Treatment of chronic fractures is controversial. Despite frequent failure after nonsurgical treatment attempts5,6,12,13,16,17 and the already long time it takes to establish diagnosis, many physicians try immobilization with a shoe or cast, sometimes with the patient non–weight-bearing on crutches. Recommendations for the duration of this approach before surgery is advocated range from 6 to 12 weeks.16,17
- If the diagnosis of stress fracture was established soon after the symptoms began, activity modification and use of a stiff-soled shoe for 6 weeks may be successful. Modification in athletic training and eating habits, with running on soft ground only, a change of sole stiffness in the athletic shoe, and increased intake of calcium and vitamin D₃ may be reasonable adjuncts in the future.

SURGICAL MANAGEMENT

- Severe (>5 mm) acute trans-sesamoidal fracture dislocations of the first MTP joint require open repair of the capsule and flexor muscles.15 The sesamoid bone fixation can be done with a compression screw or heavy no. 1 suture.
- Indications for percutaneous compression screw fixation include a transverse sesamoid stress fracture, transverse nonunion, or transverse symptomatic bipartite sesamoid. Fragments must be at least 3 mm to allow screw fixation.13
- Contraindications include infection, longitudinal sesamoid fractures, and comminuted fractures with multiple fragments that are too small for screw fixation. In these cases, partial or total sesamoid resection is indicated.
- Combined medial sesamoid fracture and hallux valgus deformity are best treated with conventional open correction of the hallux and open reduction and fixation of the sesamoid fracture by heavy no. 1 suture or compression screw.12 Débridement of the necrotic fracture zone and grafting can be done to enhance healing.1 In cases with less than 2 mm dislocation, the fracture zone can be stabilized by grafting only. The flexor brevis tendon sheath acts as tension band fixation.1

FIG 4 • Radiologic examination of sesamoid fractures. A. Conventional radiographs demonstrating horizontal sesamoid fracture dislocation. B. CT scan shows fracture line of chronic painful sesamoid, which was not visible on conventional radiographs.
In patients who are likely to be noncompliant, a temporary 2.5-mm K-wire can be placed through the first MTP joint to prevent hallux dorsiflexion and stress to the fragments. Combined hindfoot and first ray deformities with chronic sesamoid fractures must be addressed in the same surgery.12

Preoperative Planning

- Acute transsesamoidal fracture dislocations of the first MTP joint require open stabilization sometimes with an extended medioplantar L-shaped incision to reach the lateral aspect of the joint. Sesamoid fracture fixation is part of the plantar capsule or plate repair.15
- In chronic sesamoid fracture, preoperative planning should incorporate treatment of any underlying foot deformities.
  - A metatarsus primus flexus is treated with a dorsal extension osteotomy or arthrodesis.
  - A metatarsus primus varus and hallux valgus are addressed with appropriate osseous or soft tissue procedures.
  - Reduction of mechanical stress to the sesamoid bones is thought to be the main factor contributing to fracture healing. Surgical stress reduction alone may result in fracture healing even without sesamoid osteosynthesis in marked foot deformities.
- In the combined setting, medial sesamoid stress fractures are treated open because deformity correction is done at the same time as arthrotomy of the first MTP joint. Lateral sesamoid stress fractures are treated percutaneously, because deformity correction does not include arthrotomy of the first MTP joint.
- The least invasive approach can be used in the absence of foot deformities.

Chronic sesamoid fractures can be addressed by percutaneous compression screw fixation alone.
- Surgery can be performed under local anesthesia, and the stab incision of the skin can be closed with Steri-Strips.
- Healing is thought to occur because of reaming (vitalizing) of the fracture zone and fracture stabilization. Ossification of the bipartite sesamoids occurs.13
- Grafting of sesamoid nonunions (bipartite sesamoids) is inherently stabilized by the flexor brevis tendon sheath.1 In cases of persistent instability after grafting, additional suture or screw fixation is advisable.

Positioning

- The patient is placed in the supine position for isolated sesamoid bone fixation or combined deformity corrections. A tourniquet is needed, except in percutaneous fixation.

Approach

- A medial internervous or medioplantar-L-shaped approach to the lateral aspect of the first MTP joint is used for acute turf toe repair, including sesamoid fracture fixation or partial removal.15
- A standard medial internervous approach is used for grafting of medial sesamoid nonunions and combined hallux correction.12
- In the case of percutaneous fixation, a stab incision is made distal to the pole of the fractured sesamoid bone and distal to the weight-bearing area of the first MTP joint. Lateral sesamoid fractures usually are treated with percutaneous screw fixation.13

ANDERSON-MCBRYDE TECHNIQUE OF GRAFTING SESAMOID NONUNIONS

- A medial internervous skin incision is made over the first MTP joint (TECH FIG 1A).
- Longitudinal capsulotomy and subperiosteal limited exposure of the medial sesamoid wall are done.
- Débridement of the necrotic tissue at the fracture site is performed with a small curette from an extra-articular medial approach (TECH FIG 1B).
- Fenestration of the MT head is performed to enable autologous bone harvesting (TECH FIG 1C).
- The sesamoid fracture zone is grafted and stuffed, with care not to disrupt the fracture line in the joint surface. If stability is in doubt, fixation with no. 1 resorbable suture is performed to leave the least amount of foreign material in situ. Cannulated compression screws are used as well and may provide higher compression. (Screw placement is described in the next section.)
- The suture needle is introduced from the proximal lateral pole along the internal lateral cortex to the distal lateral pole. Backstitching is done outside the bone under the medial sesamoid suspensory (capsule) liga ment, back to the proximal medial pole, and knotted tight to stabilize the sesamoid joint line (TECH FIG 1D).
- The capsule and skin are closed as usual.
- A compressive dressing is applied with the foot in the neutral hallux position.

TECH FIG 1 • Anderson-McBryde technique. A, Medial internervous approach. (continued)
The hallux is held in dorsiflexion, and the sesamoid bone is pressed against the MT head to level the fracture fragments against the joint line of the MT head (TECH FIG 2A).

One 3-mm stab incision is done distal to the fractured sesamoid bone and distal to the weight-bearing area of the first MTP joint (TECH FIG 2B).

The guidewire (1.5-mm wire for 2.4-mm self-tapping Bold screws [Newdeal, Lyon, France]) is introduced under fluoroscopic control from the distal pole, perpendicular to the fracture line and subchondral to the sesamoid joint line (TECH FIG 2C).

**PREFERRED TECHNIQUE OF PERCUTANEOUS SESAMOID SCREW FIXATION**

- The hallux is held in dorsiflexion, and the sesamoid bone is pressed against the MT head to level the fracture fragments against the joint line of the MT head (TECH FIG 2A). One 3-mm stab incision is done distal to the fractured sesamoid bone and distal to the weight-bearing area of the first MTP joint (TECH FIG 2B).

- The guidewire (1.5-mm wire for 2.4-mm self-tapping Bold screws [Newdeal, Lyon, France]) is introduced under fluoroscopic control from the distal pole, perpendicular to the fracture line and subchondral to the sesamoid joint line (TECH FIG 2C).

**TECH FIG 1** (continued) B. Débridement of the fracture with a small curette using an extra-articular approach to the necrotic tissue. C. Harvesting of autologous bone from the first metatarsal head. D. Suture cerclage of the fractured sesamoid.

**TECH FIG 2** Preferred technique for percutaneous sesamoid screw fixation. A. Fixation of the hallux in hyperextension. Compress the sesamoid against the metatarsal head to level the fracture fragments against the joint line. B. Place the stab incision distal to the sesamoid outside the weight-bearing area of the MTP joint. C. Place the guidewire perpendicular to the fracture line, subchondral from proximal to distal. (continued)
The length of the headless cannulated compression screw is measured as the difference to a second guidewire that is held next to the first and is advanced to the sesamoid cortex. The usual range is between 12 and 16 mm. The shortest screw available is 10 mm (Bold screws; TECH FIG 2D and E).

The guidewire should just pierce the proximal cortex. The second guidewire is advanced to the distal cortex for exact measurement. E. Measurement using two K-wires. F. The definitive screw should incorporate both cortices for optimal compression. The usual length of the screw ranges between 12 and 16 mm.

- The guidewire should just pierce the proximal cortex. The second guidewire is advanced to the distal cortex for exact measurement.
- Measurement using two K-wires.
- The definitive screw should incorporate both cortices for optimal compression. The usual length of the screw ranges between 12 and 16 mm.

**TECH FIG 2 • (continued)**

**D.** The guidewire should just pierce the proximal cortex. The second guidewire is advanced to the distal cortex for exact measurement. **E.** Measurement using two K-wires. **F.** The definitive screw should incorporate both cortices for optimal compression. The usual length of the screw ranges between 12 and 16 mm.

**PEARLS AND PITFALLS**

| Indications | Look for foot deformities causing excessive stress to the sesamoid bones. Correction will promote sesamoid healing and prevent treatment failure.12
|            | With late diagnosis of sesamoid stress fracture, early surgery will save time for the athlete.12
| Postoperative management | In cases of uncertain patient compliance, temporary K-wire fixation of the first MTP joint will protect against early excessive MTP joint dorsiflexion.

**POSTOPERATIVE CARE**

- Full weight bearing over the heel is allowed immediately after surgery.
- A shoe with a stiff and convex sole is used to prevent dorsiflexion of the first MTP joint for 6 weeks after surgery, after which time conventional shoes are allowed.
- Return to full athletic activity is not recommended before 12 weeks after surgery.
- Anderson and McBryde1 treated their patients with 4 weeks non-weight-bearing and another 4 weeks with a weight-bearing cast. In our experience with the Anderson-McBryde procedure, hallux correction or turf toe repair requires no adaptations to the postoperative program outlined earlier.
- No suture removal or wound care is needed with percutaneous sesamoid fixation, because the stab incision has been closed by a sterile strip.
- With combined deformity correction, the type of correction performed dictates postoperative management.

**OUTCOMES**

- Blundell and colleagues4 repaired nine sesamoid fractures in athletes with percutaneous cannulated screws and achieved excellent results. All of the athletes returned to their previous level of activity, with no complications reported. Blundell et al concluded that percutaneous screw fixation is a safe and fast procedure. They also questioned the importance of diagnosing the etiology of painful sesamoid fragments, because treatment is the same regardless of the cause.
- Anderson and McBryde1 performed autogenous bone grafting of medial sesamoid nonunions in 21 athletic and nonathletic patients. Of these, 19 grafts healed, whereas 2 grafts failed because the initial fracture dislocation was greater than 2 mm. These two sesamoids were excised. All patients returned to their preinjury activity levels. No hallux deviations have been reported.
- At our institution, we performed screw fixation in eight athletes and suture fixation with grafting in two nonathletic women and had excellent results with full recovery.
The “athletic group” included six women and two men, all of whom were endurance athletes (eg, running, dancing).

We treated two lateral and eight medial sesamoid bone nonunions.

In one patient, an accompanying forefoot-driven pes cavovarus was corrected with extension osteotomy of the first metatarsus.

In four patients, concomitant hallux valgus deformity was corrected in combined open surgery. In two of these patients, screws were used, and in two other patients sutures were used to stabilize the sesamoid bone during the open approach.

The rest of the patients were treated percutaneously. Local anesthesia was sufficient in one of these cases.

All of the patients returned to their preinjury athletic or occupational activity level within 12 weeks after surgery.

Clinical healing was documented with pedobarography (FIG 5A, B), and osseous healing of the fractures was proved by CT scan in three cases (FIG 5C). One screw had to be removed because of intermittent pain with exercise 1 year after surgery.

Since then, we have used suture cerclage in open approaches, but we also continue to use percutaneous screw fixation.

No sesamoid had to be excised, and no hallux deformity has occurred.

**COMPLICATIONS**

- Persistent sesamoid pain may be caused by:
  - Unrecognized foot deformity and continuous stress to the hallux sesamoids
  - Development of arthritis or avascular necrosis
  - Screw irritation
  - Focused therapy (eg, deformity correction, screw removal) may prevent total excision as a definitive treatment of persistent sesamoid pain.

- Hallux varus after lateral sesamoid excision, hallux valgus after medial sesamoid excision, and cock-up deformity after both sesamoids were excised have been consistently described in 10% to 20% of cases in the current literature. No hallux deviation has been described after fixation of sesamoid bone fractures.\(^1,5,12,13\)

- A lever arm for flexor tendons and consecutive hallux push-off can be reconstructed with sesamoid fixation and may be important for the running athlete.\(^2,3\)

- This biomechanical advantage has been proven in vitro\(^2,3\) but has an uncertain use in praxis, given the excellent functional results if only one sesamoid bone is excised.\(^6,15,16,17\)

**REFERENCES**


DEFINITION

- Sesamoiditis is a general term that indicates an injury to the sesamoid bone. There are multiple possible causes, such as trauma (fracture, contusion, repetitive stress), infection, arthrosis, osteonecrosis, and osteochondritis dissecans.3,7,13–15

- There are two sesamoid bones located plantar to the metatarsal head of the hallux: the lateral or fibular and the medial or tibial sesamoid. The tibial sesamoid typically bears more stress than the fibular sesamoid and is more likely to be injured.4

ANATOMY

- The two sesamoid bones are located plantar to the metatarsal head within the tendon of the flexor hallucis brevis (FHB). They are held together by the intersesamoid ligament and plantar plate. The two sesamoids’ dorsal surface articulates with the head of the first metatarsal facets, and they are separated by a crista. The sesamoids function to absorb the weight-bearing stress across the medial ray as well as protecting the flexor hallucis longus (FHL) tendon that passes between them. The tibial sesamoid is typically larger and located slightly more distal than the fibular sesamoid (FIG 1).

- During the stance phase of gait the sesamoids are slightly proximal to the metatarsal head, but with dorsiflexion of the hallux the sesamoids are pulled distally, protecting the exposed surface of the metatarsal head (FIG 2). During the act of toe raising, the sesamoids bear a significant amount of stress. This stress is typically concentrated more medially over the tibial sesamoid, thus accounting for the increased incidence of tibial sesamoid injuries.

- Biomechanically the sesamoids function as a fulcrum to provide a mechanical advantage to the FHB tendon during metatarsal phalangeal joint plantarflexion.7

- Ossification of the sesamoids typically occurs from multiple centers and occurs during the seventh to tenth years of life. The multiple ossification centers may account for the incidence of bipartite and tripartite sesamoids.5

- The tibial sesamoid is bipartite in about 19% of the population and bilateral in 25% of patients (FIG 3).6

PATHOGENESIS

- Symptoms can arise from a single acute traumatic event, or more commonly there is a history of minor or repetitive trauma as the cause of sesamoid pain.

- Acute injuries typically occur with a similar mechanism to a turf toe injury, acute hyperextension to the hallux metatarsophalangeal (MTP) joint, or a direct contusion to the sesamoid region of the forefoot. This can also result in a fracture or an injury to a bipartite sesamoid.

- In nonacute injuries the patient often cannot remember a specific incident or injury and can only initially recall activity-related discomfort to the forefoot. This history is typically noted in cases of repetitive stress, osteochondritis dissecans, and arthrosis. A bipartite sesamoid can similarly be injured in this case.

- Neuritic pain has also been described with compression to the plantar medial cutaneous nerve underlying the tibial sesamoid.
NATURAL HISTORY

- Most sesamoid injuries resolve with appropriate nonoperative treatment.
- Sesamoiditis that does not resolve with conservative treatment is unlikely to improve significantly after 3 to 12 months.
  - As a result, patients often have pain that prevents them from participating in athletic activities.
  - Performing everyday activities that involve a dorsiflexed MTP joint such as stair climbing, toe raising, and in women wearing heels also can become bothersome.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Most patients cannot remember a specific incident or injury, unless it was acute, and can only recall a gradual onset of discomfort to their forefoot. This pain is often generalized and localized to the great toe region. It is localized more plantarward and is worse with weight-bearing activity. Patients will often prefer cushioned shoe wear versus barefooted activity.
  - Performing activities that require a dorsiflexed MTP joint such as running, jumping, toe raising, or stair climbing can become very irritating to this region.
  - Gait can be antalgic, specifically in the toe-off phase, and can also reveal evidence of medial off-loading and lateral foot overload as the patient walks with the foot externally rotated.
  - Clinical inspection will reveal swelling over the plantar aspect of the hallux MTP joint as well as tenderness to palpation under the tibial sesamoid. This pain can be exacerbated with forced dorsiflexion of the hallux MTP joint. There may be evidence of loss of dorsiflexion and less commonly plantarflexion of the MTP joint. Plantarflexion strength against resistance or with a single-limb toe raise may also be affected due to pain.
  - In acute injuries or in patients with a bipartite sesamoid a drawer test of the hallux MTP joint may also reveal laxity, indicating a fracture of the sesamoid or disruption of the synchondrosis of a bipartite sesamoid.
  - Direct palpation over the tibial sesamoid may also reveal a positive Tinel sign or paresthesia distally, indicating a compression over the plantar medial cutaneous nerve.
  - Assessment of hallux alignment is critical.
    - Evidence of pre-existing hallux valgus or a cavus foot requires careful planning to identify patients who may require concomitant procedures to prevent further migration after tibial sesamoidectomy.
    - Augmenting a tibial sesamoidectomy with a lateral capsular release, medial capsular reefing, or metatarsal or phalangeal osteotomy may be considered to prevent progressive deformity.5
  - Methods for examining the tibial sesamoid include:
    - Direct palpation under the tibial sesamoid with the foot in neutral and with dorsiflexion of the MTP joint
    - Range of motion (ROM): One hand should be placed on the proximal phalanx with the other stabilizing the metatarsal. Dorsiflexion and plantarflexion ROM should be assessed. Symmetry between the right and left side should be noted.
- Drawer test: The examiner grasps the proximal phalanx in one hand and the metatarsal head in the other and performs a dorsal to plantar stress of the MTP joint.
- Toe raise: The patient is asked to do double-limb and single-limb toe raises.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Routine radiographs should consist of standing anteroposterior (AP), lateral, oblique, and axial sesamoid views.
- Plain radiographs will often be diagnostic in cases of arthrosis and osteochondritis dissecans if fragmentation is present (FIG 4).
- A bipartite tibial sesamoid (Fig 3) occurs in up to 19% of the population, and differentiating it from a fracture or injury to the bipartite sesamoid can be difficult. A fractured sesamoid may have a sharp radiolucent line that may assist in differentiation.
- AP radiographs in neutral and dorsiflexion may assist in evaluating separation of the sesamoid segments.
- A triple-phase bone scan or MRI is often required to confirm the diagnosis.
- A triple-phase bone scan, with collimated views of the MTP joint, is very sensitive and may demonstrate increased uptake before radiographic changes become present (FIG 5).

- MRI is more expensive but allows the examiner to identify most causes of hallux MTP pathology in addition to sesamoiditis (FIG 6).

**DIFFERENTIAL DIAGNOSIS**

- Infection, sesamoid–metatarsal or MTP arthrosis or chondromalacia, bursitis, flexor tendinosis, fracture, osteochondritis dissecans, intractable plantar keratosis, nerve compression, bi- or tripartite sesamoid, turf toe injury

**NONOPERATIVE MANAGEMENT**

- Most patients will respond to conservative therapy. This consists of rest or immobilization for 2 to 4 weeks, followed by protected weight bearing with an orthotic, walker boot, or cast for an additional 4 to 6 weeks.
Typically a hard-soled shoe will decrease the dorsiflexion stresses across the MTP joint, and a negative-heel shoe will decrease forefoot loading.

An orthosis such as a turf-toe plate or dancer’s pad with a medial longitudinal arch support will decrease the stresses across the sesamoids (FIG 7).

In athletes, taping the MTP joint to prevent dorsiflexion may allow continued participation.

The use of nonsteroidal anti-inflammatory medication may augment treatment.

The judicious use of steroid injections for chronic sesamoiditis is also indicated.

**SURGICAL MANAGEMENT**

- Pain under the tibial sesamoid that is not responsive to conservative treatment is the main indication for operative intervention. The presence of hallux MTP malalignment, a cavus foot, or stiffness requires careful evaluation and may require additional surgical procedures to improve clinical results.
- Previous excision of the fibular sesamoid or absence of the fibular sesamoid is the main contraindication to a tibial sesamoidectomy. A history of peripheral vascular disease, soft tissue or wound healing problems, diabetes mellitus, and smoking are also relative contraindications that require proper evaluation and discussion with the patient before operative intervention.

**Preoperative Planning**

- The initial evaluation of hallux alignment is of utmost importance.
- Although there is little literature in regard to the appropriate criteria for the addition of a hallux realignment procedure in an isolated tibial sesamoidectomy, the surgeon needs to keep in mind that any failure of reconstruction of the tibial FHB complex or failure to address pre-existing hallux malalignment will compromise patient outcome.
- In general, any patient whose hallux alignment would be considered for surgical realignment without tibial sesamoiditis should have the malalignment corrected during the tibial sesamoidectomy.

**Positioning**

- Anesthesia should be similar to a bunion procedure.
- An ankle block with some mild sedation is typically well tolerated.
- A well-padded supramalleolar Esmarch tourniquet is also used and is well tolerated.
- The patient should be placed on the operating table in a supine position.
- The natural external rotation of the lower extremity allows excellent exposure to the medial aspect of the forefoot (FIG 8).

**Approach**

- Dorsomedial, straight medial, and plantar medial incisions to approach the tibial sesamoid have all been described. The most commonly used incision is a longitudinal medial skin incision that is slightly plantar to the standard incision for a bunion excision (FIG 9). With the dorsomedial incision, it is very difficult to obtain adequate exposure of the plantar aspect of the foot, while the plantar medial incision is typically directly over the plantar cutaneous nerve and near the weight-bearing surface of the foot, increasing wound complications.
TIBIAL SESAMOIDECTOMY

- The most commonly used incision is a longitudinal medial skin incision that is slightly plantar to the standard incision for a bunion excision.
- The plantar cutaneous nerve must be identified and mobilized for protection during the procedure (TECH FIG 1).
  - The nerve can usually be found along the inferior border of the abductor hallucis brevis tendon alongside the MTP joint.
  - Typically the nerve is mobilized inferior to the surgical dissection, although dorsal retraction has been described as well.
  - A vessel loop can also be placed around the nerve to protect it.
- Perform initial evaluation of the tibial sesamoid and metatarsal head articulation through an intra-articular exposure.
- Make a longitudinal incision in the capsule in line with the skin incision.
  - This incision is usually dorsal to the fibers of the insertion of the abductor hallucis tendon.
- Assess the sesamoid articular surface for significant displacement or step-off in acute fractures or bipartite sesamoids. In chronic cases, assess the resultant articular cartilage injury to the sesamoid or metatarsal head articulation of the hallux from osteonecrosis, osteochondritis dissecans, or arthrosis (TECH FIG 2).
- At this stage, when the decision is made to remove the sesamoid, the use of a Beaver mini-blade to outline the tibial sesamoid from the intra-articular approach will assist in its later removal.
- In an acute fracture or a bipartite sesamoid without articular damage, consider using bone grafting of the defect as opposed to performing a sesamoidectomy.
- Repair the capsulotomy with a 2-0 nonabsorbable suture before proceeding with the sesamoidectomy exposure (TECH FIG 3).
- Expose the sesamoid through an extra-articular plantar medial incision in line with the FHB fibers.
  - The sesamoid is embedded within a dense fibrous sheath, and careful dissection out of the FHB and its soft tissue attachments is required (TECH FIG 4).

- This can be facilitated by the use of a Beaver mini-blade, using a pushing technique rather than a cutting motion, as well as grasping the sesamoid with a small towel clamp or Köcher clamp for stability.
- Take utmost care to protect the nerve medially as well as the FHL laterally to prevent injury.
- Once the sesamoid is removed, carefully assess the continuity of the FHB complex. Typically there are some remaining fibers of the FHB complex.

**TECH FIG 1** • Intraoperative picture; the Freer elevator is underneath the plantar cutaneous nerve.

**TECH FIG 2** • Intracapsular view showing the articulation of the tibial sesamoid and the metatarsal head. (From Lee S. Technique of isolated tibial sesamoidectomy. Techn Foot Ankle Surg 2004;3:85–90, with permission.)

**TECH FIG 3** • The tip of the Freer elevator is underneath the tibial sesamoid before dissection of the flexor hallucis brevis complex. Also note the longitudinal capsulotomy and repair.

**TECH FIG 4** • After the initial incision to separate the flexor hallucis brevis in line with its fibers.
POSTOPERATIVE CARE

- Patients are limited to heel weight bearing for 2 weeks.
- At the 2-week follow-up visit stitches are removed, a toe spacer is placed, and patients are allowed to bear weight as tolerated in a postoperative shoe or a short walker boot.
- Standing radiographs should be performed to confirm maintenance of hallux alignment (FIG 10).
- The toe spacer should remain in place for 6 to 8 weeks postoperatively to prevent hallux valgus deformity.
- If a hallux realignment procedure was also performed, we use a taping technique for 4 to 6 weeks similar to a bunion procedure.
- Reapproximate the skin edges with a 3-0 nylon suture and dress the wound with a bunion dressing, with the hallux protected in plantarflexion and in mild varus.
- The patient is provided with a firm-soled postoperative shoe and allowed immediate heel weight bearing.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Hallux malalignment</th>
<th>The presence of a cavus foot, hallux valgus, claw toe, cock-up deformity, or stiffness requires careful evaluation and may require additional surgical procedures to improve clinical results.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantar cutaneous nerve</td>
<td>The nerve is most commonly located plantar to the inferior border of the abductor hallucis brevis tendon. This nerve should be visualized and protected throughout the case.</td>
</tr>
<tr>
<td>Flexor hallucis brevis repair</td>
<td>A UCL taper needle, with its smaller radius of curvature, is easier to use in the limited surgical field. Careful and meticulous repair of the FHB complex is required to prevent the development of malalignment.</td>
</tr>
</tbody>
</table>

OUTCOMES

- Hallux malalignment with resultant claw toe and cock-up and hallux valgus deformity after tibial sesamoidectomy has been described.\(^5,9,11,12\)
  - Historical studies have found a 10% to 42% incidence of hallux valgus and a 33% to 60% incidence of loss of motion on follow-up.\(^5,11,12\)
- Kaiman and Piccora\(^9\) also reviewed tibial sesamoidectomies and concluded that assessment of the osseous relationship was crucial to prevent hallux valgus deformity. Their average follow-up was only 13.2 months and they found no evidence of valgus drift, but they recommended tendon balancing or capsulorrhaphy in conjunction with the tibial sesamoidectomy.
- Van Hal et al\(^13\) found no evidence of deformity or diminished range of motion.
- Lee et al\(^10\) reported on 20 patients without preoperative malalignment and noted no significant difference in postoperative ROM or the development of subsequent hallux malalignment.
- Saxena and Krisdakumtorn\(^14\) reported on active individuals who had isolated tibial sesamoidectomies.
  - One patient developed loss of hallux flexion after surgery.
  - Two patients with hallux valgus deformity were identified before surgery. One patient had a concomitant distal metatarsal osteotomy with no further drift, while the other patient did not have a concomitant procedure at the same time and went on to a bunion correction at a later date.
- Inge and Ferguson\(^8\) and Mann et al\(^11\) found that 41% to 50% of their patients continued to have mild to severe pain after a tibial sesamoidectomy. More recently, however, Van Hal et al\(^15\), Saxena and Krisdakumtorn,\(^14\) and Lee et al\(^10\) have reported excellent pain relief in the majority of their patients with tibial sesamoidectomies in their athletic population.
- Aper et al\(^1\) showed in two cadaveric studies that the FHB effective tendon moment arms are significantly decreased with
the excision of both hallux sesamoids. However, FHL effective tendon moment arms are noted to be diminished with isolated sesamoid excisions as well. These studies may help to explain the functional weakness reported by Mann et al. However, Van Hal et al. and Saxena and Krisdakumtorn have not found any functional weakness of plantarflexion in any of their patients. Their patients were also able to return to their previous level of athletic participation with no functional deficit. Lee et al. also reported that 30% of their patients could not do a single-limb toe raise, indicating some plantarflexion weakness, but this did not affect any subsequent athletic activity.

COMPLICATIONS

- Complications related to tibial sesamoid excisions can be separated into intraoperative complications, insufficient pain relief, functional weakness, and hallux malalignment.
- The most common intraoperative complication reported is injury to the plantar digital nerve.
  - Patients typically complain of nerve irritation postoperatively. This generally responds well to observation or localized steroid injections. It occurs more commonly with fibular sesamoid excisions.
  - Complete laceration of the nerve has never been reported, and this nerve irritation appears to be the result of aggressive retraction during surgery. This can be avoided by using meticulous technique with identification and protection of the plantar digital nerve during surgery.
- Isolated complete sesamoidectomies are thought to alter the mechanical balance of the hallux MTP joint. Clinical studies have described stiffness, functional loss, cock-up deformity, claw toe deformity, and the development of a hallux valgus deformity after isolated tibial sesamoidectomies.
  - As noted earlier, identifying and addressing any significant malalignment of the hallux MTP can decrease the rate of future deformities.
- The loss of single-limb toe raise has also been reported and may be related to the decreased moment arm and inadequate repair of the FHB complex.

REFERENCES

DEFINITION

A hammer toe deformity is defined by a flexion deformity of the proximal interphalangeal (PIP) joint, typically with associated metatarsophalangeal (MTP) joint hyperextension. The distal interphalangeal joint (DIP) may be flexed, extended, or in a neutral position.

ANATOMY

- The plantar plates of the MTP and PIP joints of the toes provide insertion points for ligaments, tendons, and soft tissue septa.
- At the MTP joint the plantar plate originates from the periosteum of the shaft of the metatarsal and it inserts onto the base of the proximal phalanx. Plantar plate dysfunction has been associated with hammer toes and claw toes.
- At the PIP joint the plantar plate also attaches in a similar way as in the MTP joint, lying immediately plantar to the joint.
- The collateral ligaments insert to the plantar plate at both the PIP and MTP joints.
- The extensor digitorum longus (EDL) tendon is the primary extensor of the MTP joint; it attaches to the lateral four toes. The extensor digitorum brevis (EDB) tendon is the only dorsal intrinsic muscle of the foot, and it attaches to the medial four toes.
- These two tendons maintain their orientation in part due to the fibroaponeurotic extensor hood.
- Its proximal segment, called the extensor sling, attaches to the plantar base of the proximal phalanx. It receives contributions from the interossei muscles. Its distal segment or extensor wing receives the insertion of the lumbrical muscles.
- Extension of the PIP and DIP joints is achieved by the coordinated action of the extrinsic extensor tendons and the intrinsic flexor muscles; with paralysis of the intrinsic muscles, the extensor muscles would extend only the MTP joints.
- The extrinsic flexors are the flexor digitorum brevis (FDB) and longus (FDL) muscles. The FDB and FDL tendons unite to the base of the middle and distal phalanx, respectively. They flex the PIP and DIP joints and are weak flexors of the MTP joint.
- The intrinsic flexors are the interossei and lumbricals muscles. The lumbricals flex the MTP joints and extend the interphalangeal joints; they have a stronger effect over the extension of the PIP and DIP joints due to their distal attachment compared to the interossei, which are weak extensors of the toes (FIG 1).

PATHOGENESIS

- Any disruption of the foot’s complex and delicate balance between the static stabilizers (ligaments, plantar plate) and dynamic stabilizers (intrinsic and extrinsic tendons) creates a lesser toe deformity.
- With diminished intrinsic muscle flexion power, the extrinsic extensor tendons will extend the MTP joints. With MTP joint extension, the long flexor tendons flex the PIP and DIP joints, resulting in the intrinsic tendons being insufficient in flexing the MTP joint or extending the PIP or DIP joints. This imbalance creates deformity.
- Plantar plate disruption may also compromise the balance of the toes and promote MTP joint hyperextension, thus leading to a similar chain of events to that described above (FIG 2).
- The pathologic anatomy of claw toes and hammer toes has been investigated in cadaveric dissections.
In one of these studies, contributions of various anatomic structures to the deformity were determined:

- For MTP joint hyperextension deformity, the skin provided about 9% of total deformity, the extensor tendons (EDL + EDB) 25%, the dorsal capsule 19%, and the collateral ligaments 47%.
- For PIP joint flexion deformity, the skin accounted for about 20% of deformity, the FDB tendon 40%, and the plantar capsule 40%; the FDL tendon had no contribution.
- These numbers show the relative importance of the different anatomic structures in the deformity and suggest which structures to release in surgery.

With clawing (hyperextension of the MTP joint) the interossei become subluxated in relation to the MTP joint and their line of pull becomes dorsally situated in relation to the joint axis and center of MTP joint rotation.

This results in an increased deformity with interossei activity: instead of plantarflexion, they provide dorsiflexion at the MTP joint.

The lumbricals normally have an angle of 35 degrees with respect to the metatarsal axis. With clawing, they can subduct an angle of 90 degrees with the metatarsal axis, rendering them insufficient to flex the MTP joint.

Causes for lesser toe deformity are posttraumatic, inflammatory, neurologic, congenital, postsurgical, and nonspecific in nature.

Posttraumatic deformities include sequelae of leg injuries, fractures, soft tissue injuries, and compartment syndromes.

- In these cases a scarring or contracture of the deep compartment of the leg can lead to flexion deformities of the toes.
- A compartment syndrome after a calcaneal fracture, affecting the calcaneal compartment, will compromise the quadratus plantae muscle, thereby shortening the intrinsic musculature.
- Damage to the tibial nerve due to these same reasons may also be responsible for loss of intrinsic flexor action, resulting in an MTP joint extension deformity.

Inflammatory: in rheumatoid arthritis due to capsular inflammation and disruption
- Plantar plate attenuation may lead to MTP joint hyperextension and nonphysiologic PIP joint flexion.
- Neuromuscular and congenital causes may alter the foot’s intrinsic and extrinsic muscle balance.
- Neuromuscular causes of lesser toe deformities include cerebral palsy, Charcot-Marie-Tooth disease, Friedreich ataxia, spinal dysraphism, and polio, among others.
- Congenital causes include idiopathic cavovarus foot, clubfoot sequelae, and arthrogryposis.

Postsurgical causes
- Dorsiflexion of the metatarsal head after distal metatarsal osteotomies (to relieve metatarsalgia, or synovitis)
- Proximal metatarsal osteotomies with elevation of the distal fragment and secondary overpull of the flexor tendons
- Secondary to metatarsal lengthening due to undesired lengthening of the flexor and extensor tendons

Nonspecific causes
- Muscular imbalance, ineffectiveness of the intrinsic flexors, and age-related deficiencies of plantar structures
- Shoe wear has been implicated because of the buckling effect of the toes inside a short toe box, with resulting flexion of the PIP joint.

**NATURAL HISTORY**

The natural history of this deformity is a slow progression to a claw toe, where extension of the MTP joint increases with an increase in PIP flexion.

If the deformity is flexible, the prognosis is good, as a conservative option may be successful, or if surgery is deemed necessary, simple techniques typically meet with satisfactory outcomes.

As the lesser toe deformity becomes fixed, the chance of a successful nonsurgical treatment decreases, and surgical treatment generally involves more complex reconstructive procedures with an increased risk for postoperative stiffness.
PATIENT HISTORY AND PHYSICAL FINDINGS

- The chief complaint is pain and tenderness on the dorsal PIP joint, typically due to pressure from the shoe.
- A progressive hammer toe deformity may lead to an extended MTP joint and eventually a plantar callus under the corresponding metatarsal head. Occasionally, with associated PIP and DIP flexion, a plantar callus at the tip of the toe will develop.
- Toe position must be evaluated with weight bearing to appreciate the full extent of the deformity. With the patient seated, the range of motion of the ankle and subtalar, transverse tarsal, and metatarsophalangeal joints is inspected.
- Flexibility of the MTP, PIP, and DIP joints must be determined as it influences surgical decision making.
- Inspection and palpation of the plantar foot may reveal calluses under the metatarsal heads and tips of the toes.
- A comprehensive neurovascular examination is performed. Correction of lesser toe deformities will place digital vessels and nerves on stretch; preoperative neurovascular compromise to the toes must be identified, particularly if surgical correction is considered.
- Examinations of the lesser toes’ MTP and IP joints may include:
  - Push-up test (MTP): If the deformity is flexible, with the push-up test the MTP joint will flex to its normal position. If not, it will remain extended, defining a fixed deformity. Semiflexible deformities are those that correct partially with the push-up test.
  - Evaluation of PIP joint stiffness: Fixed deformities are present if it is not possible to obtain full extension of the PIP joint. Flexible deformities allow the PIP joint to extend fully.
  - Evaluation of MTP joint stability: Stage 0, no laxity to dorsal translation; stage 1, the base of the proximal phalanx can be subluxated with the dorsal stress; stage 2, the proximal phalangeal base can be dislocated and relocated; stage 3, the base of the proximal phalanx is fixed in a dislocated position.\(^{10}\)

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs
  - Inflammatory arthritis may be associated with periarticular erosions, and this may influence surgical management.
  - The extent of the deformity is characterized on plain radiographs: subluxation, dislocation, or medial or lateral deviation. Dislocation of the MTP joint is characterized by an overlap of the base of the proximal phalanx on the head of the metatarsal on the AP view and complete dorsal displacement of the proximal phalanx relative to the metatarsal head on the lateral view (FIG 3).

DIFFERENTIAL DIAGNOSIS

- Fixed hammer toe or claw toe deformities (not amenable to treatment with tendon transfer alone)
- Metatarsophalangeal synovitis (absence of deformity warranting tendon transfer)
- Posttraumatic toe deformities
- Soft tissue tumors of the toes

NONOPERATIVE MANAGEMENT

- For flexible deformities, an initial conservative approach is recommended.
- Stretching exercises may help but have little proven benefit as they do not alter the imbalance of extrinsic and intrinsic tendons.
- Shoe wear modifications: wider, deeper toebox to give more room to the toes
- Metatarsal pads to relieve metatarsal head pressure and toe sleeves to cushion pressure on the dorsum of the PIP joints. Orthotics with metatarsal padding must be used judiciously since they elevate the toes and may lead to greater dorsal PIP joint pressure.
- Hammer toe sling orthoses (or taping) are available that hold the proximal phalanx in a more physiologic position (FIG 4).
- The value of these measures depends to some degree on the degree of flexibility remaining in the deformity.

SURGICAL MANAGEMENT

- A toe flexor-to-extensor tendon transfer is rarely performed in isolation; typically, it is an adjunct to a more comprehensive correction of hammer toe and claw toe deformities.
- The goal of a flexor-to-extensor tendon transfer is to reposition the proximal phalanx into a more physiologic alignment, with realignment of the MTP and PIP joints. It is essentially
“taping of the toe under the skin.” Despite flexible deformity, tendon transfer may need to be performed with dorsal capsulotomy and collateral ligament release of the MTP joint. As the deformity becomes more fixed, a PIP arthroplasty—arthrodesis with or without metatarsal shortening osteotomy would typically be warranted, but a flexor-to-extensor tendon transfer may need to be added to avoid residual elevation of the toe (“floating toe”), one that does not touch the floor with weight bearing.

Preoperative Planning

■ For MTP joint hyperextension deformity, a bone-shortening procedure can be performed; We are currently evaluating this procedure.
  ▪ Generally a soft tissue procedure is chosen; the choice will vary depending on the amount of release needed.
  ▪ Progressive releases have to be made, starting with the dorsal skin, followed by extensor tendons (tenotomy or lengthening), the dorsal capsule, and collateral ligaments, until an aligned MTP joint is obtained.
  ▪ For further correction and stabilization, a flexor-to-extensor transfer should be added. In this case, the transfer should be done suturing the FDL to the EDL proximal to the middle of the proximal phalanx, to obtain more flexion power over the MTP joint.

■ For PIP joint flexion deformities, FDB releases are considered if the flexion contracture is not solved percutaneously.
  ▪ If FDB tenotomy is not enough to treat the PIP deformity, a PIP joint arthroplasty or arthrodesis should be added.
  ▪ A bone-shortening procedure can be also considered, typically a metatarsal-shortening osteotomy. In our opinion, a resection of the proximal aspect of the proximal phalanx should be avoided due to a high prevalence of postoperative MTP joint instability.
  ▪ The flexor-to-extensor transfer will correct the PIP joint flexion if flexible and will also stabilize the deformity if a FDB tenotomy or a PIP joint arthroplasty was performed. In this case, the transfer should be done suturing the FDL to the EDL proximal to the middle of the proximal phalanx to obtain more extension power over the PIP joint.

Positioning

■ A supine position is preferred, with the involved foot on the same side as the surgeon.
■ When performing the flexor-to-extensor transfer, as a plantar approach is needed, enough distance between the foot and

FIG 5 • Positioning of the patient with adequate room for the surgeon to comfortably approach the toe distally.

the distal end of the table has to be available so that the surgeon can work comfortably (FIG 5).

Approach

■ For the MTP approach, a longitudinal dorsal incision over the involved MTP joint is performed.
  ▪ The incision can be performed in a curvilinear fashion to avoid skin contractures (in our experience a rare complication).
  ▪ For the PIP joint approach, a dorsal transverse approach over the PIP joint is performed, removing the hyperkeratotic skin with the incision.
  ▪ It is also possible to perform a longitudinal incision after the tendon transfer incision, which may include the MTP incision when an additional procedure has been performed over the MTP joint.
  ▪ For the flexor-to-extensor transfer, a dorsal approach over the proximal phalanx must be made.
  ▪ In our experience, an extension deformity at the MTP joint is virtually always present, and therefore a procedure over the MTP joint is commonly performed. This MTP approach can be used, extending it distally.
  ▪ To gain access to the flexor tendons, two plantar incisions have to be made, one transverse along the proximal skin crease of the toe and the second oblique over the DIP joint.
  ▪ This last incision can be made transverse and a percutaneous FDL tenotomy can be performed.
  ▪ There is a risk of damaging the plantar plate of the DIP joint and hyperextension of the joint can be observed.

FLEXOR-TO-EXTENSOR TENDON TRANSFER

■ Make a plantar incision in a short transverse fashion along the proximal skin crease of the involved toe.
  ▪ Carry the dissection through the subcutaneous layer. Identify the flexor tendon sheath and open it longitudinally with a blade (TECH FIG 1).
  ▪ This incision can also be made longitudinally, as shown by Boyer and DeOrio, which helps to avoid damage to the neurovascular structures.
Identify the FDL tendon between the slips of the FDB (TECH FIG 2A) and retract it with a hemostat to the surface of the wound, placing it into traction (TECH FIG 2B). Keep the dissection central to avoid excursion to the adjacent medial and lateral digital neurovascular bundles.

Place a second plantar incision oblique in orientation over the DIP, just proximal to the fat pad, and identify the plantar capsule of the joint to protect it. Detach the FDL from its insertion to the distal phalanx. As noted before, this incision can be made transversely and the FDL can be detached percutaneously (TECH FIG 3). Keep the stab incision central to avoid damage to the digital neurovascular bundles. Although the incision is at the distal crease, direct the scalpel proximally at a 45-degree angle to ensure that the FDL tendon is transected and the DIP plantar plate is avoided.

Pull the FDL tendon from the proximal incision and separate it into two slips along its midline raphe. Hold each half with a hemostat (TECH FIG 4).

Place a dorsal longitudinal incision over the dorsum of the proximal phalanx just distal to its midpoint to the proximal metaphyseal flare.

Perform superficial dissection, and identify the extensor tendon and split it in line with the long axis of the phalanx (TECH FIG 5). Carry the dissection in a subperiosteal manner deep to the neurovascular bundle.

Identify the tip of the hemostat in the plantar incision. Take care to avoid pinching the bundle. The tip

**TECH FIG 2** • A. The flexor digitorum brevis appears dividing itself in two slips, and the flexor digitorum longus (FDL) rests in between. The FDL possesses a midline raphe, which helps to identify it. B. The FDL is identified with a small hemostat, and traction is being placed on it.

**TECH FIG 3** • Detachment of the flexor digitorum longus through a transverse distal incision in a percutaneous way.

**TECH FIG 4** • Splitting of the flexor digitorum longus in two following the midline raphe.

**TECH FIG 5** • Dorsal incision over the proximal phalanx, identifying the extensor tendon and splitting it following the longitudinal axis.
Chapter 31 FLEXOR-TO-EXTENSOR TENDON TRANSFER FOR FLEXIBLE HAMMER TOE DEFORMITY

Techniques

- The technique is as above up to the step where the FDL is brought through the plantar aspect of the toe. (TECH FIG 6)
- Make a dorsal longitudinal incision over the proximal phalanx from just proximal to its midpoint to the distal metaphyseal flare.
  - With the ankle held in a neutral position, the MTP joint in 20 degrees of plantarflexion, and the PIP joint in neutral, secure both slips of the FDL over the extensor tendon with two or three separate stitches of 4-0 absorbable suture.
- Evaluate the MTP joint at this time to observe for continued extension at that joint. If any is present, alternative procedures will need to be performed.
- Close the wound with absorbable stitches on the plantar incisions and nylon dorsally.
- Before breaking sterility, deflate the tourniquet to ensure revascularization of the toe.

TECH FIG 6 • Plantar view of the toe showing a small hemostat passing through the dorsal incision, deep to the neurovascular bundle and through the slips of the flexor digitorum brevis tendon to hold one of the slips of the flexor digitorum longus tendon.

FLEXOR-TO-EXTENSOR TENDON TRANSFER THROUGH A DRILL HOLE

- The technique is as above up to the step where the FDL is brought through the plantar aspect of the toe.
- Make a dorsal longitudinal incision over the proximal phalanx from just proximal to its midpoint to the distal metaphyseal flare.
  - Take the dissection down to the extensor sheath and split the sheath and periosteum in line with the incision, exposing the dorsum of the phalanx.
- Place a drill hole dorsal to plantar large enough to allow passage of the tendon, in the junction of the middle and distal third of the proximal phalanx.
- Generally we use a 2.0-mm drill and take care to avoid making a hole larger than one third of the diameter of the bone.
- Pass the tendon between the short flexors and through the hole. Position the foot as above and suture the tendon with 4-0 absorbable sutures to the extensor sheath.
- The rest of the procedure remains the same as described above.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Evaluate the stiffness of the deformity preoperatively. It is important to inform the patient about the possible additional procedures needed and the corresponding outcome. The surgery for hammer toes is a step-by-step procedure: additional surgery is commonly needed as the alignment is being corrected. Soft tissue procedures will be followed if needed by bone-shortening procedures and tendon transfers, depending on the alignment we obtain.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preoperative planning</td>
<td>Always correct the deformity going proximal to distal. Deciding to add a bone procedure is not always easy; it depends on how stiff the deformity is. A Weil osteotomy will most probably correct the extension component of the MTP joint and some of the flexion component at the PIP joint. The problem is the resulting soft tissue balance, where an MTP joint that is too unstable may lead to a floating toe. Therefore, if there is not metatarsalgia, we prefer to do soft tissue procedures before adding a bone shortening.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- Individual soft compressive dressings are placed over each operated toe; sterile strips of adhesive bandage are commonly used to keep each toe aligned.
- Small “tie-down” straps are used to hold each toe in plantarflexion (the straps are placed around the proximal phalanx of each toe). These are kept in place for 6 weeks.
- A soft compressive dressing is placed over the foot, and the foot is placed in a postoperative shoe with a rigid rocker-bottom sole.
- Immediate weight bearing as tolerated is allowed, with a planigrade foot, keeping the MTP joints neutral inside the postoperative shoe.
- From week 2 to 4, once soft tissues allow mobilization and the stitches are removed, passive plantar flexion exercises at the level of the MTP joint are done to stretch the dorsal structures.
- From the sixth week on, depending on comfort and edema, a return to normal shoes is permitted.

OUTCOMES

- The first reports of this technique used both the FDL and FDB tendons in the transfer.
  - Parrish in 1973 described the technique shown in this chapter, using only the FDL and splitting the tendon longitudinally and suturing each half to each other under the extensor tendon. Fifteen of 18 patients had good to excellent results (83%).
  - Barbari and Brevig reported 89% patient satisfaction in 39 cases.
  - Cyphers and Feiwell reported 95% good to excellent results in 20 patients with residual paralysis from myelomeningocele.
  - Boyer and DeOrio recently reported an 89% satisfaction rate, using the technique in fixed and flexible hammer toes. They reported better results for fixed deformities where a concomitant resection of the head of the proximal phalanx was performed.
  - Our experience with this technique over the past 6 years has yielded a good to excellent result in 83% of the 40 cases (unpublished data).
  - Most postoperative complaints are due to stiffness of the PIP joint, and in relation to the MTP joint when a procedure was added at this level (ostectomy, tenotomy, or capsulotomy).
  - Recurrence of deformity has been noted in 9% of the cases.
  - Retrospective evaluation of our results has shown that incomplete evaluation of the preoperative stiffness at the MTP joint may explain most of the recurrences.

REFERENCES

DEFINITION

- Hammer toe deformity is one of the most common lesser toe disorders. Its severity can range the gamut from asymptomatic to disabling.
- Appropriate treatment of lesser toe disorders begins with determination of the exact joints involved and the plane of the primary and secondary deformities.
- Sagittal plane deformities of the lesser toes are generally classified as hammer toes (FIG 1), claw toes (FIG 2), and mallet toes (FIG 3).
- Specifically, a hammer toe is a lesser toe deformity in which a sagittal plane, flexion contracture of the proximal interphalangeal (PIP) joint is the primary deformity.
- A secondary, slight extension deformity of the metatarsophalangeal (MTP) joint may be present with a hammer toe, but this deformity is secondary and does not represent the primary deformity.
- The primary deformity being at the level of the PIP joint differentiates a hammer toe from a mallet toe or claw toe, in which case the primary deformity is located at the distal interphalangeal joint or the MTP joint, respectively.
- Hammer toe deformities are further classified as flexible or fixed depending on whether they completely correct with gentle, passive manipulation.

ANATOMY

- The lesser toes comprise three articulating phalanges (distal, middle, and proximal) that, at the proximal phalanx, articulate with the metatarsal head. The only exception to this pattern is the fifth toe, which in about 15% of individuals comprises just two phalanges (distal and proximal).
- The interphalangeal joints and their corresponding ligaments normally allow flexion but not extension past neutral, while the MTP joint complex allows both flexion and extension.
- Active motion of the toe and dynamic stability of the toe are achieved by both extrinsic muscles (originating in the leg) and intrinsic muscles (originating in the foot) (FIG 4).
- The extensor digitorum longus and flexor digitorum longus are the extrinsic muscles.
- The extensor digitorum longus invests the extensor hood over the proximal phalanx as well as inserting on the dorsal aspect of both the middle and distal phalanx (FIG 5), while the flexor digitorum longus inserts only on the distal phalanx.
- The intrinsic muscles of the toes include seven interosseous muscles, four lumbricals, the abductor digiti minimi, the flexor digitorum brevis, and the extensor digitorum brevis.

PATHOGENESIS

- Although the etiology of lesser toe deformities is multifactorial and includes neurologic, congenital, traumatic, and arthritic causes, the usual culprit for hammer toe deformity is restrictive shoe wear that does not provide sufficient room for the toes.
- Crowding of the toes in a shoe’s toe box can be the result of poor shoe design, poor shoe fit, or a foot condition such as a hallux valgus deformity (and to a lesser degree bunionette deformity) that crowds the toe box so that pressure is applied
to the tips of the lesser toes and causes them to be passively flexed within the shoe for prolonged periods.

- As the extensor digitorum longus, the primary extensor of the PIP joint, simultaneously inserts on the middle and distal phalanx, the flexion of the PIP joint by the pressure of the toe box is reinforced by the inability of the extensor digitorum longus tendon to extend the PIP joint when the proximal phalanx is not neutrally aligned (ie, the MTP joint is dorsiflexed).
- This passive dorsiflexion at the MTP joint can occur from the pressure of the toe box on the toe as well as from elevation of the heel (eg, high-heeled shoe wear).
- As flexible hammer toe deformity is generally well tolerated, the patient does not usually seek treatment during the initial development of a hammer toe.
- With time, unless the factors that are stressing the toe are eliminated, the hammer toe will progress to a symptomatic fixed deformity.

NATURAL HISTORY

- Hammer toe deformity generally worsens with time if the causative factors are not mitigated. Over time, the PIP joint flexion deformity will tend to increase and the toe will eventually progress from a flexible to a fixed deformity.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The most important information to elicit from the patient’s history is whether the patient’s complaints are solely resulting from the hammer toe deformity or whether other sources of pain are present.
- Occasionally, patients will present requesting surgery, having already made the diagnosis on their own. They experience pain in the foot and because the hammer toe deformity is the only abnormality they can see, they may conclude, sometimes mistakenly, that the hammer toe is the source of their pain.
- A good patient history includes the conservative treatment measures that have been tried, the types of shoes the patient wants to wear, the sorts of shoes the patient needs to wear for his or her occupation (ie, steel-toed shoes), and other patient factors that might be relative contraindications for surgery (eg, peripheral vascular disease) or would encourage you to pursue operative intervention (eg, history of ulceration).
- Typically, patients with a hammer toe deformity present with a complaint of pain centered over the PIP joint that is relieved with removal of their shoes.
- The degree of deformity generally corresponds to the degree of symptoms.
- Symptoms of numbness and tingling in the foot, diffuse pain, pain that occurs at night, or pain that does not improve with removal of shoes or shoe modifications raises concerns that the pain may be nonmechanical or emanating from a source other than the hammer toe.
- Attempts by the patient to try different toe pads or different shoes should be noted in the history, as improvements in the patient’s pain with more reasonable shoe wear helps to clarify the diagnosis as well as direct efforts for nonoperative care.
- A history of neuropathy, peripheral vascular disease, systemic arthritides, and diabetes is important to elicit to assess for operative risk as well as to screen for other confounding sources of foot and toe pain.
- Finally, a history of ulceration or infection needs to be elicited, as this may indicate a need for more urgent operative correction of the deformity to prevent recurrence.

The physical examination for hammer toe deformity, as with all foot and ankle examinations, begins with inspection of foot posture. Calluses, scars, and previous surgical incisions should be noted, as should the degree of the toe deformity.
- Hallux valgus deformity and bunionette deformity need to be assessed as to their contribution to the crowding of the toe box.
- With the patient standing, there must be enough room for the hammer toe to lie in the corrected position if surgically corrected. If a coexistent hallux valgus deformity prevents the hammer toe from being fully corrected, then the bunion must be surgically addressed at the same time as the hammer toe to avoid recurrence of the lesser toe deformity.
Palpation of the foot and toes should reveal a point of maximal tenderness over the PIP joint, and the ability or inability to passively correct the hammer toe to neutral should be recorded.

Finally, as with all foot examinations, pulses and foot sensation area are assessed.

Methods for examining the hammer toe deformity include the following:

- Palpation of the distal interphalangeal, PIP, and MTP joints for points of maximal tenderness. The PIP joint should be the area of maximal tenderness, but the tip of the toe may be painful as well.
- Gentle manual straightening of the toe to assess the ability of the toe to correct to neutral. If the toe completely corrects to neutral it is considered a flexible deformity. If the toe does not completely correct, it is considered a fixed deformity. A flexible deformity can be addressed with a soft tissue procedure such as a flexor-to-extensor tendon transfer, but a fixed deformity will require bone resection for surgical correction.
- Push-up test: With the patient seated and knee flexed, the examiner dorsiflexes the ankle to neutral by applying pressure under the metatarsal heads. The correction of the toe deformity with this maneuver is noted. This will determine whether the deformity is fixed versus flexible and is also useful in the operating room to assess residual MTP joint contracture after the hammer toe has been corrected at the PIP joint. Residual MTP joint contracture necessitates additional surgical correction at the MTP joint such as extensor tendon lengthening, capsular release, or collateral ligament release.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standing radiographs of the foot (AP standing, lateral standing, and an oblique view) are helpful to assess alignment of the toes as well as to rule out arthritis of the various toe joints.
- Vascular studies of the lower extremity (transcutaneous PO2 readings and arterial Doppler studies with waveforms and toe pressures) are essential if surgical intervention is contemplated and there is any question of vascular compromise.

**DIFFERENTIAL DIAGNOSIS**

- Claw toe
- Mallet toe
- Crossover toe deformity
- Degenerative joint disease
- Morton neuroma
- Neuropathy
- Radiculopathy
- Vascular insufficiency
- Metatarsal stress fracture
- MTP joint instability or synovitis

**NONOPERATIVE MANAGEMENT**

Ultimately, the treatment of a hammer toe deformity involves “making the shoe fit the foot, or the foot fit the shoe.” Conservative treatment for a symptomatic hammer toe involves accommodating the deformity with a shoe the patient finds acceptable. Generally, an athletic-type shoe with a soft toe box will accommodate many mild deformities, whereas a prescription extra-depth shoe with an extra-wide toe box will be needed to accommodate others.

Occasionally, softening of the leather upper of a shoe and stretching of the shoe over the area of the deformity will allow several millimeters of extra room for the toe, and in extreme cases a “bubble patch” or cut-out and elevation of a portion of the shoe toe box can give relief.

Silicone toe sleeves or toe pads can help relieve symptoms in mild deformities, but they are not usually successful for the treatment of fixed deformities as they tend to “stuff” the already crowded toe box and make the deformity more symptomatic.

**SURGICAL MANAGEMENT**

- The primary indication for surgical correction of a hammer toe is a symptomatic (painful or preulcerative lesion) in a patient with adequate vascularity and realistic expectations who has failed to respond to conservative care.
- Generally, patients with these problems tend to present having already attempted some type of conservative treatment or change in shoe wear. If they have not, it is worthwhile to educate the patient concerning the nature of the problem and conservative treatment options.
- Generally, the most important determinant of postoperative patient satisfaction is a realistic preoperative expectation. When considering surgery, the patient should be told that by choosing surgery he or she is electing to trade a painful, thin, deformed toe with some voluntary motion for a less painful (ideally pain-free), short, scarred, possibly numb, swollen toe with little volitional control. The patient should not make the decision for surgery based on whether he or she wants a “normal” toe.
- If the patient’s preoperative expectations are too high, he or she should be advised to maximize conservative care and avoid surgery, as most likely he or she would be disappointed with the surgical outcome.
- Preoperatively, the patient’s shoe wear goals should be discussed, stressing that the goal of the operation is to allow the patient to wear “reasonable” shoes.
- A patient with a coexistent hallux valgus deformity that does not allow adequate space for the lesser toe to move down onto the floor with surgical correction will have to have the hallux valgus deformity corrected at the time of the lesser toe surgery to avoid recurrence of the hammer toe.
- In this situation the hallux valgus deformity will have to be corrected even if it is asymptomatic. The patient needs to be counseled that correction of an asymptomatic hallux valgus deformity, to provide space for the hammer toe, may lead to a painful or numb great toe (“It is difficult to make something that doesn’t hurt better”). Patients need to be aware of this possibility before electing surgery and consider it in their decision to have surgery.
- With the decision made to proceed with fixed hammer toe deformity correction, there are primarily two surgical options: PIP joint resection arthroplasty and PIP joint arthrodesis.
- With either option, the fixed nature of the hammer toe deformity requires resection of bone to shorten the toe so that, as it is straightened, the contracted, plantar neurovascular structures are not injured, which would occur with simply forcibly straightening the toe and pinning it without bone resection.
- PIP joint resection arthroplasty involves resecting the distal condyles of the proximal phalanx, which relieves the deformity and often retains a small amount of motion at the PIP joint.
This procedure has almost universally good results and is generally regarded as the gold standard for the correction of the majority of hammer toe deformities.

- When it is desirable to have permanent, multiplanar stability at the PIP joint or to perform the procedure without the use of a postoperative stabilizing Kirschner wire, arthrodesis at the PIP joint may be a better option.
- PIP joint arthrodesis involves preparation of the adjacent middle and proximal phalanx articular surfaces and some type of fixation to create stability at the fusion site. Several methods of fixation have been advocated, including Kirschner wire fixation and preparing the bone so that it interdigitates, such as in a peg and dowel fusion, intramedullary screw fixation, or an interphalangeal implant such as the StayFuse™ implant (Nexa Orthopedics) (FIG 6).
- The StayFuse implant is designed for PIP joint arthrodesis. It is composed of two matching titanium components that are individually inserted into the prepared middle and proximal phalanges and then interlocked, creating stable PIP joint fixation.
- Arthrodesis is beneficial for patients for whom recurrence of deformity is likely, such as in severe deformity or revision hammer toe surgery. Situations in which a pin extending from the toe may pose an unacceptable infection risk, such as in a patient with diabetes mellitus, rheumatoid arthritis, or compliance issues, may benefit from arthrodesis with an implant spanning the PIP joint.
- Fusion is also useful for crossover toe deformity correction, when destabilizing the PIP joint with a resection arthroplasty may result in a symptomatic angular deformity at the PIP joint, as crossover toe deformity invariably recurs with time.

- Table 1 compares PIP joint resection arthroplasty versus arthrodesis.

**Preoperative Planning**

- With any toe surgery, adequate vascularity must be ensured before proceeding with surgery.
- With lesser toe surgery, especially in the revision situation or if the patient has systemic conditions that might impair toe circulation, vascular injury to the toe and loss of the toe are possibilities and need to be discussed with the patient before the surgery.
- For PIP joint arthrodesis with use of the StayFuse implant, a preoperative AP radiograph of the foot is useful to template the size of the implant. The proximal phalanx is templated first, keeping in mind that the bone will be a millimeter or two shorter after the bone resection and that the ideal implant fit would be to just engage the cortex of the phalanx.
- The proximal phalanx and middle phalanx are each individually templated to assess the size of the canal and the appropriate implant width and length (Table 2). This, in turn, determines the size of the hand drill bit, which is color-coded gray or blue.
- The goal is to find an implant that will fill the canal, but it is generally better to err on the side of a smaller and shorter implant to avoid breaking the phalanx cortex and decreasing fusion site stability.

**Positioning**

- Positioning of the patient is supine, with the patient’s heel resting at the end of the operating table. A small padded bump may be placed under the ipsilateral greater trochanter of the hip to internally rotate the foot to give better access to the dorsum of the foot.
The procedure can be easily performed with an ankle block or forefoot block with or without a tourniquet.

We generally prefer an ankle block and use an ankle Esmarch tourniquet if there are no vascular issues with regard to the toes; otherwise we perform the procedure without a tourniquet.

**Approach**

- PIP joint resection arthroplasty and PIP joint arthrodesis are both performed through a dorsal approach to the PIP joint. We usually mark out a curvilinear incision over the MTP joint as well in case the extensor tendon or MTP joint capsule needs to be approached after the hammer toe correction to address any residual extension deformity at the MTP joint (FIG 7).

**TECHNIQUES**

- Make a straight longitudinal dorsal approach through the skin overlying the PIP joint, exposing the extensor tendon overlying the joint. The incision is about 1.5 cm long.

- Generally, for hammer toe surgery, I use a longitudinal incision, but a transverse incision can be used (TECH FIG 1A). With the toe flexed, remove a transverse-oriented ellipse of skin over the dorsum of the PIP joint. The size of the ellipse depends on the amount of redundant skin but is generally about 3 mm wide. This incision has the benefit of removing some of the redundant tissue overlying the PIP joint and may be more cosmetic, but it can make the hammer toe correction more difficult if the incision is not placed directly over the proximal phalanx condyles.

- With either initial incision, the remainder of the procedure for PIP joint arthroplasty is the same.

**PROXIMAL INTERPHALANGEAL JOINT ARTHROPLASTY**

- Retract the skin, and expose the extensor tendon and cut it transversely over the joint as the toe is slightly flexed.

- Introduce a no. 15 blade into the joint between the collateral ligament and the underlying condyle of the proximal phalanx, releasing one side and then the other (TECH FIG 1B).

- Direct the knife blade proximally, staying along the bone and not penetrating below the level of the plantar plate. Progressively flexing the toe to keep the collateral ligaments under tension helps make them easier to cut.

- With the collateral ligaments released and the toe flexed, bluntly dissect the plantar plate off the neck of the proximal phalanx with a periosteal elevator to completely expose the proximal phalanx condyles (TECH FIG 1C).

**TECH FIG 1**

- **A.** Dorsal approach for proximal interphalangeal joint arthroplasty exposing the extensor digitorum longus tendon. **B.** Releasing the collateral ligaments from the proximal phalanx with retraction of the extensor digitorum longus tendon. **C.** Releasing the plantar plate and exposing the proximal condyles. **D.** The proximal phalanx is cut at right angles while protecting the plantar soft tissues.
Resect the condyles using a sagittal saw oriented at a 90-degree angle to the axis of the proximal phalanx in both the coronal and sagittal planes at the metaphyseal–epiphyseal junction. A Freer elevator is placed under the proximal phalanx condyles to aid exposure and protect the underlying soft tissues while the bone is being cut (TECH FIG 1D).

Extend the toe to see if adequate bone has been resected. Ideally, gentle extension of the toe should bring the toe to neutral but not hyperextension. If the toe does not extend completely, if more than gentle extension is needed to do so, or if the toe seems to want to “spring back” to a more flexed position, additional bone can be resected, preferably a millimeter or two at a time until the toe is properly tensioned.

The goal is to remove enough bone so that the toe straightens completely without residual tension on the plantar soft tissues so that the deformity is corrected and the soft tissues are balanced.

Excessive resection of the bone can lead to postcorrection hyperextension at the PIP joint, which can make the patient symptomatic at the poorly padded plantar aspect of the PIP joint.

In addition, excessive shortening of the bone will result in varus–valgus instability of the toe, especially as the proximal phalanx resection moves from the metaphysis into the shaft of the proximal phalanx.

With adequate bone removed from the proximal phalanx, palpate the dorsal aspect of both the middle and proximal phalanges and smooth any bony prominences with a rongeur if necessary.

Place a 0.045 Kirschner wire (a 0.062 Kirschner wire is used if the MTP joint is to be pinned) in the center of the articular surface of the middle phalanx and pass it across the middle phalanx through the distal phalanx and out the tip of the toe.

Insert the Kirschner wire into the toe until it extends only a millimeter or two from the middle phalanx. Then reduce the PIP joint in its neutral position and drive the Kirschner wire into the proximal phalangeal shy of the MTP joint.

The pin position can be assessed with an AP fluoroscopic view (TECH FIG 2).

Perform a push-up test and assess the corrected position of the toe at the MTP joint. If the MTP joint corrects to neutral, proceed to closure, but if there appears to be extension at the MTP joint, that is addressed with a MTP joint soft tissue release.

Make a curvilinear incision over the MTP joint about 2.5 cm long. Identify and lengthen the extensor hallucis longus tendon in a Z-fashion (TECH FIG 3).

I lengthen the extensor hallucis longus tendon by dissecting out the tendon and placing a sterile tongue depressor under the tendon to both protect the underlying soft tissues and assure myself that an adequate length of tendon has been exposed (about 2 cm).

First divide the tendon longitudinally in halves and then cut it proximally and distally to create a Z-pattern cut.

Isolate the extensor digitorum brevis tendon, which travels laterally to the extensor digitorum longus tendon, and tenotomize it to further relieve any dorsiflexion contracture.

Perform the push-up test again, and if additional extension of the proximal phalanx at the MTP joint remains, cut the capsule of the MTP joint transversely and release the dorsal third of the collateral ligaments on both sides of the metatarsal head in a similar fashion to how the PIP joint collateral ligaments were released in the initial part of the procedure (TECH FIG 4).
If the MTP joint has to be addressed, use a 0.062 Kirschner wire, instead of the 0.045 Kirschner wire, to pin the PIP joint and the MTP joint. The wire is usually placed 2 cm or more into the metatarsal, across the MTP joint to stabilize the joint. Pin the MTP joint while the ankle is held in neutral flexion and the toe is held in 5 degrees of flexion at the MTP joint.

Close the PIP joint using a 4-0 plain suture to close the extensor tendon in one layer; then close the skin with simple 4-0 plain suture.

Close the extensor tendon at the MTP joint with a 2-0 nonabsorbable suture, followed by a 4-0 subcuticular closure and 4-0 nylon skin closure.

### PROXIMAL INTERPHALANGEAL JOINT ARTHRODESIS

- The surgical technique for the arthrodesis is identical to that for the arthroplasty with regard to joint exposure.
- After exposing the proximal phalanx condyles, use a sagittal saw to resect the proximal phalanx at the junction of the metaphyseal–epiphyseal junction as described previously.
- In addition to exposing the proximal phalanx, arthrodesis requires exposure of the middle phalanx. This is exposed using sharp dissection to remove the soft tissue for a millimeter or two along the dorsal, medial, and lateral aspects of the middle phalanx (TECH FIG 5).
- With the middle phalanx exposed, use a narrow sagittal saw blade to resect the articular cartilage and a millimeter or so of the subchondral bone. Be careful not to leave bony fragments or ledges in the depths of the wound, as these may later be prominent when the toe is fused.
- With both the proximal phalanx and the middle phalanx exposed, bring the toe into extension to see if the bony surfaces adequately align and if overall toe alignment is acceptable. Additional bony resection can be performed at this time. Make sure enough bone has been removed to avoid excessive tension on the contracted plantar neurovascular bundles once the toe is realigned. Once the implant is engaged, it is difficult to remove it should the toe not “pink up” after the removal of the tourniquet. However, although adequate bony resection is necessary, excessive bony resection should be avoided as it will lead to a cosmetically displeasing short toe.
- After the bone resection, place a 0.062 Kirschner wire down the center of the proximal phalanx to find the central axis of the bone. Use an AP fluoroscopic picture to confirm that the Kirschner wire is centrally placed and perpendicular to the cut surface.
- Remove the Kirschner wire and use the hand drill to create a channel for the implant in the proximal phalanx (TECH FIG 6). Preoperatively, using the radiographic template, determine the appropriate size implant for both the proximal and middle phalanges. Generally, if there is a question about whether a larger or smaller implant best fits the canal of the phalanx, it is best to err on the side of the smaller implant to avoid breaking the cortex and making the implant less stable.
- After making the channel in the proximal phalanx, place a double-sided punch (transfer template) in the channel. Reduce the cut surface of the middle phalanx and press it onto the exposed side of the double-sided punch (TECH FIG 7A). This scores the middle phalanx and indicates the proper insertion point for the middle phalanx implant.
- Pay special attention to assessing the mediolateral translation of the middle phalanx on the proximal phalanx when scoring the middle phalanx. Ideally, the medial and lateral cortices of the adjacent phalanges should align to avoid symptomatic bony prominences once the joint is fused.
After the middle phalanx has been scored, use the hand drill to prepare the implant channel for the middle phalanx (TECH FIG 7B).

With both sides prepared, insert the proximal phalanx implant first to avoid interference with its placement by the protruding flutes of the middle phalanx implant once it is inserted (TECH FIG 8A). Insert the proximal phalanx implant flush with the cut surface. The driver bit, which is used to insert the implant, is designed to disengage once the implant is flush with the level of the bone cut (TECH FIG 8B,C).

Place the middle phalanx implant with the body of the implant flush with the cut surface of the bone and the flutes of the implant exposed. The slot between the tines should be oriented in the sagittal plane as opposed to the horizontal plane to reduce the chance of the flutes bending as the implants are engaged (TECH FIG 9A).

The implants are then ready to be engaged. They are distracted and brought together, engaging the two components as horizontally as possible to avoid bending the flutes of the middle phalanx implant (TECH FIG 9B). It is very important not to lever the two components together, as this can lead to bending the implants, which can make it impossible to engage the two components. It is recommended to grasp the toe with a 4×4 dressing sponge to give better hold of the toe as you manipulate it.6

As the flutes of the one implant engage the other, a ratcheting sound will be audible. Once the middle phalanx is sufficiently engaged in the proximal phalanx, the hexagonal base of the fluted component will attempt to engage the proximal phalanx component. Slight gentle rotation of the tip of the toe may be necessary to subtly rotate the middle phalanx implant and allow the hexagonal portions of the implants to engage (TECH FIG 10A).
If some twisting of the toe is necessary, after the hexagonal portions of the implants first engage, “derotate” the toe before the final compression is achieved so that the final compression of the toe is in the properly aligned position.

As the implant is fully interdigitated, the ends of the bones should visually come to rest together and the implant should fully engage, as evident on an AP fluoroscopic view (Tech Fig 10B).

A C-arm is usually used to confirm that the component is properly engaged and the toe is well aligned.

If the implants engage, but not fully, as long as a portion of the hexagonal section of the implant is engaged, this is acceptable. If there is only a slight gap at the bone fusion site, this is acceptable as well, but I usually place some bone graft from the resected condyles to fill the gap.

With the toe implant inserted, palpate the bony dorsal surface of the toe to make sure that there are no protrusions; remove any with a rongeur to create a smooth surface.

The remainder of the arthrodesis procedure is identical to the PIP joint arthroplasty, with the exception being that if the MTP joint must be addressed, it is done so without fixing it with a Kirschner wire, as the StayFuse implant will not allow the Kirschner wire to pass down the toe. In these cases, I extend the dressing sponges or ABD pads out over the toe with the dressing to provide a block to dorsiflexion of the toe. In the immediate postoperative period, I initiate taping of the toe in neutral position at the first postoperative visit and continue it for up to 3 months.
PEARLS AND PITFALLS

Avoid vascular compromise
- Assess the circulation preoperatively.
- Keep all dissection around the phalanxes subperiosteal.
- Make sure there is adequate resection of bone at the PIP joint. The implant or Kirschner wire should only hold the correction that was obtained with the bone resection.
- If the toe does not “pink up” at the end of the case after the tourniquet is let down, wait 10 minutes for reperfusion. If this does not resolve the problem, check to see if all constrictive dressings have been removed.
- Next, apply warm saline-soaked sponges to the toe.
- If this does not allow the toe to pink up, 1% lidocaine without epinephrine can be lavaged over the neurovascular structures.
- Nitropaste applied to the toe has also been advocated in this situation.
- Finally, in the case of PIP joint arthroplasty, removal of the Kirschner wire may be necessary. Slight bending (5 to 10 degrees) of the Kirschner wire to flex the PIP joint more or dorsiflex the MTP joint slightly is acceptable, although it makes taking the Kirschner wire out more difficult postoperatively. In the case of PIP joint arthrodesis the implant might have to be removed, although we have not found this be necessary.

Avoid pinning the toe too straight (PIP joint arthroplasty)
- When pinning the toe, try to start more plantarly on the middle phalanx and then exit the tip of the toe. When the pin is then driven back in a retrograde fashion there is a slight flex at the PIP joint.

Removing the implant (PIP joint arthrodesis)
- If after insertion the implant has to be removed, the dorsal cortex of either middle or proximal phalanx must be partially removed. Whichever side of the implant is the narrower in relation to the canal diameter should be teased out by removing as little of the dorsal cortex as necessary.
- After one end of the implant is removed the implant can be grabbed and used to unscrew the implant from the opposite side. After this, one option is to insert another implant using one with a slightly larger diameter in the portion that has had the dorsal cortex partially removed.
- The larger diameter of the implant will allow the implant to have some purchase in this situation.

Avoid bending the implant (PIP joint arthrodesis)
- Do not lever the implant together, but distract, engage, and then bring the implant together with it axially aligned. It is critical to position the middle phalanx implant’s flutes so that the space between them is oriented in the sagittal plane. This will help keep the implant from bending as it is initially engaged.

Selecting the proper-sized implant (PIP joint arthrodesis)
- When using the radiographic template, remember to take into account the bone resection. Preoperatively, make sure the implant will not be too large for the toes. While we have occasionally used the StayFuse implant for the fifth toe, most of the fifth-toe phalanxes are too small for an implant.

Avoid incomplete engagement of the StayFuse implant (PIP joint arthrodesis)
- Make sure the base of the middle phalanx implant and the proximal phalanx implant are flush with the bone cut. The insertion device is designed to disengage once the implant is at the proper depth, but occasionally it will bury the implant too deeply.
- If the implant only partially engages, but a portion of the hexagonal interface is engaged, this is acceptable if the bone has been brought into proper apposition.

POSTOPERATIVE CARE
- Immediately postoperatively, the patient is advised to heel weight bear in a postoperative shoe.
- For the first 2 days activity is limited as the patient is advised to spend the majority of time with the foot up and elevated above the heart.
- After this, activity and elevation should be guided by swelling.
- Sutures are removed at 2 to 3 weeks and any pins are removed at 3 weeks.
- At 3 weeks, the patient can attempt to get into a loose tennis shoe but should be encouraged to wear the postoperative shoe as needed for comfort.
- At 6 weeks the patient can resume vigorous activity as tolerated.
- In the case of an arthrodesis with an implant, radiographs are obtained at the first postoperative visit and at 6 weeks. If the patient is asymptomatic at that time and radiographs do not show signs of arthrodesis, further radiographs are probably unnecessary.
- If the MTP joint has been addressed, we will strap the toe in a neutral position with cloth tape or a Budin splint for up to 12 weeks. We start this after the pin has been removed at week 3 or at the first postoperative visit if a pin has not been used.

OUTCOMES
- Large long-term studies on excisional arthroplasty and arthrodesis have shown high satisfaction rates, in the range of 80% to 90%. There are no published studies involving the use of the StayFuse implant, but with the rigid fixation that the implant provides one would expect similar if not better results than have been reported with other forms of PIP joint arthrodesis.
COMPLICATIONS

- Neurovascular compromise
- Prolonged
- Loss of volitional control
- Swelling
- Recurrence
- Toe “too straight”
- Infection
- Transfer lesion
- Nonunion

REFERENCES

DEFINITION
- Subluxation or dislocation of the metatarsophalangeal (MTP) joints results in a disruption of the fibers of the plantar plate, which is the central structure of the MTP joint dislocation. The plate provides a cushion to the joint and weight-bearing forces.
- The key point in deciding how to treat this pathology is to determine whether the pathology leads to abnormal pressure distribution in the forefoot.

ANATOMY
- The proximal phalanx and the fibrocartilaginous plantar plate form an anatomic and functional unit at the MTP joint.
- The plate is the major factor of dorsoplantar stability.
- The plantar plate attaches to the proximal phalanx and the plantar fascia, but except for the two collateral ligaments, it is without substantial fibrous attachment to the metatarsal head.14
- The extensor digitorum longus tendon extends to the proximal phalanx and the proximal interphalangeal joint.
- Antagonists of the extensor mechanism are the flexor tendons and the plantar plate.
- The function of the interossei and lumbral muscles is to hold the proximal phalanx in a neutral position.

PATHOGENESIS
- High functional stresses of weight bearing and repetitive hyperextension of the MTP joint can lead to attenuation or rupture of the plantar plate, followed by subluxation or dislocation of the toe.
- A hallux valgus deformity is often associated with a subluxated second MTP joint.5,10
- The hallux pushes the second toe lateral, which may lead to instability and maybe to subluxation.
- It may also result from an excessive length of the second or third metatarsal relative to the first metatarsal.
- The second MTP joint is then biomechanically more subject to the pressure of tight stockings or shoes.
- Once the plantar plate is elongated and ruptured, the dorsal capsule and the extensor tendon become contracted, leading to a chronically dislocated MTP joint.14

NATURAL HISTORY
- Weil presented in 1992 in Europe a joint-preserving, intra-articular shortening osteotomy, and Barouk first published it in 1996.1
- Researchers from Europe have shown in anatomic, clinical, and radiologic studies the advantages of the Weil osteotomy compared to alternative procedures.9,14,15
- A dorsal soft tissue release with pin fixation,3 silicone implants,4 metatarsal neck ostotomies without fixation (Helal osteotomy),5,12 and MTP joint excisional arthroplasties6 have been reported in the literature as surgical alternatives.

However, a high rate of complications such as nonunions, malalignments, and transfer lesions are associated with these alternative surgical procedures.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Physical examination methods include the following:
  - Determining circulatory status is necessary to assess not only the feasibility of an individual procedure but also whether multiple procedures can be performed, if necessary.
  - Clinical examination of cutaneous sensory response may indicate a systemic disease such as diabetes.
  - The drawer test is used to evaluate the stability of all the MTP joints and the reducibility of lesser toe deformities in plantarflexion. How stable overall is the first ray?
  - Passive range of motion: Normal range of motion is 60 to 80 degrees full extension to 40 degrees full flexion; loss of flexion may be a result of the contracted extensor tendons or because the proximal phalanx lies dorsal to the second metatarsal head.
  - Each patient must be analyzed individually, with attention to a detailed history and a careful clinical examination. Ruling out differential diagnosis is mandatory.
  - History of painful forefeet over a long period of months or years
  - The pain usually occurs dorsally over the toe and on the plantar side of the metatarsal head.
  - Plantar keratosis: This callus is a circumscribed keratotic area under the metatarsal head that usually corresponds with the patient’s complaints (FIG 1).
  - Hammer toe: A hammer toe deformity may lead to MTP joint subluxation, dislocation, or both. However, MTP joint subluxation and dislocation can also lead to a hammer toe deformity.

FIG 1 • Plantar aspect of the foot with a hyperkeratotic area under the second metatarsal head.
A simultaneous hallux valgus deformity may lead to dorsiflexion forces in the second MTP joint. The great toe may cross under the second toe ("crossover toe deformity").

- A prominent dorsal base of the proximal phalanx is easily palpated.
- Tightness of extensor tendons: The toe cannot be plantarflexed due to pain and to shortening of the extensor muscle and interossei dorsalis muscle.
- Rarely a third or fourth toe is subluxated.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Dorsoplantar and lateral weight-bearing radiographs should be obtained to rule out fractures or associated injuries and degenerative arthritic changes.
- All radiographs are examined for the length of the second and third toe relative to the first and the alignment (Maestro line).
- Radiographs must be obtained for subluxation or dislocation to assess joint congruency of the lesser MTP joints (FIG 2).
- A "gun barrel" sign may be seen on the AP radiograph. The diaphysis of the proximal phalanx projects as a round hole in the area of the distal condyle of the proximal phalanx.
- The articular cartilage of the adjoining surfaces leaves a "clear space" of 2 to 3 mm. This clear space diminishes with progression of the hyperextension of the MTP joint.
- Avascular necrosis of a lesser metatarsal head with infracture (Freiberg infraction) may be seen.
- The hallux valgus angle and the intermetatarsal angle are measured.
- Pedobarography is highly sensitive to peak pressures in the foot. It allows static and dynamic qualitative measurement of pedal pressures and load distribution for specific areas of the foot. Load imbalance may also be detected, as well as insufficiency of the first ray.

**DIFFERENTIAL DIAGNOSIS**

- Morton neuroma
- Freiberg infraction (avascular necrosis of the metatarsal head)
- Rheumatoid arthritis
- Nonspecific synovitis
- Metatarsal head fracture

**NONOPERATIVE MANAGEMENT**

- Initial treatment options for metatarsalgia include shoe wear modifications, metatarsal pads, and custom-made orthoses.
- Trimming of the callus mechanically
- Orthotics for the foot
- Reduce forefoot pressure
- Lower heel to reduce metatarsal head pressure (avoid high-heeled shoes)
- Carefully placed metatarsal pad proximal to painful metatarsal head
- If metatarsalgia is due to a ruptured volar plate (such as in rheumatoid arthritis), often a stiff, full-length insole that limits MTP hyperextension of the foot is useful.
- However, conservative treatment in an already existing dislocation is of no benefit, and surgical intervention is indicated.\(^1\)

**SURGICAL MANAGEMENT**

- The Weil osteotomy is a joint-preserving, intra-articular shortening osteotomy and has been recommended for the treatment of metatarsalgia resulting from a dislocated or subluxed MTP joint.
- The goal of the Weil osteotomy is first to alter load transmission through the forefoot by shifting the plantar fragment proximal to the area of the lesion, where thicker and more compliant soft tissue is still present, and second to resolve the hammer toe deformity or MTP subluxations that are increasing or resulting in metatarsalgia.

**Preoperative Planning**

- All radiographic images are reviewed for subluxation or dislocation, alignment of the metatarsal heads, hallux valgus deformity, degenerative changes of the joints, and claw toes.
- If there is a hallux valgus deformity or a hypermobile first tarsometatarsal joint, this pathology should be corrected to achieve a satisfying result.
- The length of shortening is measured on the plain radiographs. The second metatarsal should be even with or shorter than the first, and the third should be shorter than the second metatarsal.
- During the preoperative physical examination the surgeon must look for plantar keratotic disorders.
- The tightness of the extensor tendon is palpated.
- A drawer test of the dislocated MTP joint should be included in the examination under anesthesia (FIG 3).

**Positioning**

- The patient is positioned supine on the operating table.
- The surgery is performed either under general anesthesia or using a regional ankle block supplemented with intravenous or oral sedation.
- An Esmarch tourniquet may be used to obtain a bloodless field.

**Approach**

- A 3-cm longitudinal incision is made dorsal over the metatarsal for a single osteotomy, over the web space for a double osteotomy, and over two metatarsals for a triple osteotomy.
- A small amount of soft tissue dissection is done to identify the extensor tendons, which are lengthened in a Z fashion.
- A transverse or longitudinal capsulotomy of the MTP joint is used to identify the junction of the head and neck.
FIG 3 • A, B. The surgeon grasps the base of the proximal phalanx and attempts to sublux or dislocate the joint with a dorsally directed force.

**EXPOSURE OF METATARSAL**

- Make a 3-cm longitudinal incision dorsal over the metatarsal for a single osteotomy (TECH FIG 1A,B) or over the web space for a double osteotomy.
- Perform a small amount of soft tissue dissection to identify the extensor tendons, and lengthen them in a Z fashion (TECH FIG 1C–E).
- Incise the joint capsule in a transverse fashion and release the collateral ligaments if necessary.

TECH FIG 1 • A, B. Dorsal skin incision. C–E. Z lengthening of the extensor digitorum longus tendon; the extensor digitorum brevis tendon is usually cut. (continued)
Use a 2-mm bony slice extractor to lift the plantar fragment because the axis of motion of the MTP joint has changed with plantarflexion of the metatarsal head.

Expose the metatarsal head and mark the osteotomies (TECH FIG 2A).

Use an oscillating saw to perform the osteotomy at the dorsal portion of the metatarsal head without finishing the second cortex totally to avoid a free-gliding plantar fragment (TECH FIG 2B).

The second osteotomy through both cortices is 2 mm under the dorsal cut (TECH FIG 2C,D).

The bony slice can now be easily removed (TECH FIG 2E,F).

Expose the metatarsal head with two small Hohmann retractors. Maximally plantarflex the toe and expose the metatarsal head with the help of an elevator (TECH FIG 1F,G).

Take care not to strip the plantar soft tissue attachments to aid in stabilizing the osteotomy and maintain vascularity to the head.

OSTEOTOMY AND BONY SLICE EXTRACTION

Expose the metatarsal head with two small Hohmann retractors. Maximally plantarflex the toe and expose the metatarsal head with the help of an elevator (TECH FIG 1F,G).

Take care not to strip the plantar soft tissue attachments to aid in stabilizing the osteotomy and maintain vascularity to the head.

Use a 2-mm bony slice extractor to lift the plantar fragment because the axis of motion of the MTP joint has changed with plantarflexion of the metatarsal head.

Expose the metatarsal head and mark the osteotomies (TECH FIG 2A).

Use an oscillating saw to perform the osteotomy at the dorsal portion of the metatarsal head without finishing the second cortex totally to avoid a free-gliding plantar fragment (TECH FIG 2B).

The second osteotomy through both cortices is 2 mm under the dorsal cut (TECH FIG 2C,D).

The bony slice can now be easily removed (TECH FIG 2E,F).
Grasp the plantar mobile fragment with a pointed reduction clamp and shift it proximally to achieve the requisite amount of shortening that was measured preoperatively on the dorsoplantar radiographs (TECH FIG 3A).

- The second metatarsal should be even with or shorter than the first, and the third should be shorter than the second metatarsal.
- The plane of the osteotomy should be as parallel to the ground surface as possible. Secure the osteotomy with a special 2-mm titanium “snap off screw” (Wright Medical Technology) (TECH FIG 3B). Use a 12-mm length for the second metatarsal and 11 mm for the other metatarsals.
- Remove the resulting dorsal protuberance over the metatarsal head remnant with a rongeur or the edge of the saw blade (TECH FIG 3C,D).
- Repair the overlying Z-lengthened extensor tendon and suture the skin.

**FIXATION OF THE MOBILE FRAGMENT**

- Grasp the plantar mobile fragment with a pointed reduction clamp and shift it proximally to achieve the requisite amount of shortening that was measured preoperatively on the dorsoplantar radiographs (TECH FIG 3A).
- The second metatarsal should be even with or shorter than the first, and the third should be shorter than the second metatarsal.
- The plane of the osteotomy should be as parallel to the ground surface as possible. Secure the osteotomy with a special 2-mm titanium “snap off screw” (Wright Medical Technology) (TECH FIG 3B). Use a 12-mm length for the second metatarsal and 11 mm for the other metatarsals.
- Remove the resulting dorsal protuberance over the metatarsal head remnant with a rongeur or the edge of the saw blade (TECH FIG 3C,D).
- Repair the overlying Z-lengthened extensor tendon and suture the skin.
PEARLS AND PITFAILS

<table>
<thead>
<tr>
<th>Collateral ligaments</th>
<th>We do not routinely release the collateral ligaments when performing a Weil osteotomy. A substantial portion of the metatarsal head blood supply courses via delicate arteries in the collateral ligaments.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation of the saw blade</td>
<td>We dorsiflex the ankle and use the plantar heel as a guide to orient the saw blade in the sagittal plane and look at the whole forefoot to get the orientation in the transverse plane.</td>
</tr>
<tr>
<td>Wedge resection</td>
<td>We excise a wedge within the osteotomy in lieu of creating a single cut. Elevation is not important regarding loading of the head, but elevating the head will maintain a favorable center of rotation for the head. In theory, this will keep the intrinsic flexor tendons plantar to the center of rotation, thereby reducing the risk for postoperative toe elevation (“floating toe”).</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Dressings and a tight bandage are used to protect the suture and to prevent swelling.
- The patient’s toes are taped in slight plantarflexion.
- Weight bearing with a postoperative shoe is allowed after the first postoperative day (FIG 4A).
- Patients should wear the postoperative shoe for 6 weeks.
- Postoperative imaging includes dorsoplantar and lateral radiographs (FIG 4B–D).
- Passive motion (starting on the 5th postoperative day) of the MTP joint is indicated and necessary to prevent postoperative extension contracture.
- If swelling occurs, foot elevation, cryotherapy, and elastic stockings may keep the swelling down.

OUTCOMES

- Clinical results of the Weil osteotomy have been promising. Outcomes include a significant reduction of pain, a significant reduction in plantar callus formation, a low dislocation rate, and increased ambulatory capacity.
- No malunion or pseudarthrosis was documented in the literature.
- Bony and soft tissue modifications such as lengthening of the extensor tendon, 2-mm bony slice extraction, and inser-

FIG 4 • A. Postoperative shoe. B. Preoperative radiographs with hallux valgus deformity and subluxation of second and third metatarsophalangeal joint. C. Chevron osteotomy with pin fixation along with a Weil osteotomy on the second, third, and fourth rays. D. Seven-year radiograph showing maintenance of corrected lesser metatarsophalangeal joints.
tion of a Kirschner wire from the tip of the toe across the MTP joint and the osteotomy into the metatarsal, in a position of 5 degrees plantarflexion (in severely subluxated contracted cases), may prevent postoperative dorsiflexion contracture.

- Boyer and DeOrio described good results of a single-pin fixation for a combined metatarsal neck osteotomy with proximal interphalangeal joint resection arthroplasty and flexor digitorum longus transfer in severely dislocated MTP joints and severe hammer toe deformities.

**COMPPLICATIONS**

- Reported complications in the literature are floating or stiff toes, a high rate of postoperative dorsiflexed contracture and transfer metatarsalgia in cases of excessive shortening with variable rates, and a limitation of the range of motion in the MTP joint.7,9

**REFERENCES**

Varus or valgus angulation of the lesser toes can result in significant pain and disability and can be grouped broadly into the following subcategories:
- Crossover or crossunder second toe
- Congenital crossover fifth toe
- Curly toe deformity
- Isolated metatarsophalangeal (MTP) joint angular deformity
- Clinodactyly

Understanding the etiology behind each type of angular toe deformity is crucial for determining whether surgical or nonsurgical management is appropriate.

Angular toe deformities can occur as the result of a variety of intrinsic or extrinsic factors, including inflammatory arthritis, trauma, congenital abnormalities, neuromuscular disorders, and poorly fitting shoe wear.

Surgical management options are based on the severity of the deformity, degree of response to nonsurgical management, and underlying cause of the deformity. A variety of surgical procedures have been proposed to address angular deformity of the lesser toes:
- Tenodesis
- Tenotomy
- Tendon transfer
- Soft tissue release
- Soft tissue lengthening
- Proximal basilar osteotomy
- Resection arthroplasty
- Interphalangeal fusion

Outcomes are predicated on the degree of return to full activity, pain relief, and recurrence of deformity.

definitions
- Crossover second toe deformity (Fig 1A) is characterized by a second toe that lies dorsomedially relative to the hallux.
- Congenital crossover fifth toe (Fig 1B) represents a variable congenital anomaly involving the fifth MTP joint in which the small toe deviates medially and superiorly relative to the fourth toe. Patients typically complain of discomfort and irritation over the dorsum of the fifth toe, especially when wearing constrictive footwear.
- Curly toe deformity (Fig 1C) is a relatively common congenital anomaly, usually found in children, that may be related to intrinsic muscle paresis, although this relationship has not been clearly established. The deformity usually involves the fourth or fifth toe, or both, and is characterized by a flexible
flexion deformity of the proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints with underlapping of the fourth toe on the third and of the fifth toe on the fourth.

- **Isolated MTP angular deformity** (FIG 1D) is varus or valgus angulation of the lesser toes occurring solely through the MTP joint. This often occurs in conjunction with great toe varus or valgus deformity.
- **Clinodactyly** (FIG 1E) is varus or valgus deviation of a toe caused by angulation within the phalanx itself. This condition is more commonly seen in the fingers and is often associated with a syndrome (eg, symphalangism) or chromosomal disorder.

**ANATOMY**

- The extensor digitorum longus (EDL) forms three tendinous slips on the dorsum of each toe; the first inserts into the middle phalanx, and the remaining two merge and insert on the distal phalanx.
- In concert, the EDL and extensor digitorum brevis (EDB) extend the MTP, PIP, and DIP joints through their pull on the extensor hood.
- The flexor digitorum longus (FDL) courses deep to the flexor digitorum brevis (FDB) on the plantar surface of the toe and acts as a powerful flexor at the DIP joint.
- The PIP and MTP joints are flexed through the combined action of the FDL and FDB tendons as well as the lumbrical and interosseous muscles.
- The intrinsics first pass plantar to the axis of MTP joint rotation and then dorsal to the axis of motion of the PIP and DIP joints. This anatomic relationship allows the intrinsics to act as flexors at the MTP joint and extensors at the PIP and DIP joints.
- Disruption of this delicate balance can lead to problematic disequilibrium between the intrinsics and extrinsics, which in turn can result in characteristic lesser toe deformities and associated pressure phenomena.
- The medial collateral ligament (MCL) and lateral collateral ligament (LCL) play a vital role in stabilizing the MTP joint by acting as static constraints to joint subluxation or dislocation. The collaterals originate from the dorsal aspect of the metatarsal head and insert distally both at the base of the proximal phalanx and at the plantar plate.
- In addition to providing stability in the transverse plane, the collaterals resist dorsal subluxation of the proximal phalanx on the metatarsal head. Laxity of the collaterals is commonly noted intraoperatively with angular lesser toe deformities and, in some cases, is thought to play a causative role in the development of these deformities.

**CROSSOVER DEFORMITY OF THE SECOND TOE**

**PATHOGENESIS**

- Crossover second toe deformity most commonly occurs as the result of attritional rupture of the LCL and lateral capsule of the second toe.
- Frequently, this specific type of lesser toe deformity occurs in association with longstanding hallux valgus.
- Association with a long second metatarsal and attenuation of the first dorsal interosseous tendon and plantar plate are also common.
- Destabilization of the second MTP joint can also occur as the result of trauma, synovitis related to underlying inflammatory arthritides such as rheumatoid arthritis, nonspecific or chronic synovitis, constriction from narrow-toebox shoes, or connective tissue diseases such as systemic lupus erythematosus.
- Neuromuscular disorders such as diabetic neuropathy, Charcot-Marie-Tooth disorder, poliomyelitis, or Friedreich’s ataxia can also disrupt the dynamic stability of the foot and, subsequently, that of the lesser toes.
- Often, medial soft tissue such as the MCL, medial capsule, and interosseous and lumbral tendons are contracted at the MP joint.

**NATURAL HISTORY**

- Early synovitis, then subluxation, and finally dorsomedial or inferomedial dislocation are the characteristic stages in the natural progression of this coronal plane deformity.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Crossover second toe deformity presents either as a dorsomedially subluxated second toe that crosses up and over the hallux or as an inferomedially subluxated second toe that crosses under the great toe.
- There is often associated hyperextension or hyperflexion at the proximal phalanx at the MTP joint and adduction of the second ray from the midline.
- A painful intractable plantar keratotic lesion beneath the second metatarsal head or dorsal corn over any portion of the second phalanges (particularly over the PIP joint) may be due to impingement of the toebox of the shoe.
- Instability of the plantar plate can be evaluated by the drawer test applied in the sagittal plane.

**IMAGING AND DIAGNOSTIC STUDIES**

- All angular deformities involving the lesser toes can be appropriately studied by examining standard anteroposterior (AP), lateral, and oblique radiographs of the affected foot.

**NONOPERATIVE MANAGEMENT**

- In general, conservative measures are more effective for treatment of subluxation of the second MTP joint versus dislocation.
- Activity modification is usually necessary to resolve underlying second MTP synovitis.
- Some degree of relief is usually afforded by avoidance of shoes with a tight, narrow toebox and by modification of shoe wear to include a broad toebox with extra depth.
- Splinting or taping the second toe in plantarflexion may relieve symptoms but does not correct deformity.
- Placing a metatarsal pad in the shoe may help relieve pressure on the plantar plate.
- Wearing a shoe with a firm sole may prevent propagation of synovitis and further attenuation of the plantar plate.
- Metatarsal bars or a full-length rocker bottom sole with metal inlay may provide additional means of relieving pressure at the second MTP joint.

**SURGICAL MANAGEMENT**

**Preoperative Planning**

- All radiographs should be carefully examined to evaluate the degree of deformity of the hallux and surrounding lesser toes.
- Clinical examination should determine whether the deformities at the interphalangeal and MTP joints are flexible or rigid.
■ Hallux valgus deformity, which does not allow for correction of the second toe, must be corrected.
■ PIP deformity should be corrected with an interphalangeal joint fusion or arthroplasty.

Surgical Options and Indications
■ Dorsal capsular release and repair of the lateral collateral ligament is a soft tissue realignment procedure that is indicated for mild crossover toe deformities.
■ The Girdlestone-Taylor procedure, or transfer of the split FDL tendon to the dorsum of the proximal phalanx, is a well-established procedure.\(^3,13\) All grades of second toe deformity may benefit from it.
■ Initially described for the correction of flexible lesser toe deformities in patients with underlying neuromuscular disorders, this procedure has undergone various modifications throughout the years.
■ A PIP resection can be performed simultaneously for correction of rigid deformity.
■ The EDB tendon transfer was originally described by Haddad et al and is most appropriate in patients with mild to moderate deformity.\(^4\) Benefits include better control of sagittal plane motion and less stiffness than is associated with an FDL transfer.
■ A recent modification of the EDB transfer, as popularized by Lui and Chan, attempts to reduce the supination force of the transferred EDB, as well as to provide a more robust side-to-side suture repair.\(^5\)
■ Proximal phalanx basilar osteotomy is indicated for resistant angular deformities of the lesser toes and for failure to achieve multiplanar correction after complete soft tissue release at the MTP joint.
■ The Weil osteotomy can be used to shorten the second metatarsal as well as to decrease the overall prominence of the second metatarsal head (FIG 2).

TECHNIQUES

DORSAL CAPSULAR RELEASE AND REPAIR OF THE LATERAL COLLATERAL LIGAMENT
■ The second MTP joint is approached via a 3-cm longitudinal, curved, or Z-shaped incision.
■ A dorsal incision in the adjacent web space is also appropriate.

FIG 2 • The Weil osteotomy can be used to shorten the second metatarsal as well as to decrease the overall prominence of the second metatarsal head.

TECH FIG 1 • A. The extensor digitorum longus (EDL) and the extensor digitorum brevis (EDB) are sectioned and the dorsal capsule is opened. B. The EDL, EDB, and dorsal capsule are released. (continued)
Balancing the MCL and the LCL is required to address coronal plane deformity.
- The contracted MCL is released off the metatarsal and the phalanx from dorsal to plantar.
- The attenuated LCL is then repaired in a shortened fashion (TECH FIG 1C).
- For added stabilization, the MTP joint is pinned from distal to proximal using a 0.054- or 0.062-inch K-wire.

FLEXOR-TO-EXTENSOR TENDON TRANSFER (GIRDLESTONE-TAYLOR PROCEDURE)

- The second MTP joint is approached through a dorsal longitudinal incision extending from the MTP joint to the PIP joint.
- The extensor tendons are retracted laterally, and the MTP joint is entered through a dorsal capsulotomy.
- The MCL is then sectioned.
- In patients with more advanced deformity, further correction may be obtained with EDL lengthening and EDB tenotomy as well as a release of the interosseous and lumbrical tendons.
- A small transverse plantar incision is then made at the level of the proximal flexion crease, and the FDL tendon is identified using blunt dissection (TECH FIG 2A).
- The FDL tendon is released from its insertion onto the distal phalanx via a percutaneous tenotomy at the level of the DIP joint.
- The released FDL tendon is brought into the proximal wound and split centrally along the median raphe (TECH FIG 2B).
- Each limb is then passed from plantar to dorsal on either side of the proximal phalanx, avoiding injury to adjacent neurovascular structures.
- When a fixed contracture of the PIP is present, resection of the distal one fourth of the proximal phalanx can be performed after the extensor hood and collateral ligaments are incised.
The limbs of the split FDL are then passed over the extensor hood, tensioned (with the ankle held in a neutral or slightly dorsiflexed position), and sutured to each other with 4-0 nonabsorbable sutures (TECH FIG 2C).

Manual manipulation of the proximal phalanx can be performed to assess the tensioning of the transferred tendons. The MTP joint should remain slightly mobile, not overly tight, when correct tensioning is achieved.

EXTENSOR DIGITORUM BREVIS TENDON TRANSFER

A dorsal approach similar to that used for a flexor-to-extensor transfer is used to perform an EDB tendon transfer.

The EDB tendon is identified and freed proximally after dissection and release of the MTP joint capsule and lengthening of the EDL tendon.

After two 4-0 stay sutures have been placed longitudinally into the tendon 4 cm proximal to the MTP joint, the tendon is transected between these two sutures (TECH FIG 3A).

Care is taken to maintain the integrity of the distal EDB tendon insertion, and the distal EDB tendon stump is then passed from distal to proximal underneath the transverse metatarsal ligament and lateral to the MTP joint (TECH FIG 3B).

A 0.062-inch K-wire is placed across the MTP joint with the toe held in a corrected position.

The passed distal limb of the EDB is then tensioned and secured by a direct end-to-end tendon repair to the proximal stump, with the joint held in congruity (TECH FIG 3C).

A 0.062-inch K-wire is driven, in retrograde fashion, from the base of the proximal phalanx distally through the tip of the toe and then antegrade across the MTP joint with the toe held parallel to the floor or weight-bearing surface of the foot.

The incisions are then closed in a layered fashion (TECH FIG 2D).

TECH FIG 3 • A. Stay suture placement along the EDB tendon and transaction point identified by dashed line between the two sutures. The EDL tendon is also shown after Z-lengthening. B. Transfer of distal EDB stump plantar to transverse metatarsal ligament and lateral to second metatarsal. C. End-to-end repair of the EDB tendon with the toe pinned in a corrected position. The Z-lengthened EDL tendon is also shown following repair.
MODIFIED EXTENSOR DIGITORUM TENDON TRANSFER

- Under tourniquet control, a lazy S incision is used to expose the EDL and EDB of the second toe.
- A long Z incision of the EDL is made, and the EDB is released at the distal metatarsal level (TECH FIG 4A).
- The MTP joint is entered transversely, and the MCL is sectioned.
- A transverse bone tunnel is placed through the proximal aspect of the proximal phalanx using a 2.5-mm drill.
- The distal stump of the EDL is passed through the bone tunnel from medial to lateral. The passed tendon is then shuttled from distal to proximal, plantar to the transverse metatarsal ligament between the second and third metatarsals.
- The transferred tendon is tensioned, and a 0.062-inch K-wire is inserted across the MTP joint to hold the toe in a corrected position (TECH FIG 4B).
- The distal stump of the EDL is then repaired side to side with the proximal stump of the EDB.

MODIFIED EXTENSOR DIGITORUM TENDON TRANSFER

- Extensor digitorum longus
- Extensor digitorum brevis
- Transverse metatarsal ligament
- Stay sutures

TECH FIG 4 • A. Long Z incision through the EDL tendon. EDB transected at the level of the distal metatarsal shaft. B. Correction of deformity and pinning. The distal EDL stump has been shuttled through the transverse drill tunnel and anastomosed to the proximal stump of the EDB tendon. The proximal stump of EDL has been repaired side to side with the distal stump of the EDB. (Adapted from Lui TH, Chan KB. Technique tip: modified extensor digitorum brevis tendon transfer for crossover second toe correction. Foot Ankle Int 2007; 28:521–523.)

PROXIMAL PHALANX BASILAR OSTEOTOMY

- An oblique incision is made over the MTP joint extending longitudinally onto the dorsum of the base of the proximal phalanx.
- Extensor tenotomy or lengthening and dorsal capsular incision with collateral release can all be added for further soft tissue correction.
- If complete correction is not attainable following these soft tissue releases, the approach can be extended to the base of the proximal phalanx, where a proximal phalanx basilar osteotomy can subsequently be performed.
- Davis et al described using a small awl to make multiple perforations at the base of the proximal phalanx opposite the direction of toe deviation (TECH FIG 5A).
- After penetrating the appropriate cortex multiple times, taking care not to perforate the opposite cortex, finger pressure alone is used to complete the osteotomy and correct the underlying deformity (TECH FIG 5B).
- A 0.045-inch K-wire is placed percutaneously if added stability is needed.
DISTAL HORIZONTAL METATARSAL OSTEOTOMY (WEIL OSTEOTOMY)

- A dorsal 3-cm longitudinal incision is made over the second MTP joint, the extensor tendons are retracted, and the capsule is incised to expose the MTP joint.
- Collaterals are then released to facilitate delivery of the second metatarsal head dorsally out of the wound.
- Plantar flexion at the MTP allows for optimal exposure of the articular surface of the second metatarsal.
- With use of an oscillating saw, a cut is initiated at the articular surface of the most dorsal aspect of the second metatarsal head.

- The cut is carried proximally and parallel to the plantar plane of the foot (TECH FIG 6A).
- The plantar osteotomy fragment is then grasped with a pointed reduction clamp and slid proximally to achieve the desired amount of shortening (TECH FIG 6B).
- The osteotomy is finally secured with a compression screw placed in lag fashion from dorsal to plantar (TECH FIG 6C).
- The excess dorsal bony prominence is shaved to a smooth surface.
**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Notes</th>
</tr>
</thead>
</table>
| **Dorsal capsular release and repair of the lateral collateral ligament** | - Procedure is best used to correct mild or early deformities.  
- Before pinning the second toe, the surgeon should ensure that the toe is able to passively lie in a corrected position after adequate dorsal capsular release and LCL repair. There is a high probability that if the surgeon has to rely on pin fixation to maintain the second toe in a corrected position, this correction will be lost over time. |
| **Flexor-to-extensor tendon transfer** | - Procedure should be used for correction of moderate crossover toe deformity or for toes that display a tendency to resublux after initial correction.  
- When passing the FDL through the proximal plantar incision, flexing the toe will further relax the flexor and facilitate delivery of the tendon to the proximal plantar incision.  
- Overtensioning either limb of the FDL prior to repair can result in further malalignment of the toe and shift the toe into even greater varus or valgus deformity.  
- Rapid postoperative mobilization and early K-wire removal (2 weeks postoperatively) are crucial to preventing uncomfortable postoperative stiffness. |
| **EBD tendon transfer** | - Rapid postoperative mobilization and K-wire removal (2 weeks postoperatively) are crucial to preventing uncomfortable postoperative stiffness.  
- For advanced deformity (rigid stage 3 or 4), FDL transfer may be more appropriate.  
- Anchoring the brevis tendon into a metatarsal head drill hole may lead to a higher recurrence rate than an end-to-end transfer.  
- Supination of the second toe may result from overpull of the EDB. |
| **Modified EBD tendon transfer** | - The Z-lengthening of the EDL should be long enough to permit passage through the bone tunnel and eventual anastomosis of the transfer.  
- The EDB is cut at the distal MT level to preserve adequate length to facilitate the transfer.  
- Drill tunnel placement is critical. The tunnel should be placed close to the longitudinal axis of the proximal axis and not too dorsal or plantar.  
- Correction of the hyperextension deformity relies mainly on adequate soft tissue release. Reflection of the plantar capsule and plate off the metatarsal head using an elevator may be necessary to accomplish adequate soft tissue release.  
- Placing the drill tunnel too dorsal will lead to residual supination; locating it too plantar will lead to hyperextension of the MTP joint. |
| **Proximal phalanx basilar osteotomy** | - If complete correction of the crossover toe deformity is not attainable following initial soft tissue releases, the approach can be extended to the base of the proximal phalanx, where a proximal phalanx basilar osteotomy can be performed.  
- Care should be taken to prevent perforation of the far cortex when performing the osteotomy, or instability and delayed bony union may result. |
| **Weil osteotomy** | - The distal fragment of the osteotomy can be preliminarily secured with a K-wire prior to completion of the dorsal-to-plantar compression screw fixation.  
- Pinning across the MTP joint will decrease the risk of floating toe deformity.  
- Avoid securing the distal osteotomy fragment in plantarflexion; if anything, err on the side of dorsiflexion if accepting mild angular deformity in the sagittal plane. |

**POSTOPERATIVE CARE**

- Dorsal capsular release and repair of the lateral collateral ligament
  - The pin is left in for approximately 3 to 4 weeks.
  - Immediate ambulation is allowed in a stiff postoperative shoe.
  - Once the pin is removed, the toe is taped in plantarflexion for another 3 to 4 weeks.
  - The patient is progressed into normal shoe wear once the pin is removed.
  - Girdlestone-Taylor procedure
  - Ambulation in a hard-soled shoe using only the heel is permitted immediately following surgery.
  - The K-wire is removed between 2 and 3 weeks postoperatively.
  - The patient is instructed to adhere to 6 additional weeks of taping the toe in slight plantarflexion and lateral deviation.
- EDB tendon transfer
  - Postoperative care is essentially identical to that used for a flexor-to-extensor transfer.
  - The percutaneously placed K-wire is maintained for 2 to 3 weeks, followed by an additional 6 weeks of taping the corrected toe to maintain alignment.
  - Modified EDB tendon transfer: The pin is kept in place for 3 to 6 weeks followed by 6 additional weeks of toe taping.
  - Proximal phalanx basilar osteotomy
  - After surgery, dressings are placed with the toe maintained in an overcorrected position. The patient is placed in a hard-soled shoe, and dressing changes are performed weekly.
  - At 6 weeks postoperatively, the patient is advanced to a soft-soled shoe as tolerated.
  - K-wire is removed at 4 weeks postoperatively.
  - Postoperative radiographs are assessed at 4 to 6 weeks to evaluate for bony healing at the osteotomy site.
- Weil osteotomy
  - Sterile dressings are placed intraoperatively, and the toe is taped down in an overcorrected position.
  - Dressings are changed weekly until drainage ceases.
  - Weight bearing in a postoperative shoe is resumed immediately after surgery.
OUTCOMES

- Girdlestone-Taylor procedure
  - Thompson and Deland performed FDL flexor-to-extensor tendon transfers on 13 feet in 11 patients and reported that at an average follow up of 33.4 months all patients had substantial pain relief, with 8 of 13 becoming completely pain-free. They concluded that while flexor-to-extensor tendon transfer is successful in re-establishing MTP joint congruity and relieving pain due to instability, rapid postoperative mobilization and early K-wire removal (2 weeks postoperatively) are crucial to preventing uncomfortable postoperative stiffness.

- EDB tendon transfer
  - Haddad and colleagues performed either flexor-to-extensor or EDB tendon transfer on 38 patients (42 feet) with an average follow-up of 51.6 months. Of the 31 patients (35 feet) followed until their final examination, 24 were satisfied with their surgical correction, 6 were satisfied with reservations, and 1 was dissatisfied.

  - No statistical significance in clinical outcome was demonstrated between patients who underwent FDL tendon transfer and those who underwent EDB tendon transfer; but Haddad et al recommended the technique because they believed that it demonstrated better patient satisfaction and improved flexibility compared with the FDL transfer.

  - Other advantages favoring EDB transfer over FDL transfer that were cited were better postoperative range of motion (78 degrees for EDB versus 62 degrees for FDL) and hence better patient satisfaction, decrease in recurrence of deformity (14%), and better pain control (71% asymptomatic; 26% mild pain).

- Weil osteotomy
  - Hofstaetter and colleagues analyzed their results at 1 and 7 years in 25 feet using the Weil osteotomy for treatment of instability at the MTP joint. Good to excellent results were obtained in 21 feet (84%) after 1 year and in 22 (88%) after 7 years.

  - The authors demonstrated marked improvement in pain, diminished plantar callus formation, and an increase in walking capacity.

  - Adverse results included recurrent instability, floating toes, and restricted motion at the MTP joint, but these complications were often not clinically significant.

COMPLICATIONS

- Dorsal capsular release and repair of the lateral collateral ligament
  - Recurrence
  - MTP stiffness
  - Persistent swelling
  - Failure to achieve correction

- Girdlestone-Taylor procedure
  - Swelling
  - Recurrent deformity
  - Stiffness
  - Hyperextension

- EDB tendon transfer
  - Recurrent crossover toe deformity or failure to achieve complete correction of deformity
  - Infection

- Symptomatic incisional scar formation
- Stiffness of the MTP joint, especially with flexor-to-extensor tendon transfer
- Proximal phalanx basilar osteotomy
- Infection
- Loss of correction with persistent angular deformity
- Failure of union at the osteotomy site
- Weil osteotomy
- Persistent dorsiflexion at the MTP joint (floating toe deformity)
- Claw toe
- Nonunion or malunion at the osteotomy site
- Stiffness at the MTP joint due to incorporation of articular surface into osteotomy cut
- Overcorrection with excessive shortening of the second metatarsal
- Hardware failure or prominence
- Infection
- Neurovascular insult

PATHOGENESIS

- Isolated MTP angular deformity of the lesser toes is defined as varus or valgus deformity exclusively at the MTP joint relative to the normal anatomic axis of the toe.

- Toes 2, 3, 4, and 5 are usually involved.

- This type of deformity characteristically follows abnormal deviation of the hallux, which is frequently in a position of varus or valgus.

SURGICAL MANAGEMENT

- To achieve successful correction of the lesser toes, it is usually necessary to address any varus or valgus deformity of the hallux concomitantly.

- Procedures that are used to correct isolated MTP angular deformity are similar to those used for surgically treating mild or moderate crossover second toe deformities and are described earlier in this chapter.

PEARLS AND PITFALLS

- Deviations in the lesser toes tend to follow angular deformities of the hallux. To create lasting correction of the lesser toes, the surgeon must address deformity of the hallux concomitantly.

- Failure to address associated deformity of the hallux can result in early loss of successful lesser toe correction.

CLINODACTYLY

PATHOGENESIS

- Clinodactyly refers to the medial or lateral deviation of a toe caused by true angulation within a phalanx.

- This type of lesser toe deformity is thought to result from a failure of segmentation between the normally transverse epiphysis and metaphysis.

- Often bilateral and familial, clinodactyly most frequently involves the DIP joint of the fourth and fifth digits, although any digit may be involved.
There is also a strong predilection for involvement of the fingers with this lesser toe deformity.

A variety of syndromes and chromosomal disorders have been linked to clinodactyly of the lesser toes (sympalangism, brachydactyly, trisomy 21, Turner syndrome, Holt-Oram syndrome, Marfan syndrome).

An associated “delta phalanx,” or a triangular middle phalanx, is sometimes associated with clinodactyly.

NATURAL HISTORY

Clinodactyly is usually nonprogressive and no more than a cosmetic concern, although overlapping or underlapping of adjacent toes may occur.

If significant overlap or underlap is present, impingement on adjacent digits may cause the patient to be symptomatic.

PATIENT HISTORY AND PHYSICAL FINDINGS

The affected toe is deviated medially or laterally relative to the normal longitudinal axis of the toe.

The DIP of the involved toe is the most common site of angulation.

A complete physical examination should be performed because of the prevalence of clinodactyly with associated syndromes and chromosomal disorders.

Impingement on adjacent toes due to overlapping or underlapping may cause indentation on the toes, local irritation, corns, or callosities at variable locations from associated pressure phenomenon.

IMAGING AND DIAGNOSTIC STUDIES

All angular deformities involving the lesser toes can be appropriately studied by examining standard AP, lateral, and oblique radiographs of the affected foot.

NONOPERATIVE MANAGEMENT

For symptomatic toes, strategic padding, stretching, taping, and accommodative shoe wear may temporarily alleviate certain components of a patient’s discomfort. These conservative approaches are often ineffective, however.

SURGICAL MANAGEMENT

Surgical options include wedge osteotomies, arthrodesis, and soft tissue–lengthening procedures.

Both opening and closing wedge osteotomies can effectively address angulation at the affected joint.

Closing wedge osteotomy or arthrodesis is indicated for the treatment of symptomatic clinodactyly of any severity grade.

A closing wedge osteotomy can be performed at the middle or distal phalanx through a small transverse dorsal incision.

Intercalary allograft can be used to perform an opening wedge osteotomy and thereby preserve much of the length of the digit, but Z-plasty of the skin must also be performed for added soft tissue correction.

A closing wedge arthrodesis of the affected joint is an acceptable treatment method provided that excessive shortening of the digit is not present.

Skin dermodesis may be added for further acceptability of correction.

CLOSING WEDGE OSTEOTOMY OR ARTHRODESIS

The skin over the affected middle or distal phalanx is incised through a dorsal incision. Redundant skin, equal to the planned osteotomy, is carefully removed (TECH FIG 7A).

Subperiosteal exposure is obtained at the apex of the deformity (TECH FIG 7B).

A microsagittal saw is used to create the desired cut at an appropriate angle to facilitate a satisfactory correction.

Care should be taken to preserve a small bridge of bone at the far cortex.

The osteotomy fragment is removed, and the wedge is closed with manual manipulation (TECH FIG 7C).

If an arthrodesis is desired, the closing wedge may be removed through the interphalangeal joint.

Dermodesis is then performed, incorporating skin into the closure.

Alternatively, a K-wire can be placed percutaneously, in retrograde fashion, for added stability.

Sterile dressings are placed, emphasizing overcorrection of the affected toe.

**TECH FIG 7**  
A. The affected middle or distal phalanx is approached through a dorsal incision.  
B. Subperiosteal exposure is obtained at the apex of the deformity.  
C. The osteotomy fragment is removed, and the wedge is closed with manual manipulation.
CONGENITAL CROSSOVER FIFTH TOE DEFORMITY

PATIENT HISTORY AND PHYSICAL FINDINGS

- On examination, the fifth toe is noted to override the fourth toe to a variable degree.
- The interphalangeal joints are usually in normal full extension.
- There is often mild dorsiflexion at the MTP joint as well as malalignment and contracture of the skin at the fourth web space.
- In patients with longstanding deformity, the toe may assume a flattened, paddle-shaped appearance in the AP plane that is usually the result of years of compression by constrictive shoe wear.
- The toenail usually appears normal, and the toe is able to participate in active flexion and extension.

IMAGING AND DIAGNOSTIC STUDIES

- All angular deformities involving the lesser toes can be appropriately studied by examining standard AP, lateral, and oblique radiographs of the affected foot.
- Radiographs show dorsolateral subluxation at the MTP joint.

NONOPERATIVE MANAGEMENT

- Reliably ineffective, conservative treatment modalities include splinting, taping, accommodative shoe wear, and protective padding.

SURGICAL MANAGEMENT

- Many surgical approaches have been advocated for correction of crossover fifth toe deformity, and many modifications of these have been subsequently developed.
- The type of procedure selected is based on the severity of deformity encountered.
- Soft tissue procedures such as dorsal skin lengthening with Z-plasty of contracted skin, dermodesis of redundant skin, EDL tendon transfer, EDL lengthening or release, syndactylization of the fourth and fifth toes, and dorsal and medial capsular release have all been described and proved effective.
- Bony resection, performed in isolation or in conjunction with any of the aforementioned soft tissue procedures, has also been successful in correcting crossover fifth toe deformity.
- Proposed salvage operations include the so-called Ruiz-Mora procedure (proximal phalangectomy via a plantar elliptical incision with soft tissue realignment and plantar dermodesis) with or without syndactylization of the fifth toe to the fourth, and even amputation.
- The DuVries technique can be used to correct mild to moderate deformities.
- The Lapidus procedure can be used to address moderate to severe deformities.
- In this technique, the EDL is isolated and rerouted under the MTP joint and attached to the abductor digiti quinti muscle or lateral joint capsule.
- Unlike other procedures, the Lapidus technique allows for rotational correction, expanding the indications for its use.

POSTOPERATIVE CARE

- If a K-wire is placed, it should be removed by 4 weeks postoperatively.
- Weight bearing in a postoperative shoe is permitted to tolerance immediately after surgery.
- Dressings should be changed until drainage subsides, with continued emphasis on maintaining an overcorrected position of the toe.

OUTCOMES

- Reports are largely anecdotal but overall have been favorable and support the continued use of the procedure.

COMPLICATIONS

- Neurovascular insult due to an overaggressive exposure
- Loss of reduction due to inadequate stabilization
- Wound healing problems
- Violation of the dorsal extensor structures
- Failure of bony healing at the osteotomy site

NATURAL HISTORY

- Crossover fifth toe deformity is almost always present from birth and therefore is usually nonprogressive with respect to its degree of deformity.
- As stated, a painful callosity of either the fourth or fifth toes may develop over time because of pressure phenomenon in cases of longstanding deformity.
- Also, abnormal pressure distribution due to subluxation at the fifth MTP joint can eventually lead to pain at the plantar surface of the fifth metatarsal head and metatarsalgia.
- Approximately half of all patients experience symptoms due to an overriding fifth toe.

PATHOGENESIS

- Although the underlying cause is unknown, congenital crossover fifth toe is widely recognized as a familial problem with an equal gender predilection.
- Often bilateral (20% to 30% of cases), congenital crossover fifth toe (or congenital overriding fifth toe) deformity causes pain with restrictive shoe wear and other symptoms in about half of all patients.
- Pathoanatomy includes dorsomedial subluxation and adduction at the fifth MTP joint, with external rotation of the toe.
- There is associated contracture of the fifth toe EDL tendon, skin of the dorsal fourth web space, MCL, and dorsomedial MTP joint capsule.
- Often, impingement lesions at the base of the adjacent fourth toe identify the compressive influence of the overriding fifth toe due to its subluxated position.
- Furthermore, dorsal subluxation of the fifth toe at the MTP joint causes excessive pressure on the metatarsal head. This abnormal pressure distribution can lead to painful planar callosity under the metatarsal head.
- When the fifth toe crosses under the fourth toe, painful callosity may develop under any portion of the toe that comes in abnormal contact with the ground surface during weight bearing.

CONGENITAL CROSSOVER FIFTH TOE DEFORMITY

IMAGING AND DIAGNOSTIC STUDIES

- All angular deformities involving the lesser toes can be appropriately studied by examining standard AP, lateral, and oblique radiographs of the affected foot.
- Radiographs show dorsolateral subluxation at the MTP joint.

NONOPERATIVE MANAGEMENT

- Reliably ineffective, conservative treatment modalities include splinting, taping, accommodative shoe wear, and protective padding.

SURGICAL MANAGEMENT

- Many surgical approaches have been advocated for correction of crossover fifth toe deformity, and many modifications of these have been subsequently developed.
- The type of procedure selected is based on the severity of deformity encountered.
- Soft tissue procedures such as dorsal skin lengthening with Z-plasty of contracted skin, dermodesis of redundant skin, EDL tendon transfer, EDL lengthening or release, syndactylization of the fourth and fifth toes, and dorsal and medial capsular release have all been described and proved effective.
- Bony resection, performed in isolation or in conjunction with any of the aforementioned soft tissue procedures, has also been successful in correcting crossover fifth toe deformity.
- Proposed salvage operations include the so-called Ruiz-Mora procedure (proximal phalangectomy via a plantar elliptical incision with soft tissue realignment and plantar dermodesis) with or without syndactylization of the fifth toe to the fourth, and even amputation.
- The DuVries technique can be used to correct mild to moderate deformities.
- The Lapidus procedure can be used to address moderate to severe deformities.
- In this technique, the EDL is isolated and rerouted under the MTP joint and attached to the abductor digiti quinti muscle or lateral joint capsule.
- Unlike other procedures, the Lapidus technique allows for rotational correction, expanding the indications for its use.

OUTCOMES

- Reports are largely anecdotal but overall have been favorable and support the continued use of the procedure.

COMPLICATIONS

- Neurovascular insult due to an overaggressive exposure
- Loss of reduction due to inadequate stabilization
- Wound healing problems
- Violation of the dorsal extensor structures
- Failure of bony healing at the osteotomy site

NATURAL HISTORY

- Crossover fifth toe deformity is almost always present from birth and therefore is usually nonprogressive with respect to its degree of deformity.
- As stated, a painful callosity of either the fourth or fifth toes may develop over time because of pressure phenomenon in cases of longstanding deformity.
- Also, abnormal pressure distribution due to subluxation at the fifth MTP joint can eventually lead to pain at the plantar surface of the fifth metatarsal head and metatarsalgia.
- Approximately half of all patients experience symptoms due to an overriding fifth toe.

PATHOGENESIS

- Although the underlying cause is unknown, congenital crossover fifth toe is widely recognized as a familial problem with an equal gender predilection.
- Often bilateral (20% to 30% of cases), congenital crossover fifth toe (or congenital overriding fifth toe) deformity causes pain with restrictive shoe wear and other symptoms in about half of all patients.
- Pathoanatomy includes dorsomedial subluxation and adduction at the fifth MTP joint, with external rotation of the toe.
- There is associated contracture of the fifth toe EDL tendon, skin of the dorsal fourth web space, MCL, and dorsomedial MTP joint capsule.
- Often, impingement lesions at the base of the adjacent fourth toe identify the compressive influence of the overriding fifth toe due to its subluxated position.
- Furthermore, dorsal subluxation of the fifth toe at the MTP joint causes excessive pressure on the metatarsal head. This abnormal pressure distribution can lead to painful planar callosity under the metatarsal head.
- When the fifth toe crosses under the fourth toe, painful callosity may develop under any portion of the toe that comes in abnormal contact with the ground surface during weight bearing.

CONGENITAL CROSSOVER FIFTH TOE DEFORMITY

IMAGING AND DIAGNOSTIC STUDIES

- All angular deformities involving the lesser toes can be appropriately studied by examining standard AP, lateral, and oblique radiographs of the affected foot.
- Radiographs show dorsolateral subluxation at the MTP joint.

NONOPERATIVE MANAGEMENT

- Reliably ineffective, conservative treatment modalities include splinting, taping, accommodative shoe wear, and protective padding.

SURGICAL MANAGEMENT

- Many surgical approaches have been advocated for correction of crossover fifth toe deformity, and many modifications of these have been subsequently developed.
- The type of procedure selected is based on the severity of deformity encountered.
- Soft tissue procedures such as dorsal skin lengthening with Z-plasty of contracted skin, dermodesis of redundant skin, EDL tendon transfer, EDL lengthening or release, syndactylization of the fourth and fifth toes, and dorsal and medial capsular release have all been described and proved effective.
- Bony resection, performed in isolation or in conjunction with any of the aforementioned soft tissue procedures, has also been successful in correcting crossover fifth toe deformity.
- Proposed salvage operations include the so-called Ruiz-Mora procedure (proximal phalangectomy via a plantar elliptical incision with soft tissue realignment and plantar dermodesis) with or without syndactylization of the fifth toe to the fourth, and even amputation.
- The DuVries technique can be used to correct mild to moderate deformities.
- The Lapidus procedure can be used to address moderate to severe deformities.
- In this technique, the EDL is isolated and rerouted under the MTP joint and attached to the abductor digiti quinti muscle or lateral joint capsule.
- Unlike other procedures, the Lapidus technique allows for rotational correction, expanding the indications for its use.

OUTCOMES

- Reports are largely anecdotal but overall have been favorable and support the continued use of the procedure.

COMPLICATIONS

- Neurovascular insult due to an overaggressive exposure
- Loss of reduction due to inadequate stabilization
- Wound healing problems
- Violation of the dorsal extensor structures
- Failure of bony healing at the osteotomy site

NATURAL HISTORY

- Crossover fifth toe deformity is almost always present from birth and therefore is usually nonprogressive with respect to its degree of deformity.
- As stated, a painful callosity of either the fourth or fifth toes may develop over time because of pressure phenomenon in cases of longstanding deformity.
- Also, abnormal pressure distribution due to subluxation at the fifth MTP joint can eventually lead to pain at the plantar surface of the fifth metatarsal head and metatarsalgia.
- Approximately half of all patients experience symptoms due to an overriding fifth toe.
DUVRIES TECHNIQUE FOR CORRECTION OF CROSSOVER FIFTH TOE DEFORMITY

- A longitudinal incision is made over the fourth web space.
- An extensor tenotomy is performed, followed by dorsal capsulotomy and medial collateral ligament release (TECH FIG 8A).
- The toe is plantarflexed, bringing the skin along the lateral margin of the incision distally (TECH FIG 8B).
- Layered suture closure is performed with the toe held in an overcorrected position of plantarflexion and lateral deviation to maximize the degree of soft tissue correction afforded by this technique (TECH FIG 8C).
- Soft tissue release and skin advancement alone are usually sufficient to hold the toe in an adequately corrected position. Otherwise, a K-wire can be placed percutaneously for added stabilization and correction.

TECH FIG 8 • A. A longitudinal incision is made over the fourth metatarsal interspace and extensor tenotomy is performed. B. Plantarflexion of the fifth toe brings the lateral margin of the incision distally and the medial margin proximally. C. Layered closure is undertaken with the toe held in an overcorrected position.

LAPIDUS PROCEDURE

- A longitudinal hockey stick-shaped or curvilinear incision is carried along the dorsomedial border of the fifth toe, from the level of the medial DIP joint distally to the fourth web space proximally.
- Through this incision, a thorough dorsomedial capsulotomy of the fifth MTP joint is made.
- Any adhesions encountered between the plantar capsule and metatarsal head should be released with a curved elevator to prevent hyperextension deformity of the MTP joint after capsular release.
- The hook of the hockey stick incision is then created by extending the incision over the dorsum of the fifth MTP
joint laterally and proximally to the lateral aspect of the fifth MTP head.

- The extensor tendon is carefully exposed, maintaining the extensor hood expansion, and the fifth toe is forcibly plantarflexed, causing the extensor tendon to become taut.
- A second, 1-cm incision is made transversely over the taut EDL tendon at the mid-diaphyseal level of the fifth metatarsal (TECH FIG 9A).
- Using this incision, an EDL tenotomy is performed (TECH FIG 9B).
- The distal limb of the EDL tendon is retrieved and then passed beneath the plantar aspect of the fifth toe from the dorsomedial DIP joint to the lateral aspect of the fifth MTP joint.
- The passed extensor tendon is then sutured to the conjoined tendon of the abductor and short flexor of the fifth toe (TECH FIG 9C).
- The fifth toe is held in an overcorrected position, and the transplanted extensor tendon is placed under slight tension prior to suture fixation.
- Skin is closed with interrupted sutures or with advancement techniques if significant skin contractures are present.

**TECH FIG 9** • **A.** Incisions for the Lapidus technique. **B.** EDL tenotomy using the more proximal of the two incisions. **C.** Transfer of the distal EDL limb beneath the fifth toe and repair to the conjoined tendon.
PEARLS AND PITFALLS

| Procedure is best used for mild deformities without associated rotational deformity of the toe. If any substantial rotational deformity is present, the Lapidus procedure is a more appropriate surgical solution. |
| Failure to hold the toe in an overcorrected position while performing soft tissue advancement and layered closure will result in a higher recurrence rate. |
| Following dorsomedial capsulotomy, any adhesions encountered between the plantar capsule and metatarsal head should be released with a curved elevator to prevent hyperextension deformity of the MTP joint after capsular release. |
| If the toe is not held in an overcorrected position during repair, or if transplanted extensor tendon is incorrectly tensioned, early recurrence is common. |

POSTOPERATIVE CARE

- DuVries technique
  - The toe is taped in a slightly overcorrected (plantar-flexed and lateral) position for 6 weeks in a hard-soled postoperative shoe, after which unrestricted weight bearing is permitted.
  - If a pin is placed, it should be removed at 4 weeks post-operatively and the toe taped for a total of 6 weeks.
- Lapidus procedure
  - Postoperatively, the toe is dressed in a corrected position and weight bearing in a postoperative shoe is allowed. Sutures are removed at 2 weeks, and the toe is then taped in a corrected position for another 4 to 6 weeks. Regular shoe wear is allowed at 4 to 6 weeks.
  - Alternatively, if there is concern about the strength of the repair, the operative foot is maintained in a splint for a total of 3 to 4 weeks, and progression to full weight bearing and activity in a wide toebox shoe is gradually allowed.

OUTCOMES

- In his original description, Lapidus notes that his experience with the procedure that bears his name resulted in satisfactory outcomes in all cases.7

COMPLICATIONS

- A 5% to 10% recurrence rate has been reported using the DuVries technique. Mild swelling and clinically insignificant postoperative edema have also been reported.
- Circulatory insult and wound healing problems are potential risks of the Lapidus procedure but were not reported by Lapidus in his original description. Recurrence of deformity has also been reported.
- The fifth toe is flexed, deviated plantarward in varus, and is laterally rotated at the DIP joint.
- The EDL and dorsal capsule are often attenuated, in contrast to overlapping fifth toe deformity.
- The plantar MTP joint capsule and FDL tendon are often contracted and shortened also.

NATURAL HISTORY

- As curly toe deformity is frequently congenital, progression is limited, and cosmesis is the major concern of parents and caretakers.
- The deformity is often asymptomatic in children and may improve without intervention.
- With initiation of weight bearing and different stages of shoe wear, chronic skin irritation can develop, the toenail may become short and flattened, and other pressure phenomena such as corns and callosities may develop.

PATIENT HISTORY AND PHYSICAL EXAMINATION

- As previously stated, the fifth toe is flexed, deviated plantarward in varus, and laterally rotated at the DIP joint.
- The distal phalanx or the distal and middle phalanges under-ride the more medial toe as a result of these anatomic abnormalities.
- The deformity is usually flexible in childhood but may become rigid as an adult.
- In contrast to crossover fifth toe deformity, the skin in the web spaces is normally aligned, but it can become hyperemic from chronic irritation.
- Patients usually present with varying degrees of symptoms caused by pressure on the weight-bearing surface of the curly toe.
- Callosities, corns, or nail deformities can all develop and cause discomfort with curly toe deformities.

IMAGING AND DIAGNOSTIC STUDIES

- All angular deformities involving the lesser toes can be appropriately studied by examining standard AP, lateral, and oblique radiographs of the affected foot.
- Imaging of the curly toe is usually unnecessary and does not contribute significantly to management strategies.

NONOPERATIVE MANAGEMENT

- Conservative treatment modalities, including splinting, taping, accommodative shoe wear, and protective padding, may relieve symptoms but are usually ineffective for correcting the deformity.

PATHOGENESIS

- Although the cause of curly toe deformity is unknown, it is thought to be familial in nature, with a high instance of bilaterality.
- Frequently, this type of lesser toe deformity involves both fourth and fifth toes and is usually symmetric.
- Hypoplasia of the intrinsic musculature has been proposed as a causative influence on the development of curly toe deformity, but this notion has not been substantiated in the literature.
SURGICAL MANAGEMENT

- For flexible deformities, FDL and FDB tenotomy have been recommended in the pediatric population.
- Flexor-to-extensor transfer, syndactylization with or without partial proximal phalangectomy, middle phalangectomy, and derotational procedures have all been proposed as surgical options to address the underlying pathoanatomy.
- A simple flexor tenotomy can be used to correct mild underlapping fifth toe deformity.

- Originally described by Taylor and credited to Girdlestone in 1951, the flexor-to-extensor tendon transfer is based on the premise that curly toe deformity results from weakness of the intrinsic musculature. This technique was described earlier in this chapter.
- The Thompson technique uses resection arthroplasty of the proximal phalanx in combination with Z-plasty of the skin to achieve derotation of the toe and correction of the deformity. This technique is useful for addressing more rigid, severe crossunder fifth toe deformities.

FLEXOR TENOTOMY

- Various surgical incisions have been successfully used to perform open flexor tenotomy, including a longitudinal incision proximal to the proximal flexor crease, a longitudinal incision distal to the proximal flexor crease, and a transverse incision 1 mm from the proximal flexor crease.
- It is important not to violate the proximal flexor crease with the incision, or scar formation may occur and recurrent deformity can develop.
- The flexor sheath is incised longitudinally, long and short flexor tendons are carefully exposed, and tendons are then transected at the same level (TECH FIG 10).
- Manual manipulation may be used to improve the adequacy of correction.
- The wound is closed with interrupted 3-0 absorbable sutures.

TECH FIG 10 • The flexor sheath is incised longitudinally, the long and short flexor tendons are carefully exposed, and the tendons are then transected at the same level.

THOMPSON PROCEDURE

- A laterally based Z-type or elliptical incision is made over the proximal phalanx.
- Subperiosteal dissection is used to expose the distal half of the proximal phalanx.
- Partial phalangectomy of the distal 25% to 50% of the proximal phalanx or complete phalangectomy is then performed using a microsagittal saw.
- If persistent flexion contracture exists at the level of the PIP, a flexor tenotomy can be added for further correction.
- The digit is manually derotated and a 0.045-inch K-wire is placed in a retrograde fashion across the PIP joint for stabilization.
- Additional soft tissue correction is obtained by using a reverse-Z closure with 4-0 nylon vertical mattress sutures.
- If an elliptical incision was used initially, full-thickness closure is performed with the toe derotated using a dermodesis.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Pitfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexor tenotomy</td>
<td>Failure to transect all three plantar tendons can lead to an incomplete correction of the deformity.</td>
</tr>
<tr>
<td></td>
<td>It is important not to violate the proximal flexor crease with the incision, or scar formation may occur and recurrent deformity can develop.</td>
</tr>
<tr>
<td>Girdlestone-Taylor procedure</td>
<td>Isolated flexor tenotomy and flexor-to-extensor transfer appear to be equally efficacious. However, it is thought that the long flexor tenotomy represents the essential portion of either procedure and that flexor-to-extensor transfer is unnecessary.</td>
</tr>
<tr>
<td>Thompson procedure</td>
<td>If persistent flexion contracture exists at the level of the PIP, a flexor tenotomy can be added for further correction.</td>
</tr>
<tr>
<td></td>
<td>Overresection of the proximal phalanx can lead to a “floppy,” unstable toe as well as a transfer lesion beneath the fourth metatarsal.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- Flexor tenotomy: Sterile dressings and elastic straps are applied to maintain correction, and the wound is inspected 10 days postoperatively.
- Girdlestone-Taylor procedure: Sterile dressings are applied and full weight bearing is permitted in a short leg plaster splint with an extended toebox. Splinting is maintained for 4 to 6 weeks.
- Thompson procedure: The foot is placed in a hard-soled shoe postoperatively, and pins are removed at 4 weeks. Using taping techniques, the toe is maintained in a derotated position for 6 additional weeks.

OUTCOMES

- Flexor tenotomy
  - Ross and Menelaus reviewed their long-term outcome data on open flexor tenotomy performed in 62 children (188 toes) and found that at an average follow-up of 9.8 years, 95% of the toes examined had maintained satisfactory correction and no patients were aware of any loss of toe function.\(^1\)
  - The fourth and fifth toes had significantly more fair and poor results, hypothesized to be due to greater rotational deformity of these toes, especially the fifth.
  - Overall, the authors concluded that open flexor tenotomy is a safe, reliable, and effective method for correcting curly toes in children and is preferable to flexor-to-extensor transfer.
- Girdlestone-Taylor procedure
  - In a double-blind, randomized, prospective trial, Hamer and colleagues studied long-term data from 46 toes (19 patients) randomly assigned to either flexor tenotomy or flexor-to-extensor tendon transfer for operative correction of curly toe deformity.\(^5\)
  - In general, results were good, with all patients remaining symptom-free at final follow-up.
  - The authors concluded that neither procedure was clearly superior to the other, that long flexor tenotomy was the essential portion of either procedure, and that flexor-to-extensor transfer was unnecessary.
- Biyani and colleagues reviewed 130 curly toes in 43 children that were treated with flexor-to-extensor tendon transfer over a period of 24 years.\(^1\)
  - At an average follow-up of 8 years (range 1 to 25 years), good to excellent results were obtained in 95 toes (73%), fair results in 25 toes (19%), and poor results in 10 toes (8%).
  - In general, results of the Thompson procedure have been acceptable.

COMPLICATIONS

- Flexor tenotomy
  - When performing longitudinal skin incision, care should be taken to avoid crossing the flexion creases because scar formation and skin contracture have been reported.
  - Ten of 188 patients in Ross and Menelaus’ study were found to have tethering of the plantar skin as a result of violating some aspect of the flexor crease.\(^11\)
  - Stiffness has also been reported as a complication of flexor tenotomy.
  - Neurovascular compromise has not been reported but, in theory, represents a significant potential complication with this procedure.
  - Recurrent deformity, failure to achieve full correction, and infection are all potential complications of the Girdlestone-Taylor procedure.
- Thompson procedure
  - Digital edema from resection arthroplasty can result, as well as neurovascular insult to the digital bundle.
  - Recurrence in single or multiple planes can also result from attempts at derotation.
  - Overresection can lead to a “floppy,” unstable toe as well as a transfer lesion beneath the fourth metatarsal.

REFERENCES

DEFINITION
- A bunionette deformity is a painful prominence on the lateral aspect of the fifth metatarsal head. This is usually caused by a prominent lateral metatarsal condyle, bowing of the fifth metatarsal, or increased intermetatarsal angle.

ANATOMY
- The Coughlin classification illustrates the pertinent anatomic differences between the different types of bunionette deformities:
  - In type 1, a prominent lateral condyle may be noticeable under the callus.
  - In type 2, a curvature in the metatarsal shaft may be evident.
  - In type 3, there is a wider-than-expected angle between the fourth and fifth metatarsal. All may be associated with an inflamed bursa or callus, depending on the chronicity of the problem.

PATHOGENESIS
- This was historically named a tailor’s bunionette, because tailors spent long hours with crossed legs, causing pressure over the fifth metatarsal head and resulting in local pressure and formation of a callus and occasionally a painful bursa.
- Local pressure can also be increased by a larger-than-normal lateral metatarsal condyle, angulation in the shaft of the metatarsal, or a wide intermetatarsal space, resulting in local tissue inflammation, pain, and swelling.

NATURAL HISTORY
- It has a female-to-male ratio of between 1:1 and 10:1. The natural history is increasing formation of painful callus and bursae over the area.
- It can result in ulceration if proper foot care is not instituted or if underlying neuropathy is present.
- It usually requires regular paring of callus, wide toe box shoe modifications, or surgical treatment.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients complain of pain and tenderness over the lateral aspect of the foot over the fifth metatarsal head.
- Symptoms are usually worse with activity, especially any position causing increased pressure over the metatarsal head.
- Enclosed shoes will exacerbate symptoms when causing local pressure. Hence, it is often described as improved in the summer, with less restrictive footwear and perhaps reduced work hours.
- The examiner should view both feet simultaneously while standing.
- The examiner should look for a prominent lateral metatarsal condyle, an obvious curvature in the metatarsal shaft, or a wide intermetatarsal angle.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standing plain radiographs (AP, lateral, and oblique views) are necessary.
- For all views, the radiographs are evaluated for osteoarthritis, narrow joint space, subchondral sclerosis, osteophyte formation, enlarged metatarsal condyle, curvature of metatarsal shaft, or a wide intermetatarsal angle between the fourth and fifth metatarsal shafts.
- Oblique radiographs may give a better view of the metatarsal head.
- On the lateral radiograph, the surgeon should look for any flexion or extension of the interphalangeal joints suggestive of claw or hammer toes.

DIFFERENTIAL DIAGNOSIS
- Curly toe
- Claw toe
- Hammer toe
- Stress fracture of the fifth metatarsal
- Fifth metatarsal fracture with prominent fracture callus

NONOPERATIVE MANAGEMENT
- Nonoperative management focuses on decreasing pressure.
- It is very important for the patient to avoid sitting positions that place lateral-sided pressure on the fifth metatarsal.
- Placing lamb’s wool or cotton between the fourth and fifth toes to reduce medial deviation of the fifth toe can reduce lateral-sided pressure.
- Proper-fitting wide toe box or orthopaedic shoes can alleviate pressure caused by footwear.

SURGICAL MANAGEMENT
Preoperative Planning
- The surgeon should take into consideration any previous scars, edema, or skin abnormalities that would affect incision placement.
- Plain weight-bearing films are reviewed to determine which type of bunionette is present. Soft tissue release or osteotomy is based on the type of deformity.
- Type 1 deformity is treated with excision of the lateral metatarsal condyle.
- Type 2 deformity is treated with a distal metatarsal osteotomy. We describe the chevron type of osteotomy to correct the lateral deviation in the distal metatarsal shaft. The lateral deviation angle measures the degree of lateral bowing and is measured off the medial aspect of the fifth metatarsal shaft.
base to the center of the metatarsal head. The normal value is 2.6 degrees (range 0 to 7 degrees).4

- In type 3 deformity a wide intermetatarsal angle between the fourth and fifth metatarsal is noted, with the mean angle being 6.5 degrees (range 3 to 11 degrees).7 This is best treated with a proximal Ludloff metatarsal osteotomy.

**Positioning**

- The patient’s positioned supine on a radiolucent operating table. A small lift is placed under the buttock on the operative side. A tourniquet is placed on the upper thigh or a sterile Esmarch tourniquet is placed above the ankle.

**Approach**

- All skin incisions should be lateral, with caution to avoid any digital nerves on the lateral aspect of the fifth toe.
- This approach allows for bunionectomy and osteotomy of the shaft with screw, pin, or plate fixation, and the approach can be extended proximally or distally if needed.

---

**LATERAL METATARSAL CONDYLECTOMY WITH CAPSULAR PLICATION**

- Use a lateral approach, making an incision down to the capsule (TECH FIG 1).
- Free the soft tissue between the capsule and the overlying skin to expose the lateral aspect of the metatarsal head (TECH FIG 2A,B).
- Make a V-shaped capsulotomy with the proximal apex to allow for plication on closure (TECH FIG 2C,D).
- Expose the enlarged lateral condyle of the fifth metatarsal. Place small Hohmann retractors below and above the metatarsal head to protect both flexor and extensor tendons (TECH FIG 3A).
- With a small saw, excise the prominent lateral condyle head parallel to the shaft of the metatarsal (TECH FIG 3B,C).
- Pull the distal part of the V capsulotomy proximally to the desired amount of tension and sew with a heavy nonabsorbable suture (TECH FIG 3D).
- Close the subcutaneous tissue with small absorbable suture and the skin with small nonabsorbable suture.
- Place a small amount of gauze between the fourth and fifth toes to keep the fifth toe from deviating medially while it heals.

**TECH FIG 1 •** Lateral incision over bunionette.

**TECH FIG 2 •** A. Dissection through subcutaneous tissue to bursa. B. Excision of bursa over bunionette. C,D. V-shaped capsulotomy performed to expose bunionette.
**CHEVRON OSTEOTOMY OF THE FIFTH METATARSAL**

- Make a lateral incision down to the capsule.
- Free the soft tissue between the capsule and the overlying skin to expose the lateral aspect of the metatarsal head.
- Make a V-shaped capsulotomy with the proximal apex to allow for plication on closure.
- Expose the enlarged lateral condyle of the fifth metatarsal and perform excision of the lateral metatarsal condyle as described previously (TECH FIG 4A–C).
- Mark the center of the freshly cut lateral aspect of the metatarsal head with a sterile marker (TECH FIG 4D).
- The limbs of the chevron osteotomy are 60 degrees.
- Use your free hand to palpate the plane of the metatarsal heads, and make the chevron osteotomy parallel to the plantar surface of the foot (TECH FIG 4E,F).


**TECH FIG 4** - A. Bunionette exposed through lateral approach and V-shaped capsulotomy. B, C. Bunionette excision performed with saw. (continued)
Shift the metatarsal head medially, leaving 3 to 4 mm of exposed metatarsal shaft (TECH FIG 4G,H AND 5A,B).

- Cut the residual lateral bone with the saw again parallel to the metatarsal shaft.
- Secure the osteotomy with a mini-fragment screw inserted from proximal to distal fixing the osteotomy site.

Alternatively, a Kirschner wire can be used to secure the osteotomy site (TECH FIG 5C,D).

- Close the capsule with a heavy nonabsorbable suture.
- Close the subcutaneous tissue with small absorbable suture and the skin with small nonabsorbable suture.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pitfall/Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral metatarsal head excision</td>
<td>■ Avoid excising too much metatarsal since it can result in joint instability.</td>
</tr>
<tr>
<td></td>
<td>■ The osteotomy should be directed away from the metatarsal shaft to avoid splitting the metatarsal with the osteotomy.</td>
</tr>
<tr>
<td>Chevron osteotomy</td>
<td>■ The apex of the osteotomy should be located in the center of the metatarsal head. If it is too distal, it can fracture the head. If it is too proximal, the location of the osteotomy is diaphyseal bone, which may take longer to heal.</td>
</tr>
<tr>
<td></td>
<td>■ If the plane of the osteotomy is not parallel to the plantar aspect of the foot, it will prevent shifting of the metatarsal head.</td>
</tr>
<tr>
<td>Oblique osteotomy</td>
<td>■ A long oblique osteotomy is needed to achieve better correction and more stable fixation.</td>
</tr>
<tr>
<td></td>
<td>■ Screw placement for the osteotomy is important. If it is too close to the end of the osteotomy, it will fracture the osteotomy. If it is too distal to the end of the osteotomy, it limits the correction since the point of rotation is more distal than the apex of the osteotomy.</td>
</tr>
<tr>
<td></td>
<td>■ Stable fixation is key to union and maintaining the correction.</td>
</tr>
</tbody>
</table>

TECHNIQUES

OBLIQUE METATARSAL SHAFT OSTEOTOMY (COUGHLIN)

■ Make a lateral skin incision and carry it down to the capsule.
■ Free the soft tissue between the capsule and the overlying skin to expose the lateral aspect of the metatarsal head.
■ With a sterile marker, mark the plantar aspect of the metatarsal where the capsule meets the metatarsal neck. Then mark the osteotomy on the dorsal proximal aspect.
■ Place Hohmann retractors above and below to protect the extensor and flexor tendons.
■ Cut the osteotomy two thirds of the way, leaving the plantar third intact.
■ Insert a mini-fragment screw (2.0 or 2.7 mm) in the proximal portion of the osteotomy. Tighten the screw completely and then loosen it before completing the osteotomy.
■ Complete the osteotomy.
■ Swing the distal portion medially to the desired amount of correction and tighten the proximal screw. Insert another 2.0- or 2.7-mm screw more distally to supplement fixation.
■ Cut the excess bone from the proximal osteotomy site with the saw.
■ Close the subcutaneous tissue with small nonabsorbable suture and the skin with nonabsorbable suture.

TECH FIG 5 • (continued) C, D. Metatarsal head is stabilized with a towel clip and fixed using a mini-fragment screw. E. Overhanging bone on the proximal and lateral aspect of the metatarsal shaft is excised.
POSTOPERATIVE CARE
- The wound is checked at 1 week postoperatively to examine for any evidence of infection.
- Sutures are removed at 2 weeks.
- If a pin was used, it is removed at 6 weeks.
- Heel walking only is permitted for 6 weeks.
- In the oblique metatarsal osteotomy a postoperative fibreglass splint is applied in the operating room and is changed to an air cast at 2 weeks. This is continued for 6 weeks.

OUTCOMES
- Although the bunionette deformity is common, it is rarely symptomatic enough to warrant surgical intervention. This is reflected by the small numbers found in case studies reported in the literature.
- Kitaoka and Holiday\textsuperscript{5} reported results on 21 feet (16 patients) who underwent lateral condylar resection for bunionette. The overall results were considered good in 15 feet, fair in 3, and poor in 3. However, 23% of the patients had recurrent or persistent lateral forefoot pain. They attributed the failures to an inadequate amount of resection, MTP joint subluxation, and severe forefoot splaying. Limitations of the procedure included lack of deformity correction, a significant incidence of residual lateral forefoot pain, and difficulty treating bunionettes with intractable plantar keratosis.
- Several studies have reported good results in the surgical treatment of bunionette with chevron osteotomies.\textsuperscript{2,6,7} Moran and Claridge\textsuperscript{7} felt that stabilization of the osteotomy site with fixation was necessary to minimize the risk of displacement. One study reported that Kirschner wire fixation led to less dorsal displacement of the distal fragment.\textsuperscript{8} In Kitaoka et al’s\textsuperscript{8} series of chevron osteotomies for bunionettes, they used Kirschner wire fixation in only 1 of 19 patients due to intraoperative instability at the osteotomy site; however, they did note postoperative displacement in another patient. No incidence of displacement was found in series that routinely used fixation.\textsuperscript{2,7}
- Limited correction of the fourth–fifth intermetatarsal angle was seen, where 1 mm of translation results in a decrease of that angle of only 1 degree.\textsuperscript{3,6} The fifth metatarsal head can be shifted only 33% to 40% of its width, generally in the range of 3 to 4 mm.\textsuperscript{2,3,6,7} However, Kitaoka et al\textsuperscript{8} noted that neither the preoperative nor the postoperative intermetatarsal fourth–fifth angle correlated with the postoperative foot score.
- Oblique metatarsal osteotomies have been shown to provide the biggest correction for a type II or III deformity with a high intermetatarsal angle.\textsuperscript{4,9,12} Coughlin\textsuperscript{4} found that the intermetatarsal angle decreased from an average of 16 degrees preoperatively to 0.5 degrees postoperatively. Results have shown a reliable improvement in postoperative subjective scores.\textsuperscript{4,9,12} With the use of internal fixation, there was only one report of delayed union.\textsuperscript{4,9,12} This is compared to other series reporting rates of delayed union of up to 11% without fixation.\textsuperscript{11} However, prominent hardware can be an issue, and in one study 87% of patients required later removal.\textsuperscript{4} Proximal osteotomies are not recommended due to the poor blood supply in the region and the higher risk of delayed or nonunion.\textsuperscript{1,10}

COMPLICATIONS
- Infection
- Recurrent deformity
- Digital nerve injury
- Nonunion of the osteotomy
- Displacement of the osteotomy
- Avascular necrosis of the fifth metatarsal head
- Transfer metatarsalgia

REFERENCES
DEFINITION
- Rheumatoid arthritis is an inflammatory condition of synovial joints that usually presents as a symmetric polyarthropathy.
- Ninety percent of patients with chronic rheumatoid arthritis have involvement of the foot; the forefoot is the most commonly involved area of the foot.

ANATOMY
- The metatarsophalangeal (MTP) joint of the foot is stabilized by the plantar plate, the collateral ligaments, the capsule, and a dynamic balance between the intrinsic and extrinsic muscles of the foot.
- The intrinsic muscles are plantar to the MTP joint axis and help to plantarflex the joint.
- The proximal phalanx of the hallux has a valgus orientation of 0 to 15 degrees at the MTP joint.
- A plantar fat pad normally provides cushioning and protection for the metatarsal heads.

PATHOGENESIS
- Unrelenting synovitis leads to a painful and swollen joint. This causes a stretching of the ligamentous structures surrounding the MTP joint.
- Ligament stretching combined with forces of walking leads to soft tissue instability, articular cartilage destruction, and subchondral bone resorption.
- Residual laxity leads to subluxation and dislocation of the lesser MTP joints. This allows the metatarsal head to protrude through the plantar plate and capsule.
- The hallux most commonly develops a hallux valgus deformity, with an occasional hallux varus developing.
- MTP instability leads to intrinsic muscles becoming dorsal to the MTP axis, which leads to loss of active MTP flexion and interphalangeal extension. This leads to a claw-toe deformity.
- Dislocation of the metatarsal lesser MTP joints leads to a distal migration of the fat pad, which exposes the metatarsal heads, increasing pressure in this area.

NATURAL HISTORY
- Rheumatoid arthritis initially presents in the foot in about 17% of patients.
- It is a progressive disorder that may start as synovitis and progress to dislocations and degeneration of the joint.
- The longer active rheumatoid disease is present, the greater the likelihood the patient will develop deformities as a result of the associated synovitis.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Initially, patients often complain of an insidious onset of poorly defined forefoot pain and difficulty with ambulation.
- As synovitis leads to deformity within the forefoot, the symptoms then become more localized.
- Patients will often have shoe wear-related irritation along the medial eminence of the hallux and along the dorsal aspects of the proximal interphalangeal joints of the lesser toes.
- With the development of the lesser-toe MTP dislocation, pain on the plantar aspect of the metatarsal heads is present.
- Hallux valgus: the examiner should look for the degrees of valgus orientation and its impingement on lesser toes. Patients often have pain along the medial eminence and from pressure on the toes (FIG 1).
- Lesser MTP dislocation and plantar callus: the examiner should inspect and palpate the dorsal and plantar aspects of the forefoot. MTP instability can vary from subluxation to dislocation. Increased pressure under the metatarsal heads is a common source of pain (FIG 2).
- Examination should include range of motion for the ankle joint, subtalar joint, and MTP joints.
- The examiner should perform a complete vascular and neurologic examination of the foot.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs will often show periarticular osteopenia, symmetric joint space narrowing, marginal cortical erosions, and subchondral cysts (FIG 3).
- The severity of hallux valgus and the presence of MTP dislocation can be evaluated.

DIFFERENTIAL DIAGNOSIS
- Inflammatory arthritides such as psoriatic arthritis, Reiter syndrome (reactive arthritis), and ankylosing spondylitis
- Gout and pseudogout
- Connective tissue disorders (ie, lupus)

FIG 1 • Hallux valgus: the examiner should inspect the foot with the patient standing.
Inflammatory bowel disease (Crohn disease or ulcerative colitis)
Neurologic disorders
Osteoarthritis

NONOPERATIVE MANAGEMENT

New pharmacologic agents that can control synovitis have the potential for minimizing the severity and frequency of deformities seen.
Shoe wear modifications such as extra-depth shoes decrease shoe wear irritation.
Custom inserts can help relieve pressure from painful areas.
Plantar calluses may benefit from periodic shaving.

SURGICAL MANAGEMENT

Surgical treatment is indicated for patients whose pain is unrelied by nonoperative treatment or those with ulcerative lesions due to their deformity.
The goals of surgical treatment include:
Restoration of the weight-bearing function of the first ray
Relocation of the plantar fat pad

Reduction of pressure under the lesser metatarsal heads
Correction of claw toe or hammer toe deformities
A variety of methods have been described, but probably the most reliable method for accomplishing these goals is with fusion of the first MTP joint, resection of the lesser metatarsal heads, and either osteoclasis or open hammer toe repair.

Preoperative Planning

These patients have a relatively poor soft tissue envelope, and this may compromise wound healing.
There is no perioperative standard as to whether to continue the use of disease-modifying antirheumatic drugs.
Consideration should be given regarding the need for cervical spine evaluation before general anesthesia.

Positioning

The patient is placed supine on the operating table (FIG 4), with the foot positioned near the distal end of the table.

Approach

The first MTP joint can be exposed through a dorsal or medial approach. Both provide adequate exposure, but the medial approach may provide a greater skin bridge between incisions. Incisions from previous procedures may dictate the approach used.
Lesser metatarsal head resection can be performed through dorsal longitudinal incisions or a plantar incision. While the plantar approach may provide more direct access to the metatarsal head when the MTP joint has been dislocated for a while, there is more of a risk of problems with wound healing.

Preoperative Planning

These patients have a relatively poor soft tissue envelope, and this may compromise wound healing.

Positioning

The patient is placed supine on the operating table (FIG 4), with the foot positioned near the distal end of the table.

Approach

The first MTP joint can be exposed through a dorsal or medial approach. Both provide adequate exposure, but the medial approach may provide a greater skin bridge between incisions. Incisions from previous procedures may dictate the approach used.

Lesser metatarsal head resection can be performed through dorsal longitudinal incisions or a plantar incision. While the plantar approach may provide more direct access to the metatarsal head when the MTP joint has been dislocated for a while, there is more of a risk of problems with wound healing.

Preoperative Planning

These patients have a relatively poor soft tissue envelope, and this may compromise wound healing.

Positioning

The patient is placed supine on the operating table (FIG 4), with the foot positioned near the distal end of the table.

Approach

The first MTP joint can be exposed through a dorsal or medial approach. Both provide adequate exposure, but the medial approach may provide a greater skin bridge between incisions. Incisions from previous procedures may dictate the approach used.

Lesser metatarsal head resection can be performed through dorsal longitudinal incisions or a plantar incision. While the plantar approach may provide more direct access to the metatarsal head when the MTP joint has been dislocated for a while, there is more of a risk of problems with wound healing.
HAMMER TOE CORRECTION

- If the deformity at the proximal interphalangeal (PIP) joint of the lesser toes are not severe, then the contractures at the joint can be corrected by closed manipulation (TECH FIG 1).
  - Grasp the toe distal and proximal to the PIP joint and hyperextend it until the joint is resting in a neutral position.
- If the deformity is severe, an open hammer toe correction is performed (TECH FIG 2).
  - Make an elliptical incision along the PIP joint.
  - Remove an elliptical portion of skin over the PIP joint and open the capsule over the joint.
  - Release the collateral ligaments and expose the head of the proximal phalanx.
  - Resect the proximal phalanx at the metaphyseal-diaphyseal junction.
  - Stabilize the area with a Kirschner wire after performing metatarsal head resections.

TECH FIG 1 • Performance of osteoclasis, in which the proximal interphalangeal joint is passively manipulated to break up contracture.

TECH FIG 2 • An open hammer toe repair is performed with an elliptical incision over the proximal interphalangeal joint (A), followed by capsular release (B), and exposure (C) and resection (D) of the head of the proximal phalanx. (Adapted from Coughlin M, Mann R, eds. Surgery of the Foot and Ankle, 7th ed. St. Louis: Mosby, 1999.)

LESSER METATARSAL HEAD RESECTION

- Make longitudinal incisions over the second and fourth intermetatarsal spaces (TECH FIG 3).
- Blunt dissection is recommended to minimize trauma.
- Identify the extensor digitorum longus and retract it to one side.
- Release the dorsal capsule and collateral ligaments off the metatarsal head.
- Bring the metatarsal head into the dorsal aspect of the incision.
- A curved retractor can be useful in obtaining exposure of the metatarsal head.
- Use a sagittal saw to resect the metatarsal head. The blade is oriented in an oblique fashion from dorsal-distal to plantar-proximal.
A. Dorsal, longitudinal incisions are made in the second and fourth intermetatarsal spaces. B. The extensor tendon is identified and retracted to one side. C. The dorsal capsule and collateral ligaments are released off the metatarsal head. D. A curved retractor can be helpful in exposure of the metatarsal head. E. The metatarsal head is brought into the dorsal aspect of the incision. F. Metatarsal head resection is oriented in an oblique fashion from dorsal–distal to plantar–proximal. G. The metatarsal head is removed as one fragment if possible. H. Progressive resection from the second to fifth metatarsal is performed, creating a smooth cascade. (Adapted from Coughlin M, Mann R, eds. Surgery of the Foot and Ankle, 7th ed. St. Louis: Mosby, 1999.) (continued)
FOOT AND ANKLE • Section I FOREFOOT

Part 8

Remove the metatarsal head as one fragment if possible. Take care to avoid leaving any bone fragments.
- Make sure the plantar aspect of the metatarsal is smooth and does not have a sharp edge.
- The metatarsal head resection usually starts on the second metatarsal and moves laterally.
- Leave the third metatarsal slightly shorter than the second and the fourth shorter than the third metatarsal. This creates a smooth cascade from medial to lateral.
- Pass 0.625-mm Kirschner wires from the base of the proximal phalanx to the tip of the toes.
- Pass the wires retrograde down the metatarsal shaft.

I. Kirschner wires are passed from the base of the proximal phalanx to the tip of the toes.
J. The wires are then passed retrograde down the metatarsal shaft.

TECH FIG 3 • (continued) I. Kirschner wires are passed from the base of the proximal phalanx to the tip of the toes. J. The wires are then passed retrograde down the metatarsal shaft.

TECH FIG 4 • A. Medial incision for exposure of hallux metatarsophalangeal. B. The proximal phalanx and metatarsal head articular cartilage are exposed. C. Joint preparation using a cup and cone reamer. (continued)

TECHNIQUES

HALLUX MTP ARTHRODESIS

- Make a medial incision along the MTP joint (TECH FIG 4).
- Incise the capsule and expose the metatarsal head and proximal phalanx.
- Prepare the joint surfaces by removing the remaining articular cartilage and exposing the underlying bone.
- This can be done with the use of a cup and cone reamer system or with rongeurs and curettes.
- Flat cuts using a saw can also be used, but it is slightly more difficult to orient the cuts such that the correct alignment of the joint is obtained.
- Place the MTP joint in 10 to 15 degrees of valgus and 20 to 25 degrees of dorsiflexion relative to the metatarsal shaft.
- The correct dorsiflexion can be approximated by using a flat tray as a guide and keeping the pulp of the hallux 5 to 10 mm off the surface of the tray.
- The position is held temporarily with a Kirschner wire.
- Perform definitive fixation with cross screws or a dorsal plate or, in salvage cases, threaded pins.
- Close the wounds and apply a forefoot dressing.

PEARLS AND PITFALLS

Hammer toe correction
- Fixed deformities often require an open correction.
- Failure to correct the deformity can lead to recurrent deformity.

Metatarsal head resection
- Oblique orientation of the resection helps decrease plantar pressure and sharp plantar edges.
- Loose fragments can lead to recurrent callus formation and should be avoided.
- Adequate decompression of the lesser MTP joint is seen with about 1 cm of space between the base of the phalanx and remaining metatarsal.
- Progressive shortening of the metatarsals from medial to lateral allows better stress transfer.
- After pin fixation, check the vascularity of the toe, as compromise occasionally requires pin removal.

Hallux MTP fusion
- This is performed after the lesser metatarsal head resection to prevent an excessively long first ray.
- Excessive dorsiflexion can cause pain over the interphalangeal joint and under the metatarsal head.
- Fusion in greater than 20 degrees of valgus can increase the incidence of interphalangeal joint arthritis.
- Care must be taken to prevent excessive pronation or supination of the toe.
POSTOPERATIVE CARE

- After placement of the forefoot dressing, a walking boot is applied (FIG 5).
- Patients are instructed to bear weight on the heel of the foot.
- Sutures are removed 10 to 14 days after surgery.
- A forefoot dressing is used for the first 6 weeks.
- Kirschner wires are removed at 6 weeks.
- A walking boot is used for 8 to 10 weeks, based on healing of the first MTP fusion.

OUTCOMES

- Most studies have noted a significant improvement in ability to ambulate and in shoe wear options.
- Patient satisfaction rates are high and seem to hold up over time.
- Patients should be aware that the lesser toes are unlikely to touch the floor and can be floppy, there may be a change in shoe size, and toes may develop a rotational deformity.

COMPLICATIONS

- Recurrent intractable plantar keratosis
- Recurrent toe deformities
- Wound healing problems

- Nonunion of MTP fusion
- Infection

REFERENCES

DEFINITION

- A primary interdigital (Morton’s) neuroma is in fact not a neuroma as it does not involve the haphazard proliferation of axons seen in a traumatic nerve injury.
- Instead, this condition is best described as an interdigital perineural fibrosis.
- It was first described in 1845 by Lewis Durlacher, a chiropodist to the Queen of England.
- Recurrent neuromas are true histopathologic (haphazard proliferation of axons) amputation stump neuromas.
- Eighty-five to 90% of nontraumatic neuromas are found in the third web space. The rest are found in the second web space.

ANATOMY

- The medial plantar nerve supplies sensation to the first, second, and third digits and the medial aspect of the fourth digit. It emerges plantar and medial to the flexor digitorum brevis, coursing obliquely across the plantar surface of the muscle.
- The lateral plantar nerve supplies sensation to the lateral half of the fourth and the fifth digit.
- Both are branches of the tibial nerve and terminate with digital branches that course plantarly deep to the transverse metatarsal ligament (FIG 1).
- The lumbrical tendon appears lateral and superficial to the digital nerve as it attaches to the medial aspect of the extensor expansion of the digit and may be mistaken for nerve.
- In a cadaveric study, Levitsky et al found that 27% of specimens had a communicating branch connecting the medial and lateral plantar nerves. They also noted that the second and third interspaces were significantly narrower than the first and fourth.
- Changes in the nerve itself involve perineural fibrosis, demyelination and degeneration of nerve fibers, endoneural edema, and the absence of inflammatory changes.
- Plantar-directed nerve branches may tether the common digital nerve to the plantar skin.
- Theses nerve branches are present up to 4 cm proximal to the transverse metatarsal ligament.

PATHOGENESIS

- All histologic changes in a primary interdigital neuroma occur distal to the transverse metatarsal ligament, as shown in studies by Lassmann and Graham et al.
- The cause is unclear but is thought to evolve as an entrapment neuropathy.
- The second and third intermetatarsal spaces are narrower than the first and fourth.
- Mobility between the medial three rays and the lateral two rays may contribute to the high number of primary neuromas in the third interspace.

- In a limited number of patients (about 27%) the common digital nerve to the third interspace consists of branches from the medial and lateral plantar nerves, which perhaps increases the size of the nerve and predisposes it to entrapment (Fig 1).
- A “recurrent interdigital neuroma” may be due to several factors, including failure to make the correct diagnosis originally.
- Neurogenic pain may be due to causes other than perineural fibrosis, such as neuropathy and radiculopathy. Also, neuroma-like symptoms may be due to nerve irritation from local synovitis or bursitis.
- Beskin and Baxter found that in patients with recurrent symptoms of interdigital neuroma, about two thirds presented within 12 months and one third had recurrence 1 to 4 years after primary surgery.
- Those with “recurrence” within the first 12 months probably represent patients who were originally misdiagnosed.
Those presenting after 12 months probably represent patients with a true bulb neuroma at the cut end of the common digital nerve. It probably requires at least this length of time for a neuroma to grow big enough to cause symptoms.

Formation of a recurrent neuroma after primary surgery is usually due to inadequate resection.

Plantar-directed nerve branches may tether the common digital nerve to the plantar skin and not allow for retraction of the nerve after it is cut. These nerve branches may occur up to 4 cm proximal to the transverse metatarsal ligament.

**NATURAL HISTORY**

- Interdigital neuromas occur more commonly in females.
- The primary symptom of an interdigital neuroma is pain, most often described as burning, aching, or cramping.
- The pain often radiates to the toes or proximally along the plantar aspect of the foot.
- Relief usually occurs with removing narrow toe-box shoes.
- Walking barefoot on soft surfaces often produces no symptoms.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- In patients with an interdigital neuroma, the most common complaint is plantar pain, which is often increased by walking.
- Pain is often relieved by resting and removing shoes.
- Often there are no symptoms with barefoot walking on a soft surface.
- About half of patients describe pain radiating to the toes.
- The duration of pain varies from a few weeks to many years.
- Plantar tenderness in the web space is the most common physical examination finding.

- The examiner should inspect for deviation or subluxation of the toes or fullness of the web space. This is best done with the patient standing (FIG 2A).
- Palpat ing the web space proximal to the metatarsal heads and proceeding distally will usually reproduce the patient’s symptoms.
- It is often difficult to differentiate adjacent metatarsophalangeal (MTP) joint synovitis from a neuroma.
- Plantarflexion of the corresponding MTP joint may help with the diagnosis (FIG 2B). This maneuver often causes little increased pain in those with an interdigital neuroma but is quite painful in those with MTP joint synovitis.
- Difficulty in making a diagnosis may arise when primary synovitis causes secondary neuritic symptoms.
- The Mulder test is also useful.
- Pain may be present on the asymptomatic contralateral side but is usually not as painful and the “click” not as striking.
- This test is best performed with the patient lying prone and the knee flexed 90 degrees. The examiner places the thumb on the dorsal surface and the index finger on the plantar surface in the affected web space and applies gentle pressure (FIG 2C). With the opposite hand the examiner applies a gentle squeeze to the forefoot in a mediolateral direction (FIG 2D). A clicking sensation that reproduces the patient’s pain will often be appreciated.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- The diagnosis of an interdigital neuroma is most often made solely on the basis of the history and physical examination.
Standing AP, lateral, and oblique radiographs are necessary to exclude osseous pathology and to assess the MTP joint.

The use of nerve conduction testing has not been shown to be beneficial, as findings often are abnormal in patients without symptoms of an interdigital neuroma.

Studies differ as to the benefit of ultrasonography or MRI. If necessary, ultrasonography appears to be more useful than MRI in cases with a questionable diagnosis.

A diagnostic injection may be helpful, although other pathology in the area may improve with this local anesthetic.

- 2 cc of lidocaine is placed in the symptomatic web space through a dorsal approach.
- The needle must be plantar to the transverse metatarsal ligament.

DIFFERENTIAL DIAGNOSIS

- Adjacent web space neuroma
- MTP joint synovitis
- Freiberg osteochondrosis
- Stress fracture of the metatarsal neck
- Tarsal tunnel syndrome
- Peripheral neuropathy
- Lumbar radiculopathy
- Unrelated soft tissue tumor (eg, ganglion, synovial cyst, lipoma)

NONOPERATIVE MANAGEMENT

- Although reported results of conservative treatment vary, it is still worthwhile to try, as 30% to 40% of patients may avoid surgery.
- The patient should be fitted with a wide, soft, laced shoe with a low heel.
- A soft metatarsal support should be added just proximal to the metatarsal heads (FIG 3A).
- An injection of steroids with anesthetic may be both diagnostic and therapeutic. For there to be diagnostic value, however, the anesthetic must be directed to the common digital nerve in the affected web space and not into the MTP joint. A combination of 40 mg Depo-Medrol and 1 cc 0.25% Marcaine is used for the injection (FIG 3B). Thirty percent of patients may have relief for 2 years or longer. Steroids should be used with caution as fat pad atrophy, skin discoloration, or MTP joint capsule laxity may result and create a new problem for the patient.

SURGICAL MANAGEMENT

- The indication for surgery is failure of conservative treatment in a patient who is healthy enough to undergo forefoot surgery and who has appropriate vascular status.

Preoperative Planning

- A forefoot or ankle block may be used. Twenty to 30 cc of a 50% mixture of a short- and long-acting anesthetic (eg, lidocaine and Marcaine) without epinephrine is recommended.
- An examination under anesthesia allows for better appreciation of an interspace mass and often will produce a more striking Mulder click.
- Instruments needed include a Weitlaner or neuroma retractor (FIG 4), small tenotomy scissors, a Senn retractor, and a Freer elevator.
- An ankle tourniquet is used with cast padding and an Esmarch bandage.
- If a plantar approach is being used (recurrent neuroma), the surgeon should palpate and outline with a sterile marker the metatarsal heads corresponding to the web space being explored.

Positioning

- The patient is placed supine with a 3-inch bump under the distal leg just proximal to the heel. The heel should be floating just off the bed.
For a primary interdigital neuroma the surgeon should sit proximal to the foot with the assistant positioned at the end of the table to assist with retraction (FIG 5A).

A plantar approach is used for recurrent neuromas. The surgeon sits at the end of the table facing the plantar aspect of the foot (FIG 5B).

**Approach**

**Primary Interdigital Neuroma**

- A dorsal approach is used for primary neuromas.
- A dorsal incision is made 3 cm proximal to the web, extending distally to the edge of the web space (FIG 6).
- The incision is slightly oblique and medial to the extensor tendons. It is important not to follow the tendons themselves, as they will take a more lateral direction.
- The dissection is deepened and the dorsal sensory nerves are retracted to the side of least resistance.
- The lumbrical tendon is lateral to the dissection.
- The surgeon should proximally identify the dorsal interosseous fascia and muscle belly and follow it distally to the bursa overlying the transverse metatarsal ligament.
- The surgeon should place a Weitlaner or neuroma retractor between the metatarsals and spread them apart.
- The bursa is opened to identify the transverse metatarsal ligament.

**Recurrent Neuroma**

**Plantar Longitudinal Incision**

- A longitudinal plantar incision is made 4 cm proximal to the web, extending distally to within 1 cm of the web space.
- The incision is made between the metatarsal heads (which have been identified and marked before making an incision) and proceeds just distal to this area (FIG 7).
- A small Weitlaner retractor is placed to retract the fat overlying the plantar aponeurosis.
- Using a no. 15 blade knife, the aponeurosis is incised in line with the skin incision.

- Web space fat is retracted using a Senn retractor and the distal aspect of the intermetatarsal ligament is identified.
- A Freer elevator is placed beneath the transverse metatarsal ligament from distal to proximal, protecting the underlying structures.
- The transverse metatarsal ligament is incised with a no. 15 blade knife, staying on top of the Freer elevator.
- The lumbrical tendon is in the lateral aspect of the dissection just plantar to the intermetatarsal ligament.
- The neurovascular bundle is identified medial and plantar to the lumbrical.
A tenotomy scissors is used to bluntly spread until the common digital nerve is identified proximally. The surgeon dissects distally to identify the stump neuroma.

**Plantar Transverse Incision**

- A 3- to 4-cm transverse plantar incision is made over the affected interspace just proximal to the weight-bearing pad and parallel to the natural crease (FIG 8).
- The metatarsal heads are continually palpated to provide a reference point to the appropriate interspace to be explored.
- The dissection is carefully deepened with scissors to expose the septa of the plantar fascia.
- The interval between the longitudinal limbs of the plantar fascia septa is opened with scissors.
- The bands of the plantar fascia are retracted medially and laterally with a Senn retractor and the interspace is carefully explored with blunt dissection to identify the common digital nerve and vessel.
- The nerve (neuroma) will lie superficial (plantar) to the flexor digitorum brevis muscle or tendon and immediately deep (dorsal) to the plantar fascia.
- The surgeon dissects distally to identify the stump neuroma.
- The neuroma is identified and dissected proximally 1 to 2 cm.

**Primary Interdigital Neuroma Excision (Dorsal)**

- Once the approach has been completed the nerve should be identified in the wound. It is usually easier to identify the nerve proximally and dissect distally (TECH FIG 1A).
- Manually palpate in the wound to be sure the transverse metatarsal ligament has been completely transected, as this is essential to a successful outcome.
- Despite the size of the nerve or the obvious presence of a neuroma, the nerve should be resected as planned.
- Structures that may be mistaken for the nerve include the lumbrical tendon, which passes to the medial portion of the adjacent proximal phalanx (extensor expansion) and therefore is lateral to the nerve. The common digital artery usually crosses proximal medial to distal lateral lying dorsally over the nerve. The artery often emerges from under the metatarsal neck and if identified needs to be dissected away from the nerve and preserved.

  Using gentle traction (TECH FIG 1B), transect the nerve about 4 cm proximal to the transverse metatarsal ligament. The transverse head of the adductor hallucis may need to be retracted dorsally to identify the plantar-directed...
Once the approach has been completed, the neuroma is identified just deep to the distal extensions of the plantar fascia that fan out to attach to the plantar aspects of the MTP joints and just superficial (plantar) to the flexor digitorum brevis.

The intermetatarsal ligament is often scarred in but does not need to be transected as it is distal and dorsal to the neuroma.

Place gentle traction on the common digital nerve (TECH FIG 2A). Identify and excise the neuroma (TECH FIG 2B).

With the Weitlaner or neuroma retractor still in place, release the ankle tourniquet. Use cautery to obtain hemostasis.

Irrigate the wound with sterile saline.

Close the wound with 4-0 nylon suture in a running locking fashion.

If subcutaneous suture is desired, use a 3-0 Monocryl, taking care not to include the dorsal sensory nerves.

Place a mildly compressive dressing over a Xeroform gauze covering the wound (TECH FIG 1E,F).
MORTON’S NEUROMA AND REVISION MORTON’S NEUROMA EXCISION

Chapter 37

TECHNIQUES

■ Once the plantar transverse approach is made, the technique is exactly the same as described above for the plantar longitudinal incision.

REVISION INTERDIGITAL NEUROMA EXCISION (PLANTAR TRANSVERSE INCISION)

■ Once the plantar transverse approach is made, the technique is exactly the same as described above for the plantar longitudinal incision.

PEARLS AND PITFALLS

Always perform a thorough history and physical examination. This is the primary basis of diagnosis and treatment.

■ Perform standing, sitting, and prone examination of the foot and ankle.

Attempt conservative treatment before surgery.

Discuss with the patient possible complications of surgery, especially incomplete relief and recurrence.

■ Grasp the nerve and with gentle traction pull it distally. Transect and allow the nerve to retract.

Transect the common digital nerve at least 3 to 4 cm proximal to the transverse metatarsal ligament (Tech Fig 1C).

Release the tourniquet and obtain hemostasis before closure.

■ Hematoma formation increases the risk of slow wound healing and infection.

POSTOPERATIVE CARE

■ For 24 hours the operative extremity is maximally elevated and the patient ambulates only for bathroom privileges.

■ For a primary excision (dorsal approach), the patient is then allowed to ambulate with weight bearing as tolerated in a hard-soled postoperative shoe for 4 weeks.

■ For a revision excision (plantar approach), the patient is kept non-weight-bearing on crutches for 2 weeks and then transitioned into a stiff-soled postoperative shoe for another 2 weeks with weight bearing as tolerated.

■ Sutures are removed at 2 weeks and Steri-Strips are placed on the wound.

■ At 4 weeks after surgery the patient is allowed into a wide toe-box, soft-vamp comfortable shoe and progressed as tolerated.

OUTCOMES

■ Surgical excision of a primary neuroma has a reported success rate of 51% to 90%, although results tend to diminish with time. A recent study by Womack et al suggests long-term pain relief is not as significant as once thought.

TECH FIG 2 • A. The plantar longitudinal incision is shown with gentle traction placed on the common digital nerve. B. Excision of the recurrent neuroma through a plantar longitudinal incision.
These results seem to be similar for both second and third web space neuroma excisions.

After re-exploration for a recurrent neuroma, less-than-complete satisfaction can be expected in 20% to 40% of individuals.

**COMPLICATIONS**

- Recurrence of symptoms: This may be due to incorrect diagnosis, incomplete resection, or true recurrence.
- Recurrence of symptoms due to incorrect diagnosis and incomplete resection usually occurs within the first 12 months.
- Recurrence after 1 year is more likely related to the formation of a stump neuroma.
- Significant wound complications are rare, but slow wound healing and superficial cellulitis are more common.
- Incisional tenderness after a plantar approach is less common than one may suppose but may occur if placed under a weight-bearing portion of the forefoot.

**REFERENCES**

DEFINITION
- Morton’s neuroma is a nerve entrapment syndrome in which the intermetatarsal nerve in the second or third web space becomes compressed by the intermetatarsal ligament, enlarges, and undergoes perineural fibrosis.2–4

ANATOMY
- The most important soft tissue structure is the transverse intermetatarsal ligament (TIML), which is a continuation of the plantar plates. This structure becomes taut during the late midstance and push-off phases of gait.
- The TIML should be well visualized. It measures 10 to 15 mm long and 2 to 3 mm thick.1
- The lumbrical tendon is located on the plantar lateral aspect of the TIML. It is the most likely structure to be severed during endoscopic decompression of the intermetatarsal nerve, but with proper identification it can be spared. In my experience, inadvertent severing of the lumbrical tendon, however, has not resulted in any adverse sequelae.
- The plantar interossei muscles are superior to the TIML in the second, third, and fourth intermetatarsal spaces.
- The intermetatarsal nerve is plantar to the TIML and should not be visualized during endoscopic division of the TIML; the nerve, however, may be seen by rotating the cannula 180 degrees, to the 6 o’clock position. With the cannula in the proper position the nerve is protected.

PATHOGENESIS
- The clinical symptoms of this condition were first described by Durlacher in 1845 and later by Morton in 1876. It is Morton’s name that has remained linked to this condition.
- The most recent literature attributes Morton’s neuroma to nerve entrapment; this has been confirmed by electron microscopy.
- Perineural fibrosis has been identified at the level of nerve compression.

NATURAL HISTORY
- The symptoms of Morton’s neuroma are dull, aching pain in the ball of the foot, often radiating into the second, third, or fourth toes.
  - This may be associated with tingling, burning, or numbness.
  - It may occur gradually over several months or progress more acutely.
- Overuse activities and compression by narrow-toed shoes and high heels have been implicated.
- 75% of patients are female.
- The average age of onset is 54.5
- Occasionally trauma can result in formation of an interdigital neuroma.
- Pain is sometimes relieved by removing the shoe.

PHYSICAL FINDINGS
- Classic findings include localized tenderness in the second or third web space. Subtle swelling may be present in the affected web spaces. The two adjacent toes may be slightly separated.
- Mulder’s click (a palpable snap) may be elicited in the affected web space.
- The metatarsal compression test may be positive.
  - This is performed by grasping and squeezing the patient’s forefoot. This maneuver is positive if it reproduces the patient’s symptoms.

IMAGING AND DIAGNOSTIC STUDIES
- Plain films should routinely be performed to rule out other pathologies.
- If the diagnosis or correct web space is in doubt, sonographic imaging can be performed with a high degree of accuracy in experienced hands.
- MRI is not operator-dependent but yields a large percentage of false-negative and false-positive findings and is also much more costly than sonography.
- On ultrasound, a neuroma appears as a hypoechoic oval mass in the interspace at the level of the metatarsal heads. The size of the neuroma can be measured.3

DIFFERENTIAL DIAGNOSIS
- Metatarsal stress fracture
- Freiberg disease (avascular necrosis of the metatarsal head)
- Synovitis
- Intermetatarsal bursitis
- Metatarsophalangeal synovitis
- Peripheral neuropathy
- Lumbar radiculopathy
- Tarsal tunnel syndrome
- Vascular claudication
- Spinal stenosis

NONSURGICAL MANAGEMENT
- Conservative treatment may include metatarsal pads, orthotics, shoes with a wide toebox, steroid injections, and, more recently, alcohol injections.
- In our experience, conservative treatment has been successful in about 70% of patients.

SURGICAL MANAGEMENT
- Surgery is indicated when conservative treatment has failed to relieve pain after at least 6 months.
- The advantage of dividing the TIML without excising the interdigital neuroma is that there is no loss of sensation or possible formation of a stump neuroma, which may produce symptoms worse than those with which the patient originally presented. Barrett and Pignetti introduced endoscopic
decompression of the intermetatarsal nerve, a procedure that offers several advantages over an open procedure, including a smaller incision, faster postoperative recovery, and a reduced incidence of hematoma and infection.1

- Although these authors reported good and excellent results in 88% of patients, the original technique was difficult, with a steep learning curve.
- They have since modified their technique, changing from two portals to a single portal.

Preoperative Planning
- All patients should have plain films preoperatively to rule out other diagnoses, in particular stress fracture or Freiberg infraction.
- In our experience, preoperative ultrasound is valuable in confirming the diagnosis.
- Without ultrasound, simple palpation of the web space is typically accurate in determining which web space is most tender.
- Diagnostic lidocaine injection may also pinpoint the appropriate web space. However, if both the second and third web spaces are symptomatic, the surgeon should consider endoscopy on both spaces.

Positioning
- The patient should be positioned supine on the operating table.
- We use a bump under the ipsilateral buttock and thigh when the leg tends to externally rotate.
- The toes should extend just beyond the end of the table, with the heel firmly resting on the table.
- Anesthesia may be general or regional (popliteal or ankle block).
- Local anesthesia should be avoided, as it may distort the endoscopic anatomy.
- Prophylactic intravenous antibiotics are given when the patient comes to the operating room.
- We routinely use an ankle tourniquet inflated to 250 mm Hg. Equipment required includes the AM Surgical set and a 30-degree 4-mm scope. The AM Surgical system includes an elevator, slotted cannula and obturator, locking device, and disposable knife blade.

SINGLE-PORTAL TECHNIQUE
- Presented here is a technique originally designed by Dr. Ather Mirza for endoscopic carpal tunnel release. I have adapted the instrumentation for uniportal endoscopic decompression of the intermetatarsal nerve (TECH FIGS 1 AND 2).6
- Make a 1-cm vertical incision in the appropriate web space and spread the subcutaneous tissue gently with blunt Stevens scissors.
- Use the AM Surgical elevator to palpate and separate the TIML from the surrounding soft tissues. Scrape the elevator both dorsal and plantar to the TIML.
- Place the slotted cannula and obturator through the same path, just plantar to and scraping against the TIML. The slot should face dorsally at the 12 o’clock position (TECH FIG 3).
- Remove the obturator from the cannula and remove any fat or fluid from the cannula with absorbent cotton-tipped applicators.
- Insert a short 4-mm 30-degree scope into the cannula.
- Visualize the entire TIML by advancing the scope. The ligament is dense and white. The lumbrical tendon can often be seen just lateral to the TIML.
- The intermetatarsal nerve can be visualized by rotating the cannula 180 degrees so that the slot is facing plantar at 6 o’clock. The nerve can often be seen unless obscured.

TECH FIG 1 • Surgical technique for uniportal endoscopic decompression of the intermetatarsal nerve. Cannula is in the interspace just plantar to the transverse intermetatarsal ligament and dorsal to the intermetatarsal (interdigital) nerve. The transverse intermetatarsal ligament is being transected from distal to proximal. (Courtesy of AM Surgical.)

TECH FIG 2 • Instrumentation. From left to right: elevator, cannula and obturator, disposable knife.
Withdraw the scope and knife assembly and remove the knife from the scope. Reinsert the scope to confirm complete transection of the TIML. The divided edge of the ligament can be observed to further separate by applying manual digital pressure between the adjacent metatarsal heads.

Irrigate the wound through the cannula.

Remove the cannula, insert the elevator into the wound, and palpate the interspace. The taut TIML should no longer be palpable.

Deflate the tourniquet; irrigate and close the wound with one or two interrupted mattress sutures. Apply a soft compression dressing and postoperative shoe.

If the surgeon chooses to perform a neurectomy in cases where the nerve is very large and bulbous, the incision can be extended proximally 1 to 2 cm and neurectomy can be performed in routine fashion.
**Section I: Forefoot Techniques**

**Pearls and Pitfalls**

- The key to the procedure is isolating and separating the TIML from the soft tissues. Developing these tissue planes with the elevator is the critical step; everything else follows.
- Hugging the TIML with the cannula while cutting is very important.
- If unable to visualize the TIML, abort the procedure and perform the procedure open.

**Postoperative Care**

- Ice and elevation are recommended for the first 48 to 72 hours.
- Weight bearing as tolerated is permitted in a surgical shoe. Crutches or a walker should be provided as needed.
- Sutures are removed in 12 to 14 days. A comfortable shoe or sandal may then be worn.
- Vigorous activities such as running or racquet sports should be avoided for 4 to 6 weeks.
- Patients should be advised that complete resolution of symptoms may take up to 4 months.

**Outcomes**

- Barrett and Pignetti reported 88% good and excellent results in over 40 patients.\(^1\)
- In our first 24 patients, there were 82% good and excellent results at 6 months postoperatively.

**Complications**

- In the first 50 patients there have been no infections.
- Two wound dehiscences occurred that healed uneventfully.
- The postoperative protocol was then changed from suture removal at 10 to 14 days postoperatively.
- No further dehiscences have occurred.

**References**

DEFINITION
- Forefoot varus is a component of the multiplanar pes planovalgus deformity that occurs as a result of posterior tibial tendon insufficiency.
- In addition to being a component of adult acquired flatfoot deformity, forefoot varus is also present in some cases of congenital pes planus and posttraumatic deformities of the first tarsometatarsal joint.
- In 1936, F. J. Cotton described an adjunctive procedure for the operative treatment of flatfoot deformity using an opening wedge plantarflexion medial cuneiform osteotomy to restore what he termed the “triangle of support” of the static foot.

ANATOMY
- Forefoot varus deformity may occur through a dorsiflexion angulation or rotation at the talonavicular, naviculocuneiform, or tarsometatarsal joints.
- These joints are supported by the spring ligament and the plantar intertarsal ligaments, including the long plantar ligament.
- In addition, the naviculocuneiform and tarsometatarsal joints are supported by their relatively constrained joint architecture, which in the normal state allows only a few degrees of motion in the sagittal plane.
- Medial displacement calcaneal osteotomy, lateral column lengthening, and subtalar fusion all provide correction of heel valgus; lateral column lengthening will correct forefoot abduction, but none of these procedures adequately addresses the fixed forefoot varus component of the pes planovalgus deformity.

PATHOGENESIS
- The pathogenesis of forefoot varus in association with an adult acquired flatfoot deformity secondary to posterior tibial tendon insufficiency is not well understood.
- Forefoot varus is presumed to develop when the posterior tibialis tendon can no longer provide dynamic support to the medial column of the midfoot. In the absence of the posterior tibialis tendon acting as a dynamic stabilizer, the static ligamentous stabilizers (spring ligament complex and the plantar supporting intertarsal ligaments) stretch out due to the repetitive dorsally directed weight-bearing forces on the medial column of the foot.
- Several patterns of medial column “sag” have been described, although the understanding of why some patients have dorsal instability at the first tarsometatarsal joint, the naviculocuneiform joint, or the talonavicular joint is not well understood. The differences in the magnitude and location of the dorsal “sag” may be related to bony anatomy, generalized ligamentous laxity, the presence or absence of gastroc–soleus contracture, and the existence of an underlying congenital pes planovalgus deformity.

NATURAL HISTORY
- The natural history of forefoot varus associated with an acquired adult flatfoot deformity has not been studied. It is presumed that the severity of the forefoot varus deformity progresses as the underlying pes planovalgus deformity progresses. Longstanding instability and subluxation at the first tarsometatarsal joint or naviculocuneiform joint may result in localized osteoarthritis of these joints.
- Some acquired adult flatfeet develop a fixed forefoot varus without osteoarthritis when the deformity has been longstanding and capsular stiffness holds the joint in the deformed position.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Forefoot varus is one of the components of a pes planovalgus deformity that is determined primarily by radiographic and physical examination findings.
- In the patient history, there may be complaints of localized pain to the dorsal medial column of the midfoot, either the tarsometatarsal joint or the naviculocuneiform joint.
- Patients may complain of pressure-related discomfort beneath the base of the first metatarsal or cuneiform due to excessive weight bearing at the apex of the plantar medial column sag.
- The presence and the magnitude of forefoot varus are determined on physical examination by placing the hindfoot into the “subtalar neutral” position with the patient seated (FIG 1). With the hindfoot held in neutral, with the talonavicular joint congruent, a dorsally directed force is applied to the fourth and fifth metatarsal heads until the ankle is dorsiflexed to the neutral position. If the first metatarsal head rests above the transverse plane of the fifth metatarsal, then forefoot varus is present. Forefoot varus is quantified clinically by the degree to which the first metatarsal rests above the transverse plane of the forefoot as a mild, moderate, or severe deformity.
- The deformity is also qualified by whether the forefoot varus deformity is passively correctable by manual pressure to bring the first ray back down to the level of the other metatarsals or whether it is fixed in this position.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standing, AP, and lateral radiographs with a medial oblique view of the involved foot will determine the presence of subluxation or osteoarthritis at the first tarsometatarsal or naviculocuneiform joint.
- The lateral standing radiograph will quantify the amount of dorsiflexion based on the measurement of the lateral talo-first metatarsal angle.
The apex of the deformity may be at the talonavicular joint, the naviculocuneiform joint, or the first tarsometatarsal joint.

In the case of an acquired flatfoot deformity superimposed on a congenital pes planovalgus deformity, comparison measurements of the opposite-foot standing radiograph may help determine what amount of deformity is a result of posterior tibial tendon insufficiency.

A weight-bearing AP radiograph of the involved ankle will determine the presence of a valgus tilt of the talus within the ankle joint mortise secondary to deltoid insufficiency.

Additional procedures to address medial ankle instability due to deltoid ligament insufficiency may be needed to fully correct the valgus hindfoot deformity.

**Differential Diagnosis**

- Forefoot varus secondary to instability or osteoarthritis at the first tarsometatarsal joint
- Global forefoot varus associated with supination of the first, second, and third metatarsals

**Nonoperative Management**

If the deformity is passively correctable, a custom-molded total contact foot orthosis is fabricated with posting under the medial aspect of the hindfoot and midfoot to correct heel valgus and additional posting placed under the lateral aspect of the forefoot to promote plantarflexion of the first ray with weight bearing.

If the forefoot varus is fixed, an accommodative total contact foot orthosis would be fabricated with medial posting under the entire hindfoot and midfoot, or a medial wedge could be added to the sole of the shoe.

If pain symptoms are not controlled with foot orthoses alone, a custom-made leather and polypropylene molded gauntlet-style brace or a polypropylene custom-molded short articulated ankle-foot orthosis would be indicated. Since forefoot varus is only one component of a complex multiplanar pes planovalgus deformity, decision making about conservative versus operative treatment will most likely depend on the characteristics of the hindfoot valgus deformity rather than solely on the forefoot varus component alone.

**Surgical Management**

The plantarflexion opening wedge medial cuneiform osteotomy for correction of fixed forefoot varus associated with a flatfoot deformity is rarely performed in isolation and typically is performed as a component of multiple procedures to correct a given flatfoot deformity.

Typically, the surgeon begins with bony correction of the foot, followed by soft tissue reconstruction and tendon transfers.

The reconstructive procedure begins in the proximal aspect of the foot and ankle and proceeds distally since each level of correction is determined by aligning it to the next-most-proximal segment. Therefore, the forefoot varus is often the last portion of the bony deformity to be corrected during the realignment portion of the procedure.

Occasionally, once the hindfoot deformity correction has been performed, the apparent forefoot varus that was present preoperatively has been improved sufficiently that osteotomy of the first cuneiform is not required.

**Preoperative Planning**

This opening wedge osteotomy requires interposition of some type of bone graft material. Therefore, the surgeon
should be prepared to harvest a bone graft or have allograft or synthetic bone graft material available.
- We have used exclusively frozen tricortical iliac crest allograft bone for this interposition osteotomy without complication.

**Positioning**
- The patient is positioned supine with a small pad placed under the ipsilateral buttock to internally rotate the foot to the neutral position.

**Approach**
- The osteotomy opens dorsally; therefore, the approach is over the dorsal aspect of the first cuneiform.
- If procedures are performed on the medial side of the midfoot, the incisions should be kept at least 3 cm apart to minimize undermining.
- Performing this osteotomy through a medial approach would significantly increase the difficulty, would require significant additional soft tissue dissection, and would require retraction of the anterior tibialis tendon near its insertion.

**PLANTARFLEXION OPENING WEDGE MEDIAL CUNEIFORM OSTEOTOMY FOR CORRECTION OF FIXED FOREFOOT VARUS (COTTON OSTEOTOMY)**

- Under tourniquet control, make a dorsal longitudinal skin incision over the medial cuneiform and the base of the first metatarsal.
- Carry dissection through the skin and subcutaneous tissue to develop the interval between the extensor hallucis longus tendon (retracted medially) and the extensor hallucis brevis tendon (retracted laterally).
- Free up and retract any crossing cutaneous branches of the superficial peroneal nerve.
- Expose the dorsal portion of the medial cuneiform with identification of the first tarsometatarsal joint and the joint between the medial and middle cuneiform. It is not necessary to open the joint capsule of the first tarsometatarsal joint.
- With fluoroscopic guidance, identify the midportion of the cuneiform and draw a saw cut line on the bone. Usually this line is at or just proximal to the plane of the second tarsometatarsal joint (TECH FIG 1).
- With a small microsagittal saw, make a transverse osteotomy in the dorsal-to-plantar direction through the midportion of the medial cuneiform by cutting down to, but not through, the plantar cortex (TECH FIG 2).
- Use a thin osteotome to complete the osteotomy, leaving the plantar periosteum intact.
- Pull the osteotome distally to lever open the medial cuneiform osteotomy and plantarflex the first ray (TECH FIG 3).
- Using a ruler, measure the amount of opening of the cuneiform osteotomy needed to achieve the desired plantarflexion of the first ray.
- On average, a 4- to 6-mm wedge of bone graft is needed to plantar-displace the first metatarsal to the desired level of the other metatarsal heads (especially the fifth metatarsal) in order to restore Cotton’s normal “tripod” configuration.
- A wedge of iliac crest bone graft is either harvested from the patient or obtained from the bone bank.
- Use a microsagittal saw to shape this bone into a wedge, with the dorsal cortex of the iliac crest wedge cut to the width of the dorsal opening gap that was measured

**TECH FIG 1** • Location of first cuneiform osteotomy.

**TECH FIG 2** • The osteotomy is made dorsal to plantar across the midportion of the first cuneiform. A narrow elevator or retractor is placed into the 1, 2 intercuneiform joint to prevent inadvertent osteotomy of the second cuneiform.
An assistant levers the osteotomy open to depress the first metatarsal head while the surgeon determines when the forefoot varus deformity has been adequately corrected. Interposition of corticocancellous bone graft previously and oriented so that the exposed cancellous bone surfaces of the iliac wedge will be adjacent to the exposed cancellous surfaces of the osteotomized cuneiform.

- Use a narrow osteotome to lever open the cuneiform osteotomy while an assistant places plantar-directed pressure on the first metatarsal to help open the osteotomy maximally while the bone graft wedge is impacted from dorsal to plantar into the medial cuneiform osteotomy using a bone tamp (TECH FIG 4).

- Place small amounts of morselized cancellous bone graft, either as autograft from adjacent osteotomies of the hindfoot or from the piece of allograft, medially and laterally around the bone wedge to fill whatever gap remains in the cuneiform.

- The osteotomy is stable due to the surrounding ligamentous support and the compression across the bone wedge created by tamping the bone wedge into the osteotomy. Use percutaneous fixation across the osteotomy to prevent dorsal displacement of the bone block until early healing has occurred (TECH FIG 5).

- Bend to 90 degrees the percutaneous pin protruding from the dorsal medial aspect of the first cuneiform and apply a pin cap.

- Irrigate the wound and close it in layers.

TECH FIG 4 • The interposition bone graft wedge is placed into the dorsal opening in the first cuneiform to depress the first metatarsal and correct the forefoot varus deformity.

TECH FIG 5 • Fixation of the osteotomy with a 0.62-inch Kirschner wire placed from the distal portion of the first cuneiform obliquely into the second cuneiform.
POSTOPERATIVE CARE
- The pin site is dressed along with the other wounds and a compressive, bulky Robert Jones type of dressing is applied with medial lateral and posterior plaster slab splints covered with an elastic wrap.
- If a tendon transfer has been performed as part of the reconstructive procedure, the foot is positioned as needed for proper soft tissue healing.
- At 10 to 14 days after surgery, the splint, dressings, and sutures are removed.
- A dressing is placed around the pin site, which is then padded with a small felt doughnut, and a short-leg fiberglass cast is applied in neutral or whatever position is needed for proper soft tissue healing if a tendon transfer has been performed.
- The cast is removed at 6 weeks after surgery.
- Radiographs are obtained to ensure early incorporation of the graft without displacement.
- The percutaneous pin is removed and full weight bearing as tolerated is allowed in a removable walker boot (FIG 2). Joint and muscle rehabilitation, as indicated by the other operative procedures performed in addition to cuneiform osteotomy, is begun.

OUTCOMES
- Outcomes of this procedure have shown predictable healing. In review of 16 feet (15 patients) by Hirose and Johnson there were no malunions or nonunions. All patients at follow-up described mild to no pain with ambulation.
- Average improvement in the first metatarsal–medial cuneiform angle as measured on the lateral radiograph was 9 degrees.4
- Because of the variety of hindfoot procedures performed in patients undergoing the cuneiform osteotomy, the degree of hindfoot correction contributed by the cuneiform osteotomy alone is difficult to determine.4
- This procedure combined with hindfoot reconstruction for flatfoot provides superior correction of the flatfoot deformity (as evidenced by the lateral talo–first metatarsal angle and the medial-cuneiform-to-floor distance) compared to flexor digitorum longus tendon transfer with subtalar joint arthrodesis or medial displacement calcaneal osteotomy.4

COMPLICATIONS
- No complications have been described in the few reports on this procedure except for the need for hardware removal due to a prominent screw head.
- Structures at risk during the exposure include the extensor hallucis longus or the extensor digitorum brevis tendon and the deep peroneal nerve.
- Although predictable healing has been noted, nonunion, overcorrection, and undercorrection could occur.
- When a dorsal screw is used for fixation, removal of the hardware is often required due to dorsal shoe pressure or irritation of the overlying nerve or tendon.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Pearls and Pitfalls</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Graft placement</strong></td>
<td>Avoid placing the graft too far laterally, which would cause impingement of the graft against the second cuneiform.</td>
</tr>
<tr>
<td><strong>Fixation problems</strong></td>
<td>Dorsal screw fixation is not usually necessary, and the prominence of the dorsal screw head often requires hardware removal.</td>
</tr>
<tr>
<td><strong>Contouring bone</strong></td>
<td>After graft fixation, the microsagittal saw or a power rasp is used to smooth down any portions of the graft that extend beyond the surface of the cuneiform either medially or dorsally and to reduce any prominence of the cuneiform that may have been created by the distraction osteotomy.</td>
</tr>
</tbody>
</table>

FIG 2 • Lateral (A) and AP (B) radiographs at 10 weeks after acquired flatfoot deformity correction with first cuneiform osteotomy. The allograft bone wedge has healed.
REFERENCES
DEFINITION
- Arthrodesis of the first, second, and third tarsometatarsal (TMT) joints is a relatively uncommon procedure used for the treatment of midfoot arthrosis.
- The majority of cases arise from either posttraumatic arthrosis or as part of a systemic inflammatory arthropathy.

ANATOMY
- The medial column of the foot is anatomically designed to be rigid and impart a strong lever arm for push-off, whereas the lateral column is mobile, allowing for forefoot accommodation to walking surfaces.
- Consequently, the first, second, and third TMT joints typically exhibit minimal axial or sagittal plane motion compared to the more mobile fourth and fifth TMT joints.
- Arthrosis of the first, second, and third TMT joints is best addressed surgically via arthrodesis; arthrosis of the fourth and fifth TMT joints is best addressed surgically with a motion-preserving operation including interposition or arthroplasty.
- The goal of foot surgery is to obtain a plantigrade position with normal underlying mechanical alignment to allow for weight bearing, shock absorption, accommodation, and power for efficient painless gait.
- The first TMT joint is typically 30 mm deep.
- The second TMT joint is recessed proximally in relation to the adjacent first and third TMT joints.

PATHOGENESIS
- Equinus is often an underlying pathologic feature.

NATURAL HISTORY
- There are no reported data regarding the natural history of TMT arthrosis, although it can be reasonably assumed that, with the exception of inflammatory arthropathy, most cases of midfoot arthrosis will progress at a variable rate over time, although symptoms may wax and wane.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Pain is often well localized to the dorsum of the midfoot, although some patients may simply complain of a vague dorsal foot discomfort.
- Due to the lack of abundant subcutaneous tissue on the dorsum of the foot, inspection usually reveals localized swelling and osteophytic formation directly over the TMT joints.
- Palpation of the foot tenderness over the affected TMT joints that is exacerbated with motion is characteristic.
- Examination of the extensor tendons and subcutaneous tissue is done to rule out other pathology, including ganglions.
- Physical examination methods include the equinus or Silfverskiöld test. The examiner corrects the hindfoot to neutral subtalar position and checks dorsiflexion range of motion with the knee in straight extension and then flexed 30 degrees. An inability to obtain neutral dorsiflexion with the knee in straight extension that corrects with flexion is indicative of isolated gastrocnemius equinus.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain weight-bearing radiographs including AP, lateral, and oblique views of the foot should be obtained. Every effort should be made to obtain a true lateral radiograph with talar dome overlap.
- Seldom is a CT scan, MRI, or other imaging modality needed except to rule out a subtle Lisfranc injury.
- If there is question as to the cause of midfoot pain, a fluoroscopically guided injection of the suspected TMT joint can be both therapeutic and more importantly diagnostic.

DIFFERENTIAL DIAGNOSIS
- Lisfranc injury
- Metatarsal stress fracture
- Gout or other inflammatory arthropathy
- Ganglion
- Neuroma of the superficial or deep peroneal nerve

NONOPERATIVE MANAGEMENT
- Many patients with hallux valgus and hypermobility of the first TMT joint can be asymptomatic.
- However, once symptoms develop, progression is inevitable, in particular in patients with underlying equinus contractures.
- Initially management can be directed at resolving local symptoms, such as nonsteroidal anti-inflammatory agents, activity modification, rest, weight loss, shoe modifications, and orthotics.
- A stiff-soled rocker-bottom shoe or rigid orthotic minimizes motion across the midfoot, alleviating pain arising from the TMT arthrosis.
- In patients with equinus, a well-directed physiotherapy stretching protocol can be helpful.

SURGICAL MANAGEMENT
- Indication: persistent pain despite an adequate course of conservative management
- Contraindication: open physeal growth plates

Preoperative Planning
- AP foot plain radiographs are reviewed for the extent of involvement of midfoot joints and relative lengths of metatarsal heads.
- Lateral foot plain radiographs are reviewed for talar-first metatarsal angle and evidence of a cavus or planus foot.
Based on the above, the surgeon templates an operative plan.

The surgeon should intraoperatively assess for equinus and
the need for percutaneous tendo Achilles lengthening or gas-
trocnemius slide.

**Positioning**

Patients are placed supine on a radiolucent table with a
padded wedge or bump under the ipsilateral hip to correct ex-
ternal rotation.

The arm is placed across the chest and the ulnar nerve is
padded.

A tourniquet is applied either to the calf or the thigh. If
proximal tibial bone graft is considered, the tourniquet should
be applied on the thigh.

The limb is exsanguinated with an elastic bandage and the
tourniquet is inflated.

---

**TECHNIQUES**

- Make the medial incision between the extensor hallucis
  longus and extensor hallucis brevis, roughly in line with
  the lateral third of the first TMT joint (**TECH FIG 1**).
- Carry dissection down with caution to avoid the dorsal
cutaneous nerves.
- Identify the deep peroneal nerve with the accompanying
dorsalis pedis artery just deep to the medial aspect of the
extensor hallucis brevis tendon, coursing toward the first
web space.
- Identify the first TMT joint by moving the first metatarsal,
  and cut the capsule transverse in line with the joint to
  minimize periosteal stripping.
- Carry the dissection up between the first and second
  metatarsal bases; the second TMT joint can be identified
  more proximally relative to the first TMT joint.
- Denude all joint surfaces of cartilage with a combination
  of an AO elevator, a quarter-inch osteotome, straight
  and curved curettes, and rongeur.
- Use a 2.0-mm drill bit to create a series of perforations in
  the arthrodesis surfaces to optimize surface area and
  blood flow. A lamina spreader can be helpful for
distraction.
- Make the second longitudinal incision described above
  earlier over the third TMT joint.
- Carry dissection to the extensor digitorum brevis muscle
  belly, avoiding the dorsal cutaneous nerves (**TECH FIG 2**).
- Typically, the extensor digitorum brevis cannot be re-
  tracted plantar, so instead it is split in line with the inci-
sion to expose the underlying third TMT joint.
- Again, split the periosteum in line with the joint to avoid
  excessive periosteal stripping.
- Expose the lateral aspect of the second TMT joint and the
  space between the second and third metatarsal bases.
- Prepare these arthrodesis surfaces in a similar manner to
  that described earlier.

**EXPOSURE OF THE FIRST AND SECOND TARSOMETATARSAL JOINTS**

- In similar fashion, prepare the first TMT joint, the medial
  aspect of the second TMT joint, and the articulation be-
  tween the first and second metatarsals bases.
- Avoid using an oscillating saw, as it can predispose to the
  risk of metatarsal shortening.
- It is imperative to remove cartilage all the way down to
  the plantar aspect of the first TMT joint to prevent exces-
  sive dorsiflexion. The first TMT joint is 28 to 30 mm deep.

**EXPOSURE OF THE SECOND AND THIRD TARSOMETATARSAL JOINTS**

- Make the second longitudinal incision described above
  earlier over the third TMT joint.
- Carry dissection to the extensor digitorum brevis muscle
  belly, avoiding the dorsal cutaneous nerves (**TECH FIG 2**).
- Typically, the extensor digitorum brevis cannot be re-
  tracted plantar, so instead it is split in line with the inci-
sion to expose the underlying third TMT joint.
- Again, split the periosteum in line with the joint to avoid
  excessive periosteal stripping.
- Expose the lateral aspect of the second TMT joint and the
  space between the second and third metatarsal bases.
- Prepare these arthrodesis surfaces in a similar manner to
  that described earlier.
TEMPORARY STABILIZATION

- Before stabilization, hold the foot in a reduced position and palpate the forefoot to ensure it is plantigrade.
- Two crossed 0.062 Kirschner wires are used to hold the first TMT joint in a reduced position. They should be placed where the final screws will ultimately be positioned (TECH FIG 3A).
- Place the first from the dorsal medial cuneiform to the plantar aspect of the first metatarsal base. Place the second from the dorsal first metatarsal shaft to the plantar aspect of the medial cuneiform.
- Reduce the second metatarsal to the middle cuneiform and the first metatarsal base. Again, palpate the forefoot to ensure the plantar metatarsal heads are level.
- Make a stab incision over the medial aspect of the medial cuneiform through the skin only. Dissect down to bone with retraction of the tibialis anterior.
- Hold the second metatarsal in place with a guide pin from the 3.0-mm cannulated screw set while protecting the tibialis anterior tendon (TECH FIG 3B).
- Aim the wire from the medial cuneiform to the base of the second metatarsal.
- Make a stab incision on the lateral forefoot to facilitate insertion of another guide pin from the 3.0-mm cannulated screw set to stabilize the third metatarsal to the cuneiforms in a reduced position (TECH FIG 3C).
- Examine the foot position to confirm plantigrade position before final stabilization.

FIRST TARSOMETATARSAL DEFINITIVE STABILIZATION

- The first TMT joint is stabilized first.
- Place a 3.5-mm drill sleeve over the 0.062 Kirschner wire from the medial cuneiform to the first metatarsal and use a cautery mark to mark the angulation of the wire.
- Back the 0.062 Kirschner wire out while maintaining the drill sleeve in a fixed position. Use a 3.5-mm drill followed by a 2.5-mm drill to allow insertion of a 3.5-mm cortical screw in a lag manner. Countersink the screw head before insertion.
- Use similar steps to place an additional lag screw from the first metatarsal to the cuneiform.

SECOND AND THIRD TARSOMETATARSAL DEFINITIVE STABILIZATION

- Drill the second metatarsal cannulated wire with a cannulated drill.
- Use a 3.5-mm drill followed by a 2.5-mm drill to allow insertion of a lag screw. A washer may be needed due to the softer cuneiform bone.
- Protect the tibialis anterior tendon during insertion of this screw.
- Use a similar technique to insert the screw from the third metatarsal to the middle cuneiform.
- Obtain further stabilization of the second and third TMT joints by placing compression staples (TECH FIG 4).
Bone Grafting
- Bone graft is applied to the dorsal surfaces of all arthrodesis sites.
- Autograft or allograft may be used. We often use cancellous allograft mixed with a platelet-rich derivative to promote both osteoconduction and osteoinduction.
- Autograft may be harvested from the calcaneus, proximal or distal tibia, or iliac crest.

Intraoperative Fluoroscopy
- Obtain AP, lateral, and oblique images to ensure adequate reduction and opposition of arthrodesis surfaces in addition to appropriate hardware positioning (Tech Fig 5).

Wound Closure
- Deflate the tourniquet as pressure is applied to the wound.
- Obtain hemostasis and insert a drain to prevent postoperative hematoma formation.
- Reapproximate the capsule over the TMT joints with an absorbable suture.
- Reapproximate subcutaneous tissue with interrupted buried absorbable sutures.
- Close the skin with horizontal or vertical mattress nylon sutures with minimal tension.
PEARLS AND PITFALLS

- Persistent dorsiflexed first metatarsal or lesser metatarsalgia
- Failure to resect plantar aspect of the first TMT joint
- Prominent first, second, or third metatarsal heads
- Failure to hold the metatarsals in a plantigrade position before definitive stabilization
- Nonunion
- Inadequate joint preparation or inadequate fixation
- Lack of bone graft
- Wound complication
- Poor soft tissue handling
- Excessive skin retraction
- Poor incision placement

POSTOPERATIVE CARE

- A well-molded below-knee posterior splint is applied with toes exposed.
- Analgesic control is optimal with a local or regional anesthetic in addition to oral narcotics.
- The patient is mobilized on a knee scooter, non-weight-bearing.
- Progressive weight bearing is permitted between 6 and 12 weeks in a removable boot.
- The patient is weaned out of the removable boot into standard shoes at 12 weeks.

OUTCOMES

- Relatively little is published on outcomes of midfoot arthrodesis.
- With appropriate surgical indications, surgical technique, and patient compliance, patient satisfaction rates exceed 90%.

REFERENCES

DEFINITION
This is a procedure to definitively treat midfoot arthrosis with or without deformity.

ANATOMY
Midfoot articulations include:
- Tarsometatarsal joints
- Naviculocuneiform joints
In the coronal plane, the midfoot may be viewed as three columns:
  - Medial column (the first ray)
  - Middle column (the second and third rays)
  - Lateral column (the fourth and fifth rays)
These articulations form an arch in both the longitudinal plane and the transverse plane.
- The second cuneiform is the keystone to the transverse arch.
- Anatomic alignment in the longitudinal plane is rather simple to assess on weight-bearing radiographs of the foot.
  - In both the AP and lateral planes, the talo–first metatarsal axis should be congruent.
- Physiologically, the medial and middle columns (first through third rays) have congruent joints and tight ligaments, leaving little motion.
  - This is important to ensure the midfoot serves as a rigid lever during the gait cycle’s stance and push-off.
- In contrast, the lateral column (fourth and fifth rays) is relatively supple.
  - This is important to allow the foot to accommodate to various surfaces.
Given that the midfoot’s medial and middle columns are physiologically stiff, arthrodesis of these joints in physiologic alignment creates few functional deficits. However, arthrodesis of the lateral column is generally contraindicated, as the midfoot’s ability to accommodate to various surfaces is forfeited.

PATHOGENESIS
- When the compact and stable midfoot anatomy is compromised, the talo–first metatarsal relationship is disrupted and the foot loses its mechanical advantage during the stance and push-off phases of gait.
- In the sagittal (lateral) plane this leads to loss of the longitudinal arch at the midfoot, with a midfoot sag.
  - In the extreme case the arch will reverse and become a “rocker-bottom deformity.”
- In the coronal (AP) plane the forefoot drifts into abduction relative to the hindfoot.
- A plantigrade foot balances relatively evenly on the weight-bearing surfaces of the first and fifth metatarsals and the heel. When the midfoot collapses, this balance is disrupted and weight bearing eventually may be on the midfoot as well.

- With progressive midfoot deformity, the hindfoot may eventually lose its physiologic alignment, typically with greater-than-physiologic valgus.
  - This typically leads to shortening of the Achilles tendon and equinus contracture.
  - In extreme cases, the ankle may become incongruent as well.
- Causes include:
  - Posttraumatic arthritis (chronic Lisfranc fracture-dislocation)
  - Primary arthritis
  - Inflammatory arthropathy (rheumatoid arthritis)
  - Charcot neuroarthropathy

NATURAL HISTORY
- An injury to the midfoot articulations or the ligaments, particularly the “Lisfranc ligament” between the base of the second metatarsal and the first cuneiform, leads to destabilization of the midfoot’s architecture and a tendency toward gradual progressive arch collapse and forefoot abduction.

PATIENT HISTORY AND PHYSICAL FINDINGS
- History
  - Often (but not always) midfoot trauma is reported. Primary and inflammatory arthritis may be responsible without trauma. Also, a patient with neuropathy may develop midfoot destabilization but without recollection of trauma or with a history of what appeared to be only a minor trauma.
  - Patients experience pain with weight bearing, especially with push-off during the gait cycle.
  - They may also note a fallen arch and difficulty with shoe wear.
- Physical examination
  - The patient must be examined while weight bearing. Comparison to the uninjured contralateral foot is sometimes useful as a baseline of the patient’s physiologic alignment.
  - With advanced disease, loss of the longitudinal arch and forefoot abduction are present.
  - Midfoot tenderness and pain with stress
  - Tenderness is typically focused on the midfoot.
  - Stress of the midfoot produces midfoot pain.
  - The “piano key test” isolates the focus of the pathology to the specific tarsometatarsal joint.
- Neurologic examination
  - If there is a concern for neuropathy, the Semmes-Weinstein monofilaments should be used to determine protective sensation.
  - If the patient can sense the 5.07 monofilament, protective sensation is deemed intact.
IMAGING AND OTHER DIAGNOSTIC STUDIES
- Weight-bearing radiographs of the foot are obtained: AP, oblique, and lateral views.
- Rarely is CT required for assessment or preoperative planning.
- If there is a question of which midfoot articulations may be symptomatic, selective or diagnostic injections may be useful.

DIFFERENTIAL DIAGNOSIS
- See “Pathogenesis” on previous page.

NONOPERATIVE MANAGEMENT
- Activity modification
- Nonsteroidal anti-inflammatory agents (NSAIDs)
- Intra-articular corticosteroid injection
- Mechanical support
  - Longitudinal arch support
  - Stiffer-soled shoe with or without a slight or low-profile rocker-bottom modification
  - With limited deformity and midfoot arthritis, a rocker may be placed on a sensible regular shoe; it need not be a big cumbersome shoe.
  - However, with greater deformity, the shoe may need to be accommodative.
- Bracing
  - Stiffer-soled shoe with rocker modification in combination with a double-upright brace or ankle–foot orthosis (AFO)
  - Diabetics with neuropathy or neuroarthropathy will require the above in combination with a total-contact insert.

SURGICAL MANAGEMENT
- Surgical management is warranted with failure of nonoperative measures.
- Procedures may include arthrodesis in situ or arthrodesis in combination with realignment midfoot osteotomy. Occasionally, adjunctive hindfoot procedures and Achilles tendon lengthening may be warranted.

SCREW AND COMPRESSION PLATE FIXATION
- This patient is a 38-year-old woman with post-traumatic arthritis after chronic Lisfranc fracture-dislocation. The patient also had a “nutcracker” injury to her cuboid with some lateral column degenerative change (TECH FIG 1).
- Approach
  - Dual dorsal longitudinal incisions with adequate skin bridge
  - Medial incision
    - Extensor hallucis brevis exposed (TECH FIG 2A)
    - Deep neurovascular bundle deep to extensor hallucis longus muscle–tendon (TECH FIG 2B)
  - First and second tarsometatarsal (TMT) joint preparation
    - Particularly deep joint (2.5 to 3.0 mm)
    - Essential to remove all plantar prominences and cartilage to avoid dorsiflexion malunion (TECH FIG 2C)
  - Important to remove scar tissue between base of second metatarsal and first cuneiform to allow reduction of second metatarsal base (TECH FIG 2D)
  - Penetrate the subchondral bone to promote fusion (TECH FIG 2E).
  - Lateral incision (with adequate skin bridge) (TECH FIG 2F)
    - Protect the superficial peroneal nerve branch or branches (TECH FIG 2G).
    - Third TMT joint preparation: Remove residual cartilage and penetrate subchondral bone (TECH FIG 2H, I).
    - Add bone graft as necessary.
  - Reduce the deformity.
    - The “windlass” mechanism may be useful in reducing the TMT joints and particularly in avoiding dorsiflexion malunion. Moreover, it compresses the joints (TECH FIG 3A).

Preoperative Planning
- Preoperative weight-bearing radiographs of the foot are essential to determine the preoperative plan.
  - The goal is to restore congruency in the AP and lateral talo–first metatarsal alignment.
  - The deformity must be studied to determine the optimal method for realignment.
  - The degree of destruction or distortion of the midfoot anatomy (particularly with erosive changes of an inflammatory arthropathy) is important and factors in how to best reconstruct the midfoot.
  - Associated hindfoot deformity may need to be addressed as well.
- Equinus contracture
  - The preoperative assessment should include the condition of the Achilles tendon.
  - Often Achilles lengthening, either with a triple cut or gastrocnemius-soleus recession, is necessary to realign the foot and may serve to unload stresses on the midfoot.
- Equipment
  - Various screw and plating systems, some even dedicated to the midfoot, are available.
  - Depending on the planned reconstruction, the following options exist:
    - Standard screws and plates
    - Locking midfoot plates
    - Intramedullary screws
    - Compression staples or compression plates

Positioning
- The patient is positioned supine on the operating table.
- I routinely use a tourniquet.

Approach
- Dual longitudinal approach over the midfoot
  - One dorsal and one medial
  - Most common
- Transverse approach
  - Has been used by many surgeons but is not universally accepted
**TECH FIG 1**  •  Preoperative radiographs of 38-year-old woman with postoperative midfoot arthritis secondary to chronic Lisfranc injury. **A.** AP view. **B.** Oblique view (note distortion to cuboid: chronic “nutcracker” injury). **C.** Lateral view.

**TECH FIG 2**  •  Dorsal medial approach. **A.** Extensor hallucis brevis (EHB) muscle elevated. **B.** Immediately deep to EHB is the deep neurovascular bundle. **C–E.** Preparing medial aspect of tarsometatarsal (TMT) joints. **C.** Sharp elevator for first TMT joint. (Note: toes at top of A, B, and C.) **D.** Rongeur in junction between base of second metatarsal and first cuneiform (it is important to be sure the second metatarsal fully reduces). **E.** Drill to penetrate subchondral bone. The second TMT joint is prepared in a similar manner. (continued)

TECH FIG 3 • A. Using the windlass mechanism to assist in reduction and promote proper alignment of the tarsometatarsal (TMT) joints. Note dorsiflexion of the toes and ankle to tighten plantar soft tissues; this compresses the TMT joints and keeps them from dorsiflexing. B, C. Provisional fixation of first TMT joint. B. Proximal to distal pin. C. Distal to proximal pin. Note that the windlass mechanism is still being maintained with dorsiflexion of the toes. D. Large bone reduction clamp to ensure that the second metatarsal base is reduced, much like open reduction and internal fixation of an acute Lisfranc fracture-dislocation. Provisional pin to fix second metatarsal base.
I maintain dorsiflexion of the toes (activates windlass mechanism) while I place the provisional fixation \((\text{TECH FIG } 3\text{B,C}).\) Using a bone reduction clamp as for open reduction and internal fixation of an acute Lisfranc fracture-dislocation may be helpful. After the second metatarsal base is reduced, I place a guide pin to drill with a cannulated drill the path for a classic “Lisfranc screw” \((\text{TECH FIG } 3\text{D}).\)

- Provisional fixation of middle column \((\text{TECH FIG } 4\text{A})\)
- Thin guide pins for cannulated drills are fragile. I measure the desired screw length and then pass the wires all the way through the foot. That way, if the guide pin should break, I can retrieve both ends and not leave a pin in the foot that may block my desired screws \((\text{TECH FIG } 4\text{B,C}).\)
The “Lisfranc screw” stabilizes the base of the second metatarsal and it will limit dorsiflexion of the second TMT joint if a compression plate is used dorsally.

I routinely use two lag screws to stabilize the first TMT joint (TECH FIG 6A–F).

It is important to use a countersink on the distal-to-proximal screws so that the dorsal cortex of the first metatarsal base does not fracture when the screw is fully seated (TECH FIG 6E).

The middle column may be further stabilized with a lag screw (TECH FIG 6G–J).

I secure the third TMT joint with a dorsal compression plate; with the lag screw already placed, excessive dorsiflexion of the third TMT joint is avoided (TECH FIG 7A–F).

I also use a dorsal compression plate on the second TMT joint. Since the “Lisfranc screw” has already been placed, dorsiflexion can be avoided.

The proximal cortex (first cuneiform) is overdrilled to create lag effect. Solid screw is placed. Fluoroscopic view.

The middle column may be further stabilized with a lag screw (TECH FIG 6G–J).

I secure the third TMT joint with a dorsal compression plate; with the lag screw already placed, excessive dorsiflexion of the third TMT joint is avoided (TECH FIG 7A–F).

I also use a dorsal compression plate on the second TMT joint. Since the “Lisfranc screw” has already been placed, dorsiflexion can be avoided.

TECH FIG 6 • (continued) F. Solid screw placement. G–J. Lateral screw placement. G. Overdrill guide pin with cannulated drill (pin is measured and pin is then driven through medial foot so that both ends of the wire may be retrieved should the pin break). H. Drill with solid drill bit. I. Overdrill. J. Solid screw placed.

TECH FIG 7 • A–F. Third tarsometatarsal (TMT) joint compression plate. A. Plate positioned. B. Locking screws placed (surgeon must be sure plate is flush with the bone before locking the plate). C. View from medial side to show drill towers. (continued)
D. Compression device placed.
E. Plate in position, now being compressed.
F. Final plate position.
G–M. Second TMT joint compression plate.
G. Plate before contouring.
H. Plate after contouring to match second TMT joint.
I. Plate positioned, screw holes drilled.
J. Locking screw being inserted.
K. Surgeon must be sure that plate is flush with bone before fully seating the locking screws.

(continued)
TECH FIG 7 • (continued) L. Compression device. M. Final plate position.

- Precontouring the plate also prevents dorsiflexion (TECH FIG 7G–M).
- Intraoperative fluoroscopy of the construct confirms reduction and that dorsiflexion has been avoided (TECH FIG 8).
- The hardware is often close to the deep neurovascular bundle (TECH FIG 9A).
- I routinely use a drain for this procedure (TECH FIG 9B).
- Follow-up radiographs suggest satisfactory reduction. The patient had some residual lateral column symptoms, so I opted to add a subtalar arthroereisis implant to correct hindfoot alignment and perhaps unload some lateral column stress. Fortunately, that was a satisfactory solution in this case (TECH FIG 10).
- The first through third TMT articulations have little physiologic motion, so arthrodesing them leaves little functional deficit.
- To avoid loss of the midfoot’s accommodative capacity, I rarely if ever fuse the lateral side.

TECH FIG 8 • Fluoroscopic views of final construct. A. AP view. B. Lateral view. Note that first metatarsal is not elevated.

TECH FIG 9 • A. Deep neurovascular bundle intact but will lie directly on second tarsometatarsal (TMT) joint compression plate. Note use of a drain (my preference). B. Wounds closed without tension on skin bridge.
PLATE FIXATION WITH DEDICATED MIDFOOT PLATING SYSTEM

- More recently, midfoot-specific plating systems have been developed.
- This patient is a 48-year-old woman with midfoot Charcot neuroarthropathy failing bracing (TECH FIG 11). She had severe distortion of the midfoot anatomy and loss of the longitudinal arch.

Approach
- Medial midaxial approach to allow for medial plating (TECH FIG 12A–C)
  - Protect the tibialis anterior tendon.
  - However, should the tendon become detached, in my experience it can be sutured securely to the appropriate soft tissues during closure, and with prolonged immobilization to allow the midfoot to heal, the patient typically will retain full active dorsiflexion.
- Joint preparation: Remove residual articular cartilage and penetrate the subchondral bone (TECH FIG 12D).

- Dorsal longitudinal approach
  - The deep neurovascular bundle is immediately deep to the extensor hallucis brevis tendon. The deep neurovascular bundle must be identified and protected throughout the procedure (TECH FIG 13).
  - Joint preparation: Often this is interesting, with the amount of distortion of the anatomy from the Charcot process.
  - Reduction: As for an acute Lisfranc fracture-dislocation, a bone reduction clamp from the first cuneiform to the base of the second or third metatarsal is helpful (TECH FIG 14). Once the reduction is confirmed fluoroscopically, provisional fixation can be placed.
- Medial plating (TECH FIG 15A–C)
  - Modern dedicated midfoot fusion plates have a contour that matches, for the most part, physiologic anatomy. If the plate fits well, then the reduction is typically acceptable.

TECH FIG 10 • Final radiographs. A. AP view (note restoration of talo–first metatarsal axis). B. Oblique view. C. Lateral view (also with restoration of talar–first metatarsal axis). Note subtalar arthroereisis. This patient had some residual lateral foot pain and greater-than-physiologic hindfoot valgus, probably secondary to the injury to the cuboid. While subtalar arthroereisis does not address this directly, it reoriented the hindfoot adequately to relieve the lateral column stress. D. Clinical view of arch. E. The midfoot articulations normally have limited motion, so fusion of these joints does not restrict the foot substantially.
Also, if the plate is positioned properly on the first cuneiform, then the first metatarsal can be reduced to the plate and the reduction is typically satisfactory.

A lag screw can be added to the medial column construct, but often there is little room for such a screw and the plate, unless a headless screw is placed deep to the plate.

Dorsal plating (TECH FIG 15D–G)

Dedicated dorsal plating systems are now also available. These locking plates secure the first through third TMT joints.

Alternatively, individual plates may be used on each TMT joint; however, in my opinion, if a single plate can be used to stabilize all three TMT joints, the construct tends to be stronger.

With the distortion of anatomy from Charcot neuroarthropathy, these plates designed for physiologic anatomy sometimes are difficult to place perfectly on all three TMT joints.

Take care to protect the deep neurovascular bundle (in neuropathy, obviously the artery only matters) and the extensor tendons.

Follow-up radiographs for the same patient (TECH FIG 16)


TECH FIG 12 • Direct medial midaxial approach. A. Exposure. B. Reflecting tibialis anterior tendon to expose first tarsometatarsal joint. C. Full exposure. D. After removing residual cartilage, subchondral bone is drilled to promote fusion.
Chapter 41  MIDFOOT ARTHRODESIS


TECH FIG 14 • Bone reduction clamp used to reduce medial and middle columns of the foot after joint preparation (and bone grafting) performed.

TECH FIG 15 • A–C. Medial plate. The plate is designed to restore physiologic alignment; therefore, it may be used as a reduction tool. Occasionally I fix the plate to the first cuneiform and then “bring” the first metatarsal to the plate. (continued)
In this case of Charcot neuroarthropathy and dislocation of the fourth and fifth TMT joints, I opted to also arthrodese the lateral column.

Only in this situation of neuroarthropathy do I attempt to fuse the lateral column. Typically, I do not wish to sacrifice the midfoot’s ability to accommodate.

In this case of Charcot neuroarthropathy and dislocation of the fourth and fifth TMT joints, I opted to also arthrodese the lateral column.

Only in this situation of neuroarthropathy do I attempt to fuse the lateral column. Typically, I do not wish to sacrifice the midfoot’s ability to accommodate.

**TECH FIG 15** (continued) D–G. Dorsal plate. The plate extends from the first tarsometatarsal (TMT) joint to the third TMT joint, so it must be carefully positioned under the deep neurovascular bundle and the extensor tendons.

**TECH FIG 16** Follow-up radiographs. A. AP view. B. Oblique view. C. Lateral view. In this patient with Charcot neuroarthropathy, the lateral column of the foot was also arthrodesed. I do not routinely arthrodese the lateral column but make an exception in select cases of Charcot neuroarthropathy where added stability may be needed for preoperative 4-5 tarsometatarsal joint dislocation.
EXTERNAL FIXATION

- This patient is a 44-year-old woman with midfoot sag and forefoot abduction deformity failing nonoperative treatment (TECH FIG 17).
- Medial approach for midfoot biplanar osteotomy. Two reference pins serve to mark the desired osteotomy (confirmed fluoroscopically) (TECH FIG 18).
- Saw positioned for planned osteotomy; however, to maintain stability of the foot, I routinely apply the external fixator first and then complete the osteotomy (TECH FIG 19A).
- Application of the external fixator. In this case a "butt frame" construct is used.
- Hindfoot component

This portion of the frame stabilizes the hindfoot with two U-rings.
- The frame is first secured with thin wires (TECH FIG 19B,C).
- Next half-pins are added for further stability (TECH FIG 19D).
- I usually tension the thin wires after the half-pins have been inserted (TECH FIG 19E,F).
- Forefoot component
- Add a partial ring to the forefoot and first stabilize it with three tensioned thin wires (TECH FIG 19G).
- I typically add a half-pin to the forefoot–midfoot after I have performed the osteotomy and then know

TECH FIG 17 • Preoperative weight-bearing radiographs of 44-year-old woman with midfoot deformity leading to forefoot abduction and midfoot sag, failing nonoperative measures. A. AP view. B. Lateral view.

TECH FIG 18 • Medial midaxial approach. A. Exposure. B. Tibialis anterior tendon protected and guide pins in place to mark proposed midfoot biplanar osteotomy. C. Full exposure.
exactly where the struts connecting the forefoot to the hindfoot rings will be positioned.

- **Midfoot osteotomy**
  - I use an oscillating saw, but a Gigli saw may be used as well (TECH FIG 20A).
  - I create a biplanar wedge with a medial and plantar base to correct abduction and promote plantarflexion in order to recreate the arch.
  - I complete the osteotomy with an osteotome (TECH FIG 20B).
  - Remove the wedge of bone (TECH FIG 20C).
  - The osteotomy can then be closed (TECH FIG 20D,E).
  - If it should not close congruently, protect the soft tissues, place the saw in the osteotomy, close the osteotomy as much as possible, and run the saw gently to remove any irregularities. This trick tends to make the osteotomy appose well.
  - Through this osteotomy, the forefoot may also be derotated.
  - I often “spin” the forefoot out of varus, a common forefoot deformity associated with a flatfoot.
  - Place the struts to connect the hindfoot frame to the forefoot ring (TECH FIG 20F-I).
  - Add compression. With the system’s computer program, further correction can be added now or even postoperatively.
  - I routinely reduce the deformity as much as possible intraoperatively, always ensuring appropriate bony

**TECH FIG 19** • A. Saw blade in position for proposed osteotomy. B, C. Butt frame applied before osteotomy, initially with thin wires. B. Medial view. C. Lateral view. Note U-ring like a stirrup in coronal plane to stabilize hindfoot. Attached to this is second U-ring to provide further support in tibia. D. Frame stabilized further with half-pins from proximal U-ring into tibia. E, F. Tensioning thin wires. G. Applying the forefoot ring, primarily with tensioned thin wires, but I routinely add one small-diameter half-pin to augment the ring’s stability.
apposition at the arthrodesis site, and then compress further to promote stability and healing.
- Follow-up radiographs with frame in place are shown in TECHNIQUE FIGURE 21A–C.
- Final follow-up after frame removal is shown in TECHNIQUE FIGURE 21D–H.

Often, after flatfoot correction for midfoot collapse, the first ray may appear short.
- In my experience, as long as I plantarflex the first ray adequately and avoid dorsiflexion of the medial column, transfer metatarsalgia is rarely a problem.

TECH FIG 21 • A–C. Postoperative radiographs. A. AP view. B. Oblique view. C. Lateral view. Note supplemental wires placed across osteotomy site for initial stabilization. With external fixation, further correction and compression may be performed after the index procedure. D, E. Clinical and radiographic follow-up after external fixator removal. D. Weight-bearing AP radiograph. E. Clinical view. The first ray appears short, which is common after correction of abduction deformity with internal or external fixation. However, in my experience, provided the first ray is adequately plantarflexed and bears weight, the foot functions well with little risk of transfer metatarsalgia despite a relatively long second metatarsal. F–H. Clinical and radiographic follow-up after external fixator removal. F. Lateral clinical view. G. Lateral weight-bearing radiograph (note restoration of arch). H. Hindfoot clinical view (note healed incision for gastrocnemius-soleus recession).
ADDITIONAL CASE

- This 32-year-old man had undergone open reduction and internal fixation of a Lisfranc fracture-dislocation and subsequent hardware removal at an outside institution (TECH FIG 22). He had failed further nonoperative measures.
- I performed a midfoot medial column plantar plating in combination with middle column dorsal plating after attempted deformity correction (TECH FIG 23).
- Follow-up radiographs (TECH FIG 24) show that while his longitudinal arch appears corrected, his forefoot still remains in abduction, and he remains symptomatic.
- Further nonoperative care failed.
- Re-revision surgery was performed.
- Medial biplanar wedge osteotomy after hardware removal (TECH FIG 25A–C).


TECH FIG 23 • Revision surgery with medial plantar plating and middle column plating through dual longitudinal approaches after attempted reduction of severe abduction deformity and midfoot collapse. A–C. Screw fixation of medial column plantar plate. Note provisional wire fixation. (continued)
Further correction of abduction deformity and more plantarflexion to the medial column
I was able to reuse the plantar plate (TECH FIG 25D,E).
I performed two adjunctive hindfoot procedures:
- Medial displacement calcaneal osteotomy (TECH FIG 25F)
- Subtalar arthroereisis (TECH FIG 25G)
Follow-up weight-bearing radiographs suggest improved alignment, particularly with respect to the talo-first metatarsal axis in the AP plane (TECH FIG 26A,B).
Clinically, alignment and function were improved. In fact, he has perhaps better alignment in his operated foot than his contralateral foot (remains to be seen if this is advantageous, but anecdotally appears to be the case) (TECH FIG 26C–E).

TECH FIG 23 • (continued) D. Dorsal approach to middle column for compression plating.

TECH FIG 24 • Follow-up weight-bearing radiographs. While arch is restored, forefoot abduction is incompletely corrected. A. AP view. B. Oblique view. C. Lateral view. Patient was improved but remained symptomatic and failed orthotic management.

TECH FIG 25 • A–C. Re-revision surgery with removal of plantar plate and medial approach biplanar midfoot osteotomy to correct residual abduction deformity and promote even further plantarflexion of the medial column. A. Saw to create biplanar osteotomy along reference pins marking proposed osteotomy. B. Wedge resected. (continued)
Chapter 41 MIDFOOT ARTHRODESI S


TECH FIG 26 • A, B. Follow-up weight-bearing radiographs. A. AP view (note correction of abduction) and near-anatomic restoration of congruent talo–first metatarsal axis. B. Lateral view, also with restoration of talo–first metatarsal axis. C–E. Clinical follow-up. C. Lateral view. (continued)
PEARLS AND PITFALLS

Deformity correction
- Realign talo–first metatarsal axis in both the AP and lateral planes; undercorrection rarely leads to satisfactory outcome.

TMT joint anatomy
- The TMT joints are quite deep (2.5 to 3.0 cm).

Avoid dorsiflexion or elevated malpositioning
- Be sure to prepare the TMT joints to their bases; leaving plantar bone and cartilage will lead to a dorsiflexion malunion. Also, do not take any dorsal bone from the TMT joints.

Correct abduction
- The physiologically normal medial aspect of the medial column of the foot is relatively straight; with severe midfoot deformity the first metatarsal must really be swung around to align anatomically; then the lesser metatarsals should follow.

Forefoot balance
- When arthrodesing the TMT joints be sure to check the relative position of the metatarsal heads. The first metatarsal head and sesamoids should be slightly plantar to the lesser metatarsal heads. Palpate this balance as the midfoot is provisionally stabilized.

Tricks to correcting abduction
- (1) In severe deformity avoid first metatarsal elevation and attempt to reduce the abduction deformity. Fix the plate to the medial aspect of the first cuneiform, then reduce the first metatarsal to the plate.
- (2) As for a reduction of a Lisfranc fracture-dislocation, use a large bone reduction clamp to reduce the base of the second metatarsal by spanning the course of the first cuneiform–second metatarsal base.

POSTOPERATIVE CARE
- A splint is used that extends beyond the toes with the ankle in neutral position for 2 weeks.
- The patient returns to the clinic at 2 weeks for suture removal and application of a short-leg cast with the ankle in neutral position. Touch-down weight bearing only is permitted.
- The patient returns to the clinic at 6 weeks for radiographs out of plaster (three views of the foot). If progression toward healing is suggested by radiographs, the surgeon should consider placing the patient in a cam boot, but still only touch-down weight bearing is permitted.
- At 10 weeks, the patient returns for repeat radiographs (weight bearing, three views of the foot).
- If progression toward healing is suggested radiographically, weight bearing is gradually added over 3 weeks, in the cam boot. Then, the patient gradually transitions into regular shoes. I often recommend a longitudinal arch support and a relatively stiff sole.
- If no progression toward healing is seen, the patient is returned to the boot, with limited weight bearing, and the boot is used for 3 to 4 weeks.

OUTCOMES
- There are limited level IV studies for midfoot arthrodesis, but there are reasonable functional outcomes and improvement in pain scores for midfoot arthrodesis based on the weak literature.
- Results are generally better when restoration of physiologically normal alignment is achieved.
- There are virtually no reported outcomes for modern dedicated midfoot plating systems.
- More information and higher-level evidence are needed.

COMPLICATIONS
- Undercorrection
- Overcorrection
- Infection
- Wound dehiscence
- Nonunion
- Malunion
- Greater-than-physiologic elevation of one or more metatarsals
- Imbalance of the metatarsal heads
REFERENCES


ANATOMY AND PATHOGENESIS

- The midfoot extends from the midtarsal joint to the Lisfranc joint and connects the hindfoot and forefoot. Normal gait requires complex synergetic actions between the joints of the hindfoot and midfoot.
- Midfoot deformities can be either stiff or flexible and can present as uniplanar or multiplanar deformities.
- Midfoot deformities have a severe impact on the pedal biomechanics by altering weight-bearing forces and pedal alignment.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Preoperative clinical examination and radiographs are used to determine the degree and location of deformity.
- Clinical examination is critical with midfoot deformities for assessment of the joint range of motion, flexibility, and the degree of rotation deformity (supination and pronation).

SURGICAL TREATMENT

- The goal of surgical intervention is to restore pedal alignment, to allow proper transfer of weight from hindfoot to forefoot during gait, to decrease pain, and to re-establish functional gait without affecting adjacent joint motion.
- Conventional midfoot osteotomies are limited, as acute deformity correction can cause neurovascular compromise and requires extensive exposure, retained hardware can increase risk of infection, and wedge resection can sacrifice normal joints and alter anatomic realignment.
- In the literature, many types of osteotomies have been described for correction of midfoot deformities, each one designed to correct a specific deformity or condition.
  - Cavus: Cole, Japas, and Akron osteotomies
  - Relapsed clubfoot and metatarsus adductus: medial opening cuneiform wedge and lateral closing cuboid wedge osteotomies
- We present a percutaneous midfoot Gigli saw osteotomy technique for correction of uniplanar and multiplanar midfoot deformities.
  - This unique percutaneous saw technique was first described in 1894 by Italian obstetrician Leonard Gigli.
  - A Gigli saw is a twisted stainless steel cable that is a very effective cutting surface when used in a reciprocating fashion against bone.
- Our technique has several major advantages:
  - It is minimally invasive, which decreases the risk of soft tissue injury and infection and improves osseous healing by preserving the periosteum and soft tissues. It minimizes the soft tissue insult, which is essential for the multiply operated foot.
  - It is not limited by the magnitude of the deformity, spares joints and growth plates, and allows for ease of uniplanar or multiplanar deformity correction.
  - Gradual external fixation produces regenerated bone, which is preferred to bone resection. The bone resection can increase foot stiffness.
  - Gradual external fixation also allows for accurate anatomic realignment of the foot, which re-establishes normal ligament and muscle function.

Preoperative Planning

- Radiographic planning determines the center of rotation angulation (CORA) of the midfoot deformity.
- The level of the CORA, together with clinical examination and radiographic assessment to determine the degree and location of deformity, determines the correct osteotomy level.

Positioning

- The patient is placed in a supine position on a radiolucent table.

FIG 1 • Weight-bearing AP radiographic view shows a midfoot adduction deformity (35 degrees) in an adult patient with fibular hemimelia. In addition, she also has a hallux abductovalgus deformity. (Copyright 2008, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore.)
The leg is prepped just below a nonsterile thigh tourniquet, which allows for bending of the knee during surgery. The ability to flex the knee 90 degrees intraoperatively is advantageous in obtaining anteroposterior (AP) fluoroscopic imaging of the foot.

A hemisacral bump is placed to obtain a foot-forward position.

The patient is prepped and draped, and the tourniquet is elevated.

### MIDFOOT OSTEOTOMY

- The midfoot osteotomy is performed before external fixation application or screw insertion.
- With the aid of fluoroscopy, the level of osteotomy is identified and marked (TECH FIG 1A).
- A 1.8-mm Ilizarov wire is placed on the foot under fluoroscopic guidance, and a marking pen is used to mark the exact level of the osteotomy on both the AP and lateral views.
- All midfoot osteotomies require four percutaneous transverse incisions.
- The first incision is made transversely at the plantar lateral border of the foot, and subperiosteal dissection with a periosteal elevator is performed across the plantar vault of the foot. This subperiosteal dissection creates a subperiosteal tunnel that protects the tendons and neurovascular bundle along the plantar aspect of the foot.
  - The periosteal elevator is then maneuvered in a rocking motion against the bone and across the entire plantar arch to the plantar medial foot (TECH FIG 1B).
- A second transverse incision is made where the skin is tented by the extension of the periosteal elevator, and the elevator is removed.
  - A no. 2 Ethibond suture is clasped with a curved tonsil hemostat and passed through the previously created subperiosteal tunnel from the lateral incision to the medial incision (TECH FIG 1C).
- Once the suture is passed, the Gigli saw is tied to the suture and pulled from lateral to medial through in the same subperiosteal tunnel (TECH FIG 1D).
  - The position of the Gigli saw is checked by image intensifier to ensure that the level of osteotomy has been properly maintained.
  - Through the medial plantar incision, the periosteal elevator is passed across the dorsum of the foot subperiosteally below the tibialis anterior tendon so as to exit just lateral to this tendon.
  - The third transverse incision is made lateral to the tibialis anterior tendon, where the elevator tents the dorsal skin.
  - The curved tonsil is then passed subperiosteally from the third incision to the second incision to clasp the Ethibond suture, which is pulled with the Gigli saw through the third incision (TECH FIG 1E).
  - Again the elevator is extended from the third incision across the dorsum of the foot laterally and subperiosteally below the extensor tendons to exit at the level just dorsal to the cuboid and the first incision.
  - The fourth transverse incision is made where the elevator tents the lateral skin (TECH FIG 1F).
  - From the fourth to third incision, the curved tonsil grasps the suture attached to the Gigli saw and is pulled through the fourth incision.

**Approach**
- Various levels of midfoot osteotomies can be performed (talocalcaneal neck or cuboid-navicular or cuboid-cuneiform bones) based on preoperative planning.
- The talocalcaneal neck osteotomy is used when the subtalar joint is stiff or fused.
- When the subtalar joint is a mobile, the level of the midfoot osteotomy is across the cuboid and navicular or cuboid and cuneiform.4,5

**TECH FIG 1** Percutaneous Gigli saw osteotomy of the midfoot. A. There are three levels in the midfoot at which a Gigli saw is passed percutaneously: the talocalcaneal neck, the cuboid-navicular bones, and the cuboid-cuneiform bones. The illustration shows a cuboid-cuneiform level ostetomy. Four small incisions are used to pass the saw: one medial plantar, one lateral plantar, and two dorsal incisions. *(continued)*
TECH FIG 1 • (continued) B. Because of the concavity of the transverse arch and the multiple bones present, the plantar periosteal elevation often weaves in and out of the subperiosteal space. C. A suture is passed from lateral to medial (the reverse can also be done). D. The Gigli saw is passed from lateral to medial under the foot. E. Through a third incision, which is made on the dorsomedial aspect of the foot, the suture and Gigli saw are passed to the dorsum of the foot. F. A fourth incision is made on the dorsolateral side, and the periosteum is elevated on the dorsum of the foot. G. The suture and Gigli saw are passed around the foot from plantar to dorsal, exiting on the dorsolateral side opposite the entrance site on the plantar lateral side. H. The bone is cut by the Gigli saw to the level of the cuboid. (continued)
The Gigli saw is now circumferentially around the bones of the midfoot (TECH FIG 1G). Care must be taken during the passage of the Gigli saw to maintain the correct level of the planned osteotomy.

- The two Gigli saw handles are now attached, and, using a reciprocating motion, the midfoot is cut from medial to lateral (TECH FIG 1H). The Gigli saw handles may need to be crossed while making the reciprocating cut to avoid lateral soft tissue injury.
- To avoid injury to the peroneal tendons and lateral skin, cutting is stopped just before the lateral bone is exited.
- A periosteal elevator is placed between the fourth and first incisions crossing the Gigli saw, and then the cut is continued (TECH FIG 1I).
- When the cut is complete, the elevator will block further progression of the saw.
- After completion of the cut, the osteotomy is checked with the image intensifier.
- The Gigli saw is then cut and withdrawn from the foot (TECH FIG 1J).
- The tourniquet is deflated, and the incisions are closed.4,5

**EXTERNAL FIXATION APPLICATION**

- External fixation allows for gradual correction of deformity and lengthening, which can be accomplished by the Ilizarov external fixator or the Taylor spatial frame.
- Stirrup wires placed just proximal and distal to the midfoot osteotomy are used.
  - As a rule, forces tend to take the passage of least resistance, which in the foot are the joints and growth plates, so it is essential to add these two stirrup wires adjacent to each side of the osteotomy. Each wire is carefully inserted on either side of the osteotomy under fluoroscopic guidance (TECH FIG 2).
  - Then proceed to build the frame according to the deformity, fixing the tibia, talus, calcaneus, and proximal midfoot with the proximal fixation block and the distal midfoot and forefoot with the distal fixation block.

**TECH FIG 2** Opening medial wedge and normotrophic regenerate bone formation during distraction treatment of the patient in Figure 1 with the Taylor spatial frame. The stirrup wires are adjacent to the percutaneous midfoot Gigli saw osteotomy. A lateral olive wire is used to resist lateral forefoot translation during the distraction treatment. The hallux abducto-valgus was acutely corrected. (Copyright 2008, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore.)

- Finally, the stirrup wires are attached to the frame distally and proximally as appropriate.
- Stirrup wires do not need to be tensioned.
- Olive stirrup wires are used to limit osseous transverse plane deviation during gradual external fixation correction.

**ACUTE CORRECTION CONSIDERATIONS**

- When performing a midfoot derotation (supination and pronation) correction, the medial muscle and fascia (abductor hallucis muscle) must be released from the osseous midfoot attachments.
Wedge resection can be performed by using two separate Gigli saws passed simultaneously.
- The distal cut is performed first, and the proximal cut is performed second.

Then the two medial percutaneous incisions are connected to remove the osseous wedge.
- Screw fixation, tension band wire, plates, staples, or static external fixation can also be used for fixation.

**GRADUAL DISTRACTION THEN ACUTE CORRECTION**

- When using the Ilizarov external fixator for small feet (pediatric patients), a valuable technique is gradual distraction then acute correction.
- Initial foot distraction for 2 or 3 weeks with external fixation is performed to disengage the bone segments and distract the soft tissue envelope.
- Then, under general anesthesia, the forefoot fixation is disconnected from the hindfoot frame and acute manipulation (derotation, angulation, or translation) of the forefoot is accomplished to achieve the correct position.
- The forefoot and hindfoot fixation is reattached in the corrected position and maintained until bone consolidation.
- This technique reduces the time the external fixator is needed.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>PEARLS AND PITFALLS</th>
<th>Adjuvant procedures</th>
<th>Adjuvant soft tissue procedures can be used with midfoot osteotomy to achieve full correction and address the associated deformities.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion contracture</td>
<td>Pinning of toes is done to avoid flexion contracture during distraction treatment. Digital pins should be attached to the foot frame, thereby increasing foot frame stability.</td>
<td></td>
</tr>
<tr>
<td>Tarsal tunnel decompression</td>
<td>Tarsal tunnel decompression, either acute or gradual, should be considered for large deformity corrections.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acute corrections, patients with significant scarring, and posttraumatic foot injuries are all considerations for tarsal tunnel decompression.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>When the aforementioned situations are encountered, a prophylactic tarsal tunnel decompression is recommended.</td>
<td></td>
</tr>
<tr>
<td>Crevus deformity</td>
<td>Plantar fascial release or partial or complete excision of the plantar fascia should be considered for cavus deformity correction.</td>
<td></td>
</tr>
<tr>
<td>Equinus contracture</td>
<td>Gastrocnemius recession, gastrocnemius-soleus recession, or Achilles tendon lengthening should be performed for equinus contracture (either percutaneous or open) as deemed appropriate.</td>
<td></td>
</tr>
<tr>
<td>Proximal limb deformities</td>
<td>Assess and correct if necessary.</td>
<td></td>
</tr>
</tbody>
</table>

**OUTCOMES AND COMPLICATIONS**

- We reviewed our series of midfoot deformities corrected with the percutaneous Gigli saw midfoot osteotomy and external fixation.
  - These patients achieved our goal of a plantigrade foot position with improvement in gait (**FIG 2**).
  - Minor complications included digital flexion contractures, which were treated by flexor tenotomy, and superficial pin tract infections, which were treated with oral antibiotics.
  - Major complications included premature consolidation, which required reosteotomy, and a tarsal tunnel syndrome, which developed during treatment and required surgical decompression.
  - We also have performed a series of cadaveric midfoot Gigli saw osteotomies under fluoroscopy to determine the safety of this osteotomy.
  - After completion of the osteotomy, the dissection revealed no neurovascular or tendon or muscle damage.

**ACKNOWLEDGMENT**

The authors thank Joy Marlowe, MA, for her excellent illustrative artwork and Alvien Lee for his photographic expertise.

**FIG 2** • Final weight-bearing AP radiographic view of the patient in Figure 1 and Techniques Figure 2 shows full correction of the adduction deformity (straight lateral border of the foot). (Copyright 2008, Rubin Institute of Advanced Orthopedics, Sinai Hospital of Baltimore.)
REFERENCES
DEFINITION
- Charcot foot arthropathy is a destructive process that primarily affects the foot and ankle of patients with longstanding diabetes (10-plus years) and peripheral neuropathy (PN).4,5,8
- The resulting disabling deformity impairs walking, can be painful, and makes patients prone to develop overlying skin ulceration, leading to deep infection and eventual amputation. Outcome data derived from the AOFAS Diabetic Foot Questionnaire have revealed that Charcot foot arthropathy has a severe negative impact on health-related quality of life in affected individuals.6
- Historically, clinical management has been dictated by anecdotal observation, with little data that would stand up to current evidence-based medicine standards.
- Treatment has classically been passive and accommodative. Acute active-phase management has been accomplished with a non-weight-bearing total-contact cast until the active destructive phase has resolved. This has been followed by accommodative bracing with custom therapeutic shoes, accommodative foot orthoses, ankle–foot orthoses, and a special accommodative orthosis, the Charcot Restraint Orthotic Walker (CROW; FIG 1).
- Based on similar anecdotal observation and level IV scientific evidence, most recent publications in peer-reviewed literature recommend universal correction of deformity combined with arthrodesis.7,14,22,23
- This chapter will present an evidence-based algorithm for use in the management of Charcot foot arthropathy at the level of the midfoot.

ANATOMY
- The foot is a unique end organ adapted for weight bearing.
- The multiple linked small bones normally allow the uniquely durable soft tissue envelope of the plantar surface to be prepositioned to accept the load of weight bearing.
- The destructive process associated with Charcot foot arthropathy impairs the ability of this mechanism to orient the foot in an optimal position to take advantage of its durable soft tissue envelope.
- The ensuing deformity produces weight bearing through less durable tissues, leading to tissue failure, deep wound formation, destructive osteomyelitis, and systemic sepsis.

PATHOGENESIS
- The primary risk factor for the development of Charcot foot arthropathy is longstanding peripheral neuropathy as measured by insensitivity to 10 grams of applied pressure (FIG 2).
- While other causes of absence of protective sensation have been associated with the development of Charcot foot arthropathy, longstanding diabetes is present in well over 95% of affected individuals.
- The majority of diabetics who develop foot-associated morbidity are morbidly obese.18 Glycemic management can be with insulin, oral medications, or diet. As with all of the morbidities associated with diabetes, the risk for foot-associated morbidity is decreased with tight glycemic management.
- Trauma appears to be an important inciting factor. The trauma can be significant, seemingly trivial, or due to repetitive mechanical stress.
- The neurotraumatic theory suggests that patients with longstanding PN and a loss of protective sensation develop a mechanical “stress” fracture. Due to the absence of protective sensation, they continue weight bearing, leading to a condition that mimics a hypertrophic nonunion.
- The neurovascular theory suggests that a vasomotor PN leads to high-flow arteriovenous shunting, causing bony depletion of calcium, leading to bone weakening and the well-known deformities.
- While the presence of sensory PN is well recognized, the accompanying motor and vasomotor neuropathies are often overlooked. The motor neuropathy affects the smaller nerves and muscles of the anterior leg (foot and ankle dorsiflexors) earlier in the disease process than the posterior leg compartments. This motor imbalance is currently appreciated as an...
important component leading to breakdown of the foot at the midfoot level during the terminal stance phase of gait. The autonomic neuropathy is likely involved as a component of the neurovascular theory.

- Baumhauer has demonstrated, via histochemical studies, the cytokines involved with the development of the destructive process, which resembles acute rheumatoid pannus.2
- The answer is likely a combination of both pathologic theories. Trauma, or some unknown inciting factor, initiates a process that releases specific cytokines. These cytokines lead to the development of destructive gray tissue that histologically resembles rheumatoid pannus.2

**NATURAL HISTORY**

- Most of the background observations in common orthopaedic textbooks are based on anecdotal observation, with little information that would comply with current evidence-based medicine standards.
- Eichenholtz8 in 1966 published a detailed monograph based on his observations in 66 patients. This objective clinical, radiographic, and histologic information provides objective benchmark data. This monograph objectively describes the destructive disease process as well as the progression of deformity.
- The AOFAS Diabetic Foot Questionnaire provides objective data to support Eichenholtz’s appreciation of the severe negative impact on health-related quality of life in affected individuals.6
- This very negative clinical observation has prompted many experienced clinical researchers to arbitrarily advise, without evidence-based medicine support, correction of deformity and arthrodesis at the onset of symptoms.7,14,22,23

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- The classic presentation is a grossly swollen, painless foot, without a history of trauma, in a longstanding diabetic. In fact, better than half of patients will remember a specific traumatic event, although it might be trivial. Most patients are in their mid-50s to mid-60s, and most are obese (Fig 3).15,17–20
- Affected individuals generally have longstanding (10-plus years) diabetes with evidence of PN, as measured by insensitivity to the Semmes-Weinstein 5.07 (10-gram) monofilament (Fig 1).
- Patients often describe a feeling of “crunching” and instability at the involved site.
- On clinical examination, the foot is very swollen and warm. There is often gross nonpainful instability at the site of clinical involvement.

**DIFFERENTIAL DIAGNOSIS**

- In the least destructive presentations of the disease process, patients are frequently misdiagnosed with a deep venous thrombosis, cellulitis, acute gout, or tenosynovitis.
- Doppler ultrasound studies are normal, and patients do not respond to antibiotic therapy.
The critical differential is foot abscess.
- Patients with a diabetic foot abscess, or infective cellulitis, will feel ill.
- The first sign of occult infection in the diabetic is increasing blood sugar or increasing insulin demand. White blood cell count may not increase, as these patients are often poor hosts and are not capable of mounting a normal immune response.
- Patients with deep infection will generally have an entry portal for infection, which might be as simple as an infected ingrown toenail, or a crack or pinhole between the toes.
- Patients with acute Charcot foot arthropathy do not experience malaise, they have normal blood sugar levels (for the individual patient), and they do not have any purulent drainage. The erythema often disappears with elevation, in contrast to the patient with a diabetic foot infection.

NONOPERATIVE MANAGEMENT
- Classically, treatment has been accommodative with a non-weight-bearing total-contact cast during the acute phase.
- Long-term management has been accomplished with accommodative bracing.
- Surgery was only advised for bony infection or when orthotic management could not accommodate the acquired deformity.
- Based on clinical observations in patients who were not clinically plantigrade or would or could not use a CROW, we started to develop a clinical algorithm (FIG 4).
- We defined a desired clinical outcome as remaining ulcer-free and maintaining walking independence with commercially available depth-inlay shoes and custom accommodative foot orthoses.
- It has been determined that patients who are clinically plantigrade at the time of presentation and have a colinear lateral talar–first metatarsal axis, as determined from weight-bearing dorsal–plantar radiographs, and have no bony prominences, can achieve the desired outcome without surgery.\(^5,15\)
- Patients who meet the criteria for nonoperative treatment are initially treated with a weight-bearing total-contact cast.
- The cast is changed every 14 days until the affected joint is clinically stable and the volume of the limb stabilizes.\(^19\)
- The patient is then progressed to a commercially available pneumatic fracture boot.
- When the foot volume reaches a plateau, the patient is evaluated for long-term management with commercially available depth-inlay shoes and custom accommodative foot orthoses (FIG 5).\(^1,21\)
- The patient in FIGURE 6 demonstrates the difficulties in long-term management of the nonplantigrade patient without correction of the deformity.
- The acute destructive process can be managed with a total-contact cast.
- This patient was very compliant, wearing the therapeutic footwear full time. She returned for routine visits to the physician and pedorthist.
- Despite close monitoring, she developed an ulcer in the skin overlying the head of the talus. When multiple surgical attempts failed, a transtibial amputation was necessary because of infection.

SURGICAL MANAGEMENT
- There is disagreement whether the common midfoot location for the development of Charcot foot arthropathy is due to the mechanical forces produced by simple motor imbalance or to intrinsic contracture of the gastrocnemius–soleus muscle–tendon complex, which limits passive ankle dorsiflexion.\(^11,12\)

![Treatment algorithm for acute Charcot foot arthropathy.](https://via.placeholder.com/150)
Most experts agree that the first step in surgical treatment is a lengthening of the gastrocnemius–soleus motor group to create balance between ankle flexors and extensors. Whichever theory one subscribes to, it has become apparent that lengthening of the gastrocnemius–Achilles tendon motor unit by gastrocnemius recession or percutaneous Achilles tendon lengthening is important.

In most patients, the progressive deformity is biplanar. Correction of the bony deformity can generally be achieved by removing a sufficient wedge of bone at the apex of the deformity (ie, a partial tarsectomy) to create a plantigrade foot.

In patients who are clinically good hosts, have no evidence of open wounds overlying bony deformity and no deep infection, and appear to have a reasonable quality of bone density, surgical stabilization can predictably be accomplished with internal fixation.\(^\text{10}\)

Crossed large fragment screws (cannulated or noncannulated), long posterior-to-anterior screws, and plate and screw constructs have been advocated for maintaining the surgical correction.

Our preferred method of achieving surgical stabilization is with a tension-band 3.5-mm plate applied over the apex of the deformity. Due to the poor quality of local bone, 6.5-mm cortical bone screws are used to secure fixation (FIG 7).

In patients who clinically appear to be poor surgical hosts or have wounds or skin ulceration overlying bony deformity, deep infection, or poor-quality osteopenic bone, surgical stabilization is accomplished with a three-level ring external fixator (FIG 8).\(^\text{9,16}\)

---

**FIG 5** • **A.** This patient is clinically plantigrade with durable skin and connective tissue aligned for weight-bearing. **B, C.** Weight-bearing radiographs on presentation. Despite the deformity, treatment was accomplished with a weight-bearing total-contact cast until the acute destructive process subsided. Long-term management was accomplished with commercially available therapeutic footwear (depth-inlay shoes and custom accommodative foot orthoses).

**FIG 6** • This 55-year-old, extremely cooperative patient was successfully treated with a total-contact cast, progressing to therapeutic footwear. Despite very careful attention by the patient and close monitoring by her physicians, she developed this ulcer using therapeutic footwear 2.5 years after the development of a Charcot foot deformity.
FIG 7 • A. This 37-year-old diabetic had a nonplantigrade deformity. B–E. Photographs and radiographs at 5 years.

FIG 8 • A,B. This 50-year-old man had repeated lateral foot infections despite resection of the fifth metatarsal. Note the rotational deformity of the forefoot relative to the hindfoot. (continued)
SURGICAL STEPS

- The first step is a lengthening of the gastrocnemius musculotendinous unit by either percutaneous triple hemisection of the Achilles tendon or fractional muscle lengthening of the gastrocnemius (Strayer procedure).

- Correction of the bony deformity is accomplished through an incision placed directly over or just inferior to the apex of the deformity. A biplanar wedge of bone is resected at the apex of the deformity, allowing correction of the deformity and creation of a plantigrade foot.

INTERNAL FIXATION

- When stabilization is accomplished with internal fixation, a tension-band 3.5-mm bone plate is used with large fragment screws to optimize screw fixation in osteopenic bone (Fig 7).

EXTERNAL FIXATION

- When surgical stabilization is accomplished with ring external fixation, a percutaneous smooth pin is sometimes valuable to establish temporary fixation while the ring external fixation frame is secured.

- A neutral ring external fixation frame is assembled before surgery. The frame has limited adjustability to increase frame stability and minimize the risk for bolt or screw loosening.

- The heel is safely positioned to avoid contact between the skin and the external fixator frame. Three oblique olive wire pins are initially applied through the calcaneus and then tensioned within the inferior ring. Three oblique olive wire pins are then placed through the metatarsal, with the forefoot aligned to the hindfoot in both plans, thus creating a plantigrade foot.

- The ring is then secured to the tibia, first through the proximal ring and then through the middle ring. The rings are safely positioned to maintain alignment of the foot to the leg and to avoid contact between the limb and the frame (TECH FIG 1).
The hindfoot is initially secured to the frame with two or three 30-degree-oriented tensioned olive wires. Care is taken to avoid pressure between the skin and the frame. The forefoot is then secured in a similar fashion. Two upper levels are provided to dissipate the load. Patients are allowed to bear some weight for transfers.

**Pearls and Pitfalls**

- Many of these patients are obese and have poor balance due to their PN. It is virtually impossible for them to maintain a non-weight-bearing status. Every effort should be made to allow them to bear some weight in order to assist in transfers.
- Because of their diabetes, these individuals are poor surgical hosts. Large wounds with a great deal of soft tissue stripping should be avoided.

**Postoperative Care**

- Patients undergoing nonoperative treatment (ie, those who are clinically plantigrade and have a radiographic colinear lateral talar–first metatarsal axis) are initially treated with a weight-bearing total-contact cast.
  - The cast is changed every 2 weeks to ensure bony immobilization and to avoid pressure ulcerations from a poorly fitting cast.
  - The total-contact cast is maintained until the foot is clinically stable and the limb volume is reasonably stable. This usually can be accomplished in 6 to 8 weeks (three or four casts).
- Patients are then transitioned to a commercially available pneumatic diabetic walking boot until limb volume is sufficiently stable to allow fitting with commercially available depth-inlay shoes and custom accommodative foot orthoses.
  - The shoe is generally modified with a cushioned heel and rocker sole.
  - In the occasional patient whose foot becomes nonplantigrade or who develops a noncolinear lateral talar–first metatarsal axis or a painful nonunion, surgical stabilization is advised.
- Patients undergoing surgical correction and maintenance with internal fixation are initially immobilized with a posterior plaster splint.
  - Weight bearing is initiated 7 to 10 days after surgery with a total-contact cast if the wound is secure.
  - The cast is maintained for 6 to 8 weeks, when patients are managed in a similar fashion to the nonoperative group.
  - Patients treated with surgical correction and immobilization with a ring external fixator are allowed to bear about 30 pounds of weight during treatment.
    - The external fixator is removed at 8 to 12 weeks, at which point a weight-bearing total-contact cast is applied for 4 to 6 weeks.
    - Progression to therapeutic footwear is accomplished in a similar fashion to the other groups.

**Outcomes**

- During the past 10 years, only three patients treated nonsurgically developed a nonunion at the site of their Charcot arthropathy with sufficient pain to warrant surgical stabilization.
  - The initial complication rate in the surgical patients was high compared with current standards. Infection rates have been greatly reduced with the use of the ring external fixator in high-risk, poor-host patients with open wounds or deep bony infection.
  - Mechanical failure and deep bony infection rates were high in the early experience with crossed-screw constructs, leading to a great deal of morbidity and three transtibial amputations.
In patients with adequate bone quality, the screw-plate construct can achieve successful outcomes in more than 90% of patients.

The absolute worst hosts undergo surgical correction through small incisions followed by immobilization with a ring external fixator. The complication rate in this group is surprisingly small.

Surgical correction of the deformity is accomplished before application of the external fixator, so the frame need not be adjustable. This absence of multiple connections appears to be responsible for the limited frame-associated morbidity.

COMPLICATIONS

- Patients treated without surgery have had limited numbers of complications.
- The rare cast-associated pressure ulcer generally resolves with local skin care and cast change. Changing the total-contact cast every 14 days appears to avoid cast-associated morbidity.
- Wound infection and mechanical failure were not uncommon during the early experience with internal fixation in this group. Wound infections are treated with surgical débridement, culture-specific parenteral antibiotics, and occasional management with a vacuum-assisted wound care system.
- Mechanical failure was also more common when internal fixation was accomplished with crossed large fragment screws. It has been uncommon when the tension-band plate–large fragment screw construct has been used to accomplish internal fixation.
- Stabilization of surgical correction with tensioned olive wires and ring external fixation has greatly decreased the incidence of wound infection and mechanical failure in the highest-risk group of patients.
- Two patients in the ring external fixation group developed stress fractures months after removal of the ring external fixators. One healed with simple cast immobilization. One progressed to a nonunion. Uneventful healing was accomplished after closed antegrade intramedullary nailing.

REFERENCES

DEFINITION
- Fracture through the midfoot in the neuropathic patient may accompany minor or incidental trauma and if unchecked may lead to severe deformity or “rocker-bottom” foot deformity.
- This chapter will demonstrate a technique used for fusion of the unstable midfoot fracture dislocation.

ANATOMY
- Charcot fracture-dislocation of the midfoot may occur through the tarsometatarsal, intercuneiform, or transverse tarsal joints.
- Multiple patterns may exist and are often complicated by bony dissolution. Attempts to classify these dislocations have been described by Sammarco and Conti \(^{11}\) and Schon et al \(^{14}\) (FIGS 1 AND 2).

PATHOGENESIS
- Peripheral neuropathy is most commonly related to diabetes but may occur with other neurologic disorders as well.
- Glycosylation and diminished blood supply to the peripheral nerves result in progressive loss of sensation, motor innervation, and autonomic function.
- Longer nerves are more severely affected, resulting in the typical “stocking and glove” sensory deficit.
- Loss of protective sensation in the lower limb predisposes patients to ulceration and may make them oblivious to fractures or dislocations.
- Loss of motor function leads to intrinsic imbalance of muscles in the lower extremity and commonly leads to equinus contracture of the ankle and Achilles, which significantly increases the forces through the foot during gait.
  - Intrinsic imbalance in the foot musculature also results in clawing of the hallux and lesser digits.
  - Autonomic sensory loss results in drying and cracking of the skin, which diminishes integumentary protection from pathogens.
  - Autonomic dysfunction also is responsible for loss of vasomotor control, which may lead to edema and stasis.

NATURAL HISTORY
- Midfoot fracture dislocation in the insensate patient may result acutely from direct trauma but more commonly is due to repetitive microtrauma in insensate joints. Once instability develops, bony deformity usually follows and worsens due to neurally stimulated vasomotor response, which increases blood flow to the area and leads to bony dissolution. Because the process is typically painless, the patient may be unaware or...
unconcerned that a problem is present until massive soft tissue swelling, gross deformity, ulceration, and infection are present.

- Fracture and dissociation through the midfoot may progress to a dorsal dislocation of the metatarsals. Once bony dissociation occurs, contracture of the soft tissue envelope makes reduction of the deformity difficult or impossible without surgical resection of bone at the fracture site.

- Charcot neuroarthropathy was staged by Eichenholz.6
  - Stage I is the inflammatory stage. The foot is hyperemic, swollen, and hot. Bony dissolution and fragmentation may be present on radiographs.
  - Stage II is the coalescence phase, where swelling and edema decrease, temperature decreases, and redness improves.
  - In Stage III, bony consolidation occurs, often with significant residual deformity.

- Deformity at the level of the midfoot is poorly tolerated and leads to a significant increase in localized plantar pressures at the apex of the deformity. Commonly these increased soft tissue pressures, combined with the previously mentioned loss of protective sensation and loss of normal integumentary function, may lead to ulceration and potentially deep infection. In diabetics, these problems are worsened by impaired circulation and immunologic function and can lead to amputation of the limb. If osteomyelitis develops, limb salvage may still be possible but the risk of amputation is greatly increased.

- This technique is one of a series of evolving techniques aimed at reconstructing these significant deformities.1–5,8–13 Standard arthrodesis techniques often fail in these patients due to the poor bone quality and significant fragmentation that accompanies these cases.15 The goals of this technique are to aid in reduction of deformity and to allow the fixation devices to bridge the area of dissolution at the apex of the deformity, achieving fixation in more normal bone proximally and distally.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient with Charcot neuroarthropathy of the foot may present in any of the Eichenholz stages, but by far the most common presentation to the orthopaedist is the inflammatory stage, with presumed cellulitis and osteomyelitis.

- A history of trauma may or may not be present. Stage I and II patients will present with a swollen, red, and warm foot. Patients presenting to the orthopaedist in stage III will typically have a stable deformity that may or may not be amenable to bracing.

- Prognosis is significantly affected by four things for these patients: the presence of infection, the presence of adequate blood flow in the extremity to the level of the digits, the presence of chronic venous stasis with associated poor integument, and the ability for the patient to adequately control his or her medical comorbidities. Patients who are immunocompromised due to transplant or those receiving dialysis have a much worse prognosis than those with diabetes alone.

- The presence or absence of infection must be established at the onset of treatment. This may be difficult as many of the physical signs of stage I Charcot deformity are indistinguishable from an infection.

- Lack of constitutional symptoms does not preclude infection in diabetics, who may not be able to mount an adequate immune response, and patients are often started on antibiotics at presentation. At the time of consultation, the patient has often already been admitted to the hospital with the initiation of intravenous antibiotics, bed rest with elevation of the extremity, and a non–weight-bearing status, thus blurring the ability to distinguish whether the patient improved due to simple rest or medications.

- A history of fevers and chills, inability for diabetics to control their blood sugar levels, and a history of previous or current ulceration increase the likelihood of active infection at presentation.

- The physical examination should document the presence or absence of pulses.

- Neuropathy should be documented with a 5.07 Semmes-Weinstein monofilament, and the level of intact sensation should be noted in the patient’s record.

- Protective sensation may be present even with Charcot neuroarthropathy. Any ulceration should be carefully documented, as well as its depth and Wagner grade.16 The presence of fluctuance may be suspicious for abscess and crepitation of the skin may represent gas gangrene; both require prompt diagnosis and surgical treatment. It is important to evaluate the contralateral foot and ankle as well as the patient may have pathology that is unrecognized.

- Items in the history that suggest that surgical stabilization may be required include gross instability on physical examination, acute fracture-dislocation from trauma, and recurrent ulcerations despite appropriate nonoperative treatment (FIG 3).
IMAGING AND OTHER DIAGNOSTIC STUDIES

Radiographs
- Radiographs of the ankle and foot should be taken (weight bearing when possible) to help stage the deformity.
- Typical radiographic changes include fracture and dislocation, bony destruction, periosteal reaction, and malalignment.
- These findings are difficult to distinguish from acute or chronic osteomyelitis and alone are unreliable for determining the presence or absence of infection. Radiographs alone are sufficient for diagnosing the disease process, but other imaging studies are often necessary to determine the presence or absence of infection.

MRI
- MRI is frequently used to help determine the presence of osteomyelitis, but caution must be given to interpretation as the false-positive rate is very high. Bone destruction and bone and soft tissue edema may be present in Charcot neuroarthropathy without infection and alone should not be used to determine the presence of infection.
- Enhancement with intravenous gadolinium gives stronger support to the presence of infection.
- The presence of a fluid collection consistent with abscess formation or air associated with Charcot deformity and the above MRI findings should be considered diagnostic for deep infection.

CT
- CT scan may show extensive bony destruction, periosteal reaction, and malalignment.
- The use of CT is unnecessary for diagnosis, but it can be helpful in surgical planning.
- The presence of air on a CT scan is considered diagnostic for deep infection and may represent with gas gangrene, or more commonly communication with an ulcer.

Nuclear Imaging
- Nuclear imaging is particularly useful in helping differentiate an infected Charcot process from a noninfected process.
- A three-phase technetium bone scan alone will be of little value as increased uptake will usually be present in all three phases. However, when this study is immediately followed by a labeled white blood cell scan, the combined studies can be useful to decide whether the process is Charcot process alone, soft tissue infection, or osteomyelitis.
- Other isotopes may be useful in differentiating infection from a sterile Charcot process and include ⁹⁹ᵐTc sulfur colloid and combined bone and white cell “dual peak imaging.” A detailed discussion of nuclear imaging is beyond the scope of this text and the reader is referred elsewhere for further study.⁷

Electrodiagnostic Testing
- This is usually unnecessary when peripheral neuropathy can be documented on physical examination.
- Electrodiagnostic testing can be useful in patients who have relatively normal sensory examination but whose radiographic and clinical findings are suggestive of neuropathic arthropathy. It is useful for documentation of deficits and also may be helpful in diagnosis of the underlying reason for neuropathy.

Vascular Testing
- We recommend rigorous workup of any suspected vascular insufficiency. This usually entails screening with noninvasive arterial examination in patients who do not have readily palpable pulses on physical examination.
- Arterial insufficiency is a relative contraindication to surgical reconstruction. Referral to a vascular surgeon should be considered for staged arterial reconstruction if significant insufficiency is present.

DIFFERENTIAL DIAGNOSIS

- Osteomyelitis, acute or chronic
- Abscess or gangrene
- Traumatic dislocation

NONOPERATIVE MANAGEMENT

- The majority of patients who develop noninfected Charcot arthropathy can be treated nonoperatively.
- Nonsurgical treatment typically entails a period of cast immobilization using a total-contact cast, and possibly a period of limited or non–weight-bearing.
- The goal of nonsurgical treatment with casting is to have the foot consolidate to a plantigrade structure without significant bony prominence.
- Once the foot has entered Eichenholz stage III, the patient is fitted for accommodative orthotics and shoe wear. Accommodative devices may be as simple as an off-the-shelf Plastazote orthotic if there is little residual deformity. More commonly, there is some deformity and the patient will require a custom-molded multidiom foam orthotic.
- A Charcot restraint orthotic walker (CROW) is necessary if there is severe deformity. Surgery is typically reserved for patients with acute fracture dislocations, those with progressive or unbraceable deformities, and those with recurrent ulceration despite multiple attempts at accommodative bracing.

SURGICAL MANAGEMENT

Preoperative Planning
- It is important to establish the absence of infection. Active infection or osteomyelitis is a contraindication for this technique as the hardware is typically permanent and difficult or impossible to remove without significant bony destruction. As noted previously, vascular workup is necessary before the procedure.
- The involvement of an astute internist is important in control of diabetes and medical comorbidities. The timing of surgery is important. Acute trauma without bony dissolution or significant swelling can be safely reduced and fused within a week or two of injury, providing the dislocation is recognized and the patient has not entered the inflammatory stage of the neuroarthropathy process.
- Once the patient enters the inflammatory phase, we prefer to cast the patient for 6 to 8 weeks to allow the edema to resolve and perform the reconstruction in a staged manner.

Indications
- This technique involves passing large-bore cannulated screws across the uninvolved metatarsal heads through the metatarsophalangeal (MTP) joints and is contraindicated in patients without significant sensory neuropathy.
- This technique is most useful for deformity at the tarsometatarsal level, and can be extended across the naviculo-cuneiform joints.
A higher rate of failure, screw breakage, and nonunion is associated with fusions that cross the transverse tarsal joint, and extended non-weight-bearing may be required to achieve fusion at this level (FIG 4).

**Positioning**
- The patient is positioned supine with a bump under the hip so that the toes face perpendicular to the operating table.
- A pneumatic tourniquet is used at the thigh.
- The patient is prepared and draped above the knee. A three-step tendo-Achilles lengthening, gastroc–soleus recession, or both is performed to achieve ankle dorsiflexion of 15 degrees before inflating the tourniquet.

**Approach**
- A two- or three-incision approach is used to reduce deformity and to prepare the arthrodesis bed. A medial approach is used to expose the medial column.
- The insertions of the tibialis anterior and posterior should be left undisturbed when possible, but they are often attached to fragmented or dislocated bone and should be secured with nonabsorbable suture placed in a locking fashion during the approach, for reattachment at closure.
- A subperiosteal dissection is carried out above and below the level of the deformity. The middle column of the foot is approached though a dorsal incision centered between the second and third metatarsal bases.
- Care should be taken to preserve the dorsalis pedis artery at this level. A third incision is usually necessary for exposure and reduction of the lateral column and is carried out dorsally at the level of the fourth and fifth tarsometatarsal joints.
- Care must be taken to provide an adequate skin bridge between the dorsal incisions or wound necrosis or dorsal slough may occur.

**Resection**
- Perform bone resection with an oscillating saw at the level of deformity.
- Adequate bone resection is necessary to prevent excessive tension on the dorsal soft tissue envelope and vascular structures.
- Bone resection is at the level of the deformity and usually involves resection of some bone from the proximal and distal fragments. Carry out bone resection medially for the medial column, and dorsally for the middle and lateral columns.
- Remove bone from the dorsal incisions with a curved curette or pituitary rongeur. Adequate bone resection is indicated by the ability to manually reduce the deformity.
- Resect bone slowly so that a balanced reduction can be achieved between the metatarsal bases. It is possible to...
resect so much bone that adequate bony apposition cannot be achieved for successful arthrodesis (TECH FIG 1A–C).

- Place guidewires in the metatarsal shafts without crossing the apex of the deformity. This can be done retrograde through the MTP joints under fluoroscopic control, although this can be quite time-consuming and technically demanding. To pass retrograde guidewires, hold the MTP joint in hyperdorsiflexion and pass the wire under fluoroscopic guidance across the joint and into the metatarsal head and into the shaft. Alternatively, pass the guidewires antegrade though the apex of the deformity. After bony resection, flex the foot through the middle and enter the metatarsal base with a curved curette, then a guidewire, which is passed into the metatarsal shaft. Then dorsiflex the MTP joint and drive the wire out through the plantar skin distally. The fifth metatarsal can usually not be fixed axially because the intramedullary canal typically aligns lateral to the cuboid (TECH FIG 1D–G).

- Ream the metatarsal shafts with cannulated drills. It is best to start with a small guidewire and a small cannulated drill and then change to a larger guidewire and larger cannulated drills. The medial column is usually drilled to 5.5 mm and a screw 6.5 mm or 8.0 mm in diameter is applied. The lesser metatarsals are usually drilled to 4.5 mm and a screw 4.5 mm or 5.0 mm is applied.

- Once the guidewires are in place in the reamed metatarsal shafts, hold the deformity reduced and advance the guidewires into the midfoot. Measure screw length from the middle part of the first metatarsal head in the medial column, and from the metaphyseal–diaphyseal junction of the lesser metatarsals. A counter-sink must be applied through the metatarsal head or it may fracture as the screw head is applied. Use screws with reduced-diameter heads (TECH FIG 1H, I).

- After applying the screws, sequentially tighten them to provide compression across the arthrodesis site.

- Perform a layered closure. Close the skin with 3-0 nylon suture applied with vertical mattress technique. A drain is usually not necessary.

**TECH FIG 1** EUR Bone resection and exposure. A–C. Medial column is exposed: note the tibialis anterior tendon insertion, which must be reattached if it is released for reduction. The saw is used to resect bone plantarly and medially to restore axial alignment and to relieve soft tissue tension. D–G. Preparation of the intramedullary canals is done after the bone resection. Fluoroscopic control is used during wire placement and reaming. D, E. Medial column. (D, E, from Sammarco VJ, Sammarco GJ, Walker EW Jr, Guiao RP. Midtarsal arthrodesis in the treatment of Charcot midfoot arthropathy: surgical technique. J Bone Joint Surg Am 2010;92(Supplement 1 Part 1):1–19; reprinted with permission.) (continued)
Chapter 44 | AXIAL SCREW TECHNIQUE FOR MIDFOOT ARTHRODESI S IN CHARCOT FOOT DEFORMITIES


PEARLS AND PITFALLS

- Treatment of midfoot arthropathy is controversial and most cases can be managed nonoperatively by casting and bracing.
- Surgery is indicated for grossly instability, recurrent ulceration, a nonplantigrade foot and unbraceable deformity.
- When surgery is done: span the area of dissolution; adequate bone resection, use bigger, stronger implants; place implants where they offer mechanical advantage.
- Keys to success: do not operate on dysvascular limbs, eradicate infection/ulcer prior to applying internal fixation, aggressive surgical treatment of equinus, get a good correction.

POSTOPERATIVE CARE

- The patient is placed in a well-padded posterior splint postoperatively. This is typically changed within a few days of the surgery and switched to a cast.
- The patient is non–weight-bearing for 10 to 16 weeks, and may begin weight bearing in a pneumatic walking boot once bony consolidation is evident radiographically (average 12 weeks).
- Once edema and swelling are under control, the patient may be graduated to diabetic shoe wear with a custom multidensity foam orthotic.

OUTCOMES

- Techniques Figure 1J–L shows postoperative radiographs and a photograph.
- The authors reported on 20 patients followed for an average of 49 months (range 20 to 77 months).17
- Complete arthrodesis of all joints was noted in 75% of patients and partial fusion with stable correction was noted in all patients.
- There were five hardware failures and three patients required removal of screws that backed out partially.
All patients returned to functional status with diabetic shoe wear and orthotics. None required above-ankle bracing.

There were no amputations.

**COMPLICATIONS**

- Screw loosening, backing-out, and hardware failure may occur as fixation will sometimes cross uninvolved joints. The surgeon should avoid crossing the calcaneocuboid and talonavicular joints when possible. Crossing uninvolved joints is acceptable when necessary to achieve adequate fixation in neuropathic patients. Radiographs should be monitored carefully when weight bearing is initiated as screws will sometimes bend before failing and can be exchanged percutaneously. Screws that back out into the ankle or MTP joint should be removed or exchanged.
- Overcorrection can occur and may result in ulceration beneath the first metatarsal head.
- Partial nonunion may occur and does not need to be treated as long as the foot is plantigrade. All patients in our series maintained the majority of their correction at final follow-up.

**REFERENCES**

BACKGROUND

- The aftereffects of Charcot joint disease include joint subluxation or dislocation, loss of bone quality, and osseous malalignment (FIG 1).
- As a result of the deformed Charcot foot position, aberrant weight-bearing forces and altered muscle–tendon balance increase the risk for ulceration, infection, and amputation.
- When treating the Charcot neuropathic foot, the best results are achieved when intervention is initiated as early as possible.
- In acute Charcot neuroarthropathy, the goal of treatment is to stabilize the foot. Total contact casting is the traditional treatment.
- In this patient population, it is extremely difficult to maintain non–weight-bearing status for multiple reasons, including muscle atrophy, obesity, and diminished proprioception.
- Non–weight-bearing immobilization for months produces osteopenia of the involved foot and increased weight-bearing forces on the contralateral limb.
- The sequelae can make it difficult for subsequent surgery on the involved foot and can lead to ulceration and Charcot neuroarthropathy in the contralateral foot.

- In chronic Charcot neuroarthropathy, the goal of treatment is to realign the soft tissue and osseous structures. In general, surgeries are aimed at realignment, but in these extremely deformed feet, acute realignment is challenging.
- Traditionally, acute realignment procedures such as Achilles tendon lengthening, ostectomy, débridement, ostotomy, arthrodesis, and open reduction with internal fixation (plantar plating) have been attempted.
- Acute correction via open reduction with application of static external fixation has also been reported.
- More recently, internal fixation methods have been augmented or replaced by external fixation as a means of static fixation of a Charcot reconstruction.
- Here, we present a new two-stage minimally invasive gradual correction method with the use of external fixation for acute and chronic Charcot reconstruction, which was developed by the senior author (D.P.).
- Gradual deformity correction with external fixation is preferred for large-deformity reductions of the dislocated Charcot joints of the foot. Correction with external fixation allows for gradual, accurate realignment of the dislocated or subluxated Charcot joints.

FIG 1 • Midfoot Charcot neuroarthropathy deformity (Eichenholtz stage II, unstable, with lateral ulceration and previous resection of the fourth and fifth metatarsals). A. AP radiograph shows midfoot adduction deformity. B. Lateral radiograph shows rocker-bottom and equinus deformities. Note the dorsal displacement of the forefoot and the break in Meary’s angle. Lateral still images, obtained by using video fluoroscopy, confirm the instability of the midfoot Charcot deformity, demonstrating significant forefoot dorsiflexion (C) and plantarflexion (D). (Copyright 2008, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore.)
SURGICAL TREATMENT

- The goals of surgical intervention for the Charcot foot are to restore anatomic alignment, impart stability, prevent amputation, prevent foot shortening, and allow the patient to be ambulatory.
- Historically, open reduction with internal fixation was the mainstay for treatment of Charcot foot deformities.
- Large open incisions were made to remove the excess bone, reduce the dislocated bone, and stabilize with internal fixation (screw fixation or plantar plating).
- These invasive surgical procedures typically resulted in shortening of the foot or incomplete deformity reduction and occasionally resulted in neurovascular compromise, incision healing problems, infection, and the use of non-weight-bearing casts and boots.
- In cases of tarsometatarsal Charcot deformity, open reduction is advantageous.
- Typically, Charcot neuroarthropathy of the tarsometatarsal joints is associated with mild to moderate deformities because the tarsometatarsal joints are structurally interlocked.
- Acute realignment is achieved by performing a wedge resection or open reduction with fusion and internal fixation to produce a stable foot.
- In acute Charcot neuroarthropathy, a static external fixation is placed to stabilize the Charcot process. The smooth wire fixation for the external fixation is applied so as to avoid the “hot,” or Charcot, joint region of the foot.
- The static fixator is applied strategically so gradual realignment can begin after the acute phase of Charcot has passed. Thus, the external fixator serves a dual purpose by stabilizing both the acute Charcot joint and the subsequent realignment of the dislocated osseous anatomy.
- Once the bony anatomy is realigned, the external fixation is removed and a formal minimally invasive fusion of the Charcot joint is performed. Rigid intramedullary metatarsal screws are used to maintain the fusion.
- Chronic stable or coalesced Charcot foot deformities require an osteotomy for correction of the deformity. We prefer a percutaneous Gigli saw osteotomy technique.
- Midfoot osteotomies can be performed across three levels (ie, talar neck and calcaneal neck, cubonavicular osseous level, and cuneocuboid osseous level).
- Performing Gigli saw osteotomy across multiple metatarsals should be avoided because of the neurovascular injury.3
- For an unstable or an incompletely coalesced Charcot foot, correction can be obtained through gradual distraction.
- Despite the radiographic appearance of coalescence (superimposition of the dislocated or fragmented pedal bone due to the Charcot process), most Charcot deformities can undergo distraction without osteotomy to realign the pedal anatomy.
- An Achilles tendon lengthening is performed and held in a neutral position with the external fixation. This restores the normal calcaneal pitch and hindfoot position. Then, under fluoroscopy, acute forefoot reduction is attempted and, if possible, fixation with intermediate metatarsal screws is carried out.
- Acute reduction of the forefoot is rarely successful, however. If the forefoot cannot be acutely reduced, an external fixator is used to hold the hindfoot position while the forefoot is lengthened and realigned.

Approach

- This first stage of the procedure consists of osseous realignment of the forefoot on a fixed hindfoot, which is achieved with an external fixator using distraction.
- After realignment, the correction is maintained by minimally invasive arthrodesis of the Charcot joint and is fixed with percutaneous intramedullary metatarsal screws.

STAGE 1

Plate Fixation and Achilles Tendon Lengthening

- The first stage consists of osseous realignment achieved by performing an acute Achilles tendon lengthening and gradual soft tissue distraction with the Taylor spatial frame (TSF). Patient adjustments of the TSF (forefoot 6 × 6 butt frame) provide gradual relocation of the forefoot on the fixed hindfoot.
- The distal tibia, talus, and calcaneus are fixed with two U-plates joined and mounted orthogonal to the tibia in both the anteroposterior (AP) and lateral planes.
- The U-plate is affixed to the tibia with one lateromedial 1.8-mm wire and two or three additional points of fixation (combination of smooth wires or half-pins).
- For additional stability, a second distal tibial ring can be added, creating a distal tibial fixation block.
- It is essential to fix the hindfoot in a neutral position; an Achilles tendon lengthening typically is required to achieve a neutral hindfoot position. We prefer performing percutaneous Z-lengthening of the Achilles tendon.
- With the hindfoot manually held in a neutral position, the U-plate is fixed to the calcaneus with two crossing 1.8-mm wires. A 1.8-mm mediolateral talar neck wire also is inserted and fixed to the U-plate.

External Fixation Setup

- Two 1.8-mm stirrup wires are inserted through the osseous segment just proximal and distal to the Charcot joints.
- The stirrup wires are bent 90 degrees just outside the skin to extend and attach but are not tensioned to their respective external fixation rings distant from the point of fixation. Stirrup wires capture osseous segments that are far from an external fixation ring, thereby providing accurate and precise Charcot joint distraction.
- A full external fixation ring is then mounted to the forefoot by two 1.8-mm crossing metatarsal wires and the aforementioned distal stirrup wire.
- Digital pinning often is required whereby the digital wires (1.5 or 1.8 mm) are attached to the forefoot ring.
- Finally, the six TSF struts are placed and final radiographs obtained (AP and lateral views of the foot to include the tibia; TECH FIG 1).
- Orthogonal AP and lateral view fluoroscopic images are obtained of the reference ring; these images provide the mounting parameters that are needed for the computer planning.
- The choice of which ring (distal or proximal) to use as the reference ring is based on the surgeon’s preference; typically, a distal reference is chosen for foot deformity correction.
- Superimposition of the reference ring on the final films is critical for accurate postoperative computer deformity planning.
- Computer planning of the TSF is a critical part of this procedure. The surgeon enters the deformity and mounting parameters into an Internet-based software (www.spatialframe.com) that produces a daily schedule for the patient to perform adjustments on each of the six struts. The rate and duration of the patient’s schedule is controlled by the surgeon’s data entry.
- The patient returns for clinical and radiographic follow-up in the office weekly or biweekly.

**STAGE 2**

**Frame Removal and Arthrodesis**

- Gradual distraction for realignment of the dislocated Charcot joints is obtained in approximately 1 to 2 months. After gradual distraction with the TSF has realigned the anatomy of the foot (TECH FIG 2A), the second stage of the correction is performed.
- The external fixator is removed simultaneously with performance of minimally invasive arthrodesis of the affected joints using percutaneous insertion of internal fixation (TECH FIG 2B).
- Before frame removal, small transverse incisions (2 to 3 cm in length) are made overlaying the appropriate joints to perform cartilage removal and joint preparation for arthrodesis.
Minimally invasive arthrodesis is easily performed because the Charcot joints are already distracted.

Under fluoroscopic guidance, the guidewires for the large-diameter cannulated screws are inserted percutaneously through the plantar skin incision into the metatarsal head by dorsiflexing the metatarsophalangeal joint.

After the lateral and medial column guidewires (fourth, first, and second metatarsals) are inserted to maintain the corrected foot position, the frame is removed and the foot is reprepped.

**Intramedullary Screw Fixation and Closure**

Typically, three large-diameter cannulated intramedullary metatarsal screws are inserted: medial and lateral column partially threaded screws for compression of the arthrodesis site and one central (second metatarsal) fully threaded screw for additional stabilization.

These screws span the entire length of the metatarsals to the calcaneus and talus, provide compression across the minimally invasive arthrodesis site, and stabilize adjacent joints. The intramedullary metatarsal screws cross an unaffected joint, the Lisfranc joint, thereby protecting the Lisfranc joint from experiencing a future Charcot event.

The minimally invasive incisions are then closed, and a well-padded L and U splint is applied.

At the time of hospital discharge, the patient is placed in a non-weight-bearing short leg cast for 2 to 3 months, and then gradual progression to weight bearing is achieved. Thus, the entire treatment is completed in 4 to 5 months (TECH FIG 3).
PEARLS AND PITFALLS

- External fixation construction is challenging because of the small size of the foot. When applying the forefoot 6 × 6 butt frame, it is important to mount the U-plate on the hindfoot as posterior as possible and the forefoot ring as anterior as possible. The greater the distance between the forefoot and hindfoot ring, the more space for the TSF struts.
- Bone segment fixation is important; otherwise, failure of osteotomy separation or incomplete anatomic reduction occurs. Small wire fixation is preferred in the foot because of the size and consistency of the bones.
- When treating a patient with neuropathy, construction of extremely stable constructs is of great importance. External fixation for Charcot deformity correction should include a full distal tibial ring with a closed foot ring.

OUTCOMES

- We have performed this gradual distraction technique for the past 5 years and have achieved good to excellent success in more than a dozen feet.
- Feet were operated on at various stages of Charcot deformity (Eichenholtz stages I, II, and III).
- When comparing the average change in preoperative and postoperative radiographic angles, the transverse plane talar–first metatarsal angle, sagittal plane talar–first metatarsal angle, and calcaneal pitch angle were all found to be significantly altered.
- Most notably, no deep infection, no screw failure, and no recurrent ulcerations occurred and no amputations were necessary during the past 5 years.
- Gradual Charcot foot correction with the TSF plus minimally invasive arthrodesis has constituted a safe and effective treatment.
- Our results are promising. The advantages of our method when compared with the resection and plating method reported by Schon⁴ or the resection and external fixation method reported by Cooper¹ are preservation of foot length (no bone resection), accurate anatomic realignment of soft tissues and bone, and a stable foot. Furthermore, our method is much less invasive and allows for partial weight bearing.

ACKNOWLEDGMENT

We thank Amanda Chase, MA, for her editing assistance, and Alvien Lee for his photographic expertise.

REFERENCES

DEFINITION
- The posterior tibial tendon undergoes tearing and degeneration, and as it fails the foot falls into a planovalgus configuration. Posterior tibial tendon dysfunction (PTTD) is the most common cause of an adult acquired flatfoot deformity.
- Most cases occur spontaneously without known antecedent trauma. Women are much more commonly affected than men, with a typical age range older than 50 years.
- With time, a rigid deformity develops. The degree and flexibility of the deformity play a key role in determining treatment.

ANATOMY
- The posterior tibialis typically degenerates in an area underneath the medial malleolus and distally to its insertion. The process is not inflammatory but is rather characterized by replacement of the normal collagen fibers with amorphous scar and mucinous degeneration.6
- As the arch falls, the hindfoot will fall into valgus relative to the leg, while the forefoot will abduct through the talonavicular joint. Uncovering of the talar head results as the forefoot pivots laterally.
- The sag of the arch and the abduction of the forefoot can be described in terms of the loss of alignment of the first metatarsal and the talus. The long axes of these bones should normally be colinear. A sag of the arch is seen by an angulation in this line on the standing lateral radiograph, while abduction of the forefoot is seen by lateral angulation of this line on the AP view.

PATHOGENESIS
- In most cases the cause of PTTD is unknown and is not associated with a clear antecedent trauma.
- The collapse of the arch is the result of a tendon imbalance. The antagonists to the posterior tibialis are the peroneals, and they must be functional for the deformity to develop.
- A single study has suggested a correlation of PTTD with the HLA B-27 genotype typically associated with seronegative arthropathies.7
- Cumulative mechanical factors likely play a role in the development of the disorder; a pre-existing planovalgus deformity presumably places extra stress on the tendon and is thought to be a risk factor for degeneration.
- The presence of an accessory navicular ossicle within the tendon substance at its insertion into the medial pole of the navicular is also a risk factor for tendon degeneration, likely from local mechanical stress (FIG 1).

NATURAL HISTORY
- Dysfunction of the posterior tibialis is thought to be the initiating event in the collapse of the arch.2
- Early in the course of the disease, pain along the course of the posterior tibialis or weakness of its function will be present without any arch collapse. This is called stage I disease.
- With time, a planovalgus foot deformity develops. Initially this deformity is flexible and is called stage II disease.
- A fixed deformity eventually results; this is called stage III disease. The first component of the deformity to become fixed is usually an elevation of the first ray relative to the fifth ray. This is the result of a compensation of the forefoot for the hindfoot valgus and is called a fixed forefoot varus. Later, the valgus alignment of the calcaneus through the subtalar joint becomes contracted and irreducible.
- Rarely, a secondary failure of the deltoid ligament along the medial aspect of the hindfoot develops as the mechanical stresses placed upon it by the flattened arch increase. This is called a stage IV deformity.
- Achilles tendon contracture is commonly seen in association with PTTD. As the planovalgus deformity develops, the foot collapses through the arch and the Achilles is no longer stretched to its normal length in a standing or walking posture.
- Table 1 details the PTTD stages.

FIG 1 • The accessory navicular may be subtle and can usually be seen on the lateral or AP radiographs.
Stages of Posterior Tibial Tendon Dysfunction

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Tenosynovitis and tear without arch collapse</td>
</tr>
<tr>
<td>II</td>
<td>Tenosynovitis and tear with flexible deformity</td>
</tr>
<tr>
<td>III</td>
<td>Fixed deformity present</td>
</tr>
<tr>
<td>IV</td>
<td>Additional deltoid ligament insufficiency with tibiotalar tilt</td>
</tr>
</tbody>
</table>

PATIENT HISTORY AND PHYSICAL FINDINGS

- Most, but not all, patients present with pain along the medial arch.
- In some cases, lateral impingement develops as the valgus posture of the hindfoot becomes extreme. The calcaneus impinges against the inferior border of the fibula. This is usually a late finding and is often intractable to conservative management.
- The most painful phase of PTTD is usually as the tendon is actively degenerating. Some patients will note a history of intense pain that diminishes once the tendon finally ruptures completely. They may present with deformity or lateral pain as their primary complaint.
- Other deformities may coexist, most significantly hallux valgus or midfoot arthritis.

Methods for examining the foot for PTTD include:
- The single-leg toe rise. The examiner should note the ability to perform the maneuver, the presence of inversion, and the presence or absence of pain. This is a critical and sensitive screening test. Action of the posterior tibialis is required to invert and lock the hindfoot, allowing the foot to act as a rigid lever through which the Achilles powers the ankle into plantarflexion.
- The “too many toes” sign. The examiner observes the standing patient from behind. The more abducted forefoot will show more toes visible on the lateral side of the leg. The examiner also notes the presence of forefoot abduction. Abduction of the forefoot occurs as the posterior tibialis fails and must be corrected in treatment.
- Power of the posterior tibialis. The examiner isolates the tendon by resisted inversion past the midline with the foot held in plantarflexion. Typical muscle strength grading is used. The result can be normal early in the disease. The patient may attempt to substitute the anterior tibialis; it is also an inverter but will dorsiflex the ankle as well.
- Fixed forefoot varus. The examiner holds the calcaneus in a neutral position (out of valgus) and notes any fixed elevation of the first ray relative to the fifth. The severity of deformity is noted in degrees. Fixed forefoot varus must be accounted for in any treatment algorithm and is usually the first component of the deformity to become rigid.
- Achilles contracture. The examiner holds the calcaneus in a neutral position and notes dorsiflexion of the ankle with the knee both flexed and extended (the Silfverskiöld test). The result is measured in degrees of ankle dorsiflexion. A significant Achilles contracture limits the degree of correction possible with bracing and may require surgical correction.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs should be obtained with weight bearing to adequately describe the alignment of the foot. The talo–first metatarsal angle describes the sag of the arch when drawn on the lateral view and the abduction of the forefoot when drawn on the AP view.
- Plain foot radiographs should also be examined for the presence of hindfoot arthritis, midfoot arthritis or instability, and an accessory navicular.
- A standing ankle mortise view should be obtained to rule out deltoid laxity (stage IV disease).
- MRI is not routinely necessary and may underestimate the severity of disease, but it may be useful in ruling out other pathologies. Findings of PTTD typically include fluid in the sheath, dramatic thickening of the tendon, and a heterogeneous signal within the tendon substance indicating the presence of interstitial tears (FIG 2).

DIFFERENTIAL DIAGNOSIS

- Midfoot arthritis resulting in pes planus through tarsometatarsal joint collapse
- Medial ankle arthritis
- Medial osteochondral lesion of the talus
- Neurogenic failure of the posterior tibialis through spinal or central pathology

NONOPERATIVE MANAGEMENT

- The flatfoot that results from posterior tibial tendon failure is irreversible, but symptoms may be controllable in many patients by nonoperative means.
- A simple in-shoe semirigid or rigid foot orthotic may provide sufficient arch support to reduce symptoms in some patients.
- The gold standard for nonoperative management is the use of a cross-ankle brace. This allows direct control of the tendency of the calcaneus to fall into valgus. The most commonly used and best tolerated is a leather ankle lacer with an incorporated custom-molded plastic stirrup, often referred to as an Arizona brace after a common brand name. Other options that may be suitable for higher-demand situations or patients with edema control problems include a hinged molded ankle–foot orthosis or a conventional double-metal upright ankle–foot orthosis with a leg strap.
- Steroid injections into the posterior tibial tendon sheath are contraindicated as they may directly or indirectly precipitate frank rupture and further collapse.
- No brace, physical therapy regimen, or medication has been shown to modify the course of the disease or the ultimate outcome for the tendon. These are all best thought of as modalities to control the symptoms.

SURGICAL MANAGEMENT

- Surgery is indicated when the symptoms cannot be controlled by a nonoperative means acceptable to the patient. An active patient in his or her 50s, for instance, may find the use of an Arizona brace for the remainder of his or her life to be intolerable and may choose to pursue a surgical remedy.
Preoperative Planning

- The patient’s size must be considered before any motion-sparing tendon reconstruction in the hindfoot is considered. Although not rigorously proven in the literature, the morbidly obese patient with an acquired pes planus deformity is at greater risk to break down the repair and may be better served by a triple arthrodesis.
- The presence of hindfoot arthritis similarly requires a fusion rather than an osteotomy and tendon reconstruction.
- A fixed forefoot varus should be addressed, either as part of the procedure through a medial column osteotomy or by a triple arthrodesis if severe.
- Tightness of the gastrocnemius should also be assessed to determine if a fractional lengthening of the gastrocnemius (Strayer procedure) will be required.

Positioning

- The patient is positioned supine with a bolster under the ipsilateral hip. This internally rotates the leg to allow access to the lateral aspect of the calcaneus, which is addressed first. The bolster may then be removed to allow the leg to externally rotate and allow access to the medial aspect of the foot.
- A tourniquet is applied to the thigh.

Approach

- The posterior tibial tendon is débrided directly and augmented or replaced by transferring the flexor digitorum longus (FDL) to the navicular. This procedure alone was first described in the 1980s and proved quite effective at pain control in most cases, although static correction of the arch was minimal.\(^2\)\(^,\)\(^5\)
- A medial displacement calcaneal osteotomy is then used to provide a measure of arch correction, directly addressing the hindfoot valgus. Indirectly, this raises the sag along the medial column of the foot as well and helps correct the talo–first metatarsal angle. Correcting the mechanics of the arch is thought to confer an element of protection to the FDL transfer.\(^3\)\(^,\)\(^7\)\(^,\)\(^8\)\(^,\)\(^11\)
- If necessary, up to about 20 degrees of forefoot varus may be corrected by a plantarflexion osteotomy of the medial column through the medial cuneiform (the Cotton procedure). This allows the indications for a motion-sparing procedure to be expanded to a wider patient population, and the need for this step is assessed after the other components of the correction are complete.\(^4\)
- Once the arch is corrected, a final check of the tightness of the gastrosoleus complex is made to ensure that a lengthening is not required.

**FIG 2** The talo–first metatarsal angle is drawn down the long axis of the talus and the first metatarsal on both lateral (A) and AP (B) radiographs. Any break from a straight line demonstrates both sag and abduction of the arch. MRI findings (C) include the presence of edema within the tendon substance and enlargement. Normal absence of signal within the adjacent flexor digitorum longus and flexor hallucis longus tendons is visible on the image.
MEDIAL DISPLACEMENT CALCANEAL OSTEOTOMY

- Make a 4-cm oblique incision over the lateral aspect of the calcaneal tuberosity behind the peroneal sheath (TECH FIG 1A).
- Carefully avoid the sural nerve during dissection down to the periosteum (TECH FIG 1B).
- Pass a small elevator above and below the calcaneal tuberosity. Ensure that inferiorly the cut will be anterior to the origin of the plantar fascia.
- Place small retractors superiorly and inferiorly, and place a low-profile self-retainer in the center of the wound.
- Use a narrow microsagittal saw to cut the tuberosity from lateral to medial. Using a narrow handheld blade provides greater tactile feedback to avoid overpenetration on the medial side (TECH FIG 1C).
- Lever the osteotomy free with a large osteotome or elevator.
- Place a lamina spreader in the osteotomy and leave it for about 1 minute to allow for stress relaxation of the tissues on the medial side. If necessary, a Cobb elevator can be used to gently strip the area (TECH FIG 1D,E).
- Displace the tuberosity fragment medially, usually by about 1 cm. Fix it with one or two 5.0- to 6.5-mm screws placed percutaneously from the posterior tuberosity (TECH FIG 1F).
- Obtain lateral and axial calcaneal fluoroscopy shots to confirm displacement of the tuberosity and confinement of the screws within bone.
- With a rongeur, smooth any sharp step-off on the lateral side of the osteotomy (TECH FIG 1G,H).

TECH FIG 1 • A. Oblique incision for the calcaneal osteotomy. B. Careful dissection to the periosteum is made, avoiding the sural nerve. C. Dorsal and plantar retractors are placed and a microsagittal saw is used to make the cut. D. A Cobb elevator is used to free up the osteotomy. E. A lamina spreader is placed to provide further stress relaxation of the tissues. F. After displacement, retrograde screws are used to provide fixation. (continued)
TECH FIG 1 • (continued) G. The sharp margin of the osteotomy is impacted to form a smooth contour. H. Radiographic appearance after fixation with two 5.0 screws.

POSTERIOR TIBIAL TENDON DÉBRIDEMENT AND FLEXOR DIGITORUM LONGUS TRANSFER

- Make a longitudinal incision down the medial column of the foot, beginning behind the medial malleolus, passing over the navicular tuberosity, and following the inferior border of the first metatarsal (TECH FIG 2A).
- Open the posterior tibialis sheath and débride the tendon. Complete tendon resection is appropriate in the vast majority of cases, as any remaining diseased tendon is a potential source of pain. Leave roughly a 1-cm stump of tendon attached to the navicular tuberosity to facilitate reconstruction (TECH FIG 2B).
- Identify the FDL sheath and open it just below the medial malleolus. It is located inferior to the posterior tibialis sheath and lies superficial to the sustentaculum tali (TECH FIG 2C).
- Trace the FDL sheath distally to about 2 to 3 cm distal to the navicular tuberosity. To achieve this, develop the plane between the abductor hallucis and the first metatarsal periosteum and take down a portion of the tendinous origin of the flexor hallucis brevis. This reveals the decussation of the flexor hallucis longus.

TECH FIG 2 • A. A longitudinal incision is made along the posterior tibialis sheath and medial midfoot. B. The posterior tibialis is found to be completely deficient and is débrided. C. The flexor digitorum longus (FDL) sheath is opened proximally behind the posterior tibialis sheath. (continued)
The FDL is followed and exposed to the knot of Henry. E. A distal tenodesis of the FDL and flexor hallucis longus is made; the FDL is then cut. F. A dorsal-to-plantar drill hole is made in the navicular tuberosity. G. Placing a sucker tip to suck the sutures through the drill hole allows for easy passage. H. The FDL is passed through the navicular from plantar to dorsal. I. The FDL is turned back upon itself and sutured in place, and the spring ligament is repaired.

PLANTARFLEXION OSTEOTOMY OF THE MEDIAL CUNEIFORM (COTTON PROCEDURE)

- Make a 4-cm incision centered over the medial cuneiform. This should be a separate incision from that used for the posterior tibialis reconstruction, and usually a 3- to 4-cm skin bridge can be achieved (TECH FIG 3A).
- Identify the central portion of the medial cuneiform, essentially even with the base of the second metatarsal. Drive a Kirschner wire in to template the desired location of the osteotomy (TECH FIG 3B,C).
TECH FIG 3 • A. Residual forefoot varus is noted after the other components of the reconstruction are done. B, C. A longitudinal incision is made over the medial cuneiform and a Kirschner wire is placed to mark the center of the bone. The position is then checked fluoroscopically. D. A microsagittal saw is used to create the osteotomy, leaving the plantar cortex intact as a hinge. E. Temporary Kirschner wires are placed on either side of the osteotomy. F. A lamina spreader is used against them to lever the osteotomy open, dropping the medial column. G. A femoral head allograft is used to provide a wedge of bone, which (H) typically measures 5 to 7 mm at its base. I, J. After impaction of the allograft, the medial column has been plantarflexed and the forefoot varus has been corrected.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Medial displacement calcaneal osteotomy</th>
<th>Posterior tibial tendon reconstruction</th>
<th>Cotton osteotomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excessive forefoot varus (over 30 degrees) cannot be accommodated.</td>
<td>The sural nerve must be carefully protected; sural neuritis is a common issue postoperatively.</td>
<td>Have a low threshold for complete resection of the posterior tibial tendon.</td>
<td>Be sure the osteotomy will be parallel to the first tarsometatarsal joint by checking the templating Kirschner wire position on the lateral fluoroscopic image.</td>
</tr>
<tr>
<td>Hindfoot arthritis must be carefully ruled out using weight-bearing films.</td>
<td>Avoid placing the osteotomy cut too far posteriorly into the origin of the plantar fascia.</td>
<td>Be prepared for vascular perforators overlying the approach to the knot of Henry.</td>
<td>Slight overcorrection is usually well tolerated.</td>
</tr>
<tr>
<td>Adequate displacement is achievable only if the tuberosity can be adequately distracted before attempting the medial shift.</td>
<td>Confirm screw placement with an axial fluoroscopic image.</td>
<td>Suture anchors may provide a salvage if the FDL is harvested too short or if tunnel problems occur.</td>
<td></td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- A bulky postoperative splint is initially applied.
- The patient is transferred to a removable boot at 10 to 14 days and allowed gentle active foot motion only.
- Weight bearing may commence at 1 month for the calcaneal osteotomy alone, 6 weeks if a cuneiform osteotomy has been performed.
- Physical therapy for hindfoot motion and posterior tibialis strengthening commences with weight bearing and is continued for at least 6 weeks. Thera-Band exercises are particularly useful.
- Regular shoe wear is initiated at 2.5 to 3 months depending upon swelling. Postoperative compression stockings may be useful in some patients.
- Patients should be warned that the full effect of surgery may take up to 1 year to occur. This time is required for the small cross-sectional area of the transferred FDL tendon to hypertrophy into its new expanded role.

OUTCOMES

- Initial reports of FDL transfer with posterior tibialis débridement alone demonstrated excellent pain relief but little lasting correction of the arch.\(^2,^5\)
- The FDL transfer in combination with a calcaneal osteotomy has demonstrated lasting radiographic arch correction and the functional ability to perform a single-leg toe rise. Three-year to 5-year follow-up studies have shown success rates of 90% or greater.\(^3,^7,^8,^11\)
- Long-term follow-up of the medial cuneiform osteotomy in this setting is not yet available. One short-term study detailing its use in a variety of foot deformity corrections in adults demonstrated no nonunions in 16 feet.\(^4\)
- Dramatic hypertrophy of the FDL muscle occurs over the first year after transfer.\(^10\) No clinical difference in ultimate strength has been noted between patients in whom the diseased posterior tibialis was excised versus débrided and retained.

COMPLICATIONS

- Sural nerve injury
- Navicular tunnel failure or early FDL pullout
- Hardware tenderness from the posterior calcaneal screws
- Nonunion
- Deep venous thrombosis

REFERENCES


DEFINITION
- Posterior tibial tendon insufficiency is a common diagnosis in the foot and ankle surgeon’s practice, and the most common cause of unilateral acquired flatfoot deformity.
- The constellation of presenting findings typically include painful flatfoot deformity, dorsolateral peritalar subluxation, and hindfoot valgus.
- The degree of hindfoot deformity and stiffness is variable and may be classified along the continuum described by Johnson and Strom (and Myerson) from stage I (mild posterior tibial tendinopathy without hindfoot deformity) to stage IV (severe posterior tibial tendon insufficiency, severe hindfoot deformity, and valgus talar tilt).
- Optimal treatment continues to be debated.
- Lateral column lengthening, either used in isolation or in combination with other procedures, is our preferred technique for the treatment of the posterior tibial tendon insufficient foot with supple deformity.\(^5\)

ANATOMY
- The lateral column can be defined as the sum of the fourth and fifth tarsometatarsal joints, cuboid, calcaneocuboid joint, and calcaneus.
- The peroneus brevis inserts on the base of the fifth metatarsal and is the natural antagonist to the posterior tibial tendon.
- The calcaneocuboid joint is the primary motion segment of the lateral column.
- Fusion of the calcaneocuboid joint has no impact on subtalar joint motion and decreases talonavicular joint motion by one third.\(^1\)

PATHOGENESIS
- As the posterior tibial tendon and secondary support structures (plantar medial ligaments, including the spring ligament) fail, the midfoot displaces laterally on the hindfoot.
- The contracted Achilles tendon and gastrocnemius muscles plantarflex the calcaneus.
- The navicular and medial cuneiform are displaced dorsal to the talus.
- The forefoot loses its ability to supinate.
- With this progressive deformity, the posterior heel shifts lateral to the axis of rotation through the talus, causing the contracted Achilles tendon or gastrocnemius muscles to function as strong hindfoot evertors, thereby worsening the alignment.
- The deformity increases as the lateral column is functionally shortened and the lateral talus creates impingement in the sinus tarsi,\(^3\) and eventually on the anterior process of the calcaneus.
- We characterize this progressive deformity as dorsolateral peritalar subluxation.

NATURAL HISTORY
- A functionally shortened lateral column occurs in the patient with the supple deformity described in stage II of Johnson and Strom’s classification system.
- As the deformity approaches its maximum, the static restraints of the medial column fail and it is effectively lengthened through collapse of the naviculocuneiform or first metatarsal–cuneiform joint.
- The sinus tarsi will close and lateral impingement will become a significant clinical finding.
- The peroneus brevis may become contracted and the Achilles and gastrocnemius contracture worsens.
- Over time a supple or flexible deformity may become rigid and irreducible.
- Generally, no radiographic evidence of calcaneocuboid joint arthritis is noted.
- A structurally shortened lateral column occurs as noted by virtue of calcaneocuboid joint arthritis.
- As the transition from stage II to stage III occurs, the deformity becomes rigid and the ability of the surgeon to correct the deformity with joint-sparing procedures and without arthrodesis of essential joints becomes limited and eventually impossible.

PATIENT HISTORY AND PHYSICAL FINDINGS
- As the patient moves through the clinical stages of posterior tibial tendon insufficiency, the complaints will vary from vague discomfort behind the medial malleolus and swelling to increasing deformity, lack of propulsion power, inability to single toe raise, and finally lateral-sided “ankle” pain.
- This lateral-sided “ankle” pain usually represents sinus tarsi impingement as the lateral shoulder of the talus impinges on the sinus tarsi.
- The deformity will continue to be supple in the early stages.
- Eventually the deformity will increase and become rigid, with the complaints ranging from a tired, weak foot with medial arch pain and lateral-sided “ankle” pain to increasing ankle deformity and joint pain and potentially ipsilateral knee and hip pain.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs should be obtained with weight bearing to adequately describe the alignment of the foot. The talo-first metatarsal angle describes the sag of the arch when drawn on the lateral view and the abduction of the forefoot when drawn on the AP view.
- Plain foot radiographs should also be examined for the presence of hindfoot arthritis, midfoot arthritis or instability, and the presence of an accessory navicular.
A standing ankle mortise view should be obtained to rule out the possibility of deltoid laxity (stage IV disease).

MRI is not routinely necessary and may underestimate the severity of disease, but it may be useful in ruling out other pathologies. Findings of posterior tibial tendon deformity typically include fluid in the sheath, dramatic thickening of the tendon, and a heterogeneous signal within the tendon substance, indicating the presence of interstitial tears.

**DIFFERENTIAL DIAGNOSIS**

- Midfoot arthritis resulting in pes planus through tarso-metatarsal joint collapse
- Medial ankle arthritis
- Medial osteochondral lesion of the talus
- Neurogenic failure of the posterior tibialis through spinal or central pathology

**NONOPERATIVE MANAGEMENT**

- The resultant flatfoot after posterior tibial tendon failure is irreversible, but symptoms may be controllable in many patients by nonoperative means.
- A simple in-shoe semirigid or rigid foot orthotic may provide sufficient arch support to reduce symptoms in some patients.
- The gold standard for nonoperative management is the use of a cross-ankle brace. This allows direct control of the tendency of the calcaneus to fall into valgus. The most commonly used and best tolerated is a leather ankle lacer with an incorporated custom-molded plastic stirrup, often referred to as an Arizona brace after a common brand name. Other options that may be suitable for higher-demand situations or patients with edema control problems include a hinged molded ankle-foot orthosis (MAFO) or a conventional double-metal upright AFO with a leg strap.
- Steroid injections into the posterior tibial tendon sheath are contraindicated as they may directly or indirectly precipitate frank rupture and further collapse.
- No brace, physical therapy regimen, or medication has been shown to modify the course of the disease or the ultimate outcome for the tendon. These are all best thought of as modalities to control the symptoms.

**SURGICAL MANAGEMENT**

**Preoperative Planning**

- The surgeon should obtain and review appropriate bilateral weight-bearing foot and ankle radiographs (FIG 1), assess comorbidities, and consider whether adjunctive procedures are needed.
- The surgeon should decide whether to use allograft or autograft.
- The surgeon should note the presence or absence of calcaneocuboid joint arthritis. In our hands, symptomatic calcaneocuboid joint arthritis is an indication to perform the lateral column lengthening through the calcaneocuboid joint and not through the anterior process of the calcaneus.

**FIG 1** • Preoperative views of the foot: AP (A), oblique (B), lateral (C). D. Preoperative AP view of the ankle.
Positioning
- We position the patient supine with a sandbag bump under the ipsilateral hip (FIGS 2 AND 3).
- We routinely use a thigh tourniquet.
- We judiciously use fluoroscopy.

Approach
- While an Ollier incision may be used, we typically access the lateral column through a longitudinal lateral approach (FIG 4) or occasionally an extensile lateral approach.

LATERAL COLUMN LENGTHENING VIA ANTERIOR CALCANEUS (EVANS)

Approach
- Our standard lateral incision is centered over the calcaneocuboid joint and extended proximally to the sinus tarsi (TECH FIG 1A).
- Make the incision about 6 to 8 cm long, parallel to the plantar foot, and perpendicular to the calcaneocuboid joint.
- Identify the sural nerve and peroneal tendons and carefully retract them plantarward (TECH FIG 1B).
- Elevate the extensor digitorum brevis muscle from the anterior process of the calcaneus to expose the superior corner of the calcaneocuboid joint and the sinus tarsi at the angle of Gissane (TECH FIG 1C).
- Place small Hohmann retractors, one in the sinus tarsi and the other plantar to the anterior calcaneus, after subperiosteal dissection enhances the exposure to the lateral column.

TECH FIG 1 • A. Incision site for the lateral approach. B. Lateral incision showing exposure of the peroneal tendons. (continued)
Osteotomy

- With a Bovie electrocautery or a marking pen, mark a point on the lateral calcaneus 1.5 to 2.0 cm proximal to the superior corner of the calcaneocuboid joint (TECH FIG 2A).

- We perform the anterior calcaneal osteotomy with a small oscillating saw and routinely use irrigation to avoid thermal damage to the bone.

- Be sure to keep the saw blade perpendicular to the plantar foot.

- Take care to avoid injury to the peroneal tendons with the saw (TECH FIG 2B).

- Finish the osteotomy with an osteotome, leaving the medial hinge intact (TECH FIG 2C). You may need to obtain an intraoperative fluoroscopy image to confirm that the osteotome is approaching (but not violating) the medial bony hinge; AP and oblique fluoroscopy images typically demonstrate this best.

- Place a small lamina spreader in the osteotomy (TECH FIG 2D) and gently spread until the desired correction is achieved.

- An intraoperative AP fluoroscopy image of the foot with the lamina spreader in place is useful in determining the amount of correction by appreciating the restoration of talar head coverage by the navicular. The lateral radiograph confirms the lengthening of the lateral column.

- By removing the lamina spreader without changing the amount of “spread” on the lamina, the lamina spreader can be used as a caliper to measure the size of the graft (TECH FIG 2E).

- The distance between the teeth of the lamina determines the graft size (TECH FIG 2F).
When using allograft, use at least a 15-mm-wide iliac crest wedge or patellar wedge. Mark the wedge size from the measurement obtained above and then carefully cut the block in a “pie” or wedge shape, with the cortical side widest (TECH FIG 3A,B).

When using autograft, use a standard approach to the iliac crest, avoiding the superficial branch of the femoral nerve, and make an incision about 6 cm long. Expose the anterior iliac crest using subperiosteal dissection and Taylor retractors. Mark the size of the graft from the measurement previously obtained and score the margins with a curved osteotome. Cut the block as a “pie” or wedge in situ, or remove a standard block and trim it to a “pie” or wedge on the back table.

Place the block into the lateral column osteotomy and tamp it in securely with a bone tamp and mallet. The graft should be flush with the margins of the osteotomy (TECH FIG 3C–E).

Use caution to avoid fracturing the graft. We use a small lamina spreader without teeth and place it in the far dorsal lip of the osteotomy and distract. The allograft comes in just plantar to that and usually can be tamped in with a few taps of the mallet. Avoid striking the allograft central but, rather, on the hard cortical edges.

Avoid subluxation of the calcaneocuboid joint. Occasionally, we temporarily fix the calcaneocuboid joint in its anatomic position with a 0.062 Kirschner wire before implanting the graft.
Part 8  FOOT AND ANKLE  •  Section III  HINDFOOT

We secure the graft with a single 3.5-mm screw from the anterosuperior corner of the calcaneocuboid joint across the graft into the proximal calcaneus (TECH FIG 3F–I).

In our opinion, a fully threaded positional screw is ideal and there is no need to apply compression since the graft is already under compression in the distracted osteotomy. In fact, lag technique may lead to crushing the graft.

Supplement the lateral column osteotomy with remaining cancellous bone.

Check clinical alignment.

Use AP and lateral fluoroscopy images to confirm position and restoration of lateral column height, the talo–first metatarsal angle, and correction of dorsolateral peritalar subluxation (TECH FIG 3J,K).

Undercorrection to residual deformity or overcorrection to an adductus deformity can be avoided by checking for desired alignment with the lamina spreader in place, before sizing and inserting the graft.

We routinely close the deeper layers with 3-0 Maxon and the skin using 3-0 nylon.

Approach

Approach the calcaneocuboid joint through a standard lateral approach centered over the calcaneocuboid joint and extending a total length of 6 to 8 cm, slightly more distal than the approach for lateral column lengthening via the anterior process of the calcaneus.

Identify the peroneal tendons and sural nerve and retract them plantarward, and elevate the extensor digitorum brevis muscle dorsally.

Distract the calcaneocuboid joint with a small lamina spreader and remove the articular cartilage from both sides of the joint.

Drill the subchondral bone with a 2.0-mm drill or a 0.062 Kirschner wire to provide vascular channels.

Distract the calcaneocuboid joint using the small lamina spreader until the desired correction is obtained.

Check AP and lateral fluoroscopy images with the lamina spreader in place. The AP image confirms that the navicular is reduced on the talar head and the lateral view confirms that subluxation of the calcaneocuboid joint is avoided.

Remove the lamina spreader without changing the amount of “spread” on the lamina so it can be used as a caliper to measure the size of the graft.

The distance between the teeth of the lamina determines the graft size.

When using allograft, use at least a 15-mm-wide iliac crest wedge or patellar wedge. Mark the wedge size from the measurement obtained above and then carefully cut the block in a “pie” or wedge shape, with the cortical side widest.

When using autograft, use a standard approach to the iliac crest, avoiding the superficial branch of the femoral nerve, and make an incision about 6 cm long. Expose the anterior iliac crest using subperiosteal dissection and Taylor retractors. Mark the size of the graft from the measurement previously obtained and score the margins with a curved osteotome. Cut the block as a “pie” or wedge in situ, or remove a standard block and trim it to a “pie” or wedge on the back table.

Insert the graft in the calcaneocuboid joint, as flush as possible with the lateral column of the foot, and confirm correction clinically and fluoroscopically.

Maintain congruent alignment of the cuboid and calcaneus during graft insertion.

Secure the arthrodesis with a small H-plate, cervical plate, or semitubular plate (TECH FIG 4).

Avoid overcompression and shortening of the lateral column.

Augment the fusion with further bone graft.

Check overall clinical correction.

AP and lateral fluoroscopy images serve to confirm restoration of lateral column height, talo–first metatarsal angle, and dorsolateral peritalar subluxation.

By checking realignment with the lamina spreader before contouring or inserting the graft, overcorrection to adductus deformity and undercorrection with residual abduction is avoided.

We routinely close the wound with 3-0 Maxon and 3-0 nylon.
PEARLS AND PITFALLS

Physical examination
- Examine the patient in the sitting position with the knee bent and the hindfoot reduced to evaluate Achilles tendon contracture and with the knee straight and the hindfoot reduced to evaluate gastrocnemius contracture.
- Watch for the peroneal spastic flatfoot and evaluate appropriately for tarsal coalition.
- Evaluate for ipsilateral ankle instability.
- Assess the foot for fixed forefoot supination. Even when the hindfoot is supple and can be passively corrected, the forefoot may have compensatory supination that does not correct spontaneously. Lateral column lengthening may correct the hindfoot but could worsen the relative forefoot supination. An adjunctive medial column stabilization procedure to plantarflex the first ray may be necessary (Lapidus procedure or plantarflexion osteotomy of the medial cuneiform).

Approach
- Evaluate and be prepared to treat any concomitant peroneal tendon pathology, such as splits or contracture.

Osteotomy
- Take care not to place the osteotomy too far distal and destabilize the calcaneocuboid joint.
- Take care not to place the osteotomy too far proximal and violate the middle or posterior facet of the subtalar joint.
- If the calcaneocuboid joint is unstable, secure the joint with a 0.062 Kirschner wire before distracting the osteotomy.
- Retract the peroneal tendons with a small Lambotte osteotome under the inferior edge of the calcaneus and watch carefully to avoid accidental laceration of the tendons by the oscillating saw.
- Angle the fixation screw slightly plantar to avoid placing the screw in the subtalar joint (FIG 5).

Graft size
- Graft is usually close to 10 mm.
- Ensure that the allograft has been soaking for about 20 minutes to prevent graft fracture as you are cutting the block.
- Place the small lamina spreader in the osteotomy and open and close the device to find the appropriate amount of correction.
POSTOPERATIVE CARE

- We typically immobilize our patients in a postoperative splint (FIG 6).
- At 2 weeks, we remove sutures, obtain simulated weight-bearing radiographs (AP, lateral, oblique) and the Harris view, and allow touch-down weight bearing in a short-leg cast.
- At 6 weeks the patient is transitioned from the cast into a fracture boot and from touch-down to partial weight bearing, with gradual progression to full weight bearing over the next 4 weeks.
- Our patients participate in a simple physical therapy protocol to assist with safe mobilization, modalities, and a protocol to strengthen the posterior tibial tendon reconstruction.
- In general patients can return to wearing shoes at 10 weeks postoperatively.

OUTCOMES

- The selection of autograft versus allograft for lateral column lengthening in the adult does not alter the capacity of the osteotomy to heal.
- A prospective, randomized study of 33 patients randomized to allograft versus autograft showed no difference in the union rate.\(^2\)
- Calcaneocuboid joint arthritis has been proposed as a consequence of lateral column lengthening through the anterior process of the calcaneus.
- Mosier-LaClair et al\(^4\) showed that 14% of their patients had evidence of calcaneocuboid joint arthritis at 5 years of follow-up; however, 50% had calcaneocuboid joint arthritis preoperatively.
- Lateral column overload may be more likely with a calcaneocuboid distraction arthrodesis than an Evans-type osteotomy (FIG 7).\(^5\)
COMPLICATIONS

- Nonunion (FIG 8)
- Malunion
- Graft fracture
- Painful hardware
- Overcorrection
- Peroneal tendon irritation or injury
- Sural nerve irritation or injury

REFERENCES

DEFINITION

- Spring ligament failure consists of lengthening or disruption of the spring ligament complex resulting in subluxation at the talonavicular joint.
- Spring ligament failure is commonly associated with considerable degeneration of the ligament. The ligament complex may have tears or large defects, or it may just be attenuated.
- Tears most commonly occur in the superomedial portion of the spring ligament complex, adjacent to the posterior tibial tendon, but can occur in the inferior portion as well.
- It is necessary to look at the alignment of the foot to determine how to treat failure in the spring ligament. If a flatfoot is present with increased heel valgus or abduction (or both) through the midfoot and there is a full tear of more than 30% of the ligament or severe attenuation, the risk of progression of deformity is high.

ANATOMY

- The spring ligament actually is a complex of ligaments composed primarily of a superomedial portion and an inferior portion. The deltoid ligament blends in with the superomedial portion.
- The superomedial portion is medial to the posterior tibial tendon. It originates from the superomedial aspect of the sustentaculum tali and anterior facet of the calcaneus to insert on the medial navicular adjacent to its articular surface (FIG 1).
- The inferior portion originates from the notch between the anterior and medial calcaneal facets. It inserts on the inferior surface of the midnavicular, just lateral to the insertion of the superomedial portion of the spring ligament (FIG 2).
- Because of location, failure of the superomedial portion should result in primarily medial migration of the talar head, whereas that of the inferior portion results in primarily plantar migration. Most commonly, the migration is both medial and plantar (FIG 3).

PATHOGENESIS

- Spring ligament failure is due most commonly to the repetitive stresses of a flatfoot causing increased strain on the medial ligaments of the foot.
- Failure most often occurs in the setting of a degenerated ligament, and it can be associated with an acute episode.
- Although spring ligament failure is associated with a pre-existing flatfoot, it commonly results in progressive deformity of the foot at the talonavicular joint and hindfoot. Because the foot progresses out from under the talar head dorsally and laterally, the talar head migrates medially and plantarly compared with the rest of the foot.

NATURAL HISTORY

- Failure of the spring ligament complex most commonly occurs along with posterior tibial tendon insufficiency.
- With or without tendon insufficiency, spring ligament failure places the patient at risk for progressive subluxation at the talonavicular joint. If subluxation is already present, progression of the subluxation is likely.
- Progressive subluxation at the talonavicular joint eventually can cause enough deformity in the triple joint complex (ie, the talonavicular, calcaneocuboid, and subtalar joints) to result in lateral impingement and pain in the hindfoot, a collapsed foot.

PATIENT HISTORY AND PHYSICAL EXAMINATION

- Patients most commonly present with medial pain, which usually is associated with the posterior tibial tendon rather than the spring ligament, although isolated traumatic injuries to the spring ligament do occur. If enough deformity has occurred, pain occurs in the lateral hindfoot from impingement secondary to subluxation in the triple joint complex.

---

FIG 1 • Anatomy of the spring ligament complex (dorsal view with talar head removed). Note the location of the superomedial and inferomedial positions. The superomedial portion is medial to the posterior tibial tendon. It originates from the superomedial aspect of the sustentaculum tali and anterior facet of the calcaneus to insert on the medial navicular adjacent to its articular surface.
Depending on the presence and amount of deformity, the patient may or may not notice weakness or collapse in the arch. Most patients do notice some weakness.

Physical examination should evaluate the posterior tibial tendon and alignment of the foot with the patient letting the arch sag fully when standing.

The posterior tibial tendon should be palpated for tenderness. Inversion strength should be tested from an everted position to a plantarflexed and inverted position.

Clinical alignment should be checked for midfoot abduction and height of the arch as noted on the frontal standing view. The degree of heel valgus is assessed from the posterior standing view.

Physical examination may also include the following steps:
- Palpate the medial talonavicular joint and posterior tibial tendon to evaluate swelling. Acute and subacute tears.
- Palpate the tendon versus the joint for tenderness. Tenderness on the tendon indicates tendon involvement and often masks tenderness from a tendon tear.
- Evaluate range of motion. Compare the arc of motion (maximum eversion to maximum inversion) to the other foot. The arc of motion may be categorized as follows: full; some inversion present; motion only to neutral; or joint contracted in eversion. The joint must be mobile for tendon repair or reconstruction.
- Evaluate inversion strength. Start with the foot in eversion and have the patient push against the examiner’s hand to inversion and plantarflexion. For grades I through IV, tendon transfer may be required.

**IMAGING**

- The anteroposterior (AP) and lateral foot radiographs should be obtained standing with the patient told to let the arch sag. An AP standing radiograph of the ankle also should be performed to rule out valgus deformity at the ankle joint.
- On the AP view of the foot, abduction at the talonavicular joint can be measured with the talonavicular uncoverage angle (ie, the amount of talar head not covered by the navicular; FIG 4A).
- On the lateral view, plantar migration of the talar head in relation to the navicular can be checked (FIG 4B). The lateral talometatarsal angle, while a useful measurement, includes deformity at the naviculocuneiform and metatarsal-tarsal joints.
- Radiographs are not diagnostic tools but are helpful in assessing deformity—as long as the patient is standing and the radiographic technique allows AP and lateral views with full weight bearing.
- An MRI scan visualizing the spring ligament complex can indicate the amount of degeneration or tear in the complex and is useful for diagnosis if it is of good quality and if it is read by an experienced examiner (see FIG 3).

**DIFFERENTIAL DIAGNOSIS**

- Degeneration or tear of the posterior tibial tendon without spring ligament failure
- Congenital flatfoot
NONOPERATIVE MANAGEMENT

- Nonoperative management is particularly appropriate for those patients for whom the tear and alignment are thought to have a low probability of progression. It also may be used for those patients who wish to delay surgery, but they must be informed of the risk of progression of deformity.
- Nonoperative management consists of support for the medial longitudinal arch with one of the following devices. (They do not at all guarantee stopping the progression of deformity.)
  - A removable boot is helpful for initial management. A medial longitudinal arch support inside the boot may be used.
  - A short, articulated ankle–foot orthosis is less cumbersome and allows ankle motion with a customized arch support.
  - A custom orthotic with a medial longitudinal arch support and medial heel wedge is the least cumbersome but also provides the least support.
  - A solid leather gauntlet or Arizona brace allows minimal motion. It is best for those patients with considerable deformity and limited function.
- Patients receiving conservative care should be monitored for progression of flatfoot deformity.

SURGICAL MANAGEMENT

- Surgery is the best choice for patients with progression of flatfoot deformity associated with failure of the spring ligament complex or patients whose alignment and degree of injury to the spring ligament place them at high risk for progressive deformity.4
- Relative contradictions include medical conditions that adversely affect healing, such as diabetes, corticosteroid use, and neuropathy.
- Reconstruction of the spring ligament is not useful in those patients with rigid hindfoot deformity and is not necessary in those patients with small tears or good correction of ligament with bony procedures.

PREOPERATIVE PLANNING

- Standing clinical alignment and standing AP and lateral radiographs of the foot and ankle should be carefully reviewed to plan for correction of alignment as well as repair or reconstruction of the spring ligament.
- Surgeons should be prepared to deal with large tears or significant tissue loss in the spring ligament complex.
  - This may necessitate the use of tendon graft, possibly allograft tendon.
  - Possible Achilles contracture should be assessed.
  - Correction of the foot alignment should be considered an integral part of the procedure.
  - Remember that repair or reconstruction of the spring ligament has yet to be shown to correct bony malalignment and that a flatfoot deformity places strain on the spring complex.
  - Whether spring ligament reconstruction adds to alignment correction when bony procedures are being performed is debatable. In our experience, however, alignment correction is achieved by spring ligament reconstruction if osteotomies are performed at the same time and the foot is placed near the corrected position by the osteotomies.
  - Spring ligament reconstruction is the most logical choice for large tears and is performed along with bony realignment of deformity.5,6

POSITIONING

- The patient is placed in the supine position with a bolster under the greater trochanter so that the lower leg is neither internally or externally rotated. This allows good access to both sides of the foot.
- In this position, exposure of the spring ligament, posterior tibial tendon, and lateral hindfoot is possible.

APPROACH

- A medial incision is made from the tip of the medial malleolus to 2 cm distal to the navicular to inspect the posterior tibial tendon and expose the spring ligament complex by retracting the tendon.
- Lateral hindfoot incisions are used as necessary for calcaneal osteotomies.
SUPEROMEDIAL SPRING LIGAMENT RECONSTRUCTION

- Tendon graft is used to replace insufficient ligament tissue and block medial migration of the talar head.
- Achilles allograft is used most commonly, although peroneus longus can be used if both the longus and brevis are in good condition and overcorrection of bony realignment is avoided.
- Because the superomedial spring ligament blends in with the anterior deltoid ligament, which also can be attenuated, reconstruction of the anterior deltoid and superomedial spring ligaments is commonly performed together (TECH FIG 2A).

- Bone tunnels in the navicular and tibia are used to create a ligament path to support the medial talar head (TECH FIG 2B).
- The navicular tunnel is placed from dorsal to plantar medial over a cannulated drill. The graft is to exit plantar medially and cross the medial talar head.
- A tibial tunnel beginning at the most inferior midportion of the medial malleolus tip is used.
- The tibial tunnel exits laterally 5 to 9 cm above the ankle joint line.
- A lateral longitudinal incision over the fibula is used to access the lateral tibia and fibula.

TECH FIG 2 • A. Diagram of superomedial spring ligament reconstruction. The repaired ligament crosses the medial aspect of the talar head to block medial migration of the head. An alternative to the tibial drill hole is a drill hole in the medial talar neck. Because the superomedial spring ligament blends in with the anterior deltoid ligament, which also can be attenuated, reconstruction of anterior deltoid and superomedial spring ligaments is commonly performed together. B. Exit hole of the graft at the inferior navicular and corresponding entrance hole into the tibia at the midportion of the tip of the medial malleolus. The navicular hole is drilled from dorsal to plantar and the tibial hole from the medial malleolus out the lateral tibia above the ankle. Bone tunnels in the navicular and tibia are used to create a ligament path to support the medial talar head.

TECH FIG 1 • Operative photograph of repair of spring ligament. This repair was accompanied by a medial slide calcaneal osteotomy to address the deformity. Figure 8 or horizontal mattress sutures are placed to appose both ends with the foot in neutral position. Knots are placed to avoid impingement against the posterior tibial tendon.

PRIMARY SUPEROMEDIAL SPRING LIGAMENT REPAIR

- Primary repair rather than reconstruction is done when good tissue for repair is present and ends can be well apposed. Foot deformity is corrected at the same time.
- Figure 8 or horizontal mattress sutures are placed to appose both ends of the ligament with the foot in neutral position. Knots are placed to avoid impingement against the posterior tibial tendon (TECH FIG 1).
- If the ligament cannot be apposed with the foot in neutral or the tissue is attenuated, then reconstruction of the ligament is necessary for large tears. The reconstruction is performed together with osteotomies to correct bony alignment.

TECH FIG 1 • Operative photograph of repair of spring ligament. This repair was accompanied by a medial slide calcaneal osteotomy to address the deformity. Figure 8 or horizontal mattress sutures are placed to appose both ends with the foot in neutral position. Knots are placed to avoid impingement against the posterior tibial tendon.
Given the size of the foot, the largest drill hole in the navicular is used, so a large tendon graft (6–9 mm) is possible.

The graft is fixed at the navicular first and tensioned via the lateral ankle incision. The graft is tightened with the talonavicular joint in neutral to slight adduction.

Fixation of the graft is via whipstitch using no. 2 nonabsorbable suture tied at each end, to a dorsal screw in the navicular and a lateral screw on the fibula.

With the navicular end tied down first, the foot is placed in neutral to slight adduction and the ligament graft tensioned and tied down laterally.

Alternative fixation with interference screws can be used, but the fixation may not be as strong with this technique in the tibia.

For large abduction deformities (ie, >30 degrees of talar head uncoverage), spring ligament reconstruction alone cannot be expected to hold correction and should, based on my experience, be used as a supplement to a lateral column lengthening procedure.

Lateral column lengthening—as minimal as possible—is done to place the talonavicular joint in neutral alignment.

The lateral column lengthening procedure should allow a minimum of 5 degrees of passive eversion to avoid excessive lateral tightness and should be tested in the operating room by everting the foot.

An alternative to the tibial tunnel is a tunnel in the proximal talar neck with fixation using an interference screw.

**TECHNIQUES**

**INFERIOR SPRING LIGAMENT RECONSTRUCTION**

- Tendon grafting also is used, but for deformity that is primarily plantar migration of the talar head.
- Graft is used to replace attenuated or degenerated tissue in combination with bony procedures to correct flatfoot deformity (TECH FIG 3A).
- Bone tunnels are used in the navicular and calcaneus (TECH FIG 3B).
  - The navicular tunnel is made from dorsal to plantar medial.
  - The calcaneal tunnel is drilled from underneath the distal medial and anterior facets and exits out the lateral calcaneus. The lateral exit point is exposed using the standard oblique incision for a posterior calcaneal osteotomy.
- The graft is fixed first at the navicular, with the foot placed in 5 degrees of inversion with the calcaneus out of valgus (neutral). Calcaneal osteotomy is commonly performed and is fixed before the calcaneal drill hole is made and the graft is passed through.
- Fixation of the graft is with nonabsorbable suture sewn in to the ends of the graft and tied down to screws in the dorsal navicular and lateral calcaneus. Alternative or supplemental fixation is done with interference screws.
- The calcaneus cannot be left in valgus, or excessive strain on the graft will result.

**TECH FIG 3** • A. Diagram of plantar spring ligament reconstruction with the graft extending from the drill hole in the navicular to the calcaneus. Graft is used to replace attenuated or degenerated tissue in combination with bony procedures to correct flatfoot deformity. B. Navicular exit hole and calcaneal entrance for the graft. A drill hole is made dorsal (dorsal portion not shown) to plantar in the navicular and medial to lateral (not shown) in the calcaneus. Bone tunnels are used in the navicular and calcaneus.
COMBINED SUPEROMEDIAL AND PLANTAR SPRING LIGAMENT RECONSTRUCTION

- Combined superomedial and plantar spring ligament reconstruction is done for patients with considerable abduction of the talonavicular joint and plantar migration of the head.
- Two tendon grafts or a large tendon graft that is split at the plantar medial navicular tunnel is used (TECH FIG 4).
- The navicular tunnel is made as large as possible without fracturing the navicular to enable placement of large grafts. If allograft tendon is used, Achilles allograft with a bone block in the navicular tunnel is suggested (TECH FIG 5).
- The talonavicular joint is pinned in the corrected position (i.e., 5 degrees of inversion and the calcaneus in neutral) after any bony procedures are fixed.
- The tendon grafts are then tensioned and fixed at the lateral calcaneus and fibula.
- Reconstruction with combined techniques is intended not to replace bony procedures but to supplement them when considerable tissue loss in the spring ligament complex is noted and correction of bony alignment has been gained at or near neutral position.
- Commonly, a posterior osteotomy and, often, lateral column lengthening are performed.

**TECH FIG 4** • A. Diagram of combined spring ligament complex reconstruction shows combined superomedial and plantar reconstruction. Two tendon grafts or a single large tendon graft that is split at the plantar medial navicular tunnel is used. B. Diagram of alternative combined spring ligament reconstruction using the peroneus longus left attached to first metatarsal base (shown) or free graft from the navicular plantar hole to the calcaneus and back to the navicular dorsal hole (not shown). Two tendon grafts or a large tendon graft that is split at the plantar medial navicular tunnel is used.

**TECH FIG 5** • Drill holes for the combined spring ligament complex reconstruction with the graft exiting the plantar navicular and going into drill holes at the calcaneus. The navicular tunnel is as large as possible without fracturing the navicular, to enable placement of large grafts. If allograft tendon is used, Achilles allograft with a bone block in the navicular tunnel is suggested.
PEARLS AND PITFALLS

- Do not expect soft tissue reconstruction to correct bony malalignment.
- Avoid over- and undercorrection of deformity.
- Do not use lateral column lengthening, unless necessary.
- Avoid weakening of tendon grafts.
- Avoid unnecessary spring ligament reconstruction.

- The foot must be well aligned without excessive calcaneal valgus (≤ 5°) and without excessive abduction through the talonavicular joint (>30% uncoverage).
- Correct bony malalignment first. Then pin or hold the talonavicular joint in neutral position before tensioning the reconstruction.
- Bony procedures, while necessary to correct malalignment, have morbidity. Lateral column lengthening should not be used unless necessary, and overcorrection should be avoided.
- Fix bony procedures first to avoid crossing bony tunnels with screws, and use seizors to avoid multiple passages of the tendon grafts in tunnels.
- Small tears do not necessitate spring ligament reconstruction.

POSTOPERATIVE CARE

- Touch-down weight bearing is allowed at 2 weeks and progressive weight bearing from 8 to 10 weeks.
- In reliable patients, a cast boot can be used instead of a cast beginning at 6 weeks.
- Full weight bearing without a boot is allowed at 12 to 16 weeks.
- Active inversion and eversion can be started at 6 weeks.

OUTCOMES

- Because spring ligament reconstructions are commonly combined with other procedures, it is difficult to define the contribution of these procedures to patient outcomes, and no reports have done so until recently.
- In our experience, spring ligament reconstruction does contribute to correction of deformity but only when most of the correction has been achieved through the bony procedures. I would use the superomedial spring ligament reconstruction for those feet with more of an abduction deformity and the plantar for those with more of a plantar sag deformity at the talonavicular joint. The superomedial may adequately correct combined deformity; if not, use the combined superomedial and spring ligament reconstruction.

COMPlications

- Failure of the graft can occur, particularly when a soft tissue procedure is used to try to correct large amounts of deformity without adequate bony correction of deformity.
- Failure of fixation of the graft. Interference screws are helpful, but the fit must be tight and tunnels must be made at somewhat of an angle to avoid straight pullout of the graft.
- Overcorrection with lateral weight bearing can occur, either with a medial slide osteotomy or, more commonly, if lateral column lengthening is used. Normal eversion motion should be maintained.
- The heel should be in alignment with the lower leg (not in varus), and passive eversion into at least 5 degrees should be present after all the procedures are fixed.
- The lateral column should not feel tight on range-of-motion testing in the operating room after the bony correction—eversion should be present.

REFERENCES

DEFINITION
- A tarsal coalition is an abnormal fusion between two adjacent tarsal bones.
- Less than 2% of the general population is affected, and there appears to be no gender or racial predisposition.
- Nearly 90% of all tarsal coalitions involve either the subtalar joint or the intervening space between the calcaneus and the navicular, with nearly an equal distribution between these two areas.
- Although most calcaneonavicular coalitions are identified in children or adolescents, there does exist a subset of patients who become symptomatic in adulthood.

ANATOMY
- Unlike other tarsal coalitions, the calcaneonavicular coalition forms between two bones that normally do not articulate with each other.
- A calcaneonavicular coalition generally occurs between the anterior process of the calcaneus and the inferolateral aspect of the navicular.
- Histologically, these coalitions may be fibrous, cartilaginous, or osseous in nature, and may progress through these stages as the patient matures.

PATHOGENESIS
- Tarsal coalitions are most likely secondary to a failure of segmentation of the primitive mesenchyme.
- In adolescents and young adults, the time at which the coalition becomes symptomatic appears to coincide with its ossification.
- Although most coalitions are idiopathic, a dominant trait has been suggested.

NATURAL HISTORY
- The natural history of a calcaneonavicular coalition is one of progressive disability.
- As the coalition ossifies in adolescence, the lack of subtalar range of motion may lead to hindfoot or midfoot pain, recurrent ankle sprains, and difficulty ambulating on uneven surfaces.
- In longstanding coalitions, the increased stresses imposed on the remaining mobile tarsal joints secondary to absent subtalar inversion and eversion may contribute to degenerative arthritic changes elsewhere in the foot.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Symptomatic adults with calcaneonavicular coalitions generally present with hindfoot or midfoot pain, recurrent ankle sprains, or difficulty ambulating on uneven surfaces.
- In contrast to the often insidious onset of symptoms in adolescents with a calcaneonavicular coalition, onset in adults with this condition is abrupt and often coincides with a specific traumatic event, such as a severe ankle sprain.
- Other adults may simply present with a planovalgus foot deformity.
- Physical examination findings consistent with a calcaneonavicular coalition may include:
  - Planovalgus foot deformity (rarely, a cavovarus deformity)
  - Decreased or absent subtalar and transverse tarsal joint range of motion
  - Tenderness in the region of the coalition
  - Pain with inversion or eversion of the hindfoot
  - Antalgic gait
  - Instability secondary to multiple ankle sprains (as determined by anterior drawer testing)

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs should be obtained in every patient suspected of having a tarsal coalition and should include AP, lateral, 45-degree oblique, and axial views of the foot.
- The 45-degree oblique view of the foot is the most useful plain radiograph for identifying a calcaneonavicular coalition. On this oblique view, the coalition may be seen as a discrete bony bridge between the calcaneus and the navicular, or this may simply be suggested by the presence of an extended, narrow beak of bone projecting from the anterior process of the calcaneus in the direction of the navicular (the “anteater sign”).
- An axial view is important because it may aid in the identification of a talocalcaneal coalition.
- Computed tomographic scans should be obtained in all patients preoperatively to rule out a concomitant talocalcaneal coalition and to further evaluate for degenerative changes that may alter the surgical plan.
- Magnetic resonance imaging may help identify a fibrous or cartilaginous coalition but is not necessary in the workup and treatment of most calcaneonavicular coalitions in adults.
DIFFERENTIAL DIAGNOSIS
- Talocalcaneal (subtalar) coalition
- Trauma or fracture of the hindfoot
- Arthritis (primary osteoarthrosis, posttraumatic arthritis, or inflammatory arthritis)
- Flatfoot secondary to posterior tibial tendon insufficiency
- Chronic ankle instability

NONOPERATIVE MANAGEMENT
- Initially, all patients with symptomatic calcaneonavicular coalition should be managed nonoperatively.
- Patients are first treated with nonsteroidal anti-inflammatory medications and custom orthotics that support the medial longitudinal arch.
- The UCBL brace is another orthotic option that acts to limit hindfoot motion.
- If patients fail this early conservative treatment, they are immobilized in a fiberglass short leg walking cast for 4 to 6 weeks.
- Symptomatic coalitions that are recalcitrant to casting in feet that display no degenerative changes may require surgical resection for relief of symptoms.

SURGICAL MANAGEMENT
- For patients who do not achieve relief with an adequate trial of nonoperative management, surgical intervention is warranted.

Preoperative Planning
- Plain radiographs, as well as computed tomographic or magnetic resonance imaging scans, are reviewed.
- All images are evaluated for additional pathology, including concomitant coalitions or degenerative arthritic changes that may alter the surgical treatment plan.

Positioning
- Thirty to 90 minutes before the incision is made, the patient is given an appropriate intravenous antibiotic.
- The patient is placed supine on the operating table, and a bump is placed under the ipsilateral sacrum to internally rotate the foot.
- A pneumatic tourniquet is placed around the upper thigh, and the extremity is prepped and draped in a standard, sterile fashion.

INCISION AND EXPOSURE
- After exsanguination with an Esmarch bandage and inflation of the tourniquet, a standard Ollier incision is created.
- This incision is centered directly over the dorsal aspect of the coalition and extends along a transverse Langer line planarly to the peroneal tendon sheath and dorsally to the most lateral of the extensor digitorum longus tendons (TECH FIG 1A).
- Pre-emptive cauterization of any crossing vessels is performed.
- The sural cutaneous nerve and dorsal intermediate branch of the superficial peroneal nerve are identified and protected, as are the peroneal tendons.
- The extensor digitorum brevis muscle is visualized in the depths of the wound and subsequently elevated as a distally based flap using a scalpel and a Cobb elevator, with great care taken to preserve the overlying fascia, which will increase the suture-holding capacity of the flap (TECH FIG 1B).
- The elevated origin of the brevis is then grasped with a modified Mason-Allen stitch using 0-Vicryl (TECH FIG 1C).
- As the flap is retracted distally, the calcaneonavicular coalition is easily identified (TECH FIG 1D).

TECH FIG 1 • A. Incision. B. Elevation of the extensor digitorum brevis flap. C. Grasping of the extensor digitorum brevis with Vicryl suture. D. Flap retraction and visualization of calcaneonavicular coalition.
**RESECTION OF CALCANEONAVICULAR COALITION WITH INTERPOSITION OF THE EXTENSOR DIGITORUM BREVIS**

- After adequate visualization of the coalition, a straight osteotome is used to remove a 1-cm block to include the entire coalition.
- The osteotome cuts are made parallel to prevent the removal of a convergent, trapezoidal block of bone (**TECH FIG 2A**).
- Any remaining soft tissue within the resection site is cleared with a rongeur.
- The two limbs of the previously placed Vicryl suture attached to the extensor digitorum brevis flap are passed through the void created by coalition resection with the use of a free Keith needle (**TECH FIG 2B**).
- The tips of the Keith needles should pass just dorsal to the glabrous skin of the medial arch (**TECH FIG 2C**).
- The two limbs of the Vicryl suture are then tied over a soft dental bolster (no button; **TECH FIG 2D**).

- Alternatively, the raw bony surfaces of the resection site may be covered with bone wax, the void filled with gelfoam or autologous fat graft, and the brevis reattached to its origin.
- Radiographs are taken to confirm the adequacy of the resection (**TECH FIG 2E**).
- The wound is thoroughly irrigated, the tourniquet is released, and hemostasis is secured.
- Closure of the wound is performed using 2-0 Vicryl for the deep subcutaneous layer and 4-0 nylon horizontal mattress sutures for the skin (**TECH FIG 2F**).
- Finally, the wound is covered with a nonadherent dressing, sterile gauze, sterile cast padding, and a short leg fiberglass walking cast.

**TECH FIG 2** • Resection and interposition. **A**, Removal of a rectangular block of bone using parallel osteotome cuts. **B**, Interposition of the extensor digitorum brevis flap into the void created by the resection. **C**, Passage of Keith needles through the skin of the medial arch. **D**, Flap sutures tied over soft dental bolster. **E**, Intraoperative radiographs to confirm the adequacy of the resection. **F**, Wound closure.
PEARLS AND PITFAILS

Preoperative workup
- Evaluate plain radiographs for the presence of significant degenerative changes, which would necessitate an appropriate arthrodesis.
- Review available computed tomographic or magnetic resonance imaging scans for the presence of any concomitant coalitions.

Coalition resection
- Osteotome cuts made in a parallel fashion will remove a rectangular block of bone rather than a convergent, trapezoidal segment, which may lead to recurrent pain secondary to an inadequate medial excision of the coalition.

Interpositional graft
- Preserve the fascia overlying the extensor digitorum brevis to increase the holding power of the Vicryl stitch.

Deformity correction
- Consider adding a lateral column lengthening procedure in the face of a significant pes planus.

POSTOPERATIVE CARE
- The patient is allowed to weight bear as tolerated in the cast on postoperative day 1.
- At 3 weeks, the patient returns to clinic for removal of the cast, wound sutures, and bolster stitch. At this point, the patient is placed in a walking boot.
- Following removal of the cast, physical therapy is initiated for ankle and hindfoot range-of-motion exercises.

OUTCOMES
- In the absence of significant degenerative changes that may necessitate an appropriate arthrodesis, resection of a calcaneonavicular coalition can be a successful procedure in symptomatic adults or adolescents.
- Cohen et al reviewed results of calcaneonavicular coalition resection in 12 adult patients. Subjective relief was attained in 10 patients and the average increase in total subtalar range of motion was 10 degrees.3
- In a group of 48 child and adolescent patients, Gonzalez and Kumar achieved 77% good to excellent results following calcaneonavicular coalition resection with interposition of the extensor digitorum brevis. The results did not deteriorate with time in those patients followed up for more than 10 years.4
- The importance of using an interpositional material has been reinforced in several publications.
- No recurrences of a calcaneonavicular coalition were noted by Moyes et al on oblique radiographs when an extensor digitorum brevis interposition was performed. However, in this same study, three of seven patients who underwent resection without interposition displayed radiographic evidence of a recurrence.8
- Swiontkowski et al used an interpositional material (fat or muscle) in 38 of 39 feet undergoing calcaneonavicular coalition resection and found no radiographic recurrences.9
- Mitchell and Gibson, on the other hand, found a recurrence of the coalition in nearly two thirds of their 41 patients who had undergone a simple coalition resection without interposition of the extensor digitorum brevis.7

COMPLICATIONS
- Superficial or deep infection
- Wound dehiscence1
- Recurrence of the coalition7
- Nerve damage
- Inadequate resection3
- Reflex sympathetic dystrophy1

REFERENCES
DEFINITION
- An isolated subtalar arthrodesis can be used in the treatment of a myriad of different hindfoot conditions, including primary arthritis of the subtalar joint, posttraumatic arthritis secondary to a talar or complex calcaneal fracture, rheumatoid arthritis, and talocalcaneal coalition.
- Other indications include posterior tibial tendon insufficiency and any neuromuscular disorder presenting with instability of the subtalar joint.
- When the pathologic process resides solely in the talocalcaneal articulation, isolated subtalar arthrodesis is preferred over a triple arthrodesis for its preservation of hindfoot motion, its decreased potential for development of degenerative changes in neighboring joints, its relative simplicity, and its lower potential for pseudarthrosis of the talonavicular and calcaneocuboid joints.

ANATOMY
- The term subtalar refers to the articulation between the anterior, middle, and posterior facets of the inferior talus and the corresponding anterior, middle, and posterior facets located on the superior aspect of the calcaneus.
- The subtalar joint is a “plane type” synovial joint with a weak fibrous capsule supported by medial, lateral, and posterior talocalcaneal ligaments, as well as an interosseous talocalcaneal ligament.
- This important articulation provides for inversion and eversion of the hindfoot, which is critical for proper adaptation of the foot during ambulation on uneven terrain and for dissipation of heel strike forces.
- Isolated fusions of the subtalar joint have been shown to reduce talonavicular joint motion by 74% and calcaneocuboid joint motion by 44%.

PATHOGENESIS
- Numerous causes of subtalar joint arthritis exist, including:
  - Primary osteoarthrosis: articular cartilage degeneration of unknown etiology
  - Secondary arthritis: caused by either traumatic articular cartilage damage or increased joint stresses following an arthrodesis of an adjacent joint
  - Inflammatory arthritis: autoimmune joint destruction (eg, rheumatoid arthritis, psoriatic arthritis)
- Other etiologies that may necessitate an isolated subtalar arthrodesis include:
  - Talocalcaneal coalition: abnormal fusion between the talus and calcaneus, most likely secondary to a failure of segmentation of the primitive mesenchyme
  - Instability or deformity secondary to muscular imbalance (eg, posterior tibial tendon insufficiency, Charcot-Marie-Tooth disease, poliomyelitis)

NATURAL HISTORY
- Depends on specific etiology
- In general, the various forms of subtalar arthritis are progressive in nature.
- Despite waxing and waning of symptoms, no spontaneous resolution of the pathologic process is noted.

PATIENT HISTORY AND PHYSICAL FINDINGS
- A problem-focused history should include direct questioning regarding the exact nature of the symptoms, specific location, duration and progression of symptoms, aggravating or alleviating factors, prior therapeutic interventions, and functional disability.
- Patients often complain of lateral ankle pain and difficulty ambulating on uneven terrain.
- The pain often gets better with rest and may be mitigated by wearing high-top shoes.
- Physical examination findings consistent with subtalar joint arthritis may include:
  - Hindfoot swelling
  - Tenderness within the sinus tarsi
  - Pain with inversion and eversion of the hindfoot
  - Limited range of motion of the subtalar joint
  - Antalgic gait
- To help localize the pathology to the subtalar joint complex, palpate and observe the sinus tarsi (the soft tissue depression just anterior and slightly distal to lateral malleolus) for swelling.
- Passively dorsiflex the ankle to neutral to lock the talus within the mortise. Descriptions of normal subtalar range of motion vary widely. Therefore, it is useful to describe the range as a fraction of the asymptomatic, contralateral side. Pain and decreased range of motion may be indicative of subtalar joint arthritis. Complete loss of range of motion is consistent with a tarsal coalition.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs should include standing AP, lateral, and oblique views of the foot, and standing AP, lateral, and mortise views of the ankle.
- Additional plain radiographs may include a Broden’s view (lower extremity internally rotated 45 degrees, x-ray tube angled 10 to 40 degrees cephalad) to evaluate the posterior subtalar facet, and a Canale view (AP view of the foot in 15 degrees of pronation with tube angled 75 degrees from the horizontal) to evaluate the sinus tarsi.
- Radiographic findings consistent with a degenerative process include joint space narrowing, osteophytes, and subchondral cysts or sclerosis (FIG 1).
Computed tomography and magnetic resonance imaging offer little additional information about the arthritic process involving the subtalar joint, but they may identify a previously undiagnosed tarsal coalition or concomitant soft tissue pathology.

A diagnostic injection of a local anesthetic into the subtalar joint may help localize the patient’s complaints, and if a corticosteroid is added to the injection, this procedure may provide significant short-term relief.

DIFFERENTIAL DIAGNOSIS

- Primary osteoarthrosis
- Posttraumatic arthritis
- Inflammatory arthritis
- Acute fracture
- Sinus tarsi syndrome
- Instability of the subtalar joint or subtalar sprain
- Fibrous or cartilaginous talocalcaneal coalition
- Subtalar loose body

NONOPERATIVE MANAGEMENT

- Subtalar joint arthritis is initially managed nonoperatively in all patients.
- Nonoperative management strategies may include:
  - Activity modification
  - Nonsteroidal anti-inflammatory medications
  - Intra-articular corticosteroid injection
  - Use of an ankle-foot orthosis or UCBL orthosis to limit hindfoot motion. Other options include an air stirrup or high-top boot.
  - Patellar tendon–bearing brace to unload the subtalar joint
- Conservative treatment may also be indicated in patients with significant peripheral vascular disease, active infection, inability to comply with the postoperative regimen, or a severe sensory neuropathy.

SURGICAL MANAGEMENT

- For patients who do not achieve relief with an adequate trial of nonoperative management, surgical intervention is warranted.

Preoperative Planning

- Plain radiographs are reviewed for deformity or malalignment, loose bodies, or retained hardware from a prior surgery.
- Computed tomographic or magnetic resonance imaging scans are reviewed, if available.

Positioning

- The patient is placed supine on the operative table, and the sole of the foot is aligned with the end of the bed to facilitate later screw insertion into the heel.
- A pneumatic tourniquet is placed around the upper thigh, and a soft bump is placed beneath the ipsilateral sacrum to internally rotate the operative extremity. Placement of the bump beneath the sacrum, rather than beneath the buttock, will prevent any undue pressure on the sciatic nerve.
- The fluoroscopy unit is brought in from the contralateral side of the bed.

Approach

- A tourniquet is elevated to a pressure of 100 mm Hg greater than the patient’s systolic pressure.
- The incision begins approximately 1 cm below the tip of the lateral malleolus and progresses distally to a point just shy of the base of the fourth metatarsal (FIG 2A). Alternatively, a modified Ollier incision may be used.
- The subcutaneous tissue is incised in line with the skin incision, and preemptive hemostasis of any crossing vessels is performed using electrocautery.
- The origin of the extensor digitorum brevis muscle is identified and elevated along with the sinus tarsi fat pad as a distally based flap. A small cuff of tissue is preserved proximally for later reattachment of this flap (FIG 2B,C).
- At this point, the subtalar joint is well visualized.
PREPARATION OF THE ARTHRODESIS SITE

- After adequate visualization of the lateral aspect of the subtalar joint has been attained, any remaining fatty or ligamentous tissue is removed from the joint with a rongeur (TECH FIG 1A).
- Using a straight curette or chisel, the articular cartilage is removed from the lateral half of the inferior talus and superior aspect of the calcaneal facets (TECH FIG 1B). Note that the goal is to maintain the normal, curved contours of the articular facets.
- A lamina spreader is then inserted to allow access to the medial half of the joint, which is then cleared of its articular cartilage using a combination of straight and curved curettes (TECH FIG 1C).
- After complete removal of all articular cartilage, K-wire holes are created in the denuded inferior surface of the talus and the superior surface of the calcaneus to produce vascular channels that will aid in the fusion (TECH FIG 1D). These K-wire holes may be further augmented with larger holes created through the use of a 3-mm burr, and by feathering of the subchondral bone with a curved osteotome.
- Cancellous autograft obtained from the proximal tibia (see Techniques) is inserted into the subtalar joint, and the extensor digitorum brevis muscle is reattached to its site of origin to help seal the fusion site (TECH FIG 1E).

INSERTION OF HARDWARE

- At this point, the subtalar joint is positioned into 5 degrees of valgus.
- A 1-cm incision is created at the apex of the heel for insertion of a guide pin, which is subsequently driven through the posterior tuberosity, across the subtalar joint, and into the talar neck (TECH FIG 2A). This guide pin is placed fluoroscopically using axial (Harris) heel and lateral views.
- A second guide pin is placed through a 1-cm incision just medial to the anterior tibialis tendon into the dorsomedial aspect of the talar neck, across the subtalar joint, and into the posterior calcaneal tuberosity (TECH FIG 2B).
- The initial guide pin is occasionally overreamed proximally (not necessary with self-drilling, self-tapping screws), and a 6.5-mm partially threaded cancellous lag screw of an appropriate length is inserted after minimal use of the cannulated countersink. This procedure is repeated for the dorsomedial lag screw.
- Final fluoroscopic images are obtained to verify proper screw position (TECH FIG 2C).
The tourniquet is released and hemostasis is secured.

The wound is then closed using 2-0 Vicryl for the subcuticular layer and 3-0 nylon horizontal mattress sutures for the skin.

**WOUND CLOSURE**

- The tourniquet is released and hemostasis is secured.
- The wound is then closed using 2-0 Vicryl for the subcuticular layer and 3-0 nylon horizontal mattress sutures for the skin.

**HARVESTING OF TIBIAL BONE GRAFT**

- An incision beginning 1 cm distal to the distal aspect of the tibial tubercle and 1 cm lateral to the anterior tibial crest is carried distally for a length of 4 cm (**TECH FIG 3A**).
- The fascia overlying the anterior compartment musculature is divided in line with the skin incision.
- Muscle and periosteum overlying the anterolateral face of the tibia is elevated using a periosteal elevator, thus exposing the anterolateral cortex (**TECH FIG 3B**).
- A 1 by 1-cm square (or elliptical) window is created in the center of the anterolateral face, and a curette is inserted into the window for removal of cancellous graft (**TECH FIG 3C,D**).
- After an adequate amount of cancellous graft is harvested, the window is sealed with the previously removed square plug of bone, and a layered closure of the fascia, subcutaneous tissue, and skin is performed.
- Time from graft harvest to insertion into the fusion site should be less than 30 minutes.

**TECH FIG 2** • Internal fixation. **A.** Placement of the first guide pin and screw from the apex of the calcaneal tuberosity. **B.** Placement of the second guide pin and screw from the dorsomedial aspect of the talar neck. **C.** Final fluoroscopic images.

**TECH FIG 3** • Harvesting of the tibial bone graft. **A.** Incision. **B.** Periosteal elevation along the anterolateral cortex. (continued)
POSTOPERATIVE CARE

- The extremity is placed in a well-padded, non-weight-bearing short leg plaster cast before the patient leaves the operating room.
- In the recovery room, the cast is widely split along its anterior surface to allow for immediate postoperative swelling.
- The patient is seen in clinic at 2 weeks postoperatively, at which point the initial cast and sutures are removed.
- A short leg fiberglass cast is applied and the patient is kept non-weight-bearing.
- At the 6-week mark, radiographs are obtained, and the patient is converted to a fiberglass short leg walking cast.
- If radiographic union is appreciated at the 12-week appointment, casting is discontinued and gentle range of motion of the foot and ankle is initiated. At this point, the patient is often placed in a CAM walker to ease the transition from the cast to normal shoe wear.

OUTCOMES

- In another study by Mann and Baumgarten, subtalar joint fusion in 6 degrees of valgus resulted in the maintenance of approximately 50% of the transverse tarsal joint motion as compared with the unaffected, contralateral extremity. In this same study, minimal degenerative changes were noted at the talonavicular and calcaneocuboid joints, a finding that was not clinically significant.
- In a retrospective study, Dahm and Kitaoka demonstrated a 96% union rate in 25 adult feet.
- Similarly, Easley et al demonstrated a 96% subtalar fusion rate after excluding smokers, revision arthrodeses, fusions using a structural graft, and subtalar fusions performed in an extremity with a previously fused tibiotalar joint.

COMPLICATIONS

- Infection
- Nonunion
- Malalignment
  - Varus leading to increased lateral column forefoot pressures
  - Valgus leading to subfibular impingement
- Symptomatic hardware
- Superficial wound breakdown
- Reflex sympathetic dystrophy

PEARLS AND PITFALLS

| Preparation of joint surfaces | Remove articular cartilage only. |
| Positioning of arthrodesis | The arthrodesis is ideally placed in 5 degrees of valgus. |
| Internal fixation | Use of a partially threaded cancellous lag screw with a short threaded region will reduce the likelihood of any threads crossing the arthrodesis site. |

- Preservation of subchondral bone will provide structural support and will allow for better coaptation.
- Use of a K-wire to perforate the residual subchondral bone of the talus and calcaneus will allow communication between the marrow cavities and the arthrodesis site, and will aid in the fusion.
- Fusing the subtalar joint in varus will lock the transverse tarsal joint, leading to increased lateral forefoot pressures with weight bearing.
- Fusing the subtalar joint in excessive valgus can potentially lead to subfibular impingement.
- Use of a partially threaded cancellous lag screw with a short threaded region will reduce the likelihood of any threads crossing the arthrodesis site.
- Countersinking of the screw heads and avoidance of a screw head placed on the weight-bearing plantar surface of the calcaneus will reduce complaints related to the hardware.
REFERENCES

DEFINITION
- A calcaneal malalignment refers to residual bony malalignment and associated clinical sequelae resulting from inadequate treatment of a displaced intra-articular calcaneal fracture.

ANATOMY
- The calcaneus is an odd-shaped bone that supports full body weight and provides a lever arm through which the powerful gastrocnemius-soleus complex assists with forward propulsion during gait (FIG 1).
- The calcaneus also provides articulations for the subtalar and calcaneocuboid joints, and thus is integral to function of the triple joint complex of the hindfoot for normal ambulation and accommodation to uneven ground (FIG 2).
- The normal orientation of the calcaneus is reflected radiographically as calcaneal pitch, talocalcaneal height, and calcaneal length, which directly affect the three-dimensional alignment of the hindfoot and midfoot and indirectly affect ankle dorsiflexion (FIG 3).

PATHOGENESIS
- In a displaced intra-articular calcaneal fracture, there is typically not only intra-articular displacement of the posterior facet but also loss of calcaneal height, shortening and varus angulation of the calcaneal tuberosity, extension into the anterior process or calcaneocuboid joint, and expansion of the lateral calcaneal wall.
- Nonoperative treatment, or inadequate operative treatment, of a displaced intra-articular calcaneal fracture results in a calcaneal malalignment, which affects function of the ankle, subtalar, and calcaneocuboid joints and leads to pain and disability.4,15 Associated sequelae include:
  - Posttraumatic subtalar and calcaneocuboid arthritis due to residual articular incongruity8,17
  - Lateral subtibial impingement from residual lateral wall expansion and heel widening8,16
  - Peroneal tendon stenosis, tenosynovitis, or subluxation—dislocation as a result of adjacent bony prominence5,12
  - Anterior ankle impingement and loss of ankle dorsiflexion due to loss of calcaneal height, resulting in relative dorsiflexion of talus3
  - Hindfoot malalignment (typically varus) affecting gait pattern and shoe wear and potentially producing a leg-length discrepancy13

NATURAL HISTORY
- Patients with displaced intra-articular calcaneal fractures that go on to malunion typically have a poor result, including pain with weight bearing, limitations in shoe wear, secondary gait alterations, and progressive posttraumatic subtalar arthritis.6,11

PATIENT HISTORY AND PHYSICAL FINDINGS
- History of prior calcaneal fracture (displaced intra-articular fracture) (the examiner should note the prior method of treatment, operative or nonoperative)
- Pain with weight bearing (standing or walking, particularly on uneven terrain)
- Thorough examination of the ankle and hindfoot should also include assessment of:
  - Skin and soft tissue envelope, including location of previous surgical incisions, overall mobility of lateral hindfoot skin, swelling, or any dystrophic changes where present
  - Neurovascular status (particularly the presence or absence of palpable pulses)
  - Hindfoot malalignment: excessive hindfoot varus or valgus relative to uninvolved limb represents malalignment
  - Subtalar range of motion: decreased subtalar range of motion may result from posttraumatic arthritis
  - Subtalar arthritis: tenderness to palpation suggests articular degeneration
  - Subtibial impingement, bony prominence, and tenderness suggest peroneal stenosis or tenosynovitis from residual lateral wall expansion. Peroneal tendons may actually be subluxed or dislocated in severe cases.
Ankle range of motion: decreased dorsiflexion compared to uninvolved limb may indicate anterior impingement from relative dorsiflexion of talus and loss of calcaneal height.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standard weight-bearing radiographs of the ankle and foot, in addition to a Harris axial view of the calcaneus, reveal the calcaneal malunion.
- The lateral view of the hindfoot demonstrates loss of calcaneal height and relative dorsiflexion of the talus (FIG 4).
- The mortise view of the ankle demonstrates residual lateral wall expansion and degenerative changes in the subtalar joint, as well as a fracture-dislocation variant fragment where present (FIGS 5 AND 6).
- The axial view shows residual shortening of the calcaneus, and any hindfoot malalignment where present (FIG 7).
- Once the diagnosis is established, a CT scan of the calcaneus, including axial, sagittal, and 30-degree semicoronal images, further delineates the extent of subtalar and calcaneocuboid arthritic change, hindfoot malalignment, lateral wall exostosis, and subfibular impingement, as well as any associated talar or other ankle joint pathology (FIGS 8–10).

**DIFFERENTIAL DIAGNOSIS**

- Posttraumatic subtalar arthritis (without malunion)
- Subtalar osteoarthritis

**NONOPERATIVE MANAGEMENT**

- Nonoperative treatment options are limited but consist primarily of supportive modalities to lessen inflammation and painful motion through the hindfoot.
- A lace-up ankle brace, UCBL, ankle–foot orthosis, or Arizona-type brace may be beneficial in limiting painful subtalar motion and providing symptomatic relief. A prefabricated fracture boot may be used intermittently for episodes of arthritic flare-up.
Intermittent use of nonsteroidal anti-inflammatory medication can also be beneficial in disrupting the inflammatory cycle.

Activity modification, such limited standing and walking, particularly on uneven terrain, may also lessen symptoms.

**SURGICAL MANAGEMENT**

We use the Stephens-Sanders classification system and treatment protocol for calcaneal malunions, which is based on CT evaluation. Type I malunions include a large lateral wall exostosis, with or without far lateral subtalar arthrosis. Type II malunions include a lateral wall exostosis and subtalar arthrosis involving the entire width of the joint. Type III malunions include a lateral wall exostosis, subtalar arthrosis, and malalignment of the calcaneal body resulting in significant hindfoot varus or valgus angulation (FIG 11).

**Preoperative Planning**

- The calcaneal malunion is evaluated with plain radiographs and CT scan and classified according to the Stephens-Sanders classification. Treatment is based strictly on malunion type:
  - Type I malunions are managed with a lateral wall exostectomy and a peroneal tenolysis.
  - Type II malunions are managed with a lateral wall exostectomy, peroneal tenolysis, and a subtalar bone block arthrodesis, using the excised lateral wall as autograft.
  - Type III malunions are managed with a lateral wall exostectomy, peroneal tenolysis, subtalar bone block arthrodesis, and a calcaneal osteotomy to correct hindfoot malalignment.
- The procedure requires use of a radiolucent table and a standard C-arm.
A pneumatic thigh tourniquet is used. The procedure should be completed within 120 to 130 minutes of tourniquet time to minimize potential wound complications.

**Positioning**
- The patient is placed in the lateral decubitus position on a beanbag. The lower extremities are positioned in a scissor configuration such that the operative (“up”) limb is flexed at the knee and angles toward the distal, posterior corner of the operating table, while the nonoperative (“down”) limb is extended at the knee and lies away from the eventual surgical field. This facilitates intraoperative fluoroscopy without interference from the nonoperative limb. Padding is placed beneath the contralateral limb to protect the peroneal nerve, and an operating “platform” is created with blankets and foam padding to elevate the operative limb (FIG 12).
- Alternatively, the prone position may be used for bilateral procedures.

**Approach**
- We use the extensile lateral approach for surgical management of the calcaneal malunion, regardless of malunion type.

The lateral calcaneal artery, typically a branch of the peroneal artery, supplies the majority of the full-thickness flap. Thus, strict attention to detail with respect to placement of the incision and gentle handling of the soft tissues is of paramount importance.
- The planned extensile lateral approach is then outlined on the skin:
  - The incision begins about 2 cm proximal to the tip of the lateral malleolus, just lateral to the Achilles tendon and thus posterior to the sural nerve and the lateral calcaneal artery, and the vertical limb extends toward the plantar foot.
  - The horizontal limb is drawn along the junction of the skin of the lateral foot and heel pad; this skin demarcation can be identified by compressing the heel. We substitute a gentle curve where these two lines combine to form a right angle, primarily to avoid apical necrosis. The horizontal limb also includes a gentle anterior curve along the skin creases distally, ideally ending over the calcaneocuboid articulation (FIG 13).
EXTENSILE LATERAL APPROACH

- Place the limb on a sterile bolster and begin the incision at the proximal portion of the vertical limb. It becomes full thickness at the level of the calcaneal tuberosity—literally “straight to bone,” while avoiding any beveling of the skin. Again lessen scalpel pressure beyond the apical curve of the incision, and develop a layered incision along the horizontal limb of the incision.
- Raise a full-thickness, subperiosteal flap starting at the apex, specifically avoiding use of retractors until a considerable subperiosteal flap is developed, in order to prevent separation of the skin from the underlying subcutaneous tissue (TECH FIG 1A).
- Sharply release the calcaneofibular ligament from the lateral wall of the calcaneus, and release the adjacent peroneal tendons from the peroneal tubercle through the cartilaginous “pulley” to avoid iatrogenic injury (TECH FIG 1B).
- Use a periosteal elevator to gently mobilize the tendons along the distal portion of the incision, which then exposes the anterolateral calcaneus. Thus, the peroneal tendons and sural nerve are contained entirely within the flap, and devascularization of the lateral skin is minimized (TECH FIG 1C).
- Continue deep dissection to the sinus tarsi and anterior process region anteriorly, the calcaneocuboid joint distally, and the superior-most portion of the calcaneal tuberosity posteriorly.
- Place three 1.6-mm Kirschner wires for retraction of the subperiosteal flap: one into the fibula as the peroneal tendons are slightly subluxed anterior to the lateral malleolus; a second in the talar neck; and a third in the cuboid as the peroneal tendons are levered away from the anterolateral calcaneus with a periosteal elevator. Thus, each Kirschner wire retracts its respective portions of the peroneal tendons and full-thickness skin flap (TECH FIG 1D).

LATERAL WALL EXOSTECTOMY

- A lateral wall exostectomy is completed for all three malunion types.
- Starting posteriorly, angle the A/O osteotomy saw blade slightly medially relative to the longitudinal axis of the calcaneus, preserving more bone plantarly and thereby providing decompression of the subfibular impingement (TECH FIG 2A, B).
- Take care throughout the exostectomy to avoid violation of the talofibular joint: place a small Bennett-type retractor at the level of the posterior facet (TECH FIG 2B).

- Continue the exostectomy to the level of the calcaneocuboid joint and complete it with an osteotome. Remove the fragment en bloc as a single fragment and preserve it in saline on the back table for later use as autograft (TECH FIG 2C).

- The width of the exostectomy fragment varies (about 10 to 15 mm) but is generally proportional to the extent of loss of calcaneal height and lateral wall expansion from the original injury, which reflects the amount of initial energy involved.

- SUBTALAR BONE BLOCK ARTHRODESIS

  - In patients with a type II or III malunion, gently mobilize the subtalar joint with a small osteotome, carefully identifying the plane of the posterior facet.

  - Place a laminar spreader and meticulously débride the joint of any residual articular surface while preserving the underlying subchondral bone; we prefer to use a sharp periosteal elevator and pituitary rongeur.

  - Irrigate the joint and make multiple perforations in the subchondral surface with a 2.5-mm drill bit to stimulate vascular ingrowth. Place highly concentrated platelet aspirate both within the joint and upon the previously resected lateral wall fragment.

  - Place the lateral wall fragment within the subtalar joint as an autograft bone block; we prefer to place the laminar spreader posteriorly to facilitate bone block placement (TECH FIG 3A).

  - Position the fragment such that the widest portion of the autograft is oriented posteromedially to avoid varus malalignment (TECH FIG 3B).

  - Fill any remaining voids within the subtalar joint with supplemental allograft.

  - With the subtalar joint held in neutral to slight valgus alignment, obtain definitive stabilization with two large (6.5 to 8.0 mm) partially threaded cannulated screws placed from posterior to anterior in diverging fashion: the more lateral screw is placed in the talar dome, while the more medial screw is placed in the talar neck.

  - A third screw may be placed extending from the anterior process region into the talar neck and head, avoiding violation of the talonavicular articulation (TECH FIG 4).
TECH FIG 3 • Placement of autograft bone block. 
A. Note position of laminar spreader within subtalar joint posteriorly. B. Postoperative semicoronal CT image demonstrating proper orientation of autograft bone block (black triangle), with widest portion placed posteromedially.

TECH FIG 4 • Definitive stabilization. A. Intraoperative fluoroscopic lateral view demonstrating diverging orientation of large cannulated screws posteriorly, and supplemental screw traversing middle facet. B. Intraoperative fluoroscopic mortise view; note slight medial angulation to avoid violation of talofibular joint. C. Intraoperative fluoroscopic anteroposterior view; note transverse orientation of anterior screw, avoiding violation of talonavicular joint (black arrows). D. Intraoperative fluoroscopic axial view; note neutral hindfoot alignment.
CALCANEAL OSTEOTOMY

- For patients with a type III malunion, angular malalignment in the calcaneal tuberosity is corrected before implant placement.
- A Dwyer-type closing wedge osteotomy is performed for those with varus malalignment (TECH FIG 5).
- A medial displacement calcaneal osteotomy is used for those with valgus malalignment (rare).
- Because the plane of the osteotomy is nearly parallel to the plane of the posterior facet, the osteotomy and subtalar joint are stabilized simultaneously as described above.

TECH FIG 5 • Calcaneal osteotomy. Dwyer closing wedge osteotomy for correction of varus malalignment in calcaneal tuberosity.

PERONEAL TENOLYSIS

- Remove the Kirschner wire retractors and incise the peroneal tendon sheath along the undersurface of the subperiosteal flap over a length of 2 to 3 cm. A peroneal tenolysis is then completed.
- Advance a Freer elevator within the tendon sheath to the level of the lateral malleolus proximally, thereby mobilizing the peroneal tendons.
- Assess the competence of the superior peroneal retinaculum (SPR) by gently levering the Freer elevator forward while observing the overlying skin. The presence of an endpoint indicates an intact retinaculum, but with an incompetent SPR the elevator will easily slide anterior to the lateral malleolus, with no demonstrable endpoint.
- Advance the Freer elevator within the tendon sheath distally to the cuboid tunnel.

SUPERIOR PERONEAL RETINACULUM REPAIR

- If the SPR is incompetent, make a separate 3-cm incision along the posterior border of the lateral malleolus, exposing the tendon sheath.
- With the peroneal tendons held reduced in the peroneal groove, use one or two suture anchors to secure the detached SPR to bone (TECH FIG 6).
- Reassess tendon stability using a Freer elevator in the same manner.

TECH FIG 6 • Superior peroneal retinaculum repair and suture imbrication of incompetent superior peroneal retinaculum.

CLOSURE

- Place a deep drain exiting proximally in line with the vertical limb of the incision.
- Place deep no. 0 absorbable sutures in interrupted, figure 8 fashion, beginning with the apex of the incision and progressing to the proximal and distal ends. The sutures are temporarily clamped until all sutures have been passed, then hand-tied sequentially, starting at the proximal and distal ends, and working toward the apex of the incision, so as to eliminate tension at the apex of the wound (TECH FIG 7A).
- Because of the lateral decompression from the exostectomy, the flap should close fairly easily with minimal tension (despite restoration of calcaneal height).
- Close the skin layer with 3-0 monofilament suture using the modified Allgöwer-Donati technique, again starting at the ends and working toward the apex (TECH FIG 7B).
- Deflate the tourniquet and place sterile dressings, followed by a bulky Jones dressing and Weber splint.
TECH FIG 7 • Flap closure. A. Deep absorbable sutures placed and temporarily clamped. B. Skin closure using modified Allgöwer-Donati technique.

PEARLS AND PITFALLS

Lateral wall exostectomy
- Avoid violating the talofibular joint during lateral wall exostectomy.
- Gently place a small Bennett-type retractor within the subtalar joint at the level of the posterior facet to protect the talofibular joint.

Placing autograft bone block
- Use of an additional laminar spreader at the crucial angle of Gissane may facilitate graft placement.
- Release of the deltoid ligament should be strictly avoided as this destabilizes the ankle joint.
- The peripheral margin of the fragment may need to be shaped slightly to prevent overhang and prominence laterally.

Definitive stabilization
- Avoid violating the talofibular joint by angling slightly medially during placement of guide pins (FIG 14A).
- Fluoroscopic visualization of the ankle joint before screw placement is of paramount importance (FIG 14B).

FIG 14 • Axial orientation of guide pins traversing posterior facet of subtalar joint. A. Intraoperative photo. B. Intraoperative fluoroscopic view. Note slight medial angulation to avoid violation of talofibular joint.
Fracture-dislocation variant patterns

POSTOPERATIVE CARE

- For type I malunions, the patient is converted to a prefabricated fracture boot at 2 weeks postoperatively. Weight bearing and range-of-motion exercises are initiated once the incision has fully healed.
- For type II or type III malunions, the patient is converted to a short-leg non-weight-bearing cast at 2 to 3 weeks and again at 6 to 7 weeks postoperatively. Weight bearing is not permitted until 10 to 12 weeks postoperatively, at which point radiographic union is confirmed.
- The patient is then converted to a prefabricated fracture boot, and weight bearing is initiated. The patient is gradually transitioned to regular shoe wear and activity is advanced as tolerated thereafter.

OUTCOMES

- This is intended as a salvage procedure for pain relief and restoration of alignment.
- We recently reported our intermediate- to long-term results of this protocol:
  - The initial arthrodesis union rate was 93%.
  - Ninety-three percent had neutral or slight valgus hindfoot alignment; 100% had plantigrade foot.
  - There was no statistical difference in outcome scores among the three malunion types.
  - Significantly greater restoration of talocalcaneal height was found among patients with type III malunions.

COMPLICATIONS

- Delayed wound healing, wound dehiscence, deep infection
- Arthrodesis delayed union or nonunion
- Postoperative ankle stiffness
- (Late) Lateral ankle (“sprain”) pain from coronal plane stresses applied to ankle joint
- (Late) Compensatory ankle joint arthritis (theoretical)

REFERENCES

DEFINITION
- Malunited calcaneal fractures pose a complex reconstructive problem.
- The presenting symptoms are caused by posttraumatic subtalar and calcaneocuboid arthritis, fibulocalcaneal impingement that displaces the peroneal tendons, talotibial impingement due to the loss of normal talar inclination, and sural nerve entrapment.

ANATOMY
- As the calcaneus is exposed to axial loading, stress occurs obliquely across the tuberosity as the tuber is lateral to the axis of the tibia (FIG 1).
- Burdeaux was unable to produce calcaneal fractures with the heel inverted and in the line of the tibia.
- The bone fails along this line. The tuberosity translates proximally, laterally, and anteriorly. The lateral posterior facet is driven plantarly into the calcaneus by the talus, causing a fracture at the angle of Gissane and either a tongue or joint depression pattern posteriorly. The lateral wall expands outward, further widening the heel (FIG 2).
- Calcaneal fractures have certain recurrent patterns.
- There are four major fragments: the tuberosity, posterolateral facet, sustentaculum, and anterolateral fragments. The sustentacular fragment stays in anatomic position (FIG 2).

PATHOGENESIS
- When union occurs in this pathologic position, the lateral and proximal displacement of the tuberosity causes calcaneus–fibular impingement and displacement of the peroneal tendons.
- The disruption of the posterior facet causes posttraumatic subtalar arthritis.
- The loss of height of the heel results in the loss of the talar inclination angle and tibial talar impingement.
- Plantar subluxation of the navicular at the talonavicular joint may also occur (FIG 3).

FIG 1 • Offset forces cause internal stress, which results in primary oblique fracture. (From Kitaoka H. Master Techniques of Orthopedic Surgery series: Foot and Ankle, 2nd ed. Philadelphia: Lippincott Williams & Wilkins, 2002, with permission.)

FIG 2 • A. Diagram of fracture demonstrating primary oblique fracture, lateral, and proximal displacement of tuberosity, impaction of posterior lateral facet, and expansion of lateral wall. B. CT scan of acute calcaneal fracture demonstrating the fracture and displacement. C. Three-dimensional volumetric reconstruction of acute fracture demonstrating the displacements. (From Kitaoka H. Master Techniques of Orthopedic Surgery series: Foot and Ankle, 2nd ed. Philadelphia: Lippincott Williams & Wilkins, 2002, with permission.)
NATURAL HISTORY

- The anatomic disruption, posttraumatic arthritis, and impingement cause increasing pain with activity.
- The stiff malpositioned hindfoot will lead to arthritic changes at the talonavicular joint.
- Tibial talar impingement and loss of ankle dorsiflexion puts more stress on the transverse tarsal articulation, causing secondary arthritis there.
- The displacement of the peroneal tendons and peroneal impingement will eventually cause tendinosis or tear.

PATIENT HISTORY AND PHYSICAL FINDINGS

- There will be a history of a calcaneal fracture, which may have been treated by nonoperative or operative means. Not all patients will know that they have had a heel fracture.
- Symptoms include pain at the fibulocalcaneal junction and sinus tarsi. Hypoesthesia or dysesthesia in the sphere of the sural nerve may be present.
- Physical findings are the loss of the usual step-off or indentation just distal to the tip of the fibula, loss of subtalar motion, and some loss of dorsiflexion of the ankle.
- The examiner should look for hypoesthesia in the sphere of the sural nerve with a positive percussion or Tinel test.
- Methods for examining malunited calcaneal fractures include:
  - Examining for loss of “fibular sulcus.” The physician should palpate the area just distal to the tip of the fibula of both ankles. With a calcaneal malunion, there will be no sulcus for the peroneal tendons. This is indicative of the lateral displacement of the tuberosity fragment and “blow out” of the lateral wall, causing fibulocalcaneal impingement.
  - Evaluating for hindfoot stiffness. The physician should examine the range of motion of the hindfoot, checking inversion and eversion. A malunion will have little if any motion, which may be painful. The stiffness is indicative of subtalar arthritis and scarring of the subtalar joint.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiographs show loss of the angle of Bohler, loss of talar inclination, and widening of the heel.
- The primary fracture line is often identifiable on axial heel views and Broden views.
CT scans show all of the above and give information about the internal architecture of the heel, confirming the deformity, impingements, and arthritis.

DIFFERENTIAL DIAGNOSIS
- Posttraumatic subtalar arthritis without deformity
- Peroneal tendon tear
- Sural neuritis
- Tarsal coalition

NONOPERATIVE MANAGEMENT
- Judicious use of nonsteroidal anti-inflammatories (NSAIDs) will diminish some of the symptoms, as will sparing use of steroid injections into the sinus tarsi.
- Bracing the foot and ankle as well as the use of heel cups or heel lifts may provide some relief.

SURGICAL MANAGEMENT
- This technique is capable of correcting height losses of up to 1.5 cm. Greater height loss will require augmentation with an interpositional bone block.
- The correction-limiting factor is the amount of bone available for transverse fixation as the fragments slide relative to each other. Moving the fixation anteriorly will give windows for fixation as less translation occurs in this portion of the calcaneus.
- Indications include malunited calcaneal fractures that exhibit the signs and symptoms of fibulocalcaneoperoneal impingement, posttraumatic subtalar arthritis, loss of the angle of Bohler (and talar inclination), widening of the heel, and tibial talar impingement. Not all of these need to be present.
- Joint depression fractures are better suited for correction by this procedure than tongue-type fractures.
- If painful arthritis is present at the calcaneocuboid joint, arthrodesis of this joint may be added to the procedure.
- Smoking, diabetes, and vascular impairment must be evaluated in each patient and certainly can be contraindications to the procedure.

Preoperative Planning
- Quality radiographs are essential.
- Radiographs include weight-bearing AP, lateral, axial heel, and Broden views of the affected foot.
- A weight-bearing lateral view of the unaffected foot will provide normal parameters for the patient and allow measurement of the deformity and the amount of correction desired.
- The AP view will show the calcaneocuboid joint, which may be involved.
- The lateral view will demonstrate the loss of height and loss of talar inclination and will demonstrate tibial talar impingement.
- The axial heel film will show the oblique primary fracture line and shift of the tuberosity.
- Broden views will show the subtalar joint and demonstrate fibular calcaneal impingement.
- A CT scan of the foot with axial, semicoronal, sagittal, and three-dimensional volumetric reconstructions is suggested.
- This study will confirm what is suggested by the plain films and provide a “blueprint” of the internal architecture of the calcaneus (FIG 4).

FIG 4 • A. AP radiograph of foot with calcaneal malunion affecting the calcaneocuboid joint. B. Lateral view of calcaneal malunion showing loss of angle of Bohler, loss of talar inclination, and anterior tibial talar impingement. C. Broden view of calcaneal malunion showing tuberosity translation, lateral impingement, and subtalar arthritis. D. Axial heel view of calcaneal malunion showing oblique primary fracture line, displacement of the tuberosity, and lateral impingement.
Special instruments for the procedure are required:
- 7.0-mm cannulated screws (we tend to use fully threaded screws)
- Anterior cruciate ligament drill guide to assist in placement of the guidewire for the 7.0-mm cannulated screws
- Baby Inge lamina spreaders, with and without serrations
- “Calcaneal spreaders”—wide, flat-faced, and Steinmann pin fixation spreaders (FIG 5)
- Smaller screws; 3.5-, 4.0-, or 4.5-mm cannulated screws for transverse fixation
- A “power” osteotome is helpful.

Positioning
- The patient is positioned in lateral decubitus with the affected limb up. A tourniquet is applied to the thigh. The entire leg as well as the iliac crest is prepared and draped.

Approach
- A straight incision is made from just below the tip of the fibula, directed anteriorly in the line of the fourth–fifth ray interval past the calcaneocuboid joint. (Slight posterior elongation of the incision may be needed.)
- The area at the tip of the fibula is often congested due to the impingement, and the peroneal tendons will be displaced (FIG 6).
OBLIQUE CALCANEAL OSTEOTOMY WITH SUBTALAR ARTHRODESIS

- Enter the subtalar joint and mobilize it.
- Place a baby Inge lamina spreader in the sinus tarsi to distract the joint. Incise the scar and capsule including the fibulocalcaneal ligament laterally.
- Incise the posterior capsule and clear tissue from the posterior calcaneus up to the flexor hallucis longus tendon, which can be observed through the joint.
  - Do not incise the interosseous ligaments if possible, as these will help stabilize the sustentacular fragment to the talus (TECH FIGS 1, 2).
- The fracture line can usually be observed on the surface of the posterior facet of the calcaneus. Mark this line (TECH FIG 3).
- Decorticate the undersurface of the talus and the posterior facet of the calcaneus. Make sure that the fracture line is preserved or marked again.
- Under fluoroscopic control, drill a Steinmann pin from superior anterior lateral to inferior posterior medial in the plane of the primary fracture.
- Visualize this on the axial heel view, which may be obtained by having the C-arm in a horizontal plane or by externally rotating the leg to verify the pin placement (TECH FIG 4).
- I perform an osteotomy in the plane of the primary fracture, using the Steinmann pin as a guide. A saw is used to start the osteotomy, which may then be finished with osteotomes. This osteotomy exits the medial wall of the calcaneus posterior and inferior to the neurovascular bundle (TECH FIG 5).
- The most difficult part of the procedure then follows. This is shifting the tuberosity medially, plantarly, and slightly posterior.
- I first distract the fragments from each other by placing the calcaneal spreader, then lamina spreaders between the fragments to relax any soft tissue attachments.
  - The tuberosity may then be moved as far as possible easily, then “walked” further using small (quarter-inch to half-inch) curved osteotomes to lever the tuberosity down and the medial side up (TECH FIG 6).
- Steinmann pins may be inserted transversely into the medial fragment at the superior surface of the lateral fragment to act as “dead men” (carpentry term) to prevent loss of correction. On occasion a large Steinmann pin is

TECH FIG 1 • Peroneal tendons retracted, sinus tarsi and calcaneus exposed.

TECH FIG 2 • Subtalar joint opened; fracture can be observed.

TECH FIG 3 • Fracture marked and Steinmann pin placed in plane of fracture.

TECH FIG 4 • Intraoperative radiograph confirming Steinmann pin placement.
placed temporarily through the talus into the medial calcaneus to stabilize this fragment while the lateral tuberosity is being moved (TECH FIG 7).

- It is also helpful to plantarflex the ankle to relax the triceps surae, thus facilitating the plantar shift.
  - A smooth Steinmann pin may be placed across the anterior osteotomy to act as a pivot point to obtain more of a rotational correction (TECH FIG 7).
- I have had success with a Steinmann pin anchored calcaneal spreader placed from posteriorly, with one pin in the medial fragment and the second pin in the tuberosity.
  - Opening this spreader aids the shift, and twisting the instrument helps oppose the fragments (TECH FIG 8).
- Once the correction has been obtained, fixation from lateral to medial is obtained using the smaller cannulated screws in compression (TECH FIGS 9, 10).
- Use the anterior cruciate ligament drill guide to place a guide pin for the 7.0-mm cannulated screw. The entry point is the posterolateral tip of the tuberosity and the exit is through the medial aspect of the posterior facet, thus engaging fragments on both sides of the osteotomy (TECH FIGS 11, 12). Use the motion of the hindfoot complex to place the hindfoot in a neutral position. At this point in the procedure, the subtalar joint, talonavicular joint, and calcaneocuboid joint are mobile and height has been corrected. It is now possible to invert and evert the foot using the normal axis of motion of the hindfoot complex to a neutral position. (This is a crucial point of the procedure and differentiates it from interpositional bone block procedures where hindfoot position is dependent on the size and placement of the structural grafts.) Oppose the medial aspect of the subtalar joint to the talus and drive the guide pin into the talus. Stabilize the construct by a 7.0-mm screw in mild compression. Place a second screw if desired (TECH FIG 13).
- Check the ankle’s range of motion. If a triceps surae contracture limits ankle dorsiflexion, remedy it by a percutaneous Achilles tendon lengthening.
- Harvest bone graft from the iliac crest. This may be cancellous or a corticocancellous block. Fit this graft into the empty space under the talus created by the displacement of the tuberosity with the depressed portion of the lateral posterior facet. Position this graft only to the lateral border of the talus. If a corticocancellous block is chosen, impact it into the space after properly shaping it. I have usually used cancellous bone. Allograft bone may also be used (TECH FIG 14). If a calcaneocuboid arthrodesis is needed, it is done now.
- Place a small drain if needed, and close the wounds in layers. Apply a well-padded short-leg cast. I place an AV impulse pump bladder under the cast. The cast is bi-valved within 24 hours.
TECH FIG 9 • Transverse fixation with two cannulated compression screws.

TECH FIG 10 • Intraoperative radiograph, transverse screw placed, distractor in place.

TECH FIG 11 • Anterior cruciate ligament drill guide used to place guidewire for 7.0-mm screw through tuberosity and sustentaculum.

TECH FIG 12 • Tip of guidewire visible exiting sustentacular fragment. (From Kitaoka H. Master Techniques of Orthopedic Surgery series: Foot and Ankle, 2nd ed. Philadelphia: Lippincott Williams & Wilkins, 2002, with permission.)

TECH FIG 13 • 7.0-mm screw being inserted. (From Kitaoka H. Master Techniques of Orthopedic Surgery series: Foot and Ankle, 2nd ed. Philadelphia: Lippincott Williams & Wilkins, 2002, with permission.)

TECH FIG 14 • A. Final construct with bone graft in place. (continued)
Hansen has described an extra-articular oblique osteotomy combined with subtalar arthrodesis. This is done in a similar fashion. The osteotomy does not follow the primary fracture line, but parallels it outside the joint. The obliquity of the osteotomy may be varied.

A vertically oriented osteotomy displaced directly plantarly has also been described. This increases the height of the heel and is aimed at correcting the talar inclination. This osteotomy may be shifted medially as well.
**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Mobilization and shift of the tuberosity</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ensure that the lateral ligaments and scar about the subtalar joint are released. Also make sure that the posterior capsule and scar are released.</td>
<td></td>
</tr>
<tr>
<td>Separate the osteotomy side to side with lamina spreaders to stretch the soft tissue preliminary to the plantar shift.</td>
<td></td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- The drains are removed on the first postoperative day. The cast and bandages are changed on the third postoperative day. The patient is non-weight-bearing in a short-leg cast for 8 to 12 weeks until union is demonstrated.
- The patient then progresses to weight bearing as tolerated. A removable fracture boot may be used.
- Physical therapy is prescribed to gain ankle range of motion and calf strengthening.

**OUTCOMES**

- The first cases were reported in 1993. We have continued to perform this procedure over the intervening years; about 45 procedures have been performed. The results have been reproducible. A 1.5-cm correction and increase of the Bohler angle of 25 degrees can be expected. There have been no osteotomy nonunions and one nonunion of the subtalar fusion in a smoker. There have been two patients treated by osteotomy alone (no subtalar arthrodesis) with satisfactory results.

**COMPLICATIONS**

- Nonunions of the osteotomy or arthrodesis sites are possible but have not proven to be a problem. Malposition of the arthrodesis is possible, but attention to inversion–eversion before fixation of the calcaneal construct to the talus avoids this potential complication.
- Inadequate correction can be avoided by proper selection of patients. The magnitude of the deformity should be within the limits of correction described above. The surgeon should have patience and be persistent in gaining correction, especially in the initial procedures undertaken. The correction is not achieved immediately, but gradually as tissues are freed and stretch.
- Wound dehiscence due to skin tension after correction has not been a problem as the wound is anterior to the greatest correction. The skin is not stretched.

**REFERENCES**

DEFINITION
- Triple arthrodesis is a procedure performed to restore and maintain physiologic hindfoot alignment.
- It is typically reserved for:
  - Severe fixed deformity not amenable to joint-sparing procedures
  - Inflammatory arthropathy of the hindfoot

ANATOMY
- The hindfoot comprises the talus, calcaneus, navicular, and cuboid.
- Physiologic alignment is generally defined as a congruent talar–first metatarsal alignment in both the anteroposterior (AP) and lateral planes with weight bearing.
- The talar–calcaneal articulation is referred to as the subtalar joint.
- The combination of the talonavicular and calcaneocuboid articulations is known as the transverse tarsal joint.
- Multiple ligamentous static restraints support the hindfoot. In fact, in stance phase, the physiologically normal foot is balanced and plantigrade without any dynamic muscle forces acting on it.
- Physiologic hindfoot alignment is influenced by the ankle, midfoot, and forefoot.
- The hindfoot is a component of the ankle–hindfoot complex. To an extent, ankle malalignment can be compensated by the hindfoot.
- The foot is balanced when there is relatively even pressure distribution on the heel, first metatarsal–sesamoid complex, and the fifth metatarsal (ie, a plantigrade foot).
- Physiologically normal hindfoot alignment can be distorted by ankle, midfoot, and forefoot deformity.
- While the ankle is primarily responsible for dorsiflexion and plantarflexion, the hindfoot has some capacity to compensate in the sagittal plane with ankle stiffness, as evidenced by residual dorsiflexion and plantarflexion following ankle arthrodesis.
- Ambulation
  - With transition from heel strike to stance phase, the hindfoot becomes accommodative to the surface it contacts by “unlocking” the hindfoot joints.
  - With push-off, the posterior tibial tendon (PTT) inverts the hindfoot, thereby locking the transverse tarsal joints and hindfoot.
  - This converts the foot’s accommodative function to one of biomechanical advantage with creation of a rigid lever arm for the Achilles tendon.

PATHOGENESIS AND NATURAL HISTORY
- Hindfoot alignment is easily distorted by imbalance of its dynamic stabilizers, in particular the posterior tibial and peroneal tendons.
- If the imbalance persists and becomes chronic, the hindfoot’s static ligamentous restraints may weaken, creating a hindfoot deformity that ultimately may become fixed.
- PTT dysfunction leads to a flatfoot deformity with attenuation of the medial static restraints (spring ligament complex, medial talonavicular capsule) and pes planovalgus (flatfoot) deformity.
- Peroneal tendon dysfunction may lead to lateral ankle–hindfoot attenuation and a pes cavovarus (hindfoot varus) deformity.
- Posttraumatic or inflammatory arthritis may also create a stiff and painful hindfoot, with or without deformity.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The patient typically describes aching in the hindfoot, particularly in the sinus tarsi area, with weight bearing.
- There may be a report of a progressive deformity.
- Stiffness and swelling are common complaints.
- It is important to elicit a history of an inflammatory arthropathy.
- A neurologic and vascular examination is required.
- The patient should be examined while standing and ambulating.
- The deformity may not be obvious with the patient non–weight-bearing.
- Typically the patient will walk with a limp.
- A single limb heel rise for a patient with pes planovalgus deformity, if possible, will determine if the deformity is flexible and if the PTT is functional.
- With the patient seated, range of motion (ROM) is assessed.
- Inversion and eversion are almost always restricted in patients being considered for triple arthrodesis.
- The talus can be stabilized with a thumb on the talar neck to determine dorsiflexion and plantarflexion in the hindfoot.
- Ankle ROM and stability should be evaluated.
- An equinus contracture may be present and is important when considering surgery. Achilles tendon lengthening may be required to reposition the hindfoot anatomically. Many hindfoot deformities result in Achilles tendon contractures.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs of the weight-bearing foot in the AP, lateral, and oblique views (FIG 1).
- Occasionally, contralateral foot radiographs are useful in understanding what is physiologically normal for an individual.
- I routinely obtain ipsilateral ankle radiographs as well.
- In severe deformity there may be a pre-existing talus tilt.
  - If this is the case, proper operative realignment of the hindfoot may be compromised by the more proximal deformity.
  - One needs to be aware of pre-existing talar tilt or ankle malalignment to ensure that the hindfoot deformity is corrected appropriately.
  - I will check the ankle alignment fluoroscopically while realigning the hindfoot in surgery.
- Rarely is computed tomography or magnetic resonance imaging necessary.
Chapter 53 TRADITIONAL TRIPLE ARTHRODESIS 3869

NONOPERATIVE MANAGEMENT

Activity modification
- Nonsteroidal anti-inflammatory agents
- Corticosteroid injection
- Bracing
  - Lace-up brace
  - Hinged or fixed ankle-foot orthosis

SURGICAL MANAGEMENT

A spectrum of pathologies may warrant triple arthrodesis:
- Stage III posterior tibial tendinopathy
- Chronic peroneal tendinopathy
- Posttraumatic hindfoot arthritis
- Inflammatory arthritis
- Charcot neuroarthropathy
- Chronic spring ligament rupture
- If a joint-sparing procedure can be performed, it should be favored over triple arthrodesis.
- Selective hindfoot arthrodesis may also be considered.
- There has been a trend toward double arthrodesis in lieu of triple arthrodesis.

- The concept is to preserve the accommodative effect of the calcaneocuboid joint when possible and only perform talonavicular and subtalar joint arthrodeses.
- Isolated talonavicular joint arthrodesis restricts hindfoot motion by 90%.

Preoperative Planning

- The preoperative deformity needs to be assessed to determine what correction is warranted.
- If there is a severe pes planovalgus deformity, consider a single medial approach double arthrodesis to eliminate the risk of lateral wound problems that may occur with a lateral approach in such deformity.
- Equinus contracture: It may be necessary to lengthen the Achilles tendon to correct the deformity.

Equipment

- Fluoroscopy unit to confirm reduction and hardware placement
- Preferred screw (and plating or staple) system
- Bone graft is not required but may be useful to fill any voids or gaps with deformity correction.

Positioning

- With a traditional triple arthrodesis, the patient is placed on the operating table in a modified lateral decubitus position (“sloppy lateral position”; FIG 2). This allows access to the lateral and medial hindfoot.
- The patient’s torso is supported with a beanbag.
- An axillary roll is usually indicated.
- The contralateral hip is flexed slightly to make room for a stack of folded sheets on which the operative leg is placed.
- The opposite leg must be padded if it contacts the beanbag.
- I routinely use a thigh tourniquet if I am considering an Achilles tendon lengthening.
- If an Achilles tendon lengthening is unnecessary, a calf tourniquet is adequate.

Approach

- The traditional utilitarian lateral approach uses a 7- to 8-cm incision from the tip of the fibula toward the base of the fourth metatarsal.
- The traditional utilitarian dorsomedial approach uses a 7- to 8-cm incision from the anterior aspect of the anterior medial malleolus toward the dorsomedial base of the first metatarsal.
- If equinus contracture is present, I first perform an Achilles tendon lengthening.

FIG 1 • AP and lateral weight-bearing radiographs of patient with posterior tibial tendon dysfunction, spring ligament rupture, and fixed hindfoot deformity. Note severe talonavicular sag visible in B.

FIG 2 • The patient is placed on a beanbag in a modified lateral position that allows access to the medial and lateral foot. A stack of folded sheets is placed under foot to be operated.
LATERAL EXPOSURE

- Create a lateral longitudinal incision (TECH FIG 1A).
- Protect the sural nerve (TECH FIG 1B).
- Create the interval between the peroneal tendons and the extensor digitorum brevis (EDB) muscle.
- Elevate the EDB muscle with its fascia dorsally (TECH FIG 1C).
- Avoid "shredding" the muscle and fascia, as it will be used as the deep layer closure at the completion of the surgery.
- Release the bifurcate (calcaneonavicular and calcaneocuboid) ligament that lies deep to the EDB muscle.
- Release the calcaneocuboid capsule also (TECH FIG 1D).

**TECH FIG 1**

- **A.** Standard lateral approach.
- **B.** Protect the sural nerve.
- **C.** Elevate the EDB muscle and fascia.
- **D.** Expose the subtalar joint. A blunt retractor may be placed deep to the calcaneofibular ligament.
- **E.** Identify the calcaneocuboid joint. In this patient with an inflammatory arthropathy, the joint is distorted.
- **F, G.** Subtalar joint exposed with a distraction device.
■ Place a blunt retractor between the lateral subtalar joint and the calcaneofibular ligament (TECH FIG 1E).
■ Use a distractor to expose the subtalar joint first (TECH FIG 1F,G) and then the calcaneocuboid joint.
- The lateral talonavicular joint may also be accessed through this approach.

### SUBTALAR, CALCANEOCUBOID, AND LATERAL TALONAVICULAR JOINT PREPARATION
- The preparation is the same for all three joints.
- Remove residual articular cartilage with an sharp elevator or chisel (TECH FIG 2A).
- Preserve the native subchondral bone architecture.
- Drill or chisel (“feather”) the subchondral bone to allow for vascular channels to form at the arthrodesis surfaces while maintaining subchondral bone architecture (TECH FIG 2B,C).
- For the subtalar joint, include not only the posterior facet but also the middle and anterior facets.
  - However, be careful to not disrupt the delicate vasculature on the undersurface of the talar neck, if possible.
- The calcaneocuboid joint is a “saddle” joint, so avoid simply driving a chisel directly across the joint surfaces as it may result in more than desired bone removal, particularly when correcting pes planovalgus (TECH FIG 2D,E).
- The lateral talonavicular joint is often difficult to reach from the medial approach, but the lateral exposure affords satisfactory access to prepare this aspect of the talonavicular joint (TECH FIG 2F,G).
- I irrigate the joint before drilling the subchondral bone. Drilling creates reamings that serve as bone graft, and I do not want to wash the reamings away.

**TECH FIG 2** • A. Chisel being used to remove residual cartilage. B,C. Preparing the subtalar joint. B. Drill being introduced. C. The reamings created will serve as bone graft. D,E. Preparing the calcaneocuboid joint. D. Chisel being used to remove residual cartilage. E. Drilling the subchondral bone to promote fusion and adding reamings that serve as bone graft. (continued)
**TECH FIG 2 • (continued) F,G.** Exposure of the lateral talonavicular joint.

**MEDIAL EXPOSURE**

- Create a longitudinal incision (TECH FIG 3A).
- Cauterize connecting branches of the saphenous vein so the vein can be mobilized.
- Identify the tibialis anterior tendon and protect it throughout the procedure (TECH FIG 3B).
  - Typically fibers of the extensor retinaculum must be released to access the tibialis anterior tendon.
- Perform a longitudinal capsulotomy (TECH FIG 3C,D).
  - The spring ligament may need to be divided and the PTT tendon may need to be released from the navicular to improve access to the talonavicular joint.

**TECH FIG 3 • A,B.** Medial approach to the talonavicular joint. C. Medial exposure after capsulotomy. D. Close-up demonstrating erosive changes in the talonavicular joint in a patient with an inflammatory arthropathy.
TALONAVICULAR JOINT PREPARATION

- Use a distractor to gain full exposure to the talonavicular joint (TECH FIG 4A,B).
- In brittle bone, be careful when applying pressure to the navicular as it may fracture.
- Remove the residual articular cartilage from the talonavicular joint (TECH FIG 4C).
- In pes planovalgus deformity, the talar head may be weak, so be careful not to gouge the talar head when attempting to delaminate the residual articular cartilage.
- The lateral talar head should have already been prepared from the lateral approach.
- Remove cartilage from the navicular.
- Penetrate the subchondral bone to promote fusion.
- The talus is relatively easy to access with a small-diameter drill bit (TECH FIG 4D). Be careful using a chisel on the talar head as it may fracture.
- The navicular can also be readily drilled.
- I do not often use a burr to prepare subchondral bone for fusion, but on the navicular it is sometimes very effective, provided cold water or saline irrigation is used simultaneously to limit bone necrosis. However, this may wash away desirable reamings that could serve as bone graft.
- As for the preparation of the other joint surfaces, I irrigate the talonavicular joint before drilling then try to maintain the reamings so they can be used as bone graft.

HINDFOOT REDUCTION

- Place bone graft in the arthrodesis sites at this time, before the reduction is performed.
- I routinely use bone graft to fill voids at the surfaces to be fused. While this is not mandatory, I believe that filling the voids enhances the body’s ability to form bridging trabeculations.
- The calcaneus must be centered properly under the talus.
- Through the lateral wound, the optimal relationship of the posterior facet can be assessed and controlled (TECH FIG 5A,B).
- Physiologically there is a gap between the anterolateral talus and the anterior calcaneal process, and this should be re-created.
- In correcting severe pes planovalgus, I aim to overcorrect the calcaneus beneath the talus (TECH FIG 5C).
- Once the optimal subtalar relationship established, I provisionally pin the subtalar joint.
- I use a guide pin for the intended cannulated screw and try to place the pin in the intended trajectory for the screw (TECH FIG 5D,E).
Typically I have an assistant working with me, so I hold the reduction while the assistant places the guide pin from the calcaneal tuberosity into the talar body.

The dual-incision approach affords the surgeon the ability to palpate the talonavicular and calcaneocuboid joint reductions simultaneously.

With the subtalar joint reduced, I then attempt to reduce the talonavicular joint to an anatomic position. I can palpate both sides of the talonavicular joint by having two incisions (TECH FIG 5F).

When correcting pes planovalgus deformity, I err on the side of overcorrection of the navicular on the talar head.

Once I have the talonavicular joint reduced, I protect the tibialis anterior tendon and have my assistant drive two guide pins, appropriately spaced from one another, from the navicular into the talar head (TECH FIG 5G).

I attempt to place the screw from the most distal aspect of the navicular, even reaming the medial wall of the first cuneiform slightly, so the pin needs to be flush against the medial aspect of the first cuneiform.

Finally, I provisionally pin the calcaneocuboid joint.

To create a relief area on the anterior process of the calcaneus for the screw insertion, I remove a small wedge of bone from the anterior process using a rongeur.

I routinely push up on the cuboid and down on the anterior process of the calcaneus to reduce the joint.

Despite the lateral approach, optimal longitudinal orientation of the guide pin across the calcaneocuboid joint is not possible.

I sometimes create a stab incision behind the peroneal tendons, dissect carefully deep to the sural nerve and tendons, creating a soft-tissue tunnel, insert a drill sleeve, and then deliver the guide pin safely to the anterior process of the talus.

The guide pin is driven across the joint.

**TECH FIG 5** • Reducing the hindfoot. A, B. Checking the subtalar joint reduction. C. The hindfoot is maintained in the corrected position. Lateral (D) and mortise (E) fluoroscopic views after a guide pin was placed across the reduced subtalar joint. F. Reduction of talonavicular joint. G. Guide pins placed across talonavicular joint.
HINDFOOT STABILIZATION

- The reduction and the position of the guide pins are checked fluoroscopically (TECH FIG 6A).
- Adjustments are made as necessary.
- At this stage, I also routinely check the ankle fluoroscopically to be sure there is no ankle deformity that may distort the true hindfoot alignment.
- I determine proper screws lengths and overdrill the guide pins, but only to the initial aspect of the second bone.
- Most modern screws are self-drilling and self-tapping; however, particularly in the navicular, I prefer to predrill to diminish the risk of navicular fracture.
- By not drilling the full length of the planned screw, purchase of the screw is typically improved.
- I first place the subtalar screw, as a compression screw (TECH FIG 6B,C).
- Next, I place the two talonavicular screws (TECH FIG 6D–F).
  - The first screw is a compression screw.
  - I use a positional screw for the second screw.
  - If greater talonavicular stability is needed, I create a small dorsal incision over the midfoot; protect the superficial peroneal nerve, extensor tendons, and the deep neurovascular bundle; and using a drill sleeve, place a guide pin from the centrolateral navicular into the talar body or sometimes through the inferior talar body and into the calcaneus. Over this I place a third talonavicular screw, either positional or compression, although with two screws medially further compression is generally not possible.
- For the calcaneocuboid joint, I protect the soft tissues and overdrill only the anterior calcaneal process. Then I insert a compression or positional screw across the calcaneocuboid joint (TECH FIG 6G,H).
- If the joint is well reduced, I tend to use a positional screw; if the joint could stand to be compressed for better bony apposition, however, I place a compression screw.
- As mentioned earlier, I push up on the cuboid and down on the anterior calcaneal process to maintain the reduction and to make sure the cuboid does not sag, occasionally leaving it prominent postoperatively. However, with an anatomic reduction, this is rarely an issue.
- Occasionally, I add a lateral compression plate or staple across the calcaneocuboid joint to augment the fixation.
- I get final fluoroscopic confirmation of alignment, bony apposition at the arthrodesis sites, and hardware position (TECH FIG 6I,J).
TECH FIG 6 • (continued) G,H. Calcaneocuboid screw. A separate stab incision is made with a carefully prepared soft tissue tunnel under the sural nerve and peroneal tendons. Note thumb pressure pushing up on the cuboid to maintain joint reduction and a more favorable position of the cuboid. I,J. Final AP and lateral fluoroscopic views confirming appropriate reduction, bony apposition at the arthrodesis sites, and proper hardware position.

CLOSURE

- I routinely pack bone graft at the “quadruple arthrodesis” site, where talus, calcaneus, navicular, and cuboid meet at the lateral aspect of the talonavicular joint (TECH FIG 7).
- Medially the capsule is reapproximated.
- Laterally the fascia overlying the EDB muscle can usually be reapproximated to soft tissues adjacent to the peroneal tendons.
- Any bone graft in the soft tissues is irrigated away, as it may interfere with wound healing.
- Next, the subcutaneous tissues are closed.
- The skin incisions are then reapproximated to tensionless closures.
- I routinely release the tourniquet prior to subcutaneous layer closure.
- I also routinely use a lateral drain.
- The stab incisions for screw placement are closed.
- Sterile dressings and a posterior or sugar-tong splint are placed over adequate padding, with the ankle in neutral position.

TECH FIG 7 • Bone grafting the confluence of all four hindfoot bones, at the “quadruple arthrodesis” site.
POSTOPERATIVE CARE

- I routinely keep patients overnight for pain control, nasal oxygen (which may improve wound healing), and limb elevation.
  - While I recognize that some of my colleagues perform this surgery as a pure outpatient procedure, I believe that one night (which still qualifies as an outpatient procedure) is in the patient’s best interest after major hindfoot surgery.
- The patient wears a splint for 2 weeks.
- The patient returns to the clinic at 2 weeks for suture removal and short leg cast.
- The patient returns to the clinic at 6 weeks after surgery for radiographs out of cast and repeat casting.
- Touch-down weight bearing is the rule for a full 10 weeks.
- The patient returns to the clinic at 10 weeks and if repeat simulated weight-bearing radiographs suggest healing and no complications, he or she can be placed in a cam boot with gradual progression to full weight bearing by 12 to 14 weeks.
- The patient returns to the clinic at 14 to 16 weeks for full weight bearing radiographs (FIG 3), then gradual progression to full activities.

OUTCOMES

- Patients are generally improved with an appropriately performed triple arthrodesis.
- At intermediate to long-term follow-up, patients are functional in their activities of daily living but few are able to perform demanding recreational activities.
- With time, patients tend to develop adjacent joint arthritis, but it is unclear if this causes functional deficits.
- “Triple arthrodesis” performed through a single medial incision and including only the subtalar and talonavicular joints is gradually displacing the traditional triple arthrodesis. Results of this procedure are promising, but it is not clear if they are more favorable than those of the traditional triple arthrodesis.

COMPLICATIONS

- Nonunion
- Malunion
- Wound dehiscence
- Infection
- Sural neuralgia
- Prominent hardware
- Persistent pain despite appropriate management and satisfactory clinical and radiographic findings

![FIG 3](image-url) Follow-up weight-bearing radiographs of the patient with fixed hindfoot deformity secondary to posterior tibial tendon dysfunction and spring ligament tear. Note the congruent alignment of the talar–first metatarsal axis in both the AP and lateral views.
REFERENCES

**DEFINITION**

- Severe rigid planovalgus foot deformity may be a result of multiple underlying causes.
- In longstanding rigid hindfoot valgus deformities, the lateral skin and soft tissues may become severely contracted. In these cases, adequate correction of a severe valgus deformity may stretch and compromise the lateral soft tissues if a standard two-incision approach is used for triple arthrodesis.
- Previous surgical incisions, soft tissue injuries, or infections may further compromise wound healing if a lateral incision is used.
- A single-medial-approach triple arthrodesis technique offers adequate exposure of the subtalar, talonavicular, and calcaneocuboid joints for preparation without putting the lateral skin at risk.

**ANATOMY**

- The posterior and middle facets of the subtalar joint lie directly deep to the excised posterior tibial tendon (FIG 1).
- The flexor digitorum longus tendon and the posterior tibial neurovascular bundle lie just posterior and plantar to the subtalar joint. These must be protected with a retractor during joint preparation.
- The talonavicular joint is easily accessible through the extensile medial approach.
- The calcaneocuboid joint is directly lateral to the talonavicular joint across the foot. It can be adequately accessed through the extensile medial incision after the talonavicular joint is distracted with a lamina spreader (FIG 2).

**PATHOGENESIS**

- The medial longitudinal arch is supported by both static and dynamic anatomic structures.
- The static component includes the spring ligament (calcaneonavicular ligament), the plantar fascia, and the long plantar ligament.
- The dynamic component includes the posterior tibial tendon.
- In the adult acquired flatfoot, the spring ligament, plantar fascia, and long plantar ligament become attenuated and the posterior tibial tendon becomes dysfunctional. It is controversial whether the static or dynamic stabilizers fail first.
- In severe flatfoot patients, the peroneal tendons and the laterally shifted Achilles tendon overpower the dysfunctional posterior tibial tendon, forcing the subtalar joint into heel valgus.
- The transverse tarsal joints (talonavicular and calcaneocuboid joints) are abducted by the relative overpull of the peroneus brevis, causing lateral subluxation of the talonavicular joint and uncovering of the talar head.

**NATURAL HISTORY**

- Severe hindfoot valgus deformity, if left untreated, may lead to gradual attenuation of the deltoid ligament. Once this occurs, the tibiotalar joint becomes incongruent and tilts into valgus. This will eventually lead to ankle joint arthritis.
- The association of severe hindfoot valgus and valgus tilt of the ankle is difficult to treat and generally requires either (1) a pantalar arthrodesis or (2) ankle arthroplasty with an underlying triple arthrodesis.
- In my opinion, it is critical to intervene in these patients with severe hindfoot valgus before the deltoid ligament becomes incompetent in order to preserve the ankle joint.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- While a single-incision medial triple arthrodesis is feasible in most patients recommended for triple arthrodesis, we favor employing this technique in the most severe cases of hindfoot valgus or in high-risk patients.
- Risk factors exist that may predispose to severe pes planovalgus or may put the patient at risk for wound healing complications. Rheumatoid arthritis is a common cause of severe hindfoot valgus. Rheumatoid patients can sometimes present...
with greater than 30 degrees of valgus through the subtalar joint. Many of these patients will have gross subluxation of the posterior facet of the subtalar joint on radiographs.

- Likewise, diabetic patients with Charcot-like subtalar joint subluxation or dislocation may present with severe hindfoot valgus. These patients are at increased risk of wound healing complications, and in our opinion represent patients in whom a lateral sinus tarsi approach is not advised.

- Anyone with a history of previous soft tissue trauma laterally, open wounds, active infection, or recent surgical incisions that may compromise the ability of a lateral sinus tarsi incision to heal may benefit from a single-medial-incision technique.

Examination should include the following:

- Standing hindfoot alignment. The examiner should visually inspect the posterior heel alignment with respect to the tibia with the patient standing. Physiologic hindfoot valgus is usually 5 to 7 degrees. Significantly greater valgus may be pathologic. In patients with severe hindfoot valgus greater than 30 degrees, a lateral sinus tarsi incision may be difficult to heal once the heel is reduced.

- Subtalar range of motion. The examiner should maximally invert and evert the heel to determine the range of motion with respect to the tibial axis. Normal subtalar range of motion is 5 degrees of eversion and 20 degrees of inversion. Most severe, longstanding pes planovalgus deformities will be rigid. If the hindfoot is flexible, the surgeon may consider osteotomies or lateral column lengthening to correct the malalignment.

- Peroneal tendon contracture. With the heel maximally inverted, the examiner should palpate the peroneal tendons to determine how much they are contributing to valgus contracture. If the peroneal tendons are excessively tight, they will need to be released for the heel alignment to be corrected to neutral.

- Contracture of the skin overlying the lateral hindfoot. The examiner should visually inspect the lateral skin to see whether it is loose or taut. If the lateral skin is tight before correcting the heel valgus, a sinus tarsi incision will be very difficult to close once the heel is neutral.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standard weight-bearing radiographs of both the foot and ankle are critical in evaluating severe pes planovalgus deformities. The foot films will determine the amount of subluxation or dislocation of the subtalar and transverse tarsal joints that must be corrected. They can also determine whether there is deformity or bone loss that demands the addition of structural bone grafts. The ankle radiographs are required to confirm that the severe heel valgus is isolated to the hindfoot. Occasionally, severe valgus hindfoot deformity leads to increasing deltoid ligament incompetence, creating a valgus tilt of the talus within the ankle mortise. Deltoid ligament incompetence and valgus tilt of the ankle may necessitate surgical correction of the ankle as well should hindfoot realignment with triple arthrodesis fail to rebalance the tibiotalar joint (FIG 3).

**DIFFERENTIAL DIAGNOSIS**

- The possible underlying causes of flatfoot in an adult include:
  - Posterior tibial tendon dysfunction
  - Inflammatory arthritis

**NONOPERATIVE MANAGEMENT**

- In patients with longstanding pes planovalgus feet, the deformity is frequently fixed, meaning that the deformity cannot be actively or passively corrected. Orthotics and braces can only help by supporting the arch, unloading prominences, or immobilizing arthritic joints. Several over-the-counter braces are available commercially that may be effective in immobilizing and supporting the painful flatfoot. The gold standard is a custom-made relatively rigid lace-up ankle brace. In-shoe
orthotics for rigid flatfeet should be custom-molded to accommodate the deformity and any prominences.

- Nonsteroidal anti-inflammatory medications may be helpful in alleviating arthritic pain or synovitis. Occasionally a cortisone shot may be beneficial to relieve an acutely painful joint.

**SURGICAL MANAGEMENT**

**Positioning**

- The patient is positioned supine on the operating table with a small bump beneath the contralateral hip. This places the operative foot nearly parallel to the table, which is critical because all of the exposure and preparation will be performed through the medial incision. A well-padded thigh tourniquet is placed on the proximal thigh.

**Approach**

- An extensile medial incision affords satisfactory exposure to the talonavicular and subtalar joints. With talonavicular joint distraction, the calcaneocuboid joint may also be accessed.

**RELEASE OF THE PERONEAL TENDON CONTRACTURE**

- Make a 3-cm longitudinal incision posterolaterally about 10 cm above the level of the ankle joint. This incision is made directly over the peroneal tendons, immediately behind the posterior border of the fibula.
- Open the peroneal tendon sheath longitudinally in line with the skin incision.
- Use a hemostat to remove the peroneus longus and brevis tendons from their sheath. Transect each tendon completely and return them into the sheath (TECH FIG 1).
- Close the sheath and skin in layers.

TECH FIG 1 • The peroneus longus and brevis contractures are released through a small incision well above the level of the ankle joint to avoid wound complications.

**EXPOSURE AND PREPARATION OF SUBTALAR JOINT**

- Make an extensile longitudinal incision medially from the tip of the medial malleolus to the tarsometatarsal joint level.
- Open the sheath of the posterior tibial tendon longitudinally in line with the skin incision.
- Completely release the posterior tibial tendon from its insertion onto the navicular. Use a Köcher clamp to pull out the tendon as far as possible, and excise the posterior tibial tendon proximally in the incision (TECH FIG 2).
- Using a retractor, pull the flexor digitorum longus tendon posteriorly. This will protect the posterior tibial neurovascular bundle behind it.
- Use a scalpel blade to localize the posterior and middle facets of the subtalar joint by probing deep to the excised posterior tibial tendon. Once the joint is identified, use an osteotome or elevator to release the joint capsule and ligaments (TECH FIG 3).
- Insert a lamina spreader between the talar neck and calcaneus and open it to expose the subtalar joint for preparation (TECH FIG 4).
- Using a combination of osteotomes and curettes, remove all remaining articular cartilage from the joint down to the subchondral plate.
- Use a curved osteotome to aggressively “feather” the articular surfaces of the posterior and middle facets of the subtalar joint, creating increased surface area for fusion and serving to provide local bone graft.
Through the medial incision, the talonavicular joint is easily approached. Make a longitudinal capsulotomy in line with the skin incision over the talonavicular joint. Elevate the dorsal and plantar capsule off the joint to expose the articular surfaces. Insert an elevator across the talonavicular joint and use it to release the lateral capsule. This will permit distraction of the joint.

Use a small lamina spreader to distract open the joint for preparation. Using curettes and osteotomes, remove the articular cartilage down to the subchondral plate. Use a curved osteotome to aggressively feather the articular surfaces of the talus and navicular.

Insert a large lamina spreader into the talonavicular joint and open it to gain access to the calcaneocuboid joint across the foot. Identify the calcaneocuboid joint using a scalpel or elevator. Check this position with intraoperative fluoroscopy. Use the elevator to open the joint. Pass a scalpel across the joint to release the lateral capsule and bifurcate ligaments (ligaments that bifurcate from the anterior process of the calcaneus and the cuboid and navicular). Be careful not to violate the lateral skin from inside to out as it will be placed on stretch with correction. Remove the articular cartilage with a combination of curettes and osteotomes down to subchondral bone. Aggressively feather the articular surfaces with a curved osteotome (TECH FIG 5).

Based on the surgeon’s preference, the talonavicular or subtalar joint is reduced and fixed first. Position the subtalar joint in 5 to 7 degrees of hindfoot valgus and fix it with a partially threaded 6.5-mm cannulated screw from the heel into the body of the talus. I also make sure that the calcaneus is translated fully under the talus; residual hindfoot valgus may look good on the operating table but will fail to do so once the patient bears weight.
PEARLS AND PITFALLS

- **Osteoporotic bone**
  - When spreading open the talonavicular joint to expose the calcaneocuboid joint, the lamina spreader may crush the talar head if the bone is soft. In these cases, prepare the calcaneocuboid joint first and leave the subchondral plate of the talonavicular joint intact to distract against. This will avoid crushing the talar head.

- **Incorrect identification of calcaneocuboid joint**
  - When approaching the calcaneocuboid joint from across the foot, confirm the position of the joint fluoroscopically before preparing it. The tarsometatarsal joint can be mistakenly entered from this approach.

POSTOPERATIVE CARE

- The patient is placed in a well-padded plaster splint until the incisions have healed. A cast or removable cam-boot is then used for immobilization until 12 weeks postoperatively. Patients are instructed to be strictly non-weight-bearing for the first 6 weeks; they then may progressively bear weight as tolerated. At 12 weeks, immobilization is discontinued and the patient is sent to physical therapy.

OUTCOMES

- Seventeen patients underwent single-medial-incision triple arthrodesis.
- All 17 demonstrated clinical improvement in alignment and pain relief.
- All talonavicular and subtalar joints healed (FIG 4).
- Radiographic correction was comparable to previous series describing traditional two-incision triple arthrodesis.
- In a cadaver study, 90% of the calcaneocuboid joint articular surface was able to be prepared successfully from the medial incision.

COMPLICATIONS

- Two of the 17 patients (12%) developed a nonunion of the calcaneocuboid joint. Neither of these was symptomatic.
- Three patients developed valgus ankle arthritis after successful triple arthrodesis. These were managed with total ankle replacement in two patients and ankle arthrodesis in one patient.
REFERENCES
SURGICAL MANAGEMENT

Preoperative Planning
- Imaging studies are reviewed.
- Physical examination should be done to test for rigidity or flexibility of the foot.
- Plain radiographs should be examined for arthritic changes, with triple arthrodesis reserved for severe, rigid deformity. 6
- CT scanning can aid in determining arthritis when plain radiographs are unclear but suspicion is high.
- A tight Achilles tendon should be addressed during the same procedure (gastrocnemius recession, percutaneous, or open Achilles lengthening).
- Coleman block testing confirms forefoot-driven hindfoot varus or primary hindfoot varus.
- Concurrent problems, such as lateral ankle instability, should be addressed during the same procedure.

Positioning
- The patient is positioned supine on the table with the heel resting at the end of the bed (FIG 1).
- Thigh tourniquets are used and well padded.

A bump is placed beneath the ipsilateral hip until the foot is perpendicular to the table to facilitate medial and lateral exposure if needed.
- The leg is prepared to the knee.

Approach
- Achilles tendon pathology is addressed first so this will minimize the deforming force on the heel when shifted.
- Either a lateral displacement or Dwyer-type osteotomy is performed, depending on the surgeon’s preference, if rigid heel varus is present.
- The lateral displacement osteotomy is used for most adult cases, as the Dwyer weakens the moment arm of the Achilles and often cannot achieve the desired correction. 7
- Through the same incision, a peroneus longus to brevis transfer is done if appropriate.
- Attention is then turned toward the first metatarsal, where a dorsiflexion osteotomy of the first ray is performed until the first ray is out of plantarflexion.
- This is the most common location needing osteotomy in our practice.
- For more severe cases, multiple metatarsal dorsiflexion osteotomies may be required in a similar fashion. 5
- More advanced cases with extensive cavus through the midfoot and forefoot may require dorsal wedge osteotomies at more proximal levels, as described by multiple authors. 2,3
- Adequate preoperative planning should alert the surgeon to the need for these more advanced procedures.
- A plantar fascia release is useful as an adjunct when midfoot flexion is severe and prevents adequate reduction of the forefoot after osteotomy.
- This can also be done first in deformities associated with increased calcaneal pitch, where a proximal slide of the calcaneus is being done to lower the arch.
- A Jones procedure can be used to correct residual claw hallux with Girdlestone and Taylor hammer toe procedures for the lesser toes if required.
- Transfer of the tibialis posterior to the lateral cuneiform is a useful adjunct in cases of Charcot-Marie-Tooth associated with dorsiflexion weakness of the ankle. 4

GASTROCNEMIUS RECESSION
- Isolate the gastrocnemius fascia through a longitudinal incision just distal to the musculotendinous junction of the gastrocnemius on the medial side of the leg (TECH FIG 1).
- Identify the deep fascia of the leg and incise it in line with the incision, revealing the muscle and tendon structures beneath.
- The plantaris tendon will be visible along the medial border of the tendons and may be cut.
- Using blunt dissection, the separation of the deep soleus and the more superficial gastrocnemius can be recognized.

The gastrocnemius fascia is easily isolated using a pediatric vaginal speculum, but various retraction techniques may be employed.
- Retraction helps protect the sural nerve, which lies adjacent to the gastrocnemius at this level near the midline.
- Once isolated, cut the entire fascia transversely using tenotomy scissors.
- Fifteen to 20 degrees of increased ankle dorsiflexion with the knee extended can usually be obtained.
- Reapproximate the deep fascia using 3-0 absorbable sutures.
**LATERAL DISPLACEMENT CALCANEAL OSTEOTOMY AND PERONEUS LONGUS TO BREVIS TRANSFER**

- The incision to accomplish both of these procedures is made inferior to but parallel to the peroneus longus tendon (**TECH FIG 2**).
- Deepen the dissection from the original incision until the peroneal tendons are identified.
- Enter the sheaths for the length of the incision, making sure to preserve the superior peroneal retinaculum (SPR).
  - The SPR may be taken down directly off the posterior fibula and reattached with a suture anchor if tendon pathology exists such as tears or instability, such as in our example.
  - Otherwise, the tendons can be sutured together, preserving this structure.
- Remove a section of the peroneus longus with a knife.
- Reapproximate the longus and brevis tendons proximally and hold them together with figure 8-0 nonabsorbable suture, making sure the knot does not impinge below the SPR.
- Carry dissection inferior to the sural nerve, taking care to identify and protect it.
- Once the calcaneus is reached, carry the subperiosteal dissection inferior.

- Place small Hohmann retractors superior and anterior to the calcaneal tuberosity, protecting the insertion of the Achilles tendon and the origin of the plantar fascia, respectively.
- With soft tissues protected, use a sagittal saw to make the osteotomy perpendicular to the axis of the calcaneus.
- Shift the free tuberosity piece lateral until a physiologic valgus position of 5 degrees is obtained (usually 8 to 10 mm).
- Make a midline longitudinal incision just off the posterior plantar heel pad.
- Carry dissection straight through subcutaneous fat to bone.
- An assistant or Kirschner wire holds the heel shift in the corrected position while two 6.5-mm partially threaded cancellous screws are placed in lag fashion.
- The screws should be off the posterior weight-bearing surface of the heel and should not penetrate the subtalar joint.
- Use a rasp to smooth down the prominent lateral bone after the heel shift.
TECH FIG 2 • Lateral displacement calcaneal osteotomy and peroneus longus to brevis transfer. 
A. Lateral incision over hindfoot just posterior to peroneal tendons. B. Dissection carried down to the peroneal tendons, with the superior peroneal retinaculum still intact. C. With the superior peroneal retinaculum flap taken posterior, a section of the peroneus longus is removed. D. The peroneus longus has been sutured to the brevis, making sure the knot does not impinge under the superior peroneal retinaculum through range of motion of the tendon. E. Sural nerve is identified as dissection is carried inferior. F. A saw is used to cut across the calcaneus, perpendicular to its long axis, protecting the Achilles and plantar fascia. G. An assistant holds the lateral shift while two 6.5-mm partially threaded cancellous screws are placed across the osteotomy. H. Final screw positioning as seen from lateral and superior views.
**FIRST METATARSAL DORSIFLEXION OSTEOTOMY**

- Make a dorsal incision over the proximal first metatarsal and carry dissection down to the extensor tendons (TECH FIG 4).
  - Retract them lateral so dissection can be carried down to bone.
  - Subperiosteal dissection allows exposure of the proximal metatarsal to the first tarsometatarsal joint.
  - Mark a line transversely on the bone 1 cm from the joint for the bone cut.

- Place small Hohmann retractors around the bone to protect the soft tissues, and perform a dorsal closing-wedge osteotomy using a sagittal saw.
  - The first cut is through 90% of the bone and perpendicular to the diaphysis.
  - The second cut is 2 to 3 mm distal and angled back toward the plantar endpoint of the first cut.
  - Complete the first cut and remove the bone wedge. Take enough bone to restore anatomic alignment of the talus.

**Dwyer Lateral Closing-Wedge Calcaneal Osteotomy**

- Use the approach outlined above for the lateral sliding calcaneal osteotomy.
- Instead of a transverse cut with a shift, remove a wedge of bone, based laterally, using a sagittal saw (TECH FIG 3).
- The size of the wedge depends on the desired correction but should bring the heel to a physiologic valgus position.
- Once the bone is removed, dorsiflex the foot to close the wedge and proceed with fixation as described previously.

**Tech Fig 3** - Dwyer calcaneal osteotomy. Instead of a straight cut through bone, a lateral-based wedge is removed.

**Tech Fig 4** - First metatarsal dorsiflexion osteotomy. A. Plantarflexed first ray. B. Incision over first metatarsal. C. Measuring 1 cm from first tarsometatarsal joint. D. A small dorsally based wedge is removed. (continued)
PARTIAL PLANTAR FASCIOTOMY

- Make an incision just distal and parallel to the plantar heel pad (TECH FIG 5).
- Dissection through subcutaneous fat exposes the plantar fascia.
- When the medial and lateral borders of the fascia are identified, partial or complete release may be undertaken.
- Begin transection 1 cm from the origin on the calcaneus and proceed medial to lateral.
- More severe deformities may require more of a release.

JONES PROCEDURE

- The interphalangeal (IP) fusion of the great toe begins with a transverse incision over the IP joint dorsally (TECH FIG 6).
- Cut the extensor hallucis and make an arthrotomy in the joint, freeing up the collateral ligaments.
- Use curettes to remove the articular cartilage and use a 2-mm drill bit to fenestrate both sides of the joint.
- Place a Kirschner wire from proximal to distal through the distal phalanx and out the tip of the toe just under the nail, leaving minimal wire within the joint.
- Place the wire retrograde across the IP joint while holding it reduced.
- Make a transverse incision at the toe tip to allow drilling over the wire.
- Measure the length of screw so it does not penetrate the metatarsophalangeal joint.
- Place a 4.0-mm partially threaded cannulated screw over the wire for compression.
- Confirm the position on fluoroscopy and remove the wire.
- Center a dorsal midline incision over the first metatarsal neck.
- Identify the extensor hallucis longus and bring its distal end into the wound.
- Make 4.0-mm drill holes on the medial and lateral aspects of the metatarsal neck and connect them using a curette.
- Pass the tendon from lateral to medial through the hole and suture it back on to itself using nonabsorbable suture while holding the ankle in a neutral to slightly dorsiflexed position.
POSTOPERATIVE CARE
- Posterior sugar-tong splinting is used immediately postoperatively with the ankle in neutral dorsiflexion.
- Skin staples are removed at 2 weeks.
- Patients are kept immobilized and non-weight-bearing for a total of 8 weeks, and weight bearing is begun when bony healing has occurred.

OUTCOMES
- Long-term studies of cavovarus correction in adults are lacking, likely given the varied presentation and multiple modes of treatment for the disorder.
- Early treatment while feet are flexible is advised to prevent more extensive procedures required for rigid deformities and complications from progressive arthrosis.

COMPLICATIONS
- Painful hardware
- Infection
- Recurrence of deformity
- Wound dehiscence
- Nonunion

REFERENCES

TECH FIG 6 • Jones procedure of first toe. A. Incision is made transversely over the interphalangeal joint to remove cartilage and harvest extensor hallucis longus tendon. B. Incision is made longitudinally over the first metatarsal, transferring the tendon to the neck, and a screw is placed across the interphalangeal joint in lag mode.
DEFINITION
- Pes cavus is characterized by increased plantarflexion of the forefoot and midfoot in relation to the hindfoot. An isolated pes cavus is rare; it is commonly accompanied by other deformities of the foot. Therefore, pes cavus should be classified in different groups: pes cavovarus, pes equinocavus, pes calcaneocavus, and pes valgocavus (FIG 1). In many cases a combination of the first two types occurs, called the pes equinocavovarus.
- The equinocavovarus foot describes a mostly acquired foot deformity consisting of an increased arch of the foot (forefoot and midfoot equinus), a limited dorsiflexion of the ankle joint (hindfoot equinus), and a hindfoot varus. A concomitant forefoot and midfoot adductus, supinatus, or pronatus can occur, depending on the underlying pathology.
- “The cavovarus foot is one of the most perplexing and challenging of all foot deformities.”
- “The literature on pes cavus is extremely confusing.”

ANATOMY
- Equinus deformity of the ankle (limited dorsiflexion)
- Hindfoot in varus position (inversion of the calcaneus, flexible or rigid)
External rotation of the talus and retraction of the lateral malleolus
- Medial dislocation of the navicular and the cuboid bone in the Chopart joint
- Cavus deformity medially (flexible or rigid)
- Plantarflexed position of the first metatarsal bone (flexible or rigid)
- Pronation and adduction of the forefoot (flexible or rigid)
- Claw toes, isolated to the hallux or involving all five toes (flexible or fixed)

**PATHOGENESIS**
- "...a story of repeated failure to comprehend the basic pathogenesis and mechanics of a deformity which remains a mystery to this day, comparable only to problems such as scoliosis."6
- There are various theories concerning the pathogenesis of pes equinocavovarus:
  - "There is little doubt that the condition is caused by a muscle imbalance, involving both the intrinsic and the extrinsic muscles of the foot."13
  - Weakness of the anterior tibial muscle (progressive plantarflexion of the first metatarsal bone) because of relative overactivity of the long peroneal muscle; the long toe extensors try to compensate the reduced dorsiflexion force of the anterior tibial muscle. This results in an overbalance of the extrinsic extensor muscles in comparison to the intrinsic extensor muscles. The toes are hyperextended in the metatarsophalangeal joints. At the same time the long toe flexors pull the end phalangeal bone into plantarflexion. Both mechanisms result in increased cavus (forefoot and midfoot equinus).
  - Weakness of the short peroneal muscle (peroneus brevis). Relative overactivity of the posterior tibial muscle forces the hindfoot into varus position. The force of the long toe flexors (increased flexion of the metatarsophalangeal joints) is antagonized by increased activity of the long peroneal muscle (peroneus longus) that also pulls the first metatarsal bone into plantarflexion. Because of its limited effects on the hindfoot, the peroneus longus cannot antagonize the overactivity of the posterior tibial muscle.

**NATURAL HISTORY**
- One functionally relevant consequence of the deformity is the limited ankle dorsiflexion. Its causes can be an isolated shortened Achilles tendon, which is rare. An acquired horizontal position of the talus resulting from hindfoot supination can cause a limited dorsiflexion. The cavus deformity itself may be responsible for limited ankle dorsiflexion.
- The limited ankle dorsiflexion in pes equinocavovarus may cause a genu recurvatum. Another consequence is toe walking with excessive load transfer to the metatarsophalangeal joints and a reduced stance phase of gait.
- Pronation in the subtalar joint is inhibited, potentially causing impingement between the medial malleolus and the talus, similar to the impingement in severe clubfoot deformity.
- Another consequence is the medialization of the navicular, which migrates toward the medial malleolus to cause additional bony impingement. Osteophytes often develop at the talar neck.
- In the case of a concomitant hindfoot equinus and subtalar joint compensation, the acquired varus stress in the subtalar joint frequently cannot be compensated by the ankle joint, leading to eventual varus talar tilt in the ankle mortise.

**PATIENT HISTORY AND PHYSICAL FINDINGS**
- A characteristic description of a patient with pes equinocavovarus can be found in the book by Tubby and Jones22 for Charcot-Marie-Tooth (hereditary motor sensory neuropathy):
  - "The patient was a healthy-looking country-woman, aged fifty-six years, practically free from any disability from this condition. The patient stated that when about seven years old she found that her ankles, especially the right, easily ‘turned in’, and that consequently she often suffered from sprains. She was unaware that there was anything unusual about her hands. The muscles of the rest of the upper extremity and of the shoulder girdle did not appear to be in any way affected. In the lower extremity deformity was more advanced and unequally developed on either side. On the right the foot was hollowed and inverted, and also somewhat dropped. The tendon of the tibialis anticus stood out as a taut cord. The toes and ankle joint could be freely moved in all directions except that of eversion, owing to complete paralysis of the peronei muscles. In addition to pes cavus there was some equinovarus. The other muscles of the lower extremity were capable of causing powerful movements. The knee jerks could not be obtained."
  - "A man, aged thirty-one years, the third child of the above patient showed a marked club-foot on both sides, and the feet were inverted and dropped, but without any contracture of tendons. The power of dorsiflexion and of eversion was completely lost. The toes were in the characteristic position.”

**Dynamic Examination**
- Problems during stance phase of the gait cycle
  - Initial contact with the toes (toe walking, hindfoot equinus, limited dorsiflexion)
  - Hyperextension of the knee (genu recurvatum, due to equinus) and proximal compensatory mechanisms
  - Overload of the lateral border of the foot (varus deformity)
  - Instability in loading response of the gait cycle
  - Main load on the first and fifth metatarsal head, in some cases with ulceration
  - Limited roll-off movement due to reduced dorsiflexion in mid-stance
  - Internal rotation moment due to rolling off over the lateral border of the foot and the forefoot
  - Missing load bearing of the toe tips due to claw toe deformity
- Problems during swing phase of the gait cycle
  - Drop foot (weak extensor muscles, primarily the anterior tibial muscle) with foot clearance problems; this is aggravated by hindfoot equinus
  - Compensatory mechanisms for drop foot (eg, increased knee or hip flexion, circumduction of the leg)
  - Equinus foot at the end of the swing phase, which leads to forefoot initial contact
  - Overactivity of the long toe extensors to compensate for decreased dorsiflexion force with consecutive claw toe deformity
Methods for Examining the Equinocavovarus Foot Deformity

- In stance: medial view. The examiner inspects the medial aspect of the foot, evaluating for elevated heel, increased medial arch, plantarflexion of the first metatarsal bone, and claw toe deformity of the first column of the foot.
- In stance: lateral view. The examiner inspects the lateral aspect of the foot, evaluating for posterior shift of the lateral malleolus, convexity of the lateral border of the foot, prominent basis of the fifth metatarsal bone, and prominent head of the talus on the lateral dorsum of the foot.
- In stance: dorsal view. The examiner inspects the posterior aspect of the foot, evaluating for convex lateral border of the foot and prominent basis of the fifth metatarsal bone, increased weight bearing of the heads of the first and fifth metatarsal bones, increased skin wheal (in severe cases, the heads of all metatarsal bones are involved), and hindfoot equinus (lack of weight bearing on the heel).
- In stance: plantar view. The examiner inspects the plantar aspect of the foot, evaluating for convex lateral border of the foot and prominent basis of the fifth metatarsal bone, increased weight bearing of the heads of the first and fifth metatarsal bones, increased skin wheal (in severe cases, the heads of all metatarsal bones are involved), and hindfoot equinus.
- In stance: anterior view. The examiner inspects the ventral aspect of the foot, evaluating for lateral prominence of the talus, convex lateral border of the foot, forefoot adduction, and clawing of the first through fifth toes.
- Coleman block. With a block placed under the hindfoot and the second through fifth toes, the examiner tests the compensability of the hindfoot in fixed forefoot pronation and compensation of the plantarflexion of the first metatarsal bone.
- Silfverskiöld test. Dorsiflexion is examined in knee flexion and knee extension. This test is important for detecting equinus deformity and differentiating between the involvement of gastrocnemius and soleus muscles.

“Trying to assess actions of individual muscles is a trap for the unwary because muscle action is so much one of synergism and unassessable motive power that it becomes impossible to apportion with any accuracy the actions of single muscles.”

Problems Due to Footwear

- Ulcerations over the interphalangeal joints of the toes
- The food is broad and short (problems wearing regular shoes)
- Wearing out of the lateral border of the shoes or the forefoot, respectively

Further Problems

- Cosmetically disturbing
- Rapid fatigue
- Progressive deformities

IMAGING AND OTHER DIAGNOSTIC STUDIES

Conventional Radiographs

- Lateral view (standing) (FIG 2A)
  - Posterior shift of the lateral malleolus
  - The longitudinal axis of the talus is parallel to the axis of the calcaneus.
  - The calcaneus seems to be shortened due to varus position.
  - There is decreased distance between the navicular and the medial malleolus.
  - The calcaneocuboid joint is visible; it is normally obscured by the talonavicular joint.
  - The first metatarsal is plantarflexed and its head has a plantar prominence.
  - Claw toes
  - The posterior subtalar joint is projected horizontally.
  - Opened sinus tarsi (“sinus tarsi window”)

- AP view (standing) (FIG 2B)
  - Longitudinal axes of the talus and calcaneus are parallel.
  - There is a medial shift of the talonavicular joint and in some cases the calcaneocuboid joint.
  - The first metatarsal seems to be shortened, due to its plantarflexed position.
  - There is overlapping of the metatarsal bones, especially the fourth and fifth.

- AP view of the ankle joint (standing) (FIG 2C)
  - Varus deformity of the ankle joint?
  - Hindfoot varus

Computed Tomography with 3D Reconstruction

- In severe cases CT imaging with 3D reconstruction may be needed (FIG 2D).

Dynamic Pedobarography

- An objective method to measure the pressure distribution pattern is the dynamic pedobarography EMED® examination.
  - It is used to identify the imbalance of the major pressure points of the foot due to the deformity.
  - A mildly involved footprint is shown in comparison with the typical pattern for a severe equinocavovarus foot (FIG 2E).

FIG 2 • Conventional radiograph. A,B. Lateral view with and without correction of the forefoot equinus. (continued)
3D Foot and Gait Analysis (Heidelberg Foot Model®)
- This objective and computer-assisted method records movements between single segments of the foot in all three planes (sagittal, frontal, transverse) during walking.
- The foot and shank are equipped at typical anatomic landmarks with 17 reflective markers (FIG 3).16 Special cameras send and record reflected ultrared light while the patient walks over a defined distance.
- After processing by dedicated software, characteristic segment movements in all three planes can be visualized.

DIFFERENTIAL DIAGNOSIS
Pes equinocavovarus can occur in different primary diseases:
- Central nervous system
  - Progressive diseases
    - Increased muscle tone (eg, multiple sclerosis)
    - Reduced muscle tone (eg, tethered cord syndrome)
    - Diastematomyelia, syringomyelia, intraspinal tumor
  - Limited diseases
    - Increased muscle tone (cerebral palsy, traumatic brain injuries, stroke)
- Reduced muscle tone (eg, spina bifida)
- Lipoma, angioma
- Encephalitis
- Peripheral nervous system
  - Progressive diseases
    - Hereditary sensory motor neuropathy (Charcot-Marie-Tooth disease)
    - Spinal muscular atrophy
    - Polyneuropathy
  - Limited diseases
    - Poliomyelitis
    - Arthrogryposis multiplex congenita
- Other causes
  - Compartment syndrome
  - Burn injuries
  - Inflammatory arthritides
  - Diabetic neuropathy

NONOPERATIVE MANAGEMENT
- “Nonsurgical management of cavus, cavovarus and calcaneocavus is uniformly unsuccessful in the long run.”20
“Nonoperative measures generally do not stop progression or prevent deformity, therefore their role is extremely limited.”

Nonoperative treatment can only compensate for the functional problems in pes equinocavovarus; it cannot stop its progression.

Possible nonoperative treatment methods are:
- Orthopaedic arch support (reduced head of the first metatarsal bone and smooth bedding)
- Orthopaedic shoes

SURGICAL MANAGEMENT

Preoperative Planning

- “Muscle balance is the key to understanding the production of pes cavus.”
- “A foot will deform in the presence of a solid, well-performed triple arthrodesis when the foot is not in gross muscular balance....When definite muscular imbalance is evident, tendon transfer is mandatory.”
- Preoperative clinical examination, radiographs, EMED, dynamic foot analysis (instrumented foot gait analysis), and clinical examination (Silfverskiöld test) under anesthesia represent optimal preoperative planning.

Positioning

- The patient is placed supine on the operating table. We routinely drape the iliac crest into the operative field when there may be a need for iliac crest bone harvest (FIG 4).

Approach

- The different approaches that we consider in equinocavovarus deformity correction are shown in FIGURE 5.
  - Dorsal incision for the modified Jones procedure
  - Lateral–dorsal incision for the triple or Lambrinudi arthrodesis or the Cole procedure and the posterior tibial tendon transfer as well as the Russel-Hibbs procedure
  - Ventral incision for the posterior tibial tendon transfer
  - Distal medial shank incision for the open Achilles tendon lengthening, the posterior tibial tendon transfer, and, if needed, the intramuscular lengthening of the long toe flexors
  - Skin incision for the triple or Lambrinudi arthrodesis, the Cole procedure, and the posterior tibial tendon transfer; this incision can be connected with the previous one (distal medial shank) if needed
  - Skin incision for the Steindler procedure

FIG 4 • Positioning in the operating room.
The first step is the Steindler procedure. In mildly involved cases it is possible to correct the cavus deformity with this procedure. In most cases, however, a total correction is not possible and this procedure is followed by bony correction of the cavus component.

After the Steindler procedure, the tendon transfers are prepared (split posterior tibialis transfer, modified Jones procedure). Important: Tendon transfers and Achilles tendon lengthening are only prepared at this point; they are eventually secured with suture during the final stages of the reconstruction.

Next, we correct the clawed hallux (modified Jones procedure). Important: The tendon transfer of the extensor hallucis longus (EHL tendon) is sutured at the end of all procedures.

Bony correction of the midfoot and hindfoot is performed next. Depending on the severity of deformity, an arthrodesis of the Chopart joint or triple arthrodesis may be required. In cases of dorsal impingement of the talus on the tibia with limited dorsiflexion or extreme hindfoot equinus, we recommend adding a modified Lambrinudi procedure.

In select cases an extra-articular correction of the cavus (Cole procedure) and the hindfoot varus (Dwyer osteotomy) are indicated.

To correct hindfoot equinus, an intramuscular lengthening of the calf muscles or an open or percutaneous Achilles tendon lengthening is carried out. In cases of severe equinus tested in knee flexion and extension proximal or distal Achilles tendon lengthening (open or percutaneous) is considered. The choice of open or percutaneous lengthening depends on the surgeon’s preference. A percutaneous TAL (tendo Achilles lengthening) is more prone to overcorrection, whereas with an open technique, tension can be more easily controlled. In mildly involved cases intramuscular calf muscle lengthening is done (eg, Baumann procedure).

After correction of the hindfoot and midfoot, we typically reassess the forefoot. In the case of shortened long toe flexors (masked on initial examination by the equinovarus deformity), an intramuscular lengthening of the long toe flexors (EDL and EHL tendons) can be done through the same approach used for the open Achilles tendon lengthening.

When satisfactory correction of first metatarsal planarflexion is not possible with the modified Jones procedure alone, we routinely add a first metatarsal dorsiflexion osteotomy.

The final step before wound closure is securing all tendon transfers. We do not routinely use bone anchors but instead suture tendons directly to target other tendons or soft tissues at the site of desired transfer (EHL, tibialis posterior) and the lengthened Achilles tendon slips.

STEINDLER PROCEDURE (TRANSECTION OF THE PLANTAR APONEUROSIS)

While an important step in the correction of the equinocavovarus foot deformity, our experience is that it does not afford much correction if used in isolation. In our hands, this technique represents the first step in the treatment of pes equinovarus. It is a simple method for correcting flexible forefoot and midfoot cavus deformity.

Make a slightly dorsal convex, 3- to 4-cm-long incision at the medial border of the foot directly above the origin of the plantar aponeurosis at the calcaneus (TECH FIG 1).

Carefully divide the subcutaneous tissue and retract it with Langenbeck retractors. Expose the origin of the

TECH FIG 1 • Steindler procedure. (continued)
The purpose of this technique is the augmentation of the attenuated ankle dorsiflexor muscles that are often compromised by longstanding hindfoot equinus deformity. Furthermore, it eliminates the function of the posterior tibial muscle on the hindfoot position.

- Make a 3- to 4-cm incision over the insertion of the posterior tibial tendon (PTT) at the navicular. After dividing the subcutaneous tissue, incise the flexor retinaculum and PTT sheath. Tension the tendon using an Overholt clamp and release it at its insertion point with the scalpel as distally as possible.

- Make another skin incision (3 cm) at the distal medial calf, three to four fingerbreadths proximally to the ankle, directly behind the posterior edge of the tibia.

- After dividing the subcutaneous tissue, incise the fascia and retract it with Langenbeck retractors. Identify and retract the tendon of the long toe flexor muscle (FHL tendon). Immediately deep to the FHL tendon, identify the PTT. Expose it with an Overholt clamp and pull it out (TECH FIG 2).

- Bisect the tendon and tag both halves with atraumatic 1-0 Vicryl sutures.

- Make a third skin incision 3 cm in length on the lateral side of the shank on the same height directly ventrally to the fibular bone. Beneath the subcutaneous tissue, incise and retract the fascia.

**T-SPOTT (TOTAL SPLIT POSTERIOR TIBIAL TENDON TRANSFER, MODIFIED SPOTT)**

- The purpose of this technique is the augmentation of the attenuated ankle dorsiflexor muscles that are often compromised by longstanding hindfoot equinus deformity. Furthermore, it eliminates the function of the posterior tibial muscle on the hindfoot position.

- Make a 3- to 4-cm incision over the insertion of the posterior tibial tendon (PTT) at the navicular. After dividing the subcutaneous tissue, incise the flexor retinaculum and PTT sheath. Tension the tendon using an Overholt clamp and release it at its insertion point with the scalpel as distally as possible.

- Make another skin incision (3 cm) at the distal medial calf, three to four fingerbreadths proximally to the ankle, directly behind the posterior edge of the tibia.

- After dividing the subcutaneous tissue, incise the fascia and retract it with Langenbeck retractors. Identify and retract the tendon of the long toe flexor muscle (FHL tendon). Immediately deep to the FHL tendon, identify the PTT. Expose it with an Overholt clamp and pull it out (TECH FIG 2).

- Bisect the tendon and tag both halves with atraumatic 1-0 Vicryl sutures.

- Make a third skin incision 3 cm in length on the lateral side of the shank on the same height directly ventrally to the fibular bone. Beneath the subcutaneous tissue, incise and retract the fascia.
Chapter 56 MANAGEMENT OF EQUINOCAVOVARUS FOOT DEFORMITY

TECHNIQUES

The purpose of the modified Jones procedure\(^4\) is to eliminate the overactive EHL muscle and to correct the clawed hallux.

**Exposure**

- Make an S-shaped skin incision from the proximal first metatarsal to the first interphalangeal (IP) joint.
- After careful soft tissue dissection and protection of the dorsomedial sensory nerve to the hallux, tag the EHL tendon distally with a 0 Vicryl suture.
- Release the tendon as far distally as possible and perform an arthrotomy of the first IP joint (**TECH FIG 3**).

**Hallux Interphalangeal Joint Arthrodesis**

- We use a rongeur to remove cartilage at the hallux IP joint (**TECH FIG 4A–C**).

We then place two crossing Kirschner wires (1.4 mm for children, 1.8 for adults) through the distal fragment, antegrade from proximal to distal.

Using the wire driver on the distal aspect of the wires, retract the Kirschner wires from the IP joint arthrodesis site, reduce the IP joint, and advance the Kirschner wires retrograde across the IP arthrodesis site (**TECH FIG 4D–F**).

Avoid excessive IP joint extension because it may lead to problems with shoe wear.

Confirm proper toe rotation after placing the first wire, and then advance the second wire.

We routinely use two Kirschner wires for fixation; however, the combination of one longitudinal screw and a derotational Kirschner wire is a reasonable alternative. We caution against using only a single screw since this fixation may prove rotationally unstable.

---

**MODIFIED JONES PROCEDURE (ROBERT JONES, 1916)**

- Perform the following preparation of the interosseous membrane with caution because of the superficial peroneal nerve. Carefully direct a narrow forceps through the interosseous membrane from the medial wound to lateral wounds.
- Grab a single thread with the forceps and pull it through the medial wound. Capture the tag sutures of the two halves of the PTT in the loop. Transfer the split PTT to the lateral wound by pulling the end of the single thread.
- To maintain the ability to pull back the transferred tendons, loop another single thread around the tendons.
- Expose the anterior tibial tendon by making a 2- to 3-cm skin incision. When planning this incision, take into consideration the possible need for an arthrodesis of the talonavicular joint. If it is needed, the incision should be in line with the previous incision made to expose the PTT.
- After dissecting the subcutaneous tissue, incise the sheath of the anterior tibial tendon and pass the forceps through its sheath to the extensor compartment, where the two halves of the PTT were transferred before.
- There, grab the tagged suture of one half and transfer it distally. For the transfer of the second half of the tendon, make an additional skin incision on the dorsal foot.
- Expose the tendons of the long toe extensors (EDL) and incise their sheath. The same technique is used for the distal transfer of the other half of the PTT. Perform any other concomitant procedures now, before securing the tendon transfers.
- At the end of the operation, suture the medial half of the PTT to the anterior tibial tendon and suture the lateral half to the peroneus brevis tendon, which is previously exposed.
- When tensioning the tendon transfers, we routinely position the ankle in neutral and avoid not only undercorrection but also overcorrection of the foot.
- After suturing the transfers, the foot should rest in the corrected position. Therefore, hindfoot equinus must be corrected before suturing the tendon transfers.
TECH FIG 3 • Modified Jones procedure.

TECH FIG 4 • Modified Jones procedure.
Extensor Hallucis Longus Tendon Transfer (With or Without Dorsiflexion Osteotomy of the First Metatarsal)

- Expose the first metatarsal to the proximal third of its shaft. If the plantarflexion of the first metatarsal bone cannot be corrected by soft tissue correction alone, a dorsiflexion osteotomy of the first metatarsal must be performed. (The technique will be described in greater detail later.)
- Extend the approach a few more centimeters proximally.
- Perform the dorsiflexion osteotomy with an oscillating saw, removing a dorsal wedge of bone in the proximal third of the metatarsal and leaving the plantar cortex intact.
- Secure it with Kirschner wires, a small dorsal plate, or a screw and tension band technique.
- For the EHL tendon transfer, use a periosteal elevator to expose the bone at the first metatarsal head-neck junction.
- Place two Hohmann retractors to protect the soft tissues and drill a hole centrally in the first metatarsal bone with sequentially larger-diameter drill bits: first 2.0 mm, then 2.7 mm, followed by 3.2 mm.
- Advance the tagged EHL tendon through the hole with a needle and suture it to itself with 1-0 Vicryl.
- If the hallux tends to plantarflex after the tendon transfer, the distal end of the transferred EHL tendon or its suture tags may be reattached to the periosteum of the distal phalanx as a tenodesis to avoid undesirable postoperative flexion of the first toe.

FUSION OF THE CHOPART JOINT, TRIPLE FUSION (HOKE, 1921\(^2\)\), LAMBRINUDI FUSION (LAMBRINUDI, 1927\(^7,14\))

- Fixed hindfoot cavus deformity may warrant talonavicular and calcaneocuboid joint (Chopart joint) arthrodesis. However, when the deformity is isolated to a fixed, plantarflexed first ray, a dorsiflexion first metatarsal osteotomy may be adequate. Likewise, global cavus of the entire forefoot may be effectively treated with a dorsiflexion midfoot osteotomy (Cole procedure).
- In select cases of flexible hindfoot varus, a Dwyer lateral closing wedge calcaneal osteotomy (see below) may be performed in lieu of hindfoot arthrodesis.
- The lateral approach is performed with an S-shaped skin incision, beginning 2 cm distally and dorsally to the lateral malleolus, proceeding in an arch shape to the navicular, distally to the palpable talus head.
- Expose the sural nerve in the proximal wound edge with its accompanying vessels and retract it.
- The preparation leads to the peroneal tendon sheath and the origin of the extensor digitorum brevis muscle (EDB) at the anterior processes of the calcaneus.
- With an L-shaped incision, release the EDB. Using a concave chisel, detach its origin from the anterior processes of the calcaneal bone. Expose the calcaneocuboid joint by inserting a Vierstein retractor.
- Use an additional Vierstein retractor to expose the talonavicular joint.
- The hindfoot arthrodesis may be performed with preservation of the subchondral bone architecture or as a corrective wedge resection. If cavus was not corrected by the Steindler procedure, a dorsally based wedge must be taken from the Chopart joint.
- With extreme forefoot and midfoot adduction, the dorsal wedge resection may need to include an additional lateral-based wedge resection.
- The more conservative arthrodesis that maintains subchondral bone architecture of the joints is reserved for mild to moderate deformity. Remove the cartilage and penetrate the subchondral bone with a chisel or drill to promote fusion.
- If a wedge resection is required to correct the deformity, we prefer to use an oscillating saw.
- After the complete release of the Chopart joint, the cavus foot can be manually corrected and the navicular centered on the talus head.
- We routinely stabilize the reduced joints with Kirschner wires (two through the talonavicular joint, two through the calcaneocuboid joint). Alternatively, the fixation can be done with screws.
- If a satisfactory deformity correction is not possible by Chopart arthrodesis, especially with severe hindfoot varus, the hindfoot arthrodesis must be extended to the subtalar joint to complete the triple arthrodesis.
- In severe deformity, a laterally based wedge can be removed from the subtalar joint. Dorsal impingement of the talus on the tibia, in cases with limited ankle dorsiflexion or extreme hindfoot equinus, may warrant a modified Lambrinudi procedure.
- For both the triple arthrodesis and modified Lambrinudi procedure the sinus tarsi is freed from all soft tissue structures (interosseous ligaments and fat). The most important structure to be dissected is the interosseous ligament between the talus and calcaneus. To expose the subtalar joint, use a lamina spreader in the subtalar joint and place a Vierstein retractor below the apex of the lateral malleolus.
- Prepare the surfaces at the arthrodesis site with a concave chisel or with the oscillating saw, depending on the amount of correction needed.
- A severe hindfoot varus is corrected by removing a lateral-based wedge from the subtalar joint (TECH FIG 5). If a Lambrinudi fusion is needed, a dorsally based wedge is taken out of the subtalar joint.
- The determination of the osteotomy lines is important for the size of the remaining bone. The first osteotomy runs parallel to the ankle joint line and through the talus head. It should not take more than 50% of the talus head.
- The osteotomy ends dorsally in the posterior edge of the subtalar joint. The second osteotomy runs parallel to the
subtalar joint line and through the calcaneal bone. Both osteotomies unite in the posterior edge of the subtalar joint, forming a dorsally based wedge with its apex in the posterior aspect of the subtalar joint.

- After resecting the cartilage or the bony wedge, assess the effect of correction by the reposition of the talocalcaneal and the Chopart joint. In addition to the correction of the cavus hindfoot varus components, it is very important that the foot can be repositioned in a plantigrade position.
- The osteosynthesis can be done with six Kirschner wires (2.2 to 2.5 mm, two for the talonavicular joint, two for the calcaneocuboid joint, and two for the subtalar joint). Alternatively, the fixation may be performed with screws or a locking plate.

### COLE OSTEOTOMY

- This procedure is used for bony correction of cavus deformity when the talonavicular and calcaneocuboid joints can be reduced. A dorsally based wedge is removed from the navicular-cuneiform joints and the cuboid.
- We perform this procedure through a lazy S-incision at the lateral midfoot. Expose the sural nerve in the subcutaneous tissue and retract it.
- Make an incision between the sheath of the peroneal tendons and the EDB to expose the cuboid. Perform the osteotomies with an oscillating saw or osteotome.

**TECH FIG 6 • Cole procedure.**

- The distal osteotomy should be driven exactly through the cuneiforms and the cuboid; the proximal osteotomy runs through the cuboid and navicular. At least 0.5 cm of bone must be preserved between the proximal osteotomy and the talonavicular joint.
- These osteotomies converge on the plantar aspect of the midfoot. Remove a dorsal-based bony wedge (TECH FIG 6).
- After the resection, the osteotomy can be closed and fixed with two to four Kirschner wires (talonavicular and calcaneocuboid joint, Chopart fusion). Alternatively, screws or locking plates can be used.

### DWYER OSTEOTOMY

- This procedure is used for bony correction of hindfoot varus deformity, when subtalar joint fusion is not indicated, the hindfoot cannot be completely reduced, and a correction of the hindfoot varus correction cannot be achieved by tendon transfer alone.
- Make a skin incision (about 5 cm) at the lateral border of the hindfoot above the peroneal tendons, vertical to the longitudinal axis of the calcaneus. Expose the sural nerve in the subcutaneous tissue and retract it.
- Expose the neck of the calcaneus subperiosteally by two Hohmann retractors.
SOFT TISSUE CORRECTION OF HINDFOOT EQUINUS (BAUMANN PROCEDURE, ACHILLES TENDON LENGTHENING)

- Achilles tendon lengthening is done when both calf muscles are shortened and the equinus is severe and fixed. In case of a flexible and mild equinus, intramuscular recession (Baumann technique) is done.
- The approach for an open Achilles tendon lengthening is done through a 6- to 10-cm skin incision made at the medial distal calf, about 3 to 4 cm above the ankle joint, running proximally. The length of the skin incision varies with the amount of Achilles tendon lengthening needed for equinus correction.
- After identifying and retracting the saphenous nerve and vein, expose the fascia and incise and divide it proximally and distally. Beneath the fascia, identify the Achilles tendon and elevate it with two Langenbeck hooks, inserted under the tendon proximally and distally.
- Perform the Z-lengthening with a small scalpel over the entire tendon (TECH FIG 8A–C).
- In hindfoot varus deformity, we prefer to preserve the lateral half of the tendon distally. Do not dissect the underlying muscle tissue.
- Tag both tendon slips with 1-0 Vicryl sutures.
- The ankle joint can now be reduced to 10 to 20 degrees of dorsiflexion, so that both tendon slips slide apart.
With the ankle joint in neutral position, suture together both tendon slips with atraumatic 1-0 Vicryl suture.

- For the Baumann procedure, make a 4- to 5-cm skin incision in the medial aspect of the proximal third of the calf. Expose and incise the fascia after tagging it with two sutures.
- Open the interval between the gastrocnemius and the soleus muscle and insert two broad Langenbeck retractors.

- Perform an intramuscular recession of the aponeurosis of the gastrocnemius, soleus, or both (TECH FIG 8D–F), based on an intraoperative Silfverskiöld test.
- After recession, the ankle can be redressed. The aponeurosis will slide apart.

**TECH FIG 8 • A–D.** Open Achilles tendon lengthening. **E–F.** Baumann procedure.
This procedure is one of the final steps in the surgical correction of pes equinocavovarus. It is warranted when fixed plantarflexion of the first metatarsal fails to correct with the modified Jones procedure alone.

The approach is easily done by lengthening the incision for the Jones procedure proximally to the first metatarsal base.

Sharply incise the periosteum over the dorsal first metatarsal lengthwise approaching the first tarsometatarsal joint, protecting the soft tissues with two Hohmann retractors.

Perform the proximal limb of the osteotomy with an oscillating saw, vertical to the first metatarsal, about 0.5 cm distal to the first tarsometatarsal joint in adults and the growth plate in children. It is important to keep the plantar cortex intact to control rotation error.

The distal osteotomy converges with the first osteotomy at the plantar cortex, creating a dorsal wedge (TECH FIG 9A).

The width of the dorsal wedge is determined by the planned correction; in our experience, bone resection of 2 to 3 mm is appropriate.

Close the osteotomy with plantar pressure on the head of the first metatarsal (TECH FIG 9B).

We routinely secure the osteotomy with two crossing Kirschner wires (TECH FIG 9C). Alternatively, a dorsal locking plate or screw and tension band technique may be used to stabilize the osteotomy.

**TECH FIG 9** • Extension osteotomy of the first metatarsal bone.

**RUSSEL-HIBBS PROCEDURE (1919)**

This procedure corrects claw toes secondary to overactivity of the extrinsic (long extensor and flexor digitorum muscles) relative to the intrinsic muscle groups.

We use a convex lateral 4-cm incision over the fourth metatarsal. Identify and retract the superficial peroneal nerve.

Expose the EDL tendons of the second through fourth toes and tag them together proximally and distally (TECH FIG 10) with atraumatic 1-0 Vicryl sutures.

Cut the tendons between the two sutures.

Dissect the EDB muscle carefully and expose the underlying bone.

In children, the proximal endings of the tendons can be sutured to the periosteum. The foot should come into neutral position spontaneously after the suture.

In adults a tendon anchor is secured to the underlying bone (intermediate cuneiform body), and the tendons are secured to the anchor. The distal part of the tagged tendons should also be sutured to periosteum or the anchor to create a distal tenodesis.
WOUND CLOSURE
- Tendon transfers and lengthened Achilles tendon are sutured with atraumatic 1-0 Vicryl. All wounds are closed in layers.
- At the calf the fascial incisions are sutured with 0 Vicryl.
- If removed, the anterior processes of the calcaneus are reattached with 1-0 Vicryl.
- Afterwards the subcutaneous tissue is closed (2-0 Vicryl).
- We routinely use a simple suture technique (and occasionally the Donati-Allgower technique) for skin closure on the foot (3-0 Ethilon), and we use an intracutaneous technique for skin closure on the calf.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>A detailed clinical examination is the basis for the correct indication and a good outcome. Concomitant deformities should be considered when planning the treatment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order of procedures</td>
<td>Begin with soft tissue procedures before performing bony procedures. This may decrease the extent of bony wedge resection. Sutures of soft tissue procedures are done after the bony correction.</td>
</tr>
<tr>
<td>Joint fusion</td>
<td>Ensure that all cartilage is removed from the resection areas to avoid nonfusion.</td>
</tr>
<tr>
<td>Overcorrection</td>
<td>Avoid overcorrection; start with small wedges and extend the resection if needed.</td>
</tr>
<tr>
<td>Wound closure problems</td>
<td>In severe cases that demand significant correction, skin closure can be difficult. This should be considered before performing skin incisions. The problem often can be solved with S-shaped incisions.</td>
</tr>
</tbody>
</table>
**POSTOPERATIVE CARE**

- In the operating room, we apply a short-leg cast with the ankle in neutral ankle position and the hindfoot in slight eversion.
- On postoperative day 1, we routinely obtain a radiograph and change the plaster cast.
- With bony procedures, weight bearing is restricted for 6 weeks and 4 weeks for adults and children, respectively. At the subsequent follow-up, new radiographs are obtained, the Kirschner wires are removed, and a short-leg, weight-bearing plaster cast is applied for an additional 6 weeks and 4 weeks for adults and children, respectively.
- In contrast, without bony procedures, the weight-bearing plaster cast is applied immediately after the operation for 6 (adults) or 4 (children) weeks.
- The stitches are removed 14 days postoperatively, when we perform a routine cast change. After the removal of the final plaster cast, we advise our patients to use a brace for 6 months to a year, depending on the severity of deformity and correction required.

**OUTCOMES**

- References concerning long-term outcomes after complex foot reconstruction surgery in pes equinocavovarus are rare. Controlled outcome studies, based on clinical, radiographic, and functional data (3D foot analysis, EMED), are needed.

**Case 1**

- This 16-year-old patient with tethered cord syndrome and myelolysis suffered from a painful equinocavovarus foot on the right side with hindfoot varus and equinus, cavus...
deformity, plantarflexion of the first metatarsal, and claw toes (FIG 6A–I).

- He was treated with a Steindler procedure, a Jones procedure, a PTT transfer, a Chopart fusion, an Achilles tendon lengthening, and a dorsiflexion first metatarsal osteotomy. The postoperative results are shown in FIGURE 6J–Q.

- After his foot deformity correction he is now able to work as a roof tiler without functional limitations or pain.

Case 2

- A 32-year-old man with severe equinocavovarus had as his major problems combined forefoot and hindfoot equi-
nus, hindfoot varus, a cavus component, and clawing of the toes.
- After Achilles tendon lengthening, a split PTT transfer, a Steindler procedure, a Chopart fusion, a dorsiflexion first metatarsal osteotomy, and a modified Jones procedure, a plantigrade functional foot was restored.
- **FIGURE 7A,B** shows preoperative findings and **FIGURE 7C,D** shows findings 1 year postoperatively.

### COMPLICATIONS

- Infection
- Vessel or nerve bundle injury
- Nonunion
- Overcorrection (flatfoot, valgus foot, calcaneus foot)
- Undercorrection
- Recurrence
- Ulceration due to plaster casting
- Pin tract infection from the Kirschner wires

### REFERENCES

DEFINITION
- Chronic plantar fasciitis with distal tarsal tunnel syndrome is an underrecognized disorder in which the patients with the typical enthesopathy of plantar fasciitis develop neurogenic symptoms and signs, becoming recalcitrant to the usual management of the initial condition.
- This chapter will concentrate on the most common type of distal tarsal tunnel syndrome: chronic plantar fasciitis associated with the involvement of the lateral plantar nerve and the first branch of the lateral plantar nerve.

ANATOMY
- Proximal or classic tarsal tunnel syndrome was first described by Koppell and Thompson in 1960. It was subsequently named by Keck and Lam in two independent reports in 1962.8,10 Entrapment of the entire tibial nerve as it courses beneath the flexor retinaculum behind the medial malleolus defines proximal tarsal tunnel syndrome (FIG 1A). The flexor retinaculum or laciniate ligament is formed by joining the deep and superficial aponeurosis of the leg, and it is closely attached to the sheaths of the posterior tibial, flexor digitorum longus, and flexor hallucis tendons.

Distal tarsal tunnel syndrome, proposed by Heimkes et al in 1987,6 results from irritation of one or more of the terminal branches of the tibial nerve. The three terminal branches are the medial plantar nerve, lateral plantar nerve, and medical calcaneal nerve.
- The first branch of the lateral plantar nerve occurs just after the lateral plantar nerve branches from the posterior tibial nerve (FIG 1B). The first branch travels between the abductor hallucis muscle deep fascia and the medial fascia of the quadratus plantae muscle. It then changes direction and travels laterally in a horizontal plane between the quadratus plantae and the flexor digitorum brevis muscles, sending a sensory branch to the central heel pad, and terminates as motor branch to the abductor digit quinti.
- The lateral plantar nerve follows the same course initially, passing under the deep fascia of the abductor hallucis and the medial edge of the plantar fascia and over the quadratus plantae fascia, and then turns distally under the flexor digitorum brevis, emerging distally just under the plantar fascia to form the intermetatarsal nerves to the 4/5 interspace and contributing to the 3/4 intermetatarsal nerve as well.

**FIG 1** • A. The laciniate ligament, three branches of the tibial nerve, and the classic tarsal tunnel. B. Detailed anatomy of the tibial nerve and branches.
The medial plantar nerve leaves the tibial nerve just proximal to or just under the abductor hallucis and travels under the abductor hallucis, innervating it and forming the intermetatarsal nerves to the 1/2, 2/3, and 3/4 interspaces. Both the medial and lateral plantar nerves provide innervation to the interossei and lumbricals.

The medial calcaneal nerves may be multiple and emerge from the tibial nerve proximal to the proximal (upper) edge of the abductor hallucis.

The plantar fascia or aponeurosis arises from the os calcis and is composed of three segments—the central, medial, and lateral portions.

Clinically, the central portion is considered to be the plantar fascia and originates from the medial tuberosity of the os calcis and inserts into all five toes.

Extension of the toes and the metatarsophalangeal (MTP) joints tightens the plantar aponeurosis, elevates the longitudinal arch, and inverts the hindfoot. This mechanism, which is entirely passive and depends on bony and ligamentous stability, is referred to as the “windlass mechanism.”

**PATHOGENESIS**

Plantar fasciitis is thought to be a result of repetitive microtearing of the origin of the central band of the plantar aponeurosis.

This repetitive trauma results in inflammation and persistent pain, especially pain with the first steps in the morning or with the first steps after periods of inactivity.

Chronic symptoms of plantar fasciitis develop in about 10% of patients with plantar heel pain.

We believe that these patients experience partial ruptures or attenuation of the plantar fascia, as suggested by clinical findings in which the medial border of the fascia becomes less distinct than the normal side when the ankle and toes are dorsiflexed.

A subset of these patients has chronic, disabling plantar heel pain with associated neurogenic symptoms of distal tarsal tunnel syndrome.

**NATURAL HISTORY**

In 1986, Rondhuis and Huson described compression of the first branch of the lateral plantar nerve and its association with heel pain.

Baxter et al further studied and reported on the principle of isolated compression of the first branch and its association with chronic plantar fasciitis.

Further studies by Lau and Daniels demonstrated that increased traction in the lateral plantar nerve and in its first branch is noted as the supporting structures of the longitudinal arch are selectively divided, including the plantar fascia, which could result in a “traction neuritis” of the nerves.

Inflammatory conditions and local edema affect the nerve as it travels in the hindfoot. Entrapment, or traction irritation, of the lateral plantar nerve and its first branch is thought to occur between the abductor hallucis muscle deep fascia, the medial border of the plantar fascia, and the medial caudal margin of the quadratus plantae muscle.

Electrodiagnostic evidence of compression of the first branch lateral plantar nerve and its association with chronic plantar fasciitis have been reported by Schon et al.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

Patients with chronic proximal plantar fasciitis with distal tarsal tunnel syndrome have signs and symptoms typical of both plantar fasciitis and neuritis.

We believe that chronic plantar heel pain that does not respond to a standard nonoperative protocol is the result of attenuated or significant partial plantar fascia rupture, in addition to some degree of neuritis or nerve entrapment.

The patient population is diverse, with a wide age range and varied activity levels, and includes both nonathletes and elite competitive athletes. Occupations are also diverse, although many patients are employed in vocations that require prolonged standing or walking.

**Plantar Fasciitis**

Plantar fasciitis symptoms are considered chronic when they persist for at least 9 months.

Typically, symptoms include plantar heel pain that is most severe with the first steps in the morning or with the first steps after prolonged sitting. This pain disappears relatively quickly after walking for a few moments and is relieved immediately upon non-weight-bearing. It does not become increasingly painful with increased walking or at rest.

On physical examination, there is tenderness at the medial tubercle of the calcaneus, which correlates with the origin of the plantar fascia. This area of tenderness is focal and reproducible and is located at the plantar medial heel.

Most patients in the chronic state have evidence of attenuation of the plantar fascia and probable biomechanical incompetence.

This asymmetry between the two feet in terms of firmness of the plantar fascia is noted when recreating the windlass mechanism (ankle dorsiflexion and 1–5 MTP joint dorsiflexion) and palpating the plantar fascia medial border. This difference is thought to represent a significant chronic partial plantar fascia tear.

Significant attenuation of the plantar fascia was noted at preoperative evaluation in 15 of 22 patients in the series reported by DiGiovanni et al.

**Neuritis/Distal Tarsal Tunnel Syndrome**

Neuritic symptoms and signs may be subtle and not appreciated unless the examiner is aware of their potential presence and checks for their possible existence.

Neuritic symptoms typically include reports of a long “afterburn” rather than instant relief of heel pain with non-weight-bearing after prolonged activity.

Patients may also describe radiation of pain in the posteromedial ankle, medial hindfoot, and distal plantar foot, often with numbness or burning and often worse with prolonged standing or when resting after prolonged activity.

Neuritis pain may radiate up the medial aspect of the leg, a condition known as the Valleix phenomenon.

Radiation of the neuritic pain may occur along the lateral aspect of the plantar heel, following the course of the lateral plantar nerve first branch.

In many cases, the patient will have difficulty describing the exact nature of the pain but may report diffuse tingling, burning, or numbness.
The medial hindfoot tenderness is located over the abductor hallucis muscle at a position approximately 5 cm anterior to the posterior border of the heel at the intersection of the plantar and medial skin.

If one palpates the medial border of the heel, the examiner’s digit will suddenly feel a “soft spot,” which corresponds with the course of the lateral plantar nerve and its first branch as they pass from the ankle into the foot at the lower edge of the fascia of the abductor hallucis, an area that is associated with nerve entrapment or neuritis.

This is a separate area from the medial tubercle of the calcaneus tenderness associated with plantar fasciitis.

In athletes (especially basketball players) or individuals whose occupations involve prolonged standing, enlargement or hypertrophy of the abductor hallucis muscle may be appreciated.

Patients with such irritation of the talib nerve and its branches may also be tender over the nerves in the arch, noted with the plantar fascia relaxed by passively plantarflexing the ankle and toes.

These patients have been diagnosed with so-called distal plantar fasciitis, an entity we doubt exists except with mid-substance ruptures of the plantar fascia.

These patients with tarsal tunnel syndrome may also have tenderness in the intermetatarsal spaces, suggesting intermetatarsal neuritis, Morton’s neuroma, or a “double-crush” syndrome. This is usually not the case, however, as patients with primary pathology proximally in the distal tarsal tunnel and plantar fascia complain of heel, arch, and posteromedial ankle pain, while those with primary disease distally complain of metatarsal pain (metatarsalgia) and may incidentally also have tenderness over the nerves proximally.

### Imaging and Other Diagnostic Studies

Electrodiagnostic studies are usually performed before surgical intervention, with most aimed at ruling out associated pathology, such as radiculopathy and generalized peripheral neuropathy.

If diffuse peripheral neuropathy rather than localized nerve entrapment is suspected, screening for diabetes, thyroid dysfunction, or alcoholism may be indicated.

Lower extremity electrodiagnostic studies are known to be less reproducible than upper extremity studies and are also dependent on the expertise and skill of the electrodiagnostician in performing detailed foot and ankle studies. The studies should evaluate potential entrapment of both the lateral and medial plantar nerves.

Electromyelographic results for the abductor hallucis or abductor digiti quinti are more likely to be abnormal than are nerve conduction studies.

A positive result adds confirmation to the clinical diagnosis, but because the neuritic component is thought to be a traction neuropathy, as demonstrated by Lau and Daniels, and is believed to be most evident in the dynamic situation, which is not usually tested, a negative result does not rule out the diagnosis. Accordingly, it is not uncommon to have negative electrodiagnostic studies despite signs and symptoms of neuritis.

Serologic studies may be indicated to evaluate for possible inflammatory arthritis in patients with bilateral heel pain of simultaneous onset and similar severity.

Weight-bearing foot radiographs are obtained to rule out such associated pathology as calcaneal stress fracture and hindfoot degenerative joint disease.

Patients with subtal and sometimes ankle arthropathy or with tenosynovitis of the posterior tibial, flexor digitorum longus, and flexor hallucis may have sufficient swelling to irritate the tibial nerve.

A subset of patients with posterior tibial tendon dysfunction may also have tarsal tunnel symptoms.

If there is a history of previous fracture or significant trauma, radiographs of both the ankle and foot should be obtained to rule out external sources of nerve compression such as exostosis.

Computed tomography (CT) has a limited role but may be helpful if there is a prior history of trauma with posttraumatic changes to assess for bony exostosis and deformity.

Technetium bone scans have a poor specificity and are rarely indicated.

Magnetic resonance imaging (MRI) is sensitive for detecting frank fascial rupture and confirming proximal plantar fasciitis, but it is not indicated in most cases.

MRI can demonstrate occult pathology, such as a space-occupying lesion in the proximal or distal tarsal tunnel or a subtile calcaneal stress fracture.

### Differential Diagnosis

- Diffuse peripheral neuropathy (diabetes mellitus, thyroid dysfunction, alcoholism)
- Lumbar radiculopathy
- Inflammatory arthritis
- Calcaneal stress fracture, hindfoot degenerative joint disease

### Nonoperative Management

Initial nonoperative treatment includes relative rest, plantar fascia and Achilles tendon stretching exercises, ice, and non-steroidal anti-inflammatory drugs.

Physical therapy modalities that involve or promote heating of the tissues, such as whirlpool baths, hydroculator packs, diathermy, ultrasound, or phonophoresis, seem to irritate the neuritic symptoms and increase rather than decrease symptoms.

Iontophoresis, which diffuses steroid with electrolysis, is well tolerated and is worthwhile.

Steroid injections into the plantar fascia or the nerve itself are discouraged.

Many patients present with a history of earlier episodes of plantar fasciitis that responded to steroid injections. These patients are now unresponsive to injection and have an obviously attenuated plantar fascia. This suggests an association of steroid injection with plantar fascia rupture and the ensuing chronicity.

Inexpensive over-the-counter orthotics are prescribed to support the arch and cushion the heel. With chronicity, a semi-rigid, accommodative, custom orthotic is prescribed. These are cork based and triple layered and include a “nerv relief channel” made of viscoelastic polymer, which is placed along the path of the lateral plantar nerve beginning at the proximal abductor hallucis muscle belly and extending to the soft spot.
If the patient has more symptoms in the central heel pad, which involves the first branch of the lateral plantar, the channel is carried more posteriorly and onto the plantar heel to include the painful central area.

- The same orthotic devices are used postoperatively if the patient requires surgery.
- Preliminary studies with extracorporeal shock wave lithotripsy (ESWL), of both low and high intensity, for chronic plantar fasciitis report a positive response, and the modality appears to be safe and effective.
- For individuals with chronic plantar fasciitis and associated signs and symptoms of neuritis, however, ESWL was not as effective. The treatment has the potential to further aggravate the inflamed nerves and is therefore not recommended.
- Controlled ESWL studies in which patients with neurogenic symptoms were excluded had better results. Additional investigations are needed to clarify these issues.

**SURGICAL MANAGEMENT**

- In the late 1980s and early 90s, Baxter and colleagues \(^1\) reported on and popularized their surgical approach to painful heel syndrome in athletes with entrapment of the first branch of the lateral plantar nerve. This approach includes partial release of the plantar fascia combined with release of the first branch of the lateral plantar nerve and removal of a heel spur if present. The investigators have reported a high success rate, particularly in the athletic population.
- More recent reports using this approach in a more general patient population have noted mixed results, however, with Davies et al \(^2\) in 1999 reporting less than 50% of patients with complete satisfaction as a result of persistent symptoms.
- DiGiovanni and Gould and their colleagues \(^3,4\) have devised and reported on a modified surgical approach based partially on the work of Baxter and colleagues. The approach is also based on the observation that patients with plantar fascia rupture and chronic pain who do not have neurogenic symptoms respond to a complete surgical release of the plantar fascia.
- Patients who had the release described by Baxter and continued to be symptomatic responded to the complete release and neurolysis as described below.
- The more-extensive approach is used to allow the release of all potential sources of entrapment of the tibial nerve and its branches, and thus allow for improved rates of complete resolution of pain and elimination of activity limitations.
- This technique combines a complete plantar fascia release with a proximal and distal tarsal tunnel release, without bone spur removal.
- The philosophy behind a complete release rather than a partial release of the plantar fascia is as follows:
  - The literature does not provide information about the optimal amount of partial release to perform to allow for reproducible resolution of plantar heel pain. The amount is probably highly variable from patient to patient and depends on a number of factors, including the type of foot arch.
  - Patients with chronic heel pain commonly have evidence of attenuation of their plantar fascia and probably have pre-existing biomechanical incompetence. A further partial release in feet with pre-existing plantar fascia attenuation has not consistently led to resolution of plantar heel symptoms.
  - Complete release of the plantar fascia from the abductor hallucis to the abductor digiti quinti has consistently relieved the pain experienced after the first step in the morning or after recumbency.
  - The nerve component of the pathology is also specifically addressed. In our experience, release of the plantar fascia alone in patients with chronic plantar fasciitis often leads to increased neuritic symptoms. Consequently, the nerve procedure is always performed in addition to the plantar fascia release.
  - Rather than an isolated release of the first branch of the lateral plantar nerve, a proximal (or classic) as well as a distal tarsal tunnel release is performed to address all potential sites of nerve entrapment.
  - Proximal tarsal tunnel syndrome may coexist distal and can be difficult to differentiate and isolate.
  - In addition, more than one branch of the terminal tibial nerve branches may be entrapped.

**Preoperative Planning**

- Good history taking, specifically to determine when and in which anatomic location symptoms occur, is essential. We cannot emphasize enough that the history will differentiate metatarsalgia, pure plantar fasciitis, radiculopathy, and neuropathy.
- A careful physical examination must be done as indicated previously.
- Electrodagnostic testing is useful when the history and physical have not clearly ruled out neuropathy particularly or radiculopathy.
- Tibial nerve entrapment may coexist with neuropathy, but the prognosis for a good result with this surgery is guarded, and we believe such a combination accounts for less than optimal results.

**Positioning**

- The patient is positioned supine without a bump under the hip, allowing the leg to externally rotate.
- Multiple folded surgical towels are placed under the foot to allow the surgeon to easily operate posteromedially and to allow room for the assistant to retract. The foot is positioned near the foot of the table, but not at the end, so the surgeon has the table on which to rest the forearms and not be forced to operate in midair.
- We operate from the seated position across the normal leg and use a rolling surgical stool so that we can move from facing the medial side to the plantar side.
- When we move around to the plantar side, we ask the anesthetist to place the foot of the bed in Trendelenburg to improve access.

**Approach**

- We use a posteromedial and plantar approach to fully visualize the anatomy.
- The procedure is done with high thigh tourniquet control after exsanguination of the leg.
- Bipolar cautery is used for minimal tissue necrosis.
- Loupe magnification is always used, with a preference of 3.5 to 4.5 magnification.
TECHNIQUES

■ The surgeon easily spreads, cuts, and cauterizes superficial vessels and identifies the flexor retinaculum (laciniate ligament). This layer is divided directly over visible posterior tibial veins distally to the level of the abductor hallucis muscle. No attempt is made to isolate the tibial nerve (TECH FIG 1B).

■ The superficial fascia of the abductor hallucis is divided sharply with a no. 15 surgical scalpel or no. 64 Beaver blade.

■ The hooks are now moved distally to the plantar surface, and spreading and cutting is done with a long-handled tenotomy scissors down to the plantar fascia. Two sharp Senn retractors are now used, which gather the fat away from the fascia and improve visualization.

■ A Meyerding retractor is placed at the distal extent of the incision to expose the fascia overlying the abductor digiti quinti fascia. The knife blade is used to sharply cut the plantar fascia from its lateral extent, at the edge of

**TECH FIG 1 •** A. The skin incision for the complete release. B. Dividing the laciniate ligament. C. Dividing the entire plantar fascia. D. Dividing the deep fascia of the abductor hallucis. E. The abductor hallucis and flexor digitorum brevis interval. F. Lateral plantar nerve overlying the quadratus plantae fascia.
the abductor digit quinti fascia medially to the abductor hallucis fascia, fully exposing the flexor digitorum brevis muscle (TECH FIG 1C).

- The plantar fascia surface is actually convex and meets each of the abductor fascias more deeply or dorsally than at its midpoint.

- As right-handed surgeons, we release this deep fascia on the right foot from the laciniate ligament distally. On the left foot, we begin from the plantar fascia side. In either case, we now place a self-retaining retractor in the wound to allow the assistant to help with the next step (TECH FIG 1D).

- The blades of the tenotomy scissors are spread between the muscle of the abductor hallucis and its deep fascia to initiate its exposure. The Meyerding retractor is used to further tease the muscle off the fascia and enhance and complete its visualization.

- The fascia is divided under the muscle, exposing the neurovascular structures and the tarsal tunnel. We divide the deep fascia as far as we can see it and then expose the structure from the opposite side (either proximally and distally) and complete the release.

- The muscle of the flexor digitorum brevis is then retracted laterally, and the fine fascia overlying the neurovascular structures is divided.

- The interval between the abductor hallucis and the flexor brevis is then exposed. The self-retaining retractor is placed on the skin and subcutaneous fat at this interval. One Meyerding (or similar right-angle) retractor is placed under the abductor muscle, retracting it proximally. Another right-angle retractor is placed under the abductor hallucis and its deep fascia to start in normal tissue.

- With the confluence of the superficial and deep abductor fascias distally and the medial border of the plantar fascia, a dense band of fascia overlies the lateral plantar nerve, and with the dense band of the quadratus fascia below, it is easy to visualize a pincer effect on the nerve at this point with weight bearing and particularly when the plantar fascia is less taut.

- Closure is carried out after irrigation of the wound. The ankle subcutaneous is closed with 4-0 absorbable suture and the skin with 4-0 nonabsorbable suture. The glabrous plantar skin is closed with only 3-0 or 4-0 skin permanent suture, with no subcutaneous suture.

- A soft bulky dressing is applied and the tourniquet released. Sterility is not broken until the toes show good perfusion.

**COMPLETE PLANTAR FASCIA AND TARSAL TUNNEL RELEASE FOR PRIOR INCOMPLETE AND FAILED RELEASES**

- The same basic approach is used as just described but with several additions to the technique.

- The new incision begins proximal to the original one to start in normal tissue.

- The old incision is incorporated into the new, ensuring access to the soft spot.

- When the laciniate ligament is divided, the tibial nerve is exposed, and a vessel loop is placed around the nerve and a tie is placed on the loop as opposed to a hemostat to avoid any traction on the nerve.

- As the release proceeds, external neurolysis of the tibial nerve and of the medial and lateral plantar branches is carried out. The calcaneal nerves are identified and protected. The first branch of the lateral plantar nerve is identified.

- The muscle belly of the abductor hallucis is often divided with a cutting cautery with careful blunt dissection to protect the underlying critical structures. The muscle of the flexor digitorum brevis may also be partially or fully divided to get adequate exposure.

- If there is no evidence of damage to the nerves or marked wound scar or scar around the nerves, the wounds are closed as in the primary procedure.

**COMPLETE PLANTAR FASCIA AND TARSAL TUNNEL RELEASE WHEN EXTENSIVE SCARRING OF THE NERVE IS PRESENT, WITH THE USE OF BARRIER WRAPPING OF THE NERVE**

- The complete release as described above is performed.

- For nearly 20 years, we have used greater saphenous vein wrapping of scarred mixed nerves that must be preserved. More recently, we have used barrier wrapping with commercially available collagen tubes. Both techniques are described below.
Use of the Greater Saphenous Vein

- The greater saphenous vein is harvested with a longitudinal incision beginning in the midpoint between the crest of the tibia and its posteromedial margin. One usually has to harvest a length of vein three times the length of nerve to be wrapped.

- At harvest, metal ligacips are used for the branches, which are few in number in the distal vein. Double medium clips are used at either end of the vein, and one is left on the end of the harvested proximal vein to indicate the orientation of the vein.

- The vein is placed in lidocaine to relax the smooth muscle component. It is then dilated from distal to proximal either with mechanical dilators or hydrostatically with lidocaine inserted under pressure with a syringe, using a vein plastic adaptor fitted to the syringe.

- All metal clips are then removed and the vein divided longitudinally.

- The vein is then curled around the involved nerve in barber pole fashion with the venous intima adjacent to the nerve. The vein is wrapped without tension, and each end is attached to surrounding tissues so as not to have a closed loop at either end. The coils are attached to each other with two 7-0 Prolene sutures placed about 180 degrees apart (TECH FIG 2).

- The medial and lateral plantar nerves are wrapped separately.

  - The tibial nerve may be wrapped and then the surgeon may continue down one or the other of the branches.

  - The wrap of the other plantar nerve joins the initially wrapped portion.

- A neuroma of a calcaneal branch is treated with either a vein or a collagen conduit.

- The neuroma is exposed and excised.

- A conduit of at least 2 cm should be used.

- Collagen tubes of a proper diameter to loosely enclose the nerve are available, and the 4-cm lengths may be trimmed as needed.

- When using a vein, the diameter must also be large enough to loosely accommodate the nerve, and the lumen diameter may need to be narrowed a bit so that it fits a little more closely around the nerve end.

- A nylon suture is placed through the end of the nerve, the needle is removed, and the two ends of the suture are grasped with a hemostat.

- A suture passer (Hewson) is placed through the conduit, and the nylon suture attached to the nerve is placed through the suture passer loop.

- The conduit is slid over the nerve, overlapping by 5 mm to 1 cm, and 8-0 sutures are used to attach the conduit lumen to the epineurium of the nerve. Typically, two sutures at 180 degrees are placed. The nylon suture used to draw the nerve into the conduit is removed (TECH FIG 3).

Use of Commercial Collagen Tubes

- Use of the commercially available collagen tubes simplifies the process. The tubes come in diameters ranging from 2 to 10 mm and lengths of 2 to 4 cm. The tubes are provided longitudinally divided.

- The size to be used is determined by the surgeon’s estimation of the needed diameter and lengths. Several lengths may be joined or a slightly long segment may be trimmed.

- The slit in the tube is closed, not too tightly, with a few interrupted 6-0 nylon sutures.

USE OF CONDUITS FOR NEUROMAS OF THE CALCANEAL BRANCHES

- A neuroma of a calcaneal branch is treated with either a vein or a collagen conduit.

- The neuroma is exposed and excised.

- A conduit of at least 2 cm should be used.

- Collagen tubes of a proper diameter to loosely enclose the nerve are available, and the 4-cm lengths may be trimmed as needed.

- When using a vein, the diameter must also be large enough to loosely accommodate the nerve, and the lumen diameter may need to be narrowed a bit so that it fits a little more closely around the nerve end.

- A nylon suture is placed through the end of the nerve, the needle is removed, and the two ends of the suture are grasped with a hemostat.

- A suture passer (Hewson) is placed through the conduit, and the nylon suture attached to the nerve is placed through the suture passer loop.

- The conduit is slid over the nerve, overlapping by 5 mm to 1 cm, and 8-0 sutures are used to attach the conduit lumen to the epineurium of the nerve. Typically, two sutures at 180 degrees are placed. The nylon suture used to draw the nerve into the conduit is removed (TECH FIG 3).

- The nerve and its “conduit to nowhere” is buried posteromedially, often into the retrocalcaneal space.
POSTOPERATIVE CARE

- The patient is placed in a soft bulky dressing at surgery, and crutches are used for non-weight-bearing. From immediately after the operation, motion of the foot and ankle is encouraged.
- Sutures are removed at 2 weeks, and a light dressing is applied. Gentle range-of-motion exercise of the ankle is re-emphasized to promote gliding of the nerve, but non-weight-bearing continues for 2 more weeks.
- At 4 weeks, the patient is allowed to bear weight using the custom orthotic described earlier.
- The orthotic is used for at least 9 months and then may be phased out.
- If the patient fails to comply, pain will be experienced, usually on the dorsum and lateral border of the foot, presumably from “arch strain.” Most patients comply, without too much encouragement.

OUTCOMES

Primary Surgery

- DiGiovanni and Gould et al. reported an 82% rate of total satisfaction in primary surgery patients, with a marked decrease in pain to a level of no pain or mild, intermittent pain. This is a significant improvement over the less than 50% total satisfaction reported in most recent studies of limited plantar fascia release with a limited nerve release, or nerve release without plantar fascia release.
- The surgical technique described here is highly recommended in patients with chronic plantar fasciitis and neuritic signs and symptoms, without prior surgery.

Revision Surgery

- Less predictable results have been reported for revision surgery. Although 73% of patients indicated they were better off than before surgery, total satisfaction was reported by only 27%, and 36% were dissatisfied with the procedure. There was a much higher incidence of residual pain and activity limitation.
- In revision situations, patients with evidence of inadequate prior distal tarsal tunnel release and those with persistent mechanical plantar fasciitis are most likely to have good resolution of their symptoms.
- Although the results for barrier wrapping and of the use of conduits for neuromas are less certain than those for the primary releases, they are still superior to results for other techniques reported to date. Data on the use of collagen conduits and wraps are being collected, with encouraging early outcomes.

COMPLICATIONS

- A low rate of complications, both intraoperatively and postoperatively, can be expected with this technique.
- Meticulous technique is needed to avoid potential complications, which include wound dehiscence, perineural scarring, and direct nerve injury. We recommend using bipolar electrocautery and surgical loupe magnification.
- Development of complex regional pain syndrome is possible postoperatively. Early diagnosis and aggressive treatment improves the prognosis.
REFERENCES

DEFINITION

- Plantar fasciitis is the most common cause of heel pain in adults.
- The predominant symptom is pain in the plantar region of the foot when initiating walking.
- The cause is a degenerative tear of part of the fascial origin from the calcaneus, followed by a tendinopathy-type reaction.

ANATOMY

- The plantar fascia is a ligament with longitudinal fibers originating from the calcaneal tuberosity.
- The normal medial band is the thickest, measuring up to 3 mm.
- The central and lateral bands are 1 to 2 mm thick.\(^1\)
- Distally, the plantar fascia divides into five slips, one for each toe.
- The plantar fascia provides support to the arch. As the toes extend during the stance phase of gait, the plantar fascia is tightened by a windlass mechanism, resulting in elevation of the longitudinal arch, inversion of the hindfoot, and external rotation of the leg.
- Endoscopically, the pertinent anatomy is the abductor hallucis muscle medially, then the plantar fascia. After fasciotomy, the flexor digitorum brevis comes into view as the medial intermuscular septum.

PATHOGENESIS

- Specimens of plantar fascia obtained during surgery reveal a spectrum of changes, ranging from degeneration of fibrous tissue to fibroblastic proliferation.
- The fascia is usually markedly thickened and gritty. These pathologic changes are more consistent with fasciosis (degenerative process) than fasciitis (inflammatory process), but fasciitis remains the accepted description in the literature.

NATURAL HISTORY

- The typical patient is an adult who complains of plantar heel pain aggravated by activity and relieved by rest.
- Start-up pain when initiating walking is common.
- Strain of the plantar fascia can result from prolonged standing, running, or jumping and activities that create repetitive stress on the plantar fascia. Excessive pronation is a common mechanical cause.
- The rigid cavus foot type can also predispose to plantar fasciitis.
- Obesity is present in up to 70% of patients.
- Plantar fasciitis is common among runners and ballet dancers.
- About 15% of cases are bilateral. Women are affected more than men.

PHYSICAL FINDINGS

- Localized tenderness over the plantar calcaneal tuberosity is the most common physical finding.
- Pain is usually medial, but occasionally lateral. Rarely, pain may be located distally; this condition is called distal plantar fasciitis. Frequently there is soft tissue swelling of the plantar medial heel.
- Careful comparison to the contralateral heel is useful in confirming tenderness typical for plantar fasciitis.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Radiographs are ordered routinely in patients with plantar heel pain.
- Plantar calcaneal spurs occur in up to 50% of patients but are not thought to cause heel pain; these are commonly associated with calcification in the origin of the flexor hallucis brevis, which is located proximal to the origin of the plantar fascia.
- Stress fractures, unicameral bone cysts, and giant cell tumors are usually identified with plain radiography.
- Three-phase technetium bone scans are rarely necessary but are positive in up to 95% of cases of plantar fasciitis.
- MRI can be used in questionable cases and elegantly demonstrates thickening of the plantar fascia and rules out soft tissue and bone tumors, subtalar arthritis, and stress fractures.
- Ultrasound is cost-effective and easily measures the thickness of the plantar fascia, documenting plantar fasciitis when thickness exceeds 3 mm.

DIFFERENTIAL DIAGNOSIS

- Plantar fascia rupture: Generally occurs acutely after vigorous physical activity. There may be visible ecchymosis in the arch. MRI or ultrasound confirms the diagnosis.
- Tarsal tunnel syndrome: Compression of the tibial nerve can cause numbness and pain in the heel, sole, or toes. Positive percussion and compression tests are elicited, and electromyography and nerve conduction studies are positive in 50% of cases.
- Distal tarsal tunnel syndrome, compression of the first branch of the lateral plantar nerve (Baxter’s nerve), is often confused with plantar fasciitis and may be associated with plantar fasciitis. In fact, some surgeons recommend decompressing Baxter’s nerve with every plantar fascia release. In our opinion, these two entities are separate, and with careful examination plantar fasciitis may be isolated and effectively treated with endoscopic plantar fascia release.
- Stress fractures: With a calcaneal stress fracture, tenderness is not localized to the plantar medial heel but instead is more diffusely present in the calcaneus, suggested by a calcaneal squeeze test. Plain films usually suggest a fracture line, but if there is any doubt, MRI clearly demonstrates stress...
fractures and readily distinguishes plantar fasciitis from stress fracture.

- **Neoplasms:** Visualized on plain films at times. MRI is diagnostic. Pain is typically achy, constant, nocturnal, and even present without weight bearing and at rest.
- **Infection:** Pain is often constant. There may be swelling, redness, or fluctuance. Plain films, MRI, or a white blood cell-labeled scan can be diagnostic. Laboratory tests may show increased erythrocyte sedimentation rate, C-reactive protein, or white blood cells.
- **Painful heel pad syndrome:** Occurs most often in runners; thought to result from disruption of fibrous septa of the heel pad
- **Heel pad atrophy:** Occurs in the elderly, usually not characterized by morning pain, and a “central heel pain syndrome” with tenderness more plantar than in plantar fasciitis, directly under the bony prominence in the calcaneus
- **Inflammatory arthritis:** Usually bilateral and diffuse in nature. May be associated with positive RA, HLA, and B27 and an increased erythrocyte sedimentation rate.

**NONOPERATIVE MANAGEMENT**

- Conservative management includes rest, ice, nonsteroidal anti-inflammatories, plantar fascia and Achilles tendon stretching, plantar fascia-specific stretching protocols, silicone heel pads, prefabricated and custom orthoses, night splints, CAM walkers, casts, physical therapy, athletic shoes, judicious use of steroid injections, and shockwave therapy.
- Ninety-five percent of patients will respond to conservative management.
- Surgery is indicated after 6 to 12 months of conservative treatment.

**SURGICAL MANAGEMENT**

- Plantar fasciotomy is indicated in the few patients who fail to respond to conservative treatment.
- Although open techniques have yielded good results, endoscopic plantar fasciotomy (EPF) offers several important advantages:
  - Minimal soft tissue dissection
  - Excellent visualization of the plantar fascia

**Preoperative Planning**

- Non–weight-bearing lateral radiographs of the affected foot are performed (FIG 1).
- A point just anterior and inferior to the calcaneal tubercle is marked and measurements are made to the inferior and posterior skin lines.
- These measurements are used to select the incision site (FIG 2).

**Positioning and Anesthesia**

- The patient is positioned supine with a bump under the ipsilateral hip of the affected side to limit external rotation of the limb.
The operative foot is then elevated on a foot prop with a tourniquet in place at the distal calf. The limb is prepared and draped in this position.

- We routinely order 1 g of cefazolin (Ancef) perioperatively.
- Anesthesia may be regional or general.
- We prefer an ankle block or popliteal nerve block with intravenous sedation.
- The procedure is performed on an outpatient basis.

**SET-UP**

- The foot is prepared and draped on the foot prop and then exsanguinated with an Esmarch bandage.
- The tourniquet is inflated at the distal calf to 250 mm Hg.
- Make an 8-mm vertical incision just anterior and plantar to the medial tubercle of the calcaneus.
- Use the measurements from the non-weight-bearing lateral film as a guide.
- A good landmark is the medial malleolus.

**IDENTIFYING THE PLANTAR FASCIA ENDSOCOPICALLY**

- The incision can be placed on a line dropped from the midpoint of the medial malleolus or the junction of the middle and posterior thirds of the medial malleolus.
- Portal placement is critical to the success of the procedure.
- Deepen the incision with blunt tenotomy scissors.
- Place the plantar fascia elevator through the incision and sweep it from medial to lateral just plantar to the plantar fascia.
- Pass the obturator and cannula through this pathway and bring them out through a lateral incision overlying the tip of the obturator.
- Remove the obturator from the cannula and clear the cannula of fat with cotton-tipped applicators (TECH FIG 1). The cannula should be perpendicular to the long axis of the foot.
- Bring the 4-mm 30-degree scope into the medial portal.
- Visualize the abductor hallucis muscle medially, and then the plantar fascia. Pass the probe from the lateral portal and advance it medially to palpate the medial band of the plantar fascia (TECH FIGS 2 AND 3).

**Equipment**

- The equipment required includes the Instratek Endotract System (Instratek, Houston, TX), which consists of a plantar fascia elevator, cannula and obturator, probe, nondisposable knife handles, and disposable hook and triangle knives (FIG 3).
- We use a 4-mm 30-degree short arthroscope.
- Several cotton-tipped applicators lightly fluffed with a Bovie scratch pad are needed.
PLANTAR FASCIA RELEASE

- Remove the probe and advance the triangle knife to the medial band.
- Dorsiflex the foot to place tension on the plantar fascia.
- With a controlled motion, pull the triangle knife across the medial band of the plantar fascia (TECH FIG 4).
  - Several passes are often necessary to completely divide this band.
- The flexor digitorum brevis muscle belly should be visible after the medial band is divided (TECH FIG 5). The fasciotomy is complete when the medial intermuscular septum is visualized.
- The amount of fascia divided is usually 14 mm, which can be measured off markings on the probe. The hook knife can be used to cut the fascia, but the triangle knife can be more easily manipulated with less likelihood of cutting into the muscle.

PEARLS AND PITFALLS

- Performing the procedure on a prep stand or prop and ensuring that the foot and ankle are stable is vital to the smooth operation of this procedure. U-shaped padded foot propping devices that attach to the side of the operating table are ideal. We also use the Lift-A-Limb foot prop, which cradles the limb and is an excellent device.
- The placement of the incision is critical. A point 1.5 to 2.0 cm superior to the junction of keratinized and nonkeratinized skin, on a plumb line from the midpoint of the medial malleolus, is ideal.
- Fluffed cotton-tipped applicators and a defogging liquid to apply to the tip of the scope allow good visualization.
- Maintaining tension on the plantar fascia while cutting is key. The triangle knife is usually more predictable than the hook knife. Staying in the center of cannula and not skiving are important elements of technique.
- Although it is possible for the surgeon to hold the scope in one hand and the knife in the other hand, it is usually easier to have the assistant hold the scope and dorsiflex the foot, while the surgeon makes precise and controlled cuts with both hands on the knife, if necessary.
- In some cases, the central band is incredibly thick and gritty. Several passes of the triangle knife may be needed. Using the hook knife as well in such cases may be helpful. Remember also to clearly see the complete separation of the plantar fascia with the flexor digitorum brevis muscle plainly visible. Failure of EPF is usually due to incomplete or inadequate division of the plantar fascia.
- Other causes of failure include portal placement that is too proximal. It is difficult to release the fascia so proximally, directly off the calcaneus.
- Finally, misdiagnosis may lead to a poor result. Carefully evaluate the patient before surgery to rule out other causes in the differential diagnosis (described in detail earlier).
POSTOPERATIVE CARE
- Ice and elevation are recommended for 48 to 72 hours postoperatively.
- Minimal postoperative pain medication is required.
- Sutures are removed at 1 week postoperatively and a CAM walker, weight bearing as tolerated, is used for 3 weeks to minimize the risk of lateral column pain.
- Most patients can resume normal activities at 6 weeks postoperatively and vigorous athletic activities at 12 weeks postoperatively.

OUTCOMES
- All published literature on EPF reports greater than 90% success, with shorter recovery times than traditional open surgery. Our experience mirrors the literature, with no infections or nerve damage and only four instances of lateral column pain in over 400 cases in the past 11 years.
- The success rate of EPF is significantly higher than extracorporeal shockwave treatment. In addition, EPF is reimbursed by all insurance companies, whereas shockwave procedures still have erratic insurance reimbursement.
- EPF is minimally invasive, with a simple, easy-to-learn surgical technique. The equipment is minimal and cost-effective.
- The incision is only 8 mm, compared to open procedures, where the incision is at least 4 cm and, with some more extensive approaches, as much as 10 cm.
- Surgeons with prior arthroscopic experience should find EPF to be a straightforward procedure to master. DVDs and technique guides are readily available through Instratek.
- Training courses with cadavers are also given through the Orthopaedic Learning Center or Instratek. After 10 cases, the surgeon should feel confident with this procedure. With experience, average surgery time should be 10 to 15 minutes.

COMPLICATIONS
- Lateral column pain and arch pain have been the most common complications, reported in up to 3% to 5% of cases.
- Immobilization in a CAM walker for 4 weeks and limiting the division of the plantar fascia to the medial and central bands should reduce this complication even further.
- The Instratek system has single and double lines etched into the cannula to guide the surgeon to limit the plantar fasciotomy to 14 mm. The probe also has 1-cm markings. The disposable knives can also be marked with a marking pen to 14 mm. Using the intermuscular septum as a guide for where to stop the fasciotomy is probably the best anatomic reference as to where the central band ends and the lateral band begins.
- Infection rates are extremely low with EPF. We have had just one superficial wound infection (a diabetic patient) in over 400 cases.
- Injury to the medial and lateral plantar nerves is discussed extensively but rarely reported. Cadaver studies reveal a reasonable safe zone as long as the incision is appropriate.
- One case of pseudoaneurysm of the lateral plantar artery has been reported and a case of a cuneiform stress fracture. With appropriate technique and postoperative immobilization these complications should be rare.

REFERENCES
DEFINITION
- Nerves in the peripheral limb are at risk for damage by direct contusion, by stretch injury, and by iatrogenic insult.
- Nerve pain can be severe and crippling.
- Sensory nerves are expendable in many cases and most patients adapt well to removal.
- The resected proximal end of a nerve will usually form a neuroma as new growth seeks to reconnect with the distal nerve; thus, attempts to bury the nerve into a safe haven are desirable.

ANATOMY
- There are five sensory nerves in the foot and ankle, but anatomic variability is common.
  - The tibial nerve splits into medial and lateral plantar nerves (this is mixed motor as well).
  - The saphenous nerve is an extension of the femoral nerve, found along the lesser saphenous vein.
  - The deep peroneal nerve lies along the anterior tibia with a neurovascular bundle, passes under the extensor retinaculum, and innervates the first web space. It has some muscle components to the flexor hallucis brevis muscle and some innervation to the sinus tarsi as well.
  - The superficial peroneal nerve, with the peroneal muscles, emerges from the peroneal retinaculum to innervate the dorsum of the foot. The terminal medial branch, the dorsomedial cutaneous nerve, is at risk with bunionectomy along the dorsomedial hallux.
  - The sural nerve runs superficial to the gastrocnemius muscle and then between the peroneals and the Achilles tendon to innervate the lateral foot and two toes.

PATHOGENESIS
- Nerve injuries are most commonly iatrogenic.
- Arthroscopic ankle lateral portal placement risks damage to the superficial peroneal nerve.
  - Lisfranc fracture open reduction and internal fixation (ORIF) or second metatarsal-cuneiform arthrodesis procedures will challenge the superficial and deep peroneal nerves in the midfoot.
  - Bunion procedures threaten the dorsomedial cutaneous nerve, a distal branch of the superficial peroneal nerve.
  - Calcaneal ORIF and fifth metatarsal ORIF incisions risk damage to the sural nerve in the foot.
  - Achilles tendon procedures and Haglund resections can damage the sural nerve and especially a posterior branch of that nerve.
  - Ankle fracture ORIF risks damage to the saphenous nerve medially (FIG 1), and the superficial peroneal nerve runs a variable course in front of the fibula laterally.
  - Nerves can be damaged in a stretch injury (FIG 2). The stretch usually involves a pathologic extreme of motion as might be seen with ankle fracture or with ligament sprain.

NATURAL HISTORY
- Neuromas can behave in a variety of ways, from a small benign bulb neuroma (FIG 3) to a massive accumulation of angry hypersensitive nerve endings.
- Stretch injuries can cause dysfunction resulting in decreased sensation, in hypersensitivity, or even in severe pain with independent nerve signal generators.
- Some nerve injuries will heal with a slow distal progression of symptoms.
- Most nerve injuries are unpredictable in their natural course.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Examination of these nerve injuries requires understanding of natural anatomy.
- The nerves in the foot and ankle do not read the textbooks, and deviations from expected course are common.

FIG 1 • Saphenous nerve neuroma at site of previous ankle fracture open reduction and internal fixation.

FIG 2 • Superior peroneal nerve adherent to muscle and fascia after severe stretch injury.
Peripheral neuropathy

DIFFERENTIAL DIAGNOSIS

Nerves can suffer a stretch injury, especially the superficial peroneal nerve with severe ankle inversion due to sprain or fracture. The sural nerve can also be at risk with this injury. The saphenous nerve is especially at risk with contusion, as are all of the nerves, especially the deep peroneal nerve with a dorsal foot injury. Iatrogenic injury remains the most common form of nerve injury in the foot and ankle. Prior surgical intervention can result in confusing symptoms. Many nerve injuries are initially misdiagnosed. The nerve can often be suspected when the skin or subcutaneous tissues are hypersensitive (or hyposensitive) rather than the deep tissues. One of the best physical diagnostic findings is a nerve block using lidocaine hydrochloride (1% or 2%), Marcaine hydrochloride (0.5%), and a few drops of sodium bicarbonate solution in a mix. The bicarbonate acts to titrate the acidity of the local anesthetic and ease the burning pain of administration. The physician should return a few minutes after the injection to reexamine the patient rather than having him or her report on the effect of the injection at the next office visit.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Routine radiographs may provide evidence of mechanical imbalance, mechanical irritation (cyst or tumor), or osteophyte formation to suggest nerve entrapment. MRI helps to define any soft tissue irritation and helps to rule out impinging structures such as tumor or cyst. The MRI also helps the diagnostician by illuminating areas of inflammation. An exception is interdigital neuroma, for which MRI has proven less accurate. Electrodiagnostic studies can help differentiate between local and more proximal nerve pathology. Cervical spine or lumbosacral impingement as well as more generalized neuropathies can masquerade as local phenomena. Electrodiagnostic studies are not helpful with interdigital neuroma or many small sensory nerves. Electrodiagnostic studies should be performed in patients suspected of having tarsal tunnel syndrome. Sensory nerve conduction velocity may approach 90% sensitivity.

DIFFERENTIAL DIAGNOSIS

Degenerative disc disease, disc herniation, radiculopathy
Peripheral neuropathy
Leprosy
Diabetic neuropathy
Peripheral vascular disease
Tarsal tunnel syndrome
Joint arthrosis or synovitis
Tenosynovitis
Giant cell tumor of the tendon sheath
Intrinsic nerve damage, crush injury
Rheumatoid arthritis
Ganglion cyst
Lipoma
Neurilemmoma
Abscess or infection
Fracture
Malalignment (varus or valgus foot or ankle)
Plantar fasciitis

NONOPERATIVE MANAGEMENT

Physical support to the limb
Observation often allows a nerve to regenerate, heal, and resume its normal sensitivity.
Periods of immobilization in a short-leg cast or walking boot may allow neuritic symptoms to subside, especially when traction causes pain.
Braces and splints can provide added stability and prevent recurrent stretching injuries, especially to the superficial and deep peroneal nerves.
Tarsal tunnel symptoms caused by mechanical imbalances—such as acquired pes planus secondary to posterior tendon dysfunction—may be alleviated with orthotic devices that restore foot balance.
Multiple forms of pharmacologic intervention exist:
Nonsteroidal anti-inflammatories
Narcotics (caution must be exercised due to addiction potential, especially with chronic nerve pain)
Neuromodulators can help quiet nerve response.
Anticonvulsants such as pregabalin, gabapentin, or tricyclics often quiet nerve hypersensitivity.
Clonazepam and similar benzodiazepines may lessen nerve reactivity.
A variety of newer medications may be helpful; thus, referral to a pain management specialist often aids in complete patient care.
Lidoderm patches: Applied directly over the symptomatic area, lidocaine hydrochloride is released in a time-dependent manner through the skin.
Neuromodulators and local anesthetics and nonsteroidal in an absorbent gel for topical application; these creams can be found in compounding pharmacies.
Steroid injection, combined with local anesthetic, may serve a dual role as both therapeutic and diagnostic agent.
While sometimes useful, symptomatic relief is often temporary.
Injections should be limited to no more than two in a 1-year period.
Risks include skin discoloration, tendon rupture, atrophy of subcutaneous fat, and collateral ligament attenuation.
Ethanol injections: 4% ethanol in a Marcaine solution has been used for interdigital neuroma treatment.
The ethanol has been anecdotally useful for postincisional neuroma pain.

FIG 3 • Small nonpainful bulb neuroma from superior peroneal nerve buried in muscle.
The lesser saphenous vein serves as a key landmark in the leg. The sural nerve, perhaps the easiest to find, has anecdotal proven difficult postoperatively with nerve regrowth. The current choice for burial is very proximal in the leg. Motor nerves can be sectioned but at a higher cost. The motor loss of the deep peroneal nerve branches is relatively well tolerated, while the posterior tibial nerve governs much more muscle activity in the foot. The posterior tibial nerve has been resected only in salvage procedures as a precursor to possible amputation if unsuccessful. Some surgeons continue to manage these problems with implantable nerve stimulators.

Preoperative Planning

The preoperative planning includes patient education, careful patient evaluation, and decisions regarding the location of nerve burial. The final location of the proximal end of the nerve may be tender; thus, resection of the saphenous nerve just above the ankle in a patient who wears boots that may hit this level would be less desirable and a more proximal burial site would be advisable.

The best preoperative indicator of success remains the patient’s response to a local anesthetic block. The surgeon should confirm the location of the nerve tenderness and further discuss postoperative expectations.

Instrumentation is relatively simple. Appropriate resectors make the job easier, as does a small drill, a 2.5-mm and a 3.5-mm drill bit, and drill sleeves for creation of the bone hole. A tourniquet should be available but is often not used in order to better visualize the vessels accompanying the nerve.

Under tourniquet, the vessel and the nerve can look very similar; thus, examination of the cross-section of the presumed nerve is essential at the time of surgery. Even the most experienced surgeons have been fooled by a vein impersonating the nerve: better to know at surgery than to be told by the pathologist the next day.

If a patient had reflex sympathetic dystrophy or a complex regional pain syndrome involved with the leg, then consideration should be given to performing the surgery under epidural anesthesia. In theory, the diminution of painful stimulation may diminish the chance of triggering further hypersensitivity reactions.

Positioning

Positioning depends on the location of the neuroma.

- The saphenous nerve is best explored with the patient supine and the leg externally rotated.
- The superficial and deep peroneal nerves are best approached with the patient positioned supine. A rolled towel placed beneath the ipsilateral hip may facilitate exposure.
- Sural nerve exposure often requires use of a rolled towel beneath the ipsilateral hip to provide better access to the nerve as it courses posteriorly. Currently, due to resection of the sural nerve very proximally in the leg, the patient is positioned in a semilateral decubitus position with the use of a beanbag.

Approach

- While each nerve dictates the appropriate surgical approach, a basic extensile exposure, following the line of the neurovascular structures, seems ideal.
- The incision is made with a scalpel and deeper dissection is usually performed with dissecting scissors. The variability of several nerves, especially the superficial peroneal nerve, warrants careful exposure and identification.
- The nerve can be fully exposed and separated from the vessels before resection and burial.
- If burying the nerve into bone, the surgeon should expose the area of bone to receive the nerve, incising the periosteum and drilling the appropriate hole.

**SURGICAL MANAGEMENT**

- The decision to embark on surgical manipulation of persistent nerve pain often entails complex decision making. The resection of a nerve remains essentially a “one-way street,” and careful discussion helps alleviate confusing results. Issues surrounding nerve ending regrowth and possible neuroma formation are dealt with easily later if they are understood preoperatively.

- Motor nerves can be sectioned but at a higher cost. The motor loss of the deep peroneal nerve branches is relatively well tolerated, while the posterior tibial nerve governs much more muscle activity in the foot. The posterior tibial nerve has been resected only in salvage procedures as a precursor to possible amputation if unsuccessful. Some surgeons continue to manage these problems with implantable nerve stimulators.

**SURGICAL RESECTION AND BURIAL**

- Regional or general anesthesia may be used.
- A local block is performed along the course of the nerve.
- A tourniquet may help with exposure, but the vein and branches are better identified without.
- The sural nerve, perhaps the easiest to find, has anecdotal proved difficult postoperatively with nerve regrowth. The current choice for burial is very proximal in the leg.
- The lesser saphenous vein serves as a key landmark in the posterior leg as it courses alongside the sural nerve. The nerve does not possess a lumen.

- Begin the incision just distal to the point of maximal tenderness and carry it proximally along the posterolateral ankle and posterior leg.
- Dissection usually proceeds distal to proximal (TECH FIG 1).
Several skip incisions, usually three or four, can be made along the course of the nerve. These skip incisions can be avoided with one long incision, depending on the patient’s preferences (TECH FIG 2). Identify the nerve proximally beneath the gastrocnemius fascia. Tension is placed on the proximal end of the nerve while it is sharply cut in an oblique fashion and allowed to retract into the surrounding tissues. The resected nerve is usually quite long (TECH FIG 3). Electrocautery may also be used on the distal fragments to prevent nerve regeneration via production of neurotrophic signals. Subcutaneous and skin sutures are usually bioresorbable to avoid any irritation in neuritic patients.

The deep peroneal nerve runs along the anterior border of the distal tibia; thus, the bone offers a fine burial site for the proximal nerve ending. A straight anterolateral incision over the distal lateral border of the tibia works well; in cases of simultaneous superior peroneal nerve resection, a curved-S incision from this site more proximal and posterior allows an easy dual procedure. Incise the superficial retinaculum over the extensors in line with the incision and bluntly separate the muscles. The deep peroneal nerve usually lies between the extensor digitorum longus and the extensor hallucis longus muscles. Two large anterior tibial veins and the artery are close by the nerve; careful dissection avoids a messy field. Isolate and cut the nerve distally and cauterize the distal end. Bring the proximal nerve to a resting location over the tibia. The periosteum can be incised and drilled as above. Use a drill sleeve and round off or bevel the proximal edge of the hole to avoid a sharp edge for the nerve entry. Copiously irrigate the wound and then place the nerve into the distal tibial hole without tension. Allow the muscles to fall back over top the burial site. Repair the retinaculum if possible. Subcutaneous and skin sutures are bioabsorbable.

Start with a longitudinal incision over the anterior compartment of the leg. Find the superficial peroneal nerve as it pierces the crural fascia about 10 to 12 cm proximal to the tip of the fibula. The course is variable; the surgeon may need a more distal exposure to find the nerve and then trace it back proximally. Isolate the nerve and decide on the burial site in the fibula (TECH FIG 4) or into muscle (TECH FIG 5). The peroneal muscles can be split manually and the bone easily palpated. The fibula can then be held in easy exposure with two small Hohmann retractors on each side of the bone. The flat anteromedial wall of the fibula provides a fine resting place for the nerve. Incise the periosteum longitudinally if it is thick enough to merit such action. The resected nerve is usually quite long (TECH FIG 3). Electrocautery may also be used on the distal fragments to prevent nerve regeneration via production of neurotrophic signals. Subcutaneous and skin sutures are usually bioresorbable to avoid any irritation in neuritic patients.
Cut the nerve sharply in the distal aspect of the dissection.

- Careful observation for a proximal split and a high medial superior peroneal nerve branch is important. If found, bury both branches or resect the nerve before the split.
  - Hold the distal portion of the nerve with a hemostat and cauterize it to prevent leakage of neurotrophic hormones.
- With a 3.5-mm drill bit, make a unicortical drill hole 3 to 4 cm proximal to the distal extent of the cut superior peroneal nerve to allow sufficient slack to bury the nerve without tension (TECH FIG 6). Carefully retract the nerve to prevent it from getting caught in the drill. Once the hole is made, angle the drill proximally to bevel the edge, allowing soft entry into the bone.
- Place the cut end of the proximal superior peroneal nerve into the hole after irrigation (TECH FIG 7).
- The nerve should have little tension on it and should be stable with ankle plantarflexion or dorsiflexion.

The periosteum does not need to be sutured to the nerve epineurium to hold position.
- Gently remove the retractors, allowing the muscle to fall back over the fibula.
- Close the subcutaneous tissues with resorbable suture and close the skin with a resorbable suture as well, eliminating the need for suture removal.
- A splint is optional, depending on concomitant procedures and the amount of dissection.

**DORSOMEDIAL CUTANEOUS NERVE**

- This nerve is commonly damaged near the first metatarsal head in bunion surgery (TECH FIG 8). If a local block at the base of the metatarsal or cuneiform relieves the pain, then distal burial is a preferred solution.
- The incision often incorporates a prior incision over the dorsal metatarsal and is brought proximally over the cuneiform. Visualize the nerve and transect it as distally as possible; the surgeon need not find the distal neuroma if a proximal block relieved the pain. Cauterize the distal end and dissect the proximal end free.
- Using a 2.5-mm drill bit, drill a hole in the base of the first metatarsal or the medial cuneiform, whichever bone seems best anatomically for the nerve to inhabit. Bevel the hole proximally to allow a smooth gliding entrance for the nerve.
- Irrigate the wound and place the nerve into the hole; a tagging suture is usually unnecessary.
- Close the skin and subcutaneous tissues in a standard fashion with resorbable suture.

**TECH FIG 8** • Neuroma of the dorsomedial cutaneous nerve.
SAPHENOUS NERVE RESECTION AND BURIAL

- Make a longitudinal incision over the lesser saphenous vein in the supramalleolar region of the medial ankle. The deep dissection should allow identification of the vein as well as the saphenous nerve. The nerve can be deceptively small here and has sometimes been found directly behind the vein. Take care to look for any branching (TECH FIG 9).
- Cut the nerve distally and cauterize all distal branches to limit postoperative leakage of any chemoattractants.
- Dissect the proximal nerve ending free and clear an appropriate spot on the medial tibia.
- Incise the periosteum and use a 2.5-mm or 3.5-mm drill bit (depending on the size of the nerve) to drill a unicortical hole. Tilt the drill bit proximally to round off the proximal edge and allow atraumatic nerve entry.
- Perform final irrigation of the wound. Place the nerve in the bone hole without tension. A suture from the periosteum to the epineurium is optional but rarely used any more.
- Close the subcutaneous tissues and then the skin with absorbable suture to limit any postsurgical irritation of the surgical site.

MEDIAL PLANTAR NERVE

- Make a longitudinal incision along the course of the nerve on the plantar foot, attempting to avoid the heel and the ball, the primary weight-bearing areas.
- Gently carry the dissection through the subcutaneous tissues. The nerve lies just under the deep fascia. Take care to dissect the various branches to ensure adequate denervation (TECH FIG 10).
- Transect the nerve distally and bring it as far proximally in the midfoot as possible. Cut the nerve obliquely with an adequate length to allow burial into the deep musculature of the quadratus (TECH FIG 11).
- Close the subcutaneous tissues and skin with resorbable suture.

TIBIAL NERVE

- Approach the tibial nerve in the supramalleolar space, similar to the tarsal tunnel incision. Resection of this nerve is for extreme salvage as a possible precursor to amputation.
- Resect the tibial nerve and branches, including possible high calcaneal branches, as distally as possible, cauterizing the distal ends to reduce chemoattractants.
- Obliquely resect the nerve proximally, leaving a length adequate for tension-free burial into the medial tibia.
- Using a 3.5- to 5.0-mm drill, acquire a burial site in the tibia. Bevel the unicortical hole proximally to allow an easy slide of the nerve into the tibia without a sharp edge.
- Close the subcutaneous tissues and skin with bioreabsorbable suture.
POSTOPERATIVE CARE

- The postoperative rehabilitation must strike a balance between early return of motion and avoidance of mechanical trauma to the resected nerve.
- If the nerve is buried, immobilization time allows scarring into place.
- Many of these patients have some element of complex regional pain syndrome or reflex sympathetic dystrophy, so any stiffness will take a great deal of rehabilitation to recover full motion.
- The use of resorbable suture material seems especially prudent in these nerve patients, who are often hypersensitive after surgery.
- For simple neurectomy, the patient should have a soft compressive dressing with early range-of-motion exercises. Desensitization and nerve retraining should begin early.
- Most patients will have some degree of adjacent sensory nerve hypersensitivity; it can be better tolerated with advance warning.
- Many patients also get “zingers” starting at 7 to 14 days or so and lasting up to a month or so. These “electric” jolts of pain follow the resected nerve’s distal sensory distribution and represent irritation of the cut proximal nerve ending. They usually begin to lessen in frequency and intensity after a week or so and gradually disappear. Again, discussion with the patient beforehand eliminates frantic office calls about the nerve growing back so quickly.
- For nerve resection and burial, the patient usually has a fairly high amount of pain simply from the mobilization of the muscle to allow nerve implantation. A well-padded splint similar to a Robert Jones dressing gives nice compression and stabilization for the initial 12- to 14-day postoperative period. After this time, a simple compressive wrapping will usually be sufficient and allows gradual recovery of range of motion.

OUTCOMES

- Chiodo and Miller\(^1\) compared superior peroneal nerve resection and burial into muscle versus bone; the results favored burial into the fibula when possible.
- Sixteen patients had burial into muscle, with improvement in the verbal analogue pain score (0 to 10) of 3.1 points and 46\% relief of pain. Four required reoperation for neuroma.
- Fifteen patients had burial into bone, with improvement in the pain score (0 to 10) of 5.4 points and 75\% pain relief (statistically better than the muscle group).
- Dellon and Aszmann\(^2\) reviewed 11 cases of superior peroneal nerve resection into anterior muscle with good or excellent results. They recommended compartment release as well.
- Miller\(^3\) reviewed nine cases of dorsomedial cutaneous nerve resection and burial into the dorsal bones of the foot, with a verbal analogue scale improvement from 8.6 to 2.0 (on a 0-to-10 scale). All patients had relief of symptoms but most had a concurrent procedure to correct foot abnormality.

COMPLICATIONS

- Wound infection
- Neuroma
- Neuroma can be expected to form at the end of a cut nerve as the nerve tries to reconnect with the distal end. Nerves can grow into:
  - Bulb neuroma: a small thickening on the end of the nerve; usually causes little pain (FIG 4)
Unorganized neuroma: a thick mass of nerve endings, usually with small very irritable extensions causing pain.

- Nerve can regrow and reinnervate the distribution.
  - The speed of nerve regrowth should be 1 mm/day but can be faster.
  - Nerves can sprout new “rootlets” that will attempt to reinnervate the target area. Sometimes it may be difficult to determine whether a more proximal branch was missed at the prior surgery or if a new branch developed (FIG 5).

- Adjacent nerves can sometimes provide an unexpected “feeder” innervation to the distal aspect of the resected nerve.

- Dysesthesias can be troublesome, with persistent pain in the distal nerve distribution.

- Denervation hyperesthesias can be horrible, with difficulty eradicating pain from nerve surgery.

REFERENCES
DEFINITION

- Adhesive neuritis describes the pain from a nerve scarred to surrounding tissues. A common cause for such a condition in the lower extremity occurs after a tarsal tunnel release with subsequent scarring. While many nerves can be involved, the frequency of posterior tibial nerve involvement overwhelms that of other reported nerves and thus will be the primary focus of this chapter.

ANATOMY

- Adhesive neuritis can affect any nerve in the lower extremity. Lower extremity nerve anatomy involves the posterior tibial nerve, the superficial peroneal nerve, the saphenous nerve, and distal branches of these nerves. The most common site of adhesive neuritis anecdotally seems to be the posterior tibial nerve, a continuation of the sciatric nerve, which courses along the medial leg in a discrete retinacular anatomic tunnel with the posterior tibial artery and vein. Around the medial malleolus, the nerve splits into the medial and lateral plantar nerves. The laciniate ligament obliquely crosses at this level and can cause tarsal tunnel compression. The calcaneal branches (usually one or two) split from the main nerve trunk or occasionally from the lateral plantar nerve alone and can be constricted in the medial soft tissues. More distally, the nerves run under the abductor hallucis muscle, which has a very thick lateral fascial covering. This fascia can be thickened and can become a major source of mechanical compression of the nerve.

- The superficial peroneal nerve runs in the anterolateral aspect of the leg, often in its own sheath, between the anterior intermuscular septum and lateral muscle compartment fascia. This nerve can be constricted at several points, but by far the most common area is above the level of the ankle joint, where it emerges from the deep fascia of the peroneal muscle. The nerve becomes subcutaneous distal to this region, usually splitting into two main branches. The nerve demonstrates a wide variation in its anatomic course in this region. Prior surgery or injury to this area can cause adhesive neuritis, from the posterior aspect of the fibula to the anterolateral portal for arthroscopy.

- The sural nerve can often be enveloped by scar tissue in the lateral aspect of the foot as a complication of surgery on the posterior calcaneus (Haglund deformity), on the calcaneus for fracture, for peroneal tendinitis, or for triple arthrodesis. The nerve also is at risk with surgery on the base of the fifth metatarsal as it drapes over the bone.

- The deep peroneal nerve lies along the anterolateral border of the tibia as it approaches the ankle between the extensor digitorum longus and the tibialis anterior muscles. This nerve has a muscle branch to the extensor digitorum brevis and may also send branches to the sinus tarsi before innervating the first web space distally. The deep peroneal nerve can become pinched at the anterior ankle retinaculum as well as scarred down over the dorsum of the foot at the cuneiforms. In addition to repetitive trauma, which can cause soft tissue inflammation and scar formation, the nerve is at risk from arthritic irritation and osteophyte formation, as well as from cyst encroachment.

- The saphenous nerve travels with the saphenous vein anteromedially. This superficial nerve is at risk with open reduction and internal fixation of the ankle joint and with any medial surgery, such as triple arthrodesis or arthroscopy.

PATHOGENESIS

- Adhesive neuritis may occur after insult to the nerve or surrounding tissues resulting in adhesion between the nerve and surrounding tissue. The local damage usually comes from mechanical irritation and scar, such as surgery or soft tissue damage. While any nerve can be affected, each nerve is at higher risk where it naturally rounds a bend or courses under a retinaculum. The scar tissue then prevents movement of the nerve along with normal range of motion of the foot or ankle, thus the designation adhesive neuritis.

- The most common cause of such a condition to the posterior tibial nerve would be after tarsal tunnel release. Other trauma, such as a severe contusion or stretch, surgery on adjacent tendons, or resection of tumor or cyst, can cause adhesions with healing.

- Other nerves, such as the superficial peroneal nerve, are at risk due to surgery as well, especially due to arthroscopic portals and after open reduction of lateral malleolus fracture. The saphenous nerve is at risk from open reduction of medial malleolus fractures as well. Sural nerves are at risk with open reduction of calcaneus fracture, with repair of the Achilles tendon, with triple arthrodesis, and with insertional Achilles tendinitis as well as resection of Haglund deformity.

- While the essential pathophysiology has yet to be defined, the end result is scar and fibrous tissue adhering to the nerve epineurium. This scar can impede nerve conduction due to physical impingement. The infiltrative scarring can also directly affect nerve function and vascularity. The mechanical pull on the nerve can be irritating and limit conduction, particularly in extreme limb positions. The surgical guidance for simple nerve release versus epineurolysis has not been well delineated and remains at the surgeon’s judgment.

NATURAL HISTORY

- The typical scenario of adhesive neuralgia is an initially good result after surgery with subsequent scarring and progressive nerve irritation. While a mild problem may ease with motion and tearing of the restricting tissues, the neuralgic pain often does not ease markedly with time, and often slowly worsens.

- After tarsal tunnel release, neuritis might be a recurrence of nerve pain 2 to 4 months after the original surgery. The pain
is often related to activity and foot position. Extremes of inversion or eversion put more mechanical strain on the posterior tibial nerve and strain the adhesions to the soft tissue, causing nerve pain. The nerve does seem to be at higher risk with more proximal nerve compression, such as a radiculopathy, represented by the term “double crush” syndrome.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The patient with adhesive neuralgia will typically provide an event leading to the nerve issues. Prior surgery is a common trigger and the physician must determine whether the neuralgia is secondary to scarring or due to failure of the surgery to resolve the initial problem (ie, inadequate tarsal tunnel release). Prior medical history is essential; patients with diabetes or other metabolic insults to the nervous system should be fully evaluated and systemic neuropathy differentiated from local symptoms. The patient with any sciatica or symptoms extending proximally to the posterior thigh should be tested with electromyography and nerve conduction studies—not necessarily to diagnose the adhesive neuralgia as much as to rule out and possibly treat proximal causes of nerve pain.
- Physical examination must be taken in context of the extremity examination. A general leg examination sitting and standing is important, as varus or valgus angulation can cause many problems. Gait abnormalities may also be reflected in medial pain. A simple check for dorsal pedal pulses and toe capillary refill can find vascular insufficiency. Various joint issues such as synovitis or arthritis can contribute to nerve irritation, as could a palpable mass such as a ganglion cyst or neurilemmoma. Direct percussion can cause pain and pinpoint the location of impingement.
- Palpation of the posterior tibial nerve can often elicit pain at the area of the lancinate ligament and sometimes at the abductor fascia. Some surgeons have noted increased sensitivity of the nerve when the foot is passively placed in the dorsiflexed and everted position. Distal neural examination may map out a pattern of medial or lateral plantar nerve altered sensation or may demonstrate global peripheral neuropathy, sometimes with motor weakness. The irritation of the nerve to motion of the extremity is the hallmark of adhesive capsulitis and is a good prognostic sign for surgical intervention.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- No radiologic studies are confirmatory for this condition. Indeed, most studies help in ruling out other causes for the pain.
- Plain radiographs are important to rule out other sources of lower extremity pain, such as fracture, severe malalignment, coalition, arthritis, or bone cysts.
- MRI may discern an underlying mechanical insult to the nerve, such as tendinitis, ganglion cyst, or tumor (FIG 1).
- Ultrasonography plays a similar role as MRI but involves a great deal of interpretation.
- An electromyelogram and nerve conduction studies help to rule out a systemic neuropathy or more proximal lumbosacral pathology.
- The test may not always be confirmatory for significant tarsal tunnel nerve compression and often lacks the specificity for other peripheral nerves, but the exclusion of more proximal pathology is important.

DIFFERENTIAL DIAGNOSIS
- Intrinsic nerve damage, crush injury
- Systemic neuropathy
- Diabetic neuropathy
- Leprosy
- Peripheral vascular disease
- Posterior tibial tendinitis
- Rheumatoid arthritis
- Ganglion cyst
- Lipoma
- Neurilemmoma
- Giant cell tumor of the tendon sheath
- Abscess or infection
- Spinal or nerve root pathology
- Fracture
- Malalignment (varus or valgus foot or ankle)
- Tarsal coalition
- Plantar fasciitis

NONOPERATIVE MANAGEMENT
- Tarsal tunnel syndrome, especially with adhesive neuritis, can often be mechanically exacerbated and a trial of immobilization is usually warranted. While a cast provides the best hold, a walker boot is much more practical, especially if some relief ensues. Many patients will begin walking postoperatively in a walker boot; thus, the investment can be worthwhile even if surgery later occurs.
- Pharmacologic management continues to develop, with anticonvulsants such as pregabalin or gabapentin augmenting the use of tricyclic antidepressants such as amitriptyline. Clonazepam and similar benzodiazepines also seem to help peripheral nerve irritation. Due to the complexity of these medications, referral to a pain management specialist often helps in patient care. Systemic anti-inflammatories can also help with pain control, especially when the nerve irritation is worsened by an arthritic or synovitic condition.
- Topical anesthetic creams can help with peripheral nerve irritation, especially with nerves close to the skin surface such as the sural or superficial peroneal nerves. Lidocaine can help either in a local pad or a gel. Other medications in a topical gel can be absorbed through the skin, such as ketamine or anti-inflammatories. Some patients respond well to capsaicin pepper cream, which raises the “background noise” about the nerve.
SURGICAL MANAGEMENT

Preoperative Planning

- The surgery should be respected as a revision nerve procedure, with attendant greater risk for intrinsic nerve damage, accompanying vessel damage, and time-consuming difficulty. A careful preoperative discussion regarding indications, risks, and expectations should be mandatory.
- Loupe or microscopic magnification can be very helpful. A 2.0× magnification has proven adequate for most cases.
- A microsurgical set of tools should be available, along with finer sutures, such as 8-0 nylon or Prolene, for repair of vascular structures. Sometimes a small branch will rip off the artery, and a simple suture of that resulting hole will control bleeding without arterial sacrifice. Documenting a good dorsal pedal pulse before surgery would greatly ease fears of vascular compromise to the foot. When in doubt (and especially when the dorsal pedal pulse is not palpable), a preoperative vascular consultation may prove fruitful.
- A set of bipolar forceps can ease some of the dissection difficulty.
- These procedures can be markedly variable in difficulty and duration. Some cases will “unzip” easily and allow easy nerve exposure while others may take several hours of meticulous dissection to uncover the nerve. Surgeons must allow adequate time to perform these operations, perhaps over-booking the time allotment to avoid rushing through a tough dissection.

Positioning

- Patients should be supine, perhaps on a bean bag positioner or a bump under the contralateral hip to allow easy access to the medial aspect of the foot. These surgical procedures can be long and appropriate padding to the bony prominences should be noted.
- A tourniquet is very helpful for control of vigorous bleeding, but its routine application is discouraged; we apply a tourniquet but rarely inflate the device. The dissection often proceeds more easily if the vessels remain full, thus being easily discerned against the nerve in a scar situation.
- A table that elevates and tilts is helpful for establishing a Trendelenburg position and lessening the blood flow to the limb.

Approach

- The surgical approach to the revision tarsal tunnel is usually along the same lines as the original incision with extension both proximally and distally. When in doubt, an extensile exposure seems ideal, following the line of neurovascular bundles. Often, the initial incision will cause difficulty with distal direction plantar as it included a plantar fascia release. For these occasions, especially when the bulk of symptoms are at the medial plantar nerve entrapment by the abductor fascia, the revision incision must curve anteriorly and at an angle to the original cut. The skin seems well vascularized here and sharp angles rarely have healing problems.
- The approach to the lesser peripheral nerves in the foot and leg usually follows anatomic guidelines. The superficial peroneal nerve can be compressed and adhesive to the peroneal muscle fascia at the supramalleolar level of the leg. The nerve here often runs in its own separate sheath and must be directly visualized to ensure complete release. Very little information has been presented regarding barrier procedures for these more purely sensory nerves.

REVISION NERVE RELEASE

- The revision nerve release remains the crucial and most difficult part of these procedures. The amount of scar tissue formation varies widely and dictates the pace of the surgery. Starting more proximally in “virgin” tissue seems wise as distal dissection proceeds more easily when the nerve and vessels have been identified. The initial skin incision should be superficial, especially distally when the nerve moves more medial and superficial by the lannicate ligament. Deep dissection with dissection scissors and simple blunt clearing of tissue allows the visualization of the fascia overlying the flexor digitorum longus tendon and then the tarsal tunnel. A band of yellow fat often marks the location of the tarsal tunnel under fascia.
- Incise the fascia and isolate the nerve. Take care to cauterize small bleeding vessels; this is often made easier with use of the bipolar forceps (TECH FIG 1). The posterior tibial nerve will have a venous plexus around it, which can be stripped off with some bleeding. The larger vessels will send small branches by the nerve, and these may need cauterization or ligation depending on size.
- Separate the nerve from the artery and veins with care. Do not inflate the tourniquet unless severe bleeding occurs, as the vessels are more easily identified when full (TECH FIG 2). Persistent or vigorous bleeding can often be controlled with local pressure distally, but the tourniquet is sometimes needed to better dissect and cauterize the difficult venous plexus around the medial plantar nerve. Vessel loops aid with retraction of the vessels and for movement of the nerves without damage.
- The decision to perform epineurolysis depends on the clinical findings and on the dissected status of the nerve: grossly scarred nerves that then appear healthy after neurolysis probably do not warrant more extensive

TECH FIG 1 - Dissection of the tarsal tunnel is facilitated by the bipolar forceps.
incision of the epineurium, but no conclusive studies are available to help in this decision.

- The dissection must include the region above the ankle joint, and dissection proceeds distally beyond the abductor fascia. The abductor can be very thick and restrictive to the nerve (TECH FIG 3). The soft tissues should yield easily to a small hemostat sliding along the nerve, ensuring release.

**VEIN WRAP PROCEDURE**

- The saphenous vein can be harvested by standard fashion (when in doubt, consult with cardiovascular surgical technicians, who harvest these veins daily), either by skip incisions or one long incision (TECH FIG 4).
- Tie off small side branch vessels to allow later expansion of the vessel.
- Once the maximal length is harvested, to the knee region, the vein is prepared.
- Mark the outer lining of the vessel with a marking pen (TECH FIG 5).
- Tie off the end of the nerve and any branches.
- Tie the vein ending around a bulb-tipped needle.
- Fill and then distend the vein with a Marcaine and saline solution (TECH FIG 6).
- Cut the vein longitudinally.
Begin wrapping the nerve with the vein, inner lumen to
the nerve.
- Secure each turn with a simple suture of 7-0 Vicryl (TECH
  FIG 7).
- Once complete, put the foot and ankle through a full
  range of motion to ensure there is no binding (TECH
  FIG 8).

Close the subcutaneous tissues with a 3-0 or 4-0 re-
sorbable suture.
- Close the skin with 4-0 Monocryl suture.
- Place a bulky cotton wrap around the leg with a medial
  lateral U-splint and a posterior L-splint of plaster, cov-
ered with Coban or elastic wrapping.

Each section is simply wrapped around the nerve without
tension. The material has a shape memory to be a tube
(TECH FIG 9), and no suture is needed.
- Separate sections of NeuraWrap can be applied to each
  side branch.
- A branch can also be resected by cutting a small rectan-
gular section of the NeuraWrap around the larger nerve
to allow the branch to exit unimpeded.
- Most posterior tibial nerve segments require one or two
  7 × 4-mm sections of NeuraWrap.
- Most medial or lateral plantar nerves require a 5 × 4-mm
  section of NeuraWrap (Tech Fig 2).
- Occasionally the calcaneal branch or the first branch of
  the lateral plantar nerve will be wrapped. These usually
  require a 3 × 4-mm section of NeuraWrap (TECH FIG 10,
  which shows the wrapping of patient seen in Tech Fig 3).
Once wrapping is complete, put the limb through a range of motion to ensure stability.

Close the subcutaneous tissues carefully with resorbable suture and close the skin with resorbable suture when possible to avoid irritation in the postoperative period.

Place a bulky cotton wrap around the leg with a medial lateral U-splint and a posterior L-splint of plaster, covered with Coban or elastic wrapping.

FETAL UMBILICAL VEIN WRAP OF TARSAL TUNNEL

The use of fetal umbilical vein wrap for neuritis seems to have decreased with time. The procedure is similar to the above surgeries, with careful neurolysis (TECH FIG 11) followed by application of the vein wrap. This material is somewhat thicker than the saphenous vein but easier to apply because it can often be wrapped circumferentially rather than “barber-poled” with the labor-intensive wrap technique that the saphenous vein requires.

Cut the fetal umbilical vein longitudinally (TECH FIG 12).

Carefully wrap the material around the nerve (TECH FIG 13). The smaller side nerves may require a portal or hole cut in the nerve.

The completed wrapping must glide easily with ankle motion (TECH FIG 14).

In the case of postoperative infection, the material should be removed (TECH FIG 15), but the inflammatory reaction may leave a reasonable bed for the nerve.
OTHER PERIPHERAL NERVE WRAP PROCEDURES TO MINIMIZE ADHESIVE CAPSULITIS

- The decision to wrap the superficial peroneal nerve, the deep peroneal nerve, the saphenous nerve, or the sural nerve must be made in light of reasonable results with neurotomy.
- The procedure would be similar to that for the posterior tibial nerve, with careful neurolysis and then wrapping with either autologous saphenous vein or NeuraWrap. The superficial peroneal nerve has been wrapped most often, with encouraging results.

PEARLS AND PITFALLS

| Adequate preparation | The surgeon needs a dedicated operating suite and staff for complicated surgery. The possibility of vascular damage requires microsurgical instruments and loupes (or microscope) available for repair (or availability of a vascular surgeon if desired). A tourniquet should be on the leg or a sterile one should be close by in case of excess bleeding with the complicated dissection. |
| Incomplete decompression | Start more cephalad in virgin territory if possible to see the nerve more easily as well as to ensure adequate proximal decompression. Follow the nerve more proximally with finger exposure to confirm release. Distal release must be confirmed by easy passage of an instrument along the medial and lateral plantar nerves. We often take a piece of the abductor fascia out to prevent recurrent compression of the medial plantar nerve. |
| Residual neuritis | This symptom is common; patience is warranted. Constricted nerves may take 3 to 6 months to recover, and some never do, but the prognostic guidelines remain muddy. |
| Unexpected tumor or cyst | Most recurrent tarsal tunnel syndromes should be imaged preoperatively to rule out an extrinsic compression on the nerve. A large ganglion cyst should be completely resected, with care taken to find the stalk and source of the cyst. A neurilemmoma can often be carefully dissected, often with only minimal nerve loss. |
| Intractable damage to small nerve branches | The sensory nerve branches, especially the calcaneal nerves, are often encased in severe scar. These may be sacrificed without many sequelae other than some heel numbness. |

POSTOPERATIVE CARE

- Postoperative care depends on the extent of surgery performed and the risks of early motion on wound healing compared to the risks of stiffness.
- Most wounds are immobilized for 2 weeks to allow healing, and then a gentle range-of-motion protocol begins, often with formal physical therapy for desensitization as well.
- Weight bearing can begin at 2 weeks, progressing as tolerated.
- Physical therapy later can assist with motion, desensitization, and gait training.

OUTCOMES

- While outcome data can be difficult to interpret for initial tarsal tunnel release, the results of revision procedures can be even more confusing.
- The best study on revision tibial nerve release found the best results when the initial distal release was inadequate.
- Easley and Schoen found significant improvement with peripheral nerve wrapping (scores improving from 8.5/10 to 5/10), especially with adhesive neuritis, which fared better than crush injury. They also found wrapping with fetal umbilical vein to be as effective as autologous saphenous vein. That study also included three superficial peroneal nerves and one deep peroneal nerve.
- The data on NeuraWrap are anecdotal at the time of this writing, although initial results have been very satisfying from two centers.

COMPLICATIONS

- The complications from revision nerve release and wrapping can be daunting, and careful preoperative discussion is essential. Most patients can expect some persistent nerve irritation for up to 6 months postoperatively, as some nerves are slow to recover (if they ever do). Sensory training can be very helpful in the postoperative period to recondition the limb.
- Infection can be devastating, especially with the extensive dissection required and the dysvascular material being applied. The senior author of this chapter treated one infected fetal umbilical graft (for revision tarsal tunnel) with a simple irrigation and débridement, leaving the graft in for 3 weeks. With a more formal removal and débridement at 3 weeks, the vein left an excellent bed of shiny tissue that healed uneventfully and with excellent results. Another surgeon left the vein in for months, with resultant inflammation and irritation and a less satisfactory outcome. Superficial wound infection can be treated with local and oral antibiotics, but deep infection must be treated aggressively.
- Vascular damage can often occur with the difficult dissection. Often, a small branch of the artery will be torn from the main posterior tibial artery. This problem can often be solved with one or two stitches of 8-0 or 9-0 suture, sealing the hole adequately. Preoperative evidence of a patent dorsal pedal pulse means that the posterior tibial artery may be able to be sacrificed, important knowledge in light of possible difficult repair.
Recurrent adhesive neuritis remains a difficult complication. Physical therapy, psychological counseling to deal with the stress of such an outcome, and possible revision procedures may offer some help to these patients.

REFERENCES

DEFINITION
- Ankle distraction arthroplasty is a new technique for the treatment of ankle arthritis in younger patients who wish to defer ankle arthrodesis or ankle replacement.
- Distraction arthroplasty is based on the hypothesis that healing of arthritic cartilage can occur when the joint is unloaded and subjected to intermittent intra-articular fluid pressure changes. Unloading is achieved with an Ilizarov external fixator, which is applied for 3 months to distract the joint. During this time, it is essential that patients are weight bearing to provide the stimulus for fluid pressure changes. The flexibility of the fine wires used to construct the frame allows sufficient motion for this to occur.
- In vitro and animal studies have shown that distraction with intermittent pressure change can reduce inflammation and normalize cartilage matrix turnover. Clinical studies have demonstrated an increase in joint space and improvement in pain symptoms.
- As this technique evolves, the optimal patient and arthritis stage and pattern for distraction arthroplasty will become better defined.

ANATOMY
- The anatomy of the arthritic ankle joint selected for ankle distraction arthroplasty should be carefully assessed. A well-aligned limb with a foot that is plantigrade to the long axis of the leg is essential to a good outcome in all distraction arthroplasty patients. Deformity can be present from articular wear or collapse, from bony deformity in the tibia or foot, and lastly from ligamentous laxity.
- The ideal arthritic pattern for ankle distraction treatment has uniform cartilage loss across the tibiotalar joint with no extra-articular bony malalignment or ligamentous laxity. Ankles with intra-articular collapse or uneven wear patterns can be treated successfully with ankle distraction only if extra-articular bony deformities and ligamentous laxity are addressed. The stage of ankle arthritis does not determine who is the ideal patient for distraction arthroplasty. If patients are able to maintain ankle range of motion, then satisfactory outcomes have been achieved even with advanced arthritic changes.
- Extra-articular deformities in the distal tibia will need to be corrected before or at the same time as the ankle distraction technique. The methods to correct angular deformity, acutely with osteotomy or gradually with an osteotomy followed by distraction osteogenesis, are not included in this chapter but have been well detailed in recent texts.
- Deformities in the hindfoot and forefoot will also need to be corrected before or in conjunction with ankle distraction. This usually entails careful assessment of heel varus or valgus and compensatory forefoot deformities of forefoot valgus and varus. For most patients presenting with a primary complaint of ankle arthritis, it has been possible to acutely correct foot deformities at the same stage as ankle distraction arthroplasty. A calcaneal osteotomy or subtalar arthrodesis is performed to correct hindfoot deformity. A first metatarsal osteotomy or medial column arthrodesis is used to correct the foot.
- The presence of joint contractures will need to be carefully assessed. Ankle equinus is extremely common in ankle arthritis patients and clinically the most important feature limiting comfortable gait. It is essential to obtain 7 to 10 degrees of ankle dorsiflexion before or during ankle distraction arthroplasty to obtain a satisfactory outcome. Extra-articular contractures of the gastroc-soleus complex are less common and are readily treated with a percutaneous Achilles tendon lengthening during the frame application. Intra-articular contractures of the ankle can be corrected with the ankle distraction frame using universal hinges along the ankle joint axis and gradual correction of equinus simultaneous to ankle distraction. A more recent option is the use of Taylor Spatial struts to correct the equinus.
- Ligamentous stability will need to be assessed. Lateral ankle ligament instability is corrected before distraction. In general, medial deltoid ligament instability is addressed primarily by correcting planovalgus foot deformity or distal tibia valgus. The deltoid ligament can be tightened with nonabsorbable sutures after a medial ankle arthrotomy to débride the joint, which is usually performed in these patients.

PATHOGENESIS
- Normal ankle articular cartilage is durable and resilient and distributes loads far in excess of single limb body weight. Articular cartilage has a highly organized structure consisting of chondrocytes and an extracellular matrix. The chondrocyte is responsible for synthesis and organization of the matrix molecules. The extracellular matrix consists of tissue fluid (water and cations); a collagen fibril meshwork, which provides form and tensile strength; and proteoglycans, which are responsible for stiffness and durability.
- Osteoarthritis in the ankle is the sequential change in the chondrocytes and matrix, resulting in the degradation of articular cartilage through the sequential loss of cartilage structure and chondrocyte number and metabolism.
- Stage 1 osteoarthritis consists of matrix disruption with fibrillation, increasing water content and permeability, and changes in the matrix organization.
- Stage 2 consists of a chondrocytic response with cellular proliferation, increased matrix turnover, and a repair response.
- Stage 3 is the start of cartilage loss, with declining cellular response, bony changes, and progressive clinical symptoms.

NATURAL HISTORY
- Most patients have a history of trauma to the ankle, from an ankle or talus fracture or repetitive ankle sprains.
The time between the initial trauma and presentation for ankle distraction is highly variable.

Patients with ankle pilon fractures tend to be younger and usually develop the most rapid posttraumatic arthritis; therefore, they constitute the group to receive distraction arthroplasty closest to the time of their initial injury.

PATIENT HISTORY AND PHYSICAL FINDINGS

Patient evaluation for ankle distraction arthroplasty includes a thorough history and physical examination.

The optimal candidate is a compliant, motivated patient younger than 50 years of age who has posttraumatic arthritis or chronic ankle instability with arthritis, no previous history of ankle joint sepsis or anklyosis, no history of neuropathy, and an appropriate psychosocial support system to facilitate recovery and in-frame care.

Clinically, patients must have pain primarily at the ankle joint along with documented arthritis on radiographs.

Physical examination includes evaluation of ankle and foot range of motion.

- Ankle motion (about 25 to 30 degrees), including dorsiflexion (5 to 10 degrees), is preferred for successful ankle distraction arthroplasty.
- Subtal arthrosis may affect the ability to achieve dorsiflexion, so both active and passive subtalar range of motion should be tested with the patient seated.
- Hindfoot motion is not required but, if present, may improve the result of distraction arthroplasty.
- Foot deformity such as cavovarus or flatfoot deformity is noted.
- Ankle joint instability is assessed clinically and may be confirmed with ankle stress radiographs in addition to the radiographic evaluation of the deformity.
- Fluoroscopic evaluation is used to assess the arc of ankle motion. Hinge-type ankle motion, instead of the usual gliding tibiotalar motion, or loss of anterior ankle articular cartilage may be associated with less successful results.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Standard weight-bearing radiographs of the tibia, ankle, hindfoot, and foot provide sufficient information for the majority of ankle distraction candidates. CT scans, with or without reformations, are occasionally ordered for evaluation of complex deformity or to assist in defining local wear patterns in the ankle joint.

Standing full-length lower extremity AP and lateral radiographs from the hip to the ankle are obtained if there is deformity above the distal tibial region or a limb-length discrepancy. The long lateral view of the limb is made with the knee in full extension to assess tibial deformity, knee flexion contracture, or recurvatum from hyperlaxity. AP tibial radiographs are made with the patella facing forward. The x-ray beam is centered on the ankle to include the tibia. If a rotational deformity of the limb is present on clinical examination, an AP ankle radiograph is made in the foot-forward position to evaluate intra-articular wear or malalignment. Lateral ankle radiographs are made in the plane of the ankle malleoli.

The hindfoot alignment view is a weight-bearing radiograph that enables observation of the tibia, ankle joint, and calcaneal tuberosity on a single view. This view requires a specialized mounting box to angle the radiographic plate 20 degrees from the vertical plane.

Another radiograph is the non-weight-bearing long axial view that visualizes the tibia, subtalar joint, and calcaneal tuberosity. A line drawn on the vertical axis of the midbody of the calcaneus should be parallel and about 1 cm lateral to the mid-diaphyseal line of the tibia. Valgus deformity and lateral translation indicate a pes planus deformity; varus angulation and medial translation indicate a cavovarus type of deformity.

The weight-bearing AP foot radiograph is measured for the talo-first metatarsal angle, navicular coverage, and joint subluxation or arthritis. The lateral foot view is measured for the talo-first metatarsal angle, calcaneal pitch, and joint subluxation or arthritis.

Comparison radiographs of the contralateral, asymptomatic limb should be obtained for preoperative planning.

DIFFERENTIAL DIAGNOSIS

Arthritis associated with ankle pain is the indication for ankle distraction arthroplasty. As detailed previously, deformity evaluation and correction are needed before or in conjunction with ankle distraction.

In patients with pain out of proportion to the degree of radiographic arthritis, the surgeon should assess for occult infection with joint aspiration for culture and a blood measurement of C-reactive protein.

Any patients who are heavily narcotic-dependent or experience severe preoperative pain associated with early-stage arthritis are poor distraction candidates, as this technique is associated with the usual Ilizarov wire and pin site discomfort, especially in the foot.

These patients may not be able to perform intermittent partial weight bearing of 50 to 75 pounds in their frames and will not receive the intermittent joint pressure changes necessary for the distraction technique.

NONOPERATIVE MANAGEMENT

Conservative treatment of ankle arthritis in younger patients is primarily activity modification.

Running and jumping sports activities are discouraged; cycling, walking, and swimming are encouraged.

Supportive braces, whether soft neoprene or rigid ankle–foot orthoses (AFOs), offer varying degrees of pain relief and can improve function.

Anti-inflammatory medications, acetaminophen, and occasionally narcotics all have a role in alleviating mild to moderate arthritic symptoms.

Homeopathic, naturopathic, or acupuncture remedies can all be used, but these are beyond our expertise for treatment recommendation in ankle arthritis.

SURGICAL MANAGEMENT

All ankle distraction patients should be thoroughly counseled, including preoperative conversations with another patient who has undergone the procedure.
Patient education is facilitated with a preoperative information packet reviewing external fixator and pin site care; this is given to the patient on his or her initial consultation.

Pin and frame care is reviewed with the patient again after surgery.

Preoperative Planning

Deformity analysis is conducted in the clinic from the radiographs.

Previous scars or skin grafts are noted for their impact on planned approaches if joint débridement or tibial deformity correction is needed. The plan includes the need for possible fluoroscopic examination with the patient under anesthesia to assess joint tracking and fluoroscopic stress views to assess ankle joint stability.

Positioning

The patient is positioned supine with a folded blanket under the ipsilateral hip to keep the patella facing upward.

The entire leg to the upper thigh is draped free to allow placement of sterile bath blankets under the distal thigh and foot, leaving the posterior leg from the ankle to the knee free for ease of ring placement and positioning. This also allows optimal lateral fluoroscopic imaging during surgery.

Approach

The ankle distraction procedure is an all-percutaneous surgery and therefore has no single surgical approach.

Safe zones for wire and half-pin placement in the tibia and foot are detailed below (FIG 1). In addition, we do place sagittal half-pins in the tibia, just medial to the tibial crest.

FIG 1 • Safe pin and wire placement for mid-tibia (A), distal tibia (B), and forefoot (C).
TIBIAL BASE FRAME APPLICATION

- Frame assembly for ankle distraction arthroplasty is similar with or without deformity correction.
- Assemble a two-ring tibial base frame. The two rings are separated by four 150- or 200-mm threaded rods, depending on the size of the patient (TECH FIG 1). We use Taylor Spatial rings for their strength and also the ability to use Taylor Spatial struts, as described below.

**TECH FIG 1** • Tibial base frame. Two Taylor Spatial rings, usually 155 mm, are connected with four threaded rods.

- Pass the tibia base frame over the foot and place it proximal on the leg. For the distal ring, drive a transverse, smooth 1.8-mm reference wire through the tibia from medial to lateral, 5 cm proximal to the ankle joint.
- Connect the distal tibial ring to this wire orthogonal to the distal tibia with the limb centered within the ring to ensure soft tissue clearance between the limb and the rings, and tension the wire (TECH FIG 2A,B). A second wire may then be placed on the proximal ring and tensioned to secure the sagittal plane alignment (TECH FIG 2C).
- Six-millimeter half-pin fixation is now performed. Fix the proximal ring to the tibia with two 6.0-mm half-pins secured with connecting cubes or posts, one proximal and one distal to the ring in a multiplanar fashion; secure the most proximal half-pin to a two-hole connecting cube or post in the anteromedial to posterolateral plane, and secure the inferior half-pin to a two- or three-hole cube placed in the sagittal plane (TECH FIG 3A).
- Place two additional 6.0-mm half-pins and secure them to the distal tibial ring, also in a multiplanar orientation, one proximal and the other distal or both proximal to the distal tibial ring (TECH FIG 3B). Fluoroscopic imaging confirms appropriate half-pin insertion length. In general, the number of wire and half-pins placed increases as the patient’s weight and neuropathy increases. Poor bone quality should be addressed with a greater number of wire fixation pins.

**TECH FIG 2** • A. AP view of frame. The distal wire is placed first, 5 to 6 cm above the ankle joint. B. Lateral view. C. Tibial base frame. The proximal wire secures sagittal plane alignment. This wire may be removed in the office or later in the case once two half-pins are placed.
ANKLE HINGE PLACEMENT

- After applying the tibial base frame, place a smooth 1.8-mm wire temporarily from the tip of the lateral malleolus to the tip of the medial malleolus under fluoroscopic guidance. Cut the ends about 3 cm from the skin edges. This guidewire serves as a reference for hinge placement as it represents a good estimate of the coronal plane ankle joint axis (TECH FIG 4).

- Secure Ilizarov universal hinges to threaded rods, which are attached to the distal tibial ring, and align the hinges relative to the guidewire (TECH FIG 5A,B). Leave the threaded rods 1 to 2 cm long to allow for distraction. On the lateral fluoroscopic image, the universal hinges must align with the lateral talar process (TECH FIG 5C). If they do not, then move the hinges anterior or posterior until satisfactory position is achieved.

- After the hinges are properly positioned, remove the guidewire.
FOOT AND ANKLE • Section IV ANKLE

FOOT RING APPLICATION

- Center the foot in a foot ring and attach the hinges from the lower tibial ring to the foot ring. In most cases, the lateral hinge is placed directly on the ring, and a short threaded rod is used on the medial side (often a two-hole plate is needed off the foot ring to attach the medial hinge) (TECH FIG 6A,B). An assistant holds the foot ring in place during wire attachment (TECH FIG 6C).

- The foot ring is usually secured to the foot with five smooth 1.8-mm wires: one in the talar neck, two in the calcaneal tuberosity, and two in the forefoot. The weaker open section of the foot ring is enclosed with a half-ring placed parallel or at 90 degrees to the foot ring to prevent ring deformation (TECH FIG 6). An alternative method of enclosing the foot ring is the use of two oblique struts connected by a plate (TECH FIG 7).

- Place the first calcaneal wire from anteromedial to posterolateral, avoiding the neurovascular structures on the medial aspect of the hindfoot, and secure the foot ring to this wire parallel to the sole of the foot (TECH FIG 8). Place the first forefoot wire medial to lateral, engaging the first and second, and occasionally third, metatarsals. Tension these first two wires.

- Place the second calcaneal wire from distal-lateral to posteromedial. Then, place the second forefoot wire proximal to the fifth metatarsal head, engaging either the fifth, fourth, and third metatarsals or the fifth and first metatarsals (plantar to the second, third, and fourth metatarsals). Take care to avoid distorting the normal orientation of the metatarsals relative to one another (TECH FIG 9). At this point, the foot ring will move up and down in a constrained manner.

- Apply tension to the remaining calcaneal and forefoot wires.

- Place a 1.8-mm talar neck wire to avoid subtalar joint distraction. This wire is placed using fluoroscopic guidance. Often the attachment to this wire is performed on the inside of the foot ring to avoid the threaded rods of the universal hinges (TECH FIG 10A,B).

- Make a lateral and AP fluoroscopic check to ensure that normal ankle motion without joint subluxation is maintained after the foot ring has been applied (TECH FIG 10C,D).

**TECH FIG 6 • A.** Foot ring is attached to the universal hinges. Lateral view. **B.** AP view. **C.** An assistant holds the foot with the ankle in neutral dorsiflexion before wire fixation is begun in the calcaneus.

**TECH FIG 7 •** Oblique connecting struts are used to enclose the foot ring.

**TECH FIG 8 •** The calcaneal wire is tensioned first while an assistant holds the ankle in neutral and the footplate is parallel to the sole of the foot.
ANKLE DISTRACTION

- After applying the frame, acutely distract the ankle joint 3 to 5 mm from the preoperative position using the threaded rods attached to the universal hinges. This distraction usually is performed on the tibial ring attachment sites. Four-sided Ilizarov nuts facilitate counting the millimeters of distraction (TECH FIG 11).

TECH FIG 9 • A. Foot fixation in place except for talar neck wire. Lateral view. B. Foot fixation in place; AP view from sole of foot.

TECH FIG 10 • A. Talar neck wire. Attachment on the inside of the ring is often necessary. B. Completed ankle distraction frame with Taylor Spatial strut for anterior stability. C,D. AP and lateral fluoroscopic views to confirm concentric reduction before distraction. Note that the hinges align with the lateral talar process on the lateral view.

TECH FIG 11 • Four-sided nuts on the threaded rods allow for easy measurement of ankle distraction. Each 360-degree rotation equals 1 mm of movement along the threaded rod.
- Repeat fluoroscopic radiographs in neutral position, dorsiflexion, and plantarflexion to confirm satisfactory ankle distraction and motion without subluxation. If ankle distraction arthroplasty is done with either varus-to-valgus distal tibial or immediate equinus correction, minimize immediate ankle joint distraction to limit potential neurovascular compromise (TECH FIG 12).

- The ankle is held in neutral flexion by securing components (plates and threaded rods) from the distal tibial ring to the foot ring, which may be removed for range-of-motion exercises (TECH FIG 13).

- Alternatively, a frame strut (Fast Fix Taylor Spatial Frame Strut, Smith & Nephew Inc., Memphis, TN) may be secured from the proximal tibial ring to the foot ring, released to allow range of motion, and resecured with the foot held in neutral position (TECH FIG 14A).

- Two standard Taylor Spatial Frame struts (Smith & Nephew) placed anterior and posterior may be used for equinus correction. Take care to angle the posterior strut outward from the frame to prevent ankle joint subluxation, as shown in TECH FIGURE 14B.

**TECH FIG 13** • Anterior frame attachment with plates. This can be loosened by the patient to begin ankle range of motion.

**TECH FIG 12** • A. Lateral radiograph of a 17-year-old boy who developed rapid posttraumatic ankle arthritis after an open ankle fracture. He required daily narcotics and anti-inflammatory medications. B. AP radiograph. C,D. Lateral and AP radiographs showing ankle distraction of 5 mm measured off the intact posterior tibiotalar joint. Bone loss anteriorly creates a greater distraction gap. E,F. Lateral and AP radiographs 18 months after surgery. The patient is an active college student. Pain is controlled with anti-inflammatory medications. Range of motion is 10 degrees dorsiflexion and 20 degrees plantarflexion.
An alternative to the use of universal hinges is to use Taylor Spatial struts for ankle distraction. There are numerous advantages to these struts. First, they allow safe, controlled ankle distraction that can be performed simultaneous to an equinus correction. Second, the struts control ankle subluxation since there is the ability to posterior translate the talus and foot during equinus correction. Third, they are very strong, which can be a factor in a heavy patient, where fatigue-related failure of the universal hinges can occur. And finally, although the struts increase the expense of the frame, they make attachment of the tibial ring to the footplate quick and easy, reducing the cost of operative time (TECH FIG 15A). The struts do not allow ankle motion; however, a conversion to universal hinges can be performed in the office if the surgeon wishes to start ankle motion before frame removal.

WOUND DRESSING

- Dress the wounds in routine fashion, and dress wires and half-pins with Ilizarov sponges stacked from the skin to the fixation attachment to provide soft tissue compression. During surgery or on the first postoperative day, a walking assembly (FrameWalker, Quantum Medical Concepts, Hood River, OR; www.quantummedicalconcepts.com) is attached to the foot ring to suspend the foot 1 to 2 cm from the floor (Tech Fig 15). This new device has improved patients’ ability to comfortably bear weight due to some flex in the footplate device, and it also may decrease tibial half-pin loosening, which was occurring frequently with previous footplate designs. It also has design features that allow rapid adjustment to ensure a plantigrade foot position, and it easily snaps off and on for access to the sole of the foot for skin care.
- Place bulky roll (Kerlix, Kendall, Mansfield, MA) dressings between the rings and the limb, especially about the ankle and posterior leg and heel to limit swelling (TECH FIG 16A). Overwrap the rings with Ace bandages and an external fixator cover (Quantum Medical Concepts) for cleanliness and to protect the contralateral leg (as well as bed sheets and household furniture) from injury (TECH FIG 16B).
TECH FIG 16 • A. Postoperative dressings to absorb drainage and decrease swelling. B. Frame cover protects bedding and the other leg and helps keep the leg clean and dry.

PEARLS AND PITFALLS

- **Tibial base frame application**: Ensure 5 cm of distance between the lower tibial ring and the ankle joint. Place at least four multiplanar half-pins, two off each tibia ring.

- **Hinge placement**: Universal hinges must be aligned along the axis of the ankle joint and the tips of the malleoli on the fluoroscopic AP view and centered on the lateral talar process on the lateral view.

- **Foot ring application**: Five-wire fixation in the foot for adequate stability. Add an axial calcaneal half-pin if a gradual equinus correction is necessary.

- **Ankle distraction**: Acutely distract 3 to 5 mm, depending on the resistance of the joint capsule. Check fluoroscopic motion to ensure there is no joint subluxation.

- **Pin care**: Daily shower once wounds are healed. Avoid cleaning with hydrogen peroxide; use normal saline or sterile water. Add oral cephalexin for pin infection.

POSTOPERATIVE CARE

- Postoperative dressings remain in place for 3 to 7 days. Pin care begins as an outpatient to avoid exposing pin sites in the inpatient setting. The contralateral leg is fitted with a shoe lift to balance the pelvis for gait.

- On the first postoperative day, the patient is advanced from bed to chair and physical therapy is begun for lower extremity function and gait. Partial weight bearing may begin on the first postoperative day and is progressed during the next 1 to 2 weeks, depending on the presence of other foot and distal tibia procedures. The patient is discharged from the hospital on the second or third postoperative day. Ankle range of motion is started 1 to 2 weeks after surgery, but this may be instituted later depending on individual circumstances.

- Pin care: The pin site sponges and dressings are removed and pin care is initiated 4 to 7 days after surgery. Normal saline or sterile water is used to remove significant accumulations of drainage around wire and half-pin sites. Hydrogen peroxide is avoided because it tends to irritate skin, and this can mimic an early pin infection.

- Two to 3 weeks after surgery, sutures are removed and the pin care may continue with a daily shower using antibacterial liquid soap and a thorough water rinse to the leg and fixator. The fixator and leg are dried with a clean towel and hair dryer (cool setting).

- The most common problem encountered with ring fixation is a localized wire or pin site infection. It is important to inspect all pin sites daily to assess for signs of infection or loosening, including localized redness, pain and tenderness, warmth, swelling (firm or fluctuant), and drainage from the pin or wire that may vary in color and odor. When early signs of pin site infection are noted, pin care is increased to twice daily, the pin site is wrapped with a gauze roll dressing, ankle range of motion is discontinued, and weight bearing and physical therapy are limited. If signs and symptoms of a pin site infection do not rapidly improve, oral antibiotics are prescribed (cephalexin or clindamycin) for 5 to 7 days. The pin site infection usually begins to resolve within 24 hours of starting oral antibiotic treatment. Recalcitrant pin site infection is treated with intravenous antibiotic therapy with or without pin removal.

- Physical therapy is started in the hospital and continued until after frame removal. Lower extremity motion, conditioning, and gait are emphasized. Non-impact activities, including swimming and pool therapy if available, are encouraged with the fixator in place.

- After adequate healing of an osteotomy, nonunion, Achilles lengthening, or ligament reconstruction, ankle range of motion can be initiated with attention to optimize dorsiflexion. Ankle range of motion is initially done for 30 minutes, three to five times per day, and then progressed as tolerated by the patient and pin sites.

- Follow-up evaluation: Weight-bearing AP, lateral, and oblique ankle radiographs are made at 1, 3, 6, and 9 weeks after frame application to confirm concentric ankle distraction and alignment. Distraction of about 4 to 5 mm greater than...
traction was used for arthritis in conjunction with osteotomy. Comparable results have been achieved when ankle distraction was used for osteoarthritis, with persistent ankle swelling and crepitus noted after removal of the frame, usually within 3 days after frame removal. A later study of 22 patients with longer follow-up (average 28 months) and a more detailed examination of ankle arthritic wear pattern showed that anterior joint involvement predominates in the patients with poor outcomes.11 Of the patients without anterior wear, 83% had a successful outcome, compared to only 40% of patients with anterior wear.11

## COMPLICATIONS

The most common technical complications of ankle distraction arthroplasty are pin site inflammation or infection, wire or half-pin loosening, and frame hardware failure. Treatment for infection is usually oral antibiotics and checking to make sure the wire or half-pin is not loose. A loose wire can usually be retensioned in the office, whereas a loose half-pin can only be removed in the office. Frame modification is occasionally necessary if multiple half-pins become loose in the tibia early during the distraction period. Most broken hardware such as the universal hinges or threaded rods can be repaired in the office.

The most significant complications of ankle distraction arthroplasty are failure to relieve pain and a loss of ankle motion. As a rule, swelling and stiffness do occur after ankle distraction as a result of the underlying arthritis. A period of increased pain and disability after ankle distraction may occur for 2 to 4 months after frame removal, occasionally persisting for up to 6 to 12 months. Physical therapy and non-impact activities are emphasized during this time, including swimming and bicycling. Patients should be counseled to wait a minimum of 12 months before judging the success or failure of ankle distraction arthroplasty.

Direct neurovascular injury resulting from pin placement may occur despite operative caution because of posttraumatic distortion of the anatomy and scarring.

Immediate correction of a distal tibial or foot deformity, especially with concomitant immediate ankle distraction, may be complicated by traction injury of the posterior tibial nerve and tarsal tunnel syndrome. Initial treatment includes restoration of deformity, if possible, and release of ankle distraction to decrease nerve tension. Correction and traction may be reapplied gradually. Prophylactic tarsal tunnel release may limit this complication, and careful postoperative monitoring to enable early recognition is important. Gradual deformity correction and ankle distraction may limit the risk of traction injury to the posterior tibial nerve.
REFERENCES

DEFINITION
- Ankle arthritis is characterized by loss of joint cartilage and joint narrowing.
- Primary ankle arthritis is relatively rare; most commonly, ankle arthritis is posttraumatic in origin. Inflammatory arthropathies may also involve the ankle. While ankle arthrodesis and total ankle arthroplasty are accepted surgical treatments for advanced ankle arthritis, joint-preserving supramalleolar osteotomy is an attractive alternative in select patients with advanced ankle arthritis, particularly in ankle arthritis associated with malalignment.
- Supramalleolar osteotomy, whether opening or closing wedge, redistributes stresses on the ankle, transferring weight from an overloaded arthritic portion of the joint to a healthier aspect of the joint.\(^{5,24,29}\) In theory, realignment also improves the biomechanics of the lower extremity\(^ {28}\) and may improve function and delay the progression of the degenerative process.

ANATOMY
- The ankle joint is the articulation formed by the mortise (tibial plafond–medial malleolus and the distal part of the fibula) and the talus.
- The ankle is a modified hinge joint with a slight oblique orientation in two planes: (a) posterior and lateral in the transverse plane and (b) posterior and anterior in the coronal plane.
- This sagittal plane orientation affords about 6 degrees of rotation and 45 to 70 degrees in the flexion–extension motion arc.
- The tibiotalar joint functions as part of the ankle–subtalar joint complex during gait; portions of the medial and lateral collateral ligaments cross both the ankle and subtalar joints. The blood supply is provided by the anterior and posterior tibial arteries and the peroneal artery as well as their branches and anastomoses, forming a rich vascular ring.
- The distal tibial plafond is slightly valgus oriented, in the coronal plane, with respect to the tibial diaphysis, forming an angle called the tibial–angle surface (TAS) with a value of 93 degrees.\(^ {12}\)
- The same angle in the sagittal plane, with its apex posteriorly, is called the tibial–lateral surface (TLS), with a value of 80 degrees.\(^ {12}\)

PATHOGENESIS
- Idiopathic (primary) arthritis, or osteoarthrosis, is relatively rare in the ankle. The exact mechanism of cartilage degeneration and loss has not been clearly defined, although several theories have been proposed.
- Secondary arthritic involvement is mainly posttraumatic, occurring after intra-articular fractures, chondral or osteochondral injuries, and chronic instability.
- Other causes of ankle arthritis include peripheral neuropathy (neuroarthropathy) and various inflammatory disorders (such as rheumatoid arthritis, mixed connective tissue disorders, gout, and pseudogout), primary synovial disorders (pigmented villonodular synovitis), and septic arthritis, as well as seronegative arthropathies associated with psoriasis, Reiter syndrome, and spondyloarthropathy.
- Distal tibial deformity may be a result of malunion of a distal tibial or pilon fracture, physeal disturbance from adjacent osteochondromata, physeal dysplasia, and so forth.

NATURAL HISTORY
- Untreated ankle arthritis typically progresses, with worsening pain that eventually interferes with daily activities. Gradually, ankle stiffness in addition to pain leads to a disturbance of physiologic heel-to-toe gait.
- Low-demand patients with isolated ankle arthritis may function surprisingly well because of the adaptive effect of the healthy subtalar and transverse talar joints. However, obesity, high-demand activity levels, and concomitant subtalar or transverse tarsal joint pathology typically contribute to the morbidity of ankle arthritis.
- To our knowledge there are no absolute numbers for tibiotalar angular alignment that predispose an ankle to the development of arthritis. Several authors have reported that angulation exceeding 10 degrees was compatible with long-term normal function and absence of pain in the ankle joint,\(^ {9,14}\) while biomechanical studies on cadavers have shown that there is a decrease of the contact surface area in the ankle joint of up to 40% in the presence of malalignment,\(^ {31,32}\) with the distal tibial deformities significantly altering total tibiotalar contact area, contact shape, and contact location.\(^ {31}\)

PATIENT HISTORY AND PHYSICAL FINDINGS
- A complete examination of the ankle and hindfoot joints should include the following:
  - Soft tissue condition: previous scars, callosities, ulcers, fistulas, and so forth
  - Vascular status: peripheral pulses, microcirculation (capillary refill), ankle–brachial index
  - Sensation: light touch and, if indicated, Semmes-Weinstein monofilament testing to rule out a peripheral neuropathy. A joint-preserving realignment supramalleolar osteotomy is feasible in select patients with peripheral neuropathy, but the potential for Charcot neuroarthropathy and failure of the procedure must be considered.
  - Stability: Anterior drawer test and inversion and eversion stress evaluation are performed to evaluate the integrity of the ankle and hindfoot ligaments. Realignment osteotomy with unstable or incompetent ankle or hindfoot ligaments may fail to improve function.
  - Motor strength: Manual motor testing of the major muscle groups is performed. Realignment in patients lacking
essential motor function at the ankle will improve function in stance phase but will typically necessitate bracing for effective gait.

- Alignment: The angle made by the Achilles and the vertical axis of the calcaneus is normally 5 to 7 degrees of valgus. Altered alignment to varus or increased valgus position indicates either abnormal tilt of the talus within the ankle mortise (eg, unicompartamental cartilage wear) or abnormality of the subtalar joint.
- Effusion testing: Elimination or fullness of the gutters indicates intra-articular fluid accumulation or hypertrophied capsular tissue.
- Normal ankle and hindfoot range of motion (ROM) in the sagittal plane is 20 degrees of dorsiflexion to 50 degrees of planarflexion. Normal values of hindfoot motion are difficult to measure, since the motion is triplanar. A reasonable reference is 5 degrees of eversion and 20 degrees of inversion.
- Isolated supramalleolar osteotomy for a stiff ankle rarely improves ROM; a stiff, diffusely arthritic and malaligned ankle may be best treated with realignment.
- Hindfoot stiffness must also be documented. In patients with malaligned ankles, the hindfoot compensates. For example, a varus ankle will generally be associated with a compensating hindfoot in excessive valgus. If the hindfoot has lost its flexibility due to longstanding compensation for ankle malalignment, then supramalleolar osteotomy may realign the tibiotalar joint but create hindfoot malalignment. With a flexible hindfoot, this is generally not a problem.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Weight-bearing AP, lateral, and mortise ankle and foot radiographs determine the extent of arthritic involvement, deformity, bone defects in the distal tibial plafond or talus, and the presence of arthritis in the adjacent hindfoot articulations. Radiographs may also suggest avascular necrosis (AVN) of the talus or distal tibia.
- With deformity, a minimum of full-length, weight-bearing AP and lateral tibial radiographs must be obtained. If more proximal deformity is suspected, then mechanical axis, full-length hip-to-Ankle radiographs should be considered to accurately plan realignment. More comprehensive full-length weight-bearing radiographs are required to measure the TAS and TLS angles, the level of center of rotation of angulation (CORA) in case of existing deformity, and the preoperative leg-length discrepancy, since any substantial discrepancy may have an impact to the choice of osteotomy.
- Diagnostic injection. If there is uncertainty over whether the pain is originating from the ankle or hindfoot, selective injections may be of use in distinguishing the source of pain.

**DIFFERENTIAL DIAGNOSIS**

- Bone marrow edema
- Soft tissue pathology
- Distal tibial plafond or talar AVN
- Osteochondritis

**NONOPERATIVE MANAGEMENT**

- Nonoperative treatment of ankle arthritis includes pharmacologic agents, intra-articular corticosteroid injections, shoe wear modifications, and orthoses.

- Nonsteroidal anti-inflammatory agents (NSAIDs) are widely used and have proven efficacy in the management of arthritis, including ankle arthritis. In select patients with gastrointestinal irritation, COX-2 inhibitors may offer a reasonable alternative to NSAIDs. Inflammatory arthritides are managed with immunosuppressive agents.
- Judicious use of intra-articular corticosteroid injections may temporize inflammation associated with intra-articular ankle pathology. Moreover, initial injections of the ankle or hindfoot may serve a diagnostic purpose to distinguish ankle from hindfoot pain. Indiscreet use of corticosteroid injections may have a deleterious effect on the residual joint cartilage as a result of the steroid, the anesthetic, or perhaps the accompanying preservative.
- Bracing to immobilize and support the arthritic ankle may provide some pain relief with weight bearing and ambulation. Specifically, polypropylene ankle-foot orthoses (AFOs), double-metal upright braces, and lace-up braces, combined with the use of a stiff-soled rocker-bottom shoe, may be of benefit. Bracing tibial and tibiotalar malalignment is challenging. With a flexible hindfoot, some axial realignment may be feasible, but correction is generally not possible at the focus of deformity.

**SURGICAL MANAGEMENT**

- We use the supramalleolar osteotomy for the following indications:
  - Realignment of distal tibia fracture malunion without or with mild osteoarthritic changes of the ankle joint
  - Realignment of distal tibia malunion with mild to moderate osteoarthritic changes of the ankle joint
  - Ankle fusion malunion
  - Ankle arthritis with deformity secondary to intra-articular trauma or AVN of the distal tibia
  - Correction of valgus deformity associated with a ball-and-socket ankle joint configuration secondary to tarsal coalition
  - Tibiotalar osteoarthritis resulting from chronic lateral ankle instability or a cavovarus foot deformity
  - Restoration of a plantigrade foot position in ankle deformity resulting from Charcot neuroarthropathy, to create ankle and hindfoot alignment that may be safely braced
  - Correction of limb alignment in adolescents and young adults due to growth plate injury
  - Correction of lower limb alignment as staged planning for a total ankle replacement
- As a rule, we reserve supramalleolar osteotomy using internal fixation for mild to moderate angular deformities in the coronal or the sagittal plane. Severe angular deformities with concomitant translation of the distal segment or shortening are, in our opinion, better managed using external fixation and the principles of Ilizarov. Moreover, gradual correction of severe deformity with formation of a regenerate avoids large plates under a wound and typically thin soft tissues that would be under tension with acute correction using internal fixation.
- Comparing closing- and opening-wedge supramalleolar osteotomies: A closing-wedge osteotomy may result in limb shortening when compared to opening-wedge osteotomies. Conflicting reports exist regarding healing rates between the two methods. Studies suggest that closing-wedge osteotomies
exhibit delayed healing when compared to opening-wedge osteotomies, but other reports demonstrate more rapid healing using a closing-wedge osteotomy. One advantage of a closing-wedge osteotomy is that it does not necessitate incorporation of cancellous or structural interpositional graft. While an opening-wedge osteotomy may preserve limb length, resultant skin tension from acute correction may create problems with wound healing and potential vascular compromise if the vessels are put on sudden stretch. Gradual correction with external fixation may be a safer option in cases with severe deformity.

- In the absence of appreciable preoperative leg-length discrepancy, we recommend correcting distal tibial varus deformities with a medial opening-wedge osteotomy and valgus deformities with a medial closing-wedge osteotomy.

Preoperative Planning

- We routinely obtain bilateral, full-length weight-bearing radiographs of the tibia including the knee and ankle joints.
- We draw two lines on the preoperative radiographs: (a) the tibial mechanical axis (which for the tibia coincides with the anatomic axis) and (b) the distal tibial articular surface. On the AP view, the angle formed by these lines is the TAS angle (FIG 1). On the lateral view, these lines form the TLS angle.
- Ideally, we define the physiologic TAS and TLS angles for each patient using radiographs of the healthy contralateral limb. The goal of surgery is to realign the TAS and TLS to physiologic values and perhaps add a few degrees of (slight) overcorrection, to compensate for anticipated minor subsidence during healing of the osteotomy.
- The full-length weight-bearing radiographs serve to determine preoperative leg-length discrepancy, which may influence the choice between opening- and closing-wedge osteotomies.

- Determining the CORA of the deformity (FIG 1): The CORA is the intersection of the two lines that define the deformity, lines that are drawn to represent the mechanical axes of the proximal (line A) and distal segments (line B).
- With isolated angular deformity, the CORA is at the apex of the deformity. When translation is also present, the CORA is located proximal to of the deformity.
- In very distal tibial deformities or ankle deformities with minor to moderate alterations of the TAS angle, the CORA is at the level of the ankle joint line.
- With distal tibial procurvatum deformity (malunion) or ankle fusion malunion in equinus, the CORA is the intersection of the tibial mechanical axis and a line representing the ankle’s center of rotation. Typically, in such cases, the CORA is the level of the lateral process of the talus.
- Significance of the CORA: An osteotomy made at the level of the CORA, whether closing or opening, will predictably realign the ankle without translation of the distal segment and center of the ankle. If the osteotomy is not performed at the CORA, the center of the ankle will translate relative to the mechanical axis of the tibia, creating undesirable malalignment of the two segments and an unnecessary shift of loads to the ankle joint. To avoid secondary translational deformity when the osteotomy is intentionally made at a different level than the CORA, the distal segment must be translated relative to the proximal segment. These osteotomy rules apply irrespective of the method of fixation chosen.

- The size of the opening-wedge or closing-wedge resection can be determined by drawing the desired correction angle on the preoperative radiographs and measuring the wedge size on a template, taking magnification into account.
- The final step in preoperative planning is to determine the extent of compensation that is achieved by the subtalar joint before correction of the deformity. Deformities in the coronal plane are well compensated for by the subtalar joint, unless there is preoperative stiffness in the hindfoot.
- For example, a varus deformity of the tibia is compensated for by eversion of the subtalar joint. In cases of chronic deformity, this attempt to compensate and maintain the foot plantigrade may become fixed at the subtalar joint. Moreover, other adaptive changes may occur including the transverse tarsal joint or midfoot, creating a fixed forefoot deformity. These secondary fixed deformities may also require surgical correction after the ankle is realigned in order to create a functional, plantigrade foot.

Positioning

- The supramalleolar osteotomy is performed with the patient supine.
- A bump under the ipsilateral hip prevents the natural tendency of the lower extremity to fall into external rotation.

Approach

- The fibular osteotomy is performed first, using a small lateral incision, protecting the lateral branch of the superficial peroneal nerve.
- For the supramalleolar osteotomy, a medial skin incision is made and periosteal elevation is performed only to the extent needed to perform the osteotomy.
MEDIAL CLOSING-WEDGE SUPRAMALLEOLAR OSTEOTOMY

- Perform the fibular osteotomy first, using a small lateral incision. The osteotomy is oblique, located at the same level with the planned tibial cut. Some surgeons prefer to make the fibular osteotomy at a different level from the supramalleolar osteotomy.
- We do not routinely apply fixation to the fibular osteotomy, except in cases where it is felt that additional stability is required.
- When correcting tibial deformity, perform the osteotomy at the CORA (TECH FIG 1).
- In select cases, the supramalleolar osteotomy is not performed at the CORA. In some distal tibial deformities, the CORA may be located at the ankle joint, where the osteotomy is not feasible, and the translational component must be compensated. Also, in ankle deformity with only minor alterations of the TAS angle and when detrimental translation of the distal fragment is not a major concern, we generally perform the osteotomy 4 to 5 cm proximal to the medial malleolar tip.
- We routinely use Kirschner wires to define our proposed osteotomy; for an opening-wedge osteotomy we use a single Kirschner wire, but for the medial closing-wedge osteotomy, two Kirschner wires are required to define the tibial wedge resection. Under fluoroscopic guidance, insert the first Kirschner wire perpendicular to the mechanical axis and the second parallel to the ankle joint, intersecting the first Kirschner wire at the apex of the deformity. The size of the wedge has been determined during the preoperative planning, and the Kirschner wires are positioned 1 to 2 mm wider than the proposed osteotomy, so they can be left in place as a guide for the saw cuts. While the Kirschner wires define the osteotomy in one plane, the surgeon must also orient the saw blade perpendicular to the tibial shaft axis when performing the osteotomy. With the anterior and posterior soft tissue and neurovascular structures protected, we routinely use a broad oscillating saw, constantly irrigating the blade with cooled sterile saline or water to limit osteonecrosis. Ideally, a thin cortical bridge and periosteal sleeve on the opposite cortex will be preserved, to allow for a greenstick-like closure of the osteotomy that facilitates maintenance of alignment and enhances stability. However, when the osteotomy is intentionally performed at a level different than that of CORA, then the opposite cortex must be violated to allow the distal segment to be translated.

TECH FIG 1 • Medial closing-wedge supramalleolar osteotomy. A. Using a preoperative radiograph the center of rotation of angulation (CORA) is located at the intersection of two lines that represent the mechanical axes of the proximal and distal segments. B. Under fluoroscopy a Kirschner wire is inserted to the tibia perpendicular to the mechanical axis and a second Kirschner wire is inserted parallel to the ankle joint line intersecting the first wire, ideally at the apex of the deformity. C, D. Guide pin wires used to perform a closing medial wedge osteotomy. Pin A has been inserted to the tibia perpendicular to the mechanical axis and pin B has been inserted parallel to the ankle joint line, intersecting pin A at the apex of the deformity. E. The cut wedge. The pins have been used as a guide for the tibial cuts, while the size of the wedge has been determined during the preoperative planning. (continued)
After removing the resected wedge and performing appropriate translation of the distal segment, close the osteotomy and provisionally fix it with Kirschner wires. The provisional fixation may be guidewires for intended cannulated screws or it must be positioned so as not to interfere with the definitive fixation. Assess alignment of the tibia and ankle fluoroscopically, both in the AP and lateral planes.

Several dedicated low-profile periarticular plating systems for the distal tibia are marketed, both locking and nonlocking. The majority of these plates were designed for the contours of the physiologic tibia. With a wedge resection the fit is typically acceptable but may not be perfect. Locking plates may provide optimal stability, but if the osteotomy is not fully closed, these may in fact delay or even hinder healing. Nonlocking plates, in our opinion, allow for a small amount of settling at the osteotomy with weight bearing, potentially facilitating healing. (If additional stability is required, then cannulated or solid screws may be used from the tip of the medial malleolus across the osteotomy. Alternatively, a second plate may be added anteriorly on the tibia to provide rotational control to the tibia; however, this requires greater soft tissue dissection.)

We do not routinely apply fixation to the fibula, but if additional stability is required, then we apply a low-profile fibular plate.

Final fluoroscopic images in the AP and lateral planes confirm proper alignment, apposition of the osteotomy, and position of hardware.

TECH FIG 1 • (continued) F. Fluoroscopic view of the resected wedge. G. Fluoroscopic view of the closed osteotomy. H, I. Fluoroscopic AP and lateral views of the provisionally fixed osteotomy with Kirschner wires. J. Photo of the applied periarticular plate. Note the excellent fit on the distal tibia. K. The applied periarticular plate after completion of fixation with three screws in the distal segment. L. Fluoroscopic view of the osteotomy after completion of fixation.
MEDIAL OPENING-WEDGE SUPRAMALLEOLAR OSTEOTOMY

- Again, the osteotomy is ideally located at the level of the CORA (TECH FIG 2). If the CORA is located at the ankle joint level or if only minor correction is required and translation of the distal segment is of little concern, then we perform the osteotomy 4 to 5 cm proximal to the medial malleolar tip.
- We perform either a horizontal or slightly oblique (proximal medial to distal lateral) tibial osteotomy with a broad oscillating saw, preserving the opposite cortex and periosteal sleeve to serve as a fulcrum for the opening wedge and to enhance stability. If translation is necessary (the osteotomy is intentionally performed at a level different than that of CORA), then the opposite cortex is cut completely to allow the distal segment to move.
- Under fluoroscopy, gently distract the tibial osteotomy using a lamina spreader or alternative distraction system until desired correction is achieved.
- We routinely use contoured structural graft (generally the neck portion of a femoral head allograft) to fill the osteotomy.

- After correcting the deformity, provisionally fix the osteotomy with Kirschner wires in a manner that does not interfere with the definitive fixation. Assess the alignment using fluoroscopy, both in the AP and lateral planes.
- Several dedicated low-profile periarticular plating systems for the distal tibia are marketed, both locking and non-locking. The majority of these plates were designed for the contours of the physiologic tibia. With an opening-wedge osteotomy the fit is typically acceptable but may not be perfect. Locking plates may provide optimal stability, but if the osteotomy is not fully closed, these may in fact delay or even hinder healing. Nonlocking plates, in our opinion, allow for a small amount of settling at the osteotomy with weight bearing, potentially facilitating incorporation of the interpositional graft. (If additional stability is required, then cannulated or solid screws may be used from the tip of the medial malleolus across the osteotomy. Alternatively, a second plate may be added anteriorly on the tibia to provide rotational control to the tibia; however, this requires greater soft tissue dissection.)

TECH FIG 2 • Medial opening-wedge supramalleolar osteotomy. A. Using a preoperative radiograph the center of rotation of angulation (CORA) is located at the intersection of two lines that represent the mechanical axes of the proximal and distal segments. B. Under fluoroscopy a Kirschner wire is used to mark the osteotomy site at the CORA level. C, D. Under fluoroscopy the tibial osteotomy is gently distracted using a lamina spreader until desired correction is achieved. (A, C, D: from Myerson MS. Reconstructive Foot and Ankle Surgery. Philadelphia: Elsevier; 205:254.

WOUND CLOSURE

- After completing the fixation, close the wound routinely in layers. With opening-wedge osteotomies, the skin tension is typically greater than before surgery, but with longitudinal incisions, this is rarely problematic. Use of a drain is at the discretion of the surgeon; we do not routinely use a drain.
**PEARLS AND PITFALLS**

**Fixation**
- We recommend internal fixation for supramalleolar osteotomies in mild to moderate corrections. Complex and severe deformity may be best managed with external fixation and Ilizarov principles. Multiplanar correction with external fixation effectively manages angular and translational deformity and simultaneously compensates for potential loss of limb length. If there is no significant preoperative leg-length discrepancy, then all varus deformities are corrected using a medial opening-wedge osteotomy, while the valgus deformities are corrected with a medial closing-wedge osteotomy.

**Exposure**
- Minimal periosteal elevation preserves vascularity at the osteotomy site.

**Osteotomy level**
- A closing- or opening-wedge osteotomy at the level of the CORA will lead to complete realignment of the foot and ankle. If the osteotomy is made proximal or distal to the CORA, the distal segment and center of the ankle will translate relative to the mechanical axis of the tibia. When the osteotomy must be performed at a level different than the CORA, then the osteotomy must be completed on the lateral cortex and translated along with the angular correction. These osteotomy rules apply irrespective of the method of fixation chosen.

**Fixation of the osteotomy**
- In our experience, medial plating is typically adequate for fixation of opening- or closing-wedge supramalleolar osteotomies. However, additional stability may be gained with (a) screws from the tip of the medial malleolus that cross the osteotomy or (b) supplemental anterior plating. No fixation is applied to the fibular osteotomy, except in cases where it is felt that additional stability is required.

**Graft choice**
- The graft alternatives are to harvest it from the ipsilateral iliac crest or the proximal tibia or to use tricortical allograft. The two basic types of bone grafts are structural and cancellous. A structural bone graft is one that alters the shape during a reconstruction procedure by virtue of its size and dimension. The structural bone graft provides immediate mechanical support, with little likelihood of collapse even after the resorption that occurs during revascularization. Some structural integrity remains during the process of bone graft incorporation to allow the graft to withstand loads.

**Locked vs. nonlocked plates**
- Locked plating affords optimal stability; however, if the plate is locked with suboptimal bony contact at the osteotomy site, then there may be a delay in osteotomy healing or incorporation of a structural graft. Nonlocked plating permits some settling during weight bearing that may promote healing of the osteotomy, provided stability is satisfactory.

**POSTOPERATIVE CARE**
- The procedure may be performed on an outpatient basis, but we routinely keep the patient overnight for monitoring and pain control (23-hour observation status).
- While rare, a tibial osteotomy, albeit distal to the lower leg muscles, could potentially create a compartment syndrome, and therefore overnight monitoring is prudent. All patients are discharged with a non–weight-bearing postoperative splint, are instructed to maintain elevation of the extremity, and are to return to the clinic 2 weeks after surgery for suture removal.
- At 2 weeks we routinely place the patient in a removable, prefabricated cam walker boot. If we have concern for the osteotomy stability or patient compliance, we obtain radiographs at this time to ensure satisfactory alignment and fixation, and place the patient into a short-leg non–weight-bearing cast.
- The patient returns at 6 weeks from surgery, at which time we routinely obtain simulated weight-bearing radiographs of the ankle. Depending on the stability of fixation and evidence for progression toward healing, we allow the patient to progressively advance weight bearing in the cam walker boot.
- Typically, with follow-up at 10 weeks from surgery, full weight bearing is permitted in the cam walker boot, with a rapid transition to a regular shoe, provided that weight-bearing radiographs of the ankle suggest satisfactory healing. Early ROM exercises without resistance are initiated early (at 2 weeks), when osteotomy fixation is deemed stable and if there is no concomitant procedure (eg, ligament reconstruction or tendon transfer) dictating adjustment of the rehabilitation protocol.

**OUTCOMES**
- Several studies have shown that the overall outcome of supramalleolar osteotomy is very good in terms of pain relief, correction of any existing mechanical malalignment, and the arresting of arthritic changes in the ankle joint.\(^6,24,28,29\)
- The type of osteotomy (opening vs. closing wedge) does not influence the final outcome, even though a closing-wedge osteotomy may lead to leg-length discrepancy or decreased strength.\(^24\)
- The type of osteotomy (opening vs. closing wedge) has no influence on the time of osseous healing.\(^24\)

**COMPLICATIONS**
- Nonunion
- Delayed union
- Over- or undercorrection of the deformity
- Decreased postoperative ROM
- Failure to perform the osteotomy at the level of CORA, thus translating the distal fragment and center of the ankle away from the mechanical axis
- Failure to perform the appropriate translation of the distal segment, in cases where the osteotomy is intentionally performed at a different level than that of CORA (such as when the CORA is at the level or distal to the ankle joint), leading to mechanical axis shifting
Acknowledgment
I would like to thank my mentor Mark S. Myerson for his enlightening training, friendship, and help for the preparation of this chapter.

REFERENCES
DEFINITION
- Varus-type osteoarthritis is characterized by varus deformity combined with anterior opening of the articular surface at the distal end of the tibia.\(^1,2\)
- It often develops bilaterally in middle-aged and elderly women.
- Low tibial osteotomy (LTO) was developed to treat varus-type osteoarthritis of the ankle. Cartilage defects can be repaired with fibrocartilage by resolving the stress concentration.

ANATOMY
- The distal joint surface of the tibia appears almost perpendicular to the anterior longitudinal axis of the tibia and slight anterior opening to the lateral longitudinal axis (FIG 1).

PATHOGENESIS
- The cause of varus-type osteoarthritis is not clear.
- Radiographic measurements showed varus tilt of the distal joint surface (Fig 1). It was thought that the varus tilt was caused by acquired changes, because the ankles of infants are in the valgus position.\(^3\)
- Some biomechanical studies\(^4,10\) showed that varus tilt of the distal joint surface of the tibia caused stress concentration on the medial side of the ankle (FIG 2). The stress moved to the lateral side after valgus osteotomy at a distal portion of the tibia.\(^8\)

NATURAL HISTORY
- Osteophyte formation and sclerotic changes of subchondral bone initially appear in a medial gutter and an anteromedial corner of the ankle joint.
- Damage of articular cartilage gradually progress from the medial side to the lateral side.

Varus-type osteoarthritis of the ankle is classified into four stages (FIG. 3)\(^6,9\):
- Stage 1: no joint space narrowing, but early sclerosis and osteophyte formation
- Stage 2: narrowing of the joint space medially
- Stage 3: obliteration of the joint space with subchondral bone contact medially
- Stage 3a: obliteration of the joint space in the facet is limited to the medial malleolus
- Stage 3b: obliteration of the joint space has advanced to the roof of the talar dome
- Stage 4: obliteration of the entire joint space with complete bone contact

PATIENT HISTORY AND PHYSICAL FINDINGS
- The patient complains of ankle pain at the start of walking and after walking for a long distance.
- Pain on movement and swelling become significant as osteoarthritis progresses.
- A tender point is present at the medial joint space of the ankle.
- Motion of the ankle is retained until relatively advanced stages.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Weight-bearing AP and lateral radiographs should be taken to detect narrowing of the joint space.
- The angle between the tibial shaft and the distal joint surface of the tibia is measured on the AP view (TAS angle) and...
on the lateral view (TLS angle) (FIG 4).\(^1,2,5\) Those angles represent the varus angle and the amount of anterior opening of the joint, respectively.

- Normal values are 88 to 90 degrees for the TAS angle and 80 to 81 degrees for the TLS angle.\(^1,2,5\)
- The tibial axis is defined as the line between the midpoints of the tibial shaft at 8 cm and 13 cm above the tip of the medial malleolus.

- Varus tilt of the talus has been observed in some ankles with osteoarthritis. The varus tilt angle is evaluated on a weight-bearing AP radiograph that shows the distal joint surface of the tibia and the upper surface of the talar dome (FIG 5).

**DIFFERENTIAL DIAGNOSIS**

- Posttraumatic osteoarthritis
- Rheumatoid arthritis
- Infectious arthritis
- Charcot joint
- Crystal-induced arthritis

**FIG 3** - Stages of varus-type osteoarthritis of the ankle.

A. Stage 1: no joint space narrowing, but early sclerosis and osteophyte formation. B. Stage 2: narrowing of the joint space medially. C. Stage 3a: obliteration of the joint space in the facet is limited to the medial malleolus. D. Stage 3b: obliteration of the joint space has advanced to the roof of the talar dome. E. Stage 4: obliteration of the entire joint space with complete bone contact.

**FIG 4** - The angle between the tibial shaft and the distal joint surface of the tibia on the AP view (TAS angle) and on the lateral view (TLS angle).

**FIG 5** - Varus tilt angle on a weight-bearing AP view.
NONOPERATIVE MANAGEMENT
- Rest and avoidance of offending activity is recommended.
- Warming with hot packs and ultra microwave is effective.
- Nonsteroidal anti-inflammatories and an injection of hyaluronic acid are used for moderate and severe pain.
- A shoe insert with an outer wedge is very effective for osteoarthritis in stage 1 and stage 2 (FIG 6).

SURGICAL MANAGEMENT
- An anteromedial opening-wedge osteotomy to correct the varus and anterior opening of the distal joint surface should be planned (FIG 7). The open-wedge method of osteotomy is more effective than the closed-wedge method. The lateral closed-wedge method is difficult because of the presence of the fibula on the lateral side, and this method can weaken the peroneal muscles because it shortens the lateral side.
- LTO is very effective for patients with stage 2 or stage 3a, but clinical results for patients with stage 3b are unsatisfactory. There must be cartilage on the roof of the talar dome for this procedure to be indicated.
- If the varus tilt angle on the weight-bearing AP view is 5 degrees or less, good results can be obtained from osteotomy alone. However, no joint with a varus tilt angle exceeding 10 degrees can attain a normal joint space.9
- Although the indications for this procedure are very limited, LTO can provide relief of pain with retention of joint function.

Preoperative Planning
- In terms of the TAS angle, overcorrection has produced much better results than undercorrection, especially in cases of advanced osteoarthritis. Therefore, the ideal TAS angle is 96 to 98 degrees.
- With the TLS angle, overcorrection has been found to restrict dorsiflexion of the ankle. Consequently, the ideal TLS angle is 81 to 82 degrees.
- Preoperative drawing
  - The osteotomy site is set at 5 cm above the tip of the medial malleolus. The extent of correction is appropriate to the shape of the grafted bone.
  - The lengths of the outer and side margins of the wedge-shaped graft bone are measured during preoperative drawing for the osteotomy. The grafted bone is usually harvested from the iliac bone crest. The medial height of the graft usually ranges from 6 to 8 mm.

Positioning
- The operation is performed under general anesthesia or spinal anesthesia in a supine position using an air tourniquet.

Approach
- Usually two separate incisions are made, on the lateral side of the fibula and on the medial side of the tibia.
**FIBULAR OSTEOTOMY**

- The fibular osteotomy is performed first. Make a 2-cm lateral longitudinal incision 7 cm proximal from the tip of the lateral malleolus. The tip of the lateral malleolus is detected using a needle percutaneously.
- Make an oblique cut on the fibula running from anteroproximal to posterodistal using a bone saw. When the tibia is corrected in the valgus direction, the hindfoot usually rotates laterally. This movement puts the osteotomy site in the appropriate position.
- If opening at the tibial osteotomy site is difficult, excise a 5-mm segment from the fibular osteotomy site.

---

**TIBIAL OSTEOTOMY**

- The tibial osteotomy is performed using an open-wedge technique.
- Make an 8-cm medial longitudinal incision beginning 5 cm proximal from the tip of the medial malleolus. The tip of the medial malleolus is detected using a needle percutaneously.
- The anterior surface of the distal part of the tibia is easily exposed, but retain as much of the periosteum as possible.
- Mark an osteotomy line using a chisel 5 cm proximal from the tip of the medial malleolus.
- Perform the osteotomy using a bone saw. Do not completely bisect the tibia. Retain several areas of cortex on the lateral side of the tibia. Open the osteotomy site carefully from the medial side using a chisel (TECH FIG 1A,B).
- Harvest grafted bone, the size of which has been decided during preoperative planning, from the iliac bone crest or a distal portion of the tibia.
- Form the grafted bone into a shape appropriate to an anteromedial opening-wedge osteotomy with reference to the drawing.
- Use the grafted bone to fill any open space at the osteotomy site (TECH FIG 1C).

---

**TECH FIG 1** - Tibial osteotomy.  
**A.** The osteotomy site is opened carefully.  
**B.** The size of the opening space is measured carefully.  
**C.** Open space is filled with bone graft.
Chapter 63  SUPRAMALLEOLAR OSTEOTOMY WITH INTERNAL FIXATION: PERSPECTIVE 2

FIXATION AT OSTEOTOMY SITE

- Fix the osteotomy site in the tibia using a four- or five-hole AO/ASIF Narrow Plate (Synthes), a six- or eight-hole Form Plate (Osteo), or a four- or six-hole Cloverleaf Plate (Stryker) (TECH FIG 2).

- Use cancellous screws for fixation at the distal end of the tibia to prevent fixing the distal talofibular joint.

- Fix the osteotomy site of the fibula using a screw or Kirschner wire.

- The compression mechanism of the screw holes on the plate sometimes causes loss of correction. If a plate has a compression mechanism, take extra care during the operation.

TECH FIG 2 • Plate fixation.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indication</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LTO is indicated for stage 2 or 3A.</td>
<td></td>
</tr>
<tr>
<td>Retaining the cartilage of the roof of the talus is necessary to obtain good clinical results.</td>
<td></td>
</tr>
<tr>
<td>There is no indication for the ankle with more than 10 degrees of a weight-bearing talar tilt angle.</td>
<td></td>
</tr>
<tr>
<td>LTO cannot be expected to increase range of motion. It is indicated for the ankle that has at least 30 degrees of range of motion.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fixation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>If a plate has compression mechanism, take care to avoid loss of correction during fixation with screws.</td>
<td></td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- The leg is elevated with a pillow immediately postoperatively.

- The day after the operation, non-weight-bearing walking is allowed. Exercises for flexion and extension of the toes and knee are prescribed to prevent deep vein thrombosis and muscle weakness.

- A cast is used for 4 to 6 weeks. Touchdown with low-weight-bearing (5 kg) is allowed 2 weeks after the operation. Partial weight bearing (10 to 15 kg) is allowed 4 weeks postoperatively.

- After the cast is removed, a compression bandage is applied from the toes to the thigh to prevent edema. Active range-of-motion exercise of the ankle promotes repair of cartilage.

- The amount of weight bearing is increased gradually until full weight bearing on the ankle is allowed 2 months after the operation.

OUTCOMES

- The clinical results of 25 consecutive patients (26 feet) with varus-type osteoarthritis of the ankle who underwent LTO in our hospital were analyzed. All were women aged 37 to 76 years (mean 54 years). Mean follow-up was 8 years 3 months.

- Patients reported marked relief of pain and exhibited significantly improved walking ability and activities of daily living. However, ankle movement did not improve postoperatively.

- The overall result was excellent in 4 ankles, good in 16 ankles, fair in 2 ankles, and poor in 4 ankles.

- Radiographic evaluation showed that the mean TAS angle was corrected from 83 degrees before surgery to 98 degrees at the follow-up examination; the mean TLS angle was corrected from 79 degrees before surgery to 85 degrees at the follow-up examination.

- In ankles that were radiographically classified as stage 2 or stage 3a, the lost joint space was restored. In contrast, only 2 of the 12 ankles that were classified as stage 3b exhibited restoration of the lost joint space. These findings indicate that LTO is indicated for stage 2 or 3a (FIG 8).

COMPLICATIONS

- Delayed union and nonunion are rare.

- Arthrodesis or total ankle arthroplasty as a salvage procedure should be selected for patients with poor results.
REFERENCES

DEFINITION
- A supramalleolar osteotomy is an osteotomy at the level of the distal tibia with or without osteotomy of the fibula.
- The correction is intended to normalize altered load distribution across the joint and may be indicated in cases of asymmetric osteoarthritis, malunited fractures of the distal tibial, and osteochondral lesions.

ANATOMY
- Trauma and neurologic disorders leading to varus and valgus alignment around the ankle joint predispose to asymmetric joint load. This causes cartilage wear, in particular in the presence of associated ligamentous instability and muscular imbalance (FIG 1).

PATHOGENESIS
- Various conditions, such as neurologic disorders, congenital and acquired foot deformities, posttraumatic malunions, and instability may be associated with malalignment of the ankle joint complex.

NATURAL HISTORY
- Malalignment of the hindfoot may result from bony deformity above or below the level of the ankle joint.
- Ligamentous instability or muscular imbalance may be a contributing or even an initiating factor in the natural history of malalignment around the ankle joint.

PATIENT HISTORY AND PHYSICAL FINDINGS
- A thorough medical history should be taken.
  - Systemic diseases, such as diabetes mellitus (Charcot arthropathy), rheumatoid arthritis, and neurovascular disorders need to be assessed carefully.
  - Tobacco use should be considered a relative contraindication to supramalleolar osteotomy.
  - Disorders that alter the bone quality and healing capacity (medication, osteoporosis, age) should be assessed carefully.
  - Physical examination should include the following:
    - Drawer test and talar tilt test to assess ankle joint stability
    - Assessment of the inversion and eversion force to exclude peroneal tendon insufficiency
    - Subtalar range of motion
    - Coleman block test to exclude a forefoot driven hindfoot varus

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Weight-bearing radiographs of the entire foot, the ankle, the tibial shaft (full-length radiographs) and the Saltzman hindfoot view are necessary to assess the nature and location of the deformity. Unless deformity at the level of the knee joint or the femur can be excluded clinically, whole lower-limb radiographs are obtained.
- Next to conventional radiography, computed tomography (CT) and magnetic resonance imaging are not routinely required. However, they could be of value when assessing osteochondral lesions and peroneal tendon disorders or evaluating the aspect of the ligament insufficiency.
- SPECT-CT has been found to be a valuable tool for the assessment and staging of osteoarthritis in asymmetric osteoarthritis of the ankle joint.

DIFFERENTIAL DIAGNOSIS
- Symmetric or end-stage osteoarthritis
- Muscular imbalance (e.g., in neurologic disease)
- Forefoot-driven hindfoot deformities

NONOPERATIVE MANAGEMENT
- Asymptomatic, moderate malalignment usually is treated conservatively.
- Malalignment that is due to forces from the neighboring structures, such as plantarflexed first metatarsal or unbalanced muscle forces can be treated with physiotherapy or shoe wear modifications. Deforming forces, such as forefoot abnormalities or muscular imbalance, may require surgical procedures other than supramalleolar osteotomies.
- Recommendations for asymptomatic but severe malalignment, such as experienced by the patient in Fig 1, are controversial (surgical versus conservative). Because the deformity is likely to lead to excessive wear, surgery should be considered.
- An alternative surgical treatment is the calcaneal displacement osteotomy (medial or lateral). In my opinion, however, correction of malalignment is best performed at the level of the deformity.
SURGICAL MANAGEMENT

- Supramalleolar osteotomies are divided into opening and closing wedge osteotomies.
  - Valgus deformities are usually addressed with a medial closing wedge osteotomy.
  - Varus malalignment is corrected with a medial opening wedge osteotomy or a lateral closing wedge osteotomy.
- The decision between wedge removal laterally and wedge insertion is based on the amount of correction needed. In an extensive medial opening wedge osteotomy, the fibula may restrict the amount of correction possible, so deformities greater than 10 degrees are usually corrected through a lateral approach.

Preoperative Planning

- The most important aspect of the preoperative planning is the assessment of the origin of the deformity. Different entities need to be distinguished, and it is mandatory to separate the isolated frontal plane deformity of the hindfoot from complex deformities involving the transverse, sagittal, and coronal planes with or without muscular dysfunction and imbalanced ligamentous structures.
- To determine the size of the wedge that should be added or removed to restore anatomic alignment in the ankle, the tibiotalar angle should be measured.
  - On a standard anteroposterior image of the ankle joint, the tibiotalar angle is the angle between the tibial axis and the tibial joint surface. The wedge to be corrected can be measured out of the radiographs or calculated with the mathematical formula \( \tan \alpha = \frac{H}{W} \), where \( \alpha \) is the angle to be corrected, \( H \) is the wedge height in millimeters, and \( W \) is the tibial width (FIG 2).
- An overcorrection of 3 to 5 degrees is recommended by most authors for asymmetric osteoarthritis.
- Additional deviation (e.g., rotational or translational deformities) must be taken into consideration during the planning of the osteotomy.

Positioning

- Positioning of the patient depends on the surgical approach:
  - Anterior approach: supine position
  - Lateral approach: lateral decubitus position or supine with a sandbag under the buttock of the affected limb
  - Medial approach: supine, ipsilateral knee in slight flexion with a sandbag under the calf

Approach

- An anterior, lateral, or medial approach can be chosen to correct the deformity. The choice depends on the nature of the deformity, the local soft tissue conditions, and previous approaches.

LATERAL CLOSING WEDGE OSTEOTOMY TO CORRECT VALGUS

Details of Approach

- After exsanguination of the leg, a pneumatic tourniquet is inflated on the thigh.
- A 10-cm longitudinal slightly curved incision is made along the anterior margin of the distal fibula. If the incision needs to be extended distally, it is curved ventrally to end just distal to and anterior of the lateral malleolus (TECH FIG 1).
- The fibula and the tibia are then exposed laterally. To avoid devascularization of the bone, stripping of the periosteum is not performed.
- At the distal end of the incision, the anterior syndesmosis is exposed.
- The lateral branch of the sural nerve and the short saphenous vein run dorsal to the line of incision and are usually not seen during this procedure. Extended proximal dissection may require identification, exposure, and protection of the branches of the superficial peroneal nerve, however. Cauterization of some of the branches of the peroneal artery, which lie deep to the medial surface of the distal fibula, may be necessary.

FIG 2 • Planning of the correction: measuring of the deformity and planning of the wedge to be inserted (lower line of the white triangle indicating the level of the osteotomy).

TECH FIG 1 • Lateral approach to the distal fibula and tibia.
Chapter 64  SUPRAMALLEOLAR OSTEOTOMY WITH INTERNAL FIXATION: PERSPECTIVE 3

Fibular Osteotomy

- In most cases in which a varus deformity is addressed with a lateral closing wedge osteotomy, the fibula needs to be shortened to preserve the congruency in the ankle joint. The shortening can be done by simple bone block removal or a Z-shaped osteotomy. I prefer the Z-shaped fibular osteotomy, which confers greater control of rotation and primary stability compared to a block resection for fibular shortening.

- The length of the Z-shaped fibular osteotomy is approximately 2 to 3 cm, starting distally at the level of the anterior syndesmosis.

- Kirschner wires can be placed as a reference at the level of the transverse cuts to confirm the location of the osteotomy fluoroscopically.

- The osteotomy is then performed with an oscillating saw. After the fibula has been mobilized, bone blocks are resected on both ends of the Z based on the amount of the planned shortening (TECH FIG 2).

- To avoid interference from the dense syndesmotic ligaments when performing the Z-osteotomy, I routinely direct the proximal transverse cut anteriorly and the distal cut (which typically sits at the syndesmosis) posteriorly.

Lateral Closing Wedge Tibial Osteotomy

- To define the desired osteotomy, two Kirschner wires are drilled through the tibia, with the tips converging at the medial cortex, making sure that the angle between the K wires corresponds with the preoperative planning (see Tech Fig 2).

- Unless the deformity is located proximal to the supramalleolar area, the wires are directed from proximal to the anterior syndesmosis to the medial physeal scar (TECH FIG 3A).

- After fluoroscopic verification of the location of the wires (TECH FIG 3B), the periosteum is incised only at the level of the planned osteotomy and carefully mobilized with a scalpel or periosteal elevator.

- The osteotomy is then performed using an oscillating saw cooled with saline or water irrigation to limit thermal injury to bone.

- Placing the K-wires accurately avoids cutting through the medial cortex; ideally, the medial cortex should serve as a hinge.

- Correction of the deformity must be performed at the center of rotation and angulation of the deformity to avoid relative translational malpositioning of the distal (ankle) and proximal (tibial shaft) fragments.

- The gap is then closed, and the osteotomy is secured with a plate. I prefer locking plates that afford optimal primary stability; however, it is imperative that the osteotomy is completely closed when employing locking plate technology (TECH FIG 3C, D).

- Prior to locking the plate both proximal and distal to the osteotomy, I use a tensioning device to optimally compress the osteotomy.

- I routinely close the periosteum over the osteotomy with 2-0 absorbable sutures.
MEDIAL OPEN WEDGE OSTEOTOMY FOR CORRECTION OF VARUS DEFORMITY

Anterior Approach

- The limb is exsanguinated and the thigh tourniquet is inflated.
- The anterior incision is made anteriorly over the distal tibia and ankle, immediately lateral to the tibial crest. The superficial peroneal nerve will cross the distal aspect of the incision and must be protected.
- The extensor retinaculum is then divided longitudinally to expose the extensor tendons. The approach uses the interval between the tibialis anterior and extensor hallucis longus tendons.
- A longitudinal incision in the extensor retinaculum is made between the anterior tibial tendon and the extensor hallucis longus tendon, starting 10 cm proximal to the joint, about midway between the malleoli (TECH FIG 5).
- The anterior tibial tendon is retracted medially, and the tendon of the extensor hallucis longus is retracted laterally, if possible, without opening the tendon sheaths.
- The deep neurovascular bundle (anterior tibial artery and deep peroneal nerve), located in the lateral aspect of the approach, must be identified and protected.
- The ankle joint is covered by an extensive fat pad that contains a venous plexus and requires partial cauterization.
- If tibiotalar joint debridement or exostectomy is required, I make an anterior capsulotomy at this time. If only a supramalleolar osteotomy is planned, however, there is no need to expose the joint.
- With all soft tissues and neurovascular structures protected, the anterior surface of the tibia can be exposed.
TECH FIG 5 • Anterior approach to the distal tibia with the interval between the extensor hallucis longus and the anterior tibial tendon and the neurovascular bundle lying lateral to it.

To promote healing of the osteotomy, periosteal stripping should be limited to the osteotomy site.

The osteotomy is carried out as described below under Tibial Osteotomy.

Medial Approach

The patient is positioned supine on the operating table; a bump placed under the contralateral hip may improve exposure.

The limb is exsanguinated and the tourniquet is inflated.

The great saphenous vein and the saphenous nerve usually lie anterior to the incision. A 10-cm longitudinal incision is made beginning over the medial malleolus and extending proximally over the distal tibia (TECH FIG 6A).

- The skin flaps are mobilized, with care taken not to damage the neurovascular bundle, which runs along the anterior border of the medial malleolus (TECH FIG 6B).
- The posterior tibial tendon, which lies immediately on the posterior aspect of the medial malleolus, must be identified and retracted posteriorly. It needs to be exposed, its sheath incised, and the tendon retracted posteriorly to visualize the dorsal surface of the distal tibia.

Tibial Osteotomy

- The tibia is exposed with minimal periosteal stripping (TECH FIG 7A).
- The plane of the osteotomy is determined under image intensification, and a K-wire is placed from the medial cortex into the physeal scar or, in case of a malunion, at the apex of the deformation (TECH FIG 7B).
- The periosteum is then incised at the level of the osteotomy and elevated off the bone using a scalpel or a periosteal elevator. The osteotomy must be planned carefully because placing it inaccurately may lead to relative translation of the distal and proximal fragments, malaligning the ankle joint under the tibial shaft axis.
- I recommend using a wide saw blade to create a congruent osteotomy (TECH FIG 7C, D).
- Alternatively, a chisel or osteotome may be used instead of the oscillating saw to limit thermal injury to bone.
- The correction is based on preoperative planning.
- The gap can be filled with allograft (I use Tutoplast Spongiosa; Tutogen Medical GmbH, Neunkirchen, Germany) or autograft iliac crest bone (TECH FIG 7E).
- We typically secure the osteotomy with a medial locking plate, but plates with an integrated spacer (eg, Puddu plate; Arthrex, Naples, FL) can be used instead (TECH FIG 7F).
- Fixation of the osteotomy is as described for the lateral osteotomy (see earlier).
- The tendon sheath of the posterior tibial tendon is reapproximated with 2-0 absorbable sutures, and the subcutaneous tissues and the skin are closed with interrupted sutures. Do not overtighten the posterior tibial tendon sheath because it may create stenosing flexor tenosynovitis.
- Case results are shown in TECH FIG 8.

## MEDIAL CLOSING WEDGE OSTEOTOMY FOR CORRECTING VALGUS MALALIGNMENT
- The technique essentially is the same as for the opening wedge osteotomy described in the previous section with removal of a bone wedge.
- K-wire placement is done according to the planned correction (TECH FIG 9A).
- The bone wedge is then removed (TECH FIG 9B) and the correction secured with a medial plate.
- A clinical example is shown in TECH FIG 10.
TECH FIG 10 • Pre- and postoperative radiographs (weight-bearing anteroposterior, lateral, and Saltzman views, respectively) of a 58-year-old male patient with valgus osteoarthritis of his ankle joint. The postoperative images are made 1 year after a medial closing wedge osteotomy.

PEAKS AND PITFALLS

Laceration of the posterior tibial tendon  ■ For lateral osteotomies in posttraumatic cases with extensive scarring on the posteromedial aspect of the ankle, it may be necessary to expose the tendon through a minimal incision to protect it.

Accidental cutting through the entire tibia  ■ This loss of the hinge mechanism of the far cortex introduces the risk for rotational or translational malpositioning and postoperative displacement of the osteotomy.
  ■ Consider additional fixation with a second plate in a second plane.

Mobilization of the syndesmosis  ■ In select cases, the syndesmosis needs to be mobilized to maintain congruent tibiotalar joint alignment. I do this by releasing the anterior syndesmotic ligaments from the anterolateral distal tibia, immediately proximal to the ankle joint. The ligaments are released by removing Chaput’s tubercle from the anterolateral distal tibia using an osteotome or chisel. Once the osteotomy is secured and the fibula is reduced to the desired position to create a congruent ankle joint, the syndesmosis is stabilized at its new resting tension by reattaching Chaput’s tubercle with a screw and a washer or with transosseous sutures.

Loss of reduction of the osteotomy  ■ The risk can be lowered by the use of implants that provide angular stability and by leaving a hinge of bone and periosteum at the far cortex when performing the tibial osteotomy to achieve a controlled correction in the desired plane.

POSTOPERATIVE CARE
  ■ The leg is elevated in the immediate postoperative period.
  ■ A compressive dressing and splint are maintained for 2 days to diminish swelling.
  ■ A short leg non–weight-bearing cast is used for 6 to 8 weeks.
  ■ If radiologic evidence of consolidation is present after 6 weeks, partial weight bearing is allowed for 2 weeks, after which the patient advances gradually to full weight bearing.
  ■ A rehabilitation program for strengthening, gait training, and range of motion is prescribed 8 weeks after surgery, with gradual return to full activities as tolerated.

OUTCOMES
  ■ We have been observing our first series of 74 patients with a varus or valgus deformity of the ankle joint for 49 months (range of 24 to 146 months).

COMPLICATIONS
  ■ Apart from perioperative complications such as delayed wound healing problems or infection, postoperative concerns include delayed union or nonunion of the osteotomy.
Another potential complication is malunion, resulting from inaccurate alignment of the osteotomy at the time of surgery or postoperative loss of position.

Intraoperative complications include nerve or tendon injury. We ensure that all adjacent neurovascular structures and tendons are identified and protected.

REFERENCES

DEFINITION

- Supramalleolar osteotomy (SMO) refers to an osteotomy of the distal tibia and fibula. Typically this is at the metaphyseal-diaphyseal junction, averaging 5 cm proximal to the ankle joint.
- The technique for SMO can vary greatly and includes both open and percutaneous approaches; use of a power saw, a Gigli saw, or an osteotome; use of internal fixation or external fixation; and gradual or acute reduction of the bone.
- The most common indication for SMO is malalignment of the distal tibia. Malalignment of the distal tibia and ankle is a common problem that is largely left untreated even in this era of modern orthopaedics. There is a general lack of interest in treating these deformities, which can be attributed to the deficiency of a safe and reliable method for correction.
- In our hands, correction of distal tibial and ankle deformities using a percutaneous osteotomy and a minimally invasive circular external fixator has yielded excellent and reproducible results with minimal complications.

ANATOMY

- Bony deformity
  - Common deformities that cause malalignment include distal tibial and ankle varus, valgus, apex anterior, apex posterior, malrotation, and shortening.
  - Typically, a patient has more than one of these deformities simultaneously.
- Tibial nerve
  - With longstanding varus or flexion (procurvatum) deformities of the distal tibia, the tibial nerve is often relatively shortened. An equinus contracture of the ankle joint will worsen the situation.
  - In these cases serious consideration needs to be given to the management of the nerve to prevent neurologic injury.
  - The two most common methods for avoiding injury are gradual correction of all deformities and tarsal tunnel release.
  - As long as one of these methods is employed, then the nerve should be protected.
- Poor skin
  - The condition of the skin around the operative site must be noted.
  - Many patients with posttraumatic deformities of the distal tibia have also sustained severe soft tissue injury. The skin is often matted down and adherent to the underlying bone. Skin grafts and free flaps are not uncommon and must be considered when choosing a correction technique.
  - Poor skin will often not tolerate large incisions. Wound dehiscence and even osteomyelitis are not uncommon in these circumstances. Internal fixation often will not fit underneath this skin and will often lead to wound breakdown and deep infection.
- A minimally invasive technique relying on gradual correction is the ideal solution to avoiding further compromise of poor skin.
- Osteotomy level
  - Although the apex of the deformity (center of rotation and angulation [CORA]) often appears to be the obvious site for a corrective osteotomy, clinical factors must be weighed.
  - Often we make our osteotomy distal or proximal to the true CORA for a variety of reasons. The bone at the CORA is often very sclerotic and has suboptimal healing potential. An osteotomy through adjacent less sclerotic bone will result in more predictable and robust bone formation and a shorter time for consolidation.
  - Along the same lines, if there is a leg-length discrepancy (LLD), the surgeon must strongly consider whether the bone at the distal osteotomy site has the capacity to both heal and make good regenerate.
  - Often we will make a separate proximal tibial osteotomy for lengthening and use the SMO for deformity correction only.
- Percutaneous osteotomy
  - A thorough knowledge of the distal tibial anatomy is important before embarking on a percutaneous bone cut.
  - Judicious use of the C-arm fluoroscopy is needed to ensure that the osteotome has not passed beyond the far cortex of the bone and into the soft tissues.
  - With time this osteotomy can be done mostly by “feel” and repetition.
  - Pearls include making the incision medial to the tibialis anterior tendon and taking great care when the osteotome passes posteromedially.
  - We recommend rotating the foot internally to ensure the osteotomy is complete and to avoid stretching of the tibial nerve.
- Joint contracture
  - The surgeon must identify any coexisting joint contractures before planning the osteotomy.
  - Often there will be an equinus contracture of the ankle when there is a recurvatum deformity of the distal tibia.
  - Provisions need to be made for simultaneous correction of both the bony deformity and the capsular contracture.
  - When there is a longstanding varus deformity of the distal tibia, the subtalar joint will accommodate through hindfoot valgus. If this subtalar valgus is a fixed contracture, then further surgery will be needed to correct this second, more subtle deformity.

PATHOGENESIS

- A poorly aligned ankle joint experiences asymmetric forces on the articular cartilage that can lead to arthritis.
- We typically see two groups of patients with distal tibial malalignment: those with extra-articular deformity and those with intra-articular deformity.
Patients with extra-articular malalignment have typically had a fracture of the distal tibial metaphysis that healed with deformity, yielding a malunion.

If this deformity is corrected early, then the joint will not become arthritic and the prognosis is very good.

If there is a delay in realignment, which is often the case, the patient will have developed posttraumatic ankle arthritis.

The mechanism for the development of arthritis is the malalignment itself. The ankle joint was designed to function in its anatomic state. If the alignment of the joint is altered, there will be increased pressure in one area of the joint, and this leads to abnormal wear.

For example, if a patient has a longstanding varus malunion of the distal tibia, the ankle joint will tend to wear out on the medial side, with relative sparing of the lateral joint surface. If the joint has asymmetric wear, SMO is still indicated. The goal is realignment of the distal tibia and even overcorrection to place more pressure on the more normal cartilage. This is the same concept as high tibial osteotomy, where the goal is to place the mechanical axis through the lateral compartment of the knee as opposed to through the middle of the knee. This overcorrection will unweight the damaged cartilage and reduce pain.

The prognosis for patients with malalignment and joint arthritis is not as good as that for patients who did not present with arthritis.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

**History**

- The surgeon should obtain information about the type of bony and soft tissue injury, surgical procedures performed, history of infection, and the use of antibiotics.
- High-energy injuries and open fractures are at a higher risk for infection.
- Information about back pain, perceived LLD, use of a shoe lift, and deformity should be elicited from the patient.
- The presence of deformity will often lead patients to report feeling increased pressure on the medial or lateral part of the foot with a valgus or varus deformity respectively.
- A short leg will often lead to complaints of low back pain and contralateral hip pain.
- If antibiotics are being used to manage an infected nonunion, an attempt should be made to discontinue these for 6 weeks before surgery to obtain reliable intraoperative culture samples. Discontinuation of antibiotics must be done with caution and careful observation, particularly in compromised patients like those with diabetes or on immunosuppressive medications.
- The current amount of pain, the use of narcotics, and the ability to walk with or without support should be noted.

**Physical Examination**

- The surgeon should look for deformity and LLD with the patient standing still and walking.
- Inability to bear weight suggests an unstable nonunion.
- The view from the back is helpful to identify a coronal plane deformity.
- LLD is evaluated by using blocks under the short leg and by examining the level of the iliac crests.

- The view from the side is helpful to observe sagittal plane deformity and equinus contracture. The combination of recurvatum deformity above the ankle and equinus contracture of the ankle will lead to a foot translated forward position, with an extension moment on the knee.
- The range of motion of the ankle, subtalar joint, forefoot, and toes should be recorded.
- Compensation for ankle deformity through the subtalar joint is an important factor. For varus deformity, the subtalar joint will slide into valgus. For valgus deformity, the subtalar joint will slide into varus. These compensatory deformities of the subtalar joint may become rigid and irreducible; this typically occurs with longstanding ankle deformity.
- If hindfoot deformity is present, it must be taken into account when correcting the ankle.

- The condition of the soft tissue envelope, especially previous surgical wounds and flaps, and neurovascular findings should be recorded. This includes the posterior tibial and dorsalis pedis pulses, foot sensation, and dorsiflexion and plantarflexion motor function of the ankle and toes.
- Patients with poor pulses are sent for further vascular testing.
- Many patients with Charcot joint destruction have apparently normal sensation to light touch.
- Rotational deformity is best assessed on clinical examination with the patient in the prone position.
- The thigh–foot axis is used to assess rotational deformity of the tibia.
- The rotational profile of the femur on examination is used to assess rotational deformity in the femur. CT scan can also be used for this purpose. CT scan cuts at the proximal femur, distal femur, proximal tibia, and distal tibia allow analysis of rotational deformity.17,23

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Radiographs should include AP, lateral, and mortise views of the ankle, a Saltzman view of both feet (FIG 1), and a 51-inch bipedal erect leg radiograph including the hips to ankles with blocks under the short leg to level the pelvis.
- LLD and limb alignment can be measured from a standing bipedal 51-inch radiograph. The short leg is placed on blocks to level the pelvis, and the height of the blocks is recorded.16,17 This can be performed with the patient using crutches if necessary.
- These radiographs yield crucial information about LLD, deformity, presence of hardware, arthritis, and bony union.
- A supine scanogram can also be used to measure length discrepancy, but this is not useful for alignment analysis.
- CT scan and MRI can be used for further evaluation as needed.
- CT scan can provide more information about bony union.
- MRI can provide information about the condition of cartilage in the ankle and subtalar joints, and the presence of infection.
- Nuclear medicine studies can also be used, but we have not found them to be very helpful in this evaluation.
- Laboratory studies including white blood cell count, erythrocyte sedimentation rate, and C-reactive protein can help to diagnose the presence of infection.
Selective lidocaine injections into the ankle and subtalar joints may help to diagnose the main source of pain.

Differential Diagnosis
- Ankle fusion malunion
- Joint contracture
- Joint deformity without distal tibial deformity (fixed or dynamic)

Nonoperative Management
- Nonoperative management is not recommended because chronic deformity will lead to further ankle joint degeneration.
- Bracing is commonly employed to control pain associated with malalignment and arthritis.

Some malalignment is accompanied by ankle ligamentous instability. For example, varus ankle deformity may lead to instability of the lateral ankle ligaments. Bracing will help provide stability but cannot correct the underlying bony deformity.

Bone realignment will, however, reduce instability and obviate the need for bracing in most cases.

Surgical Management
Preoperative Planning
- The deformity is measured on AP radiographs (FIG 2A).
- The proximal tibial axis is represented with a mid-diaphyseal tibial line. The distal tibial axis is represented with a perpendicular line to the ankle joint drawn retrograde
Chapter 65 SUPRAMALLEOLAR OSTEOTOMY WITH EXTERNAL FIXATION: PERSPECTIVE 1

(normal lateral distal tibial angle is 90 degrees). The intersection of these lines is the apex of deformity (FIG 2B).

- In the sagittal plane, the distal tibial axis is drawn 80 degrees to the lateral joint line (a normal anterior distal tibial angle is 80 degrees) (FIG 2C). The intersection of these lines is the apex of deformity.

- The rotational deformity is assessed from the tibiofemoral angle measured on physical examination. If the osteotomy is at the level of the CORA, no translation is needed. If the osteotomy is done at a level that is different from the CORA, then translation at the osteotomy site will be needed to fully correct the deformity (FIG 2D,E).16,17

- Either acute or gradual correction of a nonunion or malunion can be used.20,21

   - Acute correction can be performed in conjunction with all methods of fixation, including plates, intramedullary nails, and external fixation frames.
   - Gradual correction requires the use of specialized frames.
   - The personality of the problems helps guide the surgeon toward the best method. For example, a distal tibial malunion with 15 degrees of valgus deformity and 2 cm of shortening is best handled with an osteotomy to gradually correct the angular deformity and lengthen the bone with a specialized frame.
   - The Ilizarov method allows gradual correction of all the components of deformity with distraction osteogenesis.

   - One may choose to perform the deformity correction and lengthening at one level if bone regeneration potential is good (FIG 3A,B).

   - Alternatively, one may choose to perform a double-level osteotomy: one level at the CORA for deformity correction, and one level for lengthening in the proximal tibia metaphysis (FIG 3C).

   - Gradual correction achieves lengthening and carries less risk of posterior tibial nerve stretch neuropraxia than if attempted with an acute correction.

- The use of plates and intramedullary nails requires an acute correction of angular and translational deformity.

Acute corrections are particularly useful for modest deformity correction, mobile atrophic nonunions that are opened and bone grafted, and small bone defects that can be acutely shortened.

- The principal advantage of acute correction is earlier bone contact for healing and a simpler fixation construct.

- Acute corrections are generally better tolerated in the femur and humerus, and less well tolerated in the tibia and ankle, given the possible issues of neurovascular insult.

- Gradual correction with a specialized frame is useful for large deformity correction, partial limb lengthening, bone transport to treat segmental defects, and stiff hypertrophic nonunion repair.21

- Gradual correction employs the principle of distraction osteogenesis, commonly referred to as the Ilizarov method.9,15

   - Bone and soft tissue are gradually distracted at a rate of about 1 mm per day in divided increments.
   - Bone growth in the distraction gap is called regenerate.
   - The interval between osteotomy and the start of lengthening is called the latency phase and is usually 7 to 10 days.
   - The correction and lengthening is called the distraction phase.

   - The consolidation phase is the time from the end of distraction until bony union.9 This phase is most variable and is most affected by patient factors such as age and health.

   - If the structure at risk is a nerve, such as the tibial nerve for an equinovarus deformity of the ankle, gradual correction may be the safer option. The correction can be planned so that the structure at risk is stretched slowly (FIG 4). If nerve symptoms do occur, the correction can be slowed or stopped. Neurolysis can be employed in select situations based on the response to gradual correction.17

**Positioning**

- The patient is given spinal-epidural anesthesia with intravenous sedation.

- The patient is then positioned supine on the operating table.
A large distal varus deformity seen radiographically (A). Surgical reconstruction consisted of tibial osteotomy proximal to the center of rotation and angulation (CORA) (to avoid poor skin distal to the CORA). A gradual correction was employed with the Taylor Spatial Frame (B). Further translation may be performed by simply running a residual deformity correction to fine-tune the alignment. C. A supramalleolar osteotomy is accompanied by a proximal tibial osteotomy for lengthening. This technique allows lengthening to occur in a reliable location and brings more blood flow to the compromised distal tibia, which may accelerate the distal healing rate.

- A soft bump is placed under the ipsilateral buttock until the patella is facing upward.
- A well-padded pneumatic tourniquet is then placed around the thigh and set for 250 mm Hg.
- Two sterile bumps are during the frame application, one under the knee and the other under the heel. This will elevate the leg off the bed to accommodate the Ilizarov rings.

**Approach**

- The approach for the SMO will be anteromedial but can be altered somewhat depending on the skin condition about the ankle.
- The approach for the fibular osteotomy is direct lateral and at the same level as the tibial osteotomy.
FIBULAR OSTEOTOMY

- Osteotomy of the fibula is usually performed with the use of a tourniquet at the beginning of the procedure before frame application. The leg is exsanguinated and the thigh tourniquet is inflated to 250 mm Hg.
- A small lateral exposure is a simple and safe way to approach the fibula. It is best to locate the osteotomy at or near the apex of deformity. Consider not performing the fibular cut at exactly the same level as the tibial cut to avoid formation of a synostosis.
- Cut the bone with an oscillating saw or an osteotome. Alternatively, the fibula can be fractured through the tibial osteotomy site.
- Once the tibial osteotomy is performed, keep the osteotome in the wound, redirect it posteriorly and laterally, toward the fibula, and advance it. This option works well when it is too risky to make a lateral incision.
- The shape of the osteotomy may be transverse or oblique.
- When correcting valgus deformity gradually, a transverse osteotomy is performed. As the tibia is corrected, the fibula will be distracted and the gap will fill in with regenerate.
- When correcting varus deformity, the fibula will need to be shortened. This is accomplished with either fibula resection or an oblique osteotomy where the fragments can overlap.
- Do not close the fascia.
- Close the skin in layers.

FRAME APPLICATION: WIRE AND PIN CONFIGURATION

- Tensioned Kirschner wires and half-pins lend roughly the same stability to the frame.
- The proximal ring or ring block is secured with three or four points of fixation.
- When using the Taylor Spatial Frame one ring will suffice, as these rings are quite sturdy and deflection is minimal.
- Release the tourniquet before applying the external fixator.
- We typically use one 1.8-mm Kirschner wire as a reference wire from anterolateral to posteromedial (medial face wire) for purposes of mounting the ring. This wire is placed about 150 to 180 mm proximal to the ankle joint.
- Select the ring diameter according to the size of the leg. Ideally we leave 2 cm of space between the skin and the leg circumferentially.
- Secure the ring to the wire and tension the wire to 130 kg.
- Secure additional fixation with half-pins placed in slightly different planes.
- Make a pilot hole with a 4.8-mm drill bit through both cortices.
- 6-mm hydroxyapatite (HA)-coated pins are our first choice for adult patients.
- Use tall Rancho cubes to spread the fixation and achieve maximal stability.
- The distal tibial ring is usually secured with two or three 1.8-mm Kirschner wires (tensioned to 130 kg) and a half-pin.
- Place the reference wire in the tibia parallel to the ankle joint line and proximal to the ankle joint. Attach the ring proximal to the wire and tension the wire to 130 kg.
- Next, insert a fibula-tibia wire posterolateral to anteromedial to stabilize the syndesmosis and prevent fibula migration. The ring is oriented on the lateral radiograph to be perpendicular to the sagittal plane tibial anatomic axis (not parallel to the ankle joint line, as seen on the lateral view). A posteromedial to anterolateral wire can also be added.
- Finally, use an anteromedial (medial to the tibialis anterior tendon) to posterolateral 6-mm half-pin to add stability in the sagittal plane (TECH FIG 1).
- Fixation may be extended across the ankle to the foot if additional stability of the distal segment is needed.

TECH FIG 1 • This sawbones model shows the typical fixation arrangement for the distal tibia with two tensioned wires and one half-pin.

TAYLOR SPATIAL FRAME

- The advantages of this frame over the classic Ilizarov frame are numerous. The application is easier and the fit on the leg is better when using the rings first method. Also, residual deformity at the lengthening and docking sites can be addressed by using the same frame to correct angulation and translation simultaneously in the coronal,
sagittal, and axial planes without major frame modification. This minimizes angular deformity at the lengthening sites.4,5

- The rings have now been placed on either side of the deformity site and the anticipated lengthening site or sites. The rings have been placed independently to optimally fit the leg. This is called the **rings first method**.

- One ring is chosen as the reference ring for each level of movement, and this ring must be placed orthogonal (perpendicular) to the axis of the tibia.

- The “virtual hinge” around which the correction occurs is defined by the **origin** and the **corresponding point** (CP). The origin is a point chosen on the edge of one bone segment at the defect site. A CP on the other bone segment is chosen with the goal of reducing the CP to the origin.

- **Mounting parameters** define the location of the origin relative to the reference ring. Mounting parameters are defined by the spatial relationship between the center of the reference ring and the origin in the coronal, sagittal, and axial planes. This defines a virtual hinge around which the deformity correction will occur. Struts are used to connect the rings across the deformity.

- It is important to maintain enough distance between rings so that the struts can fit properly. In this frame, one is limited by the shortest length of strut.

### Deformity Parameters

- Six deformity parameters describe the relationship between the proximal segment and the distal segment (the reference segment has the origin and the moving segment has the corresponding point) (TECH FIG 2A,B).

- Deformity parameters consist of an angulation and a translation in the coronal, sagittal, and axial planes.
  - In the coronal plane, the angulation is varus or valgus and the translation is medial or lateral.
  - In the sagittal plane, the angulation is apex anterior or apex posterior and the translation is anterior or posterior.
  - In the axial plane, the angulation is internal or external rotation, and the translation is short or long.

### Mounting Parameters

- Since the Taylor frame enables correction around a virtual hinge, the surgeon must communicate its location (origin) to the computer program (TECH FIG 2C).

- A grid projected from the reference ring allows the surgeon to specify the location of the origin. The location of the origin relative to the center of the reference ring in the coronal, sagittal, and axial planes is recorded.25

- For example, the center of the reference ring may be 10 mm lateral, 25 mm posterior, and 35 mm distal to the origin.

**TECH FIG 2** - Taylor Spatial Frame concept and language.

A. Measurement of translation deformity parameters.

B. Measurement of angulation deformity parameters.

C. Measurement of mounting parameters. *(continued)*
Structure at Risk

The surgeon determines the speed of the correction by choosing a structure that he or she wants to move at a determined rate. Typically a structure in the concavity of the deformity is the structure at risk (SAR) (TECH FIG 2D–F).

- For example, if we are correcting a varus deformity, the SAR may be the medial cortex of the tibia or the posterior tibial nerve. If we are correcting a valgus, recurvatum deformity, the SAR will be the anterolateral surface of the tibia.
- We usually move the SAR at 1 mm per day, although this can be varied.

SUPRAMALLEOLAR Tibial Osteotomy

- After the frame has been mounted on the intact tibia, the tibial osteotomy is performed.
- Record the strut connections between the rings and then remove them.
- Perform the SMO through a 1-cm skin incision, medial to the tibialis anterior tendon and about 1 cm proximal to the distal tibial pins. This will typically place the osteotomy at the metaphyseal–diaphyseal junction about 5 cm proximal to the ankle joint.
- If the CORA is closer to the joint, then appropriate translation of the bone ends must be performed to prevent a translational deformity after correcting the angular deformity.
- The C-arm fluoroscope is positioned in the lateral position.
- Use a multiple drill hole osteotomy technique.
- Pass a 4.8-mm drill bit three times along the plane of the planned osteotomy line (TECH FIG 3A). Complete the SMO by passing the osteotome across the medial cortex and lateral cortex and through the bone center to crack the posterior cortex (TECH FIG 3B).
- Rotation of the osteotome and ultimately rotation of the rings completes the osteotomy. Alternatively, a Gigli saw technique can be used to perform the SMO.
- These are low-energy and low-heat techniques that will minimize bone and periosteal injury and optimize good regenerate bone formation. We believe that osteotomy with an oscillating saw will increase the risk of thermal necrosis to the bone.
FRAME EXTENSION ACROSS THE ANKLE

- If there is an ankle contracture, then a foot ring is placed, and gradual correction of the ankle deformity can be performed simultaneously.

- Hinges are placed along the axis of the ankle joint as is done in ankle distraction arthroplasty. A pulling rod can be placed anterior or a pushing rod posterior to motor the correction.

PROXIMAL TIBIAL OSTEOTOMY

- If there is shortening of the tibia, this can be addressed at the same time as the distal deformity correction.

- An osteotomy at the proximal tibia for lengthening can be done if the bone healing potential at the distal deformity site is not optimal.

- In general, the osteogenic potential of a sclerotic malunion of a distal tibial fracture is limited to deformity correction, and a bone lengthening of any significance should be done through a virgin site. In most cases that means going to the proximal tibia and carrying out an additional osteotomy for tibial lengthening.

EXAMPLE CASE (COURTESY OF MARK E. EASLEY)

- Fifty-five year old woman with a long-standing posttraumatic varus deformity and with a several year history of worsening symptoms (TECH FIG 4A,B).

- Coronal plane deformity only

- Symptomatic lateral foot overload along with ankle pain (TECH FIG 4C)

- Failed nonoperative management

- Proximal ring block

- Reference wire placed orthogonally to the tibia with fluoroscopic guidance (TECH FIG 5A–C)

- Thin wire secured but not tensioned at this point (see TECH FIG 5B,C)

- Note that wire is initially placed using power then fully positioned using a mallet (in theory, this will diminish postoperative pin problems)

- A threaded rod extending proximally from the ring block may prove useful in determining the optimal ring position in relative to the tibial shaft axis (TECH FIG 5D)

- Second thin wire placed at a different ankle than the first (TECH FIG 5E)

- Half pins placed for further support (TECH FIG 5F,G)

- Once half pins placed, thin wires tensioned (TECH FIG 5H,I)
TECH FIG 4 • (continued) B. Lateral view. C. In addition to ankle pain, patient experiences lateral forefoot overload.

TECH FIG 5 • Proximal ring block. A. Reference wire placed under fluoroscopic guidance. B. Final position of wire achieved with a mallet to limit heat necrosis. C. Tightening the wire to the ring without tensioning at this point. D. A threaded rod may be temporarily placed on the proximal ring block to assist in sagittal plane position of the proximal ring block. E. Second thin wire being placed (note use of cold saline irrigation to limit heat necrosis). (continued)
Although this may not be in keeping with the Ilizarov principles, the half pins provide support to the ring while the thin wires are tensioned.

- If the tensioner cannot sit well on the frame, then a “socket” from the standard Ilizarov tray may be used to rest on the frame and still tension the thin wire.

- Distal ring
  - Reference wire placed orthogonally to the tibia and parallel to the tibial plafond in the coronal plane (coronal plane deformity only) (TECH FIG 6A,B)
  - First thin wire secured but not yet tensioned (TECH FIG 6C)

TECH FIG 5 • (continued) F. Half pins placed. G. Cold irrigation used to limit heat necrosis for half pins as well. H,I. Tensioning thin wires. 
H. Tensioning device on the proximal ring block.
I. Close-up of tensioning device (note use of a “socket” in locations where the tensioning device cannot fully contact the ring).

TECH FIG 6 • Reference pin for the distal ring. A. Pin place parallel to the tibial plafond (in this case in varus relative to the orthogonally placed proximal ring block. B. Final position achieved using a mallet. (continued)
TECH FIG 6 • (continued) C–E. Securing the distal ring. C. Tightening the reference wire without tensioning. D. A second thin wire. E. Half pin added in a safe zone, after which the thin wires are tensioned.

- Second thin wire placed and secured to the frame (TECH FIG 6D)
- Half pin placed for further distal ring support (TECH FIG 6E)
- Thin wires tensioned
- Connecting the struts
  - Struts are attached and each strut setting is recorded
  - This simplifies returning the tibia and fibula to their precorticotomy position after the corticotomy is performed
- Fibular osteotomy (TECH FIG 7)
  - Fibular osteotomy performed through small incision using a microsagittal saw to initiate the cut (the blade is cooled with cold saline) and completed with an osteotome
- In this case, the fibular osteotomy is routinely performed slightly proximal to the tibial corticotomy for a supramalleolar osteotomy
- It may have been prudent in this case to perform the oblique osteotomy in the opposite orientation
  - For correction of varus, the distal fibula would have been better contained under the proximal portion
- Supramalleolar tibial corticotomy
  - Minimally invasive approach with minimal periosteal stripping
  - Corticotomy predrilled
    - Larger diameter drill bit to create a defect in anterior cortex (TECH FIG 8A)
    - Smaller diameter drill bit to perform perforations in a single plane (TECH FIG 8B)

TECH FIG 7 • Fibular osteotomy.
Part 8  FOOT AND ANKLE  •  Section IV  ANKLE

TECH FIG 8  •  (continued)  B. Through the initial cortical hole created, the remaining cortex at the same level is perforated with multiple small diameter drill holes.  C. Corticotomy completed with a chisel (note the surrounding soft tissues are protected but minimal periosteal stripping is performed).  D. Be sure the tibial corticotomy and fibular osteotomy are complete by rotating the distal and proximal rings in opposite directions.  E. Secure the struts to connect the proximal and distal rings, spanning the corticotomy. We routinely place the struts prior to performing the corticotomy so that when the corticotomy is completed, we simply reset the struts at the same settings, thereby returning the tibia to its pre-corticotomy position.

- Corticotomy completed using an osteotome (TECH FIG 8C)
- Confirming complete corticotomy
- Once complete, two rings rotated in opposite directions to confirm that the corticotomy is complete (TECH FIG 8D)
- Reconnecting the struts to the precorticotomy position (TECH FIG 8E)
- Struts are reconnected at the same settings that they were prior to the corticotomy, thereby re-positioning the osteotomy at the precorticotomy orientation
- allows an appropriate gradual formation of the regenerate
- Early follow-up
- In this case the single distal ring did not afford adequate stability (TECH FIG 9A,B)
  - This was in spite of several adjustments in the clinic
  - Repeat surgery to add a foot frame that afforded greater stability to the distal ring (block) (TECH FIG 9C,D)
  - In the face of ankle arthritis, slight distraction was added to the construct to distract the ankle.
- Gradual correction
- Computer program utilized create a gradual correction of the coronal plane deformity (TECH FIG 10A,B)

TECH FIG 9  •  Early follow-up, in which the corticotomy is unstable despite several attempts at adjustments in the clinic using the Taylor Spatial Frame’s dedicated computer software.  A. AP view.  (continued)
TECH FIG 9 • (continued) B. Lateral view demonstrates that the distal fragment is displacing anteriorly relative to the proximal fragment. C,D. Foot frame added to provide greater stability to the distal ring. C. AP view. D. Lateral view.

TECH FIG 10 • Further followup after foot frame added. A,B. Clinical view of frame now with the foot plate added to stabilize the distal ring. (continued)
TECH FIG 10 • (continued) C. AP view (note the regenerate forming as the varus deformity is being gradually corrected). D. Lateral view. E,F. Patient can determine when the correction is adequate by weight-bearing on the foot as the deformity is being corrected. E. Patient weight-bearing with frame (crutches for balance, but patient able to fully bear weight). F. Close-up.

- Radiographic follow-up to confirm that the correction is progressing appropriately with formation of a regenerate (TECH FIG 10C,D)
- Determining adequate correction
- Although radiographs may be used and serve to confirm appropriate correction, simply having the patient stand on the foot as the correction nears completion allows the patient to report if the correction is adequate or if more adjustment is needed (TECH FIG 10E,F)
- This is an advantage over internal fixation where full correction must be performed acutely at the index procedure
- Frame removal
- Once the patient has achieved appropriate correction and has been weightbearing on the operated foot, follow-up radiographs dictate when the regenerate is consolidated allowing frame removal
- Further follow-up
- Follow-up radiographs (TECH FIG 11A,B)
- Improved lifestyle with less ankle pain
POSTOPERATIVE CARE

General
- Patients are admitted to the hospital for 2 to 3 days.
- Nonsteroidal anti-inflammatory medications are avoided in all osteotomy patients for fear of adverse effects on bone formation.
- Patients receive intravenous antibiotics for 24 hours and are then switched to oral antibiotics.
- Patients are discharged on oral antibiotics for 10 days and oral pain medication.
- Patients return to the office 10 days postoperatively, when sutures are removed and they are educated on how to perform strut adjustments.
- Patients are seen every 2 weeks during this adjustment period, and then once monthly during the consolidation period.
Deformity Correction
- Correction of the deformity begins after a latency period of 7 to 10 days.
- The Web-based Smith & Nephew program is used to generate a daily schedule for strut adjustments that the patient will perform at home. The computer requires the input of basic information including the side, the deformity parameters, the size of the rings and length of struts used, the mounting parameters measured during frame application, and rate of daily adjustment.
- The structure at risk is selected and entered into the program to ensure the correct speed of gradual correction. For valgus-producing osteotomy the structures at risk are the medial soft tissues, as they are in the concavity of the correction and will be stretched the greatest distance.
- Using this information, a clear and simplified prescription is produced for the patient to follow every day. We prescribe that struts 1 and 2 be turned in the morning, struts 3 and 4 in the afternoon, and struts 5 and 6 in the evening for a total movement of 1 mm per day.\(^2\)\(^3\)
- The duration of the adjustment phase depends on the amount of correction needed and is typically 14 to 28 days.
- The length of time in the frame is about 3 months.

Pain Management
- Transdermal wires and pins can be irritating, and we encourage patients to use appropriate oral pain medications. This is especially true during the adjustment period.
- Once the correction is complete, the frame is no longer moving, and the pain level decreases.
- Severe or atypical pain merits an evaluated for infection or deep vein thrombosis.

Pin Care
- The dressings are removed on the second postoperative day.
- Nurses teach proper daily pin care, consisting of a mixture of half normal saline and half hydrogen peroxide applied to the pin sites with sterile cotton swabs.
- Pins and wires are covered with dry gauze dressings at the skin.
- Patients are allowed to begin showering on the fourth postoperative day. They are instructed to wash the frame and pin sites with shower water daily.
- Antibacterial soap may be used as an adjuvant form of pin care.
- Problematic smooth wires can be removed in the office without anesthetic. This is commonly done after the distraction phase, or if a wire is painful and infected.

Rehabilitation
- Ilizarov stressed the importance of early physical conditioning in conjunction with the application of circular fixators. Early motion increases blood flow to the lower extremity, prevents joint stiffness, and shortens recovery time.\(^1\)\(^1\)
- Physical therapy assists with ambulation with weight bearing as tolerated and range-of-motion exercises for the knee and ankle joints.
- Crutches are typically needed for the first 4 to 6 weeks after surgery.
- Occupational therapy provides a custom neutral foot splint to prevent the fall into equinus during sleep.
- Patients are encouraged to attend outpatient physical therapy where they continue with their rehabilitation programs.

Frame Removal
- The fixator is removed when the patient is walking without pain or the use of an assistive device and when callus is seen on three cortices around the osteotomy site. This is typically 3 to 4 months after the index surgery.
- We prefer to remove the frame in the operating room: the removal of HA-coated pins can be painful and is best done under sedation.
- We choose to curette all half-pin sites in an effort to keep pin tracts clean.
- Transfixion wire sites are not débrided unless there is concern over a specific site.
- At the time of frame removal, bony union and maturation of the regenerate may be evaluated with routine plain radiographs or a stress test under C-arm fluoroscopy.
- If there is a real concern about bony union, then the struts are removed and the rings are manually compressed and distracted, looking for motion at the osteotomy site.
- A lack of consolidation will require replacement of the struts and prolonging the time in the frame.
- Once the fixator is removed, patients are placed into a short-leg cast for 2 weeks. They are allowed 50% partial weight bearing for 2 weeks and then progress to full weight bearing thereafter, first in a cam walker boot and then in a regular shoe.

OUTCOMES
- Associated symptomatic arthritis may be addressed as well. Ankle distraction\(^1\)\(^1\),\(^3\)\(^1\) or ankle fusion can be performed distal to the SMO with the addition of another level of treatment. In these cases the goal of realignment is to unload the area of diseased cartilage while trying to rebuild new cartilage and to ensure a well-aligned leg and foot in the setting of a fused ankle, respectively.
- The goal of PSMO is to correct the deformity in the coronal, sagittal, and axial planes. A lateral distal tibial angle of 90 degrees (Fig 2A) and an anterior distal tibial angle of 80 degrees are ideal (Fig 2C).\(^1\)\(^6\),\(^1\)\(^7\)
- The use of the Ilizarov or Taylor Spatial Frame is particularly useful for a gradual correction of a simple or large oblique plane deformity.\(^4\)\(^,\)\(^5\)\(^,\)\(^2\)\(^1\)
- At times the osteotomy is produced at a location other than the site of the malunion. For example, a malunion of the mid-third of the leg that is composed of varus and translation may have a CORA\(^1\)\(^6\),\(^1\)\(^7\) or apex of deformity in the supramalleolar region. The SMO becomes a convenient way to correct this, since the supramalleolar bone is metaphyseal, is previously uninjured, and has better healing potential that the actual site of the malunion (FIG 5).
- Ankle fusion malunion can be corrected through a PSMO.\(^1\)\(^2\),\(^1\)\(^3\),\(^1\)\(^8\)\(^,\)\(^2\)\(^3\),\(^2\)\(^8\) The osteotomy can be performed very distally, since wire penetration into the ankle joint is not a concern. One can correct all deformities effectively. If some lengthening is needed, it may be done through the same osteotomy or through an osteotomy in the proximal tibia.
- Tilt of the talus may develop with joint space narrowing on one side only of the ankle joint. In this situation, the SMO may be used to achieve a neutral talus relative to the axis of the tibia.\(^2\)\(^,\)\(^2\)\(^9\),\(^3\)\(^0\) To achieve a talus position 90 degrees to the
tibial axis the distal tibia must often be overcorrected. This can be combined with ankle distraction to stimulate cartilage regrowth.\textsuperscript{11,23}

In addition, internal rotation at the SMO can be used to compensate for some of the forefoot abduction.\textsuperscript{2,27} Correction of a foot deformity above the ankle is very powerful, as a plantigrade foot can be obtained while avoiding more intricate and risky surgery to the feet in these complex cases.

**COMPLICATIONS**

**Pin Infection**
- Pin site infection is common when using external fixation.
- Pin infections manifest with erythema, increasing pain, and drainage around the pin or wire.
- The vast majority of these respond well to more aggressive local pin care and oral antibiotics.
- If the infection does not resolve quickly, then broader-spectrum antibiotics are added, or the pin or wire is removed.
- More advanced infections are treated with removal of the pin or wire and local bone débridement in the operating room, and intravenous antibiotics as needed.
- Loose pins and wires are removed and the pin sites are débrided even in the absence of infection.
- The use of HA-coated half-pins has decreased problems with pin loosening and infection.

**Premature Consolidation**
- Incomplete corticotomy can complicate SMO.
- A circumferential division of the tibial cortex may be ensured by rotating the proximal and distal rings in opposite directions and witnessing free motion at the corticotomy site.
- Other methods have been described, including acute distraction and angulation at the osteotomy site, but these techniques are more disruptive to the periosteum and not recommended.
- True premature consolidation of the osteotomy is rare in adult patients.
- Once the osteotomy is performed, there is a latency period of 7 to 10 days before correction is started. If the latency period is prolonged, the osteotomy site will consolidate prematurely.
- Similarly, if the correction is carried out too slowly, the osteotomy site may heal, preventing further correction.

**Patient Related**
- The success of any gradual correction system is based on the patient’s ability to participate in his or her own care.
- Patients are responsible for performing their own strut adjustment three times a day at the outset of treatment.
- The Taylor Spatial Frame has simplified this process through color-coordination and a precise numbering system.
- Patients do make strut adjustment errors, but these mistakes are usually quickly acknowledged and remedied.
- Patients need to be seen frequently (every 10 to 14 days) during the adjustment period to avoid errors.

**Nonunion**
- Bony nonunion can complicate any osteotomy procedure.
- Causes may include inadequate fixation, lack of weight bearing, smoking and other causes of poor blood flow to the extremity, patient comorbidities, too rapid a correction, poor osteotomy technique, and an osteotomy through diaphyseal bone.
- Nonunions are treated aggressively with a variety of methods, including compression across the osteotomy site, percutaneous periosteal and endosteal stimulation, and additional points of fixation.
- Nonunions are rare when using the Taylor Spatial Frame technique. In fact, when there is impaired healing, this specialized frame is ideal for effective treatment.

**Nerve Injury**
- Direct injury to a nerve can occur during surgery from pin or wire insertion during the osteotomy.
- A more common mechanism is stretch injury during distraction. This is discussed above in the section on acute versus gradual correction.
- Gradual correction is much safer than acute correction and avoids stretching the nerves too rapidly.

**Deep Vein Thrombosis**
- Deep vein thrombosis is always a concern with any surgery of the lower extremity.
- Treatment is aimed at prevention. Patients are enrolled into early rehabilitation programs emphasizing immediate mobility to avoid venous stasis.
- There is no restriction to movement at the ankle, knee, or hip, and frame stability allows comfortable weight bearing early in the postoperative period.
- While in the hospital, patients receive subcutaneous low-molecular-weight heparin. After discharge, patients continue a 3-week course of subcutaneous low-molecular-weight heparin.
- Patients can then be switched to aspirin if they are still not walking well.
- With this regimen, we have not had any cases of deep vein thrombosis or pulmonary embolism.

**Septic Arthritis**
- This is a rare complication that needs to be recognized and treated quickly.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{preoperative_AP_radiograph.png}
\caption{Preoperative AP radiograph showing varus deformity at the mid-distal third of the tibia. The apex of the deformity is located in the supramalleolar region because of the lateral translation at the malunion site.}
\end{figure}
The best way to avoid this is prevention. One must be careful not to insert the wires too close to the ankle joint capsule. In general, if the wires and pins are inserted proximal to the epiphyseal scar, there is little risk of an intra-articular wire.

If ankle distraction is being performed simultaneously, then the talus wire is intra-articular and should be monitored.

The surgeon should aspirate the joint immediately in the office and send cultures before giving any antibiotics.

Septic arthritis is treated with removal of the infected intra-articular wire and open or arthroscopic joint lavage. The lavages are repeated until negative cultures are obtained.

Other

Complications we have not experienced secondary to PSMO include necrotizing fasciitis, compartment syndrome, and osteomyelitis.

REFERENCES

BACKGROUND

- Ankle arthrodesis remains the gold standard for ankle arthritis.
- Ankle arthrodesis is indicated for painful arthroses, instability, malalignment, and joint sepsis.
- Regardless of the method of arthrodesis, complications are not uncommon and include nonunion, malunion, infection, osteoarthrosis of contiguous joints, neurovascular injury, wound healing issues, and limb-length discrepancy.6
- Rates of nonunion and other complications alone have been reported to be as high as 30% and 60%, respectively.
- Malunion may be among the most consequential and detrimental complications because of its effect on functional outcome.
- Sequelae of a malaligned ankle arthrodesis include subtalar degeneration, reduced foot flexibility, compensatory foot deformities, and pain with ambulation. Correction of malaligned ankle fusion is thus critical to preserve the functional mobility of neighboring joints.
- Revision of a malaligned ankle arthrodesis can be both technically demanding and traumatic to previously operated bone and soft tissue.
- Preservation of compromised soft tissue structures, including the periosteum, is also a critical consideration when revising the failed ankle arthrodesis.
- The amount of bone resection required to obtain apposition of viable bony surfaces can create an even greater limb-length discrepancy (larger than the expected 1 cm).
- Malunion ankle deformities are typically multiaxial and therefore are not easily corrected acutely.

SURGICAL MANAGEMENT

- Our minimally invasive technique uses a four-incision percutaneous Gigli saw osteotomy with gradual external fixation correction of the ankle malunion.
- The subperiosteal Gigli saw osteotomy through a prior malaligned fusion site limits soft tissue compromise while optimizing soft tissue and bone healing.
- External fixation provides gradual accurate multiplanar (rotation, angulation, and translation) realignment, while simultaneously correcting limb length. In addition, obtaining proper alignment of an ankle fusion is paramount.

Positioning

- Under general anesthesia, the patient is positioned supine on the radiolucent table with an ipsilateral hip bump so as to place the foot in a foot-forward position.
- A nonsterile thigh tourniquet is placed, and sterile prep of the entire leg to the level of the tourniquet is performed.
- Under video fluoroscopy, a marking pen is used to indicate the desired level of the osteotomy on both the anteroposterior (AP) and lateral views. The thigh tourniquet is then inflated.

PERCUTANEOUS OSTEOTOMY

- The first incision is made transversely, just medial to the tibialis anterior tendon (TECH FIG 1A–C).
- Subperiosteal dissection with a periosteal elevator is performed across the anterior tibia.
- This subperiosteal dissection creates a subperiosteal tunnel that protects the tendons and neurovascular bundle along the anterior aspect of the ankle.
- Along the desired level of the osteotomy, the periosteal elevator is then maneuvered in a rocking motion against the bone and across the entire anterior ankle to the lateral aspect of the ankle malunion.
- A vertical second incision is made where the skin is tented by the extension of the periosteal elevator, and the elevator is removed.
- A no. 2 Ethibond suture is clasped with a curved tonsil hemostat and passed through the previously created subperiosteal tunnel from the medial incision to the lateral incision (TECH FIG 1D).
- Once the suture is passed, the Gigli saw is tied to the suture and also pulled from medial to lateral through the same subperiosteal tunnel (TECH FIG 1E).
- The position of the Gigli saw is then checked by image intensifier to ensure that the desired level of osteotomy has been properly maintained.
- Through the lateral incision, the periosteal elevator is passed posterior subperiosteally to exit just on the posterolateral corner of the ankle malunion.
- A vertical third incision is made posterolaterally, where the elevator tents the skin (TECH FIG 1F).
- The curved tonsil is then passed subperiosteally from the third incision to the second incision to clasp the Ethibond suture, and the suture with the
The Gigli saw is passed through the third incision (TECH FIG 1G).
- Again the elevator is extended from the third incision subperiosteally posterior to the ankle malunion deep to the flexor tendons to exit medially at the level just anterior to the posterior tibialis tendon (TECH FIG 1H).
- A transverse fourth incision is made where the elevator tents the medial skin.
- From the fourth incision to the third incision, the curved tonsil is used to grasp the suture attached to the Gigli saw and pull them through the fourth incision.
- The Gigli saw is now circumferentially around the ankle malunion (TECH FIG 1I).
- Care must be taken during the passage of the Gigli saw to maintain the correct level of the planned osteotomy.
- The two Gigli saw handles are now attached, and, using a reciprocating motion, the ankle is cut from lateral to medial.
- To avoid injury to the medial skin, cutting is stopped just before the medial bone is exited, a periosteal elevator is placed between the fourth and first incisions crossing the Gigli saw, and then the cut is continued (TECH FIG 1J).
- When the cut is complete, the elevator will block further progression of the saw, thereby preventing medial soft tissue damage (TECH FIG 1K, L).
- The completion of the osteotomy is confirmed with the image intensifier.
- Then the Gigli saw is cut and removed (TECH FIG M, N).
- The tourniquet is deflated, and the incisions are closed.

**TECH FIG 1** Percutaneous Gigli saw osteotomy of a malunited ankle arthrodesis. A. A Gigli saw can be passed percutaneously at the level of a previous ankle fusion. Four small incisions are used to pass the saw: two longitudinal medial and two transverse lateral incisions. B. Because of the square-shaped fusion mass, four incisions are used to safely pass the Gigli saw. The Gigli saw is passed subperiosteally starting anteromedial (1) and ending posteromedial (4). C. The medial longitudinal incision (1) is made just medial to the tibialis anterior tendon. Through the anterior medial incision, a periosteal elevator is passed subperiosteally across the anterior aspect of the fusion mass at the desired level. D. The second incision, which is transverse lateral (2), is made where the periosteal elevator tents the lateral skin. A suture is passed through the same subperiosteal tunnel from medial to lateral (the reverse can also be done). E. The suture with the attached Gigli saw is passed from medial to lateral anterior to the ankle fusion mass. F. Through the second incision, the lateral periosteum is elevated, and a third incision is made posterolateral (3). G. The suture and attached Gigli saw are passed through the third incision. H. The posterior periosteum is elevated. Care must be taken to avoid extra periosteal dissection. I. A fourth incision is made at the posterior medial corner of the ankle fusion mass. The suture and Gigli saw are passed around the malunited ankle fusion. Care must be taken to protect the peroneal tendons as the Gigli saw is being passed from the third to fourth incision. (continued)
The medial periosteum is then elevated from the fourth incision to the first incision. The Gigli saw osteotomy is performed halfway through the fusion mass. The periosteal elevator is then inserted in the previously created tunnel, crossing the Gigli saw so as to protect the medial soft tissues. The osteotomy is completed. The Gigli saw is cut and removed. (Copyright 2008, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore.)

**EXTERNAL FIXATION APPLICATION**
- The tourniquet is inflated only while passing the Gigli saw but is released before the fixator application.
- External fixation allows for gradual correction of deformity and lengthening, which can be accomplished by using the Ilizarov external fixator or the Taylor spatial frame (TECH FIG 2).
- The frame is built according to the deformity, with the proximal fixation block fixing the tibia and the distal fixation block fixing the talus, calcaneus, and foot.
- The goal is to achieve stable fixation proximal and distal to the osteotomy.
- Smooth wire (1.8 mm) or half-pin (6 mm) fixation is used per the surgeon’s preference.
- The proximal ring is mounted perpendicular to the tibia in both the AP and lateral fluoroscopic views.
- The distal ring is mounted parallel to the plantar aspect of the foot. By using this mounting technique, at the end of correction, the foot and tibial rings will be parallel, confirming a plantigrade foot position.
- The proximal ring (full ring) is mounted on a lateral-to-medial smooth wire crossing the distal tibia perpendicular to the AP long axis of the tibia and tensioned.
Part 8 FOOT AND ANKLE • Section IV ANKLE

OUTCOMES

- The subperiosteal Gigli saw osteotomy through a prior malaligned fusion site limits soft tissue compromise while optimizing soft tissue and bone healing.
- External fixation provides gradual accurate multiplanar (rotation, angulation, and translation) realignment, while simultaneously correcting limb length.
- In addition, obtaining proper alignment of an ankle fusion is paramount (FIG 1).
- Using this technique we have successfully realigned more than a dozen of these ankle malunions.

COMPLICATIONS

- Complications can occur (pin site infection, residual leg-length discrepancy, wound problems, premature or delayed consolidation, tarsal tunnel syndrome, and pin failure).
- Occasionally talar half-pins are used. Distraction of the subtalar joint is performed by rotating both talar wire fixation bolts using the Russian technique.
- The Russian tensioning technique provides compression of the osteotomy site by pushing proximally on the talus.
- Six struts are added between the distal tibial and foot rings to complete the Taylor spatial frame.
- Computer planning on an Internet-based program is then performed, which generates a daily patient turn schedule.
- Patients are followed biweekly during the gradual correction to ensure accurate final realignment.

PEARLS AND PITFALLS

Optimal clinical and radiographic positions for ankle or tibiotalocalcaneal realignment arthrodesis

- In the sagittal plane, the foot is placed at a right angle to the limb (plantigrade angle, 90°) and the tibial mid-diaphyseal line coincides with the lateral process of the talus.
- In the transverse plane, the foot is externally rotated to the limb so that the thigh–foot axis is 10° to 15° externally rotated.
- In the axial plane, the calcaneal bisection line should be parallel or slightly valgus (0° to 2°) and coincide with the mid-diaphyseal line of the tibia.
- The affected limb should be 1 cm shorter than the unaffected limb.
A well-aligned ankle arthrodesis with a plantigrade foot was achieved in all patients using the described technique. Therefore, patients with a malunited ankle fusion, with or without a limb-length discrepancy, can be successfully treated with minimally invasive Gigli saw osteotomy and gradual external fixation correction.

ACKNOWLEDGMENTS

The authors thank Joy Marlowe, MA, for her excellent illustrative artwork, and Alvien Lee for his photographic expertise.

REFERENCES

DEFINITION

- Articular defects of the tibiotalar joint, posttraumatic arthritis, and osteoarthritis can limit activity, make walking difficult, and lead to severe pain. Changes seen on radiographs include joint space narrowing, osteophytes, and subchondral bone sclerosis.
- Unlike the knee and hip, primary arthritis rarely affects the ankle. The most common causes of degenerative changes in the ankle are secondary to trauma and abnormal ankle mechanics. Posttraumatic arthritis is correlated to the severity of the fracture pattern and nonanatomic reduction of articular surfaces.
- Osteoarthritis is described by degradation of the articular cartilage, subchondral sclerosis, and subchondral cyst and osteophyte formation. It is usually secondary to previous ankle fractures, talus fractures, or ligamentous instability.
- Rheumatoid or other inflammatory arthropathies and infection can cause significant ankle pain, deformities, and arthritis.
- Options for patients who fail to respond to conservative treatment for ankle arthritis are tibiotalar arthrodesis, total ankle arthroplasty, and fresh ankle osteochondral shell allografts. Tibiotalar osteochondral shell allografts are a reasonable alternative to tibiotalar arthrodesis and total ankle arthroplasty in young patients with posttraumatic ankle arthropathy.

ANATOMY

- The ankle joint is complex, but its complexity may be simplified if the ankle is thought of as a single-axis joint in an oblique path from medial to lateral and oriented downward and backward. The main motion is dorsiflexion and plantarflexion, with some inversion and eversion of the tibiotalar joint.
- The bones that make up the ankle joint are the tibia, fibula, and talus. The tibia plafond is concave anteroposteriorly and mediolaterally.
- The talus has no muscular or tendinous attachments and 60% of its surface is covered by articular cartilage.
- In addition to the bony support of the ankle, the medial and lateral ligamentous complexes provide stability to the ankle and hindfoot.

PATHOGENESIS

- The predominant collagen in articular cartilage is type II collagen. Articular cartilage has limited blood supply, cannot proliferate, and has little reparative potential.
- Type 1 injury to articular cartilage involves microscopic disruption of chondrocytes and the extracellular matrix, while type 2 injuries involve macroscopic damage to the surface. Since the subchondral bone is not involved, there is little inflammatory response and therefore poor healing of these injuries. Type 3 injuries also involve the subchondral bone and thus heal with a fibrocartilage, consisting mainly of type I collagen.
- Ankle arthritis may cause loss of motion, pain, deformity, and instability.

NATURAL HISTORY

- Tibiotalar arthritis may result from trauma, inflammatory diseases, and osteoarthritis. Posttraumatic arthritis is the most common cause of ankle arthritis despite advances in open reduction and internal fixation of ankle and pilon fractures. Most likely, the tibiotalar chondral surfaces are injured and do not have the capacity to heal.
- Posttraumatic tibiotalar arthropathy often fails to respond to nonoperative management, and typically definitive surgical treatment has been ankle arthrodesis in a majority of patients and total ankle arthroplasty in select patients. Ankle arthrodesis has been shown to alleviate pain in the arthritic ankle. However, loss of range of motion, functional limitation, and secondary progressive arthritis in the hindfoot and midfoot have been found in long-term follow-up studies on patients with isolated ankle arthrodesis.
- Current total ankle prosthetic designs are a promising alternative to arthrodesis, but reportedly the patient’s age has an adverse effect on the risk of failure and reoperation rate.
- Osteochondral shell allografting, in which the tibial plafond and talar dome are replaced with a donor ankle matched for size, affords relief of pain, congruent articular surfaces, maintenance of bone stock, and preservation of surrounding joints. Recent improvements in surgical techniques and experience with allografts have improved short-term outcomes with this technique. Recent studies advocate the use of fresh osteochondral allografting as an alternative treatment for selected individuals with end-stage tibiotalar arthropathy.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history and physical examination of both lower extremities must be performed for any deformities or malalignment to identify multiple joint involvement, symmetric involvement, family history, and a history of trauma. The function and stability of the ligaments and tendons surrounding the ankle should be tested. This includes assessment for an equinus contracture or pes planus or pes cavus deformities. A neurovascular examination must also be performed before surgery.
- Physical examination methods include the following:
  - Anterior drawer test to evaluate the anterior talofibular ligament and ankle stability. The surgeon should look for a difference of 3 to 5 mm in the relationship between the lateral talus and the anterior aspect of the fibula.
Inversion stress test to evaluate talar instability (somewhat difficult due to subtalar motion). Compared to the contralateral ankle, a difference of more than 15 degrees is significant.

Equinus contracture assessment. A gastrocnemius recession or Achilles lengthening procedure may be required concomitantly if there is 5 degrees of equinus in the ankle.

Range of motion: Normal total range of motion of the tibiotalar joint is from 20 degrees of dorsiflexion to 50 degrees of plantarflexion. Normal subtalar joint motion is about 20 degrees from maximal inversion to eversion.

Contraindications for shell allograft ankle reconstruction are:
- Diminished peripheral pulses
- Varus or valgus malalignment of the tibiotalar joint of more than 10 degrees
- Instability of the ankle joint

IMAGING AND OTHER DIAGNOSTIC STUDIES

Weight-bearing radiographs of the ankle, including AP, lateral, and mortise views, are obtained (FIG 1).

When indicated, AP stress radiographs may be obtained to confirm instability. Anterior translation between the talus and tibia of 3 to 5 mm greater than the contralateral ankle indicates instability.³

Talar tilt on stress radiographs with the ankle internally rotated 30 degrees: A difference greater than 15 degrees compared to the contralateral ankle indicates instability.³

DIFFERENTIAL DIAGNOSIS

- Ankle instability or deformities
- Anterior or posterior impingement syndrome
- Osteochondritis dissecans lesions of talus or tibia
- Subtalar joint osteoarthritis
- Sinus tarsi syndrome

NONOPERATIVE MANAGEMENT

Conservative treatment includes mechanical aids (such as ankle–foot orthoses [AFOs] and shoe modifications), anti-inflammatories, and intra-articular steroid injections.

SURGICAL MANAGEMENT

For young healthy individuals who need alleviation of pain and retention of motion and function, osteochondral shell allografts represent an alternative to ankle arthrodesis and total ankle replacement.

Preoperative Planning

Standard radiographs on the ankle are needed for preoperative planning. In our opinion, an external fixator or distraction device is useful during the operation. We routinely use the DePuy Agility ankle arthroplasty cutting block to increase the precision of cuts.

Size-matched osteochondral allografts, based on radiographs, are procured from one of several regional tissue banks.

Positioning

The patient is supine on a radiolucent operating table.

Approach

A standard anterior approach to the ankle is used between the tibialis anterior and extensor hallucis longus tendons, while protecting the superficial peroneal nerve. The deep neurovascular bundle (deep peroneal nerve and anterior tibial and dorsalis pedis artery) is retracted laterally and dissection is carried through the joint capsule to expose the ankle.
DÉBRIDEMENT AND DISTRACTION OF THE ANKLE JOINT

- Through the anterior approach, excise synovitis and remove osteophytes using rongeurs and osteotomes. Next, apply an external fixator to distract the joint symmetrically about 1 cm (TECH FIG 1).

TECH FIG 1 • Débridement and distraction of the ankle joint. (Courtesy of Dr. Michael Brage.)

TIBIAL AND TALAR CUTS

- Although we always procure a complete ankle joint, careful inspection of the arthritic ankle may indicate that complete joint replacement may not be warranted. Occasionally, we perform only hemi-joint resurfacing, but with the disadvantage of loss of optimal articular congruency afforded by a complete or bipolar joint replacement. We determine the ideal Agility (DePuy, Warsaw, IN) cutting block by templating the ankle radiographs. Pin the corresponding Agility ankle arthroplasty cutting block into place over the anterior ankle (TECH FIG 2A). Confirm placement and size with intraoperative fluoroscopy (TECH FIG 2B).

- Using a blunt reciprocating saw, resect the tibial plafond and talar dome to a depth of about 7 to 10 mm.
- Remove an articular portion of the medial malleolus (about 3 to 4 mm) as well.
- Take extreme care as the posterior tibial neurovascular bundle is close to the posteromedial corner of the ankle joint.
- On the lateral aspect of the tibial cut, take care to avoid contract with the fibula to keep it fully preserved.

TECH FIG 2 • Tibial and talar cuts. A. Ankle arthroplasty jig is placed over tibia and pinned into place. B. Cutting jig size and placement are confirmed with fluoroscopy before cuts are made. (Courtesy of Dr. Michael Brage.)
ALLOGRAFT PREPARATION AND CUTS

- The Agility ankle cutting block for the tibial cut of the donor graft is one size larger than the block used on the recipient tibia. Pin the cutting block onto the graft using fluoroscopy and make the cut with an oscillating saw (TECH FIG 3A,B).

- Cut the talus graft free hand using an oscillating saw. The cut is made at the interface between the anterior neck and cartilage. We routinely lavage both the tibial and talar grafts to remove immunogenic marrow elements (TECH FIG 3C,D).

TECH FIG 3 • Allograft preparation and cuts. A. Cutting jig is pinned onto tibia. B. Size and position are confirmed with fluoroscopy. C. Talus allograft is cut free hand. D. Articulating tibial and talar allografts. (Courtesy of Dr. Michael Brage.)

PLACEMENT AND FIXATION OF THE GRAFTS

- With the ankle in plantarflexion, seat the grafts into the recipient mortise. We remove the external fixator and take the ankle through a range of motion to confirm graft and ankle stability.

- Imaging in the AP, mortise, and lateral planes confirms that the grafts have satisfactory apposition to the host bone and that the anatomy of the tibiotalar joint has been restored.

- Place two parallel 3.0-mm cannulated screws into each graft for fixation. Place them from the anterior portion of the tibial graft while aiming superiorly and posteriorly.

- Place two fixation screws on the anterior portion of the talar graft through the most anterior portion of the articular cartilage. Countersink these screws into subchondral bone (TECH FIG 4).

TECH FIG 4 • Placement and fixation of graft. A. Grafts are placed and fixed with two countersunk cannulated screws. (continued)
PEARLS AND PITFALLS

**Indications**
- Perform a complete history and physical examination.
- Address associated pathology, such as an equinus contracture, pes planus, or pes cavus deformity.

**Intraoperative fracture**
- Take care when making cuts to avoid fracture of the lateral or medial malleolus.

**Graft preparation**
- Take care when preparing the allografts.
- Use cutting guides to improve precision of cuts. Improper graft cuts may result in graft failure.

**Neurovascular bundle**
- Avoid injury to the posterior tibial neurovascular bundle at the posteromedial corner of the ankle joint.

POSTOPERATIVE CARE
- Perioperative antibiotics and pain control are at the surgeon’s discretion. The patient is placed in a bulky cotton splint with the ankle in neutral to slight dorsiflexion postoperatively.
- We routinely keep the operated extremity at touch-down weight bearing for 3 months.
- The patient begins range-of-motion exercises once the incision has healed (on roughly postoperative day 10).
- With satisfactory radiographs that suggest a progression toward graft incorporation, the patient may progress to weight bearing as tolerated after 3 months.

OUTCOMES
- Promising case series have reported on total ankle osteochondral shell allograft replacement of the tibiotalar joint as a
viable alternative for posttraumatic ankle arthritis in young patients (FIGS 2 AND 3).\(^8,11,17\)

- The largest case series to date reports 6 out of 11 successful grafting procedures at a minimum follow-up of 24 months. Of the other five patients, three had revision allografting and one was revised to total ankle arthroplasty. The last patient did not have any further surgery.\(^11\)

- Myerson reported that 14 of 29 fresh osteochondral shell allograft transplants had been revised to a repeat ankle transplant/arthrodesis. Six of the remaining 15 allografts were radiographic failures with progressive loss of joint space but did not require revision surgery. The remaining nine allografts (31%) were deemed a success. The authors concluded that patients with a lower body mass index, less angular deformity, and who refused arthrodesis did better. These authors did not use an external fixator during the procedure and did not use a cutting block one size bigger for the allograft as suggested in this article. Therefore their grafts may have been small/thin. Grafts should be at least 7 mm thick to prevent collapse.\(^7\)

- Gross et al reported on nine patients treated with large fresh allografts of the talus to treat OCD lesions. Of the nine patients, six had successful procedures and remained in situ with a mean survival of 11 years. Three patients had fragmentation and collapse of the grafts and were converted to arthrodeses.\(^4\)

### COMPLICATIONS

- Intraoperative fracture
- Graft collapse
- Poor graft fixation
- Nonunion
- Need for additional débridement postoperatively

### REFERENCES

DEFINITION
- End-stage ankle arthritis failing to respond to nonoperative treatment

ANATOMY
- Ankle
  - Tibial plafond with medial malleolus
    - Articulations with dorsal and medial talus
  - In sagittal plane, slight posterior slope
  - In coronal plane, articular surface is 88 to 92 degrees relative to lateral tibial shaft axis.
- Talus
  - 60% of surface area covered by articular cartilage
  - Dual radius of curvature
- Distal tibiofibular syndesmosis
- Anteroinferior tibiofibular ligament
- Interosseous membrane
- Posterior tibiofibular ligament
- Ankle functions as part of the ankle–hindfoot complex much like a mitered hinge.

PATHOGENESIS
- Posttraumatic arthrosis
  - Most common etiology
  - Intra-articular fracture
  - Ankle fracture-dislocation with malunion
  - Chronic ankle instability
- Primary osteoarthritis
  - Relatively rare compared to hip and knee arthrosis
  - Inflammatory arthropathy
  - Most commonly rheumatoid arthritis
- Other
  - Hemochromatosis
  - Pigmented villonodular synovitis
  - Charcot neuroarthropathy
  - Septic arthritis

NATURAL HISTORY
- Posttraumatic arthrosis
  - Malunion, chronic instability, intra-articular cartilage damage, or malalignment may lead to progressive articular cartilage wear.
  - Chronic lateral ankle instability may eventually be associated with:
    - Relative anterior subluxation of the talus
    - Varus tilt of the talus within the ankle mortise
    - Hindfoot varus position
  - Primary osteoarthrosis of the ankle is rare and poorly understood.
  - Inflammatory arthropathy
    - Progressive and proliferative synovial erosive changes failing to respond to medical management
    - May be associated with chronic posterior tibial tendinopathy and progressive valgus hindfoot deformity, eventual valgus tilt to the talus within the ankle mortise, potential lateral malleolar stress fracture, and compensatory forefoot varus

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patient history
  - Often a history of ankle trauma
    - Ankle fracture, particularly intra-articular
    - Ankle fracture with malunion
    - Chronic ankle instability (recurrent ankle sprains)
  - Chronic anterior ankle pain, primarily with activity and weight bearing
  - Ankle stiffness, particularly with dorsiflexion
  - Ankle swelling
  - Progressively worsening activity level
- Physical findings
  - Limp
  - Patient externally rotates hip to externally rotate ankle to avoid painful push-off.
  - Painful and limited ankle range of motion (ROM), particularly limited dorsiflexion
  - Mild ankle edema
  - Potential associated foot deformity
    - Posttraumatic arthrosis secondary to chronic instability may be associated with varus ankle and hindfoot and compensatory forefoot varus.
  - Inflammatory arthritis may be associated with progressively worsening flatfoot deformity, valgus tilt to the ankle and hindfoot, and equinus.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Weight-bearing AP, lateral, and mortise views of the ankle
- Weight-bearing AP, lateral, and oblique views of the foot, particularly with associated foot deformity
  - With associated or suspected lower leg deformity, we routinely obtain weight-bearing AP and lateral tibia–fibula views.
  - With deformity in the lower extremity, we routinely obtain weight-bearing mechanical axis (hip-to-ankle) views of both extremities.
  - We typically evaluate complex or ill-defined ankle–hindfoot patterns of arthritis with or without deformity using CT of the ankle and hindfoot.
If we suspect avascular necrosis of the talus or distal tibia, we obtain an MRI of the ankle.

**DIFFERENTIAL DIAGNOSIS**
- See the section on pathogenesis.

**NONOPERATIVE MANAGEMENT**
- Activity modification
- Bracing
  - Ankle-foot orthosis (AFO)
  - Double-upright brace attached to shoe
  - Stiffer-soled shoe with a rocker-bottom modification
- Nonsteroidal anti-inflammatories or COX-2 inhibitors
- Medications for systemic inflammatory arthropathy
- Corticosteroid injection
- Viscosupplementation

**SURGICAL MANAGEMENT**

*Preoperative Planning*
- The surgeon must be sure the patient has satisfactory perfusion to support healing and is not neuropathic.
  - Noninvasive vascular studies and potential vascular surgery consultation should be obtained if necessary.
- The surgeon should inspect the ankle for prior scars or surgical approaches that need to be considered in planning the surgical approach for total ankle arthroplasty.
- The surgeon must understand the clinical and radiographic alignment of lower extremity, ankle, and foot.
  - The surgeon must be prepared to balance and realign the ankle. Occasionally, this necessitates corrective osteotomies of the distal tibia or foot, hindfoot arthrodesis, ligament releases or stabilization, or tendon transfers.
- The surgeon should determine whether coronal-plane alignment is passively correctable; this provides some understanding of whether ligament releases will be required.
- Ankle ROM should be determined.

- Ankle stiffness, particularly lack of dorsiflexion, needs to be corrected:
  - Anterior tibiotal exostectomy
  - Posterior capsular release
  - Occasionally, tendo Achilles lengthening

*Instrumentation*
- These instruments facilitate total ankle arthroplasty:
  - Small oscillating saw to fine-tune cuts, resect prominences with precision, and easily morselize large bone fragments to be evacuated from the joint
  - A rasp for final preparation of cut bony surfaces
  - An angled curette, particularly to separate bone from the posterior capsule
  - A toothless lamina spreader to judiciously distract the ankle to improve exposure even after preparing the surfaces of the tibia and talus

*Positioning*
- The patient is positioned supine with the plantar aspect of the operated foot at the end of the operating table.
- The foot and ankle are well balanced, with toes directed to the ceiling.
- A bolster placed under the ipsilateral hip prevents undesired external rotation of the hip.
  - We routinely use a thigh tourniquet and regional anesthesia.
  - A popliteal block provides adequate pain relief postoperatively, particularly if a regional catheter is used. Moreover, hip and knee flexion-extension is not forfeited, facilitating safe immediate postoperative mobilization.
  - However, using a thigh tourniquet with a popliteal block typically requires a supplemental femoral nerve block (patient forfeits knee extension) or general anesthesia.

*Approach*
- An anterior approach to the ankle is made, using the interval between the tibialis anterior (TA) tendon and the extensor hallucis longus (EHL) tendon.
APPROACH

- Make a longitudinal midline incision over the anterior ankle, starting about 10 cm proximal to the tibiotalar joint and 1 cm lateral to the tibial crest (TECH FIG 1).
- Continue the incision midline over the anterior ankle just distal to the talonavicular joint.
- At no point should direct tension be placed on the skin margins; we perform deep, full-thickness retraction as soon as possible to limit the risk of skin complications.
- Identify and protect the superficial peroneal nerve by retracting it laterally.
  - In our experience there is a consistent branch of the superficial peroneal nerve that crosses directly over or immediately proximal to the tibiotalar joint.
- We then expose the extensor retinaculum, identify the course of the EHL tendon, and sharply but carefully divide the retinaculum directly over the EHL tendon.
  - We always attempt to maintain the TA tendon in its dedicated sheath.
  - Preserving the retinaculum over the TA tendon:
    - This prevents bowstringing of the tendon and thereby reduces the stress on the anterior wound.
- Should there be a wound dehiscence, then the TA is not directly exposed.
- Preserving the retinaculum over the TA tendon is not always possible; some patients do not have a dedicated sheath for the TA.
- The interval between the TA and EHL tendon is used, with the TA and EHL tendons retracted medially and laterally, respectively.
- Identify and carefully retract the deep neurovascular bundle (anterior tibial–dorsalis pedis artery and deep peroneal nerve) laterally throughout the remainder of the procedure.
- Perform an anterior capsulotomy along with elevation of the tibial and dorsal talar periosteum to about 6 to 8 cm proximal to the tibial plafond and talonavicular joint, respectively.
- Elevate this separated capsule and periosteum medially and laterally to expose the ankle, to access the medial and lateral gutters, and to visualize the medial and lateral malleoli.
- Remove anterior tibial and talar osteophytes to facilitate exposure and avoid interference with the instrumentation.

TECH FIG 1 • Anterior approach to the ankle. A. Approach. B. Close-up of superficial peroneal nerve. C. Division of extensor retinaculum directly over extensor hallucis longus tendon. D. Deep neurovascular bundle is identified and protected. E. After anterior capsulotomy, with ankle exposed.
TIBIAL PREPARATION

- An osteotome placed in the medial gutter serves as a reference for optimal rotation for the tibial preparation (TECH FIG 2).
- Place a pin in the proximal tibia via a 1-cm incision over the tibial tubercle.
  - When viewed in the AP plane, this pin is oriented parallel to the reference osteotome in the medial gutter.
  - When viewed in the lateral plane, the pin should be perpendicular to the tibial shaft axis if the physiologic 3 to 5 degrees of posterior slope to the tibial component is desired. We prefer to implant the tibial component perpendicular to the longitudinal tibial shaft axis (no posterior slope), aiming the pin slightly proximally. The external tibial alignment guide directs the initial tibial cut into 3 degrees of posterior slope; we aim to eliminate this slope.

- Suspend the external tibial alignment guide from the proximal pin. To further promote a perpendicular tibial preparation relative to the tibial shaft axis, we raise the proximal aspect of the external tibial alignment guide two to three fingerbreadths above the tibial spine before securing it to the proximal pin.
- Set the rotation of the cutting block for tibial preparation based on the reference osteotome set in the medial gutter. A dedicated T-guide temporarily attached to the distal aspect of the guide facilitates setting proper rotation. Lock the rotation of the distal block with the knob connecting the telescoping rods of the guide.
- While controlling rotation, set the proper length of the guide via the telescoping rods.
- Fine-tuning of the distal block’s lateral-plane position is possible. We routinely separate the distal block of the

TECH FIG 2 • Positioning the external tibial alignment guide. A, B. Positioning the proximal pin relative to a reference osteotome placed in the medial gutter. C, D. Setting rotation of the distal cutting block of the guide relative to the medial gutter reference osteotome. E, F. Fluoroscopic confirmation of proper guide position in the AP and lateral planes.
guide from the portion of the guide used to pin it to the tibia by at least 10 mm.

- If the initial position of the distal block is set at the apex of the plafond, the desired 5 mm of resection may be easily set and even greater resection is possible in a tighter ankle.
- We make sure that the block is positioned at the tibial plafond’s apex, that it is properly rotated, and that we are able to fine-tune the block’s proximal-distal position before pinning the guide to the tibia.
  - Multiple options exist to pin the guide to the tibia. We recommend using pins at different levels rather than pins in a single plane (risks creating a stress riser).
- Attach the cutting capture guide to the distal block, and insert an angel-wing resection guide in the capture guide. Use fluoroscopy in the lateral plane to determine the proper resection level for the tibial cut (TECH FIG 3).
- Adjust the cutting guide in the coronal plane to ensure that the malleoli are protected with tibial resection.
  - There is only a single capture guide size.
  - We routinely set the guide based on a pin placed loosely in the medial aspect of the capture guide.
- We aim to position the guide so that the medial extent of tibial preparation is directly proximal from the transition of tibial plafond to medial malleolus.
- Drive the pin used as a reference into the tibia through the medial aspect of the capture guide to protect the medial malleolus.
- Similarly, place a lateral pin in the lateral aspect of the capture guide and advance it into the lateral gutter.
- The capture guide has several options to place the lateral pin to accommodate any coronal plane dimension of the tibial plafond.
- With the soft tissues protected, particularly the deep neurovascular bundle, make the distal tibial cut with an oscillating saw through the horizontal portion of the capture guide. To complete the cut, use a reciprocating saw along the medial border of the capture guide, extending proximally from the medial gutter (TECH FIG 4).
- Remove the capture guide and evacuate the resected bone.
- A toothless lamina spreader may be placed judiciously on the prepared tibial surface and dorsal talus to facilitate evacuation of bone from the posterior ankle.

TECH FIG 3 • Determining tibial plafond resection level. A. Angel wing about to be inserted into capture guide attached to distal tibial cutting block. B. Angel wing in capture guide with height adjustment being made under fluoroscopy. C. Fluoroscopic image of angel wing confirming tibial resection level.

TECH FIG 4 • Initial tibial resection. A. After determining proper coronal placement of the tibial cutting block, the capture guide is pinned, with the pins used to protect the malleoli. B. Saw in the capture guide. C. Medial resection with a reciprocating saw to complete the initial tibial preparation. (continued)
Initial Talar Preparation

- Residual articular cartilage must be removed from the dorsal talar dome so that the talar cutting guide may be properly balanced on the dorsal talus. We routinely use a thin oscillating saw to remove residual cartilage.
- Position the talar guide within the ankle joint and secure it to the distal block of the external alignment guide.
- We then hold the ankle in neutral dorsiflexion-plantarflexion.
- Excessive dorsiflexion risks talar preparation, leading to anterior translation and tilt of the talar implant. Moreover, an exaggerated notch will be created in the dorsal talar neck.
- Excessive plantarflexion risks talar preparation, leading to posterior translation and tilt of the talar implant. In addition, too much posterior talus will be removed.

We routinely use a small reciprocating saw to morselize the posterior fragments and a combination of curved curette and rongeur to retrieve the fragments that need to be separated from the posterior capsule.
- The curette is used directly vertically in the ankle and never levered against a malleolus.

We routinely perform a posterior capsular resection to optimize dorsiflexion.
- To ensure that the tibial resection is adequate, use the system’s plastic spacer as a sizing guide. The 9-mm end of this sizing guide equals the combined height of the tibial component (3 mm) and the thinnest polyethylene component (6 mm).

Excessive plantarflexion may be a result of fixed equinus. If the talus cannot be brought to a neutral position (confirm with an intraoperative radiograph), then consider a tendo Achilles lengthening rather than risk resecting too much of the posterior talus.
- With perfect contact of both the medial and lateral talar dome on the intra-articularly placed paddle of the talar cutting guide and a neutral sagittal plane alignment maintained, pin the talar guide.
- Place the angel-wing resection guide in the talar cutting guide and use lateral-plane fluoroscopy to confirm proper resection level and desired orientation for the guide.
- Place two more pins in the talar guide to protect the malleoli and further stabilize the guide.
- Make the initial talar cut using an oscillating saw, remove the guide, and evacuate the resected bone from the joint (TECH FIG 5).

TECH FIG 4 (continued) D. Tibial resection after removal of the capture guide (note that the cutting block was translated slightly medial for optimal positioning). E. Removal of the resected tibial bone (note the judicious use of a toothless lamina spreader to facilitate access to the posterior ankle). F. Confirming adequate tibial resection with plastic spacer (9 mm).

TECH FIG 4 • (continued) D. Tibial resection after removal of the capture guide (note that the cutting block was translated slightly medial for optimal positioning). E. Removal of the resected tibial bone (note the judicious use of a toothless lamina spreader to facilitate access to the posterior ankle). F. Confirming adequate tibial resection with plastic spacer (9 mm).

TECH FIG 5 • Talar resection. A. Talar resection guide to be suspended from the external tibial alignment guide. B. The surgeon should ensure proper talar alignment (patient had an equinus contracture, and gastrocnemius—soleus resection was required to obtain optimal talar position). (continued)
To ensure that a balanced resection was performed on the tibia and talus and that the resection levels are appropriate, use the plastic spacer–sizing guide–impactor and confirm proper alignment and resection levels on intraoperative fluoroscopy (TECH FIG 6).

**Sizing the Talus and Positioning the 4-in-1 Talar Reference Guide (“Datum”)**

- Position a sizing guide on the dorsal prepared talar surface and properly rotate it with the second metatarsal. The proper sizing guide leaves 3 mm of medial and 3 mm of lateral bone (TECH FIG 7). Set the AP position of the sizing guide based on the resected surface; excessive bone should not be removed from the posterior talus. Mark the talar sizing guide on the prepared talar surface.

- Using the markings on the talus, position the 4-in-1 talar reference guide (“datum”) on the prepared talar surface, with proper rotation, proper mediolateral-plane alignment.
Anteroposterior Talar Chamfer Cutting Guide

- Secure the anteroposterior talar chamfer cutting guide to the 4-in-1 talar reference guide and place an additional pin in the guide to stabilize it to the talus (TECH FIG 9).

- Full dorsiflexion of the talus is not possible due to impingement of the pins securing the guide to the talus.
- If this position cannot be confirmed, then the 4-in-1 talar guide must be repositioned and repinned.
- This may be difficult, since typically only a subtle move of the guide is necessary, and securing a pin immediately adjacent to a previous pin position is possible but challenging.

Completing the Talar Preparation and Implanting the Talar Component

- Cut the posterior talar chamfer using an oscillating saw in the posterior capture guide.
- Mill the anterior chamfer with the soft tissues and deep neurovascular bundle protected.
- Remove this guide, leaving the 4-in-1 guide in place.

- Position (3 mm of talus on either side of the guide), and a best estimate of proper anteroposterior position. Secure the 4-in-1 guide to the talus with dedicated pins (TECH FIG 8).
- Confirm proper position of the 4-in-1 guide with lateral fluoroscopy. Ideally, the center point of the undersurface of the guide rests directly over the lateral talar process. Another rough estimate of proper position is that the guide is centered under the tibia.
Mediolateral Chamfer Cutting Guide

- Secure the mediolateral chamfer cutting guide to the 4-in-1 talar reference guide (TECH FIG 10).
  - Two additional smooth pins may be placed through this guide to further stabilize the guide to the talus.
- With the soft tissues and neurovascular structures protected, make the medial and lateral chamfer cuts with a reciprocal saw.
  - To accommodate the talar implant:
    - Medial cut is made to a depth of 10 mm.
    - Lateral cut is made to a depth of 15 mm.
- Remove the mediolateral chamfer and 4-in-1 reference guides.
- Evacuate the resected bone with:
  - A thin osteotome
  - A curved curette
  - A rongeur
- Inspect the prepared talus for any uneven surfaces or residual bony prominences, which may be removed judiciously with a small reciprocal saw and a rasp.

The “Window” Talar Trial

- Position the “window” talar trial on the prepared talus (TECH FIG 11).
- Often any incongruencies or prominences still need to be addressed to ensure that the guide rests completely flush on all prepared surfaces of the talus.
- Since the guide is a “window,” proper fit can be confirmed for the true implant that is resurfacing without any means of determining the actual bony contact between bone and implant.
- Pin the talar trial.
Use a router to create the slot in the talus to accommodate the talar implant’s fin (TECH FIG 12).

Use a stem punch to finish preparing the talar fin slot.

**Implanting the Talar Component**

- Orient the properly sized talar component with the longer side placed laterally (to articulate with the fibula) (TECH FIG 13).
- Gently tap the prosthesis posteriorly with the set’s plastic impactor–spacer–sizer to rest in the optimal position over the fin slot.
- Use the talar dome impaction device to impact the talar component.
  - The anterior tibial cortex must be protected.
- We make sure that despite proper initial positioning the talar component does not tilt anteriorly, which it will tend to do given the limited access to the natural talus.
- Fully seat the talar component.

**Final Preparation of the Tibial Plafond and Tibial Component Implantation**

- Measure the AP dimensions of the tibia.
- Select the corresponding tibial component.
- If the mediolateral dimensions of the tibial plafond do not accommodate this component, then judiciously remove 1 or 2 more millimeters of medial bone to safely position the tibial trial.
- Also, all syndesmotic soft tissue impinging in the joint must be removed.
- The tibial trial should align with the center of the tibial shaft axis (TECH FIG 14).
  - It should not be tilted in varus or valgus.
  - It should not be lateral to the longitudinal center of the tibial shaft.
After positioning the proper size of tibial component and confirming its position on intraoperative fluoroscopy, pin the tibial trial.

Temporarily insert a trial polyethylene insert to maintain pressure on the tibial trial and therefore optimal bony apposition of the tibial trial base plate and prepared tibial surface.

On intraoperative fluoroscopy, there should not be any posterior tibial tray lift-off from the prepared tibial surface and the tibial trial should be well aligned with the tibial shaft axis on the AP view.

Prepare the barrel holes with the corresponding drill and chisel and remove the tibial trial and trial polyethylene. Leave the pin placed to secure the tibial trial as a reference.

Irrigate the joint.

Using the dedicated tibial impaction device, impact the tibial component almost fully (TECH FIG 15).

Use the plastic spacer–sizer–impactor to advance the tibial component to its final position.

Again, use a trial polyethylene to afford further stability to the tibial trial as the final impaction is performed (TECH FIG 16).
Final Polyethylene Implantation

- With the true tibial and talar components implanted, determine the optimal polyethylene size based on the trial polyethylenes (TECH FIG 17).

- With the ankle in neutral position, there should be virtually no lift-off at the two polyethylene–prosthesis interfaces when a varus or valgus stress is applied.
- ROM must allow dorsiflexion to at least 5 to 8 degrees, preferably more.
- Occasionally, tendo Achilles lengthening is required. In these select situations we routinely perform a gastrocnemius–soleus recession.
- Contain the polyethylene meniscus under the tibial component during ROM (TECH FIG 18).
Thoroughly irrigate the joint and implant with sterile saline.

While protecting the prosthesis, fill the anterior barrel holes with bone graft from the resected bone (TECH FIG 19).

Remove the pin from the proximal tibia.

Reapproximate the capsule.

We routinely use a drain.

The tourniquet is released and meticulous hemostasis is obtained.

Reapproximate the extensor retinaculum while protecting the deep and superficial peroneal nerves.

Irrigate the subcutaneous layer with sterile saline and then reapproximate it.

Reapproximate the skin to a tensionless closure.

Place sterile dressings on the wounds, and apply adequate padding and a short-leg cast with the ankle in neutral position.

CLOSURE AND CASTING

TECH FIG 17 • (continued) B. Polyethylene in place. C. Dorsiflexion. D. Plantarflexion.

TECH FIG 18 • Final fluoroscopic views. A. AP. B. Lateral. The talus is proud posterior due to a relatively conservative initial talar cut. In our experience the component will settle (not subside) into a stable position.
POSTOPERATIVE CARE

- Overnight stay
- Nasal oxygen while in the hospital
- Touch-down weight bearing on the cast is permitted, but elevation is encouraged as much as possible.
- The patient returns in 2 to 3 weeks for cast change and suture removal.
- The patient then returns at 6 weeks postoperatively for removal of cast and weight-bearing radiographs of the ankle.

- If there is no evidence of a stress fracture or failure of the procedure, then the patient can progress to a regular shoe and full weight bearing (FIG 2).

OUTCOMES

- While some recently reported outcomes are based on high-level evidence, results of total ankle arthroplasty (TAA) are almost uniformly derived from level IV evidence. Two recent investigations of the Scandinavian total ankle replacement are
level I\(^4\) and level II\(^2\), but with short- to intermediate-term follow-up only.

- Functional outcome using commonly used scoring systems for TAA (AOFAS,\(^1\) Mazur, and NJOH [Buechel-Pappas]) suggest uniform improvement in all studies, with follow-up scores ranging from 70 to 90 points (maximum 100 points).
- Patient satisfaction rates for TAA exceed 90%, although follow-up for the patient satisfaction rating often does not exceed 5 years.
- Overall survivorship analysis for currently available implants, designating removal of a metal component or conversion to arthrodesis as the endpoint, ranges from about 90% to 95% at 5 to 6 years and 80% to 92% at 10 to 12 years.

**COMPLICATIONS**

- Infection (superficial or deep)
- Neuralgia (superficial or deep peroneal nerve; rarely tibial nerve)
- Delayed wound healing
- Wound dehiscence
- Persistent pain despite optimal orthopaedic examination and radiographic appearance of implants
- Osteolysis
- Subsidence
- Malleolar or distal tibial stress fracture
- Implant fracture (including polyethylene)

**REFERENCES**

The HINTEGRA Total Ankle Arthroplasty

Beat Hintermann and Alexej Barg

DEFINITION

- The HINTEGRA Total Ankle Prosthesis (Integra, Plainsboro, NJ) is an unconstrained, three-component system that provides inversion–eversion stability (FIG 1). Axial rotation and normal flexion–extension mobility are provided by a mobile bearing element.3,6

- The HINTEGRA ankle includes a metal tibial component, an ultrahigh-density polyethylene mobile bearing, and a metal talar component, all of which are available in six sizes. The metal components are manufactured of cobalt–chromium alloy with a porous coating of a 20% porosity. The porous coating is covered by titanium fluid and hydroxyapatite. The remaining metallic surfaces are highly polished.

- The tibial component employs a flat, 4-mm-thick loading plate with pyramidal peaks on the flat surface against the tibia and an anterior shield that allows for fixation by two screws through two oval holes. The anatomically sized flat surface allows for optimal contact with the subchondral bone, as well as optimal support of the cortical bone ring, providing a maximal load-transfer area. It also makes it possible to minimize bony resection to 2 to 3 mm of the subcortical bone. This fixation concept prevents any stress shielding from occurring.

- The talar component is conically shaped, with a smaller radius medially than laterally. It consists of a highly polished articular surface, and a medial and lateral surface. A 2.5-mm-high rim on the medial and lateral sides ensures stable position and anteroposterior translation of the polyethylene on the talar surface. The medial and lateral talar surfaces are covered by two wings that are anatomically sized and formed to the original articular, cartilage-covered surfaces. The inner, slightly curved surface of the wings allows for press-fit of the component to the bone. The anterior shield increases the bone support on weaker bone at the talar neck to increase stability in the sagittal plane and to prevent the adherence of scar tissue that might restrict motion. The current design, introduced in 2004, includes two pegs to facilitate the insertion of the talar component and to provide additional stability.

- The high-density polyethylene mobile bearing (ultrahigh-molecular-weight polyethylene) consists of a flat surface on the tibial side and a concave surface that perfectly matches the talar surface. It has a minimum thickness of 5 mm but is also available for thicker sizes (6, 7, and 9 mm). The size of the bearing is determined by the talar size. As it fully covers the talar component, it ensures optimal stability against valgus–varus forces and minimal contact stress in both the primary and secondary articulating surfaces. The bearing is restrained by the compressive action of the collateral ligaments and adjacent tissues. Further, compressive muscle forces and gravitational loads across the joint hold the bearing against the metallic articulating surfaces. Thus, when properly positioned, dislocation of the bearing is unlikely.

- The HINTEGRA ankle provides 50 degrees of congruent contact flexion–extension and 50 degrees of congruent contact axial rotation, which provides congruent contact surfaces for normal load-bearing activities, even in the case of a distinct implantation error or pre-existing deformity. Limits of motion depend on natural soft tissue constraints: no mechanical prosthetic motion constraints are imposed for any ankle movement with this device.

- The HINTEGRA ankle uses all available bone surface for support. The anatomically shaped, flat tibial and talar components essentially resurface the tibia and talar dome, respectively, and the wings hemiprosthetically replace degenerate medial and lateral facets (a potential source of pain and impingement).

ANATOMY

- The superior extensor retinaculum is a thickening of the deep fascia above the ankle, running from tibia to fibula. It includes, from medially to laterally, the tendons of tibialis anterior, extensor hallucis longus, and extensor digitorum longus.

- The anterior neurovascular bundle lies roughly halfway between the malleoli; it can be found consistently between the extensor hallucis longus and extensor digitorum longus tendons.

- The neurovascular bundle contains the A. tibialis anterior and the deep peroneal nerve. The nerve supplies the extensor digitorum brevis and extensor hallucis brevis and a sensory space interdigital I–II.

- On the height of the talonavicular joint the medial branches of the superficial peroneal nerve cross from lateral to medial. It supplies the skin of the dorsum of the foot.
On the posterior aspect of the ankle, the medial neurovascular bundle is located behind its posteromedial corner and the flexor hallucis longus tendon on its posterior aspect. The deltoid ligament is a multibanded complex with superficial and deep components.

**PATHOGENESIS**
- Primary osteoarthritis of the ankle joint is rare; degenerative disease of the ankle is more often seen after trauma and systemic diseases (eg, rheumatoid arthritis).
- Osteoarthritis of the ankle joint is often associated with malalignment, deformities, and instabilities of the foot, particularly in posttraumatic ankles.

**NATURAL HISTORY**
- Development of osteoarthritis of the ankle joint can take years, particularly in posttraumatic ankles (eg, after fractures and sprains).
- Once it has become symptomatic, osteoarthritic changes usually progress, resulting in pain under loading and finally at rest.
- If associated with instability or muscular dysfunction, misalignment and deformity may occur.

**PATIENT HISTORY AND PHYSICAL FINDINGS**
- A careful history is taken to assess:
  - Previous trauma
  - Previous infections
  - Underlying diseases
  - Actual pain
  - Limitations in daily and sports activities
- While the patient is standing, a thorough clinical investigation of both lower extremities is done to assess:
  - Alignment
  - Deformities
  - Foot position
  - Muscular atrophy
- While the patient is sitting with free-hanging feet, the examiner assesses:
  - The extent to which a deformity is correctable
  - Preserved joint motion at the ankle and subtalar joints
  - Ligament stability of the ankle and subtalar joints with anterior drawer and tilt tests
  - Supination and eversion power (eg, function of posterior tibial and peroneus brevis muscles)

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Plain weight-bearing radiographs, including AP views of the foot and ankle and a lateral view of the foot (FIG 2), are obtained to assess:
  - Extent of destruction of the tibiotalar joint (eg, tibia, talus, and fibula)
  - Status of neighboring joints (eg, associated degenerative disease)
  - Deformities of the foot and ankle complex (eg, heel alignment, foot arch, talonavicular alignment)
  - Tibiotalar malalignment (eg, varus, valgus, recurvatum, and antecurvatum)
  - Bony condition (eg, avascular necrosis, bony defects)
- A CT scan may be ordered for assessment of:
  - Destruction of joint surfaces and incongruency
  - Bony defects
  - Avascular necrosis
- Single-photon-emission computed tomography combined with computed tomography (SPECT-CT) with a superimposed bone scan (FIG 3) may be used to visualize:
  - Morphologic pathologies and associated activity process
  - Biologic bone pathologies and associated activity process
- MR imaging may be used to show:
  - Injuries to ligament structures
  - Morphologic changes of tendons
  - Avascular necrosis of bones (eg, talar body and tibial plafond)
  - Gait analysis

**FIG 2** • Preoperative assessment includes weight-bearing standard radiographs as follows: (A) AP view of the ankle; (B) lateral view of the foot; (C) AP view of the foot.
NONOPERATIVE MANAGEMENT

- Although nonoperative management is controversial, patients with less debilitating pain and dysfunction may be treated nonoperatively.
- Nonoperative treatment may consist of:
  - Shoe modifications to facilitate gait
  - Physiotherapy to decrease inflammatory response
  - Anti-inflammatory medicine for acute pain

SURGICAL MANAGEMENT

- Successful total ankle arthroplasty with an unconstrained three-component prosthesis demands thorough preoperative planning to address all associated pathologies.
- During surgery, the surgeon must continuously check whether these associated pathologies are sufficiently addressed. For instance:
  - Whether pre-existing deformity is sufficiently corrected
  - Whether the foot is properly aligned
  - Whether soft tissues are sufficiently balanced

Indications

- Primary osteoarthritis (eg, degenerative disease)
- Systemic arthritis (eg, rheumatoid arthritis)
- Posttraumatic osteoarthritis (if instability and malalignment are manageable)
- Secondary osteoarthritis (eg, infection, avascular necrosis) (if at least two thirds of the talar surface is preserved)
- Salvage for failed total ankle replacement (if bone stock is sufficient)
- Salvage for nonunion and malunion of ankle fusion (if bone stock is sufficient)
- Low demands for physical activities (hiking, swimming, biking, golfing)

Relative Indications

- Severe osteoporosis
- Immunosuppressive therapy
- Increased demands for physical activities (eg, jogging, tennis, downhill skiing)
- Bony avulsion fracture of medial malleolus (with or without fracture of the fibula–syndesmotic disruption)

Contraindications

- Infection
- Avascular necrosis of more than one third of the talus
- Unmanageable instability
- Unmanageable malalignment
- Neuromuscular disorder
- Neuroarthropathy (Charcot)
- Diabetic syndrome
- Suspected or documented metal allergy or intolerance
- Highest demands for physical activities (eg, contact sports, jumping)

Controversial Indications

- Diabetic syndrome without polyneuropathy
- Avascular necrosis of talus

Preoperative Planning

- All imaging studies are reviewed.
- Plain films should be reviewed to identify possible coexisting arthritis of adjacent joints as well as varus and valgus of the hindfoot and the longitudinal arch.
- Associated foot deformity, malalignment, and instability should be addressed concurrently.
- Examination under anesthesia should be accomplished to compare with the contralateral ankle.

Positioning

- The patient is positioned with the feet on the edge of the table.
- The ipsilateral back is lifted until a strictly upward position of the foot is obtained.
- A block is placed under the affected foot to facilitate fluoroscopy during surgery.
- The contralateral (nonaffected) leg is also draped if significant deformity is to be corrected.
- A tourniquet is applied on the ipsilateral thigh.
Approach
- An anterior longitudinal incision 10 to 12 cm long is made to expose the retinaculum.
- The retinaculum is dissected along the lateral border of the anterior tibial tendon, and the anterior aspect of the distal tibia is exposed.
- While the soft tissue mantle is dissected with the periosteum from the bone, attention is paid to the neurovascular bundle that lies behind the long extensor hallucis tendon.
- Capsulotomy and capsulectomy are done, and a self-retaining retractor is inserted to carefully keep the soft tissue mantle away (FIG 4).
- Osteophytes on the tibia are removed, particularly on the anterolateral aspect.
- Osteophytes on the talar neck and the anterior aspect of medial malleolus are also removed.
- The fibula usually cannot be fully visualized at this stage.

FIG 4 - The ankle joint is exposed through an anterior approach.

TIBIAL RESECTION
- Position the tibial cutting block with its alignment rod using the tibial tuberosity (eg the anterior cresta iliaca of pelvis in the case of leg deformity [TECH FIG 1A] as the proximal reference and the anterior border of the ankle (eg, the center of the resection block is supposed to be at intermediate line of the tibiotalar joint) as the distal reference.

TECH FIG 1 - Tibial resection. A,B. Tibial resection block is adjusted taking the tibial tuberosity or the anterior spina of iliac crest as the reference in the frontal plane, and (C) the anterior tibia in the sagittal plane. D. 2 to 3 mm of bone is removed, as measured at the apex of the tibial plafond. E. Bone is removed and resection is finalized at the lateral side, paying attention to not damaging the integrity of the fibula and at the medial side to get a sharp perpendicular cut along the medial malleolus.

- Make the final adjustment as follows:
  - Sagittal plane: Move the rod until a parallel position to the anterior border of the tibia has been achieved (TECH FIG 1B).
  - Frontal (coronal) plane: Frontal plane position is given by the position of the rod (eg there is a fixed...
90° angle between the resection surface and the rod). Once the rod is proximally centered to tibial tuberosity (TECH FIG 1C), two pins are used for fixation.

- **Vertical adjustment:** Move the tibial resection block proximally until the desired resection height is achieved. Usually resection of about 2 to 3 mm on the apex of the tibial plafond is desired. In varus ankles more tibial resection is usually needed, whereas in valgus ankles or in presence of high joint laxity, less bone resection is advised.
- **Rotational adjustment:** Rotate the tibial resection block to get a parallel position of its medial surface to the medial surface of the talus (eg, to avoid damaging the malleoli with the saw blade during resection).

- Slide the tibial cutting guide into the cutting block, creating a slot in which the saw blade will be guided. The width of the slot limits the excursion of the saw blade, thereby protecting the malleoli from hitting and fracturing.
- Once the tibial cut is made, a reciprocating saw might be used to finalize the cuts, particularly for the vertical cut on the medial side (TECH FIG 1D).
- Remove the remaining bone with a rongeur (TECH FIG 1E), including the posterior capsule.
- Use the measuring gauge to determine the size of the implant. In doubt (eg, if the anterior border of the tibia is projected onto the gauge between two markers), select the bigger size.

---

### TALAR RESECTION

- Insert the talar resection block into the tibial cutting block.
- Move the resection block distally as much as possible to properly tension the collateral ligaments (TECH FIG 2A).
- Remove all distractors and spreaders before the foot is taken into neutral position (eg, with respect to dorsiflexion–plantarflexion and pronation–supination).
- Once the foot is in neutral position, fix the resection block with two pins (medially and laterally) (TECH FIG 2B,C).
- Resect the talar dome with the oscillating saw through the slot of the talar cutting block.
- Remove the tibial and talus resection block and again mount the distractor (Hintermann spreader) to distract the joint.
- Remove the posterior capsule completely until fat tissue and tendon structures are visible to achieve full dorsiflexion.
- Insert the 12-mm-thick spacer representing the thickness of the tibial and talar components and the thinnest 5-mm inlay into the created joint space (TECH FIG 2D). While the foot is held in neutral flexion position, this allows the surgeon to check:
  - Whether an appropriate amount of bone has been resected
  - Whether the achieved alignment is appropriate
  - Whether the medial and lateral stability are approximate
- If the spacer cannot be properly inserted into the joint space, and if there is no obvious contracture of the remaining posterior capsule present, additional bony resection might be considered. In most instances, such additional resection should be done on the tibial side. Reposition the tibial cutting block using the same fixation holes for the pins. Move the distal resection block proximally as desired, and make a new cut with the saw blade.
- If the alignment is not appropriate, and if an associated deformity of the foot itself (eg, varus, valgus heel) can be excluded, consider a corrective cut. In most instances, the resection should be done on the tibial side. Make the desired...
angular correction on the tibial resection block, and reposition the tibial cutting block using other fixation holes for the pins. Move the distal resection block proximally or distally so that an angular bony resection will result.

- If the ankle is not stable on both sides, consider using a thicker inlay. If the ankle is not stable on one side, consider a release of the contralateral ligaments or ligament reconstruction on the affected side. Ligament reconstruction is better done once the definitive implants have been inserted, and if there is still an obvious instability.
- Remove the spacer and mount the distractor (Hintermann spreader) using the same pins.
- Determine the size of the resected talar block as follows (TECH FIG 2E):
  - Use the medial side of the talus as the reference; position the resection block along the medial border of the talus so that 1 to 2 mm of bone will be removed from the medial side of the talus.
  - On the lateral side, the resection block is supposed to remove as little bone as possible on its posterior aspect; usually, more bone will need to be removed on the lateral aspect of the talus as there are osteophytes.
  - On the posterior side, the resection block is supposed to remove 2 to 3 mm of bone in addition to remaining cartilage; this is given by the distance of the posterior hooks of resection block that aim to be in strong contact with the posterior surface of talus.
  - The talar size should not exceed the previously determined tibial component by more than one size; if so, a smaller talar size must be selected.
  - After selecting the appropriate size of talar cutting block, fix it with two or three short pins.
  - Make posterior resection on the talus with an oscillating saw that is guided through the posterior slot of the talar cutting block.
  - Make medial and lateral resections on the talus with a reciprocating saw that is guided along the talar cutting block. Make the cut as follows:
    - Medial side: 6 mm deep; the reference is the upper surface of the talus
    - Lateral side: 8 mm deep; the reference is the upper surface of the talus
  - Make the anterior resection on the talus with a drill that is guided through the anterior slot of the talar cutting block.
  - Remove the talar cutting block (TECH FIG 2F)
  - On the medial and lateral sides, the cuts are finalized by using a chisel to make an almost horizontal cut along the base of the cuts previously made, thereby avoiding extended loss of bone stock and potential damage to the vascular supply of the talus.
  - Clean the medial and lateral gutters using a rongeur.
  - Remove the remaining bone and capsule of the posterior compartment (TECH FIG 2G).
INSERTING TRIAL IMPLANTS AND FINALIZING CUTS

- **Talar trial:**
  - Insert the talar trial using the given impactor. The window on the posterior aspect of the trial allows the surgeon to check its proper fit to the posterior resection surface of the talus (TECH FIG 3A).
  - If proper position of the talus has been achieved, resect the anterior surface of the talus using a rongeur or the oscillating saw.
  - Fix the drill guide onto talar trial (TECH FIG 3B).
  - Make two drill holes with the provided 4.5-mm drill, and remove the trial (TECH FIG 3C).

- **Tibial trial:**
  - Use the tibial depth gauge to determine the size of tibial implant to be selected; insert it with the appropriate side (right/left) against the tibial surface, and hook the posterior edge on the posterior border of the tibia. The size to be selected can be taken from the scale on the depth gauge (TECH FIG 3D).
  - Remove the depth gauge and, if necessary, smooth the anterior border of tibia resection with an oscillating saw or rongeur according to the shape of indicated resection.
  - Insert the tibial trial. Try to get the tibial component in close contact with the medial malleolus and the anterior surface of tibia (TECH FIG 3E).

- **Trial inlay:** Insert the 5-mm inlay trial and remove the distractor (Hintermann spreader); if not enough soft tissue tension can be achieved, insert the 6-mm, 7-mm, or 9-mm trial.

- The use of fluoroscopy is highly recommended to check the position of implants while the foot is held in neutral position, particularly:
  - Appropriate length of the tibial component: its posterior border should be on line with the posterior aspect of the tibia so that the tibial surface is fully covered.
  - Proper fit of the tibial component to the tibial surface.
  - Proper fit of the posterior edge of the talar component to the posterior surface of the talus.
  - Point of contact of the talar component to the tibial component. This contact point should be between 40% and 45% of the tibial component when the anterior border is taken as 0% and the posterior border as 100%, respectively. If the point of contact is too posterior, ligament balance will not be achieved.

- Carefully check the bony surfaces. Any cysts are removed with a curette, and filling with cancellous bone taken from the removed bony material is recommended. If there is sclerotic bone left on surface, drilling with a 2.0-mm drill is recommended.

**TECH FIG 3 •** Trial implants. **A.** First, the trial implant of the talus is inserted, paying attention to obtain a proper fit to the posterior resection surface. **B.** After resection of anterior surface, the bloc is inserted and the holes for the pegs are drilled. **C.** The talus trial is removed. The resection surfaces of the talus and tibia are carefully checked for cyst formations. If present, they are meticulously removed. **D.** The tibial depth gauge is inserted and the size of tibial implant is determined. **E.** The tibial trial implant is inserted paying attention to get the tibial component in close contact with the medial malleolus and the anterior surface of tibia. If necessary, the anterolateral tibia has to be smoothed.
INSERTION OF IMPLANTS

- Insert the final implants, as previously selected, as follows:
  - Fill the talar component with bone matrix (ISOTIS) to get the cysts filled and then insert it such as the pegs can glide into the two drilled holes; use a hammer and impactor to obtain a proper fit of the component to the bone (TECH FIG 4A).
  - Insert the tibial component along the medial malleolus until proper fit to the anterior border of the tibia is achieved (TECH FIG 4B).
  - Insert the inlay (same size as the talar component). Remove the distractor (Hintermann spreader). Hammer and impactor might be used for appropriate fit to bone (TECH FIG 4C).
  - Check stability and motion clinically.

- While the foot is moved in dorsiflexion with the surgeon’s maximal power, settling of the implant might be improved, and remaining soft tissue contracture on the posterior aspect of the ankle might be released (TECH FIG 4D).

- Screw fixation of the tibial component may be considered to achieve stability against rotational and translational forces during the osteointegration process; however, this is very seldom necessary as the proper fit and pyramidal peaks do provide sufficient primary stability.

- It is also highly recommended to check the position of the implants by fluoroscopy, as described for the trial implants (TECH FIG 4E,F). This also allows the surgeon to detect any remaining bony fragments or osteophytes that could be a potential source of pain or motion restriction.

**TECH FIG 4** Insertion of definitive implants. **A.** The talar component is impacted first. **B.** After insertion of the tibial component and the polyethylene insert (C), the tibial component is impacted to obtain a proper fit to the tibial resection surface. **D.** The foot is moved in dorsiflexion with the surgeon’s maximal power, thereby settling of the implant might be improved, and remaining soft tissue contracture on the posterior aspect of the ankle might be released. **E.** Final check of the position of the implants using fluoroscopy. On the AP view the surgeon checks the position of the implants for any misalignment that may cause edge load of the polyethylene insert, overall alignment in the frontal (coronal) plane, distraction of the ankle (gap between the fibula and talus), and medial and lateral gutters for any bone left that may cause bony impingement. **F.** On the lateral view the surgeon checks the position of the implants with regard to the bone surfaces (proper fit) and alignment of the implants with regard to contact area (usually, the apex of the talar component should meet the tibial component 3 to 5 mm anterior to its midpoint).
**WOUND CLOSURE**

- The wound is closed by suturing the tendon sheath and retinaculum (**TECH FIG 5A**) and the skin (**TECH FIG 5B**).
- Dress the wound, taking care to avoid any pressure to the skin (**TECH FIG 5C**).
- A splint is used to keep the foot in neutral position (**TECH FIG 5D**).

**TECH FIG 5** • Wound closure and dressing. **A.** The extensor retinaculum is closed first. **B.** Then, the skin is closed by interrupted sutures. **C.** A compressive dressing is used to avoid swelling and hematoma formation. **D.** A splint is used to keep the foot in neutral position.

**PEARLS AND PITFALLS**

**Malalignment or malunion above the ankle joint**
- Above the ankle joint:
  - Supramalleolar osteotomy
- At the ankle joint:
  - Corrective tibial cut
  - Osteotomy of fibula or medial malleolus
- Beneath the ankle joint:
  - Calcaneal osteotomy

**Adjacent osteoarthrosis**
- Subtalar joint:
  - Subtalar arthrodesis
- Talonavicular joint:
  - Talonavicular arthrodesis

**Fixed deformity**
- Valgus deformity:
  - Triple arthrodesis
  - Medial sliding osteotomy of calcaneus
- Varus deformity:
  - Release of medial ankle ligaments
  - Reconstruction of lateral ankle ligaments
  - Peroneus longus to brevis tendon transfer
  - Lateral sliding osteotomy of calcaneus
  - Dorsiflexion osteotomy of first ray
**Ligamentous instability**
- Lateral ankle ligaments:
  - Lateral ligament reconstruction
- Medial ankle ligaments:
  - Tibiotalar tilt of less than 10 degrees: medial ligament reconstruction
  - Tibiotalar tilt of more than 10 degrees: ankle arthrodesis

**Muscular dysfunction**
- Peroneus brevis:
  - Peroneus longus to brevis tendon transfer
- Tibialis posterior:
  - Triple arthrodesis

**POSTOPERATIVE CARE**
- The dressing and splint are removed and changed after 2 days.
- When the wound is dry and proper, typically 2 to 4 days after surgery, the foot is placed in a stabilizing cast or walker that protects the ankle against eversion, inversion, and plantarflexion movements for 6 weeks.
- Active motion and lymphatic drainage may support recovery of soft tissues during the first 6 weeks. Overly aggressive motion during the first postoperative days, however, may lead to breakdown of soft tissues.
- Weight bearing is allowed as tolerated. Usually, full weight bearing is achieved after 1 week.
- In the case of additional osteotomies of the calcaneus, ligament reconstruction, or tendon transfer, cast immobilization for 6 weeks is advised.
- In the case of additional fusion of adjacent joints, cast immobilization for 8 weeks is advised.
- In the case of additional supramalleolar osteotomy, the patient should remain non-weight-bearing for 8 to 10 weeks.
- A rehabilitation program should be started for the foot and ankle after cast or walker removal, including stretching and strengthening of the triceps surae.
- First clinical and radiologic follow-up is made at 6 weeks, to check the wound site and osteointegration and position of the implants.
- The patient should be advised to wear a compression stocking to avoid swelling for a further 4 to 6 months.

**OUTCOMES**
- Between May 2000 and December 2006, 574 primary total ankle arthroplasties were performed in 549 patients (272 women, 277 men; mean age 59.7 ± 12.6 years [range 19.8 to 90 years]; left side 277, right side 297, bilateral 26). The underlying diagnosis was posttraumatic osteoarthritis in 459 ankles, primary osteoarthritis in 40 ankles, and inflammatory arthritis in 63 ankles.
- The mean follow-up was 31.9 ± 19.7 months (range 12 to 82 months). The mean AOFAS improved from 42.1 ± 17.0 preoperatively to 78.1 ± 11.1 postoperatively, and the mean pain relief was from 6.8 ± 3.9 preoperatively to 2.9 ± 2.4 postoperatively. The mean plantarflexion at latest follow-up was 28.5 ± 10.2 degrees and the mean dorsiflexion was 6.4 ± 6.1 degrees. The satisfaction grade was excellent in 213 patients (38.8%), good in 238 patients (43.4%), and moderate in 87 patients (15.8%); only 11 patients (2.0%) were dissatisfied.
- Early complications included malleolar fractures intraoperatively, 11 patients; wound healing problems, 7 patients; infection, 4 patients; and polyethylene dislocation, 5 patients.
- Late complications included loosening of components, 24 patients (talar component, 22 patients, 7 of them with subsidence or migration; tibial component, 19 patients, none of them with subsidence or migration); polyethylene dislocation, 5 patients; polyethylene wear, 0; progressive loss of motion, 38 patients; chronic pain syndrome, 11 patients.
- Taking revision of a metallic implant or conversion into ankle arthrodesis as the endpoint, overall survivorship of both components at 6 years was 98.2% (97.9% for the talar component and 98.8% for the tibial component).
- Four ankles were revised to total ankle arthroplasty (component loosening, three; pain, one), and two ankles (component loosening and recurrent misalignment, one; pain, one) were revised to ankle arthrodesis.

**COMPLICATIONS**
- Intraoperative complications
  - Malpositioning of prosthetic implant
  - Improper sizing of prosthetic implant
  - Fractures of malleoli
  - Tendon injuries
- Postoperative complications
  - Wound healing problems
  - Infection
  - Swelling
  - Deep venous thrombosis
- Late complications
  - Aseptic loosening
  - Subsidence
  - Polyethylene wear
  - Dislocation of polyethylene insert
  - Progressive loss of motion

**REFERENCES**
Severe erosions of the articular surfaces of the human ankle joint associated with arthritis drastically affect the normal interaction between muscles, bones, and ligaments and cause pain, joint instability, and disability.

**SURGICAL MANAGEMENT**

- Many surgeons maintain that arthrodesis is the surgical treatment of choice for these patients.13
- Arthrodesis has been associated with a high incidence of nonunion, secondary degenerative changes at adjacent joints, and postoperative infections.3 Moreover, total loss of ankle motion often inhibits physiologic ambulation, particularly in patients with involvement of multiple lower extremity joints.8 Patients who can walk with a fused ankle are generally inhibited in running and climbing.3 These limitations of tibiotalar arthrodesis are prompting advances in total ankle arthroplasty (TAA).
- After encouraging early results of TAA, long-term clinical follow-up studies have been disappointing,4,14,15,22 with poor results, especially in younger patients with isolated traumatic ankle arthritis. Recent clinical reports of TAA suggest only modest improvements in outcomes, outcomes that do not demonstrate the same success observed in comparable studies of total hip and knee arthroplasty.2,5,11,12,25
- However, several recent review papers6,7,9,10,23,26 have demonstrated a renewed interest in TAA. Newer generations of TAA are again being touted as viable alternatives to ankle arthrodesis, although optimal restoration of physiologic tibiotalar motion and minimization of bone resection have not been achieved in any of the newer designs.
- Our extensive original research16–21 has shown that physiologic mobility at the ankle involves rolling as well as sliding, guided by the preserved ankle joint’s natural ligament apparatus.
- The BOX total ankle replacement is devised to reproduce physiologic mobility so that the ligaments continue to function normally (Fig 1).
- The unique three-component articulating geometry is designed to be compatible with the physiologic movement of isometric fibers within the calcaneofibular and tibiocalcaneal ankle ligaments. Sophisticated instruments have been developed to achieve accurate positioning of components relative to the ligament apparatus.16,21
- In our experience with the BOX prosthesis, physiologic motion and correct position are demonstrated by characteristic motion of the meniscal bearing on the tibial component, forward in dorsiflexion and backward in plantarflexion.16,21
- The BOX total ankle replacement is capable of restoring physiologic motion in the replaced joint with full congruence at the articulating surfaces over the entire motion arc. In our opinion, full congruence should result in minimum wear of the components, as preliminary results have indicated.1
- The technique, which uses instruments unique to the BOX prosthesis, involves removing a measured amount of bone from the talus (usually 4 mm) and minimal bone from the tibia (5 to 10 mm). A joint tensioning device is used so that ligament balance and tension are taken into account before the tibial cuts are made. The thickness of the meniscal implant is set via this device so that the appropriate amount of bone is resected. The amount of tension applied with this instrument represents the initial tension in the replaced joint.

**Indications**

- Patients with primary or posttraumatic tibiotalar arthrosis and preferably a low functional demand
- In general, patients over 50 years of age
- All patients with rheumatoid arthritis involving the tibiotalar joint
- Patients refusing arthrodesis, taking into account the following contraindications

**Contraindications**

- Severe morphologic defects of the ankle
- Significant osteoporosis or osteonecrosis, particularly affecting the talus
- Prior or active infections of the foot and ankle
- Vascular insufficiency or severe neurologic deficits (motor dysfunction, spasticity, neuropathy)

**FIG 1** The kinematics of the replaced ankle in the sagittal plane when guided by a computerized model of the four-bar linkage mechanism.5,18,21 Arrangement of the two bone shapes (in gray), of the linkage (calcaneofibular in yellow, tibiocalcaneal in green) and other (slackened–tightened in brick) ligaments, muscle unit courses (dashed lines), and instantaneous center of rotation (at the crossing point between the linkage ligaments, small circle in red), corresponding joint contact line (dash-dot in white), of the metal (empty white) and meniscal (gray in between) components of the BOX Ankle, are all depicted at 20 degrees of plantarflexion (left), neutral (center), and 10 degrees of dorsiflexion (right). Details on the undersurface and fixation of the bone-anchored components are deliberately omitted because they are not relevant for this mechanism model.
For our team, the following are contraindications only if they cannot be resolved before or during surgery (while performing TAA): capsuloligamentous instability that cannot be appropriately balanced; a foot deformity that cannot be corrected to a plantigrade position (ie, unstable platform on which to position the TAA); and severe ipsilateral hip and knee deformities or malalignment or previous arthrodesis at these joints.

Preoperative Planning
- Both AP and mediolateral ankle radiographs, taken with the patient in double leg support (fully weight bearing), are required to assess preoperative alignment and deformity of the tibiotalar joint.
- Radiographic magnification must be assessed, using a radiographic scaling technique or by comparing a measurement on the radiograph and the subject, such as foot length or ankle width. Radiographic templates are provided for the BOX prosthesis from 100% to 120% in 5% intervals to compensate for magnification discrepancies.
- The surgeon must assess the best fit of tibial and talar implants and the meniscal implant thickness. For the tibia component, the surgeon assesses the AP length at the level of resection and mediolateral fit between the malleoli. For the talar component, AP fit is assessed.
- We recommend that the tibial and talar implants are matched within one size up or down (eg, small tibia with medium talar or large tibia with medium talar, but preferably not small tibia with large talar). The meniscal implant corresponds with the size and color code of the talar implant.

Positioning
- The patient is positioned supine on the operating table.

Approach
- We routinely use a tourniquet in the upper third of the thigh after the foot and ankle have been exsanguinated with an Esmarch elastic wrap. The leg must be sterile up to the knee.
- An anterolateral skin incision 8 to 10 cm long is made, leaving one third distal and two thirds proximal to the joint line (FIG 2A).
- The subcutaneous tissue is dissected, identifying and protecting the superficial peroneal nerve. The superior and inferior extensor retinaculum is incised. The peroneus tertius tendon is identified and the incision is continued between this and the extensor digitorum communis tendons.
- A longitudinal capsulotomy is performed to expose the ankle joint (FIG 2B). The capsule and soft tissues are carefully elevated medially and laterally to the malleoli and retractors are inserted deep to the soft tissues and directly on the malleoli. Potentially harmful direct skin tension is avoided with deep retraction of the soft tissues.
- It is important to fully expose the medial and lateral aspects of the tibiotalar joint; all the fibrous tissue and osteophytes must be removed. Typically, soft tissue elevation is required on the distal anterior tibia, immediately proximal to the ankle joint, to permit satisfactory positioning of the tibial alignment guide. Distally, the incision and capsular-soft tissue elevation must be extended to identify the transition between the head and the neck of the talus, while protecting the deep neurovascular bundle.
- The ankle is positioned in maximum dorsiflexion and the most anterior borders of the articulating surfaces are marked, together with the central line mediolaterally. The latter is important for the correct later positioning of the tibial alignment mediolaterally to provide better support.

BOX IMPLANT

Initial Tibial Preparation
- Trim the anterior prominence and exostosis of the distal tibia using a chisel to gain access to the joint space (TECH FIG 1).
- Assemble the tibial alignment guide with proximal clamp and connector; tighten with the proximal screw. Insert the talar cutting block onto the tibial alignment guide and tighten with the frontal screw (TECH FIG 2A).
- With the button in the unlocked position and depressed, adjust the ratchet to the START position (Tech Fig 2A). Lock the ratchet to prevent it from moving out of position during positioning and sawing.
- Place the assembled guide onto the lower leg, inserting the posterior tongue of the talar cutting block into the joint space centered between the malleoli.

TECH FIG 1 • Removal of the anterior corner of the distal tibia by a large inclined chisel, to gain access to the joint space.
■ Place the proximal clamp at the proximal tibial tuberosity (TECH FIG 2B).
■ Fasten the spring around the proximal shank.
■ Align the shaft of the tibial alignment guide parallel with the longitudinal axis of the tibia, in both anterior and lateral views, by adjusting the proximal clamp.
■ Recheck that the tongue of the talar cutting block is centered between the malleoli and pin using two or three out of four diagonally opposite pin positions (pins converge toward the center of the tibial shaft).
■ A common error is to align the shaft parallel to the front of the tibia rather than parallel to the longitudinal axis. This will result in an erroneous posterior inclination of the tibial component.

**Horizontal Talar Cut**

■ Lock the position of the tongue as far as it will go into the joint space with the frontal screw.
■ Ensure that the foot is in the neutral flexion position (0 degrees dorsiflexion and plantarflexion, 90 degrees between the tibia axis and the plantar aspect of the foot) and complete the horizontal talar cut.
■ Remove the talar block, complete the cut, and remove the resected talar bone (TECH FIG 3).
■ If the foot is in dorsiflexion or plantarflexion, a malrotation of the talar component will result, restricting final range of motion of the implanted prosthesis.

**Tibial Preparation**

■ Insert the selected size of tibial cutting block onto the tibial alignment guide (TECH FIG 4A) in neutral mediolateral adjustment (center of scale, TECH FIG 4B).
■ Assess the central position of the block relative to the malleoli. If needed, adjust on the fine scale by moving the tibial cutting block forward (as if to remove it) until it is free to slide mediolaterally. Reinsert the block in the desired medial or lateral adjustment. Tighten with the frontal screw.
■ Select the thinnest 5-mm tibial tensioner for minimum bone removal from the tibia (Tech Fig 4A). Slide the tensioner through the slot on the tibial cutting block, advancing the posterior tongue of the tensioner (most distal part of Tech Fig 4A) into the joint space.
Assemble the knob tightener into the large blue handle and unlock the ratchet button (Tech Fig 4A).

Insert the knob tightener into the ratchet knob and turn in a counterclockwise direction.

The amount of tension applied will represent the tension in the replaced joint, provided the meniscal implant matches the tibial tensioner used (TECH FIG 5).

If the selected position of the horizontal cut on the tibia is considered too distal (removing too little tibial bone), go back to the ratchet START position and insert the 6- or 7-mm tibial tensioner into the tibial cutting block and apply tension again.

Lock the ratchet when the desired tension and level of tibial cut is reached.

The position of the cuts on the tibia is now set, so that precisely the right amount of bone is resected to match the combined thickness of implant components.

Tensioning the joint and using a meniscal implant as thin as possible are recommended to prevent excessive or unnecessary bone removal from the tibia.

Complete the three tibial cuts without notching the malleoli with the saw blade.

Drill the two 3.2-mm holes with the tibial corner drill up to the depth mark (S, M, or L), taking care not to drill too far.

Select the appropriate 4.5-mm tibia drill (S, M, or L) to suit the tibial block used and drill the two 4.5-mm holes in the tibia through the tibial cutting block up to the depth stop.

Remove the tibial cutting block by releasing the frontal screw and use the tibial corner gouge assembled in the large blue instrument handle to join the cuts in the two corners (TECH FIG 6).

Fragment and remove the cut section of bone using a chisel (small 30 mm, medium 35 mm, large 40 mm long).

Fragmenting thin sections of bone requires considerable care and patience because it is thicker posteriorly and retained by the posterior periosteum and capsule. Be careful to do so without leaning against the malleoli because this may result in their fracture.

Before removing the tibial alignment guide, measure the AP length of the horizontal tibial cut with the tibial length gauge.

The measurement indicates whether a small, medium, or large size of tibial implant is appropriate (small 30 mm, medium 35 mm, and large 40 mm).

If in between sizes, size down to prevent overhang of the tibial component.

If there is a need to increase the tibial implant size, select the next biggest tibia cutting block and increase the depth of the 4.5-mm holes using the next larger drill. Redrill the two 3.2-mm drill holes, recut the side cuts, and extend the top horizontal cut to meet the small holes. Remove the complete tibial cutting guide assembly.

When increasing tibia implant size, be sure to increase the depth of the 4.5-mm holes; failure to increase the depth of the 4.5-mm holes may result in fracture of the posterior portion of the tibia.

Use the tibial keyhole cutter assembled in the slide hammer to join the two 4.5-mm holes to the horizontal tibial cuts.
cut. Care should be taken not to break out the holes by biasing the cutter proximally or distally.
- The tibial preparation is now complete (TECH FIG 7).

Completion of the Talar Preparation
- Select the appropriate size of talar chamfer guide and attach the small blue handle.
- Slide the guide onto the flat talar cut until the anterior chamfer abuts the front of the talus (TECH FIG 8).
- Using the appropriate-thickness flat spacer (blue, Tech Fig 9), assess the joint gap in neutral, maximum plantarflexion (TECH FIG 9A), and maximum dorsiflexion (TECH FIG 9B) positions.
- With the talar chamfer guide in the optimal AP position, the gaps will be equal.
- It is usually necessary to trim the anterior talus, moving the guide posteriorly to gain this optimal position because a good fit of the anterior chamfer on the talus is desired.
- Pin the guide in the final position using two short pins (pins converge centrally), and remove the anterior handle.
- Drill the two peg holes through the drill guide tube with the talar peg drill.
- Optionally, use the talar lever to distract the tibia and hold down the posterior part of the talar chamfer guide (TECH FIG 10A).
- Complete the posterior chamfer cut. Optionally, continue using the talar lever to hold down the posterior part of the talar chamfer guide.
- Remove the guide and complete the cut, removing the section of bone.
- The talar preparation is now complete (TECH FIG 10B).
- The tibial preparation is now complete (TECH FIG 11).

Trial Reduction
- Insert the selected size of talar trial using the talar impactor (TECH FIG 12).
- Insert the selected size of tibial trial using the tibial inserter (in the large blue handle) and the green profile spacer to keep the tibial trial hard up against the cut bone surface.
- A spacer one size thicker than the planned final meniscal implant is recommended (TECH FIG 13).
- Select the appropriate-sized meniscal trial matching the size of the talar trial used and the thickness of tibial tensioner used. Insert with the meniscal trial inserter–remover (TECH FIG 14).
- Assess the overall range of dorsiflexion–plantarflexion and joint function.
- The meniscal trial should traverse anterior to posterior on the tibial trial component by about 5 mm from maximum dorsiflexion to maximum plantarflexion.
Chapter 70 THE BOX TOTAL ANKLE ARTHROPLASTY

TECH FIG 10 • Final talar preparation. A. Drilling the anterior peg hole through the drill guide tube with the talar peg drill; the talar lever is used with the left hand to hold down the posterior part of the talar chamfer guide. B. The bone saw for the posterior chamfer cut. (Courtesy of Finsbury Orthopaedics Limited, Leatherhead, UK.)

TECH FIG 11 • Completed tibial and talar preparation.

TECH FIG 12 • Insertion of the talar trial using the talar impactor.

TECH FIG 13 • Insertion of the tibial trial using the tibial inserter and the green profile spacer.

TECH FIG 14 • Insertion of the meniscal trial using the relevant inserter-remover. (Courtesy of Finsbury Orthopaedics Limited, Leatherhead, UK.)
The meniscal trial should also remain in full contact with the two metal trials throughout flexion and the full range of internal-external rotation in the transverse plane.

An intraoperative fluoroscopy or radiographic control should be considered to assess the AP position of both tibial and talar implants.

If range of motion or stability is not satisfactory, it is possible to make a small adjustment in the tibial trial AP position or to try an alternative thickness of meniscal trial.

Use the meniscal trial inserter-remover to remove the meniscal trial, as in Techniques Figure 14.

Use the tibial trial remover attached to the slide hammer to remove the tibial trial (TECH FIG 15A) and the talar extractor aligned with the recesses in the anterior chamfer to remove the talar trial (TECH FIG 15B). Attaching the slide hammer is optional.

Before attempting to move the tibial trial posteriorly, it is essential to increase the depth of the relevant two drill holes; failure to do this may result in fracture of the posterior portion of the tibia while inserting the tibial trial.

Final Implantation

When selecting the implant components, ensure that the meniscal implant matches the talar implant size and color code.

Both tibial and talar components are cementless.

Clean the resected bone surfaces with a bone brush or pressurized lavage. Use suction to remove the debris and liquid. Dry thoroughly.

Position the talar implant to engage the pegs with the drilled holes. Impact in line with the pegs using the talar impactor.

Insert the tibial implant with the tibial inserter using the green profile spacer to avoid contact between the two highly polished metal components.

The profile spacer also maintains optimal contact between the tibial implant and resected tibial surface during implant insertion.

A spacer 1 mm thicker than the planned final meniscal implant is recommended. This is to avoid tibial component posterior tilting and to improve its primary fixation with a better press-fit.

Impact the tibial implant until it matches the optimal position obtained with the tibial trial.

Insert the appropriate-sized meniscal trial again using the meniscal trial inserter-remover to assess the final thickness of the meniscal implant.

Insert the meniscal implant by hand with the two raised marker ball pads anterior and a single raised marker pad posterior.

This is performed by pushing it with both thumbs. Considerable effort may be required. Usually this is expected to result in limited range of motion at the replaced joint, but this not the case for this TAA, because the meniscal implant sagittal shapes are designed to be compatible with the isometric motion of the ligaments and the operative technique allows this to be restored.16,21

Assess the ankle range of dorsiflexion-plantarflexion and joint function.

The meniscal implant should traverse anterior to posterior on the tibial implant by about 5 mm from maximum dorsiflexion (TECH FIG 16A) to maximum plantarflexion (TECH FIG 16B).
The meniscal implant should also remain in full contact with the two metal components throughout flexion and the full range of internal–external rotation in the transverse plane.

The only possible correcting actions at this stage are exchanging the meniscal implant thickness or inserting further the tibial implant (though the latter is critical because of the risk of posterior tibial fracture, as in the last paragraph of the previous section). In addition, if a limited range of dorsiflexion is observed and the replaced joint is stiff, a percutaneous Achilles tendon lengthening can be performed.

**Closure**
- Release the tourniquet and carefully cauterize any bleeding veins.
- Insert a drain and suture the anatomic planes.
- Closure of the extensor retinaculum is essential. The deep neurovascular bundle and superficial peroneal nerve must be protected. After closure, lateral and frontal radiographs are taken and the joint is cast in the neutral position.

**ADDITIONAL TECHNIQUES**
- Correction of forefoot deformity, particularly fixed forefoot varus
- Calcaneal osteotomy to correct hindfoot malalignment
- After final implantation, if the total ankle prosthesis does not provide at least 10 degrees of dorsiflexion, percutaneous Achilles tendon lengthening is performed by a laterally and medially based stab incisions of the tendon.
- Ligamentous reconstruction to treat the ankle instability, performed with a trial implant to ensure that proper ligamentous balance can be achieved with the final implant
- If widening of the mortise was present preoperatively, open reduction and internal fixation of the syndesmosis is performed by a syndesmotic screw.

**PEARLS AND PITFALLS**

**Pearls**
- Maintain proper indications.
- Address relative contraindications appropriately and TAA may still be favored over arthrodesis.
- With the ankle in maximum dorsiflexion and the most anterior borders of the tibial and talar articulating surfaces close together, mark both with a pen the central line mediolaterally. This procedure is performed for the correct positioning of the tibial alignment guide.
- Tensioning the joint by moving the tibial cutting block distally and using a meniscal implant as thin as possible implies that eventually the minimum bone removal from the tibia is performed; in other words, correct distraction of the joint prevents excessive or unnecessary bone removal from the tibia.
- If in between sizes, size down to prevent mediolateral and posterior overhang of the tibial component.
- It is usually necessary to trim the anterior talus, moving the guide posteriorly to gain this optimal position, to achieve an optimal fit of the anterior chamfer on the talus.
- A fluoroscopy or radiographic control should be considered to assess the correct AP position of both tibial and talar implants.

**Pitfalls**
- The meniscal implant should also remain in full contact with the two metal components throughout flexion and the full range of internal–external rotation in the transverse plane.
- The only possible correcting actions at this stage are exchanging the meniscal implant thickness or inserting further the tibial implant (though the latter is critical because of the risk of posterior tibial fracture, as in the last paragraph of the previous section). In addition, if a limited range of dorsiflexion is observed and the replaced joint is stiff, a percutaneous Achilles tendon lengthening can be performed.

**Closure**
- Release the tourniquet and carefully cauterize any bleeding veins.
- Insert a drain and suture the anatomic planes.
- Closure of the extensor retinaculum is essential. The deep neurovascular bundle and superficial peroneal nerve must be protected. After closure, lateral and frontal radiographs are taken and the joint is cast in the neutral position.
Pitfalls

- A green spacer 1 mm thicker than the planned final meniscal implant is recommended during tibial implantation to force the component further against the bone; this avoids tibial component posterior tilting and improves primary fixation of the component with a better press-fit.
- Perform necessary additional surgical procedures (ie, foot realignment and ligament rebalancing) to ensure optimal support and stability.

POSTOPERATIVE CARE

- Immediately after surgery a cast is placed for 2 weeks, and weight bearing is not allowed.
- After 2 weeks a brace is placed and active and passive range of ankle motion is permitted. If the part of the wound not healed is small, motion is still permitted, but if it is large motion is not permitted until complete healing.
- After 1 month full weight bearing with the brace is allowed.
- After 2 months full weight bearing without the brace is allowed after bone ingrowth is suggested on follow-up radiographs. Rehabilitation is then recommended, particularly muscular reinforcement and proprioceptive exercises as well as functional restoration of walking patterns.

OUTCOMES

- In an eight-center Italian clinical trial, 135 patients received implants between July 2003 and December 2006. Mean age was 60.7 years (range 31 to 80). The AOFAS clinical score systems and standard radiographic assessment were used to assess patient outcome, here reported only for the 90 patients with follow-up longer than 6 months.
- Intraoperatively, the components maintained complete congruence at the two articulating surfaces of the meniscal bearing over the entire motion arc, associated with considerable anterior motion in dorsiflexion and posterior motion in plantarflexion of the meniscal bearing, as predicted by the previous mathematical models.
- A mean of 10.1 degrees of dorsiflexion and 23.5 degrees of plantarflexion were measured immediately after implantation, for a mean additional range of motion of 18.6 degrees, which was maintained at follow-up.
- Radiographs showed good alignment and no signs of progressive radiolucency or loosening.
- The mean AOFAS score went from 37.0 before surgery to 64.7, 73.2, 78.4, and 85.9 respectively at 3-, 6-, 12-, and 18-month follow-ups.
- One revision was performed 3 days after implantation because of a technical error; it was successful. Another revision was performed at 19 months because of a wrong indication.
- In the scoring system used, the function and range-of-motion sections scored better than any average previous total ankle result. Pain scored similarly.

- The satisfactory though preliminary observations from this novel design encouraged continuation of the implantation, which has now been extended over a few European countries. Instrumented gait and three-dimensional fluoroscopic analyses are in progress to quantify functional progress.

COMPLICATIONS

- The most common intraoperative complication is medial malleolus fracture. The medial malleolus should always be checked for fracture before wound closure. A medial malleolar fracture must be fixed with a screw, a medial buttress plate, or both.
- Another intraoperative complication could be widening of the mortise, which is treated with open reduction and internal fixation of the syndesmosis (see above).
- Less common complications include lateral malleolus fracture (managed with screw or Kirschner wire fixation), tendon laceration (treated with direct repair), or nerve or artery injury (treated with direct repair).

REFERENCES


DEFINITION
- The Salto Total Ankle Prosthesis is a cementless resurfacing-type implant that is intended to restore near-normal joint kinematics. Fixation is achieved through bone ingrowth.
- The surgical technique is critical to a successful outcome, and some criteria are essential:
  - Tight fit of the components and extended contact area with bone to achieve good primary stability, which is a prerequisite for secondary biological fixation
  - Restoration of the mechanical axis of the ankle
  - Accurate restoration of the joint line (proper level and strict horizontal plane)
  - Preservation or restoration of the soft-tissue balance
  - Adequate soft tissue release to achieve good range of motion (ROM) intraoperatively

ANATOMY
The Mobile-Bearing Salto Prosthesis
- The Salto Total Ankle Prosthesis (Tornier SA, Saint-Ismier, France) was developed between 1994 and 1996 and has been used clinically since January 1997.

FIG 1 • A. An oblique view shows the Salto Total Ankle Prosthesis. B. An AP view shows the three main components and the malleolar component.

Dr. Donley is a paid consultant for Tonnier, Inc., the company that makes the Salto Talaris Anatomic Ankle.

Based on experience with the third-generation cementless meniscal-bearing designs, this system was designed to restore nearly normal kinematics of the ankle (FIGS 1 AND 2).
- A dedicated instrument system was developed to achieve optimal positioning of the components, and the design of the implant was optimized to better restore the natural anatomy and obtain an optimal primary fixation of the components while retaining a minimally invasive resurfacing concept.
- The tibial component accommodates the superior flat surface of the mobile bearing. Its smooth surface allows free translation and rotation of the mobile bearing. The 3-mm medial rim protects the polyethylene from impingement with the medial malleolus.
- The specific shape (segment of a cone of revolution) of the talar component replicates the anatomy of the talar dome. It is broader anteriorly than posteriorly, and the lateral condyle has a larger radius of curvature than the medial condyle. As a result, the axis of flexion and extension of the talar component, under the polyethylene, is aligned with the physiologic axis. The lateral aspect of the talus is resurfaced, allowing articulation with the lateral malleolus.
- The ultra-high-molecular-weight polyethylene (UHMWPE) insert articulates with the tibial component superiorly and with the talar component inferiorly. It maintains full congruency with the talar component in flexion and extension and accommodates as much as 4 degrees of varus and valgus in the coronal plane, thereby reducing the chance of polyethylene edge loading.
- The tibial component is available in three sizes and the talar component is available in four sizes. The mobile bearing is size-matched to the talar component in thicknesses from 4 to 8 mm.
- The mobile-bearing size must match the size of the talar component. The talar component must be equal to or one size less than the tibial component.

FIG 2 • AP (A) and lateral (B) radiographs show the Salto Total Ankle Prosthesis in situ.
In general, our indications for total ankle arthroplasty (TAA) are: end-stage ankle osteoarthritis (OA) or rheumatoid arthritis (RA).

In OA, degeneration may be due to sequelae of trauma, chronic ankle instability, and rarely primary osteoarthrits.

In our experience, RA occurs relatively infrequently in the ankle when compared to the hip or knee. However, there is no consensus on the actual rate of ankle joint involvement in RA patients, with figures ranging from 9% in the study by Vainio,8 in which clinical criteria were used, to 40% in the study by Jakubowski et al,9 which employed radiographic criteria.

Primary fixation to the tibia is ensured by close match of the tibial component to the epiphysis, and enhanced by an AP keel and a tapered cylindrical plug.

Stability of the talar component is provided by three bone cuts, and insertion of an 11-mm-diameter hollow fixation peg into the body of the talus.

Secondary fixation is provided by bone ingrowth into a dual coating of hydroxyapatite applied to a 200-μm-thick layer of plasma-sprayed titanium.

The Fixed-Bearing Salto-Talaris Prosthesis

Our experience with the Salto prosthesis has led us to revise our concept of mobility. As a matter of fact, owing to the anatomic design of the implant, the precision of the bone cuts, and the accuracy in component positioning, the need for and the potential problems associated with postoperative motion of the polyethylene bearing during flexion–extension movements have been almost completely eliminated. This has been confirmed in clinical studies based on standing dynamic views. On the other hand, intraoperative motion of the tibial component assembly is most helpful in allowing self-positioning of the bearing with respect to the talar component before the tibial keel preparation is completed.

The Salto-Talaris components and instrument system are the same as those of the Salto prosthesis, except that the tibial component is a fixed-bearing design (FIG 3). The final position of the tibial component is fine-tuned at the end of the procedure to achieve perfect alignment with the talar component. In this manner the self-positioning feature of the mobile-bearing insert has been retained.

PATHOGENESIS

In general, our indications for total ankle arthroplasty (TAA) are: end-stage ankle osteoarthritis (OA) or rheumatoid arthritis (RA).

Occasionally, end-stage erosive or degenerative changes of the ankle may develop secondary to osteochondromatosis, pigmented villonodular synovitis, hemochromatosis, or osteochondritis dissecans.

Ankle joint involvement in RA tends to occur late in the disease process, with symptoms not occurring until a mean disease duration of 17 to 19 years.

Since the tibiotalar joint is rarely affected in isolation, treatment will need to be systemic and not only for the ankle.

NATURAL HISTORY

Progressive tibiotalar arthritis typically is accompanied by progressive ankle stiffness. Loss of ankle ROM, particularly dorsiflexion, results from tibiotalar osteophytes and less resilience in the distal tibiofibular syndesmosis.

Over time, the patient may develop an equinus gait with resultant Achilles tendon contracture, posterior capsular adherions, and occasionally tibialis posterior adherions.

PATIENT HISTORY AND PHYSICAL FINDINGS

Methods for Examining the Degenerative Ankle Joint

Silfverskiold test

- Passive ankle ROM with the patient supine and the knee flexed and extended
- Physiologic ROM with this examination is 15 (dorsiflexion)/0/40 (plantarflexion).
- An isolated gastrocnemius contracture is present when lack of dorsiflexion with the knee in extension is eliminated with knee flexion.

Evaluation of ankle ROM with the patient standing and walking

- Visualizing the gait pattern. The patient may externally rotate the extremity, or female patients may be able to walk in high heels to mask the lack of ankle dorsiflexion.

Hindfoot ROM

We use three grades of hindfoot motion: physiologic, diminished, or stiff. We favor total ankle arthroplasty (TAA) over ankle arthrodesis in patients with a stiff hindfoot.

Hindfoot alignment with the patient standing or ambulating

- Hindfoot malalignment (varus or greater than physiologic valgus) may be most pronounced with the patient walking.
- Hindfoot alignment with the patient supine

- We typically assess passive hindfoot motion to determine if the deformity can be reduced to a physiologic position. In our hands, this examination determines the type of hindfoot realignment that will be performed concomitant to TAA.

Tibiotalar instability

The examiner successively assesses coronal plane and sagittal plane stability with varus–valgus stress and anterior drawer testing, respectively. In our hands, varus instability or fixed varus ankle requires careful ligament balancing.

IMAGING AND OTHER DIAGNOSTIC STUDIES

In our preoperative assessment we not only determine the extent of deformity and instability at the ankle but also assess any concomitant ipsilateral lower extremity malalignment that
may have a bearing on the outcome of TAA. We routinely obtain weight-bearing AP, mortise, and lateral radiographs of both ankles; radiographs of the uninvolved ankle typically provide some understanding of what is physiologic for the patient. Weight-bearing mechanical axis hip-to-ankle radiographs are required if there is associated deformity of the ipsilateral lower extremity.

- We recommend obtaining CT scans of the ankle and hindfoot, particularly to review coronal sections, to further evaluate tibial or talar bone loss or cysts not fully defined on plain radiographs.

**DIFFERENTIAL DIAGNOSIS**

- Septic arthritis
- Charcot neuroarthropathy

**NONOPERATIVE MANAGEMENT**

- We have had limited success with nonoperative management in active patients with end-stage ankle arthritis.
- Activity modification, rocker-bottom shoe modification, and bracing offer some relief.
- We reserve nonoperative management for low-demand patients who are poor surgical candidates.

**SURGICAL MANAGEMENT**

**Total Ankle Arthroplasty Versus Ankle Arthrodesis**

- In general, arthrodesis is favored over TAA because:
  - Lower risk of mechanical implant failure; no risk of implant wear
  - Lower risk of infection
  - Less chance of skin necrosis when the ankle has been previously operated on
- In our hands, lower incidence of residual pain
- In general, TAA is favored over ankle arthrodesis because:
  - Less risk of developing adjacent (hindfoot) joint arthritis
  - In our hands, more favorable functional outcome
- In our opinion, malunion or development of adjacent joint arthritis makes revision surgery more difficult after arthrodesis.

**Preoperative Planning**

- Preoperative evaluation of weight-bearing radiographs and CT scan to:
  - Choose the optimal implant size, with the use of available templates. This is important because an oversized prosthesis will alter the center of rotation, giving rise to pain and stiffness.
  - If the talus is particularly deformed, the template should be applied to the contralateral, unaffected ankle.
  - Determine the reference for establishing the ideal tibial resection level, taking into account the extent of wear in the tibial plafond
  - Analyze tibiotalar joint alignment relative to the tibial shaft axis. This allows differentiation between axial deviations:
    - Resulting from asymmetrical wear of the tibial plafond that may be corrected with tibial preparation.
    - Because of malunion that may require corrective osteotomy, simultaneous to or staged with TAA.
  - Analyze the residual talar body.
  - Asymmetry needs to be balanced in the talar preparation.

- Evaluate the hindfoot.

- A joint-sparing calcaneal osteotomy may be necessary to realign the hindfoot.
- In the face of hindfoot arthritis or hindfoot instability, a subtalar or even triple arthrodesis may be warranted.

**Positioning**

- The patient is positioned supine on the operating table, with a pad under the ipsilateral hip to promote a neutral tibial and foot alignment with the foot pointing to the ceiling.
- The plantar aspect of the foot should be flush with the end of the table.
- Placing a rolled towel under the ankle facilitates subtle adjustments in ankle positioning.
- We routinely use a thigh tourniquet.
- In our experience, a pillow placed behind the knee allows the Achilles tendon to relax and may improve exposure.
- We recommend including the knee in the sterile field so that the limb can be positioned more freely and so that the patella and tibial tubercle may be used to confirm optimal alignment. The surgeon stands at the foot of the table, with the assistant at the lateral side of the operative leg.

**Approach**

- The tibiotalar joint is approached through an anterior midline incision starting 8 to 10 cm proximal to the joint line and extending to the midfoot.
- The soft tissues must be handled carefully, especially in patients being managed with systemic steroid treatment.
  - The surgeon should avoid undermining the skin.
  - The surgeon should maintain deep retraction only and avoid tension directly on the skin edges.
  - Extending the skin incision will further diminish skin tension.
- While we maintain meticulous hemostasis, we ligate vessels whenever possible and use electrocautery sparingly to diminish the risk of skin burns. We typically incise the crural fascia whenever possible and use electrocautery sparingly to diminish the risk of skin burns. We typically incise the crural fascia and extensor retinaculum along the lateral border of the tibialis anterior tendon, using the interval between the tibialis anterior and extensor hallucis longus tendons.
  - Whenever possible, the tibialis anterior tendon should remain protected in its individual sheath throughout the procedure (this also separates the tendon from the anterior incision during closure).
- Alternatively, the extensor retinaculum may be incised at the lateral border of the extensor hallucis longus tendon, using the interval between the extensor hallucis and extensor digitorum longus tendons. The tendons are retracted with angled retractors, and the deep neurovascular bundle (anterior tibial artery and deep peroneal nerve) is identified in the proximal wound and carefully reflected laterally.
- The periosteum and joint capsule are incised longitudinally. The medial and lateral flaps are elevated using a scalpel and an elevator to expose the tibiotalar joint to the anterior margins of the malleoli.
- To avoid direct tension on the skin margins, we use deep retractors, one at the proximal aspects of each malleolus.
- Anterior osteophytes are removed with an osteotome, and the talar facets are cleared with a rongeur.
- We then define the physiologic aspects of both malleoli, removing any osteophytes, ossifications, and loose bodies.
The goal is to restore a physiologic tibiocalcaneal axis. Ideally, implant position should produce a joint line at right angles to the mechanical tibial axis in the coronal plane and reproduce the physiologic 7-degree posterior slope in the sagittal plane.

- Align the extramedullary guide with the anterior tibial crest or a line joining the center of the knee and the mid-point of the distal tibial surface.
- Proximally, secure the alignment guide to the anterior tibial tuberosity with a self-drilling pin, roughly perpendicular (in the sagittal plane) to the malleolar tips and distal medial tibial metaphysis in the sagittal plane (TECH FIG 1).
- We then perform five sequential adjustments.

Orientation in the Coronal Plane
- Provided there is anatomic or near-anatomic overall alignment of the lower extremity, the tibial cut should be horizontal and perpendicular to the tibial axis (TECH FIG 2).
- Perform resection using the extramedullary guide referencing off the anterior tibial border.
- A few degrees of coronal plane deviation proximal to the ankle or at the knee is readily compensated by realigning the proximal aspect of the external tibial alignment guide on the pin placed in the tibial tubercle. However, in our experience moderate to severe deformity proximal to the ankle should be corrected before TAA, typically in a staged fashion.

TIBIAL RESECTION
- The goal is to restore a physiologic tibiocalcaneal axis. Ideally, implant position should produce a joint line at right angles to the mechanical tibial axis in the coronal plane and reproduce the physiologic 7-degree posterior slope in the sagittal plane.
- Align the extramedullary guide with the anterior tibial crest or a line joining the center of the knee and the mid-point of the distal tibial surface.
- Proximally, secure the alignment guide to the anterior tibial tuberosity with a self-drilling pin, roughly perpendicular (in the sagittal plane) to the malleolar tips and distal medial tibial metaphysis in the sagittal plane (TECH FIG 1).
- We then perform five sequential adjustments.

FIG 4 • A lateral retractor is placed against the lateral malleolus and a medial retractor against the upper part of the medial malleolus. Anterior osteophytes are removed with an osteotome, and the talar facets are cleared with a rongeur.

TECH FIG 1 • A, B. Left ankle. The extramedullary guide is aligned with the anterior tibial crest. It is attached with self-drilling pins at the anterior tibial tuberosity, roughly perpendicular (in the sagittal plane) to the malleolar tips, and then at the distal medial metaphysis of the tibia. Resection is performed using the extramedullary guide, referencing off the anterior tibial border. A few degrees of axial deviation of the knee joint in the coronal plane can be compensated for by using the proximal holes (arrow) to obtain a perfect adjustment and to perform a bone cut that will be almost horizontal.
Resection Level

- The goal is to restore an anatomic joint line level. When the subchondral architecture of the tibial plafond is intact, the amount of distal tibial resection should match the metal tibial base plate plus the polyethylene insert.
- We use the apex of the tibial plafond as the reference point for tibial resection. To expose this apex, we resect the anterior margin of the tibial plafond using an osteotome. With clinical inspection or fluoroscopic confirmation in the sagittal plane, the resection level is determined from this reference point (TECH FIG 3).
- For the Salto (three-part mobile-bearing) prosthesis, the tibial resection is 7 mm (3 mm for the thickness of the metal base plate plus 4 mm for the minimum thickness of the polyethylene).
- For the Salto-Talaris (two-part fixed-bearing) prosthesis, the minimum resection is 8 mm (3 mm for the thickness of the metal base plate plus 5 mm for the minimum thickness of the polyethylene). However, as a routine we resect 9 mm, which allows for downsizing of the polyethylene in the event that the joint is too tight.
- We modify the tibial cut based on the ligamentous tension in the ankle. In stiff ankles, we typically resect 2 mm more than the minimal resection; in ankles with instability, we generally resect 2 mm less than the minimal resection.
- Bone loss in the tibia may warrant adjusting the tibial cut to re-establish the proper joint line.

Orientation in Rotation

- Since both the tibial and initial talar cutting guides are suspended from the tibial alignment guide, thus linking the tibial and initial talar resection, proper rotational alignment is critical. Malrotation of the components may interfere with the implant’s kinematics, create malleolar

Orientation in the Sagittal Plane

- The external tibial alignment guide, when positioned parallel to the anterior tibial cortex, establishes a physiologic posterior slope of 7 degrees for the tibial cut.
- In our experience, to achieve correct angulation of the tibial cutting block, the extramedullary guide must rest on the tibia at both the proximal and distal ends.
impingement, risk edge loading, and (particularly in the fixed-bearing Salto-Talaris) lead to increased constraint (TECH FIG 4).

While the mobile-bearing Salto implant may compensate for a certain degree of malpositioning, edge loading or overhang of the polyethylene on the metal tibial tray may result. Therefore, every effort should be made to orient the implant on the center bisecting line of the talus in the coronal plane, the line that is parallel with the talus when it is taken through its motion arc. We rotate the cutting guide until it is centered on the line bisecting the space between the medial and lateral talar facets.

Orienting the implant in line with the second metatarsal may be useful but introduces errors with associated midfoot or forefoot deformity.

**Coronal Plane Positioning**

The final adjustment is to center the cutting block on the tibial plafond, often necessitating medial or lateral translation of the cutting block relative to the tibial alignment guide. The proper-size cutting block must be selected; the reference landmarks for sizing are the medial axilla and the lateral edge of the tibia.

- Set the guide to avoid compromise of the malleoli. Secure pins within the cutting block at the level of resection to protect the malleoli from inadvertent saw blade excursion. (TECH FIG 5A).

- Bone resection
  - Before making the sagittal bone cuts (medial and lateral), drill holes through the appropriate-size cutting block and fully insert two short pins through the superior holes to protect the malleoli during resection. Before placing the protective pins, an AP radiograph may be obtained to confirm proper position and sizing of the cutting block in the coronal plane.
  - For a mobile-bearing Salto prosthesis, use the extramedullary guide to initially prepare for the tibial keel as it sets the rotational alignment of the tibial component.
  - When implanting a Salto-Talaris prosthesis, the rotational alignment is established using the trials and ranging the ankle to allow the tibial base and insert assembly to self-center with respect to the trial talar component.
  - The capture guide on the cutting block guides the saw blade.
  - The tibial resection must be completed through the posterior cortex of the distal tibia, without plunging the saw blade into the posterior soft tissues.
  - We typically use a saw blade of adequate length and limited excursion.

- Removing the resected bone
  - Remove the tibial cutting block but leave the external tibial alignment guide in position.
  - With a thin osteotome or small reciprocating saw, complete the two sagittal cuts through the predrilled holes created using the cutting block.
  - Remove the resected bone wafer.
  - The resected bone must be fully mobilized before attempting to extract it from the joint; abrupt mobilization of this bone may result in a fracture of

**TECH FIG 4** • The rotational alignment is of critical importance even more so as the tibial and talar resections are linked. A. The talar component must be aligned with the axis of the talar dome (1) and is centered on the line bisecting the space between the medial and lateral talar facets (2 and 3). External (B) or internal (C) rotational malpositioning of the components will result in increased stress being placed on the fixation system, impingement with the malleoli and may interfere with the kinematics of the joint replacement.
the medial malleolus if the cut is not complete, especially in an ankle with an equinus contracture. The removal of the distal tibial resection is rarely done in one piece; usually piecemeal removal is required.

- Remove the anterior half. With the Salto and Salto-Talaris prostheses removal of the posterior portion may be delayed until after the posterior talar cut is completed (TECH FIG 5B).

TECH FIG 5 • A. The instrument system provides accurate component positioning through adjustment of the resection level, translation, and rotation. Pins can be inserted in the medial and lateral holes of the guide to visualize the limits of the tibial cut with respect to the malleoli. Before the tibial cut is performed, holes are drilled through the appropriate-size cutting block, and two short pins are fully inserted through the superior holes to protect the malleoli during resection (small arrows). B. The removal of the distal tibial resection is rarely done in one piece; usually, piecemeal removal is required. The anterior half is removed, and then removal of the posterior portion can be delayed until after the posterior talar cut is completed.

TALAR PREPARATION

- Talar preparation requires that the ankle can be dorsiflexed to at least 90 degrees.
- This angle is almost always obtained at this stage, since the removal of bone from the tibia (anterior part of tibial resection) will have created more space, even in a stiff ankle.
- In the rare case that it is not achieved, then an Achilles tendon lengthening or gastrocnemius–soleus recession may need to be considered.
- Talar preparation comprises three cuts: posterior, anterior, and lateral. The native medial talar dome is left intact with this technique.

Posterior Talar Chamfer Cut

- To position the talar component properly on the prepared talar dome, the posterior talar cut must be inclined 20 degrees posteriorly.
- With the ankle maintained at 90 degrees of dorsiflexion and the hindfoot in physiologic valgus position, suspend the talar guide from the external tibial alignment guide and insert a pin into the talus (TECH FIG 6A).
- This pin dictates the sagittal orientation of the talar component.
- This reference pin must be placed with the ankle in a strictly neutral position between flexion and extension.
- Excessive dorsiflexion will lead to anterior and flexed positioning of the talar component.
- Excessive plantarflexion tilts the implant backward.
- Secure the posterior chamfer talar cutting block on this reference pin.
- Talar styli are available to determine the level for an anatomic resection that corresponds to the thickness of the talar component.
- In case of severe flattening of the talar dome, this resection level may need to be adjusted. The talar resection level depends on having satisfactory fixation of the implant in healthy bone while simultaneously trying to preserve as much talar bone stock as possible.
- The posterior chamfer cut of the talus should be anatomic, parallel to the superior margin of the talar dome.
- Asymmetric wear must be recognized and the posterior talar chamfer cut adjusted appropriately; shims are available to make such adjustments.
- We do not recommend compensating extra-articular or hindfoot deformity by means of an asymmetric posterior talar chamfer cut; instead, simultaneous or staged hindfoot correction should be performed.
- The talar guide orients the placement of four pins in the talus that are then used to guide the talar resection. Maintain the oscillating saw flush with the dorsal aspects of the pins while protecting the malleoli from injury (TECH FIG 6B).
- The residual tibial bone is relatively easy to extract at this point, along with the resected portion of talus. A lamina spreader without teeth, used judiciously, usually improves exposure.
In our experience, the threshold to deepen the anterior chamfer preparation should be low.

Removing anterior talar neck osteophytes allows the guide to be properly seated on the talus.

Appropriate anterior chamfer preparation is determined using the talar gauge.

With respect to rotation, the guide must be perfectly aligned with the axis of the talar body. The second metatarsal may be used as a reference provided there is no associated foot malalignment.

Proper positioning is essential.

In the sagittal plane, the guide should be positioned flush with the two previously resected surfaces, with no anterior overhang.

In the horizontal plane, rotation is determined with reference to the axis of the talar body.

In the coronal plane, correct mediolateral position is referenced from the lateral margin of the prepared talar dome.

Once correctly positioned, pin the cutting guide to the bone.

First, prepare the talar stem recession using the bell saw. Then insert a dedicated metal peg into this prepared portion of talus to afford greater stability to the lateral talar chamfer cutting guide. Prepare the lateral chamfer using an oscillating or reciprocating saw.

The appropriate-size talar trial is that which provides good coverage of the talus in the mediolateral plane, without medial overhang.

The talar trial lacks the plasma spray coating and thus lacks the interference fit of the actual talar implant; therefore, the talar trial may appear loose. To determine optimal polyethylene thickness and ligament balance, the talar trial remains in situ during insertion of the tibial trials.

Insertion of tibial trials
- Salto mobile-bearing prosthesis
  - Insert the selected trial tibial component flush with the bone cut; this will serve as a drill guide for creation of the press-fit hole for the tapered cylindrical plug.

Insert the mobile bearing. Bearing thickness is crucial to the stability of the implant. A bearing of correct thickness will need to be pushed rather than slipped into the joint.

Salto-Talaris fixed-bearing prosthesis
- Push the trial tibial base and insert assembly into position; it is free to rotate relative to the tibia.

As the ankle is ranged from flexion to extension the tibial trial locates its ideal position and rotation with respect to the talus, unless the tibial trial has essentially the same dimensions as the prepared tibial surface.
When this automatic adjustment is obtained, the definitive position is determined. Perform preparation for the press-fit hole for the tapered cylindrical plug as described above for the Salto prosthesis. The use of a fixed or mobile bearing allows different sizes to be employed on the tibia and on the talus; when this option is being used, the choice of polyethylene size must be by the same size as the talar component. Range the joint and check stability. The implant should be stable in the coronal plane, without any residual laxity; dorsiflexion greater than 10 degrees should be readily obtained.

**INSERTION OF THE DEFINITIVE COMPONENTS**

- Insert the definitive components.
- The prosthesis must have sound initial stability, indicating appropriate ligament balance.
- Before impacting the components, any tibial or talar subchondral cysts or other bone defects may be filled with bone graft.

**TECH FIG 8** • After insertion of the tibial component, the anterior opening of the cortex (A) is filled with bone graft obtained from the bone cuts to prevent any ingress of joint fluid (B).

**CLOSURE**

- Since the skin over the ankle is very delicate, closure must be meticulous.
- Close the wound over an intra-articular drain. Whenever possible, close the capsule with absorbable sutures.
- Suture the fascia and retinaculum. Isolate the toe extensor tendons and particularly the tibialis anterior tendon from the fascial suture line.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Difficulties with trial components</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impossible to insert even the thinnest bearing</td>
<td>Tibial side will need to be re-resected.</td>
</tr>
<tr>
<td>Dorsiflexion unobtainable</td>
<td>1. Check the size and the positioning of the talar component. 2. Check that the posterior capsular structures and the medial and lateral talar margins have been adequately cleared. 3. Perform percutaneous lengthening of the Achilles tendon. 4. Re-resect the tibia.</td>
</tr>
<tr>
<td>Lateral residual laxity</td>
<td>1. Medial collateral ligament release, and use a thicker polyethylene component. 2. Consider lateral ligament reconstruction.</td>
</tr>
<tr>
<td>Absolute contraindications for TAA</td>
<td>Active infection, Poor anterior skin (multiple scars, previous graft), Risk factors for skin necrosis, Major bone loss, Diffuse (as opposed to focal) osteonecrosis of the talus, Nonreconstructable ankle ligamentous instability</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

■ The drain is removed the day after the operation.
■ Once the swelling has subsided, a below-knee circular resin cast is applied.
■ As a rule, weight bearing may be resumed once the resin cast has been applied.
■ Patients who have undergone Achilles tendon lengthening will be non–weight-bearing for 3 weeks.
■ Where there has been a malleolar fracture, the period of non–weight-bearing will be 45 days.
■ The cast is removed after 45 days to prevent skin problems, and physiotherapy is commenced.

OUTCOMES

■ Bonnin et al⁴ reported the results of a consecutive series of their first 98 cases implanted between 1997 and 2000.
■ With a mean 35 months of follow-up (range 24 to 57 months), they reported two failures requiring conversion to ankle arthrodesis.

■ Reviewing the same consecutive series with a mean 6.4 years of follow-up (range 5 to 8.5), they reported five failures necessitating conversion into arthrodesis.⁵
■ The mean AOFAS ankle–hindfoot score preoperatively was 32.3 (SD 10) and 83.1 (SD16) at last follow-up. The mean ankle range of motion measured on dynamic radiographs improved from 15.2 degrees preoperatively (SD 10) to 28.3 degrees at follow-up (SD 7).

COMPLICATIONS

■ Technical difficulties in TAA may arise from a number of factors.

Failure to Re-establish the Physiologic Joint Line

■ The final level of the implant joint line will depend upon the level of the tibial cut.
■ The level is determined with reference to the preoperative radiographs. Depending on the status of the tibial plafond, the anatomy of the malleoli, and lateral talomalleolar congruency, four different patterns may be encountered (FIG 5):

Relative contraindications for TAA

■ Eradicated tibiotalar infection
■ Previous medial or lateral surgical approaches to the ankle (TAA incision will be anterior and central)
■ Multiple prior surgeries to the ankle
■ High body mass index
■ High-demand patient (eg, construction work)
■ Unrealistic patient expectations

FIG 5 • A, B. Ankle mortise intact, no asymmetrical wear of the tibial pilon. C, D. Ankle mortise intact, tibial pilon asymmetrically worn. (continued)
The ankle mortise is intact, with symmetric wear of the tibial plafond. The procedure should be a simple resurfacing, with the metal tibial component and polyethylene thickness replacing exactly what is resected.

The ankle mortise is intact, but the tibial plafond is asymmetrically worn. This pattern is seen in advanced RA, especially in the wake of long-term steroid therapy. In this case, a reasonable and balanced distal tibial resection level will need to be determined during preoperative planning.

The malleoli are deformed, but the tibial plafond is intact. In our experience, this deformity involves the lateral malleolus. This pattern is seen in RA with severe hindfoot valgus that has resulted in a fatigue fracture of the fibula. In this case, the lateral malleolus will need to be managed with malleolar osteotomy and plating before TAA.

The malleoli are deformed and the tibial plafond is worn or depressed. These cases will need to be managed with a combination of the principles discussed above: first, a normal ankle mortise pattern will have to be created, and then a resection level will need to be determined, taking into account the extent of loss of tibial bone stock.

Extra-articular Deformity

- The physiologic ankle joint line is perpendicular to the axis of the tibia, and the hindfoot axis is in slight (5 to 10 degrees) valgus in relation to the tibial axis. To promote long-term implant survival, physiologic alignment will need to be restored.
- Inserting a TAA prosthesis into a malaligned tibia or hindfoot is a recipe for early loosening and failure.
- Correction of deformities may be difficult in sequelae of trauma or RA. Preoperative evaluation should allow the determination of whether these deformities have an intra-articular or extra-articular origin.
- In our experience, most intra-articular deformities resulting from wear or laxity (including varus position caused by OA in chronic instability) can be corrected from within the joint with the prosthesis.
- In contrast, most extra-articular deformities cannot be corrected from within the joint with the prosthesis and must be treated independently with supramalleolar osteotomy, performed either staged or simultaneous to TAA (FIG 6A).
- In our opinion, hindfoot malalignment associated with arthritis must be corrected by doing a triple arthrodesis before TAA (FIG 6B).
We recommend performing staged triple arthrodesis and TAA to reduce the potential for skin problems and edema. In our hands, triple arthrodesis is usually done as a first-stage procedure 45 days before TAA, which avoids prolonged cast immobilization (FIG 7).

We perform the triple arthrodesis by what would be an extension of the anterior approach to the ankle to prepare the talonavicular joint and a limited lateral–subfibular approach to the subtalar joint. We avoid dissection under the talar head to minimize the risk of necrosis of the talar body.

Fixation is achieved using a talocalcaneal screw and two talonavicular and calcaneocuboid staples.

The TAA prosthesis must be positioned on a properly aligned hindfoot.

In RA patients with a valgus deformity and severe lateral bone loss, bone grafting is the rule. Graft material is harvested from a local donor site (bone slices taken from the midtarsal joint, sometimes bone material taken from the proximal tibial metaphysis) and in some cases from the ipsilateral iliac crest in case of severe deformity.

We stage the TAA 45 days after triple arthrodesis using the proximal extension of the same anterior approach. The talocalcaneal screw is removed.

Bone Loss

Implant fixation requires sufficient tibial and talar bone stock and an intact ankle mortise.

In RA patients or in posttraumatic OA, there may be major bone loss, and defects may have to be grafted. In particularly severe cases, TAA may be contraindicated.

Ankle Instability

OA secondary to chronic lateral laxity is technically challenging because the persistence of lateral laxity may cause rapid deterioration of the prosthesis.

In our experience, most cases can be balanced with TAA. We routinely restore the ankle’s soft tissue balance with TAA and comprehensive soft tissue release on the concave side of the deformity.

Medial release in a varus deformity is challenging and involves the entire deltoid ligament, which is first released subperiosteally from its malleolar attachment and then detached from the talus. We have been satisfied with this balancing technique, which, in our hands, eliminates the need for the medial malleolar osteotomy technique to rebalance the deltoid ligament.
With comprehensive and satisfactory medial release, we rarely need to perform a ligament reconstruction on the convex side of the deformity. Occasionally, however, for severe varus malalignment, we need to perform a lateralizing and valgus-producing calcaneal osteotomy to further realign the hindfoot.

### Ankle Stiffness

- End-stage tibiotalar joint arthritis almost always leads to stiffness of the tibiotalar joint.
- Stiffness with equinus deformity requires sequential steps to regain dorsiflexion, beginning with excision of anterior ossifications, then freeing of talomalleolar adhesions, and finally posterior capsulectomy from within the joint.
- The use of a lamina spreader greatly facilitates capsulectomy. However, great caution should be used to avoid avulsion of the medial malleolus and accidental penetration of the prepared tibial surface.
- In particular, the surgeon must make sure that complete capsulectomy is performed at the posteromedial corner, flush with the tibialis posterior tendon.
- Freeing up adhesions to this tendon is important as they may cause postoperative pain, particularly in patients who have previously undergone a procedure through a posteromedial approach.
- In this case, tenolysis of the tibialis posterior tendon with opening of its retinaculum through a limited posteromedial approach may be useful. This approach makes posterior capsular release and even repair of associated fissures much easier.
- Lastly, contracture of the triceps surae and Achilles tendon is often responsible for a deficit of dorsiflexion. Therefore, lengthening should be considered whenever dorsiflexion is less than 10 degrees after insertion of the trials. Release of flexors may be achieved through either tendon lengthening or fasciotomy of the triceps surae.

### Achilles tendon lengthening

- This simple procedure has little influence on the postoperative course, but it is associated with long-term persistence of posterior discomfort and sometimes with permanent loss of plantarflexion strength and range of motion.
- Lengthening technique consists of making two or three percutaneous staged incisions with a fine scalpel; each incision should involve slightly more than half of the tendon.
- The most distal incision may be performed on either side, depending on the fibers to be lengthened—laterally for a valgus deformity in order to preserve varus-oriented fibers, and medially for a varus hindfoot.
- While making incisions, the ankle should be held in forced dorsiflexion with the trial components in place. Dorsiflexion suddenly increases as fibers slide over one another (FIG 8).
- Fasciotomy of the triceps surae usually does not cause postoperative pain; it is performed through a limited midline posterior approach at the middle third of the leg. The sural vein is preserved.
- The insertion fascia of the gastrocnemius is sectioned in a V-shaped fashion, and the underlying soleus fascia is sectioned in line with the muscle fibers. The postoperative course is the same as for Achilles tendon lengthening.

### Anterior Translation of Talus

- Anterior translation of the talus must always be corrected to restore normal kinematics and avoid early wear due to overloading in a fixed-bearing prosthesis or due to overhanging of the polyethylene bearing in a mobile-bearing prosthesis (alignment between the polyethylene bearing and the talar component must be maintained at all times).
- Repositioning of the talar component requires complete soft tissue release (ie, talomalleolar compartment, posterior capsule) as well as correction of equinus deformity (if any) through Achilles tendon lengthening.
- Should these procedures prove ineffective, the talar component will have to be moved posteriorly, which means recutting the anterior chamfer.
- In our experience, the tibial component will have to be positioned as far anteriorly as possible beneath the distal tibia.

### REFERENCES

DEFINITION
- Three-component, mobile-bearing total ankle arthroplasty system indicated for end-stage ankle arthritis failing to respond to nonoperative treatment

ANATOMY
- Ankle
  - Tibial plafond with medial malleolus
  - Articulations with dorsal and medial talus
  - In sagittal plane, slight posterior slope
  - In coronal plane, articular surface is 88 to 92 degrees relative to lateral tibial shaft axis.
- Fibula
  - Articulation with lateral talus
  - Responsible for one sixth of axial load distribution of the ankle
- Talus
  - 60% of surface area covered by articular cartilage
  - Dual radius of curvature
  - Distal tibiofibular syndesmosis
  - Anterior inferior tibiofibular ligament
  - Interosseous membrane
  - Posterior tibiofibular ligament
- Ankle functions as part of the ankle–hindfoot complex much like a mitered hinge.

PATHOGENESIS
- Post-traumatic arthrosis
  - Most common cause
  - Intra-articular fracture
  - Ankle fracture-dislocation with malunion
  - Chronic ankle instability
- Primary osteoarthrosis
  - Relatively rare compared to hip and knee arthrosis
- Inflammatory arthropathy
  - Most commonly rheumatoid arthritis
- Other
  - Hemochromatosis
  - Pigmented villonodular synovitis
  - Charcot neuroarthropathy
  - Septic arthritis

NATURAL HISTORY
- Post-traumatic arthrosis
  - Malunion, chronic instability, intra-articular cartilage damage, or malalignment may lead to progressive articular cartilage wear.
  - Chronic lateral ankle instability may eventually be associated with:
    - Relative anterior subluxation of the talus
    - Varus tilt of the talus within the ankle mortise
    - Hindfoot varus position
- Primary osteoarthrosis of the ankle rare and poorly understood.
- Inflammatory arthropathy
  - Progressive and proliferative synovial erosive changes failing to respond to medical management
  - May be associated with chronic posterior tibial tendinopathy and progressive valgus hindfoot deformity, eventual valgus tilt to the talus within the ankle mortise, potential lateral malleolar stress fracture, and compensatory forefoot varus

PATIENT HISTORY AND PHYSICAL FINDINGS
- History
  - Typically, history of trauma to the ankle
  - Intra-articular ankle fracture (bi- or tri-malleolar ankle fracture; tibial plafond [pilon] fracture)
  - Chronic ankle instability
- Inflammatory arthropathy
  - Primary ankle arthritis
- Symptoms or complaints
  - Pain in anterior ankle with weight bearing and particularly with forced dorsiflexion
  - Often relieved by rest, but patient may have pain even at rest after vigorous activity or prolonged standing
- Ankle swelling
- Ankle stiffness
- Medications
  - If patient is taking anti-inflammatory agents, these will need to be stopped preoperatively to limit the risk of perioperative bleeding.
  - Rheumatoid medications may need to be stopped perioperatively to optimize wound healing and bone ingrowth into the prosthesis.
- Physical examination
  - Alignment
    - Ipsilateral limb alignment, not simply ankle alignment. The lower extremity should be examined from the hip to the foot. Optimal limb alignment is essential for longevity of the implant.
  - Ankle–foot alignment
    - The ankle functions as part of an ankle–subtalar joint complex.
    - The total ankle needs a solid, well-aligned platform on which to rest.
    - Hindfoot, midfoot, and even forefoot malalignment may need to be addressed as part of total ankle arthroplasty.
  - Range of motion (ROM)
    - Preoperative ankle ROM often dictates postoperative ROM. A stiff ankle before surgery may be a stiff ankle after surgery, despite total ankle arthroplasty. Dorsiflexion may be limited by anterior tibiotalar osteoarthropathy, a tight Achilles tendon or posterior capsular contracture, or both.
The examination may identify a distinction between anterior impingement and a tight heel cord.

- Hindfoot ROM: Limitations in ROM of the hindfoot may place eccentric stresses on the implant.

- Soft tissues
  - An intact, relatively healthy soft tissue envelope surrounding the ankle is less likely to have soft tissue complications postoperatively, provided careful soft tissue handling is maintained.
  - Previous surgical scars must be considered. Either they can be incorporated into the surgical approach or the surgical approach may be modified to limit postoperative wound complications.
  - Vascular status: Intact pulses and satisfactory refill must be confirmed; if not, a Doppler ultrasound, noninvasive vascular studies, or both must be performed before considering surgery.
  - Neurologic status: A peripheral neuropathy is a relative contraindication for total ankle arthroplasty, but in our opinion well-controlled diabetes without neuropathy is not. Established neuropathy and either existing or high risk of Charcot neuroarthropathy is a contraindication for total ankle arthroplasty.
  - Motor function: Intact motor function of the ankle and foot is essential to successful total ankle arthroplasty. In particular, lack of active dorsiflexion is a relative contraindication to total ankle arthroplasty. It is important to distinguish between anterior impingement or Achilles contracture or posterior capsular tightness versus lack of satisfactory tibialis anterior tendon function.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Weight-bearing AP, lateral, and mortise views of the ankle (FIG 1A,B)
- Weight-bearing AP, lateral, and oblique views of the foot, particularly with associated foot deformity
- We routinely obtain weight-bearing mechanical axis (hip-to-ankle) views of both extremities (FIG 1C).
- We typically evaluate complex or ill-defined ankle–hindfoot patterns of arthritis with or without deformity using CT of the ankle and hindfoot.
- If we suspect avascular necrosis of the talus or distal tibia, we obtain an MRI of the ankle.
- Electrodagnostic studies are indicated with lack of active dorsiflexion that is not due simply to Achilles contracture, posterior capsular tightness, or anterior impingement.

**DIFFERENTIAL DIAGNOSIS**

- See the “Pathogenesis” section above.

**NONOPERATIVE MANAGEMENT**

- Activity modification
- Bracing
  - Ankle–foot orthosis
  - Double upright brace attached to shoe
- Stiffer-soled shoe with a rocker-bottom modification
- Nonsteroidal anti-inflammatories or COX-2 inhibitors
- Medications for systemic inflammatory arthropathy
- Corticosteroid injection
- Viscosupplementation

**SURGICAL MANAGEMENT**

**Preoperative Planning**

- The surgeon must be sure the patient has satisfactory perfusion to support healing and is not neuropathic.
- Noninvasive vascular studies and potential vascular surgery consultation if necessary.
The surgeon must understand the clinical and radiographic alignment of the lower extremity, ankle, and foot.

- The surgeon must be prepared to balance and realign the ankle. Occasionally, this necessitates corrective osteotomies of the distal tibia or foot, hindfoot arthrodesis, ligament releases or stabilization, and tendon transfers.
- The surgeon should determine whether the coronal plane alignment is passively correctable; this provides some understanding as to whether ligament releases will be required.
- Ankle ROM is determined (FIG 2A,B).
- Ankle stiffness, particularly lack of dorsiflexion, needs to be corrected:
  - Anterior tibiotalar exostectomy
  - Posterior capsular release
  - Occasionally, tendo Achilles lengthening
- Instrumentation
  - These instruments facilitate total ankle arthroplasty:
    - Small oscillating saw to fine-tune cuts, resect prominences with precision, and easily morseize large bone fragments to be evacuated from the joint
    - A rasp for final preparation of cut bony surfaces

The surgeon should determine whether the coronal plane alignment is passively correctable; this provides some understanding as to whether ligament releases will be required.

Ankle ROM is determined (FIG 2A,B).

- Ankle stiffness, particularly lack of dorsiflexion, needs to be corrected:
  - Anterior tibiotalar exostectomy
  - Posterior capsular release
  - Occasionally, tendo Achilles lengthening
- Instrumentation
  - These instruments facilitate total ankle arthroplasty:
    - Small oscillating saw to fine-tune cuts, resect prominences with precision, and easily morseize large bone fragments to be evacuated from the joint
    - A rasp for final preparation of cut bony surfaces

Positioning

- Supine
- Plantar aspect of operated foot at end of operating table
- Foot and ankle well balanced with toes directed to the ceiling
- A bolster under the ipsilateral hip prevents undesired external rotation of the hip.
- We routinely use a thigh tourniquet and regional anesthesia.
  - A popliteal block provides adequate pain relief postoperatively, particularly if a regional catheter is used. Moreover, hip and knee flexion–extension is not forfeited, facilitating safe immediate postoperative mobilization.
  - However, using a thigh tourniquet with a popliteal block typically requires a supplemental femoral nerve block (patient forfeits knee extension) or general anesthesia.

Approach

- Anterior approach to the ankle, using the interval between the tibialis anterior (TA) tendon and the extensor hallucis longus (EHL) tendon
APPROACH

- Make a longitudinal midline incision over the anterior ankle, starting about 10 cm proximal to the tibiotalar joint and 1 cm lateral to the tibial crest.
- Continue the incision midline over the anterior ankle just distal to the talonavicular joint.
- At no point should direct tension be placed on the skin margins; we perform deep, full-thickness retraction as soon as possible to limit the risk of skin complications.
- Identify and protect the superficial peroneal nerve by retracting it laterally.
  - In our experience there is a consistent branch of the superficial peroneal nerve that crosses directly over or immediately proximal to the tibiotalar joint.
- We then expose the extensor retinaculum, identify the course of the EHL tendon, and sharply but carefully divide the retinaculum directly over the EHL tendon.
- We always attempt to maintain the TA tendon in its dedicated sheath.
- Preserving the retinaculum over the TA tendon prevents bowstringing of the tendon and thereby reduces the stress on the anterior wound. Should there be a wound dehiscence, then the TA is not directly exposed. Preserving the retinaculum over the TA tendon is not always possible; some patients do not have a dedicated sheath for the TA.
- Use the interval between the TA and EHL tendon, with the TA and EHL tendons retracted medially and laterally, respectively (TECH FIG 1).
- Identify the deep neurovascular bundle (anterior tibial–dorsalis pedis artery and deep peroneal nerve) and carefully retract it laterally throughout the remainder of the procedure.
- Perform an anterior capsulotomy and elevate the tibial and dorsal talar periosteum to about 6 to 8 cm proximal to the tibial plafond and talonavicular joint, respectively.
- Elevate this separated capsule and periosteum medially and laterally to expose the ankle, access the medial and lateral gutters, and visualize the medial and lateral malleoli.
- Remove anterior tibial and talus osteophytes to facilitate exposure and avoid interference with the instrumentation.

EXTERNAL TIBIAL ALIGNMENT GUIDE

- Position the tibial alignment jig so that the clamp adjustment bar lies over the anterior crest of the tibia and the bar is parallel to the long axis of the tibia (TECH FIG 2A).
- The proximal end of the alignment jig is held in position by a 2.5-mm stabilizing pin.
- The adjustment tube on the yoke post and the extending tibial rod should be parallel to the tibia, or with deformity, aligned with the mechanical axis of the leg.
  - Adjust alignment to obtain proper positioning for the cutting block at the tibial plafond (TECH FIG 2B).
- Reference the tibial cutting block to the medial and lateral sides of the talus (TECH FIG 2C).
- Drill two 2.5-mm pins into the tibia through the guide holes to stabilize the tibial cutting block.
  - The configuration of the guide holes allows adjustment of the cutting block proximally or distally by increments of 2.5 mm to optimize the level of tibial resection.
Initial Tibial Resection

- The tibial resection is performed with an oscillating saw (TECH FIG 3A).
- With an asymmetric wear pattern in the tibial plafond, the resection may not be congruent but should be perpendicular to the tibial shaft axis or, with deformity, to the mechanical axis.
- In our experience, a stiff ankle warrants resection of 2 or 3 mm of distal tibia in excess of the resection needed to create sufficient room for the combined thickness of the implants.
- Do not attempt to remove the resected tibial bone until making a vertical tibial cut that is a vertical extension of the medial gutter of the ankle (TECH FIG 3B). This protects the medial malleolus from fracture.
- Do not lever on either malleolus while removing the resected bone because of the risk of fracture.
- Use the gap template to confirm and adequate tibial resection to accommodate the thickness of the tibial implant and thinnest mobile polyethylene bearing (TECH FIG 3C). If the guide does not fit in the space, further bone resection is required (TECH FIG 3D,E).

B C

TECH FIG 2 • (continued) B. Anterior view. C. Initial tibial preparation, cutting block set for initial resection.

TIBIAL PREPARATION

Initial Tibial Resection

- The tibial resection is performed with an oscillating saw (TECH FIG 3A).
- With an asymmetric wear pattern in the tibial plafond, the resection may not be congruent but should be perpendicular to the tibial shaft axis or, with deformity, to the mechanical axis.
- In our experience, a stiff ankle warrants resection of 2 or 3 mm of distal tibia in excess of the resection needed to create sufficient room for the combined thickness of the implants.
- Do not attempt to remove the resected tibial bone until making a vertical tibial cut that is a vertical extension of the medial gutter of the ankle (TECH FIG 3B). This protects the medial malleolus from fracture.
- Do not lever on either malleolus while removing the resected bone because of the risk of fracture.
- Use the gap template to confirm and adequate tibial resection to accommodate the thickness of the tibial implant and thinnest mobile polyethylene bearing (TECH FIG 3C). If the guide does not fit in the space, further bone resection is required (TECH FIG 3D,E).

A B

TECH FIG 3 • Initial tibial preparation. A. Oscillating saw. B. Vertical cut to complete initial tibial cut (protects medial malleolus from potential fracture). (continued)
The proper component size is based on the markings on the upper surface of the gauge.

- Select the corresponding tibial profile guide to confirm that the size determined from the AP dimension is also appropriate in the medial-to-lateral dimension. If not, downsizing is necessary.
- The tibial components are sized 1 through 6, with 1 being the smallest and 6 being the largest.
- Subsequent tibial cuts will be specific for the size of implant selected at this stage.

### Tibial Sizing

- Use the tibial sizing gauge to determine the optimal tibial component size in the AP dimension (TECH FIG 4A).
- The talar component may be of equal in size or smaller than the tibial component (TECH FIG 4B), but it cannot be larger than the tibial component (TECH FIG 4C).
- Place the gauge on the prepared tibial surface and hook it on the posterior aspect of the tibia (TECH FIG 4D,E).

### TECH FIG 3 (continued)

- C. Gap template matches thickness of tibial base plate and the thinnest polyethylene bearing.
- D. Cutting block moved 2 mm more proximally on same pins to allow greater resection in same plane as initial cut.
- E. Repeat resection.

### TECH FIG 4

- A. Tibial sizing gauge adjacent to corresponding tibial trial.
- B. Tibial sizing gauge next to talar trial.
- C. Corresponding tibial sizing gauge, tibial trial, and talar trial. (continued)
**Tibial Window Resection**

- Select the tibial template corresponding to the size determined from the guides used for sizing (TECH FIG 5A).
- Fit the tibial window cutting block to the tibial template and secure it with the system handle adapter.
- Place the assembly flush on the prepared tibial surface, with the tibial template flat against the resected flaphond and the tibial window cutting block held firmly against the anterior tibia (TECH FIG 5B).

- The scissor distractor supports the tibial window cutting block–tibial template assembly.
- Use a 6-mm tibial drill to prepare the proximal aspect of the tibial window resection.
- Drill to the depth stop.
- Insert a tibial window peg to stabilize the tibial window cutting block.
- Remove the system handle but leave the scissor distractor to further stabilize the tibial window cutting block–tibial template assembly.

---

**TECH FIG 4 (continued)**

- **D, E.** Tibial sizing using the tibial sizing gauge. **D.** Gauge being introduced to joint. **E.** Gauge hooked on posterior tibial cortex.

**TECH FIG 5 • Tibial window preparation.**

- **A.** Tibial window cutting block adjacent to its corresponding tibial template–sizing gauge. **B.** Tibial window cutting block assembled to the tibia template and placed flush against initial tibial prepared surface and flush with the anterior tibial cortex. **C.** After drilling proximal hole and placing a stabilizing post, the oscillating saw is used to cut the anterior tibial window. **D.** Tibial window extractor. (continued)
Immediately adjacent to the window cutting block, cut the medial and lateral sides of the window with an oscillating saw (TECH FIG 5C).

- Mark the appropriate depth on the saw blade corresponding to the size of tibial component to be implanted.
- After preparing the tibial window sides, remove all instruments.
- Position the tibial window extractor on the distal tibial surface.
- The appropriate mark on its upper surface must be positioned against the anterior tibial cortex.

By carefully levering against the talus, force the cutting edge of the tibial window extractor into the firm subchondral bone of the distal tibia, thereby releasing the bony resection (TECH FIG 5D).

- Retain this bone segment, as it is replaced after trimming at a later stage.
- Use the tibial window impactor to compact the most proximal cancellous bone in the tibial window to the required depth, indicated by the markings on the impactor (ie, size 1 through 6; TECH FIG 5E).
- Insert the tibial trial to be sure it fits appropriately and is perfectly centered over the talus (TECH FIG 5F).

### TALAR PREPARATION

#### Superior Talar Flat Resection

- Assemble the tibial template used to make the tibial window resections with the tibial template post and the talar pin jig. The assembly is secured with the system handle adapter.
- There are four talar pin jigs: 5 mm, 7 mm, 9 mm, and 11 mm.
- Estimate the bearing insert thickness that is appropriately sized and avoids excessive dorsiflexion of the ankle.
- Place the tibial template, tibial post, and talar pin jig assembly in the resected tibial window (TECH FIG 6A). Use the system handle to hold this assembly in position.
- With the correct-thickness talar pin jig in place, hold the foot 90 degrees to the lower leg, and insert the first 2.5-mm pin through the talar guide (TECH FIG 6B). The foot must be held at 90 degrees relative to the lower leg; this is essential during talar drill pin insertion.
- Insert a second pin into one of the two other holes (TECH FIG 6B). Avoid the medial and lateral extremes of the talus.
- Remove all the instruments but leave the 2.5-mm talar drill pins, which should be parallel to the long axis of the talus (TECH FIG 6C).
- Slide the “standard” talar flat cutting block onto the 2.5-mm pins with the groove uppermost and on the left.
- Resect the superior flat of the talus (TECH FIG 6D,E). Keep the saw blade flush with the cutting block.

---

**TECH FIG 5** (continued)  
E. Tibial window impactor to finalize window preparation.  
F. Tibial trial confirming satisfactory window preparation.

**TECH FIG 6** (continued)  
A. Tibial template, tibial post, and talar pin guide assembly in place.  
B. With ankle at neutral position, talus is pinned through the talar pin guide. (continued)
Transfer of Joint Center to Talus

- Assemble the talar center guide (TECH FIG 7A,B).
- Insert the tibial template into the resected tibial window with the 2.5-mm drill pins and the talar flat cutting block still in position (TECH FIG 7C).
- Align the foot into the neutral position and guide the locating runners on the talar center guide into the grooves in the tibial template superiorly and the groove in the talar flat cutting block inferiorly.
- Once the correct spacing is achieved, advance the talar center guide until the superior runners contact the end of the tibial template grooves. Use a center guide packing between the talar center guide and the tibial template if the space between the tibia and the talus is excessive.
- Advance the stop block until it meets the front of the talar flat cutting block and lock it into position using the locking screw.
- Plantarflex the ankle and remove the tibial template.
- Adjust the talar center guide on the talar flat cutting block so that the talar center guide’s stop block contacts the top of the talar flat cutting block.
- The two bands marked on the talar center guide correspond to two ranges within the six available talar component sizes.
- The AP length of the talar flat must be at least equal to the bands for the smallest range of sizes marked on the talar center guide.
- If the AP talar flat is less than the bands marked on the talar center guide, then more superior talar flat must be resected.
- Use the “low” talar flat cutting block to remove more of the superior talus.
- At this point a decision must be made whether the optimal talar size falls in the size range 1–4 or 5–6. The anterior and posterior chamfer cuts are the same within these respective ranges but different as the size transitions from size 4 to 5.
- The size of the bearing insert component must match the size of the talar component.
- The size of the talar component and bearing insert must be smaller than or equal to that of the tibial component selected to prevent overhang of the bearing compared to the tibial plate.
- The sizes of subsequent cutting blocks used to further resect the talus are based on the talar size selection.
- Once the appropriate amount of talar flat cut has been confirmed, properly position the talar center guide against the talar flat cutting block and insert a 2.5-mm guide pin into the talus (TECH FIG 7D).
The forked end of the talar center guide determines the position for the 2.5-mm pin.
- Insert the pin at about 60 degrees relative to the superior talar flat.
- This 2.5-mm pin identifies the AP center of the tibial component in relation to the talus.
- Visually confirm that the 2.5-mm pin is in the AP center of the talus (TECH FIG 7E).
- If the pin is not in the optimal position, repeat the transfer of the joint center and reposition the 2.5-mm guide pin in the exact AP center of the talus.

Anterior and Posterior Talar Flat Resection
- Remove the talar center guide but leave the 2.5-mm guide pin and the talar flat cutting block in position.
- Select the talar fin drill guide, either size 1–4 or size 5–6, to correspond to the size of talar component to be implanted, and attach it to the system handle.
- Guide the runner on the underside of the fin drill guide into the groove on the left side of the talar flat guide and advance the forked end along the resected talar flat cut until it abuts the 2.5-mm talar guide pin (TECH FIG 8A).
- Using the system handle to hold the fin drill guide in position, drill four holes into the talus using the 4.5-mm drill bit (TECH FIG 8B). Be sure to seat the drill fully against the talar fin guide so that the holes are created to the required depth.
- Remove the talar fin drill guide, the talar flat cutting block, and all 2.5-mm guide pins from within the joint space (TECH FIG 8C).

Trephine Guide
- Select the appropriate trephine guide (either size 1–4 [blue] or size 5–6 [green]) to correspond to the size of talar component to be implanted, and attach it to the system handle (TECH FIG 9A).
- The four posts in the trephine guide fit into the four drill holes made in the talus, and the guide is held in position using the system handle (TECH FIG 9B).
- Two posts are marked “A” for anterior and must be inserted into the anterior two holes in the talus.
- The other two posts are marked “P” for posterior and
must be inserted into the posterior two holes in the talus.

- Trephine the superior and posterior talar sulcus using the specifically designed depth-stopped trephine.
- After the superior and posterior sulci have been trephined, remove the trephine guide (TECH FIG 9C).

### Posterior Chamfer Preparation

- Select the appropriate posterior cutting block (either size 1–4 [blue] or size 5–6 [green]) to correspond to the size of talar component to be implanted, and attach it to the system handle.
- The two posts on the posterior cutting block are marked “A” for anterior. These posts must be inserted into the anterior holes in the talus.
- In the proper position, the tongue of the posterior cutting block will sit flush in the posterior sulcus that has just been trephined. The scissor distractors may be used to steady the cutting block.
- Resect the posterior talar flat and remove the posterior cutting block (TECH FIG 10).

### Anterior Chamfer Preparation

- Select the appropriate anterior milling guide (either size 1–4 [blue] or size 5–6 [green]) to correspond to the size of talar component to be implanted, and attach it to the system handle (TECH FIG 11A,B).
- The two posts on the anterior milling guide are marked “P” for posterior; these posts must be inserted into the posterior holes in the talus.
- In the correct position the posterior face of the jig will be aligned with the resected posterior talus.
- The scissor distractors may be used to steady the jig.
- The talar anterior mill has a depth stop and is moved throughout the guide to prepare the anterior chamfer (TECH FIG 11C).
- The anterior milling guide restricts the mill from completely preparing the entire anterior chamfer.
There are six sizes of talar and tibial trials corresponding to the six available final component sizes.

- The size of talar implant must match or be smaller than the size of the tibial implant.
- Insert the proper talar trial, narrow aspect directed posteriorly. The tibial window serves as a convenient access for the talar impactor (TECH FIG 12A).
- Select the trial tibial component corresponding to the prepared tibial window and insert it straight anterior to posterior within the distal tibial window resection.
- The curved aspect of the component is directed posteriorly.
- The articular surface of the tibia component will be positioned about 85 degrees to the long axis of the leg.
- The anterior aspect of the component should be flush with the anterior cortex of the tibia.
- The posterior aspect of the component may overhang the rear of the tibia by 1 mm in the midpoint but should not do so near the malleoli as it may irritate the neurovascular bundle, tendons, or posterior soft tissues.

- The medial and lateral dimensions of the tibial trial ideally should match the tibial resection. Most importantly it must cover all aspects of the polyethylene insert (TECH FIG 12B).
- The bearing insert is available in the six sizes, and there are five different thicknesses.
- The six sizes of bearing insert trials are color-coded according to size (1, black; 2, brown; 3, purple; 4, yellow; 5, hot pink; 6, red).
- The trial bearing insert’s handle facilitates bearing removal without restricting trial joint motion or obstructing visualization of the resurfaced joint (TECH FIG 12C).
- Confirm proper alignment and trial component position fluoroscopically (TECH FIG 12D–F). Also confirm that there is no indication of stress fracture.
- Confirm that the ankle is balanced and that ROM is adequate, particularly dorsiflexion beyond neutral (TECH FIG 12G,H).

After removing the anterior milling guide, use a rongeur to remove residual anterior bony prominences.

- Finish the superior and posterior sulci by using the sulcus osteotome and the sulcus burr (TECH FIG 11D).
- The talar profile template confirms satisfactory preparation of the talus (TECH FIG 11E).

TRIAL INSERTION

- Use the fin osteotome, the rongeur, or both to remove the small piece of bone between the anterior and posterior drill holes guided by the plastic fin angle guide (TECH FIG 11F,G).
The tibial and talar components are intended for uncremented use (TECH FIG 13A).

- Seat the talar component with the narrow aspect of the component directed posteriorly and the keel fins directed in line with the slots.
  - Use the component impactor, which can be positioned in the tibial window so that the posterior talus may be fully seated.
  - To avoid anterior tilt of the component, we routinely place an instrument under the anterior aspect of the component during initial impaction (TECH FIG 13B).

- Protect the articulating surface of the talar component with a trial insert bearing and insert the tibial component.
  - The curved aspect of the component is directed posteriorly.

- Ensure that the implant is seated firmly on the prepared distal surface of the tibia (TECH FIG 13C,D).
- Check for any osteophytes that might impinge within the joint and trim if needed, taking care not to damage the polished articulating surfaces.
- Make the final decision about the thickness of the bearing, using trials as necessary.
- Insert the final polyethylene bearing (TECH FIG 13E).
- Trim and replace the resected bone in the tibial window, using slivers of bone in the saw cuts to enhance the stability of the “graft” (TECH FIG 13F–I).
- Be sure that motion is adequate, particularly dorsiflexion (TECH FIG 13J–L).
- Confirm proper alignment and implant position fluoroscopically. Also confirm that there is no indication of stress fracture.
TECH FIG 13 • Final implants. A. Surfaces prepared for cementless implantation. B. The anterior lip of the talar component is supported during its initial insertion to keep it from tilting anteriorly. C, D. Tibial component insertion (note use of a bearing trial to support the tibial component during insertion and to protect the talar component). E. Final components in place, including mobile bearing. F–L. Final steps of implantation. F. Replacing anterior tibial cortical fragment that was removed to create tibial window. G. The cancellous portion must be carefully trimmed. H–J. Anterior cortex fragment in place and then impacted. K, L. Adequate motion confirmed.
**CLOSURE AND CASTING**

- Thoroughly irrigate the joint and implant with sterile saline.
- While protecting the prosthesis, fill the anterior barrel holes with bone graft from the resected bone.
- The pin should have already been removed from the proximal tibia.
- Reapproximate the capsule.
- Use of a drain is by surgeon preference.

- Release the tourniquet and obtain meticulous hemostasis.
- Reapproximate the extensor retinaculum while protecting the deep and superficial peroneal nerves.
- Irrigate the subcutaneous layer with sterile saline and then reapproximate it.
- Reapproximate the skin to a tensionless closure.
- Place sterile dressings on the wounds, adequate padding, and a short-leg cast with the ankle in neutral position.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tibial preparation</strong></td>
<td>Use the gap template after the initial tibial resection to confirm that an adequate tibial resection has been completed. The gap template equals the combined height of the tibial base plate and the most narrow polyethylene bearing. If it does not fit, then more tibial resection is warranted.</td>
</tr>
<tr>
<td><strong>Removing resected tibial bone</strong></td>
<td>Be sure to make a vertical cut from the medial ankle gutter, all the way from anterior to posterior, before attempting to mobilize the resected portion of tibia. If it still has medial attachment, the medial malleolus may fracture.</td>
</tr>
<tr>
<td><strong>Talar sizing</strong></td>
<td>The talar preparation is in two ranges: sizes 1–4 have exactly the same talar preparation; sizes 5–6 have the same talar preparation. Therefore, a decision must be made between sizes 4 and 5 but not for sizes within a given range.</td>
</tr>
<tr>
<td><strong>Tibial window preparation</strong></td>
<td>Be sure to save the bone that is removed through the anterior tibial cortical window; it will be used to fill the defect at the conclusion of the surgery.</td>
</tr>
<tr>
<td><strong>Impacting the talar component</strong></td>
<td>The tibial window allows for optimal positioning of the talar impactor, so that it can impact directly vertically on the talar trial and final component.</td>
</tr>
<tr>
<td><strong>Relative sizes of the tibial and talar components</strong></td>
<td>The talus must be the same size as or smaller than the tibial component, and the polyethylene bearing must be smaller than the tibial base plate to avoid edge loading and impingement.</td>
</tr>
<tr>
<td><strong>Final motion</strong></td>
<td>If the ankle cannot be dorsiflexed beyond neutral with the components in place, consider a thinner polyethylene insert or a tendo Achilles lengthening versus gastrocnemius–soleus recession, or both.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**

- Overnight stay
- Nasal oxygen while in hospital
- Touch-down weight bearing on the cast is permitted, but elevation is encouraged as much as possible.
- Follow up in 2 to 3 weeks for suture removal and transition to a cam boot

- Weight bearing to tolerance starting at 3 weeks
- If the wound is stable, supervised therapy to reduce edema and optimize motion.
- At 6 weeks after surgery, weight-bearing radiographs of the ankle are obtained (FIG 3).
- If the wound is stable and radiographs suggest early bone ingrowth and no signs of stress fracture, weight bearing is

---

**FIG 3** • Follow-up weight-bearing radiographs. **A.** AP view of ankle. **B.** Lateral view of ankle. (continued)
gradually advanced and the patient is transitioned to a regular shoe.
- If there is no evidence of stress fracture or failure of the procedure, then the patient can progress to a regular shoe and full weight bearing.

OUTCOMES
- While some recently reported outcomes are based on high-level evidence, results of total ankle arthroplasty are almost uniformly derived from level IV evidence.
- Functional outcome using commonly used scoring systems for total ankle arthroplasty (AOFAS [Kofoed, Mazur] and NJOJ [Buechel-Pappas]) suggest uniform improvement in all studies, with follow-up scores ranging from 70 to 90 points (maximum 100 points).
- Patient satisfaction rates for total ankle arthroplasty exceed 90%, although follow-up data for patient satisfaction often do not exceed 5 years.
- Overall survivorship analysis for currently available implants, designating removal of a metal component or conversion to arthrodesis as the endpoint, ranges from about 90% to 95% at 5 to 6 years and 80% to 92% at 10 to 12 years.
- At the time of this writing there are no published results available for the Mobility total ankle arthroplasty.

COMPLICATIONS
- Infection (superficial or deep)
- Neuralgia (superficial or deep peroneal nerve; rarely tibial nerve)
- Delayed wound healing
- Wound dehiscence
- Persistent pain despite optimal orthopaedic examination and radiographic appearance of implants
- Osteolysis
- Subsidence
- Medial malleolar stress fracture
- Implant fracture (including polyethylene)

REFERENCES
DEFINITION

- The INBONE™ (Wright Medical, Memphis, TN) total ankle system, like other total ankle systems, is indicated for end-stage ankle arthritis failing to respond to nonoperative intervention.
- In contrast to essentially all other total ankle systems, however, the INBONE™ total ankle system uses intramedullary rather than extramedullary referencing.
- While the intramedullary alignment guide passes through the plantar foot, calcaneus, talus, and tibia, it does so anterior to the posterior facet of the calcaneus and does not violate any articulations of the subtalar joint.
- To achieve reliable intramedullary alignment, the INBONE™ total ankle system uses a leg frame that is initially cumbersome, demands more pre-incision preparation, and requires greater fluoroscopy time than other total ankle systems. However, with experience this technique becomes manageable and allows the user to correct deformities prior to making bone cut.

ANATOMY

- Ankle
  - Tibial plafond with medial malleolus
  - Articulations with dorsal and medial talus
  - In sagittal plane, slight posterior slope
  - In coronal plane, articular surface is 88 to 92 degrees relative to lateral tibial shaft axis.
- Fibula
  - Articulation with lateral talus
  - Responsible for one sixth of axial load distribution of the ankle
- Talus
  - 60% of surface area covered by articular cartilage
  - Dual radius of curvature
  - Distal tibiofibular syndesmosis
  - Anterior inferior tibiofibular ligament
  - Intercosseous membrane
  - Posterior tibiofibular ligament
- Ankle functions as part of the ankle–hindfoot complex much like a mitered hinge.

PATHOGENESIS

- Post-traumatic arthrosis
- Most common cause
- Intra-articular fracture
- Ankle fracture-dislocation with malunion
- Chronic ankle instability
- Primary osteoarthrosis
- Relatively rare compared to hip and knee arthrosis
- Inflammatory arthropathy
- Most commonly rheumatoid arthritis
- Other
  - Hemochromatosis
  - Pigmented villonodular synovitis
  - Charcot neuroarthropathy
  - Septic arthritis

NATURAL HISTORY

- Post-traumatic arthrosis
- Malunion, chronic instability, intra-articular cartilage damage, or malalignment may lead to progressive articular cartilage wear.
- Chronic lateral ankle instability may eventually be associated with:
  - Relative anterior subluxation of the talus
  - Varus tilt of the talus within the ankle mortise
  - Hindfoot varus position
- Primary osteoarthrosis of the ankle is rare and poorly understood.
- Inflammatory arthropathy
- Progressive and proliferative synovial erosive changes failing to respond to medical management
- May be associated with chronic posterior tibial tendinopathy and progressive valgus hindfoot deformity, eventual valgus tilt to the talus within the ankle mortise, potential lateral malleolar stress fracture, and compensatory forefoot varus.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient history
- Often a history of ankle trauma
  - Ankle fracture, particularly intra-articular
  - Ankle fracture with malunion
  - Chronic ankle instability (recurrent ankle sprains)
  - Chronic anterior ankle pain, primarily with activity and weight bearing
  - Ankle stiffness, particularly with dorsiflexion
  - Ankle swelling
  - Progressively increased pain with activity
- Physical findings
  - Limp
  - Patient externally rotates hip to externally rotate ankle to avoid painful push-off.
  - Painful and limited ankle range of motion (ROM), particularly limited dorsiflexion
  - Mild ankle edema
  - Potential associated foot deformity
    - Post-traumatic arthrosis secondary to chronic instability may be associated with varus ankle and hindfoot and compensatory forefoot varus.
    - Inflammatory arthritis may be associated with progressively worsening flatfoot deformity, valgus tilt to the ankle and hindfoot, and equinus.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Weight-bearing AP with contralateral ankle included, lateral, and mortise views of the ankle
■ Weight-bearing AP with contralateral foot included, lateral, and oblique views of the foot, particularly with associated foot deformity
■ With associated or suspected lower leg deformity, we routinely obtain weight-bearing AP and lateral tibia–fibula views.
■ With deformity in the lower extremity, we occasionally obtain weight-bearing mechanical axis (hip-to-ankle) views of both extremities.
■ We occasionally evaluate complex or ill-defined ankle–hindfoot patterns of arthritis with or without deformity using CT of the ankle and hindfoot.
■ If we suspect avascular necrosis of the talus or distal tibia, we obtain an MRI of the ankle.

DIFFERENTIAL DIAGNOSIS
■ See the “Pathogenesis” section.

NONOPERATIVE MANAGEMENT
■ Activity modification
■ Bracing
■ Ankle-foot orthosis
■ Double upright brace attached to shoe
■ Stiffer-soled shoe with a rocker-bottom modification
■ Nonsteroidal anti-inflammatories or COX-2 inhibitors
■ Medications for systemic inflammatory arthropathy
■ Corticosteroid injection
■ Viscosupplementation

SURGICAL MANAGEMENT
■ In contrast to essentially all other total ankle systems, the INBONE™ total ankle system uses intramedullary rather than extramedullary referencing.
■ While the intramedullary alignment guide passes through the plantar foot, calcaneus talus, and tibia, it does so anterior to the posterior facet of the calcaneus and does not violate any articulations of the subtalar joint.
■ To achieve reliable intramedullary alignment, the INBONE™ total ankle system uses a leg frame that is initially cumbersome, demands more pre-incision preparation, and requires greater fluoroscopy time than other total ankle systems. However, with experience this technique becomes manageable and allows the user to correct deformities prior to making bone cut.
■ In our opinion, the INBONE™ total ankle system is perhaps more stout than some other systems.
■ We have been able to correct coronal and sagittal plane deformities through the tibiotalar joint with appropriate soft tissue balancing and corrective osteotomies relying also on the durability of the implants, particularly the broad talar component and the tibial stem extensions to maintain correction.

Preoperative Planning
■ The surgeon must be sure the patient has satisfactory perfusion to support healing and is not neuropathic.
■ Noninvasive vascular studies and potential vascular surgery consultation if necessary
■ The surgeon must inspect the ankle for prior scars or surgical approaches that need to be considered in planning the surgical approach for total ankle arthroplasty.
■ The surgeon must understand the clinical and radiographic alignment of the lower extremity, ankle, and foot.
■ The surgeon must be prepared to balance and realign the ankle. Occasionally, this necessitates corrective osteotomies of the distal tibia or foot, hindfoot arthrodesis, ligament releases or stabilization, and tendon transfers.
■ The surgeon should determine whether coronal plane alignment is passively correctable; this provides some understanding as to whether ligament releases will be required.
■ Ankle ROM is determined.
■ Ankle stiffness, particularly lack of dorsiflexion, needs to be corrected.
■ Anterior tibiotalar exostectomy
■ Posterior capsular release
■ Occasionally, tendo Achilles lengthening
■ Instrumentation
■ These instruments facilitate total ankle arthroplasty:
■ Small oscillating and reciprocating saws for fine cuts as well as larger oscillating saw for broad bone cuts. The smaller saws make it easier to ressect prominences with precision, and easily morselize large bone fragments to be evacuated from the joint.
■ A rasp for final preparation of cut bony surfaces
■ A 90-degree angled curette, particularly to separate bone from the posterior capsule
■ A toothed lamina spreader to distract the joint and aid in realignment of preoperative ankle deformity. Since the INBONE™ prosthesis uses a monoblock cutting guide for tibial and talar resection, an intra-articular lamina spreader assists in limiting bone resection. A lamina spreader placed on the concave side of the joint also assists in realignment.
■ A toothless lamina spreader to judiciously distract the ankle to improve exposure even after preparing the surfaces of the tibia and talus
■ Large fluoroscopic scanner
■ Fluoroscopy confirms proper alignment of the cutting guide to the ankle.
■ The leg holder maintains the leg in position relative to the alignment guides and reference drill.
■ With the leg holder, the large scanner is necessary to straddle the leg and leg holder.
■ Fluoroscopy through the operating table is necessary, so a little fluoroscopy unit is inadequate.
■ Foot pedals to make adjustments to the table position
■ With the foot secured in the leg holder, subtle adjustments to the table’s rotation confirm ideal alignment relative to the alignment guides.
■ Subtle adjustments to the alignment guides relative to the ankle allow fine-tuning for the reference drill trajectory.

Positioning
■ Supine
■ Plantar aspect of operated foot at end of operating table
■ Foot and ankle well balanced with toes directed to the ceiling
■ A bolster under the ipsilateral hip prevents undesired external rotation of the hip.
■ We routinely use a thigh tourniquet and regional anesthesia.
■ A popliteal block provides adequate pain relief postoperatively, particularly if a regional catheter is used. Moreover, hip and knee flexion–extension is not forfeited, facilitating safe immediate postoperative mobilization.
■ However, using a thigh tourniquet with a popliteal block typically requires a supplemental femoral nerve block (patient temporarily forfeits knee extension in the immediate postoperative period) or general anesthesia.
The operative extremity needs adequate space for the INBONE™ leg holder. The surgeon should be sure the opposite extremity is not secured too close to the operative extremity.

**Approach**

- Anterior approach to the ankle, using the interval between the tibialis anterior (TA) tendon and the extensor hallucis longus (EHL) tendon.
- The operative extremity needs adequate space for the INBONE™ leg holder. The surgeon should be sure the opposite extremity is not secured too close to the operative extremity.

**TECH FIG 1** – In this case there is no separate sheath for the tibialis anterior (TA) tendon. Nonetheless, the retinaculum was opened lateral to the tendon, and upon closure the TA will not be immediately up against the suture line.

**TECHNIQUES**

- **Approach**
  - Anterior approach to the ankle, using the interval between the tibialis anterior (TA) tendon and the extensor hallucis longus (EHL) tendon.
  - Make a longitudinal midline incision over the anterior ankle, starting about 10 cm proximal to the tibiotaral joint and 1 cm lateral to the tibial crest.
  - Continue the incision midline over the anterior ankle just distal to the talonavicular joint.
  - At no point should direct tension be placed on the skin margins; we perform deep, full-thickness retraction as soon as possible to limit the risk of skin complications.
  - Identify and protect the superficial peroneal nerve by retracting it laterally.
  - In our experience there is a consistent branch of the superficial peroneal nerve that crosses directly over or immediately proximal to the tibiotaral joint.
  - We then expose the extensor retinaculum, identify the course of the EHL tendon, and sharply but carefully divide the retinaculum directly over the EHL tendon.
  - We always attempt to maintain the TA tendon in its dedicated sheath if present.
  - Preserving the retinaculum over the TA tendon prevents bowstringing of the tendon and thereby reduces the stress on the anterior wound. Should there be a wound dehiscence, then the TA is not directly exposed.
  - However, preserving the retinaculum over the TA tendon is not always possible. Not infrequently only the retinaculum is present over the tendon and it will be free with the EHL tendon (TECH FIG 1).
  - Use the interval between the TA and EHL tendons, with the TA and EHL tendons retracted medially and laterally, respectively.
  - Identify the deep neurovascular bundle (anterior tibial–dorsalis pedis artery and deep peroneal nerve) and carefully retract it laterally throughout the remainder of the procedure.
  - Perform an anterior capsulotomy and elevate the tibial and dorsal talar periosteum to about 6 to 8 cm proximal to the tibial plafond and talonavicular joint, respectively.
  - Elevate this separated capsule and periosteum medially and laterally to expose the ankle, access the medial and lateral gutters, and visualize the medial and lateral malleoli.
  - Remove anterior tibial and talar osteophytes to facilitate exposure and avoid interference with the instrumentation.

**TIABTOTALAR ALIGNMENT**

- Before placing the lower leg in the INBONE™ foot and ankle holder, we optimize ankle soft tissue balance and alignment.
- Varus malalignment
  - We routinely perform a comprehensive medial release for moderate to severe varus malalignment.
  - The concept is similar to balancing the varus knee for total knee arthroplasty and was well described by Bonnin et al. in their 2004 report of the Salto prosthesis.
  - We routinely subperiosteally raise a continuous soft tissue sleeve from the distal medial tibia to the medial talus.
- There is no need to be aggressive on the medial talus, as this could compromise the deltoid branch of the posterior tibial artery that perfuses the medial talar dome.
- The superficial deltoid (medial collateral) ligament is elevated but left intact proximally and attached distally. The release of these fibers is complete when the posterior tibial tendon can be visualized.
- The deep deltoid (medial collateral) ligament may be peeled off the medial malleolus to balance the ankle appropriately. In severe varus deformity, the entire deep deltoid ligament must be released to achieve
tibiotalar balance (TECH FIG 2A). Overrelease is theoretically possible, but in our experience, with severe varus deformity, the ankle will not collapse into valgus even with a complete release.

- In our experience, with an appropriate medial release, optimal bony resection and metal component alignment, and proper sizing of the polyethylene, a lateral ligament reconstruction is seldom necessary. One exception is when there has been an avulsion fracture of the tip of the fibula: in that instance it is difficult to obtain any ability to rotate the ankle against the lateral tissue, and a Brostrom ligament reconstruction can be done at the beginning of the case (TECH FIG 2B–D). This marks a significant change from our initial practices in rebalancing the varus ankle.

- A lamina spreader placed in the medial tibiotalar joint maintains the correction.

- Valgus malalignment
  - Likewise, a valgus malalignment must be rebalanced.
  - However, in our experience, we rarely need to perform a ligament release.
  - Often, valgus malalignment is secondary to lateral ankle joint collapse and some medial (deltoid) ligament attenuation. This may involve a component of lateral ankle ligament instability as well.
  - While the latter portion of this statement seems counterintuitive, it has been our experience in treating many patients with end-stage ankle arthritis and valgus malalignment.
  - Moreover, lateral release in such situations may lead to paradoxical lateral instability!
  - We use a lateral lamina spreader to realign the ankle and regain functional tension in the medial ligaments (TECH FIG 2E,F).

**TECH FIG 2**  
A. In this varus ankle a complete medial peel of the deltoid ligament has been performed and the ankle can be opened up with the lamina spreader. B. There was a large ossicle at the tip of the fibula representing an old avulsion fracture containing the anterior talofibular ligament. Hence, the bone was removed (C) and a Brostrom ligament reconstruction was performed (D). E. Valgus ankle with AP alignment guide properly rotated. However, the talus is not orthogonal to the guide or the tibia. F. In this view the lamina spreader has been placed laterally on the concave side, and now the talus is orthogonal to the tibia and the alignment guide.
INTRAMEDULLARY ALIGNMENT

- Be sure the foot and ankle frame is properly assembled and the alignment drill guide trajectory is calibrated. If unsure, you can assemble the cannula into the holder, put the drill in, and take a fluoroscopic view to make sure they coincide (TECH FIG 3A).
- The foot and lower leg are secured in the leg holder.
  - With correction of the preoperative deformity, we transfer the leg into the foot and ankle holder with the lamina spreader in place (TECH FIG 3B).
  - If the foot and ankle are secured first, it may be difficult to position the lamina spreader effectively.
- Proper rotation
  - We use a small straight osteotome in the medial gutter as a reference. The foot is rotated until the osteotome is parallel with the leg holder foot plate.
- Plantigrade foot
  - The heel must be flush with the foot plate of the guide.
  - If it is not, then the talar cut will have a posterior slope, removing an excessive amount of the talar body and increasing the risk of posterior talar component subsidence. Be sure all anterior tibiotalar osteophytes are removed. Perform a gastrocnemius release or tendo Achilles lengthening if necessary.
- Coronal plane alignment
  - In the mediolateral plane, center the heel over the starting point for the reference drill.
  - We use the AP alignment guides to grossly set this alignment.
  - This position should also be in line with the tibial shaft axis so that minimal adjustments will be necessary.
  - Preoperative deformity complicates such preliminary alignment.
- Sagittal plane alignment
  - We use the lateral alignment guides to grossly set this alignment.
  - The calf and Achilles rests need to be adjusted to optimize the lower leg’s position relative to the foot (talus) (TECH FIG 3C).
  - In our experience, proper heel position, optimal tibial alignment, and ideal rotation may make the foot appear internally rotated relative to the lower leg.
- Fluoroscopic confirmation of proper alignment
  - A large fluoroscopic scanner is needed (TECH FIG 3D,E).

TECH FIG 3 • A. Fluoroscopic view being obtained of leg holder with cannula and drill in place to ensure correct assembly of leg holder. B. Gelpi retractor holding deep tissue aside with lamina spreader on concave medial side of varus ankle. C. Leg positioned in leg holder with Achilles and calf rests supporting leg. D. C-arm coming in to obtain AP view of ankle on ipsilateral side. (continued)
Sizing

Approximate sizing for the component may be performed on preoperative radiographs of either the involved side or the uninvolved opposite ankle.

Position the cutting block in roughly the correct position by using the reference drill guide to estimate ideal alignment relative to the alignment guides.

Fine-tune the cutting block using the reference drill guide under fluoroscopy.

In the AP plane we align the cutting guide with the reference drill guide (TECH FIG 4A).

In the lateral plane, we use saw blades through the cutting guide to determine the resection level (TECH FIG 4B).

The position of the cutting block should be finalized only if proper alignment has been confirmed fluoroscopically with the alignment guides.

It is important that the guide is centered medially and laterally and no more than 1 mm of bone is removed from the medial malleolus.

Insert the drill guide to contact the plantar calcaneus.

Avoid holding the frame while inserting this guide as this could allow the drill to bend, achieving a different trajectory than the guide.

Secure the drill guide.

Advance the reference drill from calcaneus to tibia.

Since the trajectory may change when the drill hits the plantar medial calcaneus, we typically start the drill in reverse and “peck drill” (tap drill) to gradually penetrate the plantar calcaneal cortex without veering from the planned trajectory.

Once the plantar cortex is penetrated, the drill is run in forward.

Since drilling may shift the frame slightly, fluoroscopic confirmation of proper alignment must be re-established, after which proper alignment of the reference drill may be confirmed.

Advance the drill into the distal tibia, about 8 to 10 cm.

Confirm appropriate reference drill position fluoroscopically in both the coronal and sagittal planes.

Pinning the cutting block

Once proper position of the cutting block is established, the block is pinned, tibial pins first and talar pins next.

Occasionally the talar pins will skive and not engage the talus, particularly if a lamina spreader is being used to distract the joint or if the talar dome is sclerotic.

A toothless lamina spreader may be used to gently keep the talar pins in position as they are driven into the bone, but do this carefully because too much pressure may cause the pins to permanently bind in the cutting guide.

Two more pins are placed in the medial and lateral gutter.

Their mediolateral position is determined on the fluoroscopic image of the final cutting block position.

These pins protect the malleoli.

If a lamina spreader was used to distract the joint, it will interfere with the pin placement.
Try to keep it in place long enough to get enough pins in so that when the lamina spreader is removed, the correction is maintained.

- Withdraw the axial reference drill.
- Anti-rotation drill
  - The anti-rotation drill corresponding to the cutting block is used to drill the anti-rotation slot in the tibia (the sagittal prominence on the tibial base plate).
- Bone resection
  - With the soft tissues protected, make the tibial and talar cuts.
  - The bone resection should go all the way through the posterior cortex for each cut. It may not be possible on the initial pass, depending on the height of the cutting block and the particular saw used. After the initial cut, the cutting block can typically be lowered to complete the cuts, or the cuts can be freehand after the initial cuts. Obviously, avoid plunging the saw blade. Release the Achilles support to help prevent the flexor hallucis longus from being forced anteriorly and cut with the saw. Gently tapping the saw on the posterior cortex is usually possible to confirm that there is still cortex in place.
  - Once the posterior cortex has been penetrated for all cuts, the cutting guide and its pins can be removed.
  - The resected bone is evacuated from the joint.
  - A toothless lamina spreader may be used to facilitate accessing the most posterior bone.
  - Avoid levering on the malleoli with the instruments, as they may break.
  - A rongeur and an angled curette are ideal to remove the bone.
  - A fine reciprocating saw may be necessary to morselize the resected bone to facilitate removing all of the bone. Avoid cutting into the prepared tibial and talar surfaces with this saw, and protect the malleoli.
- Tibial reaming
  - Secure the reamer tip to its shaft within the joint (TECH FIG 5). A toothless lamina spreader may be required to facilitate securing the reamer tip.
  - Advance the reamer. We typically use four segments for the stem extension; this requires reaming 55 mm into the tibia.
  - Extract the reamer tip from the joint. When the wrench is placed on the reamer tip, avoid activating the driver, as it will spin the reamer and the wrench, which then may fracture a malleolus. Keep your fingers off the trigger during this portion. With the wrench secured to the reamer tip and firmly held with one hand, set the driver for reverse and disengage the shaft from the tip, thereby protecting the malleoli. Extract the reamer tip from the joint and withdraw the reamer shaft from the plantar foot.
- Talar preparation
  - Secure the talar alignment guide sleeve to the plantar aspect of the foot plate.
  - Advance the talar positioning guide through this sleeve to the prepared talar surface.

TECH FIG 4 • A. The cutting guide has been placed over the ankle and centered on the drill. B. A lateral view of the cutting guides with the saw and “dummy” blade in place gives the surgeon the amount of bone resected on the top of the talus and the bottom of the tibia.

B • Reamer tip being assembled onto reamer to ream out distal tibia.
Secure the talar pin guide to the positioning guide and place the talar pin. Check to see if the pin will be appropriately placed in the prepared talar surface; if not, then the talar pin guide affords multiple options for pin positioning. Alternatively, the pin may be placed in the “0” position and then the talar pin guide may be used over that initial pin to position a second, more appropriately positioned pin.

We have also used the talar trial to determine optimal pin position. The talar trial may be positioned in the ideal mediolateral position and on the posterior cortex (TECH FIG 6A). The pin can then be placed through the talar trial and will then be in the ideal position. The talar trial is positioned on the talar pin and a lateral fluoroscopic view confirms that the talar component will be in the desired position.

Optimally, the talar pin (which is the drill guide for the talar stem) is just posterior midpoint to the center of the calcaneal posterior facet. In the radiograph shown in Techniques Figure 6B, the component and talar pin are too far posterior. The talar trial and pin were moved anteriorly before drilling the talar stem hole. The new correct position is seen on the intraoperative films at the end of the case (TECH FIG 6C).

This also determines which of the two stem sizes is to be used. The 10-mm stem can typically be attached to the talar component on the back table and the talar dome–stem combination may be inserted simultaneously. For the 14-mm stem, we typically place this stem first and then attach the talar dome separately.

Remove the talar trial and ream the talar stem guide pin to either 10 mm or 14 mm (TECH FIG 6D).

**TECH FIG 6** • **A.** Talar component trial with hole and talar stem guide pin through it to determine position of stem. **B.** Cannulated drill being used over guide pin to create hole for stem. **C.** Lateral view of talar component with the talar stem guide through it. The guide and prosthesis are too far posterior and were brought forward. **D.** Final intraoperative lateral view showing that the prosthesis was moved forward and is in the correct position.
COMPONENT IMPLANTATION

- Assemble the tibial stem within the joint.
- We routinely leave the ankle plantarflexed, assemble the first two segments of the tibial stem on the back table, and insert them into the reamed tibia with the corresponding wrench (TECH FIG 7A).
- Return the ankle to the neutral position in which the tibia was reamed and introduce the “X-screw driver” from the plantar foot while the next tibial stem segment is positioned within the joint using the corresponding clip (TECH FIG 7B). A toothless lamina spreader to gently distract the joint may be needed to introduce the next segment.

- Using the X-screw driver and while securing the wrench holding the other two segments in the tibia, secure the third segment to the stem (TECH FIG 7C). Be sure to hold the wrench that is stabilizing the two segments already in the tibia; if the third segment is advanced and secured and then turned, the wrench could impact the malleolus and break it.
- Remove the X-screw driver and place the rod impactor from the plantar foot to advance the three-segment stem into the tibia (TECH FIG 7D). Obtaining a radiograph at this point can help ensure the correct angle of placement in this varus ankle (TECH FIG 7E). Be sure...
to attach the appropriate wrench to the third segment while impacting the stem to avoid having the stem advance too far into the tibia.  
- Repeat the steps to attach the fourth segment to the third segment. Add additional segments as needed. We typically use four segments.
- The final segment is different from the others in that it houses the female portion of the Morse taper. It also has a small hole that indicates proper rotation. Be sure this segment is aligned and rotated properly. Then the entire stem is fully seated with its corresponding wrench using the rod impactor.

**Tibial base plate**

- Introduce the tibial base plate into the joint (TECH FIG 8A).
- Withdraw the rod impactor from the stem slightly, allowing the tibial base plate to be positioned, and then use the rod impactor to secure the base plate to the stem. The tibial base plate is secured to the stem by means of a Morse taper (TECH FIG 8A).
- Once the Morse taper is secured, remove the wrench on the stem and the composite base plate and stem combination is ready to be fully seated. Make sure there is enough room for the base plate, and trim out any bone on the sides, which could lead to a malleolus fracture (TECH FIG 8B).
- During this step, rotation of the tibial component must be controlled. A narrow handle attaches to the anterior aspect of the base plate to control rotation as the tibial component is impacted. When the component is fully seated it should rest snugly in the mortise (TECH FIG 8C).

**Talar component**

- In our opinion, this is the most challenging step of the procedure, particularly if the joint was distracted to minimize bone resection or to correct deformity. In this situation, the joint space is quite tight by design, to achieve optimal soft tissue balance and ligament tension.
- We routinely assemble a 10-mm stem to the talar dome component on the back table for the size 2 and 3 prosthesis, using the dedicated assembly device to secure the Morse taper.
- Typically, a 14-mm stem is too long to be connected to the talar dome component before implantation. Therefore, we place the 14-mm talar stem first for size 4 and up if there is enough depth to the talus and seat it to the thin rib wrench that is flush with the prepared talar surface (TECH FIG 9). Since the Morse taper has not been secured, the rib wrench must remain under the 14-mm talar stem.
- The joint must then be gently distracted with a lamina spreader, followed by insertion of the talar dome component. The toothless lamina spreader may need to go under the talar dome component to obtain the distraction, while the talar component is carefully forced posteriorly into position. A handle attached to the talar dome component facilitates driving the talar dome posteriorly. A protective plastic sleeve inserted onto the tibial base plate protects the talar dome from being scratched.
Once the talar dome component seats on the stem, use the talar dome impactor to secure the Morse taper, with the rib wrench still between the talar dome component and the prepared talar surface.

Remove the rib wrench and inspect the interface between talar dome and stem to ensure that the two talar components are securely attached. Use the impactor to fully seat the talar component.

While impacting the talar component, use the handle that inserts into the talar dome to control subtle changes in rotation of the talar component.

Polyethylene insertion

- The polyethylene trials determine optimal polyethylene thickness (TECH FIG 10).
- We routinely remove the leg from the leg holder and obtain AP and lateral fluoroscopic images at this stage to confirm proper position and balance of the components.

With the ankle in neutral position, there should be a balance with varus and valgus stress. If not, the polyethylene thickness may be inappropriate or, more likely, balance needs to be established. Typically, the medial joint (deltoid ligament) is too tight. Traditionally, we have performed a lateral ligament reconstruction (modified Brostrom or Brostrom-Evans); however, in our more recent experience, we have been successful in rebalancing the ankle with a deltoid ligament release (described above) and increasing the polyethylene thickness.

The ankle should dorsiflex to at least 5 degrees, preferably 10 degrees beyond neutral. If not, the polyethylene thickness may be too thick. If the polyethylene thickness is appropriate and the foot cannot be dorsiflexed to 90 degrees, consider a gastrocnemius recession or percutaneous tendo Achilles lengthening.

Using the dedicated polyethylene insertion device, insert the polyethylene (TECH FIG 11A). In our experience, the polyethylene will engage the tibial base plate’s locking mechanism most effectively with the following maneuvers:

- Have an assistant or co-surgeon distract the joint.
- During the initial portion of the insertion, gently pull the insertion device into slight plantarflexion, thus driving the polyethylene into the tibial base plate’s locking mechanism.
- Once the polyethylene has cleared the superior dome of the talar component, ease off on the plantarflexion of the insertion device and have the assistant or co-surgeon compress the joint, thereby forcing the polyethylene into the locking mechanism.
- Remove the insertion device and fully seat the polyethylene with the dedicated impactor. With that accomplished, the prosthesis should be fully seated (TECH FIG 11B).

Obtain final AP and lateral fluoroscopic views of the valgus ankle (TECH FIG 12).
Thoroughly irrigate the joint and implant with sterile saline.

Reapproximate the capsule. We routinely use a drain.

Release the tourniquet and obtain meticulous hemostasis.

Reapproximate the extensor retinaculum while protecting the deep and superficial peroneal nerves.

Irrigate the subcutaneous layer with sterile saline and then reapproximate it.

Reapproximate the skin to a tensionless closure.

Apply sterile dressings on the wounds, adequate padding, and a short-leg cast with the ankle in neutral position.

---

**PEARLS AND PITFALLS**

**Equinus contracture**

- Since the initial tibial and talar preparation is performed using a single monoblock cutting guide, an equinus contracture will lead to excessive and undesired resection from the posterior talus. Therefore, perform a tendo Achilles lengthening to get the talus in a neutral position before securing the leg in the leg holder. If the heel does not rest fully on the leg holder’s foot plate with the toes touching the foot plate, there is equinus.

**Rotation**

- The foot and leg may be well positioned in the leg holder and fluoroscopy may suggest proper alignment, but the ankle may still be malrotated, leading to symmetric but malrotated tibial and talar preparation. Place a thin osteotome in the medial gutter of the tibiotalar joint to determine optimal rotation; the osteotome should be parallel to the side of the leg holder.

**Varus ankle and valgus malalignment**

- Balance the ankle before placing it into the leg holder. For varus perform the medial release; for valgus, the ankle is usually loose and simply needs the lamina spreader to realign the talus within the ankle mortise.

- The ankle must be in the center of the monitor or alignment cannot be accurately determined. Therefore, first place the ankle in the center of the fluoroscopic beam, and then make adjustments. Note also that as adjustments are made to the operating table to optimize alignment, the ankle may “drift” from the center of the monitor and will need to be recentered in the fluoroscopic beam while alignment is being set.

- The stop on the side of the leg holder must be set before the ankle is plantarflexed with the frame or else it is difficult to return to the same neutral position.

**Place the ankle at the center of the fluoroscopic monitor.**

**Be sure alignment is proper before any reading is made off the fluoroscopy.**

**Returning the ankle to neutral position while it is in the leg holder**

**Morse taper**

- The tibial base plate and the talar dome components attach to their respective stems with Morse tapers; be sure these are fully secured before seating either composite (combination main component and stem) fully.
POSTOPERATIVE CARE

- Overnight stay
- Nasal oxygen while in hospital
- Touch-down weight bearing on the cast is permitted, but elevation is encouraged as much as possible.
- Follow up in 2 to 3 weeks for cast change and suture removal
- The patient returns 6 weeks after surgery for cast removal and weight-bearing radiographs of the ankle.

OUTCOMES

- While some recently reported outcomes are based on high-level evidence, results of total ankle arthroplasty are almost uniformly derived from level IV evidence.
- Functional outcome using commonly used scoring systems for total ankle arthroplasty (AOFAS [Kofoed, Mazur] and NJOH [Buechel-Pappas]) suggest uniform improvement in all studies, with follow-up scores ranging from 70 to 90 points (maximum 100 points).
- Patient satisfaction rates for total ankle arthroplasty exceed 90%, although follow-up data for patient satisfaction often do not exceed 5 years.
- Overall survivorship analysis for currently available implants, designating removal of a metal component or conversion to arthrodesis as the endpoint, ranges from about 90% to 95% at 5 to 6 years and 80% to 92% at 10 to 12 years.
- At the time of this writing there are no published results available for the INBONE™ total ankle arthroplasty.

COMPLICATIONS

- Infection (superficial or deep)
- Neuralgia (superficial or deep peroneal nerve; rarely tibial nerve)
- Delayed wound healing
- Wound dehiscence
- Persistent pain despite optimal orthopaedic examination and radiographic appearance of implants
- Osteolysis
- Subsidence
- Malleolar or distal tibial stress fracture
- Implant fracture (including polyethylene)

REFERENCES

DEFINITION
- Total ankle arthroplasty (TAA) is indicated for end stage osteoarthritis or rheumatoid arthritis.\textsuperscript{2}
- The semi-constrained TNK ankle is a two-component total ankle implant (\textbf{FIG 1}).\textsuperscript{10,11}
- It is made of alumina ceramic, and its interface with bone is coated with alumina beads. This prosthesis combines biocompatibility of alumina ceramics with a design that facilitates fixation to bone.

ANATOMY
- The physiologic alignment of the tibial plafond is nearly perpendicular to the anterior tibial shaft axis in the coronal plane and has a slight posterior slope relative to the lateral tibial longitudinal axis. To match this natural anatomy, the TNK ankle’s tibial component is ideally implanted perpendicular to the anterior longitudinal axis of the tibia with a 10 degree posterior slope. The talar component is ideally set parallel to the ground or plantar aspect of the weight-bearing foot.

PATHOGENESIS
- Ankle osteoarthritis (OA) is most commonly posttraumatic in origin, often secondary to intra-articular fractures with cartilage injury and/or malunions of the tibial plafond.\textsuperscript{1,6}
- Occasionally, severe pes planovalgus deformity, particularly that associated with stage IV posterior tibial tendon insufficiency, may result in a varus-type ankle OA.\textsuperscript{5}
- In our experience, a varus-type ankle OA may develop, typically characterized by varus deformity of the tibial plafond.\textsuperscript{3,4}
- Advanced rheumatoid arthritis (RA) affects the ankle in 25\% of patients.\textsuperscript{8}
  - The talonavicular, subtalar, and calcaneocuboid joints are involved in 29\%, 39\%, and the calcaneocuboid joint in 25\%, respectively.\textsuperscript{7}

NATURAL HISTORY
- Irrespective of cause, OA is characterized by a gradual, progressive, and diffuse loss of articular cartilage with eventual complete eburnation down to subchondral bone on both sides of the joint. RA originates from an inflammatory process of the joint’s synovial tissue.
- We routinely use Larsen’s grading scheme for evaluating the stage of RA.
- TAA is indicated for Larsen’s grades 3 and 4.
- In our opinion, grade 5 (mutilans-type of RA) is contraindication for TAA.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Osteoarthritis
  - Patients typically complain of ankle pain with weight-bearing, particularly start of pain in the first few steps and also with prolonged walking. With progressive OA, pain with ankle motion and ankle edema become more common. Ankle stiffness is associated with advanced stages of OA.
- Rheumatoid arthritis
  - Morning stiffness, symmetrical joint pain, and joint swelling in the hands, wrists, and feet are distinctive symptoms of RA.
  - In our experience, the ankle is usually not involved until advanced stages of RA.
  - Typically, patients complain of pain with ankle range of motion (ROM) and swelling.
  - Because RA may affect the talonavicular joint in isolation, ankle and talonavicular joint involvement must be distinguished. Careful examination of ankle and hindfoot palpation and stress usually allows differentiation between tibiotalar and talonavicular RA, but radiographic confirmation is often warranted.
  - Advanced RA of the ankle associated with pes planovalgus often has concomitant posterior tibial tendon tendinopathy and spring ligament pathology.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Weight-bearing AP and lateral radiographs of the ankle determine the extent of arthritis and deformity at the ankle. Preoperatively, we determine the appropriate implant size using dedicated template for the TNK system.
- Generally, we select the largest possible component to optimize the biomechanical advantage of maximum surface contact between implant and bone.
- In complex cases, we utilize computer simulation to more accurately template the implants (\textbf{FIG 2}).
- Weight-bearing radiographs of the ipsilateral foot are important when ankle arthritis is associated with foot malalignment/deformity.
We routinely evaluate the hindfoot in any patient being considered for TAA.
Occasionally, computed tomography (CT) is necessary to provide greater detail of potential subtalar pathology (FIG 3).
As for laboratory tests, anticyclic citrullinated peptide (CCP) antibodies and galactose deficient IgG are useful to an early diagnosis.

NONOPERATIVE MANAGEMENT

- Osteoarthritis
  - Activity modification; bracing
  - Some patients benefit from heat treatments and ultrasound.
  - NSAIDs
  - Judicious use of corticosteroid injections
  - Viscosupplementation
- Rheumatoid arthritis
  - Anti-inflammatory medications
  - Systemic rheumatoid medical management through a rheumatologist
  - Bracing
  - Judicious use of corticosteroid injections

SURGICAL MANAGEMENT

- We favor TAA over tibiotalar arthrodesis for bilateral ankle arthritis and ankle arthritis associated with hindfoot stiffness/arthritis. In 1975, we developed a metal prototype of our TNK ankle.9
- In 1980, because of improvements in materials and operative procedures, we developed a TNK ankle made of alumina ceramic.10 However, there were problems with the interface between bone and alumina ceramic, and the clinical results of the alumina ceramic TNK ankle were not satisfactory.
- In 1991, we developed a bead-coated alumina ceramic TNK ankle11 and the current design has been modified from this version of the TNK implant.

Preoperative Planning

- Three sizes of the TNK prosthesis are available: small, medium, and large (FIG 4).
- We template for the TNK implant based on the preoperative weightbearing ankle radiographs, marking the proposed resection level. The planned resection line is 8 to 15 mm above the distal tibial surface, and has a 10 posterior slope.
- The antero-posterior dimension of the tibia plafond is measured to ensure optimal support for the tibial implant. While we favor noncemented implants, we rarely consider cement fixation for patients with osteopenic bone or bone defects that do not allow full support for the prosthesis with standard tibial and/or talar resections. In an effort to limit initial micromotion of the implant and to promote effective bone ingrowth, we routinely secure the prosthesis to bone with screw fixation.

Positioning

- Supine position
- Thigh tourniquet
- Bolster under the ipsilateral hip to prevent excessive external rotation of the operated extremity.

APPREACH

- A 10-cm longitudinal incision is centered over the anterior ankle. The extensor retinaculum is divided over the interval between the tibialis anterior and extensor hallucis longus tendons.
- The dorsalis pedis artery and the deep peroneal nerve are retracted to the lateral side.
- An anterior ankle capsulotomy is performed.
- In RA, a comprehensive synovectomy is performed, from the extensor tendon sheath(s) to the talonavicular joint.

FIG 2 • Preoperative computer simulation. A. AP view. B. Lateral view.

FIG 3 • CT is helpful for detecting subtalar lesions.

FIG 4 • Small, medium, and large sizes of the TNK ankle.
TIBIAL PREPARATION

- Tibiotalar osteophytes are removed to expose the anterior joint. Based on preoperative templating and level of the tibial plafond, the tibial resection level is determined. The tibial cutting guide is positioned at the desired tibial resection level (TECH FIG 1A).
- The external tibial alignment guide attached to the cutting block is oriented in line with the tibial shaft axis and the center of the patella.

- Once properly oriented, the tibial cutting guide is secured to the tibia with a fixation pin and the distal tibial cut is performed with an oscillating saw advanced through the cutting block (TECH FIG 1B, C).
- Although we recommend 10 degrees of posterior slope, we caution that excessive posterior slope is detrimental.
- To maintain support for the prosthesis we avoid violating the posterior tibial cortex.
- The medial malleolar preparation is performed next.

TECH FIG 1 • Osteotomy of the tibia. A. Tibial cutting guide and alignment bar. The alignment bar on the tibial cutting guide is adjusted to the center of the patella. B. Osteotomy is performed with 10 degrees of anterior opening. C. Osteotomy using a bone saw.
TALAR PREPARATION

- The superior surface of the talar cutting guide is brought into contact with the resected distal tibia, with traction applied to the ankle in approximately 10 degrees of plantar flexion.
- Proper alignment is confirmed using the external tibial alignment guide as was done prior to the tibial resection. The talar cutting is secured to the talus with a fixation pin.
- Using an oscillating saw, the superior surface of the talar dome is prepared using the talar cutting guide as a reference (TECH FIG 2A,B).
- A spacer is now inserted to confirm adequate and balanced bone resection (TECH FIG 2C).
- The mediolateral talar cutting guide is properly oriented to the talus and secured. Using an oscillating saw through the capture slots of the cutting guide, 2 mm are removed from the medial and lateral talar dome (TECH FIG 2D,E).
- Resection of more than 2 mm from either side of talus must be avoided by choosing the appropriate mediolateral cutting guide and orienting it properly; excessive resection may lead to talar component subsidence.
- Next, the appropriately sized talar peg cutting guide (TECH FIG 2F) is positioned on the prepared talar surface, and the tibial peg hole is created (TECH FIG 2G).

TECH FIG 2 • Osteotomy of the talus. A. Talar cutting guide. B. Osteotomy is performed parallel to a floor line. C. To confirm the osteotomy of the tibia and talus, a spacer is inserted under traction. D. The talar margin cutting guide. E. The talar margin is cut in a plantarflexion position of the ankle. F. The talar peg cutting guide. G. The talar peg crusher.
**PREPARATION OF THE TIBIAL ANCHOR**

- The talar trial corresponding to the component size is impacted with a talar impactor.
- The appropriately sized talar trial is positioned on the prepared talus and impacted.
- The tibial peg cutting guide is positioned on the anterior distal tibia (TECH FIG 3A).
  - The superior and medial aspects of the guide are aligned with the prepared tibial surface.
- Once properly oriented with the prepared tibial surface and the talar trial, the tibial peg cutting guide is secured to the tibia (TECH FIG 3B, C).
- The tibial anchor is prepared along the inner surface of the guide.
- We recommend preserving the posterior tibial cortex at the anchoring region must be left intact to prevent posterior tibial component migration (TECH FIG 3D).

**TRIAL AND SETTING**

- The tibial trial is inserted
- Proper alignment and satisfactory ankle ROM are confirmed (TECH FIG 4A).
- Ideally, the tibial trial should be supported by both the anterior and posterior tibial cortices.
- Once optimal alignment and ROM are confirmed, the trial components are removed.
- We favor applying bone marrow aspirate from the patient’s iliac crest to the bone ingrowth surfaces of noncemented implants to accelerate early bone ingrowth (TECH FIG 4B).
- With the ankle held in plantarflexion, the final talar component is impacted using the dedicated talar impactor.
- Then, the tibial component is impacted with its specific impaction tool.
- Via the screw hole in the tibial component, a 2.5-mm drill is advanced through the posterior tibial cortex.
- A specially designed polyethylene sleeve is placed into the screw hole of the tibial component into which a 4.0-mm AO small fragment cancellous screw is inserted to secure the tibial component to the tibia (TECH FIG 4C, D).
- Any residual gapping between the bone and tibial component should be filled with cancellous bone autograft.
- For patients with osteopenia, we routinely use bone cement for fixation of the components.
The wound(s) are thoroughly irrigated with sterile saline solution.
- We routinely use a drain.
- The retinaculum and skin are reapproximated, taking care to protect the deep neurovascular bundle and superficial peroneal nerve.
- A short leg cast is applied with the ankle in a neutral position.

**SUBTALAR ARTHRODESIS**

- In patients with concomitant ankle and subtalar arthritis, we favor performing simultaneous TAA and subtalar arthrodesis (TECH FIG 5A, B).
- Through a 2.5-cm lateral incision over the sinus tarsi, the subtalar joint is exposed and residual articular cartilage is removed using a chisel and a curette.
- To facilitate fusion, a small diameter drill is used to penetrate the subchondral bone and increase the surface area of the subtalar joint.
- Through the anterior incision, anterior to the talar component, a standard AO cancellous screw is placed from the talar neck across the subtalar joint into the calcaneus.

**CLOSURE**

- The wound(s) are thoroughly irrigated with sterile saline solution.
- We routinely use a drain.

**TECH FIG 4 •** Trial and setting. A. The tibial trial is inserted. B. Bone marrow mounting. C. Screw fixation. D. Implantation is completed.

**TECH FIG 5 •** Subtalar arthrodesis. A. Postoperative AP view with subtalar arthrodesis using a single OA cancellous screw. B. Lateral view.
PEARLS AND PITFALLS

Contraindications to the TNK ankle

- Patients planning high-impact, untreated osteoporosis, osteonecrosis of the talus, mutilans type of rheumatoid arthritis, and varus and valgus deformity of the ankle (>15 degrees); patients under the age 50 should only be considered if they have reasonable expectations and understand that they are very likely to require revision surgery in their lifetime.

Approach

- The approach is anterior, but oriented toward the medial aspect of the ankle, because the TNK ankle does not have a fibular component. The deep peroneal nerve and the anterior tibial artery should be retracted to the lateral side.

Application of bone marrow aspirate to the bone ingrowth surfaces

- The ideal timing to apply the bone marrow aspirate to the backside of the implants is when the marrow elements begin coagulating. Good timing of implantation is bone marrow just coagulating on the surface of the implant. In our opinion, this timing best promotes bone ingrowth.

Residual gap at the bone–prosthesis interface

- We recommend filling this gap with autograft or even a thin cancellous wedge of bone from the patient’s iliac crest.

POSTOPERATIVE CARE

- Patients with uncemented prostheses wear a cast for 3 weeks postoperatively, after which they gradually increase their active range of motion.
- During the first week, weight bearing is not allowed. In the following weeks, weight bearing to tolerance is permitted, with crutches. At 2 months postoperative, full weight bearing is initiated.
- Patients with cemented prostheses wear a cast for 2 weeks, and full weight bearing is allowed after the cast is removed.

OUTCOMES

- From 1991 to 2001, we performed 70 TNK TAAs in 62 patients (FIG 5).10

Follow-up was possible for 67 ankles in 60 patients: 39 ankles in 36 patients with OA (osteoarthritis group), and 28 ankles in 24 patients with RA (rheumatoid arthritis group). Duration of follow-up ranged from 24 months to 134 months, with an average of 62 months.

- Cemented TAA was performed in three ankles with OA and 19 ankles with RA (FIG 6).
- Revision surgery was performed for three ankles in three patients: two ankles with collapse of the talus, and one infected ankle.
- Clinical evaluation was performed using our rating system,9 in which the maximum score of 100 points is divided into 40 points for pain and 60 points for function. Satisfactory pain relief was obtained in majority of patients.

In the OA group, mean values of pain, function and total score improved from 14, 34, and 48 points preoperatively to 37, 49, and 86 points at last follow-up, respectively.

In the RA group, the same mean values improved from 14, 31, and 35 points to 35, 39, and 74 points, respectively.

Preoperative and postoperative mean ankle ROM was 28 and 33 degrees in the OA group and 22 and 22 degrees in the RA group, respectively.

In the OA group, overall results were excellent in 24 ankles, good in 10 ankles, fair in 3 ankles, and poor in 2 ankles. In the RA group, overall results were excellent in 6 ankles, good in 12 ankles, fair in 7 ankles, and poor in 3 ankles.

In the RA group, mean total scores (using our own ankle rating system) at the follow-up were 77 points for cemented fixation (18 ankles) and 71 points for cementless fixation (10 ankles).

Radiography showed subsidence and loosening in four prostheses in the OA group (two tibial prostheses and two talar prostheses) and 17 prostheses in the RA group (six tibial prostheses and 11 talar prostheses).

Although the results of the RA group were worse than those of the OA group, short- and medium-term results with bead-coated alumina ceramic prostheses were encouraging.

COMPLICATIONS

- Intraoperative fracture of the medial malleolus
- Superficial peroneal nerve palsy
- Wound edge necrosis
- Superficial infection
- Deep infection
- Loosening of the implant
- Subsidence of the implant

REFERENCES

DEFINITION
- The Agility ankle replacement is a fixed bearing device with a tibial base plate that requires a fusion between the distal tibia and fibula. This unique design feature allows a large surface area for bone ingrowth and also limits the likelihood of subsidence of the tibial component into the cancellous bone of the distal tibia.
- The tibial component is a porous-coated titanium implant designed to be positioned in 23 degrees of external rotation.
- It has an ultrahigh-molecular-weight polyethylene (UHMWPE) insert available in different thicknesses. The Agility LP uses a front-loading UHMWPE spacer, which makes insertion and revision simple.
- The talar component is a dome-shaped cobalt chrome alloy with a porous-coated undersurface. The Agility LP talar base plate covers the entire talar cut surface. The current design has six sizes and is a fixed bearing implant that is partially conforming (FIG 1).

ANATOMY
- The ankle joint is complex in that it involves four structures: the lower end and medial malleolus of the tibia and the lateral malleolus of the fibula and the trochlear surface of the talus (FIG 2).
- The ankle joint resembles a mortise-and-tenon joint as used in carpentry. The tibia and fibula must be bound together for the mortise to be stable. This is done by the syndesmosis, which consists of the anterior tibiofibular ligament, interosseous ligament, and posterior tibiofibular ligament. Instability of the mortise could lead to degenerative changes of the joint (FIG 3).
- The ankle acts mainly as a hinge joint, allowing plantarflexion and dorsiflexion. The ankle is strengthened on the medial side by the triangular deltoid ligament, which radiates from the medial malleolus to the sustentaculum tali of the calcaneus, the medial border of the plantar calcaneonavicular (“spring”) ligament, the tuberosity of the navicular, and the neck of the talus.
- The lateral collateral ligament consists of the anterior and posterior tibiofibular ligaments and a calcaneofibular ligament.
- All these structures are essential for accurate function and stability of the joint.

PATHOGENESIS
- The complexity of the ankle anatomy adds to the difficulty of successful ankle replacements.
- Most ankle arthritis is secondary to previous fractures. Intra-articular fractures are common, and especially pilon fractures have a high likelihood of resulting in degenerative changes.
- Syndesmosis injuries are notorious for causing ankle arthritis. One millimeter of translation of the talus in the mortis causes a 40% increase in force in the articular cartilage.4
- Collateral ankle ligament instabilities are also a major cause of ankle arthritis. Due to the close-packed nature of the ankle joint, any instability results in a significant increase in stress and force in the ankle.
Physical examination should include:
- The most common is lateral instability. This is accentuated if there is a hindfoot varus deformity.
- The foot plays a major role in the pathogenesis of ankle arthritis, and also the outcome of ankle replacement surgery. A stable plantigrade foot is a prerequisite for a successful ankle replacement.
- Close attention should be paid to posterior tibial tendon insufficiencies, deltoid attenuation, gastrocnemius contracture, hindfoot varus, and forefoot supination in planning an ankle replacement. Any of these factors should be addressed before or at the time of the ankle replacement.
- At present a ligamentous instability of more than 20 degrees varus or valgus is felt to be a contraindication for a total ankle arthroplasty.

NATURAL HISTORY
- Degenerative change of the ankle occurs either after a fracture or after ligamentous instability. Only a few cases are truly idiopathic.9
- The postfracture group could be divided in two groups. The first comprises patients with severe soft tissue injury, high-energy injury, and multiple operated tibial pilon. These patients usually have a compromised, scarred soft tissue envelope, and the ankle has limited motion. Pain is due to the ankle arthritis but also the soft tissue problems, including scar and damaged lymphatic and venous outflow.
- The second group comprises patients with simple malleolar fractures, low-energy pilon with minimal soft tissue compromise. This group behaves more like the ligament instability or idiopathic group in that the soft tissues are friendly and the ankle range of motion is generally very well preserved.
- The instability group could have additional issues, including peroneal tendinosis or rupture as well as secondary subtalar arthritis or hindfoot varus.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The history is usually very similar within the postfracture group. Depending on the severity and energy of the injury, as well as the accuracy of the reduction of the ankle mortise, the degenerative process will start early or many years after the incident.
- Patients in the ligamentous instability group usually present many years after multiple ankle sprains. The most common history is that of multiple ankle sprains while in school or college that were treated suboptimally. There is usually a history of ongoing instability and the need to use an ankle brace while playing sports in later years.
- Physical examination should include:
  - Range of motion of the ankle. Maximum plantarflexion and dorsiflexion are measured. At least 5 degrees of dorsiflexion is required for normal gait. As a general rule preoperative range of motion determines postoperative range of motion.
  - Gastrocnemius contracture. The examiner should lock the midfoot and then test passive dorsiflexion first with the knee extended and then with the knee flexed. With a gastrocnemius contracture dorsiflexion of the ankle is less with the knee extended. A gastrocnemius lengthening might need to be done.
  - Tibialis posterior tendon function. Evaluating the foot while the patient is standing and walking will show the triad of deformities: too many toes and loss of medial arch and hindfoot valgus. Grade 1 has no deformity but pain, swelling, and weakness. Grade 2 has weakness and correctable deformity. Grade 3 involves a rigid deformity.5 Tibialis posterior tendon dysfunction is best treated before proceeding with ankle replacement surgery.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Weight-bearing AP, lateral, and oblique radiographs of the ankle are necessary. The lateral radiograph should include the entire foot to evaluate for midfoot and forefoot collapse.
- Obtaining weight bearing maximum plantarflexion and dorsiflexion radiographs of the ankle is the only reliable way to measure tibiotalar and midfoot motion.2
- Long-leg standing radiographs that include the knee and ankle will help to determine the axis of the leg and any alignment issues not shown on an ankle radiograph alone.
- CT scan and MRI could be helpful to determine the presence and size of bone cysts and avascular necrosis of the talus.

DIFFERENTIAL DIAGNOSIS
- Posttraumatic degenerative joint disease
- Degenerative joint disease secondary to ligamentous instability
- Rheumatoid or other seronegative arthritis
- Avascular necrosis
- Infection

NONOPERATIVE MANAGEMENT
- Medications
  - Nonsteroidal anti-inflammatory medications might give good medium-term relief.
  - Corticosteroids could be a valuable tool to delay total ankle replacement.
- Injections
  - Diagnostic
    - Invaluable; provides a way to determine if most of the pain is coming from the ankle joint
  - Palliative
    - Corticosteroids can give good anti-inflammatory and pain control over the short to medium term, but it is seldom, if ever, permanent pain relief.
- Footwear modifications
  - Wide, extra-depth, comfortable shoes with a low heel can help normalize the gait.
  - Heel wedges can compensate for a leg-length discrepancy or an equinus deformity.
  - Sole flares provide additional stability to the foot and ankle.
    - Medial heel flare provides stability for a valgus deformity of the hindfoot.
    - Lateral flare provides stability for a varus deformity of the hindfoot.
  - Rocker-bottom sole or a solid ankle cushioned heel (SACH) improves forward progression, reduces impact on the ankle at heel strike, and reduces the amount of plantarflexion required at gait.
- Orthotics: in-shoe
  - Semi-rigid: vary from simple felt pads to custom-molded inserts
    - Accommodative inserts are best for rigid deformities. They can also support the medial arch and unload pressure areas. They can control an axial deformity to some degree.
    - Functional inserts are for flexible deformities. They support the foot and help maintain the axial alignment.
Chapter 76  THE AGILITY TOTAL ANKLE ARTHROPLASTY

Rigid orthotics
- Give better control of axial deformity or misalignment and might help to control instability patterns to some degree
- Unload pressure areas but might create new “hot spots”
- The UCBL orthotic is a rigid polypropylene insert that aims to correct a flexible hindfoot deformity. It restricts painful hindfoot motion, supports the longitudinal arch, stabilizes the midfoot, and controls the forefoot.

Laced-up ankle brace
- Made from various materials (fabric, leather, plastic). It gives reasonable support and correction.
- Limits motion to a variable degree (depending on the material)
- Helps for swelling
- Might simulate a fusion

Ankle–foot orthosis (AFO)
- Helps correct and maintain axial malalignment
- Mimics an ankle fusion
- Provides ankle stability
- Might reduce pain but does not completely unload axial forces

SURGICAL MANAGEMENT

- It is of paramount importance to have a stable balanced foot before doing an ankle replacement. Any deviation from this tenet increases the likelihood of component malalignment and subsequent prosthetic failure.
- A concurrent tibialis posterior tendon dysfunction should be treated before the ankle replacement, especially if there are already secondary changes including hindfoot valgus, loss of the medial arch, or forefoot supination.
- Preoperative range of motion determines postoperative range of motion. On average there will be only a 5-degree increase in motion after a replacement.2 Realistic expectations are therefore important.

Preoperative Planning
- The appropriate radiographs and other imaging studies should be available.

EXPOSURE OF THE ANKLE

- Use an anterior approach between the extensor hallucis longus tendon and the tibialis anterior. Leave the sheath of the tibialis anterior tendon intact, and perform the dissection lateral to the tendon (TECH FIG 1).
- The medial branch of the superficial peroneal nerve is often found in the subcutaneous tissues in the distal half of the wound. It should be identified, protected, and retracted laterally.
- The deep neurovascular bundle is found deep to the extensor hallucis longus tendon. The medial malleolar arterial branches are coagulated or divided to free the neurovascular bundle so that it can be retracted laterally.
- Incise the ankle capsule longitudinally over the midpoint of the ankle; it may be necessary to excise the central portion of this capsule to gain good exposure. An

If there is a significant ligamentous instability, one should plan to do a reconstruction at the time of the ankle replacement.
- Concurrent subtalar or talonavicular arthritis poses a challenge. If a diagnostic ankle joint injection relieved most of the pain, one should not fuse these joints. If it was necessary to inject these joints as well to get adequate pain relief, they should probably be fused at the time of the replacement.

Positioning
- The patient is placed supine on the table with a sand bag under the ipsilateral hip. It is easier to visualize the ankle if the foot is perpendicular to the bed (FIG 4). The operative extremity is placed on blankets to elevate the leg above the adjacent nonoperative extremity. This will allow easy visualization of the operative extremity on sagittal plane fluoroscopy.

FIG 4 • The patient should be positioned with the foot close to the end of the bed. That makes it easier for the surgeon to visualize the joint without having to lean forward for an extended period. A sand bag is placed under the ipsilateral buttock to turn the foot perpendicular to the bed for equal access to the medial and lateral sides of the joint. The lower calf is supported to allow the ankle to hang free. That posteriorly translates the joint and also relaxes the posterior structures.
Adequate exposure is critical. This shows the medial malleolus, fibula, and syndesmosis. At this point the syndesmosis is already prepared for fusion by removing all the soft tissues and decorticating the apposing surfaces. Extensile exposure is required: the entire medial malleolus, syndesmosis, and lateral malleolus should be visible (TECH FIG 2).

- Remove the anterior osteophytes on the tibia with an osteotome to expose the extent of the depression in the tibial plafond.
- Also remove the osteophytes from the anterior aspect of the talus to allow the cutting block to be adequately placed (TECH FIG 3).
- Identify the medial and lateral sides of the talus. It is possible at this stage to assess whether soft tissue procedures are needed to realign the foot. Severe deformity is very difficult to correct, and deformity over 20 degrees may be regarded as a contraindication for ankle replacement with the Agility ankle. The lack of complete congruent contact between the dome of the talar component and the plafond of the tibial tray may encourage tilt of the prosthesis postoperatively.
- The syndesmosis is visualized and prepared for fusion using the same incision. Remove all the soft tissues and decorticate the apposing surfaces of the tibia and fibula over the distal 4 cm.

APPLICATION OF THE EXTERNAL FIXATION

- Apply the distractor with two pins in the foot and two in the tibia, all inserted from the medial side.
- The first pin goes into the talar neck. This pin is critical and should be parallel to the talar dome. For example, if the ankle is in valgus, the pin is inserted perpendicular to the axis of the deformity, which would be corrected as distraction is applied.
- With the dissection done first the actual placement of the talar pin can be verified under direct vision, which ensures accurate placement (TECH FIG 4).
Cancellous pins are used for the talus and calcaneus. Use the distractor guide to place the second pin through the calcaneus. Accurate placement of the first (talar) pin will ensure that the calcaneal pin is posterior and superior to the neurovascular bundle.

This is followed by placing two proximal pins through the distractor guide into the tibia.

Tighten all the distractor joints with the foot at 90 degrees to the tibial axis.

Slowly distract the joint. There is no set distance for distraction, but the goal is to get close to the deltoid end-point, where the deltoid is under tension. This is usually about 1 cm of distraction.

If no distraction is possible due to scarring and ankylosis, use an osteotome to manually loosen the joint.

Be careful not to overdistract. It could cause malleolar fractures, or “overstuffing” of the joint with limited range of motion.

If distraction tilts the joint in varus or valgus, make adjustments to bring the ankle back to neutral before making the bone cuts.

Use fluoroscopy liberally to ensure that the articular surfaces are parallel, joint space is restored, and the ankle is not in equinus (TECH FIG 5).

**ALIGNMENT JIG AND CUTTING BLOCK**

Place the yoke of the tibial alignment jig on the leg so that the clamp adjustment bar lies over the anterior crest of the tibia.

Center the proximal end of the ankle clamp alignment jig over the tibial tubercle and hold it in position by wrapping the ankle clamp spring around the leg. The adjustment tube on the yoke post and the extending tibial rod should be parallel to the tibia to give the correct angle for the cutting block at the ankle (TECH FIG 6).

Turn the cutting block clamp fine-tuning screw to its halfway point. That will allow proximal and distal adjustment after securing the alignment guide to the tibia.

Proper rotation of the cutting block is critical. With the jig parallel to the tibia, use the alignment stylus to align the bone cuts.

TECH FIG 4 • The talar pin placement is critical. It should be in the “soft spot” between the medial malleolus proximal, navicular distal, tibialis anterior tendon anterior, and tibialis posterior tendon posterior.

TECH FIG 5 • Proper placement of the distractor is critical to ensure correct bone cuts.

TECH FIG 6 • The yoke of the alignment jig should be centered over the tibial crest on an AP view and should be parallel to the tibia on a lateral view.
ensure that the cutting block lines up with the second metatarsal. Then tighten the footpad assembly screw.

- Insert the correct-size cutting block into the alignment jig slot and roughly center it over the ankle joint. Secure the footpads to the tibia with the stabilizing pins.
- Center the cutting block over the ankle. Fluoroscopy is valuable. There is a notch on the lateral and medial wall of the cutting block to show the level of the joint. A lateral radiographic view can also be used to show that equal distances of the tibia and talus will be resected (TECH FIG 7).
- First insert the stabilizing pin on the proximal-medial aspect of the cutting block to ensure that the medial-lateral placement of the block will take equal bone from the medial and lateral malleolus (about one third of the width). With adequate placement of the cutting block, insert one or two more stabilizing pins.

**BONE RESECTION**

- Recheck the position of the ankle, especially in the sagittal plane, before making the saw cuts (TECH FIG 8).
- Perform the tibial, tibial keel, malleolar, and talar bone cuts using the respective slots in the cutting block. The tibial keel cut should go about half the depth of the tibia.
- Remove the cutting block and if necessary complete the corner cuts with a reciprocal saw.
- Remove the distal tibial bone, taking care not to rotate the fragments, as it can put excess pressure on the malleoli.
- This is followed by the talar fin cut. To allow placement of the burr guide, remove the distraction device to allow full plantarflexion of the ankle. Then place the burr guide centered on the cut surface of the talus, with the alignment jig parallel to the second metatarsal.
- Secure the burr guide to the talus with pins and prepare the keel. Remove the burr guide (TECH FIG 9).
Insert the trial components using the alignment handles. It might be helpful to gently spread the syndesmosis with a wide osteotome. The tibial component is inserted first, followed by the talus. A standard front-loading polyethylene component is then inserted into the tibial tray. It could be replaced with a +1 component if needed (TECH FIG 10).

- Test the range of motion and ankle ligament stability. If there is not at least 5 degrees dorsiflexion consider a gastrocnemius lengthening.
- Remove the trial components and thoroughly rinse the ankle to remove all debris. The final components are now inserted. The talar component insertion usually requires the foot to be in maximum plantarflexion (TECH FIG 11).
**SYNDESMOSIS FUSION**

- Morselize the bone taken from the bone cuts in the tibia and talus and pack it in the syndesmosis.
- Place a three- or four-hole semitubular plate over the lateral aspect of the fibula through the anterior incision.
- Insert two screws percutaneously through the plate, fibula, and tibia to compress the syndesmosis. The distal screw should be about 1 cm proximal to the keel of the tibial component (TECH FIG 12).

**TECH FIG 12**  • The syndesmosis is fused with a small plate on the fibula and two screws into the tibia. Bone taken from the bone cuts is morselized and packed into the syndesmosis.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Indications</th>
<th>A successful ankle requires a stable foot. Specifically look for and treat any muscle imbalances (ie, posterior tibial tendon dysfunction).</th>
</tr>
</thead>
</table>
| Varus or valgus malalignment | - Preoperative varus is often due to chronic lateral ligament instability.  
  - Valgus is often due to longstanding posterior tibial tendon dysfunction with secondary deltoid ligament instability. Ligamentous varus or valgus of more than 20 degrees may be a contraindication for an ankle replacement with the Agility ankle.  
  - Bone erosion varus or valgus with no ligamentous instability is an acceptable indication. |
| Syndesmosis preparation | - The entire syndesmosis should be débrided before attempting to spread the fibula from the tibia.  
  - Failure to release the posterior tibiofibular ligament could result in a fibula fracture when spreading the syndesmosis or inserting the tibial component. |
| Ankle sizing | - Take care to choose the correct ankle size. About one third of the medial and lateral malleolus should be removed. Overstuffing the joint will reduce the range of motion.  
  - Too small a component will increase the risk of subsidence. |
| Distraction of the ankle | - The talar pin should be parallel to the joint.  
  - Lock the external fixator with the foot in 90 degrees. Locking the foot in plantarflexion will tilt the talar cut toward the subtalar joint.  
  - Distract the ankle until the deltoid ligament is under tension.  
  - Use fluoroscopy to confirm cutting block position before making bone cuts. |
| Malleolar fractures | - Treat like any malleolar fracture. There is usually enough bone to insert one or two screws for fixation, or a tension band wire technique could be used. There are adequate amounts of bone from the bone cuts to graft the fracture site. |
POSTOPERATIVE CARE

- The leg is placed in a short-leg posterior splint or leg walker with the ankle in neutral.
- The patient should be non-weight-bearing, or at most toe touch.
- The splint is removed at 2 weeks to remove the sutures.
- A leg walker is applied, and the patient can start with non-weight-bearing range of motion for 5 minutes three times a day.
- The patient continues to be non-weight-bearing for a further 4 weeks.
- At 6 weeks radiographs are obtained, and if there are adequate signs of syndesmosis healing the patient can progress to full weight bearing and start physical therapy to increase range of motion, proprioception, and strength.
- If soft tissue procedures were done to correct ligamentous imbalance, it is advisable to use a short-leg cast for the first 6 weeks.

OUTCOMES

- Alvine’s series\textsuperscript{6} has the longest follow-up (7 to 16 years) on the Agility ankle replacement.
- At a mean 9-year follow-up the revision rate was 11\% (either a revision or a fusion).
- More than 90\% of patients reported that they had decreased pain and were satisfied with the outcome of the surgery.
- Eighty-nine (76\%) of the 117 ankles had some evidence of peri-implant radiolucency.
- Syndesmosis nonunion had a negative impact on the clinical and radiologic outcome.
- Deland et al\textsuperscript{7} reported results at 3.5 years of follow-up on 38 patients. The American Orthopaedic Foot and Ankle Society (AOFAS) ankle–hindfoot scores increased from 33.6 preoperatively to 83.3 at final follow-up ($P < 0.001$).
- Postoperative Medical Outcomes Study Short Form-36 (SF-36) Physical Component Summary (PCS) and Mental Component Summary (MCS) scores averaged 49.5 and 56.1, respectively.
- Migration or subsidence of components was noted in 18 ankles. Overall, 37 of 38 patients were satisfied with the outcome of their surgery and would have the same procedure under similar circumstances.

COMPLICATIONS

- Hansen et al\textsuperscript{10} reported on the complications on 306 consecutive ankle replacements.
- 28\% underwent reoperations; the most common procedures were débridement of heterotopic bone, correction of axial malalignment, and component replacement. The below-the-knee amputation rate was 3.5\%.
- Malleolar fractures happen in about 10\% of cases. Further perioperative complications include tibial nerve injury, tendon injuries, and wound problems.\textsuperscript{6}
- Late complications include syndesmosis nonunions in 6\% to 26\% of cases.\textsuperscript{3}
- Infection
- Progressive varus or valgus deformities due to ligamentous imbalance
- Osteolysis, bone cysts, and subsidence

REFERENCES

DEFINITION
- Revision of the Agility Ankle is required for a variety of circumstances. It may be necessary either relatively early after the index procedure, or delayed due to late mechanical failure.
- By definition, revision may be required around a stable arthroplasty (ie, correcting imbalance creating deformity in the prosthesis or repairing fractures around the prosthesis) or by implant removal and subsequent replacement of the prosthesis (whole or in part).

ANATOMY
- The anatomy of revision total ankle arthroplasty revolves around the specific mechanism of failure of the original prosthesis. Structures of concern include:
  - Bone: the medial and lateral malleoli, the distal tibia, and the talus
  - Ligaments: the anterior talofibular and calcaneofibular ligaments, the deltoid ligament, and the syndesmotic ligament complex
  - Muscle and tendon: the Achilles tendon and the anterior tibial, extensor hallucis longus, extensor digitorum longus, peroneus longus and brevis, and posterior tibial tendons

PATHOGENESIS
- Malleoli: Failure of the malleoli may occur from fracture of these structures. Fracture can occur early (due to a technical complication sustained during the procedure) (FIG 1A) or late (from weakened bone architecture due to osteolytic cysts, or undue stresses applied to the malleoli from deformity or altered gait mechanics) (FIG 1B). Micro- or macromotion may occur through the prosthesis–bone interface at the fibula from lack of a syndesmotic fusion, creating the potential for lateral malleolar fracture.
- Distal tibia and talus: Failure is sustained through axial load applied to this portion of bone, compounded by the physiologic effects of the prosthesis. Osteolysis may occur from shed polyethylene particles, creating a macrophage reaction and autodestruction of bone. This weakened, cystic bone allows the prosthesis to subside through the resection margin, creating deformity and failure. In addition, compromise through lack of bone ingrowth into the sintered beads may create micromotion within the prosthesis–bone interface, creating further erosions and subsidence into the tibia or talus (FIG 2A,B).
- Lateral and medial ankle ligaments: Failure is sustained through ligaments that are often compromised before the surgical procedure (FIG 3). Often deformity exacerbates this problem, as chronic tension through weight bearing continues to attenuate the ligaments, creating further compromise.
- Extensor tendon complex (anterior tibial tendon, extensor hallucis longus, extensor digitorum longus): Issues involving the extensor complex revolve around scar tissue and anterior wound complication (FIG 4A), which as a baseline creates altered motion in the form of decreased plantarflexion (FIG 4B). In more advanced circumstances, wound coverage is required due to tendon exposure. Compromised blood supply to the anterior skin, multiple prior incisions in posttraumatic or reconstructive situations, and direct apposition of the tendon complex against the skin may all accelerate anterior incision failure.
- Infection: Early incision complication may provide a portal of entry for colonized bacteria, leading to superficial cellulitis or deep infection (FIG 5A,B). Early intervention in the form of parenteral antibiotics or operative debridement may allow salvage of the prosthesis. Deep infections involving the bone

FIG 1 • Acute (A) and chronic (B) medial malleolus fractures. The former fractures occur due to an intraoperative technical error. The latter can occur from imbalance about the prosthesis with undue stresses.

FIG 2 • AP (A) and lateral (B) radiographs of talar subsidence. Note the penetration of the talus into the nascent talus. Also note the osteolytic cyst in the distal tibia.
(osteomyelitis) may result from direct extension from these superficial infections or may occur from bacteria seeded at the time of surgery, lying dormant for an undefined interval before presentation. Bacteria may cling to the prosthesis, creating a situation resistant to antibiotic intervention. They may form a glycocalyx, insulating themselves from both antibiotics and operative irrigation.

**NATURAL HISTORY**

- The natural history of all of the above-mentioned problems follows a course dependent on the index mechanism of failure.

  - Malleolar fractures may occur early or late. In either case, resolution of the fracture is compromised by the limited bone available due to removal for implantation of the prosthesis. The natural history may thus progress to either successful union after repair, or nonunion. Nonunion may lead to a relative increased length of the malleoli and subsequently the ligaments, leading to deformity potential (FIG 6). Deformity, once present, prevents union.

  - Ligament compromise follows a similar predictable course, with the endpoint being instability and subsequent deformity about the prosthesis. Lack of medial or lateral restraint allows edge-loading of the polyethylene, leading to osteolysis and implant subsidence.

  - Incision compromise may begin as focal necrosis about the anterior wound. Blistering may be evident, or full-thickness necrosis. Necrosis presents as peri-incisional devascularized skin, which may be limited in extent or of greater breadth; either allows slough of the zone of injury. Full-thickness granulation tissue may develop, though it will be temporally slow. As such, scar tissue accumulates about the anterior tendon complex as motion must be restricted to provide the best healing environment. With exposed tendon, granulation tissue is less likely and plastic surgery involvement becomes a possibility.

  - Infection may present in conjunction with wound compromise as cellulitis in the early postoperative period. Without attention, cellulitis may allow deep bacterial infestation, creating osteomyelitis or septic arthritis of the artificial joint. Salvage of
the index prosthesis becomes less likely, as a glycocalyx may form about the polyethylene, shielding the bacteria from antibiotic penetration or irrigation.

- Malleolar fracture, ligament compromise, prosthesis subidence, incision compromise, and infection will be discussed separately.

**MALLEOLAR FRACTURE**

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Evaluating the ankle for malleolar fracture should include the following:
  - Direct palpation to the medial or lateral malleoli, or pain with weight bearing medially or laterally. This is not the normal location of postoperative pain, so it creates clinical suspicion that fracture is present.
  - The examiner should look for increased swelling about the ankle joint after postsurgical resolution. The examiner should evaluate for deep vein thrombosis, but normally in combination with pain, one thinks of malleolar fracture.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs: Malleolar fractures may be subtle or obvious. Obvious fractures are visible at the level of the prosthesis, generally at the apex or superior corners of the prosthesis. In iatrogenic cases, the fractures occur at the level of the superior saw cut line on the tibia, where the sagittal saw violates the medial or lateral malleolus. Significant distraction via the uniplanar fixator upon osteoporotic bone may create avulsion fractures at the malleoli after saw cuts, where the thinned malleoli are subject to increased force per unit area. Subtle fractures are generally delayed in appearance and may involve periosteal reactions seen at the medial malleolus proximal to the prosthesis. This type of fracture occurs from an unbalanced prosthesis (FIG 7A) placing uneven load or compression about the malleoli (FIG 7B).
  - Tc99 bone scans: This study is generally not helpful, as increased uptake is visible surrounding the prosthesis, making it difficult to discern a fracture from normal pooling.
  - CT: This test is very helpful to evaluate both the presence and healing of malleolar fractures. CT scanning is not helpful during intraoperative occurrences but has value in delayed presentation, especially in subtle cases (FIG 8). Subtraction software minimizes interference from the prosthesis.

**DIFFERENTIAL DIAGNOSIS**

- Malleolar fracture
- Infection
- Deep venous thrombosis

**NONOPERATIVE MANAGEMENT**

- Conservative treatment for malleolar fractures involves cast immobilization until union is complete. Unlike malleolar fractures without ankle arthroplasty, immobilization is often extended beyond the standard 6 weeks, as the decreased surface area for healing due to the space-occupying prosthesis increases the likelihood of nonunion. If immobilization is terminated before complete union, refracture or separation of the fragments becomes likely, mandating surgical correction.

**FIG 6** • Stressing the ankle in the operating room reveals significant medial bone compromise, leading to valgus deformity and medial instability.

**FIG 7** • Hindfoot varus (A) places increased stress about the medial malleolus, which can create a delayed medial malleolus fracture. (B) Weight-bearing radiograph of the ankle demonstrates the most common pattern of late medial malleolus fracture: a vertical shear fracture pattern. Repetitive stress from the medial corner of the tibial implant creates the vertical fracture line that allows the prosthesis to shift into varus.

**FIG 8** • CT scan of subtle medial malleolus fracture in a delayed presentation due to persistent hindfoot valgus.
CT scan is important to quantify union before discontinuing immobilization.

- Use of pulsed electromagnetic fields or ultrasound to stimulate union may enhance union.

**SURGICAL MANAGEMENT**

- Surgical repair of malleolar fractures is normally the treatment of choice after the fracture is recognized. As the rehabilitative goal of total ankle arthroplasty is early range of motion, prolonged immobilization to allow conservative union may lead to undue ankle stiffness, compromising patient satisfaction. Thus, upon visualization of a malleolar fracture (either acute or delayed), surgical repair is indicated.

**Preoperative Planning**

- In acute or iatrogenic situations, no preoperative planning is possible.
- In delayed or chronic situations, a CT scan is useful to evaluate the fracture pattern and determine screw placement. In addition, the CT scan may visualize partial union, allowing percutaneous fixation of the fracture fragments.

**Positioning**

- Positioning is supine for this procedure, with a bump under the ipsilateral hip of a diameter to rotate the knee, ankle, and foot to a neutral position (FIG 9A). Generally, blankets are used to elevate the involved extremity above the sagittal plane of the unaffected extremity (FIG 9B). This position improves the accuracy of sagittal imaging and prevents the need to lift or manipulate the involved extremity during the more tenuous portions of the surgical procedure.

**Approach**

- The surgical approach depends on whether the malleolar fracture is acute (noted intraoperatively) or chronic (occurs at a later date).
- The surgical approach for acute malleolar fractures is performed in the index procedure (ie, anterior approach for reduction and fixation of the medial malleolus fracture and lateral approach for the lateral malleolus fracture). The anterior approach allows evaluation of the fracture reduction, while screws are placed percutaneously medially. The lateral approach provides direct access for reduction and plate fixation.
- In chronic situations, the lateral approach is still used for lateral malleolar fractures. However, a medial approach is preferred for medial malleolar fractures, as direct visualization of the fracture fragments is critical, and often bone loss is present. The medial approach allows placement of either screws or plates, depending on the anatomy of the fragments.

**OPEN REPAIR OF THE ACUTE MEDIAL MALLEOLUS FRACTURE**

- Reduce this fracture anatomically (TECH FIG 1A) during surgery and hold it with a reduction clamp.
- Place guidewires from the tip of the medial malleolus into the distal tibia (TECH FIG 1B). There is adequate room for one and possibly two guidewires despite the medial bone resection for the prosthesis.
- Perform screw fixation percutaneously with cannulated screws (TECH FIG 1C). Alternatively, if solid-core screws are preferred, drilling is done over the guidewire, followed by guidewire withdrawal and placement of the solid-core screws.

TECH FIG 1 • Stressing the ankle intraoperatively (A) reveals gapping at the medial malleolar fracture site. (continued)
TECH FIG 1 • (continued) Two guidewires are placed across the fracture site (B) within the substance of the medial malleolar bone. Firm compression is achieved (C) across the fracture site.

OPEN REPAIR OF THE LATERAL MALLEOLUS FRACTURE

- Currently, standard fixation of the syndesmotic fusion is done percutaneously, after placing the plate against the distal fibula through the anterior approach (TECH FIG 2A).
- However, if a lateral malleolar fracture is sustained, extend the lateral approach as a standard lateral approach for this type of fracture pattern. Clean the fracture ends of debris (TECH FIG 2B).
- After direct exposure, reduce the fragments (TECH FIG 2C,D). Often the fracture is at the apex of the lateral portion of the prosthesis. Thus, it is difficult to provide standard lag-screw fixation.
- Prebend the plate to hook around the lateral malleolus tip (TECH FIG 2E).
- Apply the plate proximal to the fracture with three screws traversing the syndesmosis.
- Distal screw fixation generally allows placement of two screws, both cortical. The first, more proximal screw should be placed with lag technique. The second screw is placed intramedullary, at the tip, to provide stabilization.
REPAIR OF A LATE MEDIAL MALLEOLUS FRACTURE

- As mentioned above, a direct medial approach is used to provide better access to the fracture fragments while avoiding violation of the ankle prosthesis (TECH FIG 3A).
- Use a curette to remove all fibrous tissue present (TECH FIG 3B). This is a critical step, as good-quality vascular bone must be visualized on both sides of the fracture (TECH FIG 3C).
- It is critical to provide direct apposition of the fracture fragments to enhance the potential for union (TECH FIG 3D,E).

- Bone graft may be required to supplement any gaps present; it is generally taken from the calcaneus (TECH FIG 3F–I).
- Normally, axial fixation is preferred, as compression is achieved through standard medial malleolar fixation techniques. However, plate fixation may be used as a supplement after compression is achieved (TECH FIG 3J–O).

TECH FIG 3 • Late medial malleolus fracture. A direct medial approach is performed (A). Due to the delayed presentation and subsequent longevity of motion about the fracture site, significant bone erosion is present. The fracture site is curetted (B) and stressed (C) to check the stability of the prosthesis. The fracture is manually reduced (D) and clamped to maintain the reduction (E). The base of the fracture is packed with cancellous bone graft (F). (continued)
Tricortical graft is harvested (G), templated (H), and prepared (I) for a perfect fit in the cortical defect. A plate is contoured (J) and the bone graft inserted into the defect (K,L). The plate is applied (M) under compression (note eccentric placement of proximal screws). In addition, an axial screw (N) assists with this compression. (continued)
Chapter 76  REVISION AGILITY TOTAL ANKLE ARTHROPLASTY

TECH FIG 3  • (continued) The fracture achieves successful union (O).

PEARLS AND PITFALLS

It is critical to assess for deformity if the medial or lateral malleolar fracture appears late.
- If deformity is present, this must be corrected at the time of malleolar fracture. At a minimum, a calcaneal osteotomy is required. Additional procedures such as first-ray osteotomies may be used in supplement.

POSTOPERATIVE CARE
- Rigid internal fixation allows early motion, which is important after an ankle arthroplasty.
- After a brief period of immobilization (generally 10 days to 2 weeks), the patient is converted to a controlled-ankle-motion (CAM) boot.
- Range of motion is initiated at this time without weight bearing. Weight bearing is restricted until 6 weeks postoperatively, when union is generally present. It is extremely important not to allow an increase in activity or discontinuance of the CAM boot until union is complete. Nonunion of malleolar fractures in total ankle arthroplasty can severely compromise the result of the arthroplasty by creating intra-articular deformity and edge loading.

OUTCOMES
- Fracture fixation rarely results in nonunion. Without fixation, the risk of nonunion is high, compromising the arthroplasty through the potential for late deformity.

COMPLICATIONS
- Nonunion is the major potential complication.

LIGAMENT INSTABILITY

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients with ligament instability creating late malalignment of the prosthesis will develop increasing pain in the medial or lateral gutters around the prosthesis as the progressive tilt creates gutter impingement.
- Examination of the total ankle arthroplasty for ligament instability should include the following:
  - Medial-lateral stress radiographs. Medial and lateral stress is applied to the ankle, specifically looking for a soft endpoint or gross ligamentous laxity. This test will assist the examiner in determining the incompetence of the ligaments directly. Without a firm endpoint to stress, the ligaments are clearly compromised.
  - Thumb-to-forearm test, or hyperextension for the elbow: These basic tests examine for gross ligamentous laxity, often congenitally based. Patients with gross ligament laxity are at higher risk for failure of the prosthesis due to tilt, edge loading, and subsequent osteolysis.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Manual stress radiographs may assist the examiner in quantifying ligament laxity. Similar to the test mentioned above, stress is applied across the ankle joint while a mortise ankle radiograph is obtained. The examiner will specifically look for increased tilt of the talus upon the tibial tray.
- Weight-bearing AP and mortise radiographs may also be used to quantify ligament laxity, as the tilt of the prosthesis can be directly measured.
- Both radiographs must be interpreted with caution, for this tilt may be compounded by underlying foot deformities. Thus, these deformities must be corrected simultaneously, or any ligament reconstructive procedures will ultimately fail due to recurrent tension across the newly created ligament.
DIFFERENTIAL DIAGNOSIS

- Varus or valgus foot deformity
- Posterior tibial tendon insufficiency
- Peroneal tendon rupture

NONOPERATIVE MANAGEMENT

- Conservative care revolves around stabilizing the ankle with medial and lateral posts, often in the form of a lace-up brace, a U-shaped stirrup brace, a Ritchie-type brace, or an Arizona brace (FIG 10). All braces serve to limit varus or valgus thrust, and thus limit tilt.

SURGICAL MANAGEMENT

- Surgical ligament reconstruction is challenging due to the space occupied by the prosthesis. Thus, standard techniques need to be modified to accommodate the bone architecture provided by resection necessary for prosthesis implantation.

Preoperative Planning

- Patients with ligament incompetence are assessed for laxity via the stress radiographs mentioned above. The patient is assessed for hindfoot and forefoot deformities that may require simultaneous correction. Gross ligament laxity must be accounted for, as balance achieved through tightening one side of the ankle may create the opposite deformity from that corrected due to a lack of contralateral restraint. Finally, a diagnostic ultrasound may be used to assess the quality of the posterior tibial tendon and peroneal tendons, as an MRI will be compromised by the prosthesis.

Positioning

- Depending on the involved ligaments, the patient is positioned either laterally on the operating table for lateral ligament incompetence, or supine with a bump under the opposite hip for medial ligament incompetence.

Approach

- The approach parallels the standard anterior incision performed for ankle arthroplasty, maximizing the skin bridge to minimize wound complications. Exposure is carried proximal to the ankle joint a minimum of 5 cm and distal to the ankle joint a minimum of 6 cm. This generous incision allows access to reconstruct all aspects of the failed ligaments.

**DELTOID RECONSTRUCTION**

- The patient is placed supine on the operating table, with a bump under the contralateral hip to externally rotate the involved extremity.
- The incision is medially based, extending from 1 cm proximal to the medial malleolus past the sustentaculum tali (TECH FIG 4A).
- Retract the posterior tibial tendon posteriorly, exposing the insertions of the deep and superficial components to the deltoid ligament (TECH FIG 4B,C).
- Using standard EndoButton technique, place drill holes at both insertions, exiting anterior to the fibula (TECH FIG 4D–F).

![Protective Arizona brace](right) offers a more secure option for stability over the UCBL orthotic (left).
A cadaveric anterior tibial tendon is used for the reconstruction. Weave a Krackow suture stitch with no. 2 Ethibond through both ends of the tendon and anchor it to two separate EndoButtons with 1 cm of suture lead between the EndoButton and the tendon ends (TECH FIG 4G). The tendon is prestretched to minimize late plastic deformation of the tendon graft.

- Pass the ends through the drill holes and flip the buttons, providing secure fixation at both the superficial and deep insertions (TECH FIG 4H–J).
- Securely reproduce the ligament origin by placing a drill hole at the tip of the medial malleolus, directing the hole toward the anterior central tibia. This hole is placed obliquely to avoid the tibial component to the prosthesis (TECH FIG 4K,L).
- Double the tendon upon itself and thread it through this drill hole, with the looped end exiting the anterior tibia.
- Place a 4.5-mm drill hole proximal to the exit point of the looped tendon, 1 cm beyond the maximum stretch of the loop component of the tendon. By placing the drill hole 1 cm proximal to the extent of the loop, the ligament reconstruction will remain taut (TECH FIG 4M).
- Anchor the loop with a large-fragment screw and a spiked ligament washer (TECH FIGS 4N–P).

TECH FIG 4 • (continued) This ligament may be sectioned for lateral imbrications (C). Guidewires are passed for the EndoButton in a plane that emerges anterior to the fibula (D) and transtalar (E). The guidewires are placed at the insertion points of the native deep and superficial deltoid ligaments (F). The cadaveric tendon is prepared by placing Krackow suture weaves at both ends (G) and tensioned to minimize late plastic deformation. Each end of the graft is placed into the respective deep and superficial deltoid tunnel (H,J), held in place on the lateral side of the talus by the EndoButtons (J). (continued)
TECH FIG 4 • (continued) The ankle replacement remains in valgus (K) until the tendons are placed through a tunnel drilled from the tip of the medial malleolus directed toward the anterior distal tibia (L). The spiked ligament washer is placed proximal to the exit point of this tunnel to place the graft under maximal tension (L). The looped end of the graft is placed around the screw, and the ligament washer is tightened against it (M). The ankle is now aligned in neutral (N), and this position is confirmed under fluoroscopic imaging in the AP (O) and sagittal (P) planes. Note the position of the EndoButtons on the sagittal plane, anterior to the fibula and transtalar (P).

LATERAL LIGAMENT RECONSTRUCTION

- Unfortunately, a modified Brostrom procedure is not sufficient to stabilize the lateral ligaments in light of an ankle replacement. Thus, a similar cadaveric tendon transfer is performed to stabilize the deficient lateral ligaments.
- Use a cadaveric anterior tibial tendon, tubularizing the tendon and weaving a Krackow suture with no. 2 Ethibond on one end. Secure an EndoButton to this suture with a 1-cm gap between the end of the tendon and the EndoButton.
- Make a drill hole through the talar neck at the insertion of the anterior talofibular ligament, exiting anterior to the medial malleolus. The far cortex of the hole is smaller than the length of the EndoButton.
- If sufficient fibula is present distal to the lateral portion of the tibial tray, place 7.3-mm drill holes at the origins of the anterior talofibular ligament and calcaneofibular ligament. These holes meet in the central fibula.
- Place the allograft tendon through these holes, with the distal segment exiting through the inferior (calcaneofibular) hole.
- If there is not sufficient fibula at the tip, carry the plate for securing the syndesmotic fusion to the tip of the fibula, and place the cadaveric tendon deep to the plate.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>■ The surgeon must assess the patient for associated foot pathology (cavus with lateral ligament laxity, and flatfoot with deltoid ligament laxity). This must be addressed simultaneously in the form of osteotomies or arthrodeses, or the ligament repair will fail.</td>
</tr>
<tr>
<td>■ The surgeon must assess the patient for generalized ligament laxity. Care must be taken not to overtighten the reconstruction, or the opposite deformity may occur.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Graft management</th>
</tr>
</thead>
<tbody>
<tr>
<td>■ The graft should be tubularized before performing the Krackow weave. This will increase the structural integrity of the cadaveric graft.</td>
</tr>
<tr>
<td>■ The graft must be stretched to a minimum of 20 lbs of tension to prevent late stretch.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tunnel placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>■ The lateral (or medial, in lateral ligament reconstruction) portion of the tunnels (talar and calcaneal) must exit anterior to the fibula (or medial malleolus). Failure to achieve this placement will compromise flipping of the EndoButton and create malleolar impingement.</td>
</tr>
<tr>
<td>■ The far cortical bridge of the tunnel must be a smaller diameter than the length of the EndoButton to ensure rigid fixation.</td>
</tr>
<tr>
<td>■ Occasionally, a small incision is placed at the exit point of the EndoButton suture to assist with the flip. A hemostat can be used to assist with this maneuver.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spiked ligament washer fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>■ Placing the spiked fixation beyond the maximum stretch of the proximal end of the cadaveric tendon is critical to maximizing tension on the ligament repair. The ligament must be tensioned to prevent late sag or recurrence.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- If the fixation is rigid and strong, the patient is placed in a cooling boot for 2 to 3 days and admitted to the hospital. This minimizes the risk of incision complications, but the patient must remain dormant with the leg elevated to prevent stretch on the newly reconstructed ligament.
- If the fixation has the potential for compromise, the patient is placed in a stirrup-type plaster splint in combination with a posterior mold splint. This construct will take tension off the ligament repair while simultaneously keeping the ankle flexed to neutral.
- The patient is changed to a cast at 5 to 7 days with windows placed in the cast for direct incision observation.
- Physical therapy is used at 6 weeks postoperatively to increase ankle range of motion. No inversion or eversion is attempted until 3 months postoperatively. The patient is in a CAM boot fully weight bearing at this time.
- The patient is placed in a lace-up brace at 12 weeks postoperatively. This brace may be discontinued at 4 months postoperatively.

OUTCOMES

- This technique is newly developed, so there are no long-term outcome studies at this time. A trial is under way.

COMPLICATIONS

- Wound infection, cellulitis, wound necrosis
- Nerve damage to superficial peroneal, deep peroneal, saphenous, sural, or tibial nerves
- Recurrence of deformity, tendon transfer failure
- Opposite deformity in cases of gross ligament laxity

PROSTHESIS SUBSIDENCE

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with subsidence of the prosthesis have collapse and eventual impingement in the medial or lateral gutters. They often complain of increasing stiffness upon a prosthesis that was previously functioning well. This is rarely an acute phenomenon (unless fracture through an osteolytic cyst created the subsidence) and is often noticed as a part of a routine office visit. Pain follows the stiffness and is normally located deep, medial, and lateral to the prosthesis.
- The methods for examining the total ankle arthroplasty for subsidence include the following:
  - Standing flexibility (range of motion) of the ankle: The patient stands with the involved ankle anterior to the axis
of the body and the opposite ankle behind the body. To determine dorsiflexion, the knee is flexed forward as far anterior as possible (runner’s stretch), and the angle between the foot and the tibia is measured. Plantarflexion is assessed by having the patient lean back on the involved extremity as far as possible while keeping the entire foot flat on the ground. The angle is then measured. This should be compared at each office visit and documented. Increasing stiffness is commonly seen with subsidence of the prosthesis. If this test is done routinely as a part of each office visit, accurate and reproducible values will allow measured changes in ankle flexibility.

- Direct palpation: The examiner must palpate deeply the medial and lateral gutters to elicit pain. In addition, the syndesmotic fusion is painful to palpation if a nonunion has led to tibial tray subsidence. Pain signifies increasing gutter impingement as the arthritic bone interacts due to loss of height. Pain in the syndesmotic region signifies a syndesmotic nonunion, which allows tibial tray subsidence (common in an undersized prosthesis).

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standard radiographs include weight-bearing AP, lateral, and mortise views of the ankle. These radiographs reveal a tilt in the components if subsidence is not uniform. The lateral radiograph (FIG 11) is assessed for tibial tray subsidence (often at the anterior cortex of the tibia) and for talar subsidence (the talar fin may be penetrating the subtalar joint). The AP and mortise radiographs allow an assessment of measurable tilt and bone loss (FIG 12). Gutter impingement becomes obvious as contact between the talus and the mediolateral malleolus is visible.

- A CT scan is critical to assess penetration of the prosthesis into the subtalar joint (FIG 13). In addition, the nonunion of the syndesmotic fusion may be visualized, contributing to tibial tray subsidence. The surgeon can assess for an undersized prosthesis by examining the coverage of the tibial tray underlying the fibula. Lack of coverage by the fibula can lead to valgus subsidence of the tibial tray. The CT scan will reveal osteolytic cysts contributing to subsidence of the tibial tray or talar component, and potential fracture through these cysts. Finally, the CT can assess for ingrowth of the prosthesis and potential loosening. Subtraction software will assist in eliminating artifact due to the prosthesis.

**DIFFERENTIAL DIAGNOSIS**

- Infection (osteolysis vs. osteomyelitis)
- Residual posttraumatic osteoarthritis in the medial or lateral gutters

**NONOPERATIVE MANAGEMENT**

- Nonoperative management involves bracing to prevent pain from arthritic or collapsed bone surfaces. In particular, a nonarticulating ankle-foot orthosis may limit pain.

**SURGICAL MANAGEMENT**

- The indications for surgical treatment of subsidence are three: pain, stiffness that is unacceptable to the patient, and prevention of substantial subsidence that will diminish bone stock to the point of preventing revision of the prosthesis in the future. Subsidence to this level may necessitate implant removal followed by arthrodesis of the ankle joint.

**Preoperative Planning**

- Assessment of the remaining bone stock after implant removal allows the surgeon to predict whether a custom prosthesis will need to be constructed to salvage the failed joint replacement. The most accurate way to make this assessment is a careful review of the CT scan.

- In addition, assessment for revision of the syndesmotic fusion may be made by CT scan. Underlying foot deformity that may have contributed to prosthesis subsidence is determined to allow planning for simultaneous flatfoot–cavovarus foot correction. The revised prosthesis must be placed upon a
plantigrade foot to prevent uneven stresses leading to secondary failure.

- Infection is assessed via markers such as the white blood cell (WBC) count, erythrocyte sedimentation rate, and C-reactive protein. We have found limited value in a tagged-WBC scan, as the prosthesis itself may create an inflammatory foreign body reaction that mimics osteomyelitis on nuclear medicine scans.
- Bone stock and osteoporosis may be assessed via CT scan, plain radiographs, and a DEXA scan. If osteoporosis is present, a concerted effort to increase bone mass will assist in providing structural support to the prosthesis and should be performed before revision.

### Positioning

- The patient is placed supine on the operating table.
- A bump is placed under the hip to rotate the extremity to neutral with respect to the knee.
- The lower leg is placed on multiple blankets to provide a firm working surface while simultaneously allowing shoot-through lateral radiographs to enhance the assessment of prosthesis coverage (anterior and posterior pillar).

### Approach

- The surgical approach is anterior, following the initial incision done for the primary arthroplasty. The interval is the same as that mentioned above.

---

**TALAR SUBSIDENCE**

- Expose the talus by removing all associated scar tissue and necrosis. The fixator is applied to provide distraction and easy component access while providing stability (TECH FIG 5A–D).
- Remove the talar component. It is normally not ingrown and comes out simply after replacing the insertion rod and joysticking the component (TECH FIG 5E,F).
- Make saw cuts to restore the axis of the prosthesis to be perpendicular to the axis of the tibia (TECH FIG 5G–I). These cuts may use a standard (though larger) cutting block.

- There is often a rectangular void in the talus after component removal (TECH FIG 5J,K). Curette any fibrous tissue within that void, achieving healthy bleeding bone. There is normally a rim of excellent cortical bone in the nascent remaining talus, as the original Agility talar component does not conform to the entire talus after the initial cut.
- This rim of bone is advantageous, as the new Agility LP talar component does conform to the entire talus. As such, the talar component will sit on this rim, establishing the height of the nascent talus made with the original saw cut at the index procedure.
The fin on the Agility LP will have no stability, due to the rectangular defect present in the central talus (TECH FIG 5L). One could consider bone grafting this defect, but I do not believe the bone graft will provide adequate stability in the short term, allowing the talar component to rotate or shift from the desired position after closure and rehabilitation. In addition, in the long term, it would be unusual for the bone graft to incite ingrowth into the Agility LP talar component.

Thus, I use cement fixation for the talar fin. I fill the void present with polymethylmethacrylate while it is still softer and malleable. I then onlay the Agility LP talar component onto the talus, allowing it to sit on the rim of nascent bone while the fin conforms to the cement in the desired position (TECH FIG S M–O). To do this, the tibial component must be in place so that appropriate rotation and mediolateral positioning can be determined. The remaining native talus provides some element of bone ingrowth into the prosthesis, while the cement interdigitates with the residual sintered beads on the talar component.

I allow the cement to harden while I manually reduce the ankle joint, maintaining the correct position until the cement cures. The talus is now stable and ready to articulate (TECH FIG SP–T).
Chapter 76  REVISION AGILITY TOTAL ANKLE ARTHROPLASTY

TECH FIG 5  (continued) Clinical inspection demonstrates a preserved cortical rim in the tibia (J) and talus (K) with the central rectangular defect expected. The trial prosthesis confirms adequate rim support for the Agility LP (L), with restoration of height. The central defect is apparent and is filled with polymethylmethacrylate. The final components (M) are two sizes larger than the original. The syndesmosis has also been grafted, with fixation revised. The rim coverage is apparent on intraoperative fluoroscopy (N,O). At 1 year postoperatively (P–R) the prosthesis is stable and balanced, without laxity or tilt. The range of motion has been improved substantially by providing an appropriately articulating ankle replacement (S,T).
Expose the tibia using the above-mentioned technique. Remove all associated scar tissue, and define the defects present.

Remove the tibial component by replacing the insertion rod and joysticking the component.

Generally, when the tibial component subsides, it creates significant bone loss in the distal tibia at the resection site. Often there is lack of appropriate fibula coverage on the tibial component, particularly those components that subside into valgus. This allows the surgeon to plan appropriate tibial tray coverage to ensure that the revised tibial tray will cover the fibula. In these instances, simply inserting a larger tibial tray will complete the revision.

However, if bone loss is present, the height of the tibial component must be re-established (TECH FIG 6A). In this instance, a custom tibial component must be created (TECH FIG 6B). It is important to note the size of the original component when designing the revision component. The component itself may be based on standard mediolateral dimensions, simply adding height to the tibial tray. In this instance, it is important to use knowledge based on the size of the initial component in combination with calibrated radiographs (TECH FIG 6C) to determine the size (width) necessary to provide appropriate fibula coverage. This will lessen the risk of future tibial component subsidence.

Unlike the talar component, which does not require a new cut in the talus due to the isolated central core subsidence, tibial component subsidence does erode the supportive bone, and as such will require a new cut perpendicular to the plane of the tibia. One may use the standard cutting blocks to make this cut, although custom cutting blocks can be manufactured.

Once cuts are made, the revision component fits securely into its new space. Unlike revision of the talar component, polymethylmethacrylate is not necessary, as the new tibial component has the ability for ingrowth into the newly cut surfaces.

PEARLS AND PITFALLS

**Indications**
- The surgeon must carefully assess the patient preoperatively with plain radiographs as well as CT scans to estimate the residual bone present after removal of the subsided prosthesis. The CT will also document whether the talar fin has violated the subtalar joint. This may necessitate a subtalar fusion in conjunction with the revision. For tibial component subsidence, the surgeon must carefully assess syndesmotic fusion on the axial cuts. Revision of the syndesmotic fusion must be performed in conjunction with tibial tray revision in this instance.

**Saw cuts**
- Use a large C-arm in the sagittal plane when making revised saw cuts. This will ensure that the cuts are perpendicular to the tibial–talar axis, avoiding a sloping of the components that will affect stability and flexibility. In addition, direct visualization in the sagittal plane will prevent violation of posterior neurovascular structures.

**Fixation**
- Do not be afraid to use polymethylmethacrylate under these circumstances. This is essentially a hybrid revision. Some of the component remains in congruence for bone ingrowth, which will lessen the stress across the cement interface. Even in the tibial component revision, where a majority of the tray will be in contact with quality bone, I sometimes use cement at the fin to provide additional stability and allow early motion without worries of the component shifting.
POSTOPERATIVE CARE

- If the fixation is rigid and strong, the patient is placed in a cooling boot for 2 to 3 days and admitted to the hospital. This minimizes the risk of incision complications. We normally do not cast in the operating room under these circumstances, for preventing tension on the anterior surgical incision is the best method to avoid incision complications.
- The patient is changed to a cast at 5 to 7 days with windows placed in the cast for direct incision observation.
- Physical therapy is used at 2 weeks postoperatively to increase ankle range of motion, assuming the incisions have healed. Full weight bearing may be instituted before the standard 6-week interval if the patient had a previous successful fusion of the syndesmosis. If that is not the case, then weight bearing is restricted until the syndesmosis is fused.
- The patient may discontinue use of the CAM boot before 12 weeks if strength is appropriate and the syndesmosis is fused. Stability is enhanced if polymethylmethacrylate is used, and thus weight bearing without assistive devices is accelerated.

OUTCOMES

- These techniques are newly described, so there is no literature to support their use at this time. Anecdotal experience supports the techniques, however, with short-term outcomes (1 year) demonstrating substantial improvement at this time.

COMPLICATIONS

- Wound infection, cellulitis, wound necrosis
- Nerve damage to superficial peroneal, deep peroneal, saphenous, sural, or tibial nerves
- Subsidence of the newly placed components into poor-quality bone. This is a particular problem in patients with rheumatoid arthritis or other systemic conditions.

INFECTION

PATIENT HISTORY AND PHYSICAL FINDINGS

- The presentation of infection depends on the organisms involved. However, the common pathway is cellulitis, with or without a wound complication. Patients with joint infections often have fever and may have chills. Pain is often present about a previously painless prosthesis.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain radiographs may reveal a lucent line around the prosthesis, documenting lack of ingrowth. Cystic changes may be visualized in the bone surrounding the prosthesis.
- A CT scan is more specific for lucency about the prosthesis and poor ingrowth. In addition, the CT scan is more specific for bone cysts. Air or gas in the soft tissues is visible on CT scan. Contrast-enhanced CT scans can reveal a soft tissue abscess or a sinus tract communicating with an anterior wound complication.
- A nuclear medicine Tc scan combined with a tagged WBC scan may assist in differentiating infection from aseptic loosening of the components. The results should be interpreted with caution, however, for even in cases of aseptic loosening, inflammation around the prosthesis and foreign body reaction can create a false-positive WBC scan. Thus, this scan must be interpreted in combination with clinical and hematologic findings.
- Blood work must include a complete blood count with differential, an erythrocyte sedimentation rate, and C-reactive protein. Again, these results must be interpreted in combination with clinical and radiographic findings.

DIFFERENTIAL DIAGNOSIS

- Aseptic component loosening and subsidence

NONOPERATIVE MANAGEMENT

- Antibiotic management is the staple in treating infection but must be done in a thoughtful manner.
- Empiric therapy is appropriate only in cases of pure cellulitis without deep infection.
- If deep infection is suspected, débridement and deep cultures should be obtained before starting antibiotics. The exception to this rule would be circumstances where the patient’s life is in danger (ie, the patient is septic and hemodynamically unstable).

SURGICAL MANAGEMENT

- The indications for surgery are the suspicion of a deep infection. If any suspicion is present, this is an indication for surgery.
- The above-mentioned studies are all performed and interpreted.
- The incision is assessed for closure and the need for plastic surgery. If a wound complication is present, a preoperative assessment by a plastic surgeon is appropriate but not mandatory. If wound closure does not seem likely, the surgeon should plan on having a Wound VAC readily available for intraoperative application.

Positioning

- The patient is placed supine on the operating table.
- A bump is placed under the hip to rotate the extremity to neutral with respect to the knee.
The lower leg is placed on multiple blankets to provide a firm working surface while simultaneously allowing shoot-through lateral radiographs to enhance the assessment of prosthesis coverage (anterior and posterior pillar).

**Approach**

The surgical approach is anterior, following the initial incision done for the primary arthroplasty. The interval is the same as that mentioned above.

**IMPLANT REMOVAL**

- Localize the implant through deep dissection. Follow any sinus tracts present to confirm direct communication with an infected incision.
- Remove the implant (all components) by applying the insertion rods and joysticking the components.
- Remove screws and plates about the syndesmotic fusion, as they are in direct communication with deep infection.
- Curette the bone surfaces and remove all necrotic tissues. Perform bone débridement. All residual tissue should be viable and demonstrate good vascularity. If a tourniquet is used, it should be released at this time.
- Perform irrigation with at least 6 liters of antibiotic-impregnated normal saline.
- Prepare the polymethylmethacrylate mixed with a heat-stable antibiotic (vancomycin, gentamicin). Often two bags are needed to manufacture enough cement to fill the void left by removing the prosthesis.
- Insert the cement into the newly created space while placing some distraction between the tibia and talus (**TECH FIG 7A**). This will maintain height by allowing the cement to fill the entire void. Ensure that the cement contacts the cut surfaces of the tibia and talus to maximize the local effect of the antibiotic and to provide enough stability to allow some weight bearing (**TECH FIG 7B,C**).
- Close the wound over a large suction drain, or, if this is not possible, apply a Wound VAC.

**TECH FIG 7** • Implantation of an antibiotic-impregnated cement spacer (**A**) allows structural support and maintenance of height by providing complete fill in the AP (**B**) and sagittal (**C**) planes.

**IMPLANT REINSERTION**

- After 6 weeks of intravenous antibiotics and 6 weeks off of antibiotics (3 months total), hematologic tests are done to determine the potential for residual infection.
- The identical anterior approach is used.
- If bone loss was present, custom components are created based on both CT data and measured plain radiographs.
- Remove the spacer (**TECH FIG 8A**) and curette the bone of any defects or necrotic tissue.
- Make new bone cuts with a cutting block (TECH FIG 8B) to ensure that there is viable tibial and talar bone for ingrowth (TECH FIG 8C).
- Insert the prosthesis. If stability is in question, place polymethylmethacrylate on the fins of the tibia and talus before insertion (TECH FIG 8D,E). This limited application of cement allows bone ingrowth to the remaining prosthesis (the majority) while providing enough stability to allow early range of motion and weight bearing (TECH FIG 8F–H).

**TECH FIG 8** - Revision after cement spacer. The spacer is first removed (A), followed by revision of the saw cuts (B). This allows a larger prosthesis seated against quality vascular bone (C). The prosthesis is balanced and stable (D,E). At 1 year postoperatively, there is no visible subsidence or cystic changes in the bone to suggest recurrent infection (F,G), and the incision demonstrates no compromise (H).
PEARLS AND PITFALLS

Indications
- If there is any question of deep infection, obtain adequate deep cultures and biopsy specimens before starting antibiotics. Targeting specific organisms provides a better chance of eradicating infection than using broad-spectrum antibiotics.

Débridement
- A generous débridement is critical to lowering the possibility of infection recurrence. This includes any posterior bone or abscesses deep to the posterior capsule.

Weight bearing
- Caution should be used in patients wanting to bear weight on the cement spacer. This firm implant can cause additional bone destruction with full weight bearing, compromising revision surgery (FIG 15A,B).

POSTOPERATIVE CARE
- After the index débridement, further débridement may be required with gross infections. In addition, if necessary, plastic surgery is performed once Wound VAC application has resulted in a stagnant incision. It is important to obtain excellent soft tissue coverage (often necessitating a free flap) to improve resolution of the infection and allow implantation of the revision prosthesis. In this scenario, by the time revision surgery is performed, the flap has healed sufficiently to allow the anterior approach.
- After revision surgery, the protocol is no different from that for subsidence.

OUTCOMES
- These techniques are newly described, so there is no literature to support their use at this time. Anecdotal experience supports the techniques, however, with short-term outcomes (1 year) demonstrating substantial improvement.

COMPLICATIONS
- Recurrent infection, osteomyelitis
- Recurrent wound breakdown
- Nerve damage to superficial peroneal, deep peroneal, saphenous, sural, or tibial nerves
- Subsidence of the newly placed components into poor-quality bone. This is a particular problem in those with rheumatoid arthritis or other systemic conditions.

REFERENCES
DEFINITION

■ The procedure to fuse the tibiotalar joint for isolated end-stage tibiotalar arthrosis.

ANATOMY

■ Ankle
  ■ Tibial plafond with medial malleolus
  ■ Articulations with dorsal and medial talus
  ■ In sagittal plane, slight posterior slope
  ■ In coronal plane, articular surface is 88 to 92 degrees relative to lateral tibial shaft axis.

■ Fibula
  ■ Articulation with lateral talus
  ■ Responsible for one sixth of axial load distribution of the ankle.

■ Talus
  ■ 60% of surface area covered by articular cartilage
  ■ Dual radius of curvature
  ■ Distal tibiofibular syndesmosis
  ■ Anterior inferior tibiofibular ligament
  ■ Interosseous membrane
  ■ Posterior tibiofibular ligament

■ Ankle functions as part of the ankle–hindfoot complex much like a mitered hinge.

PATHOGENESIS

■ Posttraumatic arthrosis
  ■ Most common cause
  ■ Intra-articular fracture
  ■ Ankle fracture-dislocation with malunion
  ■ Chronic ankle instability

■ Primary osteoarthrosis
  ■ Relatively rare compared to hip and knee arthrosis

■ Inflammatory arthropathy
  ■ Most commonly rheumatoid arthritis

■ Other
  ■ Hemochromatosis
  ■ Pigmented villonodular synovitis
  ■ Charcot neuroarthropathy
  ■ Septic arthritis

NATURAL HISTORY

■ Posttraumatic arthrosis
  ■ Malunion, chronic instability, intra-articular cartilage damage, or malalignment may lead to progressive articular cartilage wear.
  ■ Chronic lateral ankle instability may eventually be associated with:
    ■ Relative anterior subluxation of the talus
    ■ Varus tilt of the talus within the ankle mortise
    ■ Hindfoot varus position

■ Primary osteoarthrosis of the ankle is rare and poorly understood.

■ Inflammatory arthropathy
  ■ Progressive and proliferative synovial erosive changes failing to respond to medical management
  ■ May be associated with chronic posterior tibial tendinopathy and progressive valgus hindfoot deformity, eventual valgus tilt to the talus within the ankle mortise, potential lateral malleolar stress fracture, and compensatory forefoot varus

PATIENT HISTORY AND PHYSICAL FINDINGS

■ History
  ■ Typically, history of trauma to the ankle
  ■ Intra-articular fracture (bi- or tri-malleolar ankle fracture; tibial plafond [pilon] fracture)
  ■ Chronic ankle instability
  ■ Inflammatory arthropathy
  ■ Primary ankle arthritis

■ Symptoms and complaints
  ■ Pain in anterior ankle with weight bearing and particularly with forced dorsiflexion
  ■ Often relieved by rest, but patient may have pain even at rest after vigorous activity or prolonged standing

■ Ankle swelling
  ■ Ankle stiffness

■ Medications
  ■ If patient is taking anti-inflammatory agents, these will need to be stopped preoperatively to limit the risk of perioperative bleeding.
  ■ Rheumatoid medications; may need to be stopped perioperatively to optimize wound and bone healing

■ Physical examination
  ■ Alignment
    ■ Ipsilateral limb alignment (not simply ankle alignment). The surgeon should examine the lower extremity from the hip to the foot. Optimal limb alignment is essential for the ankle arthrodesis to function well. Any ability for the lower limb to compensate for malalignment through the ankle is forfeited with ankle arthrodesis.
    ■ Ankle–foot alignment
      ■ The ankle functions as part of an ankle–subtalar joint complex.
      ■ Ankle fusion must be positioned on a sufficiently supportive and plantigrade foot.
      ■ Hindfoot, midfoot, and even forefoot malalignment may need to be addressed simultaneous to or staged with ankle arthrodesis.
  ■ Range of motion (ROM)
    ■ Ankle ROM is not critical since the ankle will be stiff following arthrodesis.
- Hindfoot ROM is essential for successful ankle arthrodesis. A stiff hindfoot and fused ankle allows very little accommodation and functions as a tibiotalocalcaneal or even pan-talar arthrodesis. Ankle arthritis associated with hindfoot stiffness, particularly if due to hindfoot arthritis, may be better treated with total ankle arthroplasty (TAA).

- Soft tissues
  - An intact, relatively healthy soft tissue envelope surrounding the ankle is less likely to have soft tissue complications postoperatively, provided careful soft tissue handling is maintained.
  - Previous surgical scars must be considered. Either they can be incorporated into the surgical approach or the surgical approach may be modified to limit postoperative wound complications.
  - Vascular status: Intact pulses and satisfactory refill must be confirmed; if not, a Doppler ultrasound or non-invasive vascular studies must be performed before considering surgery.
  - Neurologic status: A peripheral neuropathy is a relative contraindication for TAA; in our opinion, well-controlled diabetes without neuropathy is not. However, if there is any question about risks, then arthrodesis should be considered in lieu of arthroplasty for end-stage ankle arthritis. Established neuropathy and either existing or high risk of Charcot neuroarthropathy is a contraindication for TAA. Ankle arthrodesis or even tibiotalocalcaneal arthrodesis is favored over TAA for end-stage ankle arthritis associated with a dense peripheral neuropathy and risk of or existing Charcot neuroarthropathy.
  - Motor function: Intact motor function of the ankle and foot is essential to successful ankle arthrodesis. Lack of active dorsiflexion, plantarflexion, inversion, or eversion is a relative contraindication to ankle arthrodesis. Tibialis anterior function is still required to dorsiflex the foot at the transverse tarsal (talonavicular and calcaneocuboid) joints. Gastrocnemius–soleus function is needed to plantarflex the hindfoot. Posterior tibial and peroneal tendon function is necessary to maintain a dynamic balance of the foot under the ankle arthrodesis. Without these functioning muscle groups, a tibiotalocalcaneal or pan-talar arthrodesis or possibly a bridle tendon transfer may be warranted.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Weight-bearing AP, lateral, and mortise views of the ankle.
- Weight-bearing AP, lateral, and oblique views of the foot, particularly with associated foot deformity.
- With associated or suspected lower leg deformity, we routinely obtain weight-bearing AP and lateral tibia–fibula views.
- With deformity in the lower extremity, we routinely obtain weight-bearing mechanical axis (hip-to-ankle) views of both extremities.
- We typically evaluate complex or ill-defined ankle–hindfoot patterns of arthritis with or without deformity using CT of the ankle and hindfoot.
- If we suspect avascular necrosis of the talus or distal tibia, we obtain an MRI of the ankle.

**DIFFERENTIAL DIAGNOSIS**
- See “Pathogenesis.”

**NONOPERATIVE MANAGEMENT**
- Activity modification
- Bracing
- Ankle–foot orthosis (AFO)
- Double upright brace attached to shoe
- Stiffer-soled shoe with a rocker-bottom modification
- Nonsteroidal anti-inflammatories or COX-2 inhibitors
- Medications for systemic inflammatory arthropathy
- Corticosteroid injection
- Viscosupplementation

**SURGICAL MANAGEMENT**
- The trend is to perform ankle arthrodesis through an anterior approach with preservation of the malleoli. Recently there have been favorable outcomes in conversion of ankle fusion to TAA.
- While ankle arthrodesis is typically successful in relieving symptoms related to end-stage ankle arthritis, over time the hindfoot may develop compensatory degenerative changes (ie, adjacent joint arthritis).
- If one or both of the malleoli are sacrificed, then this potential conversion is compromised.
- The anterior approach is also used for the majority of TAA cases.

**Preoperative Planning**
- Vascular and neurologic examination
- It is easy to focus on the patient’s symptoms and radiographs demonstrating end-stage ankle arthritis.
- Satisfactory circulation is essential to allow wound healing and fusion.
- A neuropathy may warrant a more extensive ankle–hindfoot stabilization.
- Deformity correction
  - A sound preoperative plan facilitates effective intraoperative deformity correction.
  - The surgeon should evaluate the contralateral extremity and ankle to have an understanding of what is physiologic for that patient.

**Positioning**
- Supine
- Plantar aspect of operated foot at end of operating table
- Foot and ankle well balanced, with toes directed to the ceiling
- A bolster under the ipsilateral hip prevents undesired external rotation of the hip.
- We routinely use a thigh tourniquet and regional anesthesia.
  - A popliteal block provides adequate pain relief postoperatively, particularly if a regional catheter is used. Moreover, hip and knee flexion–extension is not forfeited, facilitating safe immediate postoperative mobilization.
  - However, to use a thigh tourniquet with a popliteal block typically requires a supplemental femoral nerve block (patients temporarily forfeit knee extension postoperatively) or general anesthesia.

**Approach**
- Anterior approach to the ankle, using the interval between the tibialis anterior (TA) tendon and the extensor hallucis longus (EHL) tendon
**APPROACH**

- Make a longitudinal midline incision over the anterior ankle, starting about 10 cm proximal to the tibiotalar joint and 1 cm lateral to the tibial crest (TECH FIG 1A).
- Continue the incision midline over the anterior ankle just distal to the talonavicular joint.
- At no point should direct tension be placed on the skin margins; we perform deep, full-thickness retraction as soon as possible to limit the risk of skin complications.
- Identify and protect the superficial peroneal nerve by retracting it laterally.
- In our experience there is a consistent branch of the superficial peroneal nerve that crosses directly over or immediately proximal to the tibiotalar joint.
- We then expose the extensor retinaculum, identify the course of the EHL tendon, and sharply but carefully divide the retinaculum directly over the EHL tendon (TECH FIG 1B,C).
- We always attempt to maintain the TA tendon in its dedicated sheath.
- Preserving the retinaculum over the TA tendon
  - Prevents bowstringing of the tendon and thereby reduces the stress on the anterior wound
  - Should there be a wound dehiscence, then the TA is not directly exposed.
  - Preserving the retinaculum over the TA tendon is not always possible; some patients do not have a dedicated sheath for the TA.
- Use the interval between the TA and EHL tendon, with the TA and EHL tendons retracted medially and laterally, respectively.
- Identify the deep neurovascular bundle (anterior tibial–dorsalis pedis artery and deep peroneal nerve) and carefully retract it laterally throughout the remainder of the procedure (TECH FIG 1D).
- Perform an anterior capsulotomy along with elevation of the tibial and dorsal talar periosteum to about 6 to 8 cm proximal to the tibial plafond and talonavicular joint, respectively (TECH FIG 1E).
- Elevate this separated capsule and periosteum medially and laterally to expose the ankle, access the medial and lateral gutters, and visualize the medial and lateral malleoli (TECH FIG 1F,G).
- Remove anterior tibial and talar osteophytes to facilitate exposure and avoid interference with the instrumentation (TECH FIG 1H,I).
FOOT AND ANKLE • Section IV ANKLE


TIBIOTALAR JOINT PREPARATION

- I routinely use joint distraction (TECH FIG 2A,B).
- I prefer to maintain the subchondral bone architecture.
  - In preserving the essential anatomy of the talar dome and tibial plafond, I have the ability to adjust dorsiflexion–plantarflexion without compromising limb length or bony apposition at the arthrodesis site.
  - Flat cuts tend to forfeit limb length and the ability to adjust alignment without forfeiting optimal bony apposition.
  - Obviously, with deformity correction through the joint, some of the subchondral architecture may need to be sacrificed.
- I remove the residual cartilage with a sharp elevator or chisel (TECH FIG 2A).
- While preserving the subchondral architecture as best as possible I penetrate the subchondral bone with a drill bit, a narrow chisel, or both (TECH FIG 2C–E).
  - This increases surface area and promotes fusion.
  - While careful to preserve the malleoli, I still prepare the tibiotalar joint gutters to further increase the surface area for fusion (TECH FIG 2F,G).
  - Use of bone graft is at the surgeon’s discretion.
  - I routinely use bone graft to fill any voids at the arthrodesis site.
  - Avoid excessive use of bone graft; the best chance for fusion is if the physiologic surfaces are appropriately prepared and well apposed.

TECH FIG 2 • A,B. Tibiotalar joint preparation. A. Using a lamina spreader for distraction and a sharp elevator to delaminate residual cartilage. B. Alternatively, an invasive joint distractor may be used, here with drilling of the subchondral bone to promote healing. (continued)
Chapter 77 ANKLE ARTHRODESIS

For me, optimal tibiotalar joint alignment for arthrodesis is:

- Neutral dorsiflexion–plantarflexion (TECH FIG 3A)
  - Many years ago, there was a tendency to fuse women’s ankles in plantarflexion to facilitate wearing a heel. This is an idea that should be abandoned.
  - The tendency is to underestimate how much dorsiflexion is needed to get the ankle to neutral. Therefore, I typically dorsiflex the talus within the mortise just slightly more than what I think it may need. This usually results in neutral dorsiflexion–plantarflexion.

- Slight hindfoot valgus
  - Balance the talus within the ankle mortise, but be sure that the hindfoot is in slight valgus.
  - If not, then contour the tibiotalar preparation to get the hindfoot in slight valgus.
  - A reasonable landmark is to have the lateral bony aspect of the calcaneus be in line with the fibula; if it is medial to the fibula, then a neutral to varus position is inappropriately set.

- Rotation
  - Align the second metatarsal with the anterior tibial crest.

- When the malleoli are preserved, rotation is often auto-adjusted.
- External rotation is recommended by some authors, but I consider this only if the contralateral extremity dictates this position.
- The goal is to avoid internal rotation.

- Sagittal plane relationship of the talus to the tibia
  - Avoid anterior translation of the talus relative to the tibia. This places the ankle and foot at a biomechanical disadvantage.
  - With some deformity, it may be difficult to translate the talus posteriorly to a more physiologic position. In some cases, I have had to resect some of the posterior malleolus (through the joint from the anterior approach with joint distraction) to allow such posterior translation (TECH FIG 3B). Also, judiciously, the deltoid ligament may need to be partially released to allow posterior translation. Perform this cautiously, though, as some of the talar dome blood supply travels though the deltoid branch off the posterior tibial artery.

- I routinely obtain intraoperative fluoroscopic views in the AP and lateral planes to confirm appropriate alignment and bony apposition.
INTERNAL FIXATION WITH ANTERIOR PLATING—SCREW FIXATION

- Internal fixation is contraindicated or less than optimal in the face of:
  - Infection
  - Osteopenic bone
- Traditionally, I performed screw fixation and added an anterior plate for further stability; more recently, I have switched to a technique where anterior plating is the primary technique, and I supplement with screws (other than those in the plate) only if I feel further stability is needed.
- Provisional fixation once optimal reduction is achieved
- Traditional screw fixation and supplemental anterior plate

- 55-year-old high-demand patient with anterior translation of the talus within the ankle mortise (TECH FIG 4A–C)
- Patient is positioned supine on the operating table with a bump under the ipsilateral hip to resist external rotation of the extremity.
- I typically use a medial screw first (TECH FIG 4D).
- Next, I place the posterior-to-anterior screw, the "home-run" screw.
- With the newer anterior plating techniques that provide satisfactory stability, this screw has been largely abandoned; it is awkward to place and equally difficult to remove (TECH FIG 4E).

TECH FIG 3 • A. Tibiotalar joint reduction, with neutral dorsiflexion–plantarflexion, slight hindfoot valgus, and second metatarsal rotated to anterior tibial crest. B. If the talus fails to translate posteriorly in the ankle mortise, then the posterior malleolus may need to be weakened to allow the talus to reduce under the tibial axis.

TECH FIG 4 • A–C. Fifty-five-year-old man with chronic instability and posttraumatic arthritis. A. AP view with comparison to contralateral ankle. B. Mortise view. C. Lateral view. There is considerable anterior translation of the talus from the ankle mortise. (continued)
I add an anterolateral screw, one that is relatively vertical (TECH FIG 4F).

Finally, I augment the fixation with an anterior plate. In this case a small fragment, non-locking plate was used (TECH FIG 4G–I).

In my experience, adding a supplemental anterior plate to an ankle arthrodesis construct adds considerable stability.

Follow-up radiographs (TECH FIG 4J–N)

Patient returned to full activities, even playing doubles tennis.

He lacks some plantarflexion; time will tell what effect this will have on the hindfoot articulations that are attempting to compensate.

The talus is again in a physiologic relationship with the tibia, improving his biomechanics despite ankle arthrodesis.

Plate fixation as the primary fixation

33-year-old man with posttraumatic ankle arthritis and syndesmotic disruption (TECH FIG 5A–C)

Same joint preparation as described above

Provisional fixation with desired joint reduction

Plate locked to the dorsolateral talar neck with locking screws

Plate is precontoured based on average anterior ankle morphology.

Compression device is secured and compression is applied, thereby approximating the arthrodesis surfaces (TECH FIG 5D–F).

TECH FIG 4 • (continued) D. Medial screw placed first from the medial tibia to the talar dome, placed through a medial stab incision. E. Traditional posterior-to-anterior screw, placed via a posterolateral stab incision (care must be maintained to avoid injury to the sural nerve). F. Anterolateral screw placed through the anterior approach. Provisional fixation was placed adjacent to this screw. G–I. Anterior plating. G. Proximal screw fixation. H. Talar screw fixation. I. Final view of plate before closure. (continued)

Preoperative radiographs of patient undergoing double anterior plating arthrodesis technique. A,B. AP and mortise views with end-stage ankle arthritis and chronic syndesmosis disruption. C. Lateral view. (continued)
While the locking plate creates axial compression, a mild but desirable valgus moment may be introduced since the lateral plate is being used for compression.

To obtain optimal compression, provisional fixation is removed before compression is applied but after the screws are locked into the talar neck and the compression device is secured proximally.

After performing compression and securing the lateral plate in the tibia, the medial plate is applied (TECH FIG 5G,H).

Since compression has already been performed, this medial plate, which is also precontoured, serves to statically lock the arthrodesis.

Each plate has a screw hole to allow non-locking screw fixation from the plate to the posterior talar body (TECH FIG 6A,B).

Follow-up of case example (TECH FIG 6C–G)

A supplemental screw may be added from the medial tibia to the talar body, but often this is unnecessary (TECH FIG 6H,I).

Closure

- I use a drain for 24 hours.
- Standard wound closure
  - I routinely close the capsule, extensor retinaculum, subcutaneous layer, and skin (to a tensionless closure).
  - The deep neurovascular bundle, extensor tendons, and superficial peroneal nerve need to be protected during closure.

Sterile dressings on wound

Padding

Posterior–sugar-tong splint

While the locking plate creates axial compression, a mild but desirable valgus moment may be introduced since the lateral plate is being used for compression.

To obtain optimal compression, provisional fixation is removed before compression is applied but after the screws are locked into the talar neck and the compression device is secured proximally.

Follow-up of case example (TECH FIG 6C–G)

A supplemental screw may be added from the medial tibia to the talar body, but often this is unnecessary (TECH FIG 6H,I).

Closure

- I use a drain for 24 hours.
- Standard wound closure
  - I routinely close the capsule, extensor retinaculum, subcutaneous layer, and skin (to a tensionless closure).
  - The deep neurovascular bundle, extensor tendons, and superficial peroneal nerve need to be protected during closure.

Sterile dressings on wound

Padding

Posterior–sugar-tong splint
Infection is not a contraindication for external fixation.
- There will be no implant directly at the tibiotalar joint.
- In some cases, I have performed a staged arthrodesis, with initial débridement and antibiotic bead placement. The external fixator may be placed at that initial procedure or at the definitive procedure when the antibiotic beads are removed and the joint is reduced and compressed with the external fixator.

Forty-five-year-old patient with posttraumatic arthritis and deformity of the ankle, failing to respond to a prior attempt at ankle arthrodesis.

Radiographs demonstrate nonunion and residual deformity (TECH FIG 7A–C).

- Clinically, there are poor soft tissues anteriorly and a prior medial incision that will need to be incorporated into the surgical approach (TECH FIG 7D,E).
- A standard anterior approach is too risky and, in my opinion, would leave an insufficient skin bridge to the prior incision.

Supine on the operating table, again with a bolster under the ipsilateral hip to direct the ankle anteriorly

- This patient also had a distal tibial external rotation malunion and an ankle nonunion with residual ankle external rotation (TECH FIG 7F).
- Hardware removal

I used the prior incision and added another “mini-arthrotomy” incision laterally, thereby avoiding the unhealthy skin directly anteriorly over the ankle (TECH FIG 8A).

- I prepared the joint through the medial incision and used the lateral incision to provide joint distraction (TECH FIG 8B). I also switched the lamina spreader to the medial wound so that I could prepare the remainder of the joint via the lateral incision.

From the preoperative radiographs it is obvious that there is distal tibial deformity and nonanatomic malleolar anatomy (TECH FIG 8C,D).

- For this reason, the talus is not locked within the ankle mortise and rotation will need to be carefully controlled. However, this is more important with internal fixation; with external fixation such malrotation could still be corrected postoperatively with external fixator frame adjustment.
Joint reduction
- Neutral dorsiflexion–plantarflexion
- Slight hindfoot valgus
- Correct malrotation
  - Align second metatarsal with the anterior tibial crest.
- Provisionally pin the joint
  - I usually place two Steinmann pins axially. While this violates the subtalar joint, I do not believe that this has significant consequences in these patients with deformity, severe ankle arthritis, and compensatory hindfoot alignment.
- I routinely close the wounds at this point because once the external fixator is in place, suturing is particularly tedious. However, if you prefer to delay the wound closure until the external fixator is in place, one or two struts can easily be reflected to allow adequate access to the wound or wounds.
- Proximal ring block (TECH FIG 9A)
  - I place the proximal ring block (I usually use two rings to create the “block”) orthogonally to the tibia.
  - Initially, I stabilize the rings with two thin wires but do not tension them at this point.
  - I supplement the proximal ring block fixation with three half-pins (TECH FIG 9B).
  - Once the half-pins are secured, I tension the thin wires (TECH FIG 9C).
- Foot plate
  - I suspend the foot plate (“horseshoe”) from a transverse forefoot wire. This way I can control the foot’s position within the foot plate (TECH FIG 10A).
  - Once I am satisfied with the foot’s position relative to the foot plate, I secure the hindfoot with two crossed thin wires, making sure the plantar surface of the foot is distal to the foot ring (TECH FIG 10B).
  - I typically place a midfoot wire as well.
  - Before tensioning the thin wires, I close the horseshoe-shaped foot plate anteriorly.
  - This can be done by adding a half-ring to the anterior foot plate, or I can have a double-decker foot plate and close the more proximal of the two foot plates (TECH FIG 10C).
  - Having two foot plate components affords less interference between the struts (that will connect the proximal ring block to the foot plate) and the thin wires to be passed through the foot from the foot plate.
  - I then tension the thin wires in the foot (TECH FIG 10D).
  - I also place one or two talar wires to provide greater support and to protect the subtalar joint (TECH FIG 10E,F).
  - These two wires either need to be built up from a single foot plate or connected to the proximal component of a two-ring foot plate set-up.
TECH FIG 9 • A. Building the proximal ring block, first with thin wires. Wounds were closed before applying external fixator. B. Half-pins added to stabilize the proximal ring block. C. Thin wires are tensioned within the proximal ring block.

TECH FIG 10 • A. Forefoot wire placed to suspend the foot plate. B. Foot balanced within the foot plate. Foot plate suspended from forefoot wire and calcaneal wires being passed to stabilize the hindfoot. C. Tensioning the thin wires in the foot. The ring has been closed on the foot frame so that tension in all wires can be effectively maintained. D. In this case, two rings were used for the foot plate portion of the frame. Closing the top ring allows the foot frame to be closed even without placing a half-ring on the anterior portion of the “horseshoe.” (continued)
This is also essential to protect the subtalar joint from compression. If fixation from the foot plate to the foot is limited to the forefoot, midfoot, and calcaneus and no fixation is added to the talus, then axial compression will not be isolated to the tibiotalar joint but will also include the subtalar joint (with potential detrimental effects to the subtalar joint cartilage and motion). A perhaps more sophisticated (but not more complicated) construction of the foot plate is to distract between the two components of the foot plate, so that the subtalar joint is distracted while the tibiotalar joint is compressed. Although unproven, this may have a protective effect on the subtalar joint.

- I routinely add a calcaneal half-pin for added foot plate stability (TECH FIG 10G).
- Connect the proximal ring block and foot plate by struts and apply tibiotalar compression (TECH FIG 11A).
- I make subtle adjustments at this point, which sometimes warrants removing one or both of the provisional fixation pins (TECH FIG 11B).
- If the alignment is optimal, then I can leave one provisional pin in place (provided it is truly axial) to act as a rail as I compress the tibial talar joint with the external fixator.

TECH FIG 10 • (continued) E,F. Two talar wires are passed. Without talar wires compression would be placed not only on the tibiotalar joint but also on the subtalar joint. G. Calcaneal half-pin for added foot frame stability.

TECH FIG 11 • A. Adding struts to be used for compression between the proximal ring block and the foot frame. B. Proper position of the foot and leg within the external fixator. Ankle with neutral dorsiflexion–plantarflexion and plantar foot is distal to most distal ring–plate. The provisional fixation was removed for compression. (continued)
If no translation, angulation, or rotation is required, which is often the case if the initial reduction was appropriate, then simply tightening the struts uniformly leads to satisfactory axial compression (TECH FIG 11C,D).

If adjustments need to be made, the computer program may be used to run an effective correction at this time. However, on the operating table, the struts may simply be loosened, a gross manual adjustment can be made (with the provisional fixation removed), and the struts again secured. Then, uniform tightening of all struts can be performed.

Final fluoroscopic views in the AP and lateral planes are sometimes difficult to interpret with an external fixator in place, but with subtle rotation of the limb, appropriate alignment and bony apposition can be confirmed.

Final check to be sure that all bolts and connections are stable
- Sterile dressings on the wound
- Sterile dressings on the wires and half-pins
- Pin irritation typically occurs because of skin motion or tension about the half-pins or thin wires.
- I routinely place thick dressings around the thin wires and half-pins, creating moderate pressure from the dressing on the skin immediately adjacent to the half-pin or wire and thereby stabilizing the skin.
- Prefabricated bolsters are also available to stabilize the skin around the pins.

Final follow-up for external fixation case example (TECH FIG 12)
- Alignment restored
- Fusion apparent despite distorted distal tibial alignment


TECH FIG 12 • Follow-up radiographs suggesting successful revision ankle arthrodesis using external fixation. A. AP view. B. Mortise view. C. Lateral view.
PEARSLS AND PITFALLS

<table>
<thead>
<tr>
<th>Position of arthrodesis</th>
<th>Avoid varus and internal rotation. Optimal position is neutral dorsiflexion–plantarflexion, slight hindfoot valgus, and the second metatarsal aligned with the anterior tibial crest.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior or active infection</td>
<td>Internal fixation for ankle arthrodesis is probably contraindicated; however, arthrodesis is still possible with external fixation.</td>
</tr>
<tr>
<td>Joint preparation</td>
<td>Internal and external fixation may stabilize the joint, but satisfactory joint preparation for arthrodesis is essential for fusion to occur.</td>
</tr>
<tr>
<td>Preservation of subchondral bone architecture</td>
<td>If possible, maintain the subchondral bone architecture. This allows adjustments in dorsiflexion–plantarflexion position without forfeiting bony apposition at the arthrodesis site before fixation.</td>
</tr>
<tr>
<td>Potential advantages of internal fixation over external fixation</td>
<td>No need for pin care; perhaps less intimidating to the patient</td>
</tr>
<tr>
<td>Potential advantages of external fixation over internal fixation</td>
<td>Further compression and adjustments at the arthrodesis site are possible postoperatively; perhaps earlier weight bearing.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- With advances in anesthesia, ankle arthrodesis may be performed on an outpatient basis.
- However, we typically keep these patients at least overnight for pain control, nasal oxygen (which may have some positive effect on anterior wound healing), and prophylactic intravenous antibiotics.
- Follow-up in 10 to 14 days
  - Internal fixation
    - Suture removal
    - Short-leg, touch-down weight-bearing cast
  - External fixation
    - Suture removal
    - Radiographs to assess bony apposition at the arthrodesis site and alignment. If a subtle adjustment needs to be made, it is done at this time, typically with the computer program.
    - We routinely add more compression to the arthrodesis site at this and subsequent visits. Simple axial compression does not require use of the computer program; instead, uniform tightening of all struts creates axial compression at the arthrodesis site. This is a major advantage of external fixation over internal fixation. With internal fixation, bony apposition at the arthrodesis site cannot be altered after the index procedure.
    - The patient is instructed how to perform pin care. We do not usually have the patient perform pin care in the first 10 to 14 days in order to protect the wound. My routine pin care includes once-a-day pin cleaning with a sponge moistened with a 50–50 mixture of sterile saline and hydrogen peroxide. I instruct the patients to “shoeshine” the pins with the sponge so that the debris is removed at the pin–skin interface. If a pin is irritated, then we recommend placing an antibiotic ointment at that pin’s interface with the skin and to continue to stabilize that particular pin with dressings that stabilize the skin adjacent to the pin. Oral antibiotics may be required in some situations.
    - We have the orthotist create a tread for the foot plate. Once the wounds have healed adequately and edema is controlled, the tread can be added and weight bearing through the external fixator is possible, another potential advantage of external over internal fixation.
  - Follow-up at about 6 weeks
    - Internal fixation
    - Ankle radiographs
    - If healing is progressing well, the patient is progressed to a cam boot.
    - If more healing is necessary, a short-leg cast is continued.
    - Weight bearing may be progressively increased if healing is progressing, but we typically restrict the patient from full weight bearing until 10 weeks (longer if healing is delayed).
    - External fixation
      - Radiographs
      - We routinely add more axial compression.
      - Pin care is reinforced.
      - Weight bearing is encouraged with the tread on the foot plate.
  - Follow-up at 10 to 12 weeks and beyond
    - Internal fixation
      - Radiographs
      - If healing is suggested, then the patient can progress to full weight bearing, first in the cam boot and then transitioning to a regular shoe by 12 to 14 weeks. If healing is delayed, then this protocol is delayed.
    - External fixation
      - Radiographs
      - More axial compression is added.
      - If healing is suggested radiographically, then the surgeon should plan for external fixator removal between 12 and 16 weeks.
      - If healing is delayed, more axial compression is added and follow-up is set for 3 to 4 more weeks. External fixator removal is delayed until healing is suggested.
      - Frame removal may be performed in the office, but removal of half-pins may be particularly uncomfortable for the patient (especially if hydroxyapatite-coated pins are used).
      - A short operating room procedure should be considered for frame removal with the patient under anesthesia.
      - We routine add a short-leg walking cast for an additional 2 to 4 weeks, then transition to a cam boot and regular shoe.

OUTCOMES

- The literature suggests favorable outcomes of ankle arthrodesis, with good relief of ankle pain and high rates of patient satisfaction (mostly level IV retrospective studies without standardized foot and ankle outcome measures).
- At intermediate follow-up, good to excellent results have been reported in 66% to 90% of patients (mostly level IV retrospective studies without standardized foot and ankle outcome measures).
- In long-term follow-up, a considerable number of patients with ankle arthrodesis develop adjacent joint (subtalar and, to a lesser degree, transverse tarsal joint) arthrosis.
- Although most patients with arthrodesis report satisfactory pain relief, functional outcome, particularly gait analysis, is not physiologic.

**COMPLICATIONS**

- Both internal and external fixation
- Infection
- Wound dehiscence or delayed wound healing
- Nonunion
- Malunion
- Late development of subtalar (and, to a lesser degree, transverse tarsal joint) arthritis (adjacent joint arthritis)
- Internal fixation
- Prominent hardware
- Residual gaping at tibiotalar arthrodesis site that cannot be compressed postoperatively
- External fixation
- Pin tract infection

**REFERENCES**

Ankle arthrodesis is performed for treatment of end-stage ankle arthritis, refractory to nonsurgical management. While ankle arthroplasty has become an increasingly popular procedure, arthrodesis remains an accepted surgical treatment for end-stage arthritis. Over 40 different techniques of ankle arthrodesis have been described in the literature. A traditional method of ankle arthrodesis is the transfibular approach, which uses a distal fibular osteotomy, allowing for optimal visualization of the joint surface, and provides a source of autogenous bone graft for fusion.

**ANATOMY**

- The ankle is a highly constrained hinge-type joint between the tibial plafond, the distal fibula, and the dome of the talus. Compressive forces across the ankle joint approach five times the body’s weight at heel rise.
- The ankle is subjected to more weight-bearing force per square centimeter than any other joint. The articular cartilage of the ankle is relatively thin (1 to 2 mm) and the contact area is only one third of the hip or knee.
- The ankle joint is responsible for the majority of dorsiflexion and plantarflexion of the ankle–hindfoot complex.

**PATHOGENESIS**

End-stage arthritis of the ankle results from progressive loss of the articular cartilage between the tibial plafond and the talus dome, resulting in inflammation, osteophyte formation, progressive loss of ankle motion, and increasing ankle pain with motion or weight bearing.

- Tibiotalar arthritis may be (1) posttraumatic arthritis (following ankle fracture, pilon fracture, talus fracture), (2) arthritis secondary to chronic ankle ligament instability, (3) primary arthritis, (4) one of a number of inflammatory arthritides (rheumatoid arthritis, gout or pseudogout, and mixed connective tissue disorders), (5) neuropathic arthrosis, or (6) postinfectious arthritis.

**NATURAL HISTORY**

Most commonly, ankle arthritis is posttraumatic in origin, either from direct injury to the ankle’s articular cartilage or due to chronic ligament instability.

- Primary ankle arthritis is relatively rare when compared to primary arthritis of the hip and knee.
- In general, once the cascade of cartilage degeneration is initiated, it will continue to progress, albeit at a variable rate.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

A careful history is obtained from the patient, including the cause of posttraumatic arthritis. Evaluation of posttraumatic arthritis should determine if there was a history of open fracture-dislocation and infection; evaluation of an inflammatory arthritis includes reviewing the patient’s medications, particularly immunosuppressive medications. Diabetic neuropathic arthritis may also be responsible for ankle arthritis.

- Social history includes the patient’s age, occupation (and associated functional demands), and degree of functional limitation due to the arthritic ankle. Social history should also include tobacco use. Moreover, any concerns for the patient being incapable of maintaining a protected weight-bearing status postoperatively should be identified, including any restrictions to upper extremity function.
- Prior surgery, particularly to the arthritic ankle, is documented. When available, the surgeon should review prior operative reports. The most common symptom of ankle arthritis is anterior ankle pain that is increased with weight bearing and relieved by unloading the ankle joint, causing the patient to limp. Patients often report ankle stiffness and difficulty walking up inclines, which exacerbates their symptoms. Patients also notice that their foot is “turning out.” Painless ankle arthritis may be indicative of a peripheral neuropathy, typically diabetic neuroarthropathy.

While the ankle is not responsible for inversion and eversion, the surgeon should document any difficulties the patient may have walking on uneven terrain. This may indicate that there is associated hindfoot arthritis.

- Physical evaluation should include:
  - Evaluation of ankle and hindfoot alignment. The patient should be weight bearing. The examiner should inspect the position of the patient’s foot and ankle, noting particularly any varus–valgus deformities. This is typically best accomplished from a posterior perspective, looking at the lower leg and heel. The lateral perspective may identify equinus.
  - A careful understanding of weight-bearing preoperative alignment or malalignment allows for optimal intraoperative correction, which is done with the patient supine and non–weight-bearing.
  - Ankle range of motion. Passive and active range of motion of the ankle should be assessed and documented. This is best determined actively with the patient standing or passively with the patient seated. The patient with ankle arthritis typically experiences pain with ankle range of motion. Normal ankle range of motion is about 20 degrees of dorsiflexion and 50 degrees of plantarflexion. Limited dorsiflexion is most common, due to anterior ankle impingement or equinus contracture. It is often difficult to isolate ankle range of motion since the ankle functions in concert with the hindfoot, which also allows some dorsiflexion and plantarflexion, mostly through the transverse tarsal joint.
  - Hindfoot motion. Hindfoot motion is tested by grasping the hindfoot with one hand while the other hand passively inverts and everts the subtalar joint. The talar neck may be supported with one finger to ensure that hindfoot motion is
being tested in isolation. With isolated ankle arthritis, hindfoot range of motion is typically minimally symptomatic. Normal hindfoot motion is about 20 degrees of inversion and 10 degrees of eversion. Dorsiflexion and plantarflexion through the hindfoot is about 15 degrees for each. Ankle arthrodesis increases stresses in the hindfoot. With pre-existing hindfoot arthritis and stiffness, symptoms may persist despite successful ankle arthrodesis.

- Vascular examination. Dorsalis pedis and posterior tibial pulses should be palpated and compared to the contralateral side. Capillary refill to the toes is also documented. Any asymmetry in pulses should prompt a further evaluation, including ankle-brachial indices and noninvasive vascular studies. Any reconstructive procedure for the foot and ankle requires satisfactory circulation. It is easy to recommend ankle arthrodesis based on the ankle’s radiographic appearance but lose sight of the vascular status.
- Soft tissue envelope. The physiologically normal ankle affords little soft tissue reserves and is at risk for wound complications. Previous surgical scars or scars from soft tissue trauma about the ankle may increase the risk of reoperation on the ankle. Careful documentation of previous surgical scars is mandatory. The surgical approach must be carefully planned, particularly when there are prior surgical incisions or prior soft tissue trauma. In post-traumatic arthritis, open reduction and internal fixation of the fibula may have been performed, affording an ideal access to the ankle through the same incision for transfibular ankle arthrodesis.
- Gait. A limp is typically present, and as a compensatory mechanism, the patient often externally rotates the hip to avoid anterior impingement at the ankle. Gait analysis permits further understanding of the patient’s hindfoot–ankle alignment and should be taken into consideration in planning ankle arthrodesis. External rotation occurs at the hip as a compensatory mechanism; a dramatic external rotation deformity at the ankle is rarely present.
- Edema, erythema, warmth, and draining sinus. A history of open fracture or postoperative infection after prior surgery should prompt comprehensive evaluation for septic arthritis and osteomyelitis.

**DIFFERENTIAL DIAGNOSIS**

- Osteoarthritis
- Posttraumatic arthritis
- Rheumatoid arthritis
- Inflammatory arthritis
- Postinfectious arthritis
- Osteonecrosis
- Idiopathic
- Congenital
- Neuroarthropathy

**NONOPERATIVE MANAGEMENT**

- Nonsteroidal anti-inflammatory agents (NSAIDs) are the mainstay of pharmacologic management of the arthritic ankle. With approval from the patient’s primary care physician, COX-2 inhibitors can be considered if NSAIDs fail to relieve symptoms.
- Intra-articular corticosteroid injections may be judiciously used to help control flares of symptoms. We recommend administering these at no more than 3-month intervals.
- Shoe modifications, including the use of a stiff-soled rocker-bottom sole and solid ankle cushion heel (SACH), help some patients with mild to moderate arthritis. In patients with more advanced disease, bracing that further limits the degree of ankle motion may be required. These include a custom-molded ankle–foot orthosis (AFO), a rigid leather lace-up brace, or a double-upright bar brace.

**SURGICAL MANAGEMENT**

- The primary indication for ankle arthrodesis is the development of painful arthritis of the ankle joint that leads to progressive functional limitation. In such cases, the failure of nonoperative treatment is an indication for ankle arthrodesis.
Preoperative Planning

- Before planning an ankle arthrodesis, the adjacent joints must be carefully assessed. Concomitant moderate to severe arthritic changes in the adjacent joints (subtalar and transverse tarsal joints) are a relative contraindication to isolated fusion of the ankle joint. It is not unusual to see radiographic evidence of arthritis in the adjacent joints. In carefully selected patients, total ankle replacement in combination with hindfoot arthrodesis may afford a functional advantage over simultaneous ankle–hindfoot arthrodesis.
- Examination of the entire lower extremity should be performed to identify any proximal malalignment (internal rotation, external rotation, varus, valgus, and shortening) that needs to be corrected, either concomitant to ankle arthrodesis or in a staged fashion.
- As for any reconstructive procedure, patients should be medically optimized preoperatively. For example, diabetics must have their blood glucose levels normalized, and we recommend that smokers cease smoking 4 weeks before and 8 weeks after surgery. Infected wounds, septic arthritis, or osteomyelitis must be managed properly before internal fixation or bone graft is placed for ankle arthrodesis. It may be necessary to perform a preliminary irrigation and débridement and antibiotic bead placement to clear the infection, followed by a staged ankle arthrodesis.

Positioning

- The patient is placed supine on the operating table with a large bump underneath the ipsilateral hip to facilitate exposure. We routinely use a thigh tourniquet.

Approach

- For the transfibular approach, we make an incision over the posterior half of the fibula, starting about 8 to 10 cm proximal to the tip of the fibula, extending along the fibular shaft to the tip of the fibula, then curving anteriorly and distally over the sinus tarsi another 6 to 8 cm toward the base of the fourth metatarsal (FIG 1).
- The approach uses the internervous plane between the sural nerve posteriorly and the superficial peroneal nerve anteriorly.
- When performing the dissection at the level of the fibula, we create full-thickness flaps and perform a subperiosteal dissection to minimize soft tissue tension. At the proximal extent of the wound, the superficial peroneal nerve is protected; posteriorly the peroneal tendons and sural nerve are protected. We strip a minimal amount of fibular periosteum, with the majority being anterior using a periosteal elevator. We attempt to preserve a posterior hinge of fibular periosteum.
- The anterior syndesmotic ligaments, the anterior talofibular ligament, and the calcaneofibular ligament are fully exposed. An anterolateral ankle capsulotomy is performed and the anterior joint capsule and anterior distal tibial periosteum are elevated to expose the anterior tibiotalar articulation. Care is taken to avoid overzealous stripping over the talar neck in order to prevent devascularization of the talus.

TRANSFIBULAR APPROACH FOR ANKLE ARTHRODESIS

- We perform a fibular osteotomy about 3 to 5 cm proximal to the level of the ankle joint. We prefer making an oblique osteotomy, from proximal lateral to distal medial. The cut edge is beveled to avoid creating a bony prominence. Alternatively, we make a transverse osteotomy 6 to 8 cm proximal to the ankle. We use a microsagittal saw to create the osteotomy while protecting the soft tissues. The anterior syndesmotic ligaments, the anterior talofibular ligament, and the calcaneofibular ligament are then transected, allowing the distal fibula to hinge on the intact posterior soft tissues and allowing some vascularity to remain intact. Using the microsagittal saw in the sagittal plane, the medial third of the fibula is removed, morselized, and saved as bone graft. Traditionally, the entire distal fibula was resected and used as bone graft. However, current practice favors leaving the malleoli, particularly because there has been some reported success in takedown of ankle fusions and conversion to total ankle arthroplasty; future conversion to ankle replacement is not possible when the distal fibula is removed (TECH FIG 1A).

- At the distal tibia, elevate the anterior joint capsule and periosteum further, and remove impinging osteophytes that may block reduction. Posteriorly, use a periosteal elevator to elevate the soft tissues from the lateral and posterior aspect of the tibia and from the posterior talus.
- Once the soft tissues are released, retractors can be safely placed anteriorly and posteriorly about the distal tibia to protect the soft tissues and neurovascular structures. We typically use a joint distractor or laminar spreader to fully expose the tibial plafond and dome of the talus (TECH FIG 1B). Occasionally, we perform a limited medial arthroscopy to expose the medial gutter of the ankle joint.
- Tibial plafond and talar dome preparation may be performed with transverse flat cuts, a chevron pattern, or maintenance of the residual tibiotalar subchondral anatomy. We prefer maintaining the physiologic subchondral architecture to (1) maximize surface contact area, (2) maintain limb length, and (3) allow for subtle adjustments to tibiotalar arthrodesis without sacrificing contact area. We remove the residual articular cartilage...
with a sharp elevator, osteotomes, curettes, and a high-speed burr. The burr should be used with some cold sterile water or saline irrigation to minimize osteonecrosis. Once all cartilage has been removed, a small-diameter drill is used to penetrate the subchondral bone; alternatively, a narrow chisel may be used to “feather” the surfaces. Penetration of the subchondral bone by either method increases blood inflow to the arthrodesis site and increases surface area for fusion. Without disrupting the structure of the talar subchondral bone, the medial and lateral gutters should be denuded of residual articular cartilage. The accessory anteromedial arthrotomy affords access to the medial gutter that may not be feasible from the lateral approach. Based on the surgeon’s preference, bone graft may be added directly to the arthrodesis site. We position the ankle and hindfoot in neutral dorsiflexion and plantarflexion, rotation to align the tibial shaft with the second metatarsal, and the hindfoot in slight (5 degrees) of valgus. The goal is to place the talar body directly under the tibial shaft axis. Often, this requires a few millimeters of posterior and medial talar translation in the ankle mortise. To accomplish the medial translation, we typically remove some of the medial malleolus, without disrupting the medial malleolar architecture. If cannulated screws are used for fixation, the guide pins are typically used for provisional fixation. We verify the position of the tibiotalar joint fluoroscopically using intraoperative C-image intensification. Multiple methods for insertion of the arthrodesis screws have been described, to include parallel and crossed screw techniques. In general, cross screws are more rigid than parallel screws, and three screws provide better compression and better resistance to torque than two screws.

We routinely use cannulated screws for fixation of the tibiotalar arthrodesis. 6.5-mm, 7.3-mm, 7.5-mm, and 8.0-mm cannulated screw systems are available, and a variety of patterns for arthrodesis have been described. After manually positioning the tibiotalar joint in optimal position for arthrodesis, we typically place one guidewire from the lateral aspect of the base of the talus, aiming proximally and posteriorly through the body of the talus and laterally toward the medial tibial cortex. Alternatively, the initial guidewire may be placed from the medial tibia to the lateral talus dome. A second guidewire is inserted from the lateral tibia into the medial talus (TECH FIG 2). A final screw
(“home run screw”) is inserted from the posterior malleolus into the neck of the talus (TECH FIG 3). We recommend using intraoperative fluoroscopy to confirm appropriate alignment, bony contact at the arthrodesis site, and satisfactory guidewire position and length. Three partially threaded cancellous screws are inserted over the guidewires, making sure that all threads cross the joint, to ensure compression. However, if one or two compression screws are supplemented with a fully threaded positional screw, the construct will be stable as well.

- Pack the morselized bone graft obtained from the excised section of the fibula anteriorly, laterally, and posteriorly at the arthrodesis site. The residual fibula is then repositioned as an onlay strut graft on the lateral aspect of the tibiotalar arthrodesis and secured with one screw from the distal fibula to the talus and a second more proximally from the fibula to the talus.

PEARLS AND PITFALLS

- Denuding cartilage from the medial malleolus and resecting some of the medial malleolus allows for slight medial translation and improved positioning of the talar body under the tibial plafond. A small accessory medial arthrotomy facilitates access to the medial gutter. Do not penetrate the subtalar joint with the screws.
- Varus and excessive valgus ankle and hindfoot position should be avoided.
- Equinus must be avoided; this is a particular risk if there is associated cavus or relative forefoot plantarflexion.
- The rate of nonunion for ankle arthrodesis is 10%.
- When transecting the anterior syndesmotic ligaments, avoid injuring the peroneal artery that lies directly posterior to the interosseous membrane.
- Resect the medial third of the fibula, morselize it to use as a bone graft, and use the residual fibula as a strut graft with a cancellous surface to heal to the tibiotalar arthrodesis.

POSTOPERATIVE CARE

- We routinely use a bulky Jones dressing with a plaster splint postoperatively. This is changed to a short-leg non-weight-bearing cast at the initial postoperative visit (usually in 7 to 10 days). Patients are kept non-weight-bearing for a total of 6 weeks, followed by a period of 6 weeks in which weight bearing is gradually progressed in a short-leg walking cast or cam walker boot. Weight bearing is then advanced in the cam boot and regular shoe over the subsequent few weeks.
- The use of a drain postoperatively is left to the discretion of the surgeon. Sutures are typically removed at 3 weeks. We typically observe radiographic evidence of tibiotalar fusion between 3 to 6 months.

OUTCOMES

- Reported rates of successful ankle fusion by any technique range from 60% to 100%. A recent study of transfibular approach ankle arthrodesis with screw fixation in 40 patients showed a fusion rate of 95%. Delayed unions were seen in four patients and nonunions in two patients. The mean AOFAS scores improved significantly in this patient population, and all patients except one said they would have the surgery again.
- Long-term follow-up demonstrates that two thirds to three quarters of patients are completely satisfied with minimal reservation. About 90% of patients would undergo ankle fusion again. Calf atrophy and adjacent joint hindfoot arthritis are universal findings during long-term follow-up. Eighty percent of patients demonstrate a gait abnormality.
Chapter 78 TRANSFIBULAR APPROACH FOR ANKLE ARTHRODESIS

COMPLICATIONS

• The incidence of wound complications and infections with ankle arthrodesis is roughly the same as in other elective foot and ankle cases. They can generally be managed with local débridement and antibiotics.

• Delayed union and nonunion occur relatively infrequently after ankle fusion, with a nonunion rate of about 10%. Infection must be ruled out as the cause for nonunion. Aseptic tibiotalar nonunion may be successfully managed with removal of hardware, repeat preparation of the arthrodesis site, bone grafting, and more rigid fixation. In osteopenic bone or where there is substantial bone loss at the arthrodesis site, a tibiotalocalcaneal arthrodesis may be warranted and external fixation may need to be considered. 4,5 Other potential complications of ankle arthrodesis include malunion, symptomatic hardware, reflex sympathetic dystrophy (complex regional pain syndrome), the development of symptomatic arthritis in adjacent joints, deep venous thrombosis, pulmonary embolism, and late stress fracture.

REFERENCES

Ankle arthritis is characterized by loss of joint cartilage and joint space narrowing.

The etiology of ankle arthritis may be primary osteoarthrosis, inflammatory arthritis, or posttraumatic, with posttraumatic being most common. Depending on the etiology, there may be a spectrum of concomitant findings, ranging from bone sclerosis and hypertrophy to osteopenia or absorption. Likewise, varying degrees of deformity and severity are observed, with and without inflammatory synovial proliferation.

Other causes of ankle arthritis include:

- Neuropathic arthritis is usually associated with diabetes mellitus, alcoholism, spinal cord injuries, peripheral nerve injuries, hereditary sensorimotor neuropathy, and proprioceptive nervous system injuries, or, more rarely, with congenital indifference to pain, tabes dorsalis, and leprosy.
- Other causes of ankle arthritis include:
  - Systemic inflammatory processes (rheumatoid arthritis, mixed connective tissue disorders, gout, and pseudogout)
  - Primary synovial disorders (pigmented villonodular synovitis)
  - Septic arthritis
  - Seronagative arthritides (associated with psoriasis, Reiter syndrome, and spondyloarthropathy)

The natural history of ankle arthritis is gradual progression of diffuse joint cartilage degeneration or erosion, osteophyte formation, and loss of joint space in the tibiotalar joint.

In some cases, cartilage wear is not symmetric and deformity accompanies this arthritic process; this is particularly true of arthritis secondary to chronic ankle ligament instability and malunion.

Body weight, level of activities, and concomitant subtalar or transverse tarsal joint pathology contribute to the morbidity of the disease. Patients with relatively low demands and isolated ankle arthritic involvement may function surprisingly well because of the adaptive effect of the healthy subtalar and transverse talar joints.

The ankle joint is the articulation formed by the mortise (tibial plafond–medial malleolus and the distal part of the fibula) and the talus.

The ankle functions in concert with the subtalar joint as the ankle–subtalar joint complex, which is coupled by the medial collateral, lateral collateral, and tibiofibular ligaments to allow free movement of the ankle joint, stability, and cooperation with the subtalar joint during gait.

The blood supply is provided by the anterior and posterior tibial arteries, the peroneal artery, and their branches and anastomoses, which form a rich vascular network.

DEFINITION

- Ankle arthritis is characterized by loss of joint cartilage and joint space narrowing.
- The etiology of ankle arthritis may be primary osteoarthrosis, inflammatory arthritis, or posttraumatic, with posttraumatic being most common. Depending on the etiology, there may be a spectrum of concomitant findings, ranging from bone sclerosis and hypertrophy to osteopenia or absorption. Likewise, varying degrees of deformity and severity are observed, with and without inflammatory synovial proliferation.

ANATOMY

- The ankle joint is the articulation formed by the mortise (tibial plafond–medial malleolus and the distal part of the fibula) and the talus.
- The ankle is a modified hinge joint obliquely oriented in two planes (posteriorly and laterally in the transverse plane of the leg and laterally and downward in the coronal plane).
- The unique orientation of the physiologically normal ankle allows not only sagittal plane motion (approximately combined dorsiflexion and plantarflexion of 45 to 70 degrees) but also rotation (6 degrees) in addition to the movement in the sagittal plane.
- The ankle functions in concert with the subtalar joint as the ankle–subtalar joint complex, which is coupled by the medial collateral, lateral collateral, and tibiofibular ligaments to allow free movement of the ankle joint, stability, and cooperation with the subtalar joint during gait.
- The ankle joint is the articulation formed by the mortise (tibial plafond–medial malleolus and the distal part of the fibula) and the talus.
- The blood supply is provided by the anterior and posterior tibial arteries, the peroneal artery, and their branches and anastomoses, which form a rich vascular network.

PATHOGENESIS

- Idiopathic (primary) arthritis is better characterized by the term osteoarthrosis since it is not an inflammatory process.
- The exact mechanism of cartilage degeneration and loss has not been clearly defined. Secondary ankle arthritis is mainly posttraumatic, occurring after intra-articular fractures, chondral or osteochondral injuries, and chronic instability.
- Neuropathic arthritis is usually associated with diabetes mellitus, alcoholism, spinal cord injuries, peripheral nerve injuries, hereditary sensorimotor neuropathy, and proprioceptive nervous system injuries, or, more rarely, with congenital indifference to pain, tabes dorsalis, and leprosy.
- Other causes of ankle arthritis include:
  - Systemic inflammatory processes (rheumatoid arthritis, mixed connective tissue disorders, gout, and pseudogout)
  - Primary synovial disorders (pigmented villonodular synovitis)
  - Septic arthritis
  - Seronagative arthritides (associated with psoriasis, Reiter syndrome, and spondyloarthropathy)

NATURAL HISTORY

- The natural history of ankle arthritis is gradual progression of diffuse joint cartilage degeneration or erosion, osteophyte formation, and loss of joint space in the tibiotalar joint.
- In some cases, cartilage wear is not symmetric and deformity accompanies this arthritic process; this is particularly true of arthritis secondary to chronic ankle ligament instability and malunion.
- Body weight, level of activities, and concomitant subtalar or transverse tarsal joint pathology contribute to the morbidity of the disease. Patients with relatively low demands and isolated ankle arthritic involvement may function surprisingly well because of the adaptive effect of the healthy subtalar and transverse talar joints.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with end-stage ankle arthritis complain of severe ankle pain interfering with activities of daily living and typically note and demonstrate an obvious limp. Patients often report that their “foot is turning out” when walking; typically, this is a compensatory hip external rotation that relieves painful heel-to-toe gait. Recent literature suggests that ankle arthritis is as debilitating as hip arthritis.
- A complete examination of the ankle and hindfoot joints should include the following:
  - Soft tissue condition, including previous scars, callosities, ulcers, fistulas, and so forth. Elimination or fullness of the gutters indicates intra-articular fluid accumulation, or hypertrophied capsular tissue.
  - Vascular status, including peripheral pulses, microcirculation (capillary refill), ankle–brachial index
  - Sensation. Light touch is always tested to rule out peripheral neuropathy.
  - Stability. Anterior drawer and inversion and eversion stress tests are performed to evaluate the integrity of the lateral collateral ligaments.
  - Motor strength: Manual motor test of the major muscular groups is performed.
  - Range of motion (ROM) of the ankle and hindfoot articulations. Loss of ankle extension may be the result of significant tibiotalar arthrosis, abutment of large anterior tibiotalar osteophytes, Achilles tendon contracture, or a combination of these. Loss of flexion may be related to significant tibiotalar arthrosis or subtalar pathology. Loss of hindfoot motion is the result of subtalar pathology (arthrosis, fibrosis).

DEFINITION

- Ankle arthritis is characterized by loss of joint cartilage and joint space narrowing.
- The etiology of ankle arthritis may be primary osteoarthrosis, inflammatory arthritis, or posttraumatic, with posttraumatic being most common. Depending on the etiology, there may be a spectrum of concomitant findings, ranging from bone sclerosis and hypertrophy to osteopenia or absorption. Likewise, varying degrees of deformity and severity are observed, with and without inflammatory synovial proliferation.

ANATOMY

- The ankle joint is the articulation formed by the mortise (tibial plafond–medial malleolus and the distal part of the fibula) and the talus.
- The ankle is a modified hinge joint obliquely oriented in two planes (posteriorly and laterally in the transverse plane of the leg and laterally and downward in the coronal plane).
- The unique orientation of the physiologically normal ankle allows not only sagittal plane motion (approximately combined dorsiflexion and plantarflexion of 45 to 70 degrees) but also rotation (6 degrees) in addition to the movement in the sagittal plane.
- The ankle functions in concert with the subtalar joint as the ankle–subtalar joint complex, which is coupled by the medial collateral, lateral collateral, and tibiofibular ligaments to allow free movement of the ankle joint, stability, and cooperation with the subtalar joint during gait.
- The blood supply is provided by the anterior and posterior tibial arteries, the peroneal artery, and their branches and anastomoses, which form a rich vascular network.

PATHOGENESIS

- Idiopathic (primary) arthritis is better characterized by the term osteoarthrosis since it is not an inflammatory process.
- The exact mechanism of cartilage degeneration and loss has not been clearly defined. Secondary ankle arthritis is mainly posttraumatic, occurring after intra-articular fractures, chondral or osteochondral injuries, and chronic instability.
- Neuropathic arthritis is usually associated with diabetes mellitus, alcoholism, spinal cord injuries, peripheral nerve injuries, hereditary sensorimotor neuropathy, and proprioceptive nervous system injuries, or, more rarely, with congenital indifference to pain, tabes dorsalis, and leprosy.
- Other causes of ankle arthritis include:
  - Systemic inflammatory processes (rheumatoid arthritis, mixed connective tissue disorders, gout, and pseudogout)
  - Primary synovial disorders (pigmented villonodular synovitis)
  - Septic arthritis
  - Seronagative arthritides (associated with psoriasis, Reiter syndrome, and spondyloarthropathy)

NATURAL HISTORY

- The natural history of ankle arthritis is gradual progression of diffuse joint cartilage degeneration or erosion, osteophyte formation, and loss of joint space in the tibiotalar joint.
- In some cases, cartilage wear is not symmetric and deformity accompanies this arthritic process; this is particularly true of arthritis secondary to chronic ankle ligament instability and malunion.
- Body weight, level of activities, and concomitant subtalar or transverse tarsal joint pathology contribute to the morbidity of the disease. Patients with relatively low demands and isolated ankle arthritic involvement may function surprisingly well because of the adaptive effect of the healthy subtalar and transverse talar joints.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with end-stage ankle arthritis complain of severe ankle pain interfering with activities of daily living and typically note and demonstrate an obvious limp. Patients often report that their “foot is turning out” when walking; typically, this is a compensatory hip external rotation that relieves painful heel-to-toe gait. Recent literature suggests that ankle arthritis is as debilitating as hip arthritis.
- A complete examination of the ankle and hindfoot joints should include the following:
  - Soft tissue condition, including previous scars, callosities, ulcers, fistulas, and so forth. Elimination or fullness of the gutters indicates intra-articular fluid accumulation, or hypertrophied capsular tissue.
  - Vascular status, including peripheral pulses, microcirculation (capillary refill), ankle–brachial index
  - Sensation. Light touch is always tested to rule out peripheral neuropathy.
  - Stability. Anterior drawer and inversion and eversion stress tests are performed to evaluate the integrity of the lateral collateral ligaments.
  - Motor strength: Manual motor test of the major muscular groups is performed.
  - Range of motion (ROM) of the ankle and hindfoot articulations. Loss of ankle extension may be the result of significant tibiotalar arthrosis, abutment of large anterior tibiotalar osteophytes, Achilles tendon contracture, or a combination of these. Loss of flexion may be related to significant tibiotalar arthrosis or subtalar pathology. Loss of hindfoot motion is the result of subtalar pathology (arthrosis, fibrosis).
Assessment of preoperative ankle, lower leg, and hindfoot alignment is important to understand what corrections must be considered in the ankle arthrodesis.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain weight-bearing radiographs—including anteroposterior (AP), lateral, and mortise views of the ankle joint—determine the extent of arthritis, deformity, bone defects in the distal tibial plafond or talus, potential avascular necrosis (AVN) in either the talar body or the distal tibia, and concomitant hindfoot arthritis.
- The lateral and mortise ankle radiographs provide limited views of the hindfoot articulations; if foot arthritis or deformity is suggested, weight-bearing foot radiographs should be obtained (FIG 1).
- Full-length weight-bearing bilateral radiographs are important in patients with suspected limb malalignment proximal to the ankle.
- Weight-bearing radiographs of the foot are needed when the ankle arthritis is associated with pes cavus or pes planus or suspected concomitant hindfoot arthritis.

**DIFFERENTIAL DIAGNOSIS**

- Bone marrow edema
- Soft tissue pathology
- Distal tibial plafond or talar AVN
- Osteochondritis

**NONOPERATIVE MANAGEMENT**

- Nonoperative treatment of ankle arthritis includes pharmacologic agents, intra-articular corticosteroid injections, shoe wear modifications, and orthoses.
- Nonsteroidal anti-inflammatory agents (NSAIDs) are widely used to provide pain relief, and other agents, such as gold, antimalarials, and immunosuppressives, are prescribed by rheumatologists to treat various inflammatory disorders.
- Intra-articular corticosteroid injections should be used judiciously since their repeated use accelerates the need for surgical treatment.
- High-top shoes restricting ankle motion or stiff-soled shoes with a rocker sole may be beneficial for pain relief.
- Polypropylene ankle-foot orthoses, with or without hinges, and orthoses with double metal upright bars and calf sleeves hold the joint still and limit the amount of pain.

**SURGICAL MANAGEMENT**

- Originally, the miniarthrotomy technique for ankle arthrodesis was described for use in arthritic ankles without deformity, bone defects, or AVN of talar dome or distal tibia.5,8
- With evolution of the technique, the indications for this procedure expanded to include end-stage ankle arthritis associated with the following9:
  - Marked joint space narrowing
  - Severe ankle pain interfering with daily activities and walking ability
  - Failure of conservative treatment, including NSAIDs, intra-articular steroid injections, physical therapy, and use of ankle-foot orthoses
  - Absence of mechanical malalignment proximal to the ankle
  - A moderately deformed ankle joint with varus or valgus under 10 degrees
  - Less than 25% posterior or anterior subluxation
  - AVN of the talus involving less than 25% of its articular surface
  - Articular surface cavitations smaller than $1 \times 2$ cm
  - Intact sensation (absence of neuroarthropathy)
Preoperative Planning

- All imaging studies are reviewed.
- The ankle and adjacent hindfoot joints are evaluated for ROM and alignment.
- We typically perform diagnostic injections of the hindfoot articulations if symptomatic hindfoot arthritis is masked by the ankle arthritis. (Ankle arthrodesis in the face of hindfoot arthritis and stiffness will leave the patient with persistent symptoms.) Manual motor testing of the major muscular groups about the foot and ankle is important to identify weakness that may leave the patient with hindfoot imbalance despite successful ankle arthrodesis.
- Neuropathy, vascular insufficiency, venous stasis disease, or skin compromise at the ankle may warrant further evaluation or treatment before ankle arthrodesis. The advantage to the miniarthrotomy technique is minimal soft tissue and periosteal disruption, so it lends itself well to patients with some of these conditions.

Positioning

- The patient is positioned supine on the operating table. A support under the ipsilateral buttock allows balanced visualization to both sides of the ankle joint since the natural tendency of the lower extremity is to fall in external rotation.
- It is important to drape the leg well above the knee so that the patella may be used as a reference point for the aligning the ankle arthrodesis.
- We do not routinely use a tourniquet; this allows us to confirm that bleeding surfaces for fusion have been created.

EXPOSURE AND VISUALIZATION OF THE JOINT

- Two 2.5-cm incisions are made, one anteromedial and one anterolateral, in approximately the same positions as arthroscopic portals created for standard ankle arthroscopy.
- The first incision is made just medial to the anterior tibial tendon, and the second immediately lateral to the peroneus tertius tendon (TECH FIG 1A).
- The medial incision is deepened through the subcutaneous tissues, avoiding inadvertent injury to the saphenous vein and nerve (TECH FIG 1B).
- The ankle retinaculum is identified and incised along the same line with the skin incision, and the anterior tibial tendon is retracted to identify the joint capsule.
- Sharp dissection or a rongeur is used to remove the hypertrophied capsular tissue from the anterior aspect of the joint, further improving the working space and visualization.

A hemostat is driven through the medial incision, across the anterior aspect of the ankle joint, toward the lateral side to confirm the predetermined position of the lateral incision (TECH FIG 1C).
- The lateral incision is deepened through the subcutaneous tissues with careful subcutaneous dissection to avoid injury to the lateral branch of the superficial peroneal nerve (TECH FIG 1D).
- Again the ankle retinaculum is identified and incised along the same line with the skin incision, and the peroneus tertius tendon is retracted to identify the joint capsule.
- After removal of the hypertrophied capsular tissue from both the medial and the anterolateral aspects of the joint, resection of most osteophytes from the anterior tibia with flexible chisels further improves visualization.
- Any visible cartilage of the anterior ankle joint is resected with curettes of various sizes and shapes and a set of small rongeurs (TECH FIG 1E,F).
D. Identification and protection of the lateral branch of the superficial peroneal nerve during deepening of the lateral incision through the subcutaneous tissues. E. Any visible cartilage of the anterior ankle joint is resected with curettes of various sizes and shapes and a set of small rongeurs. F. Appearance of the ankle after completion of the exposure.

**PREPARATION OF THE ARTICULAR SURFACES**

- A small lamina spreader is inserted into either the medial or the lateral joint space, and further débridement is performed through the contralateral incision (TECH FIG 2A).
- This process is alternated between medial and lateral incisions (TECH FIG 2B).
- With the joint distracted, various instruments (rongeurs, curettes, and chisels) are used to débride any remnants of cartilage, synovial tissue, loose bodies, and sclerotic subchondral bone.
- The joint must be irrigated frequently to visualize the cancellous bone surfaces and to confirm uniform bleeding.
- Small bone wedges may be resected to obtain the ideal joint position, particularly when moderate deformity is present.

**TECH FIG 2 • Preparation of the articular surfaces.**

A. A small lamina spreader is inserted into the lateral joint space, and further débridement is performed through the medial incision. B. The position of the instruments has been alternated. C. Any dense sclerotic subchondral bone of the distal tibia is drilled with a 2.5-mm drill bit to enhance revascularization. (continued)
Although the optimal position for an ankle arthrodesis has been debated, there is a consensus that the ankle should be in neutral position in the sagittal plane, with minimal valgus (up to 5 degrees) and external rotation symmetric with the contralateral uninvolved side (usually no more than 5 to 10 degrees). I generally set rotation by aligning the anterior tibial crest with the second metatarsal, when the foot is in a subtalar neutral position; with the miniarthrotomy technique, the ankle anatomy is left relatively undisturbed, and excessive malrotation is rarely possible. Most important is to avoid varus and internal rotation, both of which are poorly tolerated. I prefer to provisionally fix the ankle with three guide pins from a cannulated, self-tapping screw system. The first pin is inserted from the posterolateral aspect of the tibia in an anteromedial direction into the talar head. The guide pin is inserted immediately lateral to the Achilles tendon, approximately 3 cm proximal to the ankle joint. If there is some difficulty in maintaining the ankle position while inserting this first pin, the second pin can be placed first to lock the talus into the ankle mortise (TECH FIG 3A).

Through the miniarthrotomies, the posterior 25% of the tibiotalar joint is not always accessed and therefore not prepared. In my experience, properly preparing the anterior 75% of the joint is sufficient to achieving union rates that equal or even exceed those of other ankle techniques for ankle arthrodesis. Cancellous allograft chips are used to fill in any defects.

Any remaining cartilage on the lateral articular surfaces of the talus and of the articular surfaces of the malleoli is then meticulously removed. Any dense sclerotic subchondral bone can be drilled with a 2.5-mm drill bit to enhance revascularization (TECH FIG 2C). The use of a drill bit is preferable to use of a Kirschner wire, which is more likely to create osteonecrosis at the drill sites (TECH FIG 2D,E).

Any remaining cartilage on the lateral articular surfaces of the talus and of the articular surfaces of the malleoli is then meticulously removed. Any dense sclerotic subchondral bone can be drilled with a 2.5-mm drill bit to enhance revascularization (TECH FIG 2C). The use of a drill bit is preferable to use of a Kirschner wire, which is more likely to create osteonecrosis at the drill sites (TECH FIG 2D,E).

Through the miniarthrotomies, the posterior 25% of the tibiotalar joint is not always accessed and therefore not prepared. In my experience, properly preparing the anterior 75% of the joint is sufficient to achieving union rates that equal or even exceed those of other ankle techniques for ankle arthrodesis. Cancellous allograft chips are used to fill in any defects.

Position of the Arthrodesis Site and Screw Placement

Although the optimal position for an ankle arthrodesis has been debated, there is a consensus that the ankle should be in neutral position in the sagittal plane, with minimal valgus (up to 5 degrees) and external rotation symmetric with the contralateral uninvolved side (usually no more than 5 to 10 degrees). I generally set rotation by aligning the anterior tibial crest with the second metatarsal, when the foot is in a subtalar neutral position; with the miniarthrotomy technique, the ankle anatomy is left relatively undisturbed, and excessive malrotation is rarely possible. Most important is to avoid varus and internal rotation, both of which are poorly tolerated. I prefer to provisionally fix the ankle with three guide pins from a cannulated, self-tapping screw system. The first pin is inserted from the posterolateral aspect of the tibia in an anteromedial direction into the talar head. The guide pin is inserted immediately lateral to the Achilles tendon, approximately 3 cm proximal to the ankle joint. If there is some difficulty in maintaining the ankle position while inserting this first pin, the second pin can be placed first to lock the talus into the ankle mortise (TECH FIG 3A).

The second pin is inserted from the anteromedial aspect of the tibia directly above the medial malleolus distally and anteriorly toward the sinus tarsi. The third guide pin is inserted from the lateral aspect of the joint anterior to the fibula and directed toward the medial talus neck. Occasionally, there is not enough space to insert the pin if there is no flare of the distal lat-
eral tibia. In this case, the pin is inserted through the fibula into the talus.

- The positions of the guide pins and satisfactory tibiotalar apposition are then checked under fluoroscopy, and appropriate length 6.5-mm partially threaded cancellous screws are then inserted (TECH FIG 3B–E).
- Because the screws are not introduced parallel to each other, eccentric loading of the arthrodesis site may occur as the first one is inserted. This can be avoided by alternately tightening each screw until compression is obtained.
- After screw insertion, I check the stability of the construct. If there is residual motion in the arthrodesis, I retighten or reposition the screws.
- Final fluoroscopic views in the AP, mortise, and lateral planes confirm proper bony apposition, alignment, and screw position (TECH FIG 3F).
- With satisfactory stability, I place bone graft at the anterior tibiotalar arthrodesis.
- After closure of the retinaculum, the residual capsule, subcutaneous tissue, and skin are closed in routine fashion. I do not use a drain.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Screw insertion</th>
<th>The screw length inserted from the medial malleolus should be carefully checked because of the screw’s proximity to the subtalar joint.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The screw inserted from the posterolateral tibia is critical because it obtains the best purchase in the talus and is in the plane of the most direct line of compression across the joint.</td>
</tr>
<tr>
<td></td>
<td>Because the screws are not introduced parallel to each other, eccentric loading of the arthrodesis site may occur as the first one is inserted. This can be avoided by alternately tightening each screw until compression is obtained.</td>
</tr>
<tr>
<td>Position of the arthrodesis site</td>
<td>I aim for neutral position in the sagittal plane, minimal valgus (up to 5 degrees), and external rotation symmetric with the contralateral physiologically normal ankle (no more than 5 to 10 degrees).</td>
</tr>
<tr>
<td>Preparation of the articular surfaces</td>
<td>A high-speed burr and smooth K-wires tend to create localized osteonecrosis that may delay healing. Moreover, the slurry created with a burr may predispose to symptomatic anterior joint synovitis.</td>
</tr>
<tr>
<td></td>
<td>The joint must be irrigated frequently to visualize the cancellous bone surfaces and confirm uniform bleeding.</td>
</tr>
<tr>
<td></td>
<td>Any dense sclerotic subchondral bone can be drilled with a 2.5-mm drill bit to enhance revascularization.</td>
</tr>
<tr>
<td></td>
<td>It is important to position the lamina spreader correctly to avoid tilting the talus from the neutral position.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- A bulky cotton dressing is applied with a medial to lateral coaptation-type splint and posterior mold of plaster.
- Radiographs are obtained at 2, 6, and 10 weeks to evaluate healing, maintenance of alignment and bony apposition, and screw position (FIG 2).
- If the operation was performed under regional ankle block, the patient is discharged the same day. The patient is given oral narcotics, NSAIDs, and oral antibiotics (at the surgeon’s discretion).

- At 2 weeks after surgery, the postoperative bulky cotton dressing is changed to a below-the-knee cast, and only touchdown weight bearing is permitted for 6 weeks or until early radiographic and clinical signs of healing are noted.
- Typically, we initiate progressive weight bearing in a cam boot at 6 weeks, unless a delay in healing is suggested on postoperative radiographs. With delayed union, we keep the patient in a short leg cast and on partial weight-bearing status. Once healing is confirmed (bridging trabeculation at the arthrodesis site), the patient is rapidly progressed from the cam walker boot to a regular shoe. Occasionally, transient use of a rocker-bottom shoe modification allows a more comfortable transition to normal gait.

OUTCOMES

- With appropriate indications and surgical technique, fusion rates for ankle arthrodesis in general are 90%.
- Clinical results and fusion rates of the miniarthrotomy arthrodesis technique are comparable to results with open and arthroscopic procedures.3,4,6,7
- Postoperative radiographs have demonstrated a fusion of the anterior three quarters of the joint as a result of inadequate visualization and débridement of the most posterior portion of the ankle joint. In our experience, lack of bony fusion across the posterior ankle is not a problem.

COMPLICATIONS

- Inadvertent laceration of the saphenous nerve and vein or the lateral branch of the superficial peroneal nerve
- Nonunion (limited incidence using the miniarthrotomy technique)
- Inadvertent penetration of the screws into the subtalar joint
- Infection
- Malposition of the ankle
- Symptomatic prominence of the screw heads

Acknowledgment
I would like to thank my mentor Mark S. Myerson for his enlightening training, friendship, and help for the preparation of this chapter.

REFERENCES

DEFINITION
- Arthritis of the ankle can evolve from multiple causes, including, but not limited to, osteoarthritis, rheumatoid arthritis, and posttraumatic conditions. As the condition progresses, it generally leads to increased pain, gait abnormalities, and diminished function.
- Surgical remedies are employed when conservative measures fail; they consist of the time-honored tibiotalar arthrodesis as well as total ankle replacement.2–4,9,19,21,28
- We will be discussing and illustrating the technique of arthroscopic ankle arthrodesis (AAA).7,12,17,23

ANATOMY
- The ankle joint is composed of the tibiotalar and fibulotalar articulations, with the fibula bearing about one fifth of the weight-bearing stress across the ankle joint (FIG 1).

PATHOGENESIS
- As with any condition, when articular cartilage is destroyed, either by systemic or local disease, the progression of arthritis may be unpredictably slow or rapid. If malalignment is an accompanying factor, the progression and pain are usually more pronounced.

NATURAL HISTORY
- Once the breakdown of the articular surface has begun, it will progress at a rate that is not always predictable. Radiographic changes will not always reflect the degree of pain that the patient presents with. Some patients will come to surgery early while others may languish for decades without needing surgical intervention.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Generally the patient will complain of pain with weight bearing, usually lateral more than medial. Generally it localizes anteriorly in a band from the lateral to the medial side of the ankle. There may be associated swelling and occasional night pain. The symptoms may in part be relieved by nonsteroidal anti-inflammatories (NSAIDs), acetaminophen, crutches, bracing, and activity modification. When other joints are involved, such as the knee and the hip, the discomfort in these areas may overshadow the ankle symptomatology.
- The patient will generally walk with an antalgic gait, and if there is any leg-length discrepancy, there may be a short-leg component to it. Gait will generally improve with the assistance of crutches or a cane.
- Stability is assessed with talar tilt and anterior drawer tests.
- Standing evaluation is critical in determining the feasibility of arthroscopic technique versus open as well as necessary osteotomies.
- Range of motion will be restricted in all planes, and pain will be elicited at the extremes of range of motion.
- Loss of dorsiflexion with plantarflexion contracture needs to be addressed at surgery.
- There will usually be associated swelling about the ankle joint. Synovial hypertrophy, osteophytes, and generalized enlargement of the ankle will present rather than a frank effusion, which could indicate a systemic component.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standing AP, lateral, and mortise radiographs are necessary to determine the extent of arthritis, alignment, presence of osteophytes, and the presence or absence of avascular necrosis of the talus (FIG 2). Minor degrees of malalignment may be corrected up to 7 degrees, varus being the most important element to reverse to neutral.
- MRI scans may be helpful if avascular necrosis is suspected.
- CT may be indicated if bone loss needs to be addressed.
Should there be questions on the circulatory status, a vascular workup may be necessary.

DIFFERENTIAL DIAGNOSIS

- Infection
- Charcot joint
- Pseudogout and gout
- Osteochondral lesions of the talus
- Impingement
- Inflammatory synovitis

NONOPERATIVE MANAGEMENT

- As with most arthritic conditions, a wide variety of nonoperative measures can be employed. Medication in the form of NSAIDs, acetaminophen, and glucosamine sulfate can be used with careful monitoring for side effects. Bracing with simple soft tissue supports or a custom-made ankle–foot orthosis (AFO) can be effective. Cortisone injections, if used sparingly, can offer short-term pain relief. Off-label hyaluronic acid injections have been used with some reported success.

SURGICAL MANAGEMENT

- When patients fail to respond to conservative care, a number of procedures can be undertaken for isolated end-stage ankle arthritis. The time-honored procedure is an open ankle arthrodesis, but over the past 15 years some surgeons have come to prefer AAA.
- Total ankle arthroplasty has been popularized recently and has the obvious advantage of motion preservation at the cost of a more challenging technical procedure and a higher complication rate.\textsuperscript{16}
- AAA will be discussed in detail in the following section.

Preoperative Planning

- We cannot overstress the need for a thorough evaluation of alignment before AAA is undertaken (FIG 3). The films must be done in a standing position and compared to the opposite side. Often patients will present with outside films showing a pseudo-varus deformity, but when a weight-bearing film is taken, the alignment is satisfactory.
- All medical conditions must be addressed. Vascular status needs to be examined as well as the skin condition. Patients

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image1.png}
\caption{Posterior view of varus malalignment, right ankle.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image2.png}
\caption{Sterile traction device with tensionometer applied to right ankle.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image3.png}
\caption{Standard and accessory anterior portals for ankle arthroscopy.}
\end{figure}
need to stop smoking 3 months before the operative procedure and must stay off NSAIDs 5 days before and 3 months after the surgery.

- Perioperative antibiotics are used as well as postoperative deep venous thrombosis prophylaxis in high-risk patients.

### Positioning
- The patient is placed in a supine position.
- The use of a leg holder and tourniquet allows the extremity to be placed in a neutral position so that both the anteromedial and anterolateral aspects of the ankle can be easily accessed.
- The foot of the table is dropped about 30 degrees.
- The ankle is placed in a sterile traction device using a tensionometer controlling traction to about 25 pounds (FIG 4).

### Approach
- The approach that will be described is that of an AAA.
- Generally a two-portal technique can be used with anteromedial and anterolateral portals, and on occasion accessory portals located anterolateral, anteromedial, or posterolateral for additional flow or drainage (FIGS 5 AND 6).

### TRACTION AND EXPOSURE
- Delineate anatomic landmarks with a marking pencil (TECH FIG 1).
- Apply a traction device after thoroughly preparing and draping the ankle.
- Apply traction to about 25 pounds (TECH FIG 2).
- Countertraction is effective with the use of a tourniquet and leg holder.
- Dorsiflexion and plantarflexion are facilitated by the design of the traction strap.
- Instill 8 cc of normal saline into the ankle joint.
- Using a “nick and spread” technique, create the anteromedial portal with a no. 11 blade.
- Use a hemostat to bluntly dissect down to the capsule.
- Introduce a 2.7-mm wide-angled and small joint arthroscope through the anteromedial portal (TECH FIG 3).

**FIG 6** - Standard and accessory posterior portals for ankle arthroscopy.
- Establish drainage through the anterolateral portal.
- Use a pump to control pressure at about 30 mm Hg.
- Take care, as with any infusion technique, to avoid excessive pressure and fluid extravasation.
- Anterior osteophytes may impede entry and visualization in the joint (TECH FIG 4).
  - Osteophytes can be removed anteriorly to create a space for visualization and performance of the arthrodesis.

**TECH FIG 4** • Lateral radiograph of an ankle with prominent tibial and talar osteophytes that need to be resected for access to the ankle joint during arthroscopy.

---

**ARTHRODESIS**

- Perform a synovectomy with a 3.5-mm resection blade (TECH FIG 5A).
- Use a soft tissue motorized blade and a burr to remove the articular cartilage.
- 1 to 2 mm of subchondral bone is generally removed with the burr (TECH FIG 5B).
- Spinal curettes can be used to débride the medial and lateral gutters as well as the posterior tibial plafond and posterior talus (TECH FIG 5C).
- A radiofrequency device can be used for débridement in some areas where access is limited.
- During débridement, maintaining the normal architecture of the tibiotalar joint is imperative.

- Medial and lateral gutters need to be débrided thoroughly, removing 1 to 2 mm of subchondral bone as well (TECH FIG 5D).
- Débriding the gutters allows for coaptation of the tibiotalar surfaces (TECH FIG 5E).
- Multiple spot welds placed on the tibiotalar surfaces will allow increased vascularity (TECH FIG 5F).
- Release the tourniquet and visualize the vascularity of both surfaces (TECH FIG 5G).
- Further débridement may be necessary if diminished vascularity is encountered in any one particular area.

**TECH FIG 5** • **A.** A soft tissue resection blade is being used to perform a synovectomy in the ankle joint. **B.** 1 to 2 mm of subchondral bone is removed with a burr and spot welds are created. **C.** A spinal curette is used to débride the medial gutter of the ankle. **D.** A burr is used to remove subchondral bone. **E.** Tibial–talar surfaces are prepared, as well as the gutters, for coaptation of the surfaces. **F.** A spot weld vascular access channel is created in the talus. **G.** After release of the tourniquet, vascularity of the tibiotalar surface is assessed.
STABILIZATION, FIXATION, AND CLOSURE

- Hold the ankle in the acceptable corrected neutral position and insert guidewires.
- Use two 7.3-mm AO cannulated cancellous screws to stabilize the tibiotalar joint.
- Place screws parallel and obliquely from the medial tibia into the lateral talus (TECH FIG 6).
- Perform fixation under fluoroscopic control to avoid any potential encroachment on the subtalar joint.
- Apply compression alternately to each screw.
- Check the final position both clinically and under fluoroscopy.
- Close the arthroscopic portals with Steri-Strips and close the operative site for screw insertion with 3-0 nylon sutures.
- Apply a local anesthetic and incorporate the leg into a bulky dressing and a bivalve cast.

TECH FIG 6 • A. AP radiographs showing two parallel oblique screws used for fixation of the arthroscopic fusion. B. Lateral radiographs showing two parallel oblique screws fixing the ankle fusion.

PEARLS AND PITFALLS

Indications
- If possible, avoid operating on smokers and patients with Charcot joints and avascular necrosis of the talus.
- Carefully explain to the patient what the associated stiffness and lack of motion of the ankle will involve.
- Avoid noncompliant patients.

Arthroscopic procedure
- Use careful fluid management to avoid extravasation and compartment syndrome.
- Do not exceed 25 to 30 pounds of traction.
- Have the appropriate small joint arthroscopy system available.

Surgical technique
- Early removal of the anterior osteophytes will aid in visualization.
- Do not remove excessive amounts of subchondral bone.
- Spot weld technique will increase the vascular access.
- Medial and lateral gutters need to be débrided for better coaptation.
- Guide pins need to be checked carefully under fluoroscopy.
- Avoid violating the subtalar joint with screws.

POSTOPERATIVE CARE

- Patients are placed in a bulky dressing with a bivalve cast in the operating room. Circulatory checks are done in the recovery room and 24 hours postoperatively.
- The cast is removed and the wounds are inspected at 7 days postoperatively. The patient is then fitted for an AFO brace (FIG 7).
- The patient is allowed touch weight bearing the first few days after surgery, with progressive weight bearing, and may attain a full weight-bearing status as soon as tolerated.
- Generally the patient will use crutches for 2 to 3 weeks. Full weight bearing is encouraged.
- The patient is allowed to remove the AFO for bathing and range-of-motion exercises. Range of motion and weight bearing

FIG 7 • An AFO brace is used for immobilization, postoperative week 1.
reduce stress deprivation. The patient is allowed to remove the AFO and walk with normal shoe wear when radiographic union has taken place, there is no motion at the screw sites, and the patient is essentially pain-free.

OUTCOMES
- Fusion rates for AAA are generally in the range of 90% to 95%.10,13,27,30
- There is definitely less pain after the arthroscopic procedure than with the open procedure.
- The operation is generally done as an outpatient procedure.
- Alignment is thought to be easier to obtain because of the maintenance of the normal architecture and geometry of the tibiotalar joint.

COMPLICATIONS
- The complication rate from ankle arthroscopy has been reported to be about 9%.1,5,6,8,11,13,14,18,20,24–26
- Infection
- Synovial fistula (FIG 8)
- Delayed union (FIG 9)
- Nonunion
- Charcot joint
- Secondary degenerative changes, subtalar and midfoot
- Equinus or dorsiflexion malposition
- Residual varus malalignment
- Fibular–talar and fibular–calcaneal impingement (FIG 10)
- Neurapraxia and nerve injuries
- Vascular injuries
- Skeletal traction complications (FIG 11)
- Screw encroachment in subtalar joint (FIG 12)
REFERENCES

DEFINITION
- Tibiotalocalcaneal arthrodesis is the surgical procedure to simultaneously fuse the ankle and the subtalar joints.
- In cases of posttraumatic, neuropathic, or avascular talar body bone loss, tibiocalcaneal arthrodesis may be indicated. The term pan-talar arthrodesis refers to the surgical procedure to fuse all bones that articulate with the talus: the distal tibia, calcaneus, navicular, and cuboid. In essence, this is a combined ankle and triple arthrodesis.
- In our opinion, the term medullary refers to the inner marrow cavity of a long bone and the word intramedullary is a redundant, less useful term.
- The goal of tibiotalocalcaneal arthrodesis is to create a painfree ankle and hindfoot that are biomechanically stable and fused in functional position.
- In our hands, tibiotalocalcaneal arthrodesis is a salvage operation performed for severe ankle and hindfoot deformity, bone loss, and pain.

ANATOMY
- Tibiotalocalcaneal arthrodesis aims to recreate physiologic ankle and hindfoot alignment with a plantigrade foot position (the foot is at a 90-degree angle to the long axis of the tibia) and about 5 to 7 degrees of hindfoot valgus.
- In general, rotation of the foot relative to the longitudinal axis of the tibia in the coronal plane is congruent with the anterior tibia—that is, the second ray of the foot is usually in line with the anteromedial crest of the tibia.
- Hindfoot position influences forefoot position. With longstanding ankle and hindfoot deformity, forefoot pronation, supination, adduction, and abduction may be affected. Proper positioning of a tibiotalocalcaneal arthrodesis must take forefoot position into account. Ideally, in stance phase the foot has near-equal pressure distribution under the heel and first and fifth metatarsal heads.

NATURAL HISTORY
- Severe ankle and hindfoot deformities and pathologic processes result in disabling pathomechanics and, when left untreated, often confine patients to cumbersome brace use, limited ambulation with assistive devices, or a wheelchair.
- Tibiotalocalcaneal arthrodesis is a major reconstructive process usually applied to otherwise disabling conditions.
  - Gellman et al. noted that the dorsiflexion and plantarflexion deficits after ankle fusion compared to the nonfused contralateral ankle were 51% and 70%, respectively. Surprisingly, for tibiotalocalcaneal arthrodesis, dorsiflexion and plantarflexion deficits were 53% and 71%, respectively.
  - This same study concluded, however, that inversion and eversion were 40% less after tibiotalocalcaneal fusion than after tibiotalar fusion alone.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The patient being considered for tibiotalocalcaneal arthrodesis with a medullary nail presents with a myriad of orthopaedic pathology affecting gait, weight bearing, and ability to earn a living.
- This patient may present with limited mobility, an equinus posture associated with genu recurvatum, and transverse plane deformity ranging from severe varus and instability of the hindfoot through profound valgus and ulceration over the medial structures (FIG 1).
- The neuromuscular or neuropathic patient may present with ulceration, intrinsic muscle loss, and multiple fractures in various stages of healing.
- The posttraumatic patient often has a compromised soft tissue envelope, previously placed hardware, and already medullary canal sclerosis that must be considered in preoperative planning (FIG 2). Evaluation must include gait and...
weight-bearing posture, assessment of the soft tissue envelope, and a thorough neuromuscular examination.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- We routinely obtain three weight-bearing radiographs of the ankle and foot. As many of these patients have deformity, we often obtain additional long-cassette radiographs of the ankle or even mechanical axis views of the lower leg from the hip to the foot.
- Posttraumatic and osteoarthritis
- Radiographs may reveal joint space narrowing, osteophyte formation, and subchondral sclerosis and cysts, all characteristic of osteoarthritis. Posttraumatic deformity and retained hardware may be identified and must be considered in preoperative planning (**FIG 3**).
Rheumatoid arthritis and other inflammatory arthritides
- Radiographs typically identify periarticular erosions and osteopenia.

Neuropathic arthropathy or Charcot neuroarthropathy
- In our experience, this presentation is radiographically characterized by numerous fractures or microfractures in various stages of healing, hypertrophic new bone formation, and loss of normal weight-bearing architecture.
- Bone resorption may be seen, along with vascular calcification and joint subluxation or dislocation.
- Plain tomography or CT may further define deformity, arthritis, bone loss, and prior malunion or nonunion (FIG 4).
- We have not found three-dimensional CT reconstructions helpful in the routine setting.
- CT is also useful in assessing progression toward union following tibiotalocalcaneal arthrodesis.

MRI may complement CT by evaluating for fluid in and around the joints, bone marrow edema, talar vascularity, infection, and periarticular tendon and ligament pathology (FIG 5).
- Technetium-99 bone scans may be useful in the evaluation of osteonecrosis after talus fracture, arthritic involvement of one or several joints, stress fracture, or neoplasm.
- Indium-labeled white blood cell scans can be helpful in the diagnosis of osteomyelitis or septic arthritis.

DIFFERENTIAL DIAGNOSIS
- Primary and secondary osteoarthrosis, including posttraumatic osteoarthritis
- Rheumatoid arthritis and other inflammatory arthritides (gout, pseudogout, pigmented villonodular synovitis, septic arthritis, psoriatic arthritis, spondyloarthropathy, Reiter syndrome)
- Neuropathic arthropathy (diabetes mellitus, spinal cord injury, hereditary sensory and motor neuropathy, syringomyelia, congenital indifference to pain, alcoholism, peripheral nerve disease, tabes dorsalis, and leprosy)
- Infectious arthritis (sepsis, open trauma, or previous surgical procedure for fixation of fractures)
- Arthritis and joint subluxation resulting from generalized ligamentous laxity, mixed connective disease, posterior tibial tendinopathy, spring ligament insufficiency

NONOPERATIVE MANAGEMENT
- Selective (diagnostic) injection of local anesthetic may help locate the exact anatomic source of the patient’s pain.
- Tibiotalar arthritis may be associated with a stiff, painful subtalar joint that has a relatively normal radiographic appearance.
- The injection of 5 to 10 mL of 1% lidocaine into the subtalar joint can clarify whether the pain may not be isolated to the ankle but in fact be generated in both the ankle and subtalar joints.
- This has important implications when considering isolated tibiotalar versus tibiotalocalcaneal arthrodesis. We do not routinely incorporate the subtalar joint into the arthrodesis when performing an ankle arthrodesis. In select cases of end-stage ankle arthritis associated with severe deformity and talar bone loss, we consider including an otherwise normal asymptomatic subtalar joint in the fusion mass achieved for tibiotalocalcaneal fusion. Alternatively, an injection carefully placed in the peroneal tenosynovial sheath may prove that pain may be related to the tendons rather than the joint.
- While often challenging for the patient with deformity, we recommend bracing for the patient with prohibitive medical illness or a dysvascular extremity, particularly for the patient with a non-fixed, passively correctible deformity. A custom
polypropylene ankle–foot orthosis (AFO) or a supramalleolar AFO with Velcro closures may be considered as an alternative to tibiotalocalcaneal arthrodesis in poor surgical candidates (FIG 6).

- For the neuropathic patient in whom bracing can achieve a relatively plantigrade posture for the hindfoot and ankle, we prescribe a double-metal-upright AFO attached to an Oxford shoe that includes Plastazote liners (total contact inserts).
- In our experience, polypropylene in-shoe braces lead to ulceration in these patients with complex deformity.
- In severe deformity, a Charcot retention orthotic walker (CROW) may prove effective.
- While we favor tibiotalocalcaneal arthrodesis for patients with posttraumatic arthritis and deformity, we have had some success in relieving pain and improving function with a patellar tendon bearing brace for poor surgical candidates.

SURGICAL MANAGEMENT

Indications and Contraindications

- Indications for tibiotalocalcaneal arthrodesis
  - Sequelea of degenerative, posttraumatic, or inflammatory arthritis
  - Avascular necrosis of the talus
  - Severe instability or paralytic ankle and hindfoot weakness
  - Neuropathic arthropathy
  - Failed ankle arthroplasty with subtalar intrusion
  - Failed ankle arthrodesis with insufficient talar body
  - Severe deformity of talipes equinovarus
  - Neuromuscular disease
  - Skeletal defects after tumor resection
  - Pseudarthrosis
  - Flail ankle

- Absolute contraindications for tibiotalocalcaneal arthrodesis with internal fixation
  - Dysvascular extremity
  - Active infection

- Relative contraindication to tibiotalocalcaneal arthrodesis with closed nailing techniques
  - Severe, fixed deformity that precludes a colinear reduction of the tibia, talus, and calcaneus for rod placement

Preoperative Planning

- We glean essential information for preoperative planning from a thorough history and physical examination of the soft tissue envelope, vascular status, degree of deformity, and assessment of the entire limb and contralateral limb.
- We review all imaging studies, including longstanding radiographs of the lower extremity. Many of these patients have comorbidities, so we ensure that medical clearance is obtained.
- The availability of implant and instruments is ascertained and arrangements for perioperative care are confirmed.

Positioning

- The patient with severe preoperative valgus deformity is positioned supine on a radiolucent operating table with a well-padded bump under the ipsilateral buttock to rotate the involved extremity internally (FIG 7A). Another pad can be placed under the heel to facilitate cross-table fluoroscopic imaging.
- Alternatively and preferably, the patient with neutral to varus deformity is positioned in the lateral position with the affected extremity up (FIG 7B).
- We pad bony prominences and use an axillary roll in the recumbent axilla.
- The patient is usually fastened to the table with a beanbag and chest brace devices, and pneumatic tourniquet control at the level of the thigh is used.
- Parenteral, prophylactic antibiotics are administered before the tourniquet is inflated.
INCISION

- For the patient with severe preoperative valgus, we make a longitudinally oriented incision over the medial malleolus starting just at the supramalleolar level and carried 2 to 3 cm distal to the tip of the medial malleolus.
  - This allows a subperiosteal approach to the ankle and the removal of medially based closing-wedge osteotomies of diseased tibiotalar bone and cartilage to correct the preoperative valgus deformity.
- We identify and protect the medial neurovascular structures during this approach.
- For all patients other than those who present with severe preoperative valgus, we routinely use a lateral transfibular approach through a longitudinal incision over the distal fibula carried onto the sinus tarsi, curving slightly anteriorly as one extends beyond the distal end of the fibula.
  - This approach affords wide access to both the ankle and subtalar joints and eliminates the possibility of the lateral malleolus rubbing in normal shoe wear postoperatively, and the fibula serves as a source of abundant cancellous and corticocancellous bone graft material during the case (TECH FIG 1).
  - Fibular ostectomy should be especially considered at the time of hindfoot fusion if there is significant varus deformity or loss of tibial length relative to the fibula.
  - Resect the distal fibula in a beveled fashion with a microsagittal saw no more than 3 cm proximal to the level of the tibiotalar joint to preserve the distal tibiofibular syndesmosis and thereby minimize postoperative discomfort caused by distal tibiofibular movement and crepitus.

We would like to clarify that the transfibular approach with or without fibulectomy is reserved for patients with severe deformity who are not candidates, nor will ever be candidates, for future ankle fusion takedown and conversion to total ankle arthroplasty (TAA). For patients who may be considered for future TAA, every attempt should be made to preserve anatomy, especially the fibula—that is, the arthrodesis should be performed via an anterior or posterior approach.

ANKLE ARTHROTOMY

- We use a lateral ankle arthrotomy with the incision carried over the sinus tarsi and subtalar joint to correct any deformity that may be present across the tibiotalar and subtalar joints and to prepare the joint surfaces by removing what is left of the diseased articular cartilage (TECH FIG 2).
  - Small wedges of bone may be removed to obtain the appropriate plantigrade postoperative posture for the foot and ankle.
  - These arthrotomies also leave space for insertion of bone graft as needed.
  - Often combined medial and lateral arthrotomies are needed to achieve the appropriate plantigrade posture of the foot and to remove medial malleolar prominence.
  - In the case of the ankle with preoperative valgus deformity, we use a medial approach to the tibiotalar joint in combination with a limited lateral exposure to decorticate and decancellate the subtalar joint via a separate lateral incision over the sinus tarsi.

TECH FIG 1 • Lateral approach to the tibiotalar and subtalar joint after distal fibulectomy.

TECH FIG 2 • The lateral arthrotomy, with removal of fibula, allows easy access to the ankle joint as well as extending to the subtalar joint.
PLANTAR INCISION FOR GUIDEWIRE INSERTION AND REAMING

- As is true with all other medullary fixation procedures, the starting point for insertion of the guidewire and subsequent medullary rod is critical to the success of the case.
- The correct starting point is midway between the tips of the medial and lateral malleoli, anterior to the subcalcaneal heel pad, and about 2.5 cm posterior to the transverse tarsal joints, in line with the longitudinal axis of the tibia (TECH FIG 3A).
  - Make a 2-cm, longitudinally oriented plantar incision just anterior to the weight-bearing subcalcaneal heel pad.
  - After the incision is carried through dermis sharply, blunt dissection only is taken down to the plantar fascia, which is split longitudinally.
  - The intrinsic muscles can be swept aside and the neurovascular bundle protected and retracted with the intrinsic flexors.
  - Place a smooth Steinmann pin or a guidewire, over which is passed a cannulated drill to provide access to the talus and tibial medullary canal after calcaneal corticotomy (TECH FIG 3B).
- Confirm optimal insertion of the cannulated drill, which passes sequentially through the inferior cortex of the calcaneus, the calcaneal body, the subtalar joint, the talar body, across the ankle, and finally into the distal tibial canal, using intraoperative fluoroscopic views in both the AP and lateral planes.
- After removing the cannulated drill, pass a bulb-tipped guidewire through the calcaneus and talus into the distal tibial medullary canal.
- Pass a series of progressively larger, flexible reamers over the guidewire, and use them to enlarge the tibiotalocalcaneal canal.
- We recommend that the final reamer diameter is a full 0.5 to 1 mm larger than the anticipated implant’s diameter.
  - In our experience, overreaming avoids the risk of intraoperative and postoperative fracture at the proximal tip of the rod without compromising the construct’s stability.
  - Overzealous reaming in osteopenic bone may result in an intraoperative tibial fracture that then warrants using a longer medullary nail for spanning the fracture. When in doubt, check thereamer position with the fluoroscope.
  - We are aware of several articles reporting fractures of the tibia at the proximal portion of the medullary nail when the nail is left at the relatively sclerotic distal tibial diametaphysial isthmus.
  - When closing the plantar wound, use simple interrupted or horizontal mattress sutures for a flat rather than inverted skin edge closure.

NAIL SELECTION

- In most cases a nail length of 15 to 18 cm suffices for tibiotalocalcaneal arthrodesis with the proximal extent of the nail in metaphyseal bone, distal to the diaphyseal isthmus, where the risk of tibia fracture is greatest.
- Nail diameter is dictated by the size of the native tibia.
  - In most cases, a 10-mm-diameter nail affords satisfactory stability to allow progression toward fusion.
  - While we acknowledge that an increase in nail diameter affords greater strength to the construct, we caution that aggressive overreaming of the cortex to place a larger-diameter nail may compromise the cortex, leading to a stress fracture.
In profoundly neuropathic patients, we have used a long tibiotalocalcaneal nail that bypasses the distal tibial isthmus by a length equal to at least three times the diameter of the tibial canal measured at the level of the isthmus. A longer nail generally reduces the possibility of a distal tibial stress fracture, albeit by requiring more reaming of the tibia.

**NAIL PLACEMENT ACROSS THE ARTHRODESIS SITE**

- We find that locking the nail to its targeting arm, with each of two drill bits inserted through the drill guides and the two proximal-most screw holes in the nail before the nail and its targeting arm are tightened, ensures optimal alignment before placement.
- The medullary nail is attached to its alignment and targeting guide. As it is inserted in retrograde fashion at plantar foot, it is slightly internally rotated so that when the locking screws are passed from lateral to medial they will pass into the tibia without impingement upon the distal fibula (**TECH FIG 4A**).
- During insertion, the distal aspect of the nail should be countersunk at least 5 mm cephalad to the plantar surface of the os calcis or at least countersunk the same distance that the surgeon anticipates achieving axial compression across the ankle and subtalar fusion sites. Be sure not to leave the nail prominent on the plantar aspect of the foot (**TECH FIG 4B**).

**SCREW PLACEMENT IN THE INTRAMEDULLARY NAIL**

- When determining the final position for the nail, we simultaneously estimate the position of locking holes in the nail relative to the distal tibia, the talar body, and the calcaneal body.
- It is preferable but not necessary to fill all the locking holes.
- Nail failure is likely to occur in the heavyset or neuropathic patient if locking holes are left open at the level of either the ankle or subtalar fusion site. Early reports of nail failure at the subtalar joint often noted failure to fuse the subtalar joint.
- An advantage of modern nail design includes placement of locking screws at various angles to one another.
- The position of the nail for the proximal screws into the tibia will dictate the final rotation; thus, the guide for the posteroanterior screw may be applied and used to check (including fluoroscopy) the later position for the posteroanterior screw in the calcaneus as well as the talus screws (**TECH FIG 5A**).
- A posterior-to-anterior calcaneal locking screw increases the torsional rigidity of the nail construct by at least 40% and improves purchase of the calcaneal bone exponentially when compared to simply locking in one plane relative to the long axis of the nail (**TECH FIG 5B**).
- Further manual compression and impaction can be done across the arthrodesis sites before the proximal interlocking screws are inserted. Some nails use an extramedullary compression device, while others use compression of the heel against the tibial screws.
- Some medullary rods include an inline compression device that can provide up to 15 mm of compression across the ankle and subtalar fusion sites (**TECH FIG 5C**).
Some nails also provide for compression of the talar screw proximally toward the tibial screws, further compressing the ankle joint 7 mm (TECH FIG 5D).

Do not remove this compression until the rod is locked both in the talus and the calcaneus so that the benefits of compression across both fusion sites (ankle and subtalar) can be achieved.

**END CAP INSERTION**

- While some surgeons consider the end cap optional, we routinely secure it to the distal end of the nail after removal of the targeting arm. It restricts medullary bleeding, limits heterotopic calcification, and protects the threads of the nail should extraction be needed later.

- Permanent radiographs may be obtained in the operating room, both with AP and lateral projection, to ascertain appropriate alignment, position, and fixation.

**BONE GRAFTING**

- Autogenous or allograft bone grafting is done to improve healing rates.

- Medullary reamings can be mixed with a fibular autograft and inserted at the tibiotalar and subtalar fusion sites even before placement of the nail.

- After insertion of the nail, place bone graft anterior, lateral, and posterior to the fusion sites.

- For large defects, such as removal of ankle prostheses, a femoral head allograft may be cut to fit the large defect, and then the nail can be placed directly through the allograft (TECH FIG 6A–D).

- Because of the bleeding, cancellous surfaces of bone achieved at surgery, and the large amounts of bone graft employed, closed suction drainage is recommended.

- Some surgeons and investigators advocate internal or external electrical bone stimulators for improving healing rates in neuropathic, multiply operated patients or smokers.

- We have also used bone stimulation for patients with pre-existing avascular necrosis at the arthrodesis site.
Take care to approximate the tissues in the ankle region. A layered closure is preferable.

Apply a sterile, nonadherent dressing with adequate padding from the tips of the toes to just below the knee.

This dressing includes a posterior plaster splint with the ankle and foot at neutral position and a gentle compressive wrap over padding.

The patient is a 58-year-old man with posttraumatic talar avascular necrosis who failed brace wear.

Preoperative radiographs are shown in TECHNIQUE FIGURE 7A–C. The patient had pain from tibiotalar arthritis due to talar dome collapse. With increasing talar collapse, the foot gradually migrated anterior to the tibia, a biomechanically unfavorable position.

Postoperative radiographs are shown in TECHNIQUE FIGURE 7D,E. Tibiotalocalcaneal arthrodesis with a medullary nail was performed. The anatomic relationship of the foot to the tibia has been re-established. The nail is not proud on the plantar foot. Despite the relatively large diameter of the nail, a supplemental cannulated screw can be placed adjacent to the nail from the calcaneus to the anterior tibia to provide further support to the construct. Also, a large buttress (much like the flying buttress on a French cathedral) was placed on the posterior tibia and dorsal calcaneus to increase the surface area for fusion.
TECH FIG 7 • Preoperative weight-bearing ankle radiographs with avascular necrosis of the talar dome and some degree of anterior translation of the talus relative to the tibial axis. A. AP view. B. Mortise view. C. Lateral view. D, E. Postoperative weight-bearing ankle radiographs of the same patient after tibiotalocalcaneal arthrodesis. Fusion appears to have been successful based on the bridging trabeculation at the arthrodesis sites. In our experience, the increased surface area afforded by the bone graft to the prepared posterior tibia and dorsal calcaneus increases the chance of fusion. Note that the physiologic relationship of talus to tibial shaft axis has been re-established. Despite the nail’s relatively large diameter, a supplemental cannulated screw could be passed adjacent to the nail to provide greater stability to the construct. D. AP view. E. Lateral view.

PEARLS AND PITFALLS

- The most important goal of tibiotalocalcaneal arthrodesis with medullary nail fixation is achieving satisfactory pain-free union of the ankle and hindfoot with the foot in optimal plantigrade posture.
- In our experience, radiographic and clinical assessment on the operating table before completion of the case is most important in achieving plantigrade posture.
- Intraoperative pearls include the need for appropriate positioning so that full access to the entire lower extremity is obtained.
  - We recommend that the patient with limited internal and external hip rotation should be positioned in slightly less than extreme lateral position to facilitate access to the medial malleolar side of the ankle and optimize AP imaging with a C-arm fluoroscope.
  - The optimal insertion point for the nail is immediately lateral to the plantar calcaneus’ midpoint and in line with the longitudinal tibial axis.
- Nail and targeting arm
  - Be sure that the targeting arm is rigidly coupled to the nail. Rigid coupling of the nail to its targeting arm in the appropriate position and alignment will save the surgeon a lot of effort and frustration in locking the nail proximally.
- Medullary nailing for tibiotalocalcaneal arthrodesis in the face of open ulcers or wounds is not absolutely contraindicated, but ulcers or wounds should be clean, non-cellulitic, and granulating before medullary nail fixation is considered.
- Rotational alignment of the tibiotalocalcaneal arthrodesis: Satisfactory rotational alignment is most readily achieved by comparison to the contralateral uninvolved limb and by preserving the natural concave-convex relationship of the tibiotalar and subtalar fusion sites at the time of removal of diseased cartilage and subchondral bone.
POSTOPERATIVE CARE

- Most patients undergoing tibiotalocalcaneal arthrodesis with medullary nail fixation can be discharged the day after surgery with oral analgesics and after having received 24 hours of parenteral antibiotics.
- The typical case will require non-weight-bearing protection in a short-leg splint or cast for 6 weeks, followed by 4 to 6 weeks of weight bearing to tolerance in a short-leg walking cast.
- At 10 to 12 weeks postoperatively the patient is fitted with a removable fracture orthosis equipped with a rocker sole to ease the transition to weight bearing in more normal shoe wear by 12 to 16 weeks postoperatively.
- Less than half of the patients fused in the appropriate plantigrade posture with otherwise normal neuromuscular function will have a noticeable limp by 6 to 12 months postoperatively.
- Those requiring shoe wear modification are often best treated with a rocker-bottom sole or a cushioned heel to make up for the rigidity of the fused joints.
- Heel lifts can be employed to equalize limb lengths to within 10 to 15 mm, the side undergoing tibiotalocalcaneal fusion desirably being the short one to allow for toe clearance during the swing phase of gait.
- The vast majority of our patients are ambulatory postoperatively in a non-custom, off-the-shelf shoe.
- Rod removal has been required in less than 1% of Dr. Quill’s operative series.

COMPLICATIONS

- We have not encountered plantar wound healing problems in any patient when the procedure is done as described above.
- Damage to the medial and lateral plantar nerves can be avoided by following the technique mentioned above and by dissecting with nothing sharper than a large key elevator deep to the dermis on the plantar aspect of the foot.
- A three-quarter-inch key elevator can be used to bluntly spread the fibers of the plantar fascia and the intrinsic flexor muscles in line with the incision and to sweep soft tissues medially and laterally before inserting the guidewire through the sole of the foot.
- Complications of medullary nail fixation for ankle and hindfoot fusion include those germane to any orthopaedic procedure, such as infection, medical illness, and anesthetic perioperative complication, as well as hardware prominence.
- The complications unique to medullary nail fixation for tibiotalocalcaneal arthrodesis include delayed union, nonunion, and malunion and can be minimized by adhering to the technique described.
- The proximal dissection for screw fixation may encounter the superficial peroneal nerve and the distal dissection may expose the sural nerve; care must be taken to avoid damage. In cases in which the medial malleolus is removed, the tibial nerve can be exposed to injury very easily.

OUTCOMES

- Medullary nail advantages over traditional fixation for arthrodesis of the ankle and hindfoot include the fact that a medullary nail is a load-sharing device that is especially indicated for the osteopenic or neuroarthropathic patient.
- Dr. Quill’s personal clinical series includes a 93% union rate in an average of 12.2 weeks postoperatively (range 10 to 20 weeks).
- Delayed nonunions have occurred in neuropathic patients, but most are asymptomatic.
- Mean improvement in the AOFAS clinical scores for this series of patients has been 52 points.
- Nail-related problems include the removal of 17 of 932 locking screws removed for fracture or local irritation.
- There have been two fractured nails, both of which were in the face of severe persistent valgus and subtalar nonunion in neuropathic, obese patients.
- One tibial fracture was sustained intraoperatively in an osteopenic rheumatoid patient. It was incomplete and healed during routine casting.
- Excellent early stability and rigid early fixation are achieved and maintained, providing for less perioperative morbidity and discomfort and shorter casting.
- The medullary nail ensures position and alignment from the immediate postoperative time frame, and the patients often require less activity restriction postoperatively.
- Medullary nail fixation for tibiotalocalcaneal arthrodesis has filled a particular niche in treating patients with severe deformities, disabilities, and bone loss who otherwise would have been severely disabled or would have needed to undergo limb amputation.
REFERENCES

DEFINITION
- Tibiototalocalcaneal arthritis is formally defined as the loss of cartilage from both the tibiotalar (ankle) and the talocalcaneal (subtalar) joints.
- Tibiototalocalcaneal arthritis can cause significant disability in terms of pain and limitation of function. Nonoperative treatment options are limited, as in most instances they only partially relieve pain and usually cannot correct deformity.
- The goal of tibiotalocalcaneal arthrodesis is to produce a stable, plantigrade, pain-free foot and ankle.
- Achieving stable fixation can be challenging in osteopenic bone. Blade plate fixation of the tibiotalocalcaneal joint has been shown in biomechanical studies to have higher initial and final stiffness.

ANATOMY
- The ankle joint comprises the talus as it articulates with the tibial plafond. The body of the talus is saddle-shaped dorsally and fits congruently within the mortise created by the distal tibia and fibula. In addition, the talus and the tibial plafond are narrower posteriorly to accommodate rotation with ankle dorsiflexion and plantarflexion.
- The subtalar joint comprises the talus and the calcaneus as they articulate through anterior, middle, and posterior facets.
- The talus is divided into head, body, and neck. Roughly 70% of the bone is covered with cartilage, and there are no muscular or tendinous attachments. The main blood supply of the talar body enters retrograde through the neck of the talus, which makes the body prone to avascular necrosis in the case of displaced talar neck fractures.
- The lateral aspect of the foot is innervated by the superficial peroneal and sural nerves. The superficial peroneal nerve typically exits the crural fascia 10 to 12 cm proximal to the tip of the lateral malleolus. The nerve then courses anteriorly to give sensation to the dorsal aspect of the foot.
- The sural nerve has contributions from branches of both the tibial and common peroneal nerves. It courses lateral to the Achilles tendon and is found about 1 cm distal to the tip of the fibula at the level of the ankle.

PATHOGENESIS
- Arthritis of the tibiotalar and subtalar joints has multiple causes, including primary osteoarthritis, trauma, neuroarthropathy, infection, avascular necrosis, inflammatory arthritis, and failed surgery.
- Patients typically complain of diffuse ankle pain and cannot differentiate tibiotalar from subtalar symptoms. Although it is preferable to fuse only one joint to retain an adjacent motion segment, such isolated fusion in the setting of residual arthritis can result in persistent pain.
- In posttraumatic cases, failure to restore articular congruency can result in increased contact stresses, with resultant cartilage wear and the development of arthritis.

NATURAL HISTORY
- Hindfoot arthritis is usually a progressive disorder, although the rate of progression can vary. However, arthritis due to malalignment, trauma, and avascular necrosis of the talus can progress relatively rapidly.
- Nonoperative treatment of hindfoot arthritis in an ankle–foot orthosis (AFO) likely does not prevent or slow progression of the disease, but merely decreases symptoms. Failed surgery can be quite debilitating and frequently needs expedited treatment.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Physical examination should include:
  - Gait. The surgeon should watch the patient walking both forward and backward from him or her and should clinically determine whether gait is normal or antalgic on both sides. The examiner should look for any assistive devices. Patients with painful arthritis will have an antalgic gait on that side. The patient may require the use of a cane or a walker.
  - Hindfoot alignment. The hindfoot is examined from behind. The surgeon should determine whether the hindfoot is in varus or valgus. Patients can have both varus and valgus malalignment.
  - Tibiotalar range of motion. Active and passive sagittal plane motion is assessed. Normal ankle motion is about 30 degrees of plantarflexion and 10 to 20 degrees of dorsiflexion. Tibiotalar motion is usually significantly decreased compared to the unaffected side.
  - Subtalar range of motion. Active and passive coronal plane motion is assessed. Normal subtalar motion is about 10 to 20 degrees of inversion and 5 to 10 degrees of eversion. Subtalar motion is usually significantly decreased compared to the unaffected side.
  - Past medical history may be significant for antecedent ankle or hindfoot trauma, talar osteonecrosis, diabetes, neuroarthropathy, osteochondral defect, or recurrent ankle instability.
  - Past surgical history may include previous ankle or hindfoot surgery, including open reduction and internal fixation, total ankle arthroplasty, and previous arthrodesis.
  - Patients usually complain of pain and instability with weight bearing. Selective anesthetic injections into the ankle or subtalar joints can help to determine which joints are symptomatic.
  - Upon examination, hindfoot swelling and tenderness are usually evident. Most patients have decreased passive range of motion in both joints. Malalignment is also often present.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Weight-bearing plain radiographs including AP, lateral, and mortise views of the ankle and AP, lateral, and oblique views of the foot are standard.
A weight-bearing lateral should be performed to assess talo–calcaneal and talo–first metatarsal angles (FIG 1).

CT is often helpful preoperatively to assess bony anatomy, alignment, and articular integrity in greater detail.

DIFFERENTIAL DIAGNOSIS
- Talar avascular necrosis
- Talar osteochondral injury
- Isolated ankle arthritis
- Isolated subtalar arthritis
- Ankle instability
- Foreign body

NONOPERATIVE MANAGEMENT
- Nonoperative treatment is aimed primarily at alleviating symptoms rather than correcting deformity. The patient is placed in a robust brace such as an ankle–foot arthrosis (AFO) or Arizona brace in an attempt to provide support and limit motion.
- Bracing may not always be possible depending on the severity of the deformity. In addition, bracing typically does not prevent progression of disease.

SURGICAL MANAGEMENT
- Surgical management is generally indicated when nonoperative modalities have failed to provide adequate relief or are impractical (eg, a non-braceable deformity).
- Tibiotalocalcaneal fusion is indicated in patients with arthritis in both the tibiotalar and subtalar joints. The goal of surgical intervention is to obtain a stable, plantigrade, and pain-free foot and ankle.
- Blade plate fixation can be used primarily or in instances when the surgeon feels that intramedullary rod fixation is contraindicated. The latter may include poor bone stock or advanced osteopenia, a distal tibia deformity greater than 10 degrees, or significant loss of calcaneal height.
- The main two contraindications to this procedure are (1) the presence of active infection and (2) destruction of calcaneal bone stock to the extent that purchase with the blade is compromised. In these instances, the use of a small wire ring fixator should be considered.

Preoperative Planning
- A full patient assessment is made before the operation. Smokers should be counseled with regard to smoking cessation because in this population, a 14-fold increase in the nonunion rate has been documented.
- If active infection is suspected, an appropriate workup should be performed. This may include laboratory studies, MRI with contrast, and nuclear imaging. If there is still uncertainty despite these tests, a bone biopsy or joint aspirate may be necessary.
- Disease-modifying antirheumatic drugs (DMARDs) should be held preoperatively, typically for 2 weeks or a period determined in conjunction with a rheumatologist.
- Patients with significant comorbidities such as diabetes, cardiovascular disease, and nephropathy should be medically optimized by their primary care doctor before surgical intervention.

Positioning
- The patient is placed supine on the operating table with a bump under the ipsilateral buttock to maintain the foot in neutral or slightly rotated medially.
- The extremity is prepared and draped, including the iliac crest if structural autograft is desired. An alternative bone graft harvest site is the proximal tibia. A thigh tourniquet is used (FIG 2).

Approach
- Traditionally, an extensile lateral approach to the ankle and subtalar joints is used, although a posterior approach has also been described.
- A 15- to 20-cm curvilinear incision is made through the skin centered over the fibula shaft proximally, then curving toward the base of the fourth metatarsal distally.

FIG 1 • Preoperative AP (A) and lateral (B) radiographs of the ankle.

FIG 2 • Preoperative positioning of the patient.
With deep dissection, care is taken to avoid injury to the superficial peroneal nerve, which exits the fascia about 12 cm proximal to the fibular tip. Distally, the surgeon must take care to avoid injury to the sural nerve along its course lateral to the fifth metatarsal (FIG 3).

Distally, the extensor digitorum brevis is elevated to expose the subtalar joint.

In some instances, a medial (longitudinal) incision may be necessary. These include (1) to remove medial bony prominences and debris and (2) to assist in resection of medial bone when advanced varus deformity precludes reduction of the foot to neutral.

OSTEOTOMY OF THE FIBULA AND PREPARATION OF THE TIBIOTALAR JOINT

- Make an osteotomy of the fibula about 6 to 10 cm proximal to the tip of the lateral malleolus (TECH FIG 1).
- Resect the distal section of the fibula. If desired, this can be morselized for bone graft. Retract the peroneal tendons posteriorly and protect them.
- Enter the ankle joint sharply and fully expose it by releasing the lateral ligaments and anterior and posterior capsule.
- Distract the joint using a lamina spreader.
- Remove any remaining cartilage with a curette.
- After removing the cartilage, prepare the joint surface with flexible chisels or a small, low-speed burr. If using a burr, use copious irrigation to avoid thermal necrosis. Burr holes should be just through the subchondral bone and separated by about 3 mm on all sides to avoid weakening or fracture of the cortex.

PREPARATION OF THE SUBTALAR JOINT

- Enter the subtalar joint sharply with release of the lateral ligaments, capsule, and the talocalcaneal intraosseous ligament.
- Maintain distraction of the joint using a lamina spreader.
- Curette the remaining cartilage off the joint surface and prepare the subchondral bone with flexible chisels or a burr as described above.
- If there is significant bone loss or fragmentation of the talus, the tibia may have to be fused directly to the talus.

In this case, the calcaneal articular processes will need to be removed with an osteotome to create a flat surface that will lie flush with the tibial plafond.

Bone graft can be packed into the subtalar and ankle joints. If there is a large bony deficit with substantial loss of limb length, structural graft in the form of iliac crest autograft or femoral head allograft can be used to restore height.

INSERTION OF THE BLADE PLATE

- After preparing the joint surfaces, insert a 90- or 95-degree fixed-angle blade plate for fixation. The use of both an adolescent blade plate and a humeral blade plate has been described. The length of the blade is typically 40 mm. The side plate can range from five to eight holes based on the size of the patient and the surgeon's preference.
- Ensure that the hindfoot is positioned in neutral to 5 degrees of valgus and the ankle is in neutral dorsiflexion and plantarflexion. External rotation should
Remove the drill guide and insert the blade plate over the guidewire using the inserter-extractor handle (TECH FIG 2B). Impact the blade until it is flush with the lateral cortex of the tibia. Rotational control is best achieved by using a slotted hammer.

Contour the plate to the lateral aspect of the tibia and fill the screw holes sequentially. Use 4.5-mm cortical screws proximally and 6.5 mm cancellous screws distally. A single 6.5-mm or 7.3-mm cortical screw can be used to augment the blade plate fixation. Place the screw under fluoroscopic guidance from the calcaneal tuberosity into the anterior tibial cortex at roughly a 60-degree angle.

**PEARLS AND PITFALLS**

**Pearl:** Use a proximal guidewire to maintain sagittal plane alignment.

**Pitfall:** Once the blade engages the calcaneus, the position of the plate proximally cannot be changed. To avoid sagittal plane malalignment (ie, the plate coming off the tibial anteriorly or posteriorly), consider using another guidewire through the most proximal hole of the plate as the blade plate construct is inserted (FIG 4).

**CLOSURE**

- Given the large amount of bleeding cancellous bone exposed during the procedure, a meticulous layered closure should be performed. Further steps that will aid in the prevention of a postoperative hematoma include releasing the tourniquet and assessing hemostasis before closure, the use of drains, and the use of a compression dressing.
POSTOPERATIVE CARE

- Postoperatively, patients are placed in a splint and admitted for 24 hours of intravenous antibiotics.
- After 10 to 14 days, patients return to the office for evaluation of the wound and suture removal. At this visit patients are placed in a non-weight-bearing short-leg cast.
- Patients remain non-weight-bearing in a short-leg cast for 6 to 12 weeks, based on radiographic healing.
- Thereafter, patients are transitioned to a short-leg walking cast or boot and progressive weight bearing is begun.

- The fusion is protected until sufficient clinical and radiographic healing is obtained (FIG 6). A CT scan may be needed to assess the adequacy of the fusion.

OUTCOMES

- A successful outcome is usually the norm for tibiotalocalcaneal fusion.
- Most studies report combined results of different approaches to fusion. In studies examining the use of blade plate fixation exclusively, the reported fusion rates have ranged from 90% to 100%.2,8,10
COMPLICATIONS

- Overall complication rates for tibiotalocalcaneal fusion have been as high as 50% in some series. The most common complications include nonunion, malunion, infection, and neuroma.
- In patients undergoing tibiotalocalcaneal fusion (regardless of fixation technique) the nonunion rate ranges from 0% to 40%. This is most common when there is avascular necrosis of the talus. In this patient population, the nonunion rate has been as high as 89%. Nonunion rates are also significantly higher in smokers and patients with neuroarthropathy (33% to 75%).
- Superficial and deep wound infection can be minimized through the use of appropriate perioperative antibiotics, meticulous soft tissue handling, a layered wound closure, avoidance of hematoma formation, and postoperative elevation.
- Peripheral neuroma of either the sural or superficial peroneal nerves can be minimized by careful incision placement and gentle retraction and soft tissue handling. In patients with neuroarthropathy, there is usually decreased if not absent distal sensation. In these patients, peripheral nerve injury is usually clinically insignificant.

REFERENCES


DEFINITION

- Because of the increased life expectancy of diabetic patients, neuropathic arthropathy is becoming a more prevalent problem.
- Resulting severe ankle and hindfoot deformities frequently are non-braceable. Bearing weight on such deformities can result in abnormal ipsilateral stresses on the knee, leg, ankle, hindfoot, and forefoot, causing ligament laxity, stress fractures, and recurrent ulcerations leading to cellulitis, abscess, and osteomyelitis (FIG 1).
- Before the 1990s, efforts in the reconstruction of these deformities often resulted in a below-knee amputation.
- Reconstructive efforts have included pan-talar and tibiotalocalcaneal fusions. These required an intact talus, adequate vascularity, and no infection. The prevailing feeling was that a fusion through a Charcot joint was impossible. After 1990, new techniques evolved, starting with blade plate fusions and soon followed by rods and Ilizarov techniques. All are important methods of solving these complicated problems.
- Each has its place in treating severe hindfoot and ankle deformity; however, the blade plate offers immediate deformity correction, rigid fixation, and skin closure in patients with talar fragmentation, avascular necrosis, or resorption.
- An additional problem for which the blade plate can be helpful is simultaneous tibiotalar and subtalar traumatic arthritis, frequently caused by talar fractures and untreated varus or valgus adult-acquired hindfoot problems.

PATHOGENESIS

- Most commonly, the severe ankle and hindfoot deformity with talar fragmentation and resorption is seen in diabetic neuropathy. Other causes of Charcot arthropathy include tabes dorsalis, Hansen disease, syringomyelia, alcoholic neuropathy, Charcot-Marie-Tooth disease, lumbar radiculopathy, peripheral nerve lesions, Riley-Day syndrome, renal dialysis, congenital insensitivity to pain, and intra-articular steroid injections. Similar changes on radiographs can be seen in inflammatory arthritis, and in posttraumatic arthritis with talar avascular necrosis (FIG 2).
- Although the exact mechanism of neuropathic arthropathy is unknown, the presence of peripheral neuropathy (autonomic, sensory, and motor) is required.
- The sympathetic nerves supply the small vessels, sweat glands, sebaceous glands, and the erector pilae muscles of the hair follicles. The deficit of autonomic nervous system nerves results in the dry, flaky, warm skin with decreased skin appendages. However, more importantly, the loss of vasomotor tone produces a dramatic increase in the peripheral circulation, with the same effect as a surgical sympathectomy: warmth, vasodilation, and increased blood flow through the involved extremity.
- In the past, medical teaching was that complete anesthesia of the feet and/or legs had to be present for the Charcot joint and ulcerations to occur. However, patients frequently retain some sensation. Sensory neuropathy includes both skin sensations (eg, touch, pain, pressure) and proprioception. Decreased proprioception results in balance and gait difficulties that potentially result in injury from falls or missed steps. These injuries can include wounds, ligament injuries, and fractures. Because of the decreased sensation, injuries can be perceived as minor by patient, doctor, and podiatrist. However, for the diabetic patient, in the face of continued pain and swelling, a Charcot joint should be considered.
- Motor neuropathy involves weakness of extrinsic and intrinsic muscles of the leg and foot. The relative disproportional stronger plantarflexors of the ankle (greater cross-sectional area than anterior muscles) inevitably lead to a tight heel cord. Abnormal stresses of a tight heel cord predispose the foot both to neuropathic ulcers, specifically under the interphalangeal...
joint of the great toe, first metatarsal head, and fifth metatarsal heads, and to tarsometatarsal, Chopart, or hindfoot collapse.

- In the hindfoot, the tight heel cord is also responsible for increased stress on the talus, by not allowing normal rotation of the tibia over the talus. The tibia, instead of rotating over the talus, crushes down into the talar body, fragmenting the talus by the so-called nutcracker effect. This devastating deformity is usually not braceable and often includes a large ulcer at the tip of the medial malleolus (FIG 3).

NATURAL HISTORY

- Eichenholtz described three stages of development for the Charcot joint, and to this Shibata added the stage 0.
  - Stage 0 (Shibata): Clinical signs of pain or swelling similar to what is seen in ankle and midfoot sprains. An overuse-type syndrome or minor fracture may preclude stage I. The presence of calcified vessels on a radiograph should arouse suspicion.
  - Stage I: In this “fragmentation” stage, clinically the joint appears hot, red, and swollen. Fragmentation, dissolution, or dislocation can appear on radiographs.
  - Stage II: The “coalescence” stage begins the reparative process with reduction of clinical signs. There may be residual inflammation, but without the severe warmth and edema. New bone formation appears on radiographs.
  - Stage III: In the “consolidation” stage the joint usually heals enlarged and deformed. Skin temperature and edema eventually decrease to normal. Radiographs show sclerotic bone formation with smoothing of fracture fragments, and fibrous ankylosis. The fixed deformity is usually associated with bony prominences. In the hindfoot, the patient may walk on the medial malleolus.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Most cases of neuropathic arthropathy occur in patients with type 2 diabetes mellitus. Typically, the patients are obese, and many do not realize they have diabetes mellitus. Ten percent of these newly diagnosed patients will already have peripheral vascular disease, cardiovascular disease, cerebrovascular disease, and retinopathy. Many who are aware of their diabetes maintain poor control of their glucose level due to lack of information or lack of compliance.
- The diabetic with peripheral neuropathy typically has dry, flaky, hairless skin distally. The extremity may exhibit swelling, redness, and warmth. Patients complain of dysesthesia (eg, stinging, burning, cramping) rather than anesthesia. Stage 0 patients may complain of sprain-type pain and deep joint or deep bone pain, with or without a clear history of injury. Early, there may be little if any swelling. Later, as stage I approaches, swelling occurs. As the peripheral motor neuropathy progresses, Achilles contracture occurs. The appearance of a high arch in the foot actually may represent intrinsic muscle wasting. Early on before collapse occurs, the foot appearance is similar to that seen in Charcot-Marie-Tooth disease. Pulses in the extremity are usually present (FIG 4).
The examiner must rule out infection, especially in a patient with ulceration where deep infection (ie, abscess or osteomyelitis) must be considered. When in doubt, the physician should look at the patient: patients with osteomyelitis look and feel sick. Typically, if a Charcot extremity is elevated above the patient’s heart, there is a decrease in redness and swelling after about 10 to 15 minutes (Brodsky test) compared with the infected extremity, which will remain unchanged. If there is no break in skin integrity, infection is unlikely.

The physical examination should include:
- A comprehensive neurologic evaluation using Semmes-Weinstein monofilament test, which indicates protective sensation
- A vascular examination: Palpating pulses may be challenging with deformity. The threshold should be low to use a Doppler ultrasound or obtain noninvasive vascular studies.
- Skin condition examination: The skin should be in satisfactory condition, to allow deformity correction. Even with complete or partial talocalcaneal fusion, correcting severe valgus deformity via lateral approach is risky. If the skin is suspect in valgus deformity and the heel is realigned, then skin perfusion may be compromised.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographs showing calcified vessels may be an early warning of impending neuropathic problems. In fact, the surgeon must beware of a routine ankle fracture that has undergone an open reduction and internal fixation if calcified vessels are present on the radiograph. Often, the fracture falls apart and metal breaks with early range of motion and weight bearing. It is best to treat these two to three times longer with non-weight bearing and immobilization (FIG 5).
- Often, Charcot joints are confused with infection. Monitoring systemic clinical and laboratory markers of infection is important. However, a bone biopsy with a large-bore needle under fluoroscopy can quickly rule out osteomyelitis.

DIFFERENTIAL DIAGNOSIS
- Posttraumatic arthritis
- Inflammatory arthritides
- Charcot neuroarthropathy

NONOPERATIVE MANAGEMENT
- Goals of treatment are to achieve the third stage of bony healing, with as little resultant deformity as possible, and to minimize and treat soft tissue breakdown and ulcerations.

- A high index of suspicion is necessary to initiate treatment while the patient is still in stage 0. Patient compliance may be an issue. Risk factors for noncompliance include age, obesity, poor proprioception, and debilitation.
- The Charcot joint should be immobilized and elevated to reduce swelling. No weight bearing should be allowed until swelling and redness are resolved. The gold standard is total-contact casting (TCC) that should be changed weekly until stage III is reached. A Charcot rehabilitation orthotic walker (CROW) can be used once the limb is in stage II. At stage III, a custom ankle-foot orthosis (AFO) accommodates the resultant deformity.
- However, if the deformity is great, it may not be braceable. The brace may cause more soft tissue breakdown. Surgery becomes necessary to make the extremity braceable. The amount of talar body fragmentation and resorption with ensuing varus or valgus varies. Ulceration at the tip of the medial malleolus or lateral malleolus warrants a trial of nonoperative CROW bracing or TCC. Ideally, if wound healing can be accomplished and maintained, nonoperative management can be continued for the hindfoot. This most likely will be a CROW or molded solid ankle bivalved open AFO and a rocker shoe. However, most of these deformities are so severe that salvage surgery becomes necessary in an effort to save the extremity.

SURGICAL MANAGEMENT
- The surgical goal of correcting the alignment to make the foot and leg braceable can be achieved with a fibrous union, although bony union is preferable.
- There are four indications:
  - Non-braceable deformity
  - Chronic ulceration secondary to pressure from deformity not responding to bracing
  - Adequate circulation (usually not a problem)
  - Alternative to amputation

Preoperative Planning
- Patients must commit to 5 to 8 months of non-weight-bearing and must understand that complications can occur, such as incomplete healing, infection, hardware failure, and loss of correction. Amputation must be accepted as a possible consequence of failure of the procedure. Medical clearance should be obtained from the patient’s internist or diabetologist. Emphasis should be that the patient must have strict control of blood glucose both preoperatively and in the postoperative healing period. Nutrition is, therefore, important.
- If there is a question of adequate circulation, even if pulses are present, a toe-level Doppler index or transcutaneous oxygen index at the first web space should be obtained; a reading greater than 0.45 predicts a 96% healing rate. Successful revascularization by a vascular surgeon may be necessary to reach the appropriate pressure.
- The presence of an ulcer is not a contradiction to this salvage as long as it is clean. If there is a question of infection, joint aspiration and talar biopsy should be acquired before proceeding.
- Absolute contraindications to hindfoot salvage include a patient who smokes, a patient who cannot comply with postoperative recommendations, or the presence of a deep abscess or osteomyelitis. A good indicator of patient compliance can be obtained during preoperative immobilization in a non-weight-bearing cast or CROW.

FIG 5 • Calcified vessels commonly seen radiographically in diabetics.
Positioning

- The patient is placed in the lateral decubitus position with operative side up. Imaging should be checked to ensure the ability to obtain AP and lateral views of the ankle and an axial view of the hindfoot.
- The skin is prepared with tincture of iodine and alcohol solution, as Betadine paint prevents Tegaderm from sticking and effectively marking the skin incision.
- The extremity is draped above the knee. The surgeon must make sure that the anterior superior iliac spine can be palpated through the drapes.
- Ulcers are covered with Tegaderm to isolate them from the rest of the surgical field (FIG 6).

INCISION

- Make a curvilinear incision over the distal 14 cm of the fibula and extend the incision over the lateral calcaneus, curving anterior.
- Try to incorporate previous incisions when possible if they are less than 2 years old.
- Developing a full-thickness soft tissue flap and retracting with skin hooks are particularly important in this patient population.
  - In patients with neuropathy, sacrificing the sural nerve as it crosses the field helps avoid excessive dissection and skin retraction.
  - A longer incision can be made to reduce skin retraction forces.
- Strip only the amount of periosteum needed to expose bone for cuts and fixation (TECH FIG 1).

BONY EXCISION

- Once the fibula is exposed, the distal 10 to 14 cm of fibula may be excised using an oscillating saw. The fibula will serve as autograft. Take care to avoid damaging the perforating peroneal or anterior tibial arteries during the dissection.
- Excise the remaining talar body fragments. Preserve the remaining talar head and neck (TECH FIG 2).
BONE GRAFT PREPARATION

- If the fibula is associated with any ulcerations, autograft from other sites or allograft can be used.
- Use a bone mill to morselize the fibula to 4-mm pieces.
  - If necessary, the autograft harvested from the fibula can be mixed with 4-mm cancellous chips.
- Combine the autograft and allograft combination with tobramycin (400 mg) and vancomycin (500 mg) powder.
- The antibiotic bone graft mixture is to be packed between the bony surfaces and to the anterior, posterior, medial, and lateral aspects of the tibia and calcaneus to facilitate an extra-articular fusion in addition to the intra-articular fusion.
- Tobramycin and vancomycin levels are not drawn as they do not reach systemic therapeutic levels (TECH FIG 3).

TECH FIG 3 • Our routine allograft bone for tibiocalcaneal arthrodesis. Note the addition of antibiotic powder to the graft (we typically use vancomycin and tobramycin).

PREPARING ARTICULAR SURFACES

- Drennen’s principles for fusing neuropathic joints
  - Remove all cartilage and debris.
  - Remove all sclerotic bone down to bleeding, well-vascularized bone.
  - Fashion congruent surfaces for apposition.
  - Rigid fixation
  - Complete débridement of all synovial and scar tissue
- Cut the distal tibial surface flat with an oscillating saw and contour it with a large burr. Take care to maintain as much length as possible. The medial malleolus can be denuded of articular cartilage with a curette and a burr (TECH FIG 4).
- The anterior tibia will sit against the remaining talar neck and head. It can be slightly flattened with a saw or burr. Denude the calcaneus articular surfaces of cartilage, maintaining as much subchondral bone as possible. The posterior facet may need slight flattening so the tibia will sit stable on the calcaneus with the anterior tibia resting against the talar neck.
- Drill surfaces with a 3.2-mm bit to make holes in the subchondral bone of the calcaneus, the neck of the talus, the anterior tibia, and the pilon to provide channels for revascularization. Surfaces should be stable but not necessarily flat, as gaps can be filled with bone graft.

TECH FIG 4 • Sawbones model demonstrating preparation of the arthrodesis site. A. Tibial plafond preparation, including medial malleolus. B. Calcaneal preparation. C. Preparation of the anterior tibia to include an arthrodesis to residual talar head and neck.
STABILIZATION

- The deformity should be reduced so that the tibia sits flat on the calcaneus and the talar neck is flush to the anterior tibia. The foot should be plantigrade, at 90 degrees with respect to the leg and aligned with respect to the anterior superior iliac spine, anterior tibia tubercle, and second toe. The hindfoot should be placed in 5 degrees of valgus, with 5 to 10 degrees of external rotation of the foot.

- Use AO guide pins to hold the reduction. Place one 2.8-mm guide pin from the anterior distal tibial metaphysis into the posterior calcaneus. Place one 2.8-mm guide pin from the posterolateral distal tibial metaphysis into the talar head and neck. This pin may be advanced into the navicular if more purchase is needed. The pins serve as guides for 7.3-mm AO screws once the plate is fixed.

- Preparing for placement of the pediatric AO condylar blade plate
  - Place a pediatric blade plate laterally on the calcaneus near the posterior facet in line with the tibia. To do this, select the entry point for the blade plate at the junction of the lower and middle thirds of the calcaneus, at least 1 cm above the plantar cortex of the calcaneus.
  - Although rarely needed, the plate can be contoured to the lateral tibia with the table plate bender.
  - The 95-degree-angled pediatric condylar blade plate (PCBP) has a blade with a T profile.
  - The plate portion has varying lengths depending on the length needed to span. We have selected the five-hole plate with a 40-mm blade to traverse the width of the calcaneus. A longer plate may be necessary in fusions where the talus body is preserved (ankle and subtalar fusions) (TECH FIG 5A).

- Hold the alignment of the tibia on the calcaneus and the anterior tibia on the neck of the talus with the 2.8-mm guide pins for the cannulated 6.5- or 7.3-mm screws. Select an area at the lateral calcaneus at the junction of the middle and distal thirds, no less than 1 cm above the plantar cortex of the calcaneus and in line with the lateral tibia shaft. It is important that the plantar cortex of the calcaneus remain intact.

- Before the angled blade plate can be inserted into bone, a channel must be precut with the T profile seating chisel for the PCBP.

- To do this, slide the base of the condylar blade guide (this subtends an angle of 85 degrees for the 95-degree angle of the PCBP) in the slot above the triple drill guide. Place this so that the 85-degree-angled plate guide portion of the condylar blade guide aligns with the tibia and the three-hole drill guide sets at the lateral calcaneus preselected entry point for the blade.

- Drill three holes with the 4.5-mm drill bit no more than 1 cm deep.

- Use a router or rongeur to convert the drill holes into a slit.

- To receive the shoulder of the PCBP, bevel the slit hole proximally a few millimeters. This prevents shattering of the lateral calcaneal cortex.

- To cut the channel into the calcaneus, slide the seating chisel into the slot of the seating chisel guide with the adjustable flap to go proximally and the T profile

TECH FIG 5 • A. Typical fixed-angle blade plate used for tibiocalcaneal arthrodesis. B. Chisel used to create slot in calcaneus to insert blade plate. C. Compression device for the laterally applied blade plate. (continued)
distally toward the plantar calcaneus. The angle between the flap and the body of the seating chisel guide may be set with a triangular guide on the PCBP and maintained by tightening the screw with a screwdriver (TECH FIG 5B).

- This angle should be 85 degrees for the 95-degree PCBP (remember, this subtends an angle of 95 degrees with the tibia shaft). Now align the flap with the tibia and the chisel in the slot. The flap should align flat with the lateral tibia and the chisel handle 90 degrees to the lateral wall of the calcaneus (TECH FIG 5C).

- Hammer the chisel several centimeters and withdraw until the medial cortex is penetrated.

- Using the plate holder, insert the PCBP into the pre-cut channel to within 5 mm.

- Remove the plate holder and use the impactor to drive and seat the plate into the bone.

- At this point, bone graft can be added to fill voids between the tibia and calcaneus and the anterior tibia and neck of the talus.

- Fix the articulated tension device to the tibia shaft and apply axial tension to mid-green.

- Avoid overcompression with the tension device so that the calcaneus is not pulled into too much valgus. Compression can also be achieved with the plate's dynamic compression holes.

- Fix the plate to the tibia with 4.5-mm cortical screws (6.5-mm cancellous screws may be needed in the distal tibia depending on screw purchase).

- Use the previously placed 2.8-mm guide pins for placing 6.5- or 7.3-mm screws for the anterior tibia into the neck and head of the talus (navicular for more purchase).

- A screw is placed from the anterior tibia into the talar calcaneus for a more rigid construct (TECH FIG 5D,E).

**FIXATION**

- Finally, use the guide pins to place a 6.5- or 7.3-mm cannulated cancellous screw from the posterior tibia into the head of the talus to increase rigid fixation and further control rotation and from the anterior tibia into the tuberosity of the calcaneus (TECH FIG 6).
CLOSURE

- Close the wound in layers with 2-0 and 3-0 absorbable sutures.
- The skin may be closed loosely with 4-0 nylon or skin staples.
- If skin closure is tight, peroneal tendons may be excised to facilitate closure. However, with a curvilinear incision this will rarely be needed.

- The wound is dressed with Adaptic soaked in Betadine solution followed by fluff gauze and a well-padded cast applied from the tips of the toes to the tibial tubercle.

TIBIOCALCANEAL ARTHRODESIS (COURTESY OF MARK E. EASLEY, MD)

- Patient history and imaging studies
  - 60-year-old patient with avascular necrosis of talus and a 2-year history of pain with weight bearing
  - Walks with a severe limp and has failed bracing, including patellar-tendon bearing brace (TECH FIG 7A)

- Imaging studies
  - Initial review of AP and lateral radiographs suggests that talar anatomy is relatively well preserved; however, closer inspection of AP radiograph demonstrates some potential lucency/irregularity in

Chapter 83  TIBIOCALCANEAL ARTHRODESIS USING BLADE PLATE FIXATION 4187

- talar body, and lateral radiograph reveals some talar body collapse and subtalar incongruity (TECH FIG 7B, C).
  - CT scan shows fatigue fractures through avascular talar body (TECH FIG 7D,E).

Positioning and surgical approach
- Patient in lateral decubitus position, supported with a beanbag
- Lateral transfibular approach
- Fibula may be sacrificed and used as a bone graft in these patients since they are generally not candidates for total ankle arthroplasty, so fibular preservation is not critical.
- Exposure of lateral ankle and subtalar joints. Note the fragmentation of the inferior surface of the talar body (TECH FIG 8).

Extraction of residual talar body
- It is always a difficult decision to extract a talar body, especially when the anatomy is relatively well preserved, at least on initial inspection.
- However, this talar body was completely avascular. Note the unhealthy appearance of the talar body (TECH FIG 9A).
- The talar body is extracted from the joint, in this case using a chisel. Note the fracture in the medial aspect of the talus that was revealed when the avascular lateral portion of talus is removed (TECH FIG 9B,C).

- Tibial, talar head, and calcaneal preparation
- In addition to comprehensive removal of residual tibial plafond cartilage and penetration of the subchondral bone:
  - Prepare the anterior distal tibia to promote healing of the viable talar head to the distal anterior tibia (TECH FIG 10A).
  - Likewise, the talar neck must be prepared to promote fusion to the tibia.


TECH FIG 8 • Lateral approach to ankle and subtalar joint after distal fibular resection.
In our experience, a medial malleolar osteotomy is necessary to allow the tibia to collapse to the calcaneal posterior facet. Even if structural autograft or allograft is introduced, then some of the medial malleolus should be scalloped out to allow better positioning of the allograft (TECH FIG 10B).

Finally, the posterior facet of the calcaneus must also be prepared.

Some degree of distal tibial and dorsal calcaneal contouring is necessary to optimize the match of these two noncongruent surfaces. Morselized fibular bone graft and cancellous allograft chips serve to fill any voids, but some contact between the tibia and the calcaneus or between the tibia, structural graft, and calcaneus is necessary.

Initial positioning and provisional fixation

Alignment

- Neutral dorsiflexion–plantarflexion, with a plantigrade foot
- Slight heel valgus. If slight (physiologic) heel valgus is to be achieved and the lateral blade plate is compressed, then we recommend initially setting the heel in neutral position so that when compression is applied, the heel then aligns into slight valgus. If the heel is initially set in physiologic valgus and compression is placed on the lateral plate, then excessive heel valgus will result.

Rotation. Ideally, rotation is equal to that of the contralateral extremity. Internal rotation must be avoided, but likewise, excessive external rotation is not well tolerated. Since the extremity will tend to be slightly shorter than the contralateral leg, aligning the second ray of the foot with the anterior tibial crest is appropriate and allows for adequate clearance with a heel-to-toe gait.

Sagittal plane position. We ensure that the talar head and neck contacts the prepared anterior distal tibia. A foot forwardness position must be avoided; the majority of the calcaneus and all of the calcaneal tuberosity should be posterior to the tibia. Otherwise, the foot will be too anterior, necessitating that the patient vault over the foot to ambulate, which creates considerable mechanical disadvantage.

TECH FIG 10 • A. Preparation of the anterior distal tibia to promote fusion between the distal tibia and the head and neck of the residual talus. B. Partial resection of the medial malleolus to facilitate bony apposition of the tibia and calcaneus and potentially improve the position of a structural graft if it were used.
Chapter 83  TIBIOCALCANEAL ARTHRODESIS USING BLADE PLATE FIXATION

Provisional fixation
- Once this alignment is achieved, the construct should be provisionally pinned. Often a guide pin from the calcaneus to the anterior tibia that will then serve as the trajectory for one of the permanent screws is ideal. Also, an axial pin from the plantar calcaneus into the tibia is effective; however, it may interfere with the blade of the blade plate.

Fluoroscopic confirmation
- Be sure the position is confirmed in all planes and that bony contact is satisfactory at the arthrodesis site or sites.

Bone graft
- At this point, before permanent fixation and compression, we routinely add bone graft to fill any voids at the arthrodesis site.

Permanent fixation
- Positioning the blade plate
  - Since the blade plate is a fixed-angle device, we routinely place it backwards on the lateral tibia and calcaneus (TECH FIG 11A–C).
  - There is often a ridge of bone on the lateral tibia at the former incisura; this bone needs to be resected.

Occasionally a small relief area needs to be created in the calcaneus for the blade to sit flush on the lateral calcaneus.
- We attempt to preserve the peroneal tendons so that they still function on the midfoot, but if they interfere, then they may be transected without appreciation of functional deficit in tibiocalcaneal arthrodesis.

Provisionally pin the blade to the lateral tibia and talus.
- Place the pins so that the blade is optimally positioned on the tibia and calcaneus and so that the blade can easily be removed, turned to the correct orientation, and impacted.
- Obtain fluoroscopic confirmation that the blade will be in the optimal position, both in the lateral and AP planes (TECH FIG 11D,E).

Reverse the blade and impact it on the calcaneus, using the pins to guide the blade into the optimal position.
- Once fully seated, remove the guide pins and apply compression.
- If the heel was set in neutral to begin, then the heel will end up in physiologic valgus.
Secure the plate to the tibia with several cortical or locking screws, depending on the implant used (TECH FIG 11F).

We routinely augment the blade plate fixation with two screws.

One screw is directed from the plantar calcaneal tuberosity to the anterior tibia (TECH FIG 11G).

The second screw, from the posterior tibia to the center of the talar head, lags the talar head to the prepared anterior distal tibial surface (TECH FIG 11H). An AP view of the foot confirms that the guide pin is in the center of the talar head.

Obtain fluoroscopic confirmation of the construct in the AP, mortise, and lateral planes.

Bone graft on the posterior tibia and calcaneus. In our opinion, one key to successful fusion is raising an osteoperiosteal flap on the posterior distal tibia and dorsal calcaneus and densely packing bone graft chips along the posterior construct, essentially creating a “flying buttress” effect.

Follow-up (3 years)

Patient is ambulating comfortably without an assistive device; only a slight limp is appreciable.

She was issued a brace with a small lift but does not routinely wear it.

She is far more functional than preoperatively.

Radiographs demonstrate solid ankle and hindfoot fusion with near-physiologic alignment (TECH FIG 12).
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>PEARL</th>
<th>PITFALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arthrodesis of residual talar head and neck to the anterior distal tibia</td>
<td>This will stabilize the construct and creates a more physiologic transition from fused hindfoot to supple midfoot.</td>
</tr>
<tr>
<td>Initial position with heel in neutral varus–valgus position</td>
<td>If the heel is positioned in physiologic valgus before compression is applied through the blade plate, then excessive valgus will result.</td>
</tr>
<tr>
<td>Bone graft the posterior tibia and dorsal calcaneus</td>
<td>Create an osteoperiosteal flap on the posterior distal tibia and dorsal calcaneus to densely pack bone graft that should incorporate to create a “flying buttress” of bone that greatly increases the surface area of the arthrodesis.</td>
</tr>
<tr>
<td>Avoid anterior translation of the foot relative to the tibia</td>
<td>Be sure the foot is properly positioned under the tibia; if not, the lower extremity will be at a mechanical disadvantage.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Intravenous antibiotics are continued for 2 to 3 days or until the patient is discharged.
- The cast should be changed first at 24 to 48 hours, then at 2- to 4-week intervals until the wound has healed.
- A CROW is used after this for non–weight-bearing immobilization for 4 to 6 months and weight bearing for 3 to 4 additional months and swelling has subsided.
- Using a CROW instead of cast changes postoperatively allows patients to bathe around 2 to 4 weeks postoperatively.
- Once the fusion is well healed, the patient may be changed to a bivalved AFO with a rocker sole.
- Weight bearing is started around the fourth to fifth month after there is radiographic evidence of healing of the fusion.
- Starting at 25 pounds, weight is increased by 25 pounds at 1- to 2-week intervals.
- Once 75% of the patient’s weight is reached, full weight bearing is allowed in the CROW.
- Limb-length discrepancy can be corrected using a buildup for the rocker sole.
- A solid ankle cushion heel (SACH) can be added to dampen heel stride and simulate plantar fixation.
- The patient should be braced for life in a bivalved AFO that fits in a shoe.

OUTCOMES

- Fusion occurs in 93% of cases at an average of 16 weeks (range 12 to 18). Preoperative ulcerations heal after the precipitating deformity has been corrected.
- Tibial stress fractures occurring at the proximal end of the blade plate (the reason for bracing for life) can be prevented by placing the patient in a bivalved AFO. The anterior shell of the AFO prevents the moment or progression force of the tibia over the foot, thus reducing the chance of fracture.

REFERENCES

DEFINITION

- Talus fractures are high-energy fractures that can have traumatic bone loss, avascular necrosis (AVN), and infected nonunion as the outcome of the injury.\(^1\),\(^3\),\(^6\),\(^16\),\(^23\)
- Acute talar bone loss and subsequent AVN and infection will present a cascade of hindfoot reconstruction problems (FIG 1).
- Excision of the talus causes 3 to 4 cm of leg-length discrepancy (FIG 2). This defect can be reconstructed with internal fixation and bone grafting to maintain leg length.\(^17\)
- Traumatic loss of the talus or AVN is also treated with tibial calcaneal arthrodesis using internal fixation without reconstruction of leg length.\(^4\),\(^12\),\(^15\),\(^19\)
- Replacement of the traumatic extrusion of the talus has had a high level of infection in case studies.\(^6\),\(^16\)
- In recent case series, there has been success in reimplanting extruded talus fractures without a high incidence of infection.\(^2\),\(^8\),\(^20\)
- If there is severe comminution of the talus, contamination from extrusion, infection, or a compromised soft tissue envelope, massive bone grafting and internal fixation would have a high risk of failure and infection. Half-pin fixators with a calcaneal tibial Steinmann pin have had a poor rate of arthrodesis.\(^18\)
- Circular fixation provides an alternative to amputation in these complex cases.\(^3\),\(^10\),\(^11\),\(^22\)
- Because the pins and wires used in circular fixation are not in the zone of injury, a carefully débrided arthrodesis site can be compressed to achieve arthrodesis without foreign body internal fixation.
- Wounds can heal by secondary intention over many weeks and the foot can be salvaged.
- For patients with appropriate physiology, a proximal leg lengthening can be added to the reconstruction to equalize leg length.
- The reconstructed extremity requires shoe modifications to improve gait.
- With a well-aligned tibial calcaneal arthrodesis, the patient may participate in an active life without the problems and expense of a below-knee prosthesis.

ANATOMY

- The talus has precarious blood supply because approximately two thirds of the surface area is covered by articular cartilage.
- The ankle articulation, talar navicular joint and the three facets of the subtalar joint leave limited areas on the neck of the talus and inferior surface for penetration of blood vessels into the dense bone of the talus.\(^\)
- The talus has no muscular attachments and is surrounded by the joint capsules of the multiple joints and a thin layer of soft tissue with bypassing tendons, vessels, and nerves.
- Open fracture dislocations of the talus are high energy injuries that cause disruption of the blood supply by dislocation, ejection of fragments, and fracture through the neck of the talus. This causes avascular necrosis of the body or entire talus, which is susceptible to infection (see Fig 1).
PATHOGENESIS
- High-energy ankle trauma
- Postoperative infection of open reduction and internal fixation of talus fractures
- Postoperative infection of ankle arthrodesis and ankle replacement

PATIENT HISTORY AND PHYSICAL FINDINGS
- Painful ankle with swelling and local inflammation
- Ankylosis of the hindfoot and ankle
- Shortening of the extremity
- A draining sinus indicates a deep infection.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- An ankle series of radiographs will reveal the extent of the bone loss, the extent of AVN, and the location of internal fixation hardware in the talus and plafond (FIG 3).

DIFFERENTIAL DIAGNOSIS
- Charcot joint

NONOPERATIVE MANAGEMENT
- The patient may use a cane and ankle brace to improve gait.
- There will be chronic pain with AVN of the talus, infection, or traumatic ejection of the talus.
- There is no conservative treatment for an infected nonunion of the talus.
- Treatment with oral or intravenous antibiotics will only suppress the infection.

SURGICAL MANAGEMENT
Preoperative Planning
- Infection of the talus is treated with aggressive débridement.
- Oral antibiotics should be discontinued 2 weeks before the débridement to obtain accurate cultures.
- If there is infection and drainage that requires emergent débridement, the patient is taken to surgery and deep cultures are obtained before starting intravenous antibiotics.
- It is essential to identify the infecting organism.
- Mycobacterium, yeast, and aerobic organisms may be the source of an infection, and cultures should be obtained.
- The organisms cultured in our series include methicillin-resistant *Staphylococcus aureus*, *Enterobacter cloacae*, *Escherichia coli*, *Staphylococcus aureus*, streptococcus (non-hemolytic), *Alcaligenes xylosoxidans*, and *Pseudomonas aeruginosa*.

DÉBRIDEMENT OF INFECTION
- Use an anterior medial approach located medial to the anterior tibial tendon to explore the talus (TECH FIG 1A).
- Before making the incision, elevate the leg for 3 minutes to drain blood from the extremity.
- Do not use an elastic compression bandage when there is a deep infection.
- Use a tourniquet during the initial excision of bone. Without a tourniquet, the field would be flooded with blood, obscuring the appearance of the infected bone.
- Carefully explore the infected talus.
- There may be local bone erosion of the talus, plafond, and malleoli from the chronic infection in the joint.
- A white blood cell count, erythrocyte sedimentation rate, and C-reactive protein study are screening tests that will indicate the possibility of a deep infection.
- Aspiration of the ankle joint under fluoroscopic guidance is indicated if there is suspicion of an infection.
- CT scanning will define the fragmentation of the talus and may reveal erosions of the plafond and malleoli compatible with infection.
- MRI will have diffuse signals caused by the fracture and inflammation that will provide little useful data in making the diagnosis.
- The necrotic bone will have a discolored avascular consistency.
- Necrotic bone tends to have a brittle consistency compared to viable bone.
- Excise the bone in small fragments, carefully observing for vascularity and the transition from necrotic infected bone to viable bone.
- The preoperative radiographic evaluation may not clearly identify the extent of infection.
- The talar head may be necrotic without the appearance of AVN on the radiograph.

FIG 3 • A,B. Anterior and lateral x-ray of ankle with infected nonunion of talus. The ankle had a draining sinus. The talus body is avascular and the talar head has bone lysis around the two fixation screws. The plafond has erosion and destruction of the cartilage. There is reactive bone on the medial malleolus compatible with infection.
Remove all hardware as the talus is débrided.
Take cultures from an area clearly involved with purulence.
The infection and necrotic bone may be limited to the body of the talus, or the infection may have spread to the head of the talus, requiring excision of the entire talus (TECH FIG 1B).
There may be a posteromedial section of the talus that is viable bone, but it is not large enough to be used for a pantalar arthrodesis.
Once all necrotic bone is removed, lavage the joint with low-pressure saline and deflate the tourniquet.7
Viable bone will have punctate bleeding.
If the margin of the bone resection does not bleed, excise the bone until bleeding is encountered.
This may lead to excision of the talar head.
The tibial plafond can have invasion of infection and require removal of the joint surface and metaphysis for several centimeters (TECH FIG 1C).

**Antibiotic Beads**

Antibiotic beads are manufactured on the back table.
The beads should have a small diameter (7 mm) to allow complete filling of the irregular volume created by the excision at the necrotic bone.
2.4 grams of tobramycin powder is dry mixed with 1.0 gram of vancomycin and crushed with the rounded end of a Cobb elevator until there is a fine powder.
The antibiotics are dry mixed with 20 grams of methylmethacrylate cement before adding the liquid monomer.
Using this large amount of antibiotics causes the cement to mix poorly, and it must be mashed into a paste before making the beads.
The cement is rolled into long 1-cm cylinders and cut into small pieces, which will form small-diameter beads.
The beads are formed and placed on a number 2 nylon suture that has had the heavy needle straightened.
Fifteen to 20 minutes of drying time is needed for the beads.
Once the beads have cooled, they are carefully packed into the wound to fill all of the space created by the talus excision (TECH FIG 1C).
The beads can be divided into two strings.
A half string usually fills the defect.
The remaining beads are placed in a sterile container for repeat débridement if needed.

**Wound Closure**

Close the wound with 2-0 nylon.
Because of the thorough débridement, the wound can be closed primarily.
Copious postoperative hemorrhage will drain through the single-layer closure.
If the wound is left open, the edges will retract and a large open wound will develop that will take weeks to months to heal by secondary intention.
If the infection was virulent, the patient is returned to surgery 24 to 48 hours later for a repeat débridement and bead exchange.
The fibula is not excised at this time.
With beads filling the defect and the fibula intact, the extremity is placed in a splint or fracture boot.

**Postoperative Care**

Broad-spectrum antibiotics that cover methicillin-resistant *S. aureus* and gram-negative rods are administered until the cultures have identified the infecting organism.
The extremity and surgical wound are examined daily.
If the wound does not rapidly improve, a second débridement is indicated.
After a week of intravenous antibiotics, the ankle is ready for tibial calcaneal arthrodesis.
Extending the intravenous antibiotic course for 2 to 3 weeks and further observation may be indicated if the condition of the extremity requires further time to be ready for surgery.
TIBIAL CALCANEAL ARTHRODESIS

- Technically, the most difficult aspect of the surgery is fitting the concave surface of the plafond to the asymmetric surface to the posterior facet of the calcaneus, anterior calcaneus, and neck of the talus or the navicular (TECH FIG 2A).

- Cut the bone away in small shavings, with multiple trial fittings until the plafond fits securely into the calcaneus and talus or navicular.

- Approach the plafond and calcaneus from the lateral and medial sides of the ankle.

**TECH FIG 2**

A. Fitting the incongruent surfaces of the tibial plafond to the calcaneus and talar neck or navicular requires craftsmanship. The osteotomy cuts are made with small cuttings until a stable compression surface is created. B. The anterior plafond is cut to align with the talar neck when the talar head is viable (white arrow). The posterior plafond osteotomy requires an oblique osteotomy to fit the posterior facet of the calcaneus (striated arrow). C. The anterior prominence of the tibial plafond is not removed when the talar head has been excised (black arrow). The anterior cortex is prepared to bleeding bone. The bone resection of the posterior plafond is shaped to fit the posterior facet (gray arrow). The resection of the posterior plafond is less because the tibia is located anteriorly with the talar head excised. The anterior process of the calcaneus is leveled to allow the tibia to compress onto the calcaneus. D. An inferior-to-superior Steinmann pin is placed to align the calcaneus with the tibial shaft after the arthrodesis osteotomies have been completed (black arrow). One or two Steinmann pins are placed from posterolateral through the plafond into the head of the talus to improve stability of the fixation if the talar head is preserved in the reconstruction. E. Acute shortening causes the soft tissues to bulge in the horizontal plane. After the calcaneal tibial pin is in place, the wounds can be closed with the extremity distracted. The tibia is compressed to the calcaneus after closure. Shortening causes distortion of the blood vessels crossing the ankle. Vascular flow must be carefully monitored after shortening. F. Monofocal tibial calcaneal talar head arthrodesis circular fixator. The frame consists of a double-ring fixation block and a foot fixation ring. The fixator is used to compress the arthrodesis. This illustration represents reconstruction of a talus with a viable talar head. G. Bifocal tibial calcaneal navicular arthrodesis circular fixator. The frame incorporates a proximal 5/8-full ring block and corticotomy to combine proximal lengthening with distal compression. The illustration depicts reconstruction after complete excision of the talus.
Retain the lateral malleolus.
Excise the lateral malleolus through a lateral incision and perform an osteotomy 5 to 6 cm proximal with an oblique cut superior to lateral to inferior medial.
Carefully elevate the fascia overlying the lateral malleolus from the surface.
This fascia provides a deep closure of the lateral tissues after completion of the osteotomy.
The lateral approach exposes the posterior facet of the calcaneus, lateral calcaneus, and anterior process.
Do not extend the vertical incision past the level of the peroneal tendons to prevent injury to the sural nerve.
The anterior medial approach exposes the navicular, talus neck, and medial facets of the calcaneus.
Evaluate the plafond and posterior facets of the calcaneus.
If the posterior facet is intact, excise the cartilage and expose the subchondral bone to bleeding bone.
Debride the medial facet of cartilage and level the facet with the middle and anterior calcaneus.
Cut the plafond at an angle to match the posterior facet and remove the cartilage from the central plafond (TECH FIG 2B, C).
If the talar neck is viable, cut the anterior plafond away to match the plane of the talar neck and flatten the undersurface of the anterior plafond to march the contour of the middle and anterior calcaneus (Tech Fig 2B).
Cut away small amounts of bone from the tibia and calcaneus until there is a good fit between the tibia and calcaneus.
Assess the alignment of the calcaneus with the tibia.
With the tibia compressed onto the calcaneus, the sole of the foot and heel should be in a foot-flat position.
The foot should be rotated straight forward or in slight external rotation.
Equinus must be avoided.
Neutral plantarflexion and slight dorsiflexion are functional positions.
If the arthrodesis is in equinus, the patient must wear shoes with a heel wedge to accommodate this malposition.
The osteotomies of the tibia plafond and calcaneus must be fitted so that when the tibia is compressed onto the calcaneus, the fit of the osteotomy forces correct alignment of the foot.
If the osteotomies are not correct, the compression applied by the circular fixation will malalign the arthrodesis.
The bone cuts of the anterior plafond are modified if the talar head has been excised because of infection (Tech Fig 2C).
Denude the navicular of cartilage to bleeding bone.
Shape the bone contour of the anterior plafond to match the navicular concave surface.
Flatten the anterior inferior plafond to fit the anterior calcaneus.
The tibia is located in an anterior position toward the midfoot compared to the arthrodesis position if the talus head is present.
Because of this anterior position, the osteotomy of the posterior plafond may require less bone resection.
Always align the plafond over the calcaneus and slowly cut away bone until there is a good fit of the bone surfaces.
After completing the osteotomies, copiously lavage the operative field with low-pressure bulb irrigation to remove debris before closure.
The use of high-pressure pulsed irrigation destroys the exposed trabecular bone.
Deflate the tourniquet and examine the bone surfaces for punctate bleeding.
If there is no bleeding, further bone resection is needed until viable bone is observed.
Compress the calcaneus and align it manually, and drill a smooth Steinmann pin through the planter surface into the tibial shaft (TECH FIG 2D).
This pin will guide the calcaneus to the correct position during compression with the circular fixator later during the technique.
Close the medial and lateral incisions with a deep layer of absorbable suture and the skin with vertical nylon mattress sutures.
The sutures may need to be in place for 3 to 4 weeks before there is adequate wound healing.
Never use staples for the skin closure.
The shortening of the calcaneus onto the tibia will cause the soft tissues to expand in the horizontal plane (compression of a cylinder causes expansion of the diameter of the cylinder) (TECH FIG 2E).
To facilitate closure, distract the calcaneus on the Steinmann pin and close the wounds with the foot out to length.
The amount of edema and fibrosis of the soft tissue will affect the ability to acutely shorten the arthrodesis.
If there is severe edema and fibrosis, an acute shortening may not be possible, and a delayed shortening may be required to compress the arthrodesis.
The surgeon will gauge the effect of the shortening.
If the calcaneus is compressed against the plafond and the foot becomes cyanotic, a delayed shortening will be needed for the reconstruction.
The circular fixator is constructed as a monofocal frame or as a bifocal frame (TECH FIG 2F, G).
The circular rings are sized to provide 2 cm of soft tissue clearance.
Most frames are constructed with 160- or 180-mm rings.
If the patient is a candidate for proximal distraction ostogenesis, the frame is assembled with a proximal 5/8-full ring block, a midtibial double ring fixation block, and a foot fixation block.
If the patient has poor physiology for lengthening (end-stage diabetes, tobacco abuse, ischemic vascular disease, steroid dependency, or psychosis), the frame is assembled as a monofocal frame with a two-ring tibial fixation block and a foot fixation block.
Carefully assess the ability of the patient to undergo distraction histogenesis.
If there is failure of the arthrodesis, the salvage is a below-knee amputation.
If a proximal corticotomy has been done on a patient with poor physiology, the below-knee level of salvage could be lost.
PROXIMAL LENGTHENING

- The proximal and midtibial ring blocks are assembled as a unit.
  - The proximal ring block is constructed with a 5/8 or 2/3 ring connected to a full ring with three 3.0-cm hexagonal sockets (TECH FIG 3A).
  - The midtibial ring block is constructed with two rings connected with four 120- or 150-mm threaded rods (TECH FIG 3B,C).
  - The proximal and midtibial ring blocks are connected with four 40-mm distraction telescopic rods (clickers).
  - A horizontal reference olive wire is placed 15 mm below the tibial plateau with a 3-degree varus alignment.

- The varus of the reference wire aligns the frame with the axis of the tibia shaft (TECH FIG 3D).
  - The frame is aligned and centered on the tibia with adequate soft tissue clearance (TECH FIG 3E).
  - Observe the posterior gastrocnemius muscle to ensure proper clearance.

- Tension the horizontal reference wire to 110 kg.
- The center of the frame should align with the tibial shaft.
  - If the alignment is not axial, washers can be placed under the lateral or medial reference wire to correct the alignment.

- During this phase of the procedure, an assistant must support the distal leg and foot to prevent distorted positions, which could injure the soft tissues.
  - A towel block under the heel also prevents displacement.

- Align the distal tibial ring block with the tibia and place a 5-mm half-pin in the AP plane. Secure it with a universal Rancho cube on the distal ring (TECH FIG 3F).
  - The universal cube allows the ring to be aligned on the lateral view in an orthogonal position.

- The tibial shaft double-ring fixation block is aligned orthogonally on the tibia with two AP 5-mm half-pins placed on universal Rancho cubes. The Rancho cube mountings allow the fixation block to be aligned orthogonally. One or two medial pins are added once the fixation block is aligned. The distal ring is located about 6 cm superior to the arthrodesis. (continued)
An alternative method to align the stable base is to place a horizontal reference above the plafond. The wire should be placed posterior on the shaft to avoid the anterior tibial artery. The distal wire is located about 6 cm proximal to the arthrodesis. The joint surface of the plateau forms a varus 87-degree angle with the shaft. A horizontal reference wire placed 90 degrees to the shaft will be slightly closer to the medial plateau compared to the lateral. The proximal 5/8 ring block and the tibial shaft double-ring block are connected by 40-mm distraction rods. The frame is aligned on the proximal reference wire followed by a 5-mm half-pin placed on the distal ring. Manipulating these two fixation points aligns the frame orthogonally on the tibia. The rings must have soft tissue clearance at the posterior gastrocnemius muscle and anterior ankle soft tissue prominence. Universal Rancho cube pin fixation. Three-axis adjustment of the pin alignment allows the frame to be aligned orthogonally with the tibia. Rancho cubes bolted directly to the ring fix the ring in the alignment of the half-pin. If the half-pin is not perfect, the ring block will be malaligned. The foot fixation block is constructed with a long footplate closed on the anterior open end with a half-ring. The ring extends above the toes to keep bed linen from irritating the toes. The surgeon should avoid wires that could penetrate the posterior tibial or plantar nerve. Two opposed olive wires are placed in the calcaneus and two opposed olive wires are placed in the forefoot.

- Manipulate the foot on the footplate to control rotational alignment and align the arthrodesis.
- Close the footplate anteriorly with a half-ring before tensioning.
- Tension the wire to 100 kg and tighten the slotted fixation bolts.
- If the alignment is not satisfactory, repeat the process.
- Connect two threaded rods to the anterior foot plate with threaded rods using extension plates from the stable base.
- Stabilize the forefoot with opposed olive wires through the cuneiform row and metatarsal bases.
- Place a second wire from the posteromedial calcaneal tuberosity to the anterolateral calcaneal wall on the superior side of the foot plate.
- Assess the vascularity of the foot with the foot in the acutely shortened position.
- There should be brisk capillary refill.
- Use a Doppler device to verify pulsatile flow in the dorsalis pedis and posterior tibial artery.
- If the vascular flow is good, maintain the foot in the acute shortened position.
- If the foot is cyanotic and no pulses are detected with the Doppler, slowly distract the foot by lengthening the threaded rods between the tibial fixation block and the foot ring.
- Once pulsatile flow is detected, lock the threaded rod position in place.
- This position will create a gap between the tibia and calcaneus.
PEARLS AND PITFALLS

The arthrodesis must be in a plantar-neutral position. A fusion with the foot in equinus will severely compromise the functional outcome.
POSTOPERATIVE CARE

- The foot is observed for blood flow every 4 hours for the first 2 postoperative days.
  - If the foot becomes ischemic, the threaded rods connecting the foot frame to the tibia fixation block are lengthened until the blood flow improves.
  - A delayed shortening is then carried out until the arthrodesis is compressed (Fig 4).
- The patient is encouraged to mobilize the forefoot and toes and knee.
- Toe loops on rubber bands are placed on a wire scaffold to prevent toe flexion contractures by the physical therapy service.
- There will be significant bloody drainage and the bulky dressing placed in surgery may need to be changed on the first postoperative day.
- Open wounds are treated with normal saline wet-to-dry dressings until closure by secondary intention.
- Vacuum dressings are an alternative to wet-to-dry dressings.
- The sutures are left in place for at least 2 weeks.
- Many patients will require 3 to 4 weeks of suture closure before it is possible to remove the sutures.
- Intravenous antibiotics are administered for 2 days in patients without infections.
  - If the wounds are complex, the intravenous antibiotics will be continued for 7 days.
  - Patients with infected talus nonunions will be treated for additional weeks using intravenous antibiotics appropriate for the infecting organism.
- There is debate on whether the antibiotics need to be given for an additional week or continued for a total of 6 weeks during the treatment course.
- The dressing sponges are removed 2 weeks after surgery and the pin sites are cleaned daily.
- Once the surgical wounds are healed, the leg is washed in the shower with soap and water, removing all dried secretions from the pins and wires.
  - Hydrogen peroxide 3% solution is used only occasionally to clean crust that cannot be removed with soap and water.
  - Cephalexin, trimethoprim–sulfamethoxazole (Septra DS), and ciprofloxacin are used if needed to control local pin or wire skin infections.
  - Some patients will need only occasional use of antibiotics while others will require constant oral antibiotic coverage while the circular fixator is on the leg.
- Rarely, a more aggressive pin or wire infection will develop.
  - The infecting organism is most commonly methicillin-resistant S. aureus.
  - A 1-week course of intravenous vancomycin will be needed to control the wire infection.
  - If this is not successful, the wire is removed.
  - The plantar and talar neck and navicular Steinmann pins are removed in the clinic 6 weeks after surgery.
  - The patient is started on partial weight bearing, increasing to 50% weight over the following month.
    - A shower sandal is placed over the toes when walking.
    - The sandal is elevated with a full sole elevation to equalize the leg lengths and the sole is cut down on the band saw as the lengthening progresses.
    - Most patients cannot tolerate full weight with wires in their foot.
    - Lengthening proximally is at a rate of 0.25 mm (one quarter-turn) twice a day.
    - Younger patients can distract at a rate of 0.25 mm every 8 hours.
    - The lengthening is started 3 to 4 days postoperatively after the patient’s pain has improved from the surgery.
    - The starting rate is always 0.25 mm twice a day.
      - If the patient forms robust new bone, this can be increased to 0.25 mm every 8 hours.
      - The leg is lengthened until the leg length is equal (Fig 4).
      - Given the choice, most patients request equal leg length rather than on to 2 cm of shortening.
      - The distraction index is between 1.5 and 2.0 months per centimeter.
  - For a patient with tibial bone loss, the lengthening required can exceed 5 cm, resulting in 10 or more months in the circular fixator.
  - Some patients will heal the arthrodesis before the lengthening is mature.
  - The foot frame can be removed before the proximal transport is mature.
  - The tibial calcaneal arthrodesis requires 6 months for union.
    - The footplate is compressed 1 or 2 mm at each clinic visit to maintain compression over the course of treatment.
    - The fixator is removed under anesthesia.
    - A short-leg walking cast is applied and the patient walks with partial weight bearing.
  - The patient continues partial-weight gait until there is defined bone healing at the tibial calcaneal arthrodesis and the proximal bone transport has a well-developed medial, lateral, and posterior cortex.
  - Often patients will return to the clinic stating that they have advanced to full weight bearing around the house walking in the frame.
    - To increase the force transmitted across the transport, the frame is neutralized before frame removal.
    - This is accomplished by loosening the distraction clickers and allowing the distraction force to become neutral.
    - The rods are bolted in this neutral position and the patient is observed for several weeks to see if the cortex of the regenerate is strong enough to prevent collapse.
    - The fixator is removed under general anesthesia.
    - The leg is casted for 2 weeks after frame removal.
    - The radiograph out of plaster in the office with the Ilizarov fixator removed is analyzed for healing of the transport bone and arthrodesis.
    - A fracture walking boot with a rocker-bottom sole is applied.
      - The patient walks 50% weight bearing for 4 weeks.
      - The patient advances to full weight bearing with a cane and gradually increases his or her activity over the following year.
      - Activity is limited to walking on flat surfaces and light stress on the extremity.
    - The force applied to the leg is gradually increased with mature healing of the bone transport and arthrodesis observed at 1 year after fixator removal (Fig 4C,D).
    - The patient self-selects walking and training shoes that have cushioned heels with a rounded radius heel.
    - Patients who do not have proximal bone transport to equalize leg length have full sole elevations of 3 to 5 cm added to their walking shoes (shoe prosthesis) with a rocker sole.
If the patient has mild valgus or varus foot alignment, an orthotic is prescribed that improves their foot loading when standing and walking.

Long-term follow-up reveals osteophyte development at the talar navicular joint, which is associated with arthritic pain.

OUTCOMES

The average AOFAS foot and ankle score was 65 for the 11 patients in our case series.13

- Patients lose the ability to participate in sports and work as laborers.
- The work status is reduced to light or sedentary work.
- They can still ride motorcycles and drive cars.
- Patients are aware of the asymmetry of their legs from atrophy of the muscles motorizing the foot and ankle.
- When queried, no patient to date has considered having an amputation.
- The long-term follow-up will probably reveal progression of midfoot arthritis.

COMPLICATIONS

Failure of the bone transport to mature is a major complication.

- The distraction index is between 1.5 and 2.0 months per centimeter of lengthening.
- Bone growth is stimulated by weight bearing, so during the treatment course, the patient is encouraged to place 50% partial weight on the extremity.
- An Exogen Bone Stimulator (Smith-Nephew) can be used once the distraction is completed.
- Bone grafting of the distraction can also stimulate maturation if poor bone formation is observed.
- If deformation of the transport occurs after frame removal, this problem can be treated by several methods.
- If there is less than 5 degrees of angulation, the patient is treated with a knee brace and non-weight-bearing for 6 weeks.
- If greater deformity is observed, a second circular fixator is applied with angular correction and further time in the frame is indicated.
- An alternative is to place a locked plate spanning the transport on the medial or lateral tibial shaft (Fig 4D).
- An intramedullary nail can also be used for bone transport with poor bone formation.
- The pin and wire tracks must be free of infection to use internal fixation after external fixation.
- The patients walk 50% partial weight with crutches until healing of the transport.
- Failure to achieve arthrodesis is directly related to the physiologic status of the patient.
- Patients with rheumatoid arthritis who are using steroids chronically are prone to nonunion of their tibial calcaneal arthrodesis.
- If union has not occurred by 6 months of frame time, further time in the frame will not alter the outcome.
- If the patient is not on steroids and is in good health, a revision arthrodesis is attempted.
- Patients with rheumatoid arthritis are placed in a cast and encouraged to walk.
- The mobile nonunion forms a pseudo-joint similar to fascial arthroplasty that allows them to walk independently (FIG 5).
- We have observed four patients who have maintained this pseudo-joint for years and are able to participate in activities of daily living.

FIG 4 • A. Lateral x-ray of bifocal external fixator. The proximal tibia has been lengthened between the 5/8-full ring block and the double ring block on the mid tibia. B. Lateral x-ray of the tibia calcaneal arthrodesis with compression between the mid tibia and the foot plate. The foot is in plantar neutral alignment. C. Mature tibia1 calcaneal arthrodesis with the plafond fused to the calcaneus and navicular. D. AP x-ray with axial alignment of arthrodesis. The patient had a valgus deformity after frame removal of the transport. The tibia was realigned with a lateral locked plate.
REFERENCES

Femoral Head Allograft for Large Talar Defects

Bryan D. Den Hartog

INDICATIONS
- Talar body avascular necrosis with collapse or infection (FIG 1) is one indication for femoral head allograft.
- Failed total ankle arthroplasty with insufficient bone remaining for revision (FIG 2) also warrants a femoral head allograft.
- Use of a femoral head graft for those patients with severe (> 25 degrees) hindfoot valgus may not be appropriate, because correction of the deformity can cause significant lateral soft tissue tension and lead to tissue necrosis and poor wound healing. In those cases, a tibiocalcaneal fusion with shortening of the medial ankle may be more appropriate.

POSITIONING
- Under a general or spinal anesthetic block, the patient is placed in a supine position on the operating table with the ipsilateral hip bumped to facilitate internal rotation of the leg.
- The lower extremity is prepped and draped in the usual fashion, and a thigh tourniquet inflated to 250 mm Hg is applied after exsanguination of the leg with an Esmarch bandage.

PREPARATION FOR ALLOGRAFT
- A 12- to 14-cm lateral incision is made along the distal fibula, starting 6 cm above the ankle joint and extending distally along the anterior border of the peroneal tendons to the peroneal tubercle (TECH FIG 1).
- The tendons are carefully retracted posteriorly to expose the distal fibula, lateral ankle, and subtalar joints.
- The fibula is osteotomized 6 cm above the joint, then excised and morcelized for later grafting (TECH FIG 2).
- Debridement of avascular bone and removal of osteophytes and implant is performed until only viable bone surfaces remain (ie, distal tibial plafond, talar head and neck, and posterior facet of the subtalar joint).
- Determine the size of acetabular reamer from the total hip arthroplasty set that best fits the defect (TECH FIG 3).
- Only enough subchondral bone is removed from the tibia, talar neck, and calcaneus to expose viable, softer cancellous bone for fusion to the femoral head graft. If an assistant holds the foot and ankle in the desired position, the

FIG 1 • Lateral radiograph demonstrating avascular necrosis and infection of the talar body after open fracture–dislocation.

FIG 2 • Radiographs of a failed total ankle arthroplasty with severe loss of talar bone stock.

TECH FIG 1 • Patient positioned supine on the operating table. A lateral incision is made over the distal fibula and lateral hindfoot.
The surgeon can ream the defect safely, without the ankle bouncing around. No provisional fixation is necessary: the ankle is still relatively stable even after the ankle implant or necrotic bone is removed.

- With the ankle and hindfoot held in neutral, the defect is reamed (TECH FIG 4). The desired position of fusion is with the ankle in neutral plantar/dorsiflexion flexion and the hindfoot in approximately 5 degrees of valgus in relation to the distal tibia.
- It is critical to protect the soft tissue about the ankle with either Army-Navy or Hohmann retractors while the acetabular reamers are used.
- Bone shavings are saved and mixed with the morcelized fibular graft.

**TECH FIG 2** • A fibulectomy is performed to expose the ankle and subtalar joints and lateral calcaneus.

**TECH FIG 3** • The defect remaining after takedown is sized with the male reamers from the hip arthroplasty set.

**TECH FIG 4** • The bone surrounding the defect is reamed until cancellous bone is exposed on the distal tibia, talar neck, and calcaneus.

**PREPARATION AND PLACEMENT OF ALLOGRAFT**

- An allograft femoral head is thawed in a warm saline bath at the beginning of the procedure and placed in the bone vice (Allogrip Vice, DePuy), with the three limbs of the vice gripping the femoral neck.
- The female reamer corresponding to the same size male reamer used for reaming the defect is used to decorticate the allograft (TECH FIGS 5 AND 6).
- The head can be drilled multiple times in areas that still contain hard sclerotic bone to facilitate fusion.
- The appropriately sized and decorticated femoral head allograft is then placed in the defect (TECH FIG 7).
- Ankle and foot position is then checked for neutral position (ie, neutral ankle dorsiflexion–plantarflexion, 5 degrees of hindfoot valgus, and neutral rotation of the foot).

**TECH FIG 5** • A. A frozen femoral head allograft is thawed and placed in the Allogrip Bone Vice (DePuy). B. The female reamer (DePuy) is used to remove the subchondral bone from the allograft to expose cancellous bone and size the allograft.
the foot on the tibia). Because the femoral head graft is spherical, it is relatively easy to dial in the correct position of the ankle and hindfoot.

- The femoral neck is marked flush with the lateral tibia, the graft is removed, and the femoral neck is cut with a large oscillating saw.
- A bone slurry graft, made up of the autograft from the fibula and male reamers, is then placed in the defect to fill any voids around the fusion site (TECH FIG 8).
- The male reamers can again be placed and used in reverse to evenly spread the graft.
- The femoral head graft is placed back in the defect, and alignment is checked to ensure that it sits flush with the lateral fusion surface. Again, no provisional fixation is needed, as the interference fit between the femoral head and the recipient site is very stable.
  - This will allow unimpeded placement of the lateral blade plate.

**PLACEMENT OF PLATE AND SCREWS**

- The 90-degree blade plate is then sized by placing it along the lateral fusion surface equidistant between the anterior and posterior surfaces of the tibia and femoral head graft.
- In my experience, fixation with six to eight cortical screws in the tibia proximal to the femoral head allograft is desirable; therefore, a blade plate of appropriate length is required. The decision depends on the quality of bone. Typically, for six cortical screws to be positioned in the tibia above the graft, a nine-hole blade plate will be needed.
- The distal end of the plate (the blade end) should line up with the center of the calcaneal body to ensure maximum hold and minimize the chance of fracturing the calcaneus with insertion.
  - Usually a six- to eight-hole plate with the short blade fits well.
- Once the plate size has been selected, place the plate “backward” along the lateral fusion area so the blade is pointing lateral (TECH FIG 9). This technique allows for proper angle of insertion of the guidewire and, therefore, the blade of the plate.

**TECH FIG 6** • The femoral head graft is placed in the defect to ensure proper sizing.

**TECH FIG 7** • The femoral head graft is placed in the defect to ensure proper sizing.

**TECH FIG 8** • Once sizing is complete, a slurry of graft reamings is placed in the base of the defect and the reamers placed in reverse to spread the graft.

**TECH FIG 9** • The blade plate is placed in a “backward” position along the fusion site for sizing. A guidewire is passed through the hole in the blade into the calcaneus.
Check the hole alignment to ensure that at least one screw hole is over the calcaneus, one in the femoral head allograft, and two or three in the distal tibia.

Drive the guidewire through the cannulated hole in the blade to the distal cortex of the calcaneus.

- Pull the plate off the wire.
- Because the plate could theoretically still rotate on the distal guide pin in the calcaneus, I often place a second wire through the plate. I use one of the screw holes proximally to ensure that when I flip the plate and impact it there is no chance that it will lose its desired proximal position on the tibia and potentially throw off the sagittal alignment or not be seated ideally on the tibia.

Attach the driving device onto the plate and insert the blade plate over the guidewire (TECH FIG 10A,B). The 30-mm blade is most commonly used, because the 40-mm blade can easily penetrate the medial cortex and injure the neurovascular bundle.

- Be sure to have an assistant apply counterpressure with a padded bolster while driving the plate into the calcaneus.
- A separate guidewire driven through a proximal hole in the plate may help avoid unwanted twisting or rotation of the plate during insertion.

Once the plate is seated, the position of the blade is checked to make sure it has not penetrated the medial cortex of the calcaneus. Again, if the 30-mm blade is used, penetration of the medial cortex should not occur.

The screws (cancellous or cortical, depending on the type and quality of bone) are then inserted (TECH FIG 10C). In addition to the blade in the calcaneus, I like to have one additional screw through a distal hole in the plate, immediately above the blade, to enhance fixation in the calcaneus.

- A 7-mm cannulated screw is then placed from the posterior side of the distal tibia through the femoral head graft into the talar head and neck.
- Fluoroscopy is used to check guidewire placement.
- Avoid penetration into the talonavicular joint.

A second cannulated screw can be placed from the calcaneal tuberosity into the femoral head graft if the blade-plate fixation to the calcaneus is not stable, as indicated by visible micromotion at the fusion interface or if the patient’s bone is osteoporotic. In about half of my patients, this second screw is needed to gain adequate stability of fixation.

Use the remaining autograft to fill any remaining gaps at the fusion sites anteriorly, posteriorly, and laterally.

- A layered closure over a drain is done, and a bulky Jones dressing applied.

**TECH FIG 10**

A. The blade is pulled off the wire and the driving device attached. B. The blade is driven into the calcaneus over the guidewire. C. Appropriate length screws are applied.
POSTOPERATIVE CARE

- Remove the bulky dressing 10 to 14 days postsurgery.
- The patient is in a short-leg cast for 6 to 8 weeks, with touch-down weight bearing permitted.
- The patient can begin weight bearing in a cam-soled walker at 2.5 to 3 months postoperatively if radiographs show signs of incorporation of the bone graft placed about the femoral head and fusion between the graft and the surrounding cancellous bone (FIG 3).

We recommend that all of our patients use a non-hinged, light-weight, plastic ankle–foot orthosis (AFO) in a shoe with a soft anatomic cushioned heel indefinitely to protect the remaining joints of the foot.

OUTCOMES

- Our clinical experience with this technique includes five patients who underwent tibiotalocalcaneal fusion over 3 years. Four patients showed radiographic healing by 3 months and began protected weight bearing with a lightweight plastic AFO. One of these four patients subsequently died of a myocardial infarction. The fifth patient was paralytic with severe hindfoot valgus and developed lateral skin breakdown with subsequent meticillin-resistant *Staphylococcus aureus* (MRSA) infection postoperatively over the graft site; that patient eventually underwent below knee amputation.

- Of the four patients who had a good result, the average follow-up was 1.5 years. None of the femoral grafts had collapsed, and all patients had good or excellent relief of their preoperative pain with no loss of leg length. The three surviving patients are community ambulators and use the lightweight AFO for walking outside the home to protect the remaining foot joints from excessive stress.

- The lateral blade–plate–screw construct for stabilizing tibiotalocalcaneal fusions has been previously described as a method to gain exceptional stability in patients with Charcot ankle fracture who had unbraceable deformity and severe instability of the ankle. This fixation construct has been found to be biomechanically superior to an intramedullary rod for this type of fusion.

- Myerson et al have previously described the use of femoral head grafts through an anterior approach to fill large defects of the talar body. They have found them useful for filling large defects and avoiding severe limb shortening.

REFERENCES

DEFINITION

- The number of total ankle arthroplasties (TAA) both designed and implanted continues to grow rapidly worldwide.
- The success and survivorship of any joint replacement are difficult to determine before a minimum 5-year follow-up. Because the early stage of most new arthroplasties can be marked by a steep learning curve while the later stage is often plagued by some level of polyethylene-induced osteolytic failure, foot and ankle specialists can expect to face increasing numbers of patients requiring revision or salvage surgery—even with the newest-generation TAA designs.
- Failure of a total ankle replacement can broadly be defined as septic or aseptic and usually results from either clinical (recalcitrant pain, instability, or malalignment) or radiographic (progressive loosening, subsidence, or osteolysis) deterioration.
- Implant failure due to septic or aseptic failure typically necessitates removal and leaves the surgeon with extensive areas of bone loss that must be addressed. Other potential problems include wound breakdown, infection, limb length discrepancies, scar formation, instability, malalignment, and, of course, choosing between complex and limited reconstructive options.
- Due to the anatomy and limited bone stock inherent to the ankle and particular to the talus, revision ankle replacement is frequently not possible in these cases, and arthrodesis of the ankle or tibiotalocalcaneal region remains the only viable salvage option.
- Fusion has traditionally been reported and performed through either an anterior or lateral approach. These approaches and the hardware used for them, however, are often limited by wound complications from the thin or previously operated soft tissue envelope, as well as difficulties in assessing rotatory, angular, and longitudinal alignment.
- The posterior approach usually provides the healthiest and deepest soft tissue bed for any postimplant failure reconstruction (through a single incision), permits ready access to the area of greatest potential bone graft harvest (posterior superior iliac spine [PSIS]), uses the fibula to aid in healing and in determining proper alignment, allows use of large fixed-angle devices applied on the tension side to enable safe and early postoperative weight bearing, and facilitates rapid intraoperative assessment of radiographic and clinical position.
- Because the fibula rarely provides enough bone to fill any remaining defect after TAA failure, it is often more useful in its native position as part of the reconstruction as opposed to being partly or completely sacrificed as part of a lateral or combined anterior operative approach.

ANATOMY

- The posterior aspect of the lower leg, ankle, and hindfoot is covered by several layers of well-vascularized soft tissues.
- The superficial posterior compartment contains the gastrocnemius and soleus complex, separated from the deep posterior compartment by a dense investing fascia.
- The sural nerve and the lesser saphenous vein should be carefully avoided as part of the superficial midline dissection in this approach.
- Once the superficial posterior compartment fascia is opened, the gastrocnemius–soleus complex can be mobilized as a unit medially or laterally, or the Achilles tendon can be Z-lengthened to enable immediate access to the deep posterior compartment septum.
- The flexor hallucis longus (FHL) muscle is considered the “lighthouse” to the back of the ankle and hindfoot. It is readily identified by its uniquely low-lying muscle belly within the deep posterior compartment and provides the landmark for the posterior tibial neurovascular bundle, which courses immediately medial to it through the lower aspect of the leg and into the foot (FIG 1).
- Once identified, the FHL can be easily swept medially to protect the bundle during retraction and provide maximal exposure of the posterior aspect of the distal tibia, ankle joint, and subtalar joint (FIG 2).
- Once the reconstruction has been performed and fixation is indwelling, the deep soft tissue bed present in this region enables the hardware and any bone graft augmentation to thereafter be safely covered by repositioning of the FHL and Achilles complex before untensioned subcutaneous and skin closure.

PATHOGENESIS

- TAA failure can result from many causes, but the predominant mechanism, based on hip and knee replacement data, will likely become aseptic failure. This can occur from polyethylene wear over time, ballooning osteolysis, subsidence of...
If history is any indication, it is quite possible that the next decade or two of foot and ankle specialists will have to become very familiar with reconstructive salvage of failed TAA in the form of revision replacement or fusion.

Since the survivorship of the average total hip or knee arthroplasty approaches 90% to 95% at 15 to 20 years and TAA has never approximated this success, the rapidly increasing number of ankle replacement designs being accepted by the FDA and in countries abroad, as well as the seemingly exponential rate of TAA implantation today as an alternative to primary fusion, would suggest that revision ankle replacement surgery will need to be a part of every foot and ankle specialist’s armamentarium in upcoming years.

### PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history and physical examination, as well as an appropriate set of weight-bearing ankle radiographs, are paramount to identifying the patient with a failed TAA.
- Unremitting or new-onset pain is often the chief complaint of a poorly functioning or infected ankle replacement.
- Patients should also be assessed for associated ankle swelling and warmth, which if recent are reasonable indications for a more in-depth evaluation to assess the integrity of the TAA.
- Time from initial implantation as well as any history of prior surgery or implantation in this region should be noted.
- Patients who are diabetic or neuropathic or who have any systemic illness that could predispose them to infection, immunologic compromise, or undetected abnormal wear (Charcot) should also be more carefully assessed.
- Any history of fever, chills, sweats, or recent dental surgery without antibiotic prophylaxis should be noted, as should complaints of ankle or hindfoot instability.
- The examiner should look for obvious ankle or hindfoot deformity, either new or old. Particular attention should be paid to the varus or cavus foot malalignment, which has the highest association with implant failure.
- Restricted range of motion or the presence of pain, crepitance, or grinding on examination should be noted.
- The examiner should look for any surrounding fluctuance, erythema, or draining sinus around the ankle.

### IMAGING AND OTHER DIAGNOSTIC STUDIES

- When implant failure is suspected, the initial screening blood work to rule out sepsis should include a complete blood count with differentiation, erythrocyte sedimentation rate, and a C-reactive protein level.
- Weight-bearing, standing plain films of the affected ankle (anteroposterior, lateral, and oblique views) should be obtained. If necessary, particularly when a form of aseptic failure from mechanical malalignment of the foot is suspected, a routine set of plain films of the foot should also be obtained.
- Radiologic signs of loosening include radiolucent lines around the components, as well as malposition and subsidence of any component. These are most valuable when they are indentified as acute changes from previous films or shown to be slowly progressive over time.
- Ballooning osteolysis behind an implant is a poor prognosticator for impending implant subsidence and failure. In such

The most recent (third-generation) designs seem to have begun capitalizing on many newer technologies and design concepts ushered in by the successes in the hip, knee, and shoulder, and while early and midterm survivorship data (5 to 10 years) appear to be promising for these modular implants, time of implantation will be the ultimate judge.

The natural history of any component is clearly influenced by the quality of the soft tissue envelope, its limited native motion, its size-to-weight bearing ratio, and our present inability to completely resurface it such that the same stress is borne by the same surface area.

Much of our understanding about ankle joint replacement stems from the adult reconstructive literature regarding hip and knee replacement. Most, if not all, earlier-generation ankle replacement designs have been considered failures by today’s standards, and a great number eventuated into fusion or other forms of revision surgery.

The most recent (third-generation) designs seem to have begun capitalizing on many newer technologies and design concepts ushered in by the successes in the hip, knee, and shoulder, and while early and midterm survivorship data (5 to 10 years) appear to be promising for these modular implants, time of implantation will be the ultimate judge.

### NATURAL HISTORY

- Although historically TAA has been in existence since the earliest hip and knee designs of the late 1960s and early 1970s, it has never enjoyed the same clinical success.
- This reason is likely multifactorial but no doubt stems in part from the many unique design aspects of the ankle joint that set it apart from the many other large joints that undergo very successful replacement today. These issues include the ankle’s functional dependence upon the alignment and quality of many surrounding nearby joints, its inability to be dislocated during implant insertion, its thin and unforgiving soft tissue envelope, its limited native motion, its size-to-weight bearing ratio, and our present inability to completely resurface it such that the same stress is borne by the same surface area.

- The examiner should look for obvious ankle or hindfoot deformity, either new or old. Particular attention should be paid to the varus or cavus foot malalignment, which has the highest association with implant failure.

- The examiner should look for any surrounding fluctuance, erythema, or draining sinus around the ankle.

- Patients should also be assessed for associated ankle swelling and warmth, which if recent are reasonable indications for a more in-depth evaluation to assess the integrity of the TAA.

- Time from initial implantation as well as any history of prior surgery or implantation in this region should be noted.

- Patients who are diabetic or neuropathic or who have any systemic illness that could predispose them to infection, immunologic compromise, or undetected abnormal wear (Charcot) should also be more carefully assessed.

- Any history of fever, chills, sweats, or recent dental surgery without antibiotic prophylaxis should be noted, as should complaints of ankle or hindfoot instability.

- The examiner should look for obvious ankle or hindfoot deformity, either new or old. Particular attention should be paid to the varus or cavus foot malalignment, which has the highest association with implant failure.

- Restricted range of motion or the presence of pain, crepitance, or grinding on examination should be noted.

- The examiner should look for any surrounding fluctuance, erythema, or draining sinus around the ankle.

- When implant failure is suspected, the initial screening blood work to rule out sepsis should include a complete blood count with differentiation, erythrocyte sedimentation rate, and a C-reactive protein level.

- Weight-bearing, standing plain films of the affected ankle (anteroposterior, lateral, and oblique views) should be obtained. If necessary, particularly when a form of aseptic failure from mechanical malalignment of the foot is suspected, a routine set of plain films of the foot should also be obtained.

- Radiologic signs of loosening include radiolucent lines around the components, as well as malposition and subsidence of any component. These are most valuable when they are indentified as acute changes from previous films or shown to be slowly progressive over time.

- Ballooning osteolysis behind an implant is a poor prognosticator for impending implant subsidence and failure. In such
patients, polyethylene wear (a narrowed joint space) is often identifiable on plain radiographs.

- An implant should be considered to be infected until proven otherwise when the history, physical examination, and blood work suggest such.
- A bone scan can also be useful as an adjunct for diagnosing septic or aseptic loosening.
- In these patients or in those with an equivocal examination, an office based or radiologically guided aspiration is indicated for routine Gram stain and culture.
- Percutaneous biopsy can also be performed, although intraoperative cultures are considered most sensitive and specific for the etiology of the implant failure. These can be assessed pathologically for polymorphonucleocytes per high-power field, as well as for the presence of bacteria and poly debris.
- In cases of suspected or documented infection, consultation with the infectious disease team is suggested to determine the appropriate microbiologic and chemotherapeutic aspects of the subsequent management.

Differential Diagnosis

- Pain of unknown etiology (implants still well fixed): complex regional pain syndrome, stiffness, fibromyalgia, neumora, tendon incarceration, neurovascular injury or compromise, heterotopic ossification, occult fracture, syndesmotic nonunion, arthritis or impingement of nearby joints
- Septic failure (infection)
- Aseptic failure (impingement, osteolysis, implant or polyethylene fracture, subsidence, circumferential loosening, malposition, malalignment, dislocation, instability, periprosthetic fracture, syndesmotic nonunion when applicable)

Nonoperative Management

- Nonoperative management is generally not indicated for a septic TAA failure. When these are very acute, these can occasionally respond to serial aspiration and antibiotic therapy, but even in these cases surgical intervention (arthroscopy or single-stage exchange) has proven most effective.
- In cases of aseptic failure, treatment depends on the cause.
  - Gross instability, uncontrollable pain, catastrophic implant failure (fracture), periprosthetic fracture, and aggressive (ballooning) osteolysis are generally best treated surgically.
  - Other causes of aseptic failure can be considered for conservative management, which includes some form of bracing, mechanical offloading with assistive devices, pharmacologic pain control (or osteolytic inhibition), and a RICE protocol.
  - Sometimes simple tolerance is the most appropriate course when the risks of revision surgery might outweigh any of the potential benefits.
- The risks of such complex surgery, as well as its limitations, must be discussed in detail with any patient in this situation, and this discussion should always include the possibility of below-knee amputation.

Surgical Management

- A blade plate or fixed-angle device applied from posteriorly in the prone-positioned patient addresses all the problems associated with arthrodesis of a failed TAA, and it is our preference.
- This procedure can be performed as a single- or two-stage procedure.
- The technique is versatile because it can be used for both tibiotalar or tibiotalocalcaneal arthrodesis, with the only difference being the size of the fixation device.
- Many different implant sizes can be used for this technique, varying from small- to large-fragment fixation, locking or non-locking constructs, and fixed-angle or straight plates.
- The prone position allows access to a deep and usually healthy, unscarred soft tissue bed capable of accessing or removing the indwelling TAA as well as covering appropriate hardware and bone graft without tension.
- The prone position also allows for the easiest clinical determination of hindfoot position before fusion, and it affords access to the posterior iliac crest for maximal amounts of bone graft procurement. The opposite leg can also be prepared out, if need be, for comparison.
- AP and lateral radiographic images are also easily obtainable, requiring minimal to no manipulation from the surgeon when the operative leg is elevated on two or three folded blankets.
Lastly, the fixation in this approach is placed on the tension side. This acts to compress the fusion mass under the load of weight bearing, facilitating a more rapid return to ambulation.

Preoperative Planning
- All radiographs and laboratory parameters, as well as the patient’s skin envelope, are reviewed before surgery.
- If the patient has an infected TAA, this procedure should be performed in staged fashion and only after the decision has been made not to reimplant an ankle prosthesis at the second stage. A carefully contoured, anatomic polymethylmethacrylate antibiotic spacer impregnated with tobramycin and vancomycin can easily be inserted and removed through the same approach to maintain alignment and soft tissue tension between stages.
- Symptom production from the subtalar joint must be carefully assessed preoperatively (but can also be assessed visually intraoperatively) to determine any potential need for adding subtalar fusion to an isolated tibiotalar arthrodesis. Surrounding bone quality and stock should also be a major factor in making this determination, particularly on the talar side.
- Preoperatively, two-stage office-based or fluoroscopically guided diagnostic differential injections of the talocalcaneal and subtalar joints with local analgesic are well suited for this purpose.
- Precontouring the blade plate (and determining its size) using an ankle sawbones model and a preoperative template saves significant tourniquet time (FIG 4).

Positioning
- The patient is positioned prone on an image table with gelpads, using a few folded blankets as a “workbench” under the affected leg to elevate it sufficiently above the contralateral extremity to permit unimpeded imaging of the operated extremity in the cross-table lateral projection (FIG 5).
- Gelpads should not be used in the area intended for fluoroscopy, since the material is radiopaque. The image machine should be checked for clearly visible AP and lateral views of the patient’s ankle and hindfoot before preparation and draping.

FIG 4 • Precontouring the blade plate with sawbones as template.

FIG 5 • Posterior midline approach.

A tourniquet should be placed about the thigh, and the ipsilateral posterior iliac crest should be squared off with preliminary drapes in anticipation of bone graft procurement.

Approach
- The entire ipsilateral leg and PSIS are then prepared and draped in the usual sterile fashion.
- The ankle and hindfoot should be operated on to establish the size of the defect and amount and configuration of bone required before autologous harvest from the PSIS.
- Under tourniquet control, a midline longitudinal incision 12 to 16 cm long is initially made directly posterior to the
ankle and hindfoot (Fig 5). Imaging can be useful at times to establish this position ideally, although we prefer simply centering this over the ankle in the midline. If it is determined intraoperatively that more exposure is required distally to access the subtalar joint, this incision can be easily extended by curving it slightly posteromedially as it courses over the heel.

- No skin retraction is used, and retractors are used only once the deeper tissues are encountered.
- The paratenon of the Achilles and the superficial fascia are first carefully opened with the intention of later closure and separation from overlying skin and subcutaneous tissues in the rare event of wound breakdown.
- A Z-plasty of the Achilles is performed longitudinally to allow access to the deep posterior compartment. Incising the fascia over the superficial posterior compartment can ease tension and improve retractability of the gastrocnemius and soleus during exposure. Care should be taken to maintain full-thickness flaps (“canyon walls”) (FIG 6).
- The deep posterior compartment fascia is then incised, exposing the FHL and the remaining deep extrinsic musculature.
- The neurovascular bundle is identified but not dissected, and then carefully retracted medially by retracting the lateral side of the FHL.
- This permits unimpaired full access of the posterior tibia, the capsules overlying the ankle and subtalar joints, and the distal fibula immediately beneath a portion of the inferior peroneal musculature (FIG 7).

**FIG 6 • Z-plasty of the Achilles.**

**FIG 7 • Deep compartment open, flexor hallucis longus retracted medially. The failed ankle implant has been removed and the defect débrided.**

**TAA REMOVAL**

- Although most implants are placed through an anterior approach, it is generally not difficult to remove these current designs from a posterior approach.
- Use of a femoral distractor, or, alternatively, an external fixator with medial pins in the tibia and the calcaneus will facilitate distraction of the joint for easy implant removal in the event of soft tissue contracture.
- Once the ankle implants have been removed, any fibrous membrane or other debris within the joint can be excised and the remnant viable bone stock (defect void) and quality can be assessed to plan alignment, bone graft requirements, and implant size for the reconstruction.
- Only healthy, bleeding bone should be left behind amidst a viable soft tissue envelope.
- At this point, the subtalar joint should also be inspected—and fused, if deemed necessary by virtue of its integrity or the remaining available bone stock for fixation. In the case of TAA salvage, this technique is usually recommended.
- Despite any preconceived opinions about the presence or absence of infection, under all circumstances it is advisable to obtain multiple deep tissue samples for pathology and culture. These should be taken ideally before antibiotic prophylaxis is given, and we recommend taking three samples for pathology and three for microbiology, all with separate instruments, from separate sites, labeled with separate identifiers, and placed in separate sterile containers. Under no circumstances should the skin be touched when performing this task, for fear of inadvertent contamination.

**INFECTED TAA REMOVAL**

- If the joint is infected, or presumed infected, a radical débridement is performed at this time, taking similar cultures and pathology specimens from separate “high-yield” areas.
- In these cases, the ankle joint is then prepared for a second-stage procedure by thorough saline irrigation and interposition of a PMMA antibiotic-laden spacer fashioned to fit the bony defect and maintain alignment, length, and stability (TECH FIG 1).
- Since cultures are often not yet indicative of an infecting organism, both vancomycin and tobramycin should be included in the spacer for both gram-negative and gram-positive coverage.
After final takedown and decortication of the ankle (and possibly the subtalar joint) the surgeon can determine how much bone graft to harvest. Occasionally this includes preference of size or shape (eg, tricortical, trapezoidal, cancellous only).

If the subtalar joint is to be taken down, it is prepared in a similar manner. Bone (laminar) spreaders are very useful for this purpose in both joints.

Bone graft blocks are taken from the posterior iliac crest with a sagittal saw and osteotomes, and thereafter are fashioned to fit and bridge the resected ankle gap. Generally, tricortical grafts are most amenable to this construct and can be easily contoured into appropriate position to maintain alignment. Once these are taken, the cancellous graft between the remaining inner and outer table of the pelvis can also be harvested for packing the remaining joint space. In all these cases the cancellous bone graft should be mixed with tobramycin and vancomycin powder before being packed into all remaining articular interstices after hardware implantation.

The foot should be placed in neutral alignment and preliminarily held in reduction with one or two large non-threaded Steinmann pins. Typically, this alignment includes 0 degrees of ankle flexion with 5 degrees of hindfoot valgus and external rotation appropriate to the opposite side. This step is performed identically for both ankle and tibiotalocalcaneal fusion.

Hence, once proper length and position are established clinically and radiographically, one or two eighth-inch Steinmann pins are placed through the calcaneus from directly inferiorly, and run into the midtibia to maintain this alignment. Foot and ankle position is then verified in both the lateral and AP planes with imaging. The pre-contoured 4.5-mm 90-degree fixed-angle blade plate (recommended) is then laid next to this to assess proper contouring and positioning via imaging. Small alterations in this device are best made at this time before it is actually implanted.

Predrilling a trough for the blade of the plate is usually unnecessary when doing a tibiotalocalcaneal fusion because of the soft cancellous bone found within the calcaneus. In this case, the starting position and angle of insertion are far more important. In the less common circumstance of having enough talar bone to simply fuse only the ankle primarily, a precut trough is advisable before the blade plate is introduced into the denser talus bone. In this latter circumstance, often a smaller blade plate (3.5 mm) is more amenable to this fusion construct.

In both cases, attention must also be paid to the following:

- Proper length of the blade to avoid cutout upon implant seating
- Proper angle of the blade to ensure adequate positioning once seated
- Number of screw holes traversing the tibia such that adequate fixation is maintained above the fusion mass
- Proper rotation of the blade such that it sits centrally located along the posterior tibial metadiaphysis once fully seated (TECH FIG 2)

Serial imaging during blade plate insertion can be very helpful in making these determinations before completely bottoming out the implant.

Once the blade plate is fully seated, the position of the limb clinically and radiographically should be reassessed. After this, the plate can be locked in position by placing...
a single proximal and distal compressive screw, followed by Steinmann pin removal.

- The remaining compressive screw fixation construct for the plate can then performed in routine fashion, including the use of the articulating tensioning device where applicable.
- Often, several screws can be used to cross several joints not only to enact a neutralization plate construct but also to permit some articular compression across the fusion mass as well.

- After fixation, any residual graft can be packed in and around the plate and joints (TECH FIG 3).
- Final films should be taken and saved, and a repeat clinical examination should be performed to ensure satisfactory alignment before final closure (TECH FIG 4).
- The deep posterior compartment is then swung back into place to easily cover the plate (TECH FIG 5) and the Achilles can be reapproximated in neutral position. A Hemovac drain should be placed at this time before the overlying fascia, subcutaneous tissue, and skin are closed.

TECH FIG 2 • Blade plate placed posteriorly with foot in neutral position, calcaneus in 5 degrees of valgus, held by Steinmann pin.

TECH FIG 3 • Additional bone graft is packed around the blade, the ankle, and the subtalar joint.

TECH FIG 4 • Lateral fluoroscopic image verifying blade and screw placement and alignment.

TECH FIG 5 • The flexor hallucis longus is replaced in its anatomic position covering most of the implant.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Large bony defect</th>
<th>Posterior iliac crest bone graft, corticocancellous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard talus bone</td>
<td>Predrilling blade trough in talus</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- An ankle blockade with Marcaine and lidocaine eases pain in the immediate postoperative setting, but it should be placed well above the operative site to avoid wound tension.
- Steri-Strips should be applied across the incision site to distribute stress optimally at this level, and away from the incision itself. To this end, these should be uncut, and benzoin should be avoided to minimize blister formation.
- A meticulously padded Jones dressing, posterior splinting, and taped suction drainage help to avoid edema, hematoma, and pressure sore formation.
- While the patient recovers in bed or rests in a supine position, no pressure should be permitted beneath the lower leg, ankle, and foot. Hence, this area should be “suspended in midair” by placing pillows or blankets underneath the proximal calf, knee, and thigh to avoid pressure on the incision.
- The patient should remain strictly non–weight-bearing for the first 2 weeks postoperatively.
- After the posterior skin wound has healed and sutures have been removed, cast immobilization with partial weight bearing is allowed until week 6. Placing the plate posteriorly across the ankle creates a tension band phenomenon during the gait cycle, helping to compress the fusion site with weight bearing. Physical therapy can also begin during this time interval. At 6 weeks, consideration can be given to transitioning the patient to boot immobilization, depending on the clinical and radiographic progress, and slow progression to full weight bearing can begin.
- All forms of cast or boot immobilization are discontinued after radiographic evidence of healing, usually at about 12 weeks postoperatively (FIG 8). The patient can be advanced into a sneaker with a SACH heel or rocker sole.

OUTCOMES

- In our experience, this operation has been very effective for salvaging difficult revision of failed TAA with reasonable patient satisfaction.
- We have not done enough of these procedures, however, to enable us to reasonably discuss outcome. We do believe, though, that this operation will become more pertinent over time, and that it is a very easy, safe, and versatile technique to address this difficult problem.

COMPLICATIONS

- In our limited experience with this approach, we have encountered no complications, although we believe the potential complication list would certainly be similar to any major revisional fusion operation dealing with intercalary defects.

REFERENCES


FIG 8 • Weight-bearing lateral radiograph 3 months postoperatively.
DEFINITION
- Arthroscopy of the ankle has become an invaluable tool for evaluating and treating pathology in the ankle joint.
- Arthroscopy allows a minimally invasive approach to the structures of the ankle with a magnified view.
- Detailed knowledge of the anatomy surrounding the ankle joint as well as the different structural variations is key to avoiding complications.

ANATOMY
- The anteromedial portal is located medial to the tibialis anterior tendon at the level of the ankle joint (FIG 1). Care should be taken to avoid injury to the long saphenous vein and nerve usually located medial to the portal.
- The anterolateral portal lies on the anterior joint line just lateral to the peroneus tertius tendon or alternatively lateral to the extensor digitorum longus tendons (Fig 1). The intermediate cutaneous branch of the superficial peroneal nerve lies in close proximity to this portal.
- Posteromedial and posterolateral coaxial portals lie parallel to the bimalleolar axis (FIG 2).
- The posterolateral coaxial portal (FIG 3) is located immediately posterior to the peroneus longus tendon, and the posteromedial coaxial portal (FIG 4) ideally lies between the posterior colliculus (of the medial malleolus) and the posterior tibial tendon. (Placement between the flexor digitorum longus and the posterior tibial tendon is also acceptable.)
- The sural nerve is located an average of 6.6 mm from this posterolateral portal, while the posterior tibial nerve is found an average of 5.7 mm from the posteromedial portal.

DIFFERENTIAL DIAGNOSIS
- Anterior ankle impingement
- Ankle arthritis or frozen ankle
- Osteochondral tibial or talar defects
- Lateral ankle instability
- Ankle fractures
- Recalcitrant ankle synovitis (often seen in patients with systemic inflammatory disease)

NONOPERATIVE MANAGEMENT
- In general, conservative treatment will include a trial with activity modification, immobilization with a brace, and non-steroidal anti-inflammatories.
Physical therapy using modality treatment, range-of-motion exercises, neuromuscular coordination training (eg, balance board), and strengthening of the secondary or dynamic stabilizing muscles surrounding the ankle is a useful adjunct to most conditions.

**SURGICAL MANAGEMENT**

**Preoperative Planning**
- Imaging studies are reviewed to determine ideal portals to be used.
- Standard anteromedial and anterolateral portals are sufficient to access the anterior and central tibiotalar pathology.
- Posterior portals are considered when drilling posterior talar lesions or when it is necessary to address pathology (eg, synovitis, loose bodies) within the posterior capsule.
- A preoperative popliteal block is placed by anesthesia. Over the past 5 years, we have been able to perform 75% of ankle arthroscopies with regional anesthesia and light sedation.
- An examination under anesthesia including anterior drawer as well as a talar tilt test should be performed before positioning.

**Positioning**
- The patient is placed on a regular operating table with a well-padded tourniquet on the proximal thigh.
- The supine position with a towel roll placed underneath the ankle is used when only anterior portals are necessary. In this situation the tourniquet may be placed on the proximal calf.
- If access to posterior portals is likely, then we lower the leg extension of the bed and use a standard arthroscopy knee holder (FIG 5). This restricts thigh motion but allows free leg motion and access to the posterior hindfoot (FIG 6). The contralateral leg is placed in a well-padded holder or pillow (FIG 7).
- Alternatively a noninvasive ankle distractor is used.

**Approach**
- Currently the standard working approaches include the anteromedial and anterolateral portals.
- Auxiliary anterior portals (such as the antero-central) should be used with caution because of the high incidence of neurovascular injury.
- The standard posteromedial and posterolateral portals should also be used with extreme caution due to the close proximity of neurovascular structures (FIG 8).
We prefer to use posterior coaxial portals parallel to the bimalleolar axis when addressing the posterior ankle joint. Although the standard 4-mm arthroscope may be used, we prefer to use the 2.7-mm arthroscopic instruments, which facilitate access and simplify the approach.

Instruments usually include 2.5-mm shaver, 3.5-mm shaver, thermal ablation device (this is especially helpful for synovectomy and débridement of the joint; however, care must be taken to avoid articular cartilage damage), and small arthroscopic biter and grabber devices.

**ANTERIOR PORTAL PLACEMENT**

- The operative leg is identified and marked preoperatively.
- The patient is placed supine on the operating table.
- Inject the ankle with 10 cc of sterile saline via the anteromedial ankle. This step also allows identification of the correct orientation and location for the anteromedial arthroscopy portal.
- Make a 5-mm longitudinal skin incision and spread the subcutaneous tissue down to and then through the capsule with a small hemostat. A small gush of fluid confirms the intra-articular location.
- Use the blunt-tip trocar with the arthroscopic cannula to enter the joint. Insert the arthroscope and start the water flow. Place the water pressure about 5 mm Hg above the systolic pressure if possible (no higher than a pressure of 120 mm Hg). This significantly reduces bleeding, which often obscures the view.
- Unless there is severe arthrofibrotic tissue in the anterior ankle, the anterolateral ankle is easily visualized upon introducing the arthroscope (TECH FIG 1).
- Introduce an 18-gauge needle from the anterolateral portal location. This serves two purposes: (1) it allows for water flow through the needle, allowing for better visualization and (2) it identifies the correct location of the portal incision in order to access the joint properly.
- Inspect the joint. Distraction allows for much greater joint inspection than otherwise would be possible.
- Make the anterolateral portal in a similar fashion to the anteromedial portal.
- Using both portals, various arthroscopic instruments are used to address the individual patient’s pathology.
- The addition of an anteromedial inferior portal is very helpful when dealing with synovitis near the deltoid insertion. This is performed by visualizing the medial gutter with the arthroscope through the anteromedial portal. An 18-gauge needle is introduced under arthroscopic visualization into the inferior medial gutter (usually about 10 mm inferior to the normal anteromedial portal location). Once the needle is confirmed to be in the proper position, a new portal is then made as described earlier. This portal in combination with the conventional anteromedial portal can be used to first inspect and then débride the far inferomedial ankle joint and deltoid insertion.

**POSTERIOR COAXIAL PORTALS**

- With the arthroscope and inflow in the anterolateral portal, make the posterolateral portal with a small, vertical skin incision immediately posterior to the peroneal tendon sheath and 1.5 cm proximal to the tip of the fibula (TECH FIG 2).
- While holding the ankle in neutral dorsiflexion, insert the arthroscopic sheath and blunt trocar anterior and slightly inferior on a plane parallel to the bimalleolar axis. Confirm intracapsular placement by briefly inserting the arthroscope.
- Insert a long switching rod through the cannula and direct it toward the medial malleolus. Use the rod to palpate the posterior colliculus and penetrate just anterior to the posterior tibial tendon (TECH FIG 3).
- Tent and incise the skin over the posteromedial ankle. Subsequently, pass a second cannula over the switching stick into the posterior ankle recess.
- Alternatively, the medial portal can be made directly using a small, vertical skin incision posterior to the medial malleolus (posterior colliculus). The arthroscopic
sheath and blunt trocar are inserted anterior and slightly inferior on a plane parallel to the bimalleolar axis. Intracapsular placement is confirmed by briefly inserting the arthroscope (TECH FIGS 4 AND 5).

For synovectomies or posteromedial osteochondral lesions, the arthroscope is placed in the posterolateral cannula while the posteromedial cannula is used as the working portal.

\section*{ANKLE DISTRACTOR PLACEMENT}

- Inspect all instruments, and confirm that all parts of the noninvasive external distractor are sterile and on the operative field (TECH FIG 6).
- The patient is placed supine on the operating table.
- The patient is placed so the foot rests within 10 cm of the end of the bed.
- A bump (made from a rolled blanket) is placed under the hip to rotate the leg so the toes point straight up.
- A tourniquet is placed on the calf below the level of the fibular head to prevent peroneal nerve impingement (TECH FIG 7).
The hip is flexed 60 degrees and the posterior thigh is placed in a padded thigh holder and secured with straps. It is very important that the thigh holder be placed so that the leg rests in the holder and does not rest in the popliteal fossa. If the thigh holder rests in the popliteal fossa, the pressure on the popliteal vein will increase bleeding throughout the case and make arthroscopic visualization much more difficult. With limited pressure on the popliteal space, the tourniquet is rarely needed during the arthroscopic portion of the case (TECH FIG 8).

The operative leg and ankle region is prepared and then draped using a standard arthroscopy drape.

The distal portion of the arthroscopy drape is pulled off the end of the foot to allow for the distractor placement.

The bed clamp is placed as far distal on the bed as possible. For the clamp to fit properly, the circulating nurse should make sure all of the underlying drapes except the top layer are moved away from the clamp attachment site (TECH FIG 9).

The external distractor strap is placed with the foam portions over the posterior inferior heel and on the dorsal foot. After creating equal lengths on the medial and lateral sides of the foot, the hook-loop is pulled distally with manual distraction.

The L-shaped metal post is placed and secured.

The foot is then pulled manually via the strap and connected to the threaded attachment rod. We recommend the initial placement requires moderate effort to get the hook-loop secured so that initial manual distraction provides the majority of distraction. Once this is connected, use the threaded rod to provide further distraction to the ankle (TECH FIG 10).

The joint can be flexed or extended while in the distraction device to allow for complete evaluation of the joint.

PEARLS AND PITFALLS

**Indications**

- Careful analysis of preoperative films will allow proper planning of necessary portals (anterior only vs. both anterior and posterior).

**Coaxial portal placement**

- Spread soft tissues laterally directly behind the peroneals to avoid sural nerve injury.
- Palpate the posterior colliculus medially with a switching stick before penetrating between the posterior tibial tendon and medial malleolus.
- Occasionally the medial coaxial portal will occur between the posterior tibial tendon and the flexor digitorum longus.
- Avoid forceful medial penetration, which can result in tendon splitting.
- When exposing the medial portal directly, posteromedial skin incision lies along the course of the posterior tibial tendon behind the posterior colliculus. The posterior tibial tendon can be retracted anteriorly or posteriorly to visualize bulging capsule.
POSTOPERATIVE CARE

- For most conditions addressed with ankle arthroscopy, patients are placed in a well-padded short-leg splint. Five to seven days postoperatively the splint is removed and patients are allowed weight bearing as tolerated in a brace.
- In cases where drilling, microfracture, or retrograde bone grafting of an osteochondral lesion is performed, a period of non-weight-bearing is emphasized.
- Early range of motion is always encouraged unless a fusion is performed.

OUTCOMES

- Ankle arthroscopy allows the surgeon to address a myriad pathology with a minimally invasive technique. Success of outcomes varies according to underlying pathology but is generally in the range of 85% good to excellent.
- The complication rate ranges from 0.7% to 17%, with neurologic injuries accounting for most of these problems. The superficial peroneal nerve is the most commonly injured nerve, followed by the sural nerve and then the saphenous nerve.
- In one study using the posterior coaxial portals in 29 ankles, no complications were observed at an average 45 months of follow-up.\(^1\)

COMPLICATIONS

- Neurovascular injury
- Cartilage damage
- Reflex sympathetic dystrophy
- Sinus tract formation
- Infection
- Skin necrosis

REFERENCES

DEFINITION
- The terminology of osteochondral lesions is not uniform: transchondral fractures, osteochondral fractures, flake fractures, and osteochondritis dissecans (OCD) are used to describe the same entity. Most recently, “osteochondral lesions of the talus” (OLT) has emerged as the most common term used to describe these lesions.
- OLTs are characterized by aseptic separation of a fragment of articular cartilage, with or without attached subchondral bone.
- The causes for OLTs remain controversial. The most important distinction to make is if the lesion is acute or chronic.

ANATOMY
- The talar body is trapezoidal. The anterior surface is on average 2.5 mm wider than the posterior surface. The dome is covered by the articular surface, which articulates with the tibial plafond. The medial and lateral facets articulate with the medial and lateral malleoli.
  - About 60% of the talar surface is covered by articular cartilage.
  - Most of the blood supply enters through the neck of the talus via the sinus tarsi.
  - Biomechanical studies have shown that the talar cartilage is stiffer at the postero-lateral corner, whereas the maximum thickness is found at the posterolateral corner.
  - The tibial cartilage is 18% to 37% stiffer than the corresponding sites on the talus.

PATHOGENESIS
- Lateral lesions are most frequently caused by acute trauma, with a common mechanism being a dorsiflexed ankle forced into inversion. This results in impaction of the talus on the fibula.
  - In our experience, lateral lesions are often located in the anterior part of the talus dome. They tend to be shallower than medial lesions.
- Medial lesions are mostly associated with a single or repetitive supination trauma (microtrauma).
  - Impaction of the medial talus on the tibia with a plantarflexed ankle forced to hindfoot inversion combined with external rotation is regarded as the causative mechanism.
  - Medial lesions are more common (inversion ankle sprains are the most common sports injury) than lateral lesions and occur mostly in the middle or posterior third of the talus. These lesions appear cup-shaped and deeper than lateral lesions.
- Injury to the talus dome associated with supination trauma to the ankle generally exhibits one of two trends in recovery:
  - In most, swelling and pain resolve expeditiously.
  - Occasionally, swelling and pain persist. In these cases, our investigations using MRI suggest that 20% of these ankles with persistent pain and swelling have an identifiable bone bruise on the medial talar dome.
- The question is the long-term effect of an episode of subchondral effusion (hemorrhage?) on the cartilage layers: Minor trauma on the tide zone with a prolonged separation?
- In our experience, chronic ankle instability creates a medial talar dome lesion with an abrasive character that suggests a repetitive insult. Unlike the classic OCD with a subchondral origin of the pathology, these deteriorations of the cartilage derive from a classic mechanical overload. The long-term damage is a full-thickness cartilage lesion at the medial talus and tibia plafond with varus hindfoot alignment. Medial lesions may be detected bilaterally, mostly with coincidence of bilateral ankle sprains.
- In contrast to chronic osteochondral lesions occurring as a result of repetitive trauma, acute osteochondral injuries result in an acute separation of an osteochondral fragment.
- Other reported causes for OLTs are genetic predisposition and endogenous factors. These causes lack meaningful evidence-based support and represent little more than theories.

NATURAL HISTORY
- Initially, the patient experiences ankle pain with impact activities such as jogging and sports that subsides immediately with rest.
- With time, increasing ankle pain generally forces the patient to stop impact sports activities. The time frame varies from patient to patient based on the patient’s pain threshold and age.
- Some cases have an identifiable traumatic incident (ie, ankle sprain) where an initially inapparent lesion is detected and the patient never returns to a pain-free state. (For us this is an interesting phenomenon: does the lesion cause the pain or is there a psychosomatic influence once the lesion is detected on the imaging study?)
- Some OLTs are incidentally discovered with screening imaging studies (radiographs or MRI scans). For instance, an imaging study is obtained for an acute ankle sprain and an obviously nonacute OLT is noted. These patients have an anticipated normal healing course of the ankle injury with complete subsidence of pain and swelling and should never be treated for the asymptomatic OLT.
- Over the past 20 years our clinical experience (H.T.) in treating OLTs suggests that there is no evidence to support that the natural history of untreated OLTs is the development of osteoarthritis of the ankle. We thus view surgical management of OLTs as one of pain relief and not as a salvage procedure to prevent osteoarthritis of the ankle joint.
- McCullough and Venugopal found that in five of six patients treated conservatively for OLTs, radiologic assessment at a mean follow-up of nearly 16 years (range 7 to 28 years) showed that the lesions had failed to heal and that in each instance the ankle joint was relatively asymptomatic, without evidence of diffuse degenerative changes.
PATIENT HISTORY AND PHYSICAL FINDINGS

- Acute OLTs must be ruled out after traumatic events when an OLT or osteochondral fracture is suspected.
- In most cases patients complain of chronic ankle pain with or after sports activities. Swelling and stiffness are accompanied in advanced cases with more constant pain. Occasionally, but not always, mechanical symptoms are present, including catching, locking, and giving way.
- The severity of symptoms may not correlate with the severity of the lesion.
- Physical examination is relatively nonspecific in OLTs.
  - By having the patient plantarflex the foot and ankle, the anterior aspects of the talar dome can be palpated at the anteromedial and anterolateral joint space. Tenderness in the specific area may indicate an osteochondral lesion.
  - Tenderness behind the medial malleolus by having the patient dorsiflex the ankle may indicate a posteromedial lesion.
  - Range of motion of the ankle is tested with the knee flexed to eliminate restriction by shortened gastrocnemius muscles. Range of motion is limited only in case of ankle synovitis and effusion.
  - The examination should also include evaluation of associated pathology, taking into account the differential diagnosis.
    - Bony structures, tendons, ligaments, and soft tissue structures should be palpated and tested against resistance to discern tenderness of the specific anatomic part.
    - Ligamentous instability or laxity is assessed with the anterior drawer test and passive varus or valgus stress test.
    - Pushing the ankle against resistance helps identify inflammation or partial tears of tendons of the contracted muscles.
    - Palpation of pulses and neurologic assessment should be part of every examination.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Standard ankle plain film radiographs should include AP, lateral, and mortise views. However, only 50% to 66% of osteochondral defects can be visualized by plain film radiographs alone. The radiologic signs vary from a small area of compression of subchondral bone to a detached osteochondral fragment.
  - The four-stage classification system by Berndt and Harty is still the gold standard based on radiologic appearance:
    - Stage I: Compression lesion, no visible fragment
    - Stage II: Fragment attached
    - Stage III: Nondisplaced fragment without attachment (FIG 1)
    - Stage IV: Displaced fragment
    - Stress view radiographs are frequently recommended if instability is suspected. However, a thorough clinical examination is more important and in most cases is sufficient for assessment.
    - A CT scan offers more accurate staging and characterization of the lesion, with clear definition of the exact dimensions of the osseous portion of the lesion, but subjects the patient to relatively high radiation. We recommend and use limited CT studies with minimal radiation exposure to the patient and sufficient characterization of the OLT.
  - MRI is an ideal screening tool and, in our opinion, the method of choice for all patients with suspected OLTs. MRI defines occult injuries of the subchondral bone and cartilage that may not be detected with routine radiographs. Furthermore, the MRI is accurate in diagnosing associated stress fractures and stress reactions—for example, in the medial malleolus. While MRI may demonstrate associated edema in the talar body, in our hands accurate sizing of the OLT is feasible.
  - Dipaola et al developed an MRI classification system based on Berndt and Harty’s original radiographic system:
    - Stage I: Thickening of articular cartilage and low signal changes
    - Stage II: Articular cartilage breached, low-signal rim behind fragment indicating fibrous attachment
    - Stage III: Articular cartilage breached, high-signal changes behind fragment indicating synovial fluid between fragment and underlying subchondral bone (FIGS 2 AND 3).
    - Stage IV: Loose body

DIFFERENTIAL DIAGNOSIS

- Degenerative joint disease (any origin)
- Soft tissue or bony impingement on the ankle joint
- Ankle or subtalar instability
Immobilization with partial weight bearing has healing potential only for fresh traumatic osteochondral lesions. In an area with little perfusion, some contact pressure is necessary to create a healing response.

- We rarely use cast or walker boot immobilization because we believe that ankle motion is important. The occasional cast or boot is applied for only brief periods (2 weeks) to reduce pain and patient insecurity. Cast immobilization is associated with inferior results compared with restricting the activity of the patient by partial weight bearing. Flick and Gould concluded that therapy of 4 to 6 weeks with cast immobilization is inadequate immobilization, resulting in poor results for most transchondral fractures.

- In summary, nonoperative treatment is applied for every patient who is opposed to surgical intervention. There is no time frame when a lesion has to be operated on to prevent deterioration. Pain is the benchmark, not the radiographic or MRI findings. In our opinion, an OLT that is primarily cystic and has an intact cartilage surface suggested on MRI (if detectable) should prompt nonoperative rather than operative management.

- If deterioration or no improvement is evident after a period defined by the patient, the optimal means of determining the status of the articular cartilage is arthroscopic probing of the OLT, which is useful in determining the appropriate surgical procedure.

**SURGICAL MANAGEMENT**

- In our opinion, asymptomatic OLTs should not be treated. Many incidentally discovered OLTs do not become symptomatic and are unrelated to the trauma that prompted the imaging study that led to the detection of the OLT. When, however, the OLT is the most likely source of pain and nonoperative treatment has failed, we recommend arthroscopic surgery for evaluation and treatment of the OLT.

- Retrograde drilling is suggested for a symptomatic subchondral cyst with an overlying intact cartilage surface. High levels of evidence or grades of recommendation for retrograde drilling do not exist. Our theory for the mechanical pain from OLTs is an irreversible separation in the cartilage’s tide zone. Drilling may decompress edema but may create heat necrosis and cystic degeneration. Moreover, without 3D CT or navigation, drilling may miss the smaller to intermediate lesions. If the chondral surface is found to be softened and is easily detachable, unstable cartilage and fibrous tissue have to be débrided.

- Our preferred surgical management for stage II to IV OLTs is microfracture to stimulate fibrocartilage formation. After débridement of unstable cartilage in the OLT, microfracture awls designed for small joints are penetrated into the subchondral bone to open the zone of vascularization. Blood from within the talus escapes through the subchondral bone and leads to clot formation in the lesion. This clot contains pluripotent, marrow-derived mesenchymal stem cells that typically produce a fibrocartilage repair with varying amounts of type II collagen content.

- The microfracture technique using dedicated small-joint awls avoids the risk of thermal necrosis associated with other marrow stimulation techniques such as abrasion or drilling. Moreover, all lesions may be accessed without more invasive steps such as transtibial drilling or osteotomy of the medial malleolus.

**NONOPERATIVE MANAGEMENT**

- The approach and objectives in nonoperative treatment of OLTs vary from those of surgical management.

- In children and adolescents, the goal is to reverse the cartilage separation and to treat the pain. Partial weight bearing (not unloading) of about 15 kg for 2 to 3 months and nonsteroidal anti-inflammatory agents (NSAIDs) at appropriate doses adjusted for age and weight for 1 to 2 months to relieve the patient’s pain are important from physical and psychological standpoints. Given the advantages shown in clinical and experimental trials, we recommend use of the combination of chondroitin and glucosamine sulfate for at least 6 months. We also encourage the daily use of moist heat to enhance vascularity to the ankle and talus. In select cases of extensive talar body edema, we have observed, based on anecdotal experience, that hyperbaric oxygen (HBO) therapy (20 dives, 20 minutes each) results in resolution of edema and pain. We favor low-impact exercise such as biking and swimming for about 1 year. Regardless of MRI findings, the young patient should gradually return to age-appropriate activities once she or he is pain-free. We recommend yearly serial MRI and clinical examinations to monitor talar body status.

- While osteochondral transfer systems and autologous chondrocyte implantation are accepted salvage procedures, to date we lack an optimal reconstruction of an OLT. Nonoperative treatment for OLTs is the treatment of choice if the adult patient has minor complaints. The goal of nonoperative treatment is not to ameliorate the cartilage lesion but to make the ankle pain-free and resilient. We recommend NSAIDs, physiotherapy, ice or moist heat applications, well-cushioned shoes, biking, swimming, and cross-training for 6 months.

- We allow our adult patients with OLTs activity to tolerance. Immobilization with partial weight bearing has healing potential only for fresh traumatic osteochondral lesions. In an area with little perfusion, some contact pressure is necessary to create a healing response.

Subtalar joint pathologies (ie, chondral lesion, subtalar impingement lesion)

- Tendinitis or partial rupture of the tibialis posterior, tibialis anterior, or peroneal tendons

Tarsal coalition (talocalcaneal)

- Stress fracture (medial or lateral malleolus; talus)

**FIG 3 • Sagittal MRI (T2-SE-2000/90) showing an osteochondral lesion stage III.**
If the microfracture technique failed to relieve symptoms, repeat microfracture has been shown to be effective in select cases. However, in our hands, particularly if we performed the index microfracture procedure, we recommend salvage with a matrix-based autologous chondrocyte implantation (MACI).

Based on first-generation results after injecting the cultured cells under a periosteal flap, this appeared to be a viable alternative when treating osteochondral or chondral lesions of the talus. MACI with cultured cells in scaffolds seems to be more promising and technically less demanding, with good and excellent short-term results. However, costs for the procedure are high, the approach is more invasive, and longer-term results remain to be evaluated to prove superiority over microfracture technique. Moreover, in the United States, MACI lacks FDA approval.

Osteochondral autograft transfer (OATS) or mosaicplasty is an option in the repair of severe osteochondral lesions with a significant lack of subchondral bone or in cystic lesions. The osteochondral plugs can be harvested by either open arthrotomy or arthroscopy of the knee. The option of local osteochondral grafting has also been reported. Major problems with these techniques include the different characteristics of knee (donor) and ankle (recipient) cartilage (different thicknesses and radii of curvature), which may lead to edge loading and graft deterioration. Donor site morbidity can be significant, resulting in a decline of knee function and problems in performing activities of daily living.

Preoperative Planning

Review of all imaging studies, especially MRIs, is in our opinion most important for preoperative planning. The OLT size, location, topical geography, and depth must be identified to determine the correct approach and technique.

Ankles must be inspected for severe swelling, warmth, or erythema. We consider elevated blood sample parameters that indicate an acute inflammatory process a contraindication to surgical intervention for OLT management. In our experience, any OLT in any location within the ankle can be treated arthroscopically through standard portals.

In some cases, an accessory posterolateral portal facilitates access to posterior OLTs in relatively tight ankles.

Examination under anesthesia allows for better assessment of coexisting ankle instability.

In case of lateral ligamentous instability, lateral ligament stabilization should be performed along with OLT management. Ankle instability may increase the contact forces and shear stresses on the OLT.

Positioning

The procedure is performed under general anesthesia with a tourniquet placed at the thigh.

The patient is preferably positioned with a leg holder that allows the gastrocnemius–soleus complex to be fully relaxed.

We recommend that the patient be positioned in the lateral position if a posterolateral approach may need to be performed.

Noninvasive ankle distraction may be performed using bandages.

However, in our experience, most OLTs may be safely performed without distraction.

Approach

We use standard anteromedial and anterolateral arthroscopic portals. The anteromedial portal enters the ankle...
between the medial malleolus and the talar dome 0.5 to 1 cm distal to the joint line and just medial to the anterior tibial tendon. The anterolateral portal enters the joint between the fibula and talus at the same level as the medial portal, lateral to the common extensor tendon.

- If necessary, the posterolateral portal is placed adjacent to the Achilles tendon and behind the peroneal tendon, slightly below the level of the joint line. A Kirschner wire can be directed under vision of the arthroscope from the anteromedial portal posteriorly to find the same location (Wessinger Rod technique). The patient must be fully relaxed and the joint adequately distracted and distended.
- In addition, a superomedial portal located 1 cm above the joint line, medial to the tibialis anterior tendon, might be helpful to achieve more perpendicular angles for microfracturing (FIG 7).

**FIG 7 • Superomedial portal for better angles for microfracturing.**

### ARTHROSCOPY

- Fill the joint with 20 mL saline solution through the anteromedial portal (TECH FIG 1).
- We recommend using a 2.5-mm or 2.7-mm arthroscope, with 25- to 30-degree and 70-degree angled lenses, needed to assess and treat defects in all areas of the joint (TECH FIG 2).
- Perform a limited synovectomy in all cases. This enhances visibility during the procedure and allows the surgeon to remove inflamed synovium that may contribute to ankle pain and swelling.
- Systematically inspect the ankle and document all pathology.
- Remove loose bodies, if present.
- We assess and probe all articular surfaces of the ankle, including the talar dome, medial and lateral gutters, and the tibial plafond.

**TECH FIG 1 • Filling the joint with 20 mL saline solution.**

**TECH FIG 2 • 2.5-mm and 2.7-mm arthroscopes for ankle arthroscopy.**

### PREPARATION OF THE LESION

- Identify the lesion with a probe (TECH FIG 3).
- Address all unstable cartilage and fibrous tissue of the OLT and the cartilage that lies immediately adjacent to the defect with débridement and curettage (TECH FIG 4).
- Create sharp, perpendicular margins to optimize conditions for the attachment of the marrow clot.
- Completely remove the calcified cartilage layer with a burr.
**MICROFRACTURE**

- The microfracture technique is performed if the subchondral bone layer is healthy and intact.
- Arthroscopic awls of different angles permit appropriate perpendicular access to all areas of the prepared OLT. Place the microfractures about 3 to 4 mm apart and 2 to 4 mm deep; fat droplets indicate that the subchondral bone has been adequately penetrated.
- We ensure that the awl is always placed perpendicular to the surface and that penetration of subchondral bone is performed judiciously to maintain the subchondral bone plate integrity and architecture (TECH FIG 5).
- Before removing the arthroscope from the ankle, we release the tourniquet and stop the flow of saline through the ankle to confirm that blood is indeed escaping from the talus into the talar defect (TECH FIG 6).
- We do not routinely use a drain for arthroscopy. Portals are closed in standard fashion.

**LESIONS ASSOCIATED WITH SUBCHONDRAL CYSTS (CANCELLOUS BONE TRANSLATION TECHNIQUE)**

- In OLTs associated with subchondral cysts, we débride the damaged, unhealthy cartilage, perform microfracture, and use the cancellous bone translation technique.
- Fenestrate the cortex at the opposite side, and under fluoroscopic visualization translate the cancellous bone (like a snowplow) with a curved 4-mm AO plunger into the cyst.
PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take care to address associated pathology. In case of lateral ligament instability, a stabilizing procedure has to be added to guarantee the success of the microfracture.</td>
<td>Use a superomedial portal to achieve perpendicular penetration of the awl. Use a swan-neck-shaped awl. Postero lateral approach with the Wessinger Rod technique: A rod is inserted through the anteromedial portal in a postero lateral direction to identify the optimal entry for the postero lateral portal. The calcified cartilage layer must be thoroughly removed by a small abrader to provide optimal amount and attachment of repair tissue.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Compressive bandaging is applied up to the thigh. The ankle is elevated and immediate cryotherapy is applied.
- Continuous passive motion (CPM) from the first day, as tolerated by pain and swelling, is used for 6 to 8 hours per day for 4 to 6 weeks.
- Partial weight bearing of 15 kg is allowed for the first 6 weeks, 30 kg for the next 2 weeks. If the ankle is pain-free, then weight bearing can be advanced as tolerated.
- Biking, swimming, and cross-training are permitted after 8 weeks. Impact sports are permitted after 5–6 months if the ankle is pain free with normal activities. Otherwise, we recommend to wait 10–12 months after surgery.
- Dietary supplements (glucosamine and chondroitin sulfate) may have beneficial effects for cartilage regeneration (6 months).

OUTCOMES

- The results of prospective studies have shown significant improvement 2 years after microfracture of the talus.5
- Ninety-five percent of the ankles with osteochondral lesions had excellent or good results.
- Outcomes did not differ significantly between patients older than 50 years versus younger patients.
- Location and grade of the defect showed no statistically significant impact on the results.
- MRI studies showed regeneration of tissue in the microfractured area. Subchondral signal changes were observed in almost all postoperative images.5
- No distinct correlation between clinical and imaging results was detected.5

COMPLICATIONS

- Development of ossifications at the anterior tibia with subsequent restriction in dorsiflexion
- Damage to the deep peroneal nerve with subsequent hypoesthesia in the distribution area
- Infection
- Deep vein thrombosis
- Arthrofibrosis

REFERENCES

DEFINITION
- Posterior ankle impingement syndrome (PAIS) is a clinical disorder characterized by posterior ankle pain that occurs during forced plantarflexion.13,14

ANATOMY
- The posterior ankle region comprises the soft tissue structures situated behind the tibiotalar joint and the dorsal aspect of the calcaneus.
- This region extends superiorly to a horizontal line 4 cm above the tip of the lateral malleolus and inferiorly to a curved line 4 cm below the lateral malleolus.3
- The Achilles tendon constitutes the central axis of this region. Neurovascular and musculoskeletal structures in the medial and lateral retromalleolar sulcus surround the calcaneal tendon.
- The posterior talar process protrudes posterior to the articular surface of the ankle joint. The body of the posterior process extends both posteriorly and medially from the talus and has two projections designated as the posteromedial process and posterolateral process. These processes are divided by a groove containing the flexor hallucis longus (FHL) tendon (FIG 1).
- The posterolateral process, injuries of which are the most common cause of posterior ankle impingement syndrome, is also called the trigonal process.
- When the posterolateral process remains separated from the talus, it is called os trigonum.

PATHOGENESIS
- The etiology of the posterior ankle pain in forced plantarflexion is varied and may involve any part of the posterior ankle anatomy. PAIS compression pathogenesis has been likened to a “nut in a nutcracker”9 (FIG 2).
- Trigonal process pathology includes fractures, disrupting of a pre-existing synchondrosis, or compression/impingement phenomena.
- FHL tendon pathology, including stenosing tenosynovitis and impingement from a prominent posterior talar process, is another cause of PAIS.
- PAIS may be produced by intrinsic tibiotalar pathology resulting from ankle trauma. Articular chondral damage or bony injury may cause pain in extreme plantarflexion.
- Posttraumatic thickened, inflamed, and sometimes calcified soft tissues in the posterior ankle, including the capsule, synovium, and ligaments, may contribute to chronic impingement with ankle plantarflexion.
- A prominence of the posterior calcaneal process also can impinge on the hindfoot.
- In posterior ankle impingement, combined pathologies are common. For example, ballet dancers frequently present with associated trigonal process injury with FHL tenosynovitis.8

NATURAL HISTORY
- Once injured, patients typically compensate for the loss of plantarflexion by placing the foot in an antalgic position. For example, dancers may begin to assume a more inverted en pointe position to decrease impingement of the posterior structures; doing so, however, may place increased loads on the

Table 1

<table>
<thead>
<tr>
<th>Etiologic Classification of Posterior Ankle Impingement Syndrome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigonal process pathology</td>
</tr>
<tr>
<td>Fracture (acute or chronic)</td>
</tr>
<tr>
<td>Synchondrosis injury</td>
</tr>
<tr>
<td>True compression</td>
</tr>
<tr>
<td>Flexor hallucis longus dysfunction</td>
</tr>
<tr>
<td>Tenosynovitis</td>
</tr>
<tr>
<td>Tibiotalar pathology</td>
</tr>
<tr>
<td>Posterior capsuloligamentous injuries</td>
</tr>
<tr>
<td>Osteochondritis</td>
</tr>
<tr>
<td>Fractures</td>
</tr>
<tr>
<td>Synovial cysts</td>
</tr>
<tr>
<td>Subtalar pathology</td>
</tr>
<tr>
<td>Osteochondritis</td>
</tr>
<tr>
<td>Arthritis</td>
</tr>
<tr>
<td>Others</td>
</tr>
<tr>
<td>Calcified inflammatory tissue</td>
</tr>
<tr>
<td>Anomalous muscles</td>
</tr>
<tr>
<td>Tumors</td>
</tr>
<tr>
<td>Prominent calcaneus posterior process</td>
</tr>
<tr>
<td>Combined</td>
</tr>
<tr>
<td>Flexor hallucis longus tenosynovitis and os trigonal synchondrosis injury</td>
</tr>
</tbody>
</table>

FIG 1 • Posterior talar process anatomy. Superior view of the talus shows the close relationship of the flexor hallucis longus tendon and the trigonal process.
anterior tibiofibular ligament, which thus predisposes the dancers to frequent ankle sprains.
- Calf strain and contractures, plantar foot pain, and toe curling are also typical compensatory problems in dancers that result from efforts to force the foot into a better en pointe position.7
- Subtalar joint pathology, especially in posterior articular facets, can produce posterior ankle pain in forced plantarflexion. Furthermore, in chronic PAIS, with limited ankle motion, the subtalar joint may show degenerative changes as a result of higher compensatory loads imposed to maintain ankle range of motion (ROM) during closed kinetic athletic activities.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The patient usually reports chronic or recurrent posterior ankle pain caused or exacerbated by forced plantarflexion or push-off activities, such as dancing, kicking, downhill running, and walking on high heels. Biomechanical analysis showed that ankle plantarflexion is required during the swing limb phase and foot contact with the ball of kicking.2 Pain is usually deep and mechanical.
- There may be a recent or remote history of ankle trauma, but overuse should be considered.
- Tibiotalar, subtalar, and hallux ROM should be measured and recorded.
- The diagnostic approach should be based on cause-related conditions.
- The forced plantarflexion test tries to reproduce the typical painful motion of PAIS. It also allows one to estimate the passive ROM limitation.
- The Maquirriain test tries to reproduce the typical painful motion of PAIS in a closed position. It also allows one to estimate the passive ROM limitation.
- The one-leg hop test provides valuable functional information to rule out Achilles tendon pathology.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- A complete history and physical examination is often sufficient to diagnose PAIS. However, ancillary imaging studies should be done to establish the cause, thus allowing proper and timely treatment.
- Ankle radiographs should be obtained routinely with lateral view clearly defining trigonal process anatomy. This projection also is used to measure ankle ROM.14
- Demonstration of the presence of an os trigonum by conventional radiographs is not necessarily indicative of current clinical relevance.13 Lateral views may show fracture lines, but they cannot differentiate chronic or acute pathology.
- Bone scintigraphy is a helpful diagnostic tool. Increased activity is present in all patients with an acute fracture of the trigonal process and synchondrosis disruption.15 A normal bone scan virtually rules out trigonal process pathology.11
- MRI is considered the technique of choice to investigate patients with PAIS5,20 because it enables determination of the nature of the osseous and soft tissue lesions and excludes other causes of posterior ankle pain (FIG 3A,B). Bone contusions of the trigonal process are prevalent in individuals with PAIS5 (FIG 3C).
DIFFERENTIAL DIAGNOSIS

- Misdiagnosis is common among patients with posterior ankle pain. Frequently patients had been previously treated for a Achilles tendinopathy.
- When a patient has pain in the posterolateral aspect of the ankle, the differential diagnosis includes Achilles tendinopathy, peroneal tendinopathy or tear, retrocalcaneal bursitis, Sever’s disease, and sural neuralgia.
- When the patient has pain in the posteromedial aspect of the ankle, the differential diagnosis includes a posterior deltoid sprain, osteochondral lesion of the talus, soleus syndrome, posterior tibial tendinopathy, tarsal tunnel syndrome, and posteromedial tarsal coalition.

NONOPERATIVE MANAGEMENT

- Initial treatment for PAIS due to overuse includes rest, non-steroidal anti-inflammatory drugs, cryotherapy, and avoidance of activities that require forced plantarflexion.
- Casting is rarely indicated, but acute articular or bony injuries may benefit from a brief period of immobilization and limited weight bearing.
- Physical therapy is indicated to improve ankle and subtalar ROM, as well as strength and flexibility of regional muscles.
- Successful nonoperative treatment has been reported in about 60% of patients with PAIS.
- Corticosteroid injection for trigonal process pathology and other chronic causes of PAIS can effectively provide pain relief and should be done at least once before surgery is undertaken.

SURGICAL MANAGEMENT

- Indications for surgical intervention include failure of nonsurgical treatment and rehabilitation exercises and a positive response to a diagnostic posterior ankle injection.
- Simultaneous bilateral posterior ankle surgery is not recommended. While bilateral mechanical posterior ankle impingement is possible, this presentation should prompt a careful workup for systemic causes of posterior ankle pain.

Preoperative Planning

- All imaging studies are reviewed.
- The ankle–hindfoot score from the American Orthopaedic Foot and Ankle Society (AOFAS) scale is determined.
- Ankle and subtalar ROM are tested under anesthesia.

Positioning

- The patient is placed in a prone position and a tourniquet is applied on the thigh. Both feet are suspended off of the end of the bed, and a small triangular support is placed under the lower leg, making it possible to move the ankle freely and allow fluoroscopic examination. A support is placed at the ipsilateral side of the pelvis to allow slight rotation of the operating table in a safe manner when needed.
- The surgeon must be aware of the potential complications of this position, such as damage to the genitalia, brachial plexus, and ulnar nerves, among other structures.

Approach

- Posterior ankle disorders can be approached by either an open or endoscopic technique.
- Open medial and lateral approaches have been described, with both approaches carrying an inherent risk of damaging neurovascular structures. A posterolateral approach should be used to treat isolated bony impingement. A medial approach should be used when both FHL tendinopathy and bony impingement are being treated.
- In our experience, hindfoot endoscopy is an advanced procedure with a learning curve that needs to be overcome by practicing on cadavers. The difficulty with endoscopic procedure is the initial orientation in the posterior ankle to achieve a safe access to the pathologic structures.

TECHNIQUES

POSTEROMEDIAL APPROACH

- A 4-cm curvilinear incision is made posterior to the medial malleolus at the level of the superior border of the calcaneus, following the underlying course of the neurovascular bundle.
- The bundle and the FHL are retracted posteriorly with a blunt retractor.
- The bony disorder of the posterior talar process (ie, symptomatic os trigonum) is removed.
- The area is rasped smooth, and hypertrophic capsulitis and inflamed tissue are débrided.
- Finally, the FHL excursion is checked and the tunnel is released as needed from proximal to distal to the level of the sustentaculum tali.

POSTEROLATERAL APPROACH

- A curvilinear incision is begun at the posterior ankle mortise in line with the posterior border of the peroneal tendons so that it lies anterior to the sural nerve.
- A capsulotomy is performed with the ankle in slight dorsiflexion, and the lateral talar process or os trigonum is identified lateral to the tunnel. According to Hamilton et al, the fibro-osseous tunnel of the FHL tendon cannot be released safely from the lateral side.
- Adequate osseous decompression is assessed by plantarflexing the foot and palpating for any bone-on-bone impingement.
**POSTERIOR ANKLE ENDOCOPY**

- According to van Dijk’s technique, the posterolateral portal is made first at the level or slightly above the tip of the lateral malleolus, just lateral to the Achilles tendon; a clamp is directed anteriorly, pointing in the direction of the first interdigital space (TECH FIG 1A).

- When the tip of the clamp touches bone, it is exchanged for a 4.5-mm arthroscope shaft with blunt trocar pointing in the same direction. The blunt trocar is situated extra-articularly at the level of the ankle joint, but it is not necessary to enter the joint capsule.

- The posteromedial portal is made just medial to the Achilles tendon at the same level as the posterolateral portal in the horizontal plane.

- A clamp is introduced and directed toward the arthroscope shaft to guide the anterior travel of the clamp.

- The blunt trocar is exchanged for a 30-degree 4.0-mm scope using a lateral view direction to prevent lens damage. The scope in pulled backward until the tip of the clamp comes into view.

- The fatty tissue and adhesions overlying the joint capsule are partially removed using a 3.5-mm full-radius shaver.

The posterior compartment of the subtalar joint can be visualized, including the posterior talar process and the FHL tendon. The FHL is an important landmark to prevent damage to the more medially located neurovascular bundle.

- By applying manual distraction to the os calcis, the posterior compartment of the ankle joint opens and allows better visualization. The talar dome can be inspected over almost its entire surface as well as the complete tibial plafond. An osteochondral defect or subchondral cystic lesion can be identified, débrided, and drilled.

- Removal of a symptomatic os trigonum or a nonunion of a fracture of the posterior talar process involves partial detachment of the posterior talofibular ligament and release of the flexor retinaculum, both of which attach to the posterior talar prominence (TECH FIG 1B,C).

- Releasing the FHL involves detachment of the flexor retinaculum from the posterior talar process.

- Bleeding is controlled, the new ankle range of motion is checked and recorded, and portals are sutured closed.

**TECH FIG 1**

A. Cross-section of the ankle joint at level of the arthroscope. (1) The arthroscope is placed through the posterolateral portal, pointing in the direction of the webspace between the first and second toe. (2) The full-radius resector is introduced through the posteromedial until it touches the arthroscope shaft. (3) It then glides into an anterior direction until it touches bone. B. Posterior left ankle endoscopic view. The os trigonum synchondrosis was released, and the ossicle is ready for excision. The FHL tendon is marked. C. Posterior ankle endoscopic view after trigonal process resection.
POSTOPERATIVE CARE

- An elastic bandage is applied, and the ankle is placed in a walker boot.
- Weight bearing is allowed after 2 or 3 days. Chondral lesion débridement requires longer non–weight-bearing period.
- Early motion (especially plantarflexion) is emphasized.

OUTCOMES

- Most experts agree that results of surgery for PAIS are highly satisfactory.1,4,6,8–10,14,19,21
- Outcomes after endoscopic treatment of PAIS reported in the literature compare favorably with results of open surgery.19 Advantages include decreased morbidity, less scarring, and the potential for faster recovery.19,21
  - In a series of 55 patients treated endoscopically, van Dijk et al19 reported an average improvement of the AFOS score from 75 points preoperatively to 90 points after surgery.
  - Results may vary according to the cause of symptoms. Patients treated for PAIS caused by overuse have better results than those treated following trauma.19 Furthermore, patients with osseous impingement do better postoperatively than do patients with soft tissue impingement.

COMPLICATIONS

- Sural nerve damage (after posterolateral approach)
- Peroneal tendon fibrosis (after posterolateral approach)
- Tibial nerve injury (after posteromedial approach)
- FHL injury through lateral approach; also during endoscopic technique
- Reflex sympathetic dystrophy
- Infection
- Wound healing problems
- Ankle stiffness
- Deep vein thrombosis

REFERENCES

Because of their nature and deep location, posterior ankle problems pose a diagnostic and therapeutic challenge. Arthroscopic evaluation of posterior ankle problems by means of routine ankle arthroscopy using an anteromedial, anterolateral, and posterolateral portal is difficult because of the shape of the ankle joint. In cases in which the ankle ligaments are lax, it is possible to visualize and treat the pathology of the ankle joint itself, but periparticular or extracapsular posterior pathologic conditions are not accessible through conventional arthroscopic portals.

A two-portal posterior endoscopic approach with the patient in the prone position affords excellent access to the posterior ankle, the subtalar joint, and the periparcticular and extra-articular structures.

**ANATOMY**

- Posterior ankle arthroscopy and hindfoot endoscopy enable visualization and accessibility to the posterior half of the tibiotaral joint, the subtalar joint, and extra-articular structures such as the os trigonum, the flexor hallucis longus (FHL) tendon, and the posterior syndesmotic ligaments.
- The posterior intermalleolar ligament, also called the tibial slip or marsupial meniscus, is a structure with consistent location but varying size and width. It is distinct from the posteroinferior tibiofibular ligament and separated from it by a small gap filled with synovial tissue.
- The os trigonum is a secondary center of ossification of the talus. It is present in 1.7% to 7% of normal feet. When this ossification center remains separate from the posterolateral process of the talus (the trigonal process or the Stieda process), it is referred to as the os trigonum. The prevalence of unilateral and bilateral (ununited) os trigona is 10% and 1.402%, respectively.
- The FHL tendon originates in the posterior leg then runs posterior to the FHL tendon in two specimens.
- The posterior intermalleolar ligament (tibial nerve and posterior tibial artery) are consistently medial to the FHL.
- The FHL tendon throughout its course. Instruments introduced from the posterolateral portal do not risk injuring the neurovascular bundle provided they remain lateral to the FHL.
- Sitler et al dissected 13 cadavers and found that the tibial nerve was located posterior to the FHL tendon in two specimens.
- A posteromedial portal located 1 cm proximal to the level of the tip of the lateral malleolus is on average 2.9 mm further removed from the medial neurovascular bundle than a portal placed 1 cm more proximally.

**PATHOGENESIS**

- Posterior ankle pain may be a result of:
  - Posterior ankle impingement or os trigonum syndrome
  - FHL, posterior tibial, or peroneal tendinopathy
  - Posttraumatic calcifications or exostoses
  - Bony avulsions
  - Tibial or subtalar loose bodies
  - Tibial or subtalar osteochondral lesions or arthrosis
  - Any combination of these entities
- Overuse injuries play an important role in the pathogenesis of posterior ankle pain.
- Repetitive minor trauma in the ankle, as seen in athletes, can induce posterior ankle and/or hindfoot osteophyte formation.
- Typically, to produce symptoms, an os trigonum must be disturbed by some traumatic event, such as a supination or forced plantarflexion injuries, dancing on hard surfaces, or pushing beyond physiologic limits.
- The pain is thought to be a result of:
  - Symptomatic motion between the relatively unstable os trigonum and talus
  - Compression of thickened joint capsules (intermalleolar ligament)
  - Impinging scar tissue between the os trigonum and tibia
  - Compression between os trigonum and calcaneus (referred to as “dancers’ heel”)
  - Irritation of the FHL tendon that courses between the os trigonum and the medial tubercle of the talus
- FHL tendinopathy is usually attributable to stenosing tenosynovitis rather than tendinosis or rupture; it has only rarely been reported at sites other than the posteromedial ankle. However, immunohistochemical studies have suggested an avascular zone of the tendon in the segment of tendon that passes behind the talus.

**NATURAL HISTORY**

- Patients present with posterior ankle pain.
- Posterior ankle impingement can be caused by overuse (chronic pain) or trauma (acute pain). It is important to differentiate between these two, because posterior impingement from overuse has a better prognosis.
- Overuse injuries typically occur in ballet dancers, soccer players, and downhill runners.
- In chronic conditions, stenosing tenosynovitis of the FHL tendon may coexist with os trigonum syndrome; this leads to poorer outcome if surgical treatment is delayed.
- Nonsurgical treatment for os trigonum syndrome is successful in approximately 60% of patients.

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Patients experience deep pain in the posterior aspect of the ankle joint, mainly with forced plantarflexion.
On examination, there is pain on palpation of the posterior aspect of the talus.

During the passive forced plantarflexion test, the investigator can apply a rotational movement on the point of maximal plantarflexion, thereby “grinding” the posterior talar process or os trigonum between the tibia and the calcaneus.

A positive test result, in combination with pain on posterolateral palpation, should be followed by a diagnostic infiltration of an anesthetic (with or without corticosteroid).

Posteromedial pain on palpation does not necessarily indicate impingement.

Tenderness on palpation over the musculotendinous junction of the FHL is diagnostic for FHL tendinitis; pain can be elicited by forced simultaneous ankle and first metatarsophalangeal joint dorsiflexion.

“Pseudo hallux rigidus” may coexist with posteromedial ankle pain. Hallux dorsiflexion may be limited with ankle dorsiflexion but restored with ankle plantarflexion. This exam finding/phenomenon has been reported to be secondary to nodular thickening of the proximal FHL that impinges within the fibro-osseous tunnel on the posteromedial ankle.

Palpation of posterior talar process is a sensitive test for posterior ankle impingement. A positive test should be followed by a hyperplantarflexion test.

The hyperplantarflexion test is positive when the patient experiences recognizable pain at the moment of impact. It is a highly sensitive test for posterior ankle impingement. A negative test rules out a posterior ankle impingement syndrome.

If the pain on forced plantarflexion disappears, the diagnosis is confirmed.

Posteromedial ankle palpation is sensitive for FHL tendinitis.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

In patients with posterior ankle impingement, the AP ankle view typically fails to demonstrate abnormalities (Fig 1A).

- On the lateral view, a prominent posterior talar process or os trigonum can sometimes be recognized.
- As the posterolaterally located posterior talar process or os trigonum is often superimposed on the medial talar tubercle, detection of an os trigonum on a standard lateral view is often not possible (Fig 1B).
- For the same reason, calcifications can sometimes not be detected by this standard lateral view.
- We recommend lateral radiographs with the foot in 25 degrees of external rotation in relation to the standard lateral radiographs (Fig 1C).
- Bone scintigraphy effectively localizes talar and peritalar injuries.
- Computed tomography defines the exact size and location of calcifications, bony fragments, osteochondral lesions, or intraosseous talar cysts (Fig 1D).
- Magnetic resonance imaging (MRI) is useful for detection of bone contusions, edema, posterior capsular or ligament thickening, talar osteochondral lesions, and FHL tenosynovitis.
- MRI has been reported to accurately identify FHL tendinitis in 82% of patients, represented by intermediate or low signal intensity on T2-weighted images.
- Fluid in the FHL tendon sheath is frequently seen in MRI without clinical signs of FHL tendinitis. Fluid in the tendon sheath of the FHL must be combined with changes in the tendon itself to be a sign of a tendinitis.
- Bone edema in the os trigonum is an important diagnostic finding.
- It is a sign of chronic compression of the os trigonum between distal tibia and calcaneus.
- It can be a sign of degeneration of the cartilage of the undersurface of the os trigonum. In these cases, the bone edema is combined with bone edema of the calcaneus.
- It can also be a sign of movement between the os trigonum and the talus. In these cases, there is bone edema in the posterior talus as well. These cases represent a pseudoarthrosis type of lesion.

**DIFFERENTIAL DIAGNOSIS**

- Tarsal tunnel syndrome
- Plantar fasciitis
- Peroneal tenosynovitis
- Posterior tibial tenosynovitis
- Pseudo hallux rigidus (in FHL tenosynovitis)
- Bony avulsions
- Ankle and subtalar arthrosis

**FIG 1 • Imaging posterior ankle impingement.** A. AP ankle view showing no abnormalities. B. Standard lateral view. C. Lateral radiograph with the foot in 25 degrees of external rotation. D. Sagittal CT scan showing os trigonum.
NONOPERATIVE MANAGEMENT

- Initial treatment of os trigonum syndrome consists of rest, ice, anti-inflammatory medication, avoidance of forced plantarflexion, and, occasionally, ankle immobilization for 4 to 6 weeks. If there is an established nonunion, immobilization with casting is not recommended.8
- Physical therapy, such as progressive resistive exercises and strengthening, may be helpful.8
- Corticosteroid injection for os trigonum syndrome can effectively provide temporary pain relief.4,8
- Nonsurgical treatment for FHL tenosynovitis includes rest, ice, anti-inflammatories, longitudinal arch supports, standard physical therapy, and stretching exercises.8,10

SURGICAL MANAGEMENT

- Indications for posterior ankle arthroscopy and hindfoot endoscopy are listed in Table 1.
- The procedure is performed as outpatient surgery with the patient under general or epidural anesthesia.17

Preoperative Planning

- All imaging studies are reviewed to address not only the individual pathology but also the associated bone, cartilage, or ligament injuries, as well as osteophytes, loose bodies, accessory muscles, and calcifications (FIG 2).
- Ankle and subtalar joint stability, stability of the peroneal tendons, and Achilles tendon tightness should be determined by examination under anesthesia.
- Instability is a clinical diagnosis, and these patients are identified by their symptoms. They complain of recurrent giving-way. Laxity can be present without clinical symptoms of giving. If laxity is detected without clinical symptoms of giving-way, it is not an indication for lateral ligament reconstruction.
- For irrigation, a single bag of normal saline with gravity flow can be used.
- A 4.0-mm arthroscope with a 30-degree angle is routinely used for posterior ankle arthroscopy.
- For posterior ankle arthroscopy, a noninvasive distraction device can be used when the ankle joint has to be entered for the diagnosis and treatment of an intra-articular pathology.
- A 4-mm chisel and a periosteal elevator may be needed during posterior arthroscopy for excision of osteophytes and ossicles.

Positioning

- The patient is placed in a prone position. The patient should be placed properly to avoid tension on the brachial plexi, avoid pressure on the ulnar nerve at the elbow, and protect the genitalia.
- A tourniquet is applied around the upper leg, and a small support is placed under the lower leg, making it possible to move the ankle freely (FIG 3).

Table 1

<table>
<thead>
<tr>
<th>Articular pathology</th>
<th>Posterior compartment ankle joint</th>
<th>Débridement and drilling of osteochondral defects</th>
<th>Removal of loose bodies, ossicles, calcifications, avulsion fragments</th>
<th>Resection of posterior tibial rim osteophytes</th>
<th>Treatment of chondromatosis and chronic synovitis</th>
<th>Posterior compartment subtalar joint</th>
<th>Removal of osteophytes and loose bodies</th>
<th>Subtalar arthrodesis</th>
<th>Treatment of intraosseous talar ganglia by retrograde curettage and drilling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periarticular pathology</td>
<td>Posterior ankle impingement</td>
<td>Deep portion of deltoid ligament: removal of posttraumatic calcifications or ossicles</td>
<td>Flexor hallucis longus tenosynovitis: débridement of flexor retinaculum, posterior talofibular ligament, prominent talar process, and opening the sheath of the tendon</td>
<td>Posterior syndesmotic ligaments: hypertrophic ligaments can be excised</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FIG 3 • Positioning for hindfoot endoscopy. Small leg support (A), tourniquet (B), and leg holder (C).
Chapter 90

POSTERIOR ANKLE ARTHROSCOPY AND HINDFOOT ENDOSCOPY

FIG 4 • Posterior (A), posteromedial (B), and posterolateral (C) views of foot and ankle with the cutaneous landmarks for posterior ankle arthroscopy and hindfoot endoscopy. 1, Achilles tendon; 2, lateral malleolus; 3, medial malleolus; *posterolateral portal; **posteromedial portal.

- The foot is placed at the very end of the operating table so that the surgeon can fully dorsiflex the ankle.

Approach
- The landmarks on the ankle are the lateral malleolus, medial and lateral border of the Achilles tendon, and the sole of the foot. With a marking pen, a line is drawn as a reference from the tip of the lateral malleolus to the Achilles tendon, parallel to the sole of the foot.
- Posterolateral and posteromedial portals are made just above this line, at the same level in the horizontal plane, and just lateral and medial to the Achilles tendon (FIG 4).

CREATION OF THE POSTEROLATERAL PORTAL

- A vertical stab incision is made for posterolateral portal.
- The subcutaneous layer is split by a mosquito clamp that is directed anteriorly, in the direction of the interdigital web space between the first and second toes (TECH FIG 1A).
- When the tip of the clamp touches the bone, it is exchanged for a 4.5-mm arthroscope shaft with the blunt trocar pointing in the same direction (TECH FIG 1B).
- The level of the ankle joint and subtalar joint can be distinguished by palpating the bone in the sagittal plane because the prominent posterior talar process or os trigonum can be felt as a posterior prominence between the two joints.
- The trocar is positioned extra-articularly at the level of the ankle joint.
- The trocar is exchanged for the 4-mm arthroscope; the direction of view is 30 degrees to the lateral side.

Creation of the Posteromedial Portal

- A vertical stab incision is made for the posteromedial portal.
- A mosquito clamp is introduced and directed toward the arthroscope shaft at a 90-degree angle (TECH FIG 2A).
- When the mosquito clamp touches the shaft of the arthroscope, the shaft is used as a guide for the clamp to move anteriorly in the direction of the ankle joint, touching the arthroscope shaft until it reaches the bone (TECH FIG 2B).
- Next, the arthroscope is withdrawn slightly, directly over the mosquito clamp until the tip of the mosquito clamp is visualized (TECH FIG 2C).
The clamp is used to spread the extra-articular soft tissue in front of the tip of the lens.

In situations in which scar tissue or adhesions are present, the mosquito clamp is exchanged for a 5-mm full-radius shaver.

The tip of the shaver is directed in a lateral and slightly plantar direction toward the posterolateral aspect of the subtalar joint.

When the tip of the shaver has reached this position, shaving can begin.

**Working Posterior to the Ankle**

- The joint capsule and adipose tissue can be removed. The adipose tissue is removed first and with it the very thin joint capsule.

- The subtalar joint can now be recognized. The posterior talar fibular ligament that attaches to the talus at this level can be recognized as well.

- At removal of the thin joint capsule, the posterior subtalar joint can be inspected (TECH FIG 3A).

- At the level of the ankle joint, the posterior tibiofibular and talofibular ligaments are identified and the posterior ankle joint can be visualized (TECH FIG 3B).

- The posterior talar process can be freed of scar tissue, and the FHL tendon, an important landmark, is identified. Motion of the hallux helps isolate the fibers of the FHL tendon in the posterior ankle.

- The shaver should never be used medial to the FHL tendon because of the proximity of the posteromedial neurovascular bundle.
Chapter 90 POSTERIOR ANKLE ARTHROSCOPY AND HINDFOOT ENDOSCOPY

**TECH FIG 4** • Endoscopic procedure for débridement and drilling of a subtalar osteochondral cyst lesion in a right ankle (same patient as in Fig 2). 
**A.** Endoscopic image with an arrow indicating the defect. **B.** A hook is introduced via the posteromedial portal and penetrates the osteochondral defect up to the cyst. **C.** By retrograde drilling, the cyst is reached. The hook is used for guiding the exact direction of the drill. **D.** Postoperative overview.

- After removal of the thin posterior ankle joint capsule, the ankle joint is entered with the arthroscope and inspected.
- On the medial side, both the tip of the medial malleolus and the deep portion of the deltoid ligament are visualized.
- By opening the joint capsule from inside out at the level of the medial malleolus, the tendon sheath of the posterior tibial tendon can be opened.
- With manual distraction on the os calcis, the posterior aspect of the ankle joint is opened, and the shaver can be introduced into the tibiotalar joint.
- For greater distraction, a noninvasive ankle distractor can be applied (TECH FIG 3C).
- A total synovectomy or capsulectomy can be performed. In our experience, nearly the entire talar dome tibial plafond can be visualized via this posterior approach.
- An osteochondral defect or subchondral cystic lesion can be identified, débrided, and drilled (TECH FIG 4).

**Removal of an Os Trigonum**
- The posterior syndesmotic ligaments are inspected and, if hypertrophic, are partially resected.
- Removal of a symptomatic os trigonum (TECH FIG 5), a nonunited fracture of the posterior talar process, or a symptomatic large posterior talar prominence requires partial detachment of the posterior talofibular ligament and release of the flexor retinaculum, both of which attach to the posterior talar prominence.

**Release of the Flexor Hallucis Longus Tendon**
- Release of the FHL tendon involves detachment of the flexor retinaculum from the posterior talar process by means of a punch (TECH FIG 6).
- A tight, thick crural fascia, if present, can hinder the free movement of instruments. It is helpful to enlarge the hole in the fascia using a punch or shaver.
- Bleeding is controlled by electrocautery at the end of the procedure.

**Wound Closure and Dressing**
- After removal of the instruments, the stab incisions are closed with 3-0 nylon to prevent sinus formation.
- A sterile compression dressing is applied.
- In patients with combined anterior and posterior symptoms, the posterior pathology is addressed by means of the two-portal hindfoot approach, and the anterior pathology is approached by a two-portal anterior approach.
- This can be done in two ways. The anterior arthroscopy can be performed with the knee flexed and the foot upside down, but we typically prefer a two-stage procedure. First the two-portal hindfoot approach is finished. The patient is then turned and a routine anterior ankle arthroscopy is performed.
TECH FIG 5 • Endoscopic procedure for removing an os trigonum and releasing the flexor hallucis longus in a left ankle. A. Os trigonum (OT) with its connection to the posterior talofibular ligament (PTFL), flexor retinaculum and talocalcaneal ligament (TCL). B. Cutting through the flexor retinaculum. C. Cutting through the TCL. D. Releasing the PTFL. IML, intermalleolar ligament. E. Overview of the os trigonum released from its related anatomic structures. F. Postoperative overview.

TECH FIG 6 • Endoscopic procedure for releasing of the flexor hallucis longus tendon (B) involves detachment of the flexor retinaculum (C) from the posterior talar process (A) by means of a punch. D, talus; E, subtalar joint.
PEARLS AND PITFALLS

Position of the arthroscope
- The direction of view should always be lateral.

Rouvière ligament
- This ligament runs to the FHL retinaculum.
- It can be attached to the posterior talus process.
- An arthroscopic punch or scissors can be used to enlarge the entry through this ligament.
- Usually it has to be detached from the posterior talus process to get to the ankle joint.

Safe areas
- The arthroscope should point into the direction of the web space between the first and second toes.
- It should be positioned lateral to the FHL tendon. It can be positioned medial to the FHL tendon only when a release of the neurovascular bundle is required (posttraumatic tarsal tunnel syndrome).

Removing the hypertrophic posterior talar process using the chisel
- Care should be taken not to place the chisel too far anterior, so as to avoid entering the subtalar joint (FIG 5).

How to initially visualize or gain proper orientation in the posterior ankle
- The most important trick is to start shaving at the level of the subtalar joint on the lateral side. This is an area in which it is relatively safe to start shaving. The opening of the shaver is directed toward the joint.
- Once the subtalar joint has been identified, the posterior talofibular ligament is identified. This ligament attaches to the lateral surface of the talus in this area.
- If we move the scope and shaver proximal from the posterior fibular ligament we are at the level of the os trigonum. The soft tissue in this posterolateral area can now be removed.
- The ankle joint usually can now be identified by applying some traction to the calcaneus. Dorsiflexing the foot can also help.
- Part of the posterior ligaments can be removed to enter the ankle joint when desired.
- From the posterolateral corner, the instruments now can be moved over the posterior talus process or os trigonum to the medial side, while staying in contact with the posterior ankle ligaments and the proximal surface of the os trigonum all the way. The flexor hallucis longus then comes into view.

FIG 5 • Removal of the hypertrophic posterior talar process using the chisel. Care should be taken not to place the chisel too far anterior, so as to avoid entering the subtalar joint.

POSTOPERATIVE CARE
- As soon as possible after surgery, the patient is advised to start range-of-motion exercises as tolerated. It is not necessary to immobilize the ankle postoperatively to prevent sinus formation. The posterior ankle joint has a good soft tissue covering. The advantage of the procedure is that patients can start to move the ankle directly postoperatively.
- Postoperatively for 2 or 3 days, the patient is allowed weight bearing on crutches as tolerated.
- The dressing can be removed after 3 days. We remove the sutures 2 weeks postoperatively.
- The patient is reevaluated 1 week postoperatively. If necessary, physical therapy can be prescribed for range of motion, strengthening, and stability.

OUTCOMES
- In a consecutive series of 146 posterior ankle arthroscopies (136 patients) performed at the Academic Medical Center University of Amsterdam between 1994 and 2002, all patients were satisfied postoperatively. There were no complications other than 2 patients who experienced a small area of diminished sensation over the heel pad of the hindfoot.
- The main indication was a posterior ankle impingement syndrome. Procedures, all carried out by the same surgeon, were as follows:
  - Removal of a bony impediment (os trigonum or hypertrophic posterior talus process; n = 52)
  - Additional release of the flexor hallucis longus tendon (n = 37)
Postoperatively, the average postoperative AOFAS scale was 86.4 points 3 years time. None of these patients had deterioration of the result over time. Marumoto and Ferkel treated 11 patients with painful os trigonum by arthroscopic removal of the os trigonum. The average postoperative AOFAS scale was 86.4 points 3 years postoperatively.

Jerosch and Fadel applied the same treatment method to 10 patients with symptomatic os trigonum; 9 of them were symptom-free 4 weeks postoperatively, and the average AOFAS scale increased from 43 preoperatively to 87 at a mean follow-up time of 25 months. They observed no complications in these 10 patients.

Tey et al endoscopically treated 15 patients with posterior ankle impingement and reported that all but 1 patient (7%) improved at an average 3 years of follow-up. Willis et al performed 24 posterior ankle arthroscopies with an indication of posterior ankle impingement. The average time to return to work was 1 month and to sports was 5.8 months. Mean score on the AOFAS scale was improved to 91 at a mean follow-up time of 32 months postoperatively.

COMPLICATIONS

Potential complications of this technique include tibial nerve and vascular injury, FHL tendon injury, and sural nerve injury.

To prevent sural nerve injury it is important to create the posterolateral portal as described previously, close to the Achilles tendon, first making a stab incision and then continuing with blunt dissection by a mosquito clamp.

Avoiding the potential complications of working through a posteromedial portal, the trick is to angle the instrument (shaver, Burr, punch) in the posteromedial portal at 90 degrees to the arthroscope shaft.

The arthroscope shaft subsequently is used as a guide for the instrument to travel into the direction of the joint. All the way, the mosquito clamp should be felt to touch the arthroscope shaft. In this manner, the neurovascular bundle is passed without problem.

Precise control of the aspirator and shaver is mandatory to prevent tibialis posterior nerve and vessel injury and to prevent damage to the FHL tendon. In areas close to the neurovascular bundle, the aspirator should be set to a minimum amount of suction.

We have applied this technique since 1994 without any complications other than two patients who experienced a small area of diminished sensation over the heel pad of the hindfoot.

When performed in the manner described above, hindfoot arthroscopy is a safe and reliable method of diagnosing and treating a variety of posterior ankle problems.

The decision to treat posterior as well as anterior pathology is made preoperatively. If preoperatively it is decided to treat both anterior and posterior pathology, we start with addressing the posterior pathology by means of the two-portal hindfoot approach. After finishing the posterior procedure, the portals are sutured and the patient is turned and the anterior procedure is performed.

ACKNOWLEDGMENT

The authors would greatly like to thank P.A.J. de Leeuw from the department of orthopaedic surgery in the Academic Medical Center in Amsterdam, The Netherlands, for providing all the images for this chapter.

REFERENCES

DEFINITION

- **Posterior ankle impingement syndrome** is a clinical disorder characterized by posterior ankle pain that occurs in forced plantarflexion. It can be caused by an acute or chronic injury, with the os trigonum or trigonal process of the talus as the most offending structure.\(^{10,19}\)

- Synonyms used for posterior ankle impingement syndrome include *posterior block of the ankle, posterior triangle pain, talar compression syndrome, os trigonum syndrome, os trigonum impingement, posterior tibiotalar impingement syndrome, and nutcracker-type syndrome.*\(^{4,11,20,36}\)

- The os trigonum is a secondary ossification center of the talus. It mineralizes between the ages of 11 and 13 years in boys and 8 and 11 years in girls. It fuses with the posterior talus within 1 year, forming the posterolateral process, often called the Stieda or trigonal process. The os trigonum remain as a separate ossicle in 1.7% to 7% of normal feet, twice as often unilaterally as bilaterally.\(^{3,8,16,24}\)

ANATOMY

- The posterior process of the talus is composed of a smaller posteromedial process and a larger posterolateral or trigonal process flanking the sulcus for the flexor hallucis longus (FHL) tendon.

- The os trigonum may be found in connection with the posterolateral tubercle *(FIG 1)*. It is completely corticalized and has three surfaces: anterior, inferior, and posterior.

- The anterior surface connects to the posterolateral tubercle via fibrous, fibrocartilaginous, or cartilaginous tissue. The inferior surface forms the posterior part of the talocalcaneal joint.

- The posterior surface is nonarticular and has the attachments of posterior talofibular ligament, posterior talocalcaneal ligament, deep layer of the flexor retinaculum, and the talar component of the fibuloastragalocalcaneal ligament of Rouviere and Canela Lazaro.\(^{28}\)

- The tibialis posterior tendon, the flexor digitorum longus tendon, and the flexor hallucis longus tendon situate in their own fibrous tunnels in continuity with the fascia of the deep posterior compartment.

- The neurovascular bundles are just medial and posterior to the flexor hallucis longus tendon at the level of the ankle joint, with the tibial nerve as the most lateral structure *(FIG 2)*.

- In some variants, the posterior Tibial artery can be thin or absent (0–2%), with the dominant peroneal artery traversing across the posterior ankle toward the tarsal tunnel.\(^{2,6}\)

PATHOGENESIS

- Most cases of posterior ankle impingement syndrome occur in athletes such as ballet dancers or soccer players who have sustained acute or repetitive injuries with the ankle in forced plantarflexion, causing the “nutcracker effect”\(^{12,20,36}\) *(FIG 3)*. Ankle sprain may cause avulsion fracture of the posterior talofibular ligament and secondary impingement.\(^{13,21,25,34}\)

- Symptoms can be aggravated by any structures localized between the posterior tibial plafond and the calcaneal facet of the posterior subtalar joint, such as the os trigonum, long trigo- nal process, flexor hallucis longus tendon, posterior inferior tibiofibular ligament, intermalleolar ligament, and any osseous, articular cartilage, capsule, or synovial lesions of the posterior ankle or subtalar joint.

- FHL tenosynovitis is commonly associated with posterior ankle impingement due to the intimate relationship between the tendon and the os trigonum or the trigonal process at the
posterior aspect of the talus. This lesion can be an associated injury or secondary to the inflamed surrounding structures.\textsuperscript{17,26,30}

**NATURAL HISTORY**
- The natural history of posterior ankle impingement is currently unknown. Os trigonum is a benign condition and usually is asymptomatic.
- When symptomatic, nonoperative treatment has been found to be successful in 60\% of cases. However, Hedrick and McBryde\textsuperscript{10} reported that only 40\% of those successfully treated patients could achieve full preinjury activity levels. The prognosis with nonoperative treatment is generally poor in high-activity patients such as ballet dancers.\textsuperscript{20}

**PATIENT HISTORY AND PHYSICAL FINDINGS**
- The routine history should include sex, age, occupation, sports activities, and mechanism of the injury.
- Patients should be asked for the description of pain, its location, and any aggravating positions or activities. Pain from the impingement usually is directly posterior or posterolateral to the ankle joint. Pain in the posteromedial aspect may be associated with tenosynovitis of the FHL tendon, which is usually described as pain along the tendon longitudinally. Aggravation of the symptoms with the ankle in full plantarflexion is essential to the diagnosis.
- Examination must be performed to rule out other pathologies causing posterior ankle and hindfoot pain, such as Achilles tendinopathy, Haglund syndrome, “pump bump” syndrome, tibialis posterior tendinitis, and peroneal tendon injuries. Diligent palpation of the described structures for tenderness and crepitus. The presence of FHL tenosynovitis should be documented, and it should be treated accordingly. Tenderness from FHL tenosynovitis is produced with active/passive motion of the hallux while a thumb palpates the tendon for tenderness and crepitus. The presence of FHL tenosynovitis should be documented, and it should be treated accordingly. Tenderness of other posterior ankle structures. Individual palpation of the peroneal tendons, tibialis posterior tendon, Achilles tendon, and posterior aspect of the calcaneal tuberosity is essential to exclude other pathologies. Palpation of the os trigonum itself is difficult due to its depth. Other diagnoses should be considered if there is no pain with passive ankle plantarflexion and the positive test for other possible lesions in spite of the presence of the os trigonum on radiographs.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- A lateral radiograph of the ankle usually demonstrates the osseous lesions sufficiently (FIG 4). Lateral radiographs can be taken in full ankle plantarflexion and slight external rotation of the limb to visualize impingement from the os trigonum.\textsuperscript{9} Bone scanning has been reported to identify the symptomatic os trigonum. It is not routinely obtained, however, and does not replace accurate history taking and physical examination (FIG 5). False-positive results in patients with high activity levels make this study less useful.\textsuperscript{29} CT scan can help clarify osseous or osteochondral lesions, especially when the posteromedial facet fracture is suspected. MRI is the most useful imaging examination for posterior ankle impingement syndrome (FIG 6). Anatomic variants and a range of osseous and soft tissue abnormalities have been found to be associated with this condition. Posterior tibiotalar synovitis and marrow edema within one or more of the tarsal bones were found in all cases. In contrast, os trigonum was found in only 30\% of cases.\textsuperscript{5,23,26} Diagnostic injection can be helpful when the signs and symptoms are inconclusive.\textsuperscript{14,25} The postinjection symptoms have
been shown to be parallel to results after surgical excision of the os trigonum. However, injection directly into the junction between the os trigonum and the talus is difficult and must be done under fluoroscopic guidance in experienced hands.

**DIFFERENTIAL DIAGNOSIS**
- Haglund syndrome
- Tendinitis (Achilles tendon, peroneal tendons, posterior tibial tendons)
- Loose bodies
- Ankle or subtalar arthritis

**NONOPERATIVE MANAGEMENT**
- Nonoperative treatment is always the first approach. However, it has shown less than optimal results in the published literature, with, at best, a 60% rate of improvement plus long-term modification of activities.10
- Avoidance of aggravating activities such as forced plantarflexion is the most important factor, because it will avoid impingement and aggravation of the inflammatory response. This measure may not be tolerable in athletes who routinely require this position, such as ballet dancers and soccer players.

- Supportive treatments include rest, ice, anti-inflammatory medications, and immobilization in a short-leg walking cast.
- One or two cortisone injections under fluoroscopic guidance have shown more than 80% response rate at 2 years.25 Its use was not routinely recommended due to the risk of FHL tendon rupture and potential disabilities especially in ballet dancers.
- Physical therapy can be instituted as symptoms improve. It consists of phonophoresis, isometric exercises, heel cord stretching, and selected isometric strengthening.

**SURGICAL MANAGEMENT**
- **Indications**
  - Failure of nonoperative treatment after at least 3 months
  - Inability to return to required activities after nonoperative treatment

**Preoperative Planning**
- All imaging studies are reviewed. MRI is helpful in the evaluation of associated lesions.
- All the pathologies should be carefully detected. Surgical steps with informed consent can be added accordingly, such as loose body removal, treatment for osteochondritis dissecans lesions, or an open FHL repair.
- When surgery is indicated, the treatment for an os trigonum, an acute or chronic fracture of the trigonal process, or an intact large trigonal process is virtually the same. Further studies, eg, CT scan, to distinguish them may not be necessary.
- If arthroscopic or open surgery is planned, the posterior tibial pulse must be palpable in the soft spot posterior to the medial malleolus, because an absence or a minor artery may be associated with a dominant peroneal artery. This artery traverses across the posterior ankle and is at high risk during arthroscopy.

**Positioning**
- The patient is placed in the prone position with standard padding (FIGS 7 AND 8).
- The patient’s ankles are at the level just distal to the end of the bed to leave enough room for possible anterior or lateral arthroscopic portals.
- The surgeon’s body can be used to dorsiflex the ankle by leaning forward.
The posteromedial approach is recommended by the author. When the bony impingement is accompanied by pathologies in the neurovascular bundles or lesions in the FHL tendon that may require a repair, a posteromedial approach is advantageous.

The posterolateral approach also may be used for cases that require only excision of the os trigonum and trigonal process or release of the FHL tendon.

The arthroscopic approach has advantages over open surgeries in terms of minimizing surgical injury, postoperative pain, and early return to activities.

We prefer the prone over the supine or lateral decubitus position because it provides a more direct approach, minimizing the risk of instrument skiving off toward the neurovascular bundles.

Apart from the magnification advantage, we have found that this method also aids in visualization of intra-articular pathologies.27

This technique requires familiarity with the hindfoot anatomy and arthroscopic skills.

ESTABLISHMENT OF PORTALS

The anatomic landmarks of the posterior ankle are drawn, including the Achilles tendon, the medial and lateral malleoli, and the superior aspect of the calcaneal tuberosity.

The posterolateral and the posteromedial portals are located 1.5 cm proximal to the superior aspect of the calcaneal tuberosity on either side of the Achilles tendon (TECH FIGS 1 AND 2).

Ankle joint injection can be performed through the posterolateral portal, but it is not necessary, because the joint will be inspected easily after the os trigonum or the trigonal process has been removed.

The posterolateral portal is established first with a vertical skin incision, followed by blunt dissection with a straight hemostat. The tip of the hemostat should be kept just next to the Achilles tendon laterally to minimize injury to the sural nerve.

The dissection proceeds through a fat layer directly anteriorly.

The os trigonum usually is palpable, and a blunt trocar is inserted toward its superior aspect.

A 4-mm arthroscope is inserted through the cannula. Next, the posteromedial portal is established at the same level just medial to the Achilles tendon.

A straight hemostat is used to dissect into the same soft tissue tunnel as the arthroscope. The hemostat is advanced while it is kept in contact with the arthroscopic cannula until the tip is seen by the arthroscope.

The soft tissue is gently dilated. A full-radius 3.5-mm shaver is inserted into the posteromedial portal until the tip is seen (TECH FIGS 3 AND 4).

Approach

- The posterior aspect of the ankle and subtalar joints can be accessed open or arthroscopically.
- Open approaches can be posteromedial or posterolateral, on either side of the Achilles tendon.

TECH FIG 1 • Placement of posteromedial and posterolateral portals with the patient in the prone position.

TECH FIG 2 • Topographical landmarks of the pertinent structures.
**DÉBRIDEMENT OF THE SOFT TISSUE**

- The initial débridement of the fatty tissue is performed first to make room for the arthroscopic maneuvers. This step will improve visualization tremendously.
- The shaver is kept deep just above or below the os trigonum, with its cutting surface turned laterally.
- The shaver is gradually moved medially until the FHL tendon is seen. The FHL tendon indicates the location of the neurovascular bundles, which lie medial and superficial to it.
- The os trigonum is débrided off all the attached soft tissue circumferentially (TECH FIG 5).
- Medially, the retinaculum of the FHL is released off the os trigonum with a shaver or arthroscopic scissors (TECH FIG 6).
- Tenosynovitic lesions of the FHL, if seen, may require a release and débridement further distally. Great care is taken to release the fibrous sheath from only the posterior attachment on the calcaneal wall. A partial tear of the FHL can be débrided, but a tear greater than 50% may require an open repair.
- The posterior talofibular ligament attached on the lateral aspect of the os trigonum is released.

**RESECTION OF THE OS TRIGONUM AND TRIGONAL PROCESS**

- The synchondrosis is palpated by a Freer elevator coming from the superior aspect.
- Next, the tip of the instrument is pushed into the synchondrosis.
- Cracking of the synchondrosis is performed by levering maneuvers from either the superior or inferior surface (TECH FIG 7).
The os trigonum is removed as a whole using a grasper (TECH FIG 8). In the presence of an intact enlarged trigonal process it is removed entirely with a burr. The most posterior aspect of the articular cartilage of the posterior talar facet of the subtalar joint is always removed together with the os trigonum.

The posterior aspect of the talus is evaluated, and any sharp bony edges are rounded off (TECH FIG 9).

There should be no impingement at the completion of the procedure.

If arthroscopic evaluation or treatment of the anterior ankle joint is required, it can be performed in two ways.

The first way is to reposition the patient into the supine position and redrape the limb.

The second way is to bend the knee to 90 degree and perform the anterior ankle arthroscopy in the upside-down manner. This requires experience and familiarity of the ankle anatomy.

EVALUATION OF ASSOCIATED LESIONS

The posterior aspect of the ankle joint is evaluated. Synovitis or a thickened intermalleolar ligament is débrided. Stay lateral to the FHL tendon. Loose bodies are removed if present. Intra-articular views of the ankle joint are best achieved with a 2.7-mm arthroscope.

The subtalar joint is evaluated in the same manner (TECH FIG 10). The dynamic view of the hindfoot is inspected when the ankle is manipulated into full plantarflexion.

Multiple views of the ankle and subtalar joint.
Chapter 91  ENDOSCOPIC TREATMENT OF POSTERIOR ANKLE IMPINGEMENT THROUGH A POSTERIOR APPROACH 4249

PEARLS AND PITFALLS

Diagnosis
- Good history taking and physical examination are paramount.
- MRI and diagnostic injection can help in questionable cases.

Preoperative planning
- Open surgery is preferred when the posterior tibial pulse is not palpable behind the ankle joint. This approach is limited in its access to anterior ankle lesions and may require redraping. However, simple ankle procedures can be performed when the knee is flexed to 90 degrees and the foot held by an assistant.
- Patients should be informed of the possibility of conversion to open surgery, especially when a complete rupture of the FHL tendon is anticipated.

Portal placement
- The ankle is placed firmly on the bed in true AP or slight external rotated alignment. The ankle is placed firmly on the bed in true AP or slight external rotated alignment. The incision is made through the skin only. Blunt dissection is used to dissect through the soft tissue planes.

Débridement of soft tissue
- The shaver is kept deep on the joint capsule and lateral to the FHL.

Resection of the os trigonum and trigonal process
- Palpation with a Freer elevator to identify the synchondrosis.
- "Death roll maneuver" is performed before removal of the bony fragment. Adequate portal size is needed.

POSTOPERATIVE CARE
- Portal incisions routinely are left unsutured.
- A compressive soft dressing is applied. The patient is informed about the possibility of some drainage in the first couple of postoperative days. The dressing can be changed if necessary.
- Leg elevation is encouraged.
- No immobilization is required.
- Patients can bear weight as tolerated in a postoperative shoe.
- When acute pain subsides, usually 2 to 3 days postoperatively, patients can begin early range-of-motion and strengthening exercise.
- Full activities are allowed gradually as tolerated.

OUTCOMES
- Nonoperative treatment has not shown promising results, especially in high-demand athletes, but a success rate of more than 80% could be achieved when cortisone injections are routinely given under fluoroscopic guidance.10,25
- When nonoperative treatment has failed, excellent outcomes have been reported with either open or arthroscopic resection of the os trigonum.1,13,18,20,22,32,33
- Arthroscopic techniques can help minimize morbidities associated with open dissection, such as a painful scar, severe postoperative pain, and wound complications. It requires arthroscopic skills and familiarity with hindfoot anatomy.31,35

COMPLICATIONS
- Neurovascular injuries are possible with either arthroscopic or open approaches. Neurapraxia of the tibial, peroneal, and sural nerves has been reported; most patients recovered spontaneously. Permanent sensory deficit and neuroma formation have occurred when the nerves were transected, especially the sural nerve when the open posterolateral approach is used.1
- Symptoms can persist after operative treatment. Correct diagnosis and adequate treatment of all associated pathologies are the keys.

REFERENCES
DEFINITION
- The subtalar joint is a complex and functionally important joint of the lower extremity. It plays a major role in inversion and eversion of the foot.
- Subtalar arthroscopy can be applied as a diagnostic and therapeutic instrument.

ANATOMY
- For arthroscopic purposes, the subtalar joint is divided into anterior (talocalcaneonavicular) and posterior (talocalcaneal) articulations (FIG 1).
- The anterior and posterior articulations are separated by the tarsal canal, which has a large lateral opening called the sinus tarsi.
- Within the tarsal canal and sinus tarsi are found the interosseous talocalcaneal ligament, the medial and intermediate roots of the inferior extensor retinaculum, the cervical ligament, fatty tissue, and blood vessels.5,6,8,12
- The lateral ligamentous support of the subtalar joint consists of the lateral talocalcaneal ligament, the posterior talocalcaneal ligament, the lateral root of the inferior extensor retinaculum, and the calcaneofibular ligament (FIG 2).
- The anterior subtalar joint is generally thought to be inaccessible to arthroscopic visualization because of the thick interosseous ligament that fills the tarsal canal.1–4,18 Because of this, the region normally has no connection with the posterior joint complex.

PATHOGENESIS
- One of the most common indications for subtalar arthroscopy is chronic pain in the sinus tarsi, historically referred to as “sinus tarsi syndrome.”2
- Sinus tarsi syndrome has been described as persistent pain in the tarsal sinus secondary to trauma (80% of the cases reported).2
- There are no specific objective findings in this condition.
- The exact etiology is not clearly defined, but scarring and degenerative changes to the soft tissue structure of the sinus tarsi are thought to be the most common cause of pain in this region.
- Therefore, sinus tarsi syndrome is an inaccurate term that should be replaced with a specific diagnosis, as it can include many other pathologies, such as interosseous ligament tears, arthrofibrosis, and joint degeneration.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients with subtalar joint pathology often present with lateral ankle pain that is aggravated by standing and walking activities, particularly on uneven terrain.
- Walking on uneven terrain can result in a feeling of instability.

FIG 1 • The subtalar joint is divided into the anterior (talocalcaneonavicular) and posterior joint (talocalcaneal).
motion of the subtalar joint is not simple inversion and eversion. However, motion is best tested by holding the left heel in the right hand and vice versa, then using the opposite hand to hold the forefoot and move the foot from inversion to eversion. This motion should be smooth and painless.

Inversion and eversion are coming primarily from the talo-calcaneal (subtalar) joint. Exact measurements are difficult using standard techniques. Restricted motion may be seen with acute ankle sprain, arthritis, posterior tibial tendon dysfunction, tarsal coalition, fracture, chondral injury, adhesions, synovitis, and inflammatory conditions.

There may be swelling or stiffness in the joint.

Subtalar stiffness and pain indicate pathology in and around the subtalar joint but are not specific to one diagnosis.

Clinical examination reveals pain on the lateral aspect of the hindfoot aggravated by firm pressure over the lateral opening of the sinus tarsi.

Relief of symptoms with injection of local anesthetic directly into the sinus tarsi confirms the diagnosis of pain or dysfunction in the sinus tarsi.

Pathology of the interosseous ligaments of the subtalar joint usually is associated with focal pain over the lateral entrance to the sinus tarsi. Patients often have slight restriction and discomfort with passive subtalar motion.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Differential injections may be required to confirm pathology in the subtalar joint.

Anteroposterior (AP), lateral, and modified AP views of the foot are necessary to identify the subtalar joint.

The lateral and posterior processes are better seen on hindfoot oblique views.

The oblique 45-degree foot films show the anterior portion of the subtalar joint.

Borden’s view shows the posterior facet of the subtalar joint. This view is obtained by rotating the foot medially 45 degrees with dorsiflexion. The x-ray beam is pointed at the lateral malleolus and angled 10 degrees cephalad. Different views are obtained by changing the angle of the x-ray beam from 10 to 40 degrees.

Computed tomographic (CT) scans in the coronal plane are best for visualizing the talar body or posterior and lateral processes of the talus. CT can be used to show intra-articular pathology.

CT scans in the transverse or sagittal planes are best to visualize the talar neck and dome.

Magnetic resonance imaging (MRI) may detect chronic inflammation or fibrosis within the subtalar joint. Ligament injury, bone contusions, osteochondral lesions, chondral injury, impingement, synovitis, and fibrous or cartilaginous coalitions can be well demonstrated on MRI.

The preoperative imaging studies predict subtalar cartilage damage less accurately than does arthroscopy.

DIFFERENTIAL DIAGNOSIS

- Chronic lateral ankle pain
- Chronic ankle instability
- Peroneal tendon pathology
- Posterior tibial tendon dysfunction
- Superficial peroneal nerve pathology
- Fracture of the anterior process of the calcaneus
- Fracture of the lateral process of the talus
- Fracture of the posterior process of the talus
- Navicular fracture
- Calcaneal cuboid arthrosis/subluxation
- Calcaneus fracture
- Coalition

NONOPERATIVE MANAGEMENT

- Injection of anesthetic agent or corticosteroid
- Foot orthosis, including a UCBL
- Anti-inflammatory medication
- Ankle brace with a hindfoot lock
- Peroneal tendon strengthening

SURGICAL MANAGEMENT

- Indications for subtalar arthroscopy include chondromalacia, subtalar impingement lesions, osteophytes, lysis of adhesions with posttraumatic arthrofibrosis, synovectomy, and the removal of loose bodies.
- Other therapeutic indications include instability, débridement and treatment of osteochondral lesions, retrograde drilling of cystic lesions, evaluation of coalition, removal of a symptomatic os trigonum, evaluation and excision of fractures of the anterior process of the calcaneus and lateral process of the talus, and subtalar fusion.

Preoperative Planning

- Confirm the diagnosis with diagnostic testing, including differential injections to exclude ankle pathology.
- The absolute contraindications to subtalar arthroscopy must be ruled out. These include localized infection leading to a potential septic joint and advanced degenerative joint disease, particularly with deformity.
- Relative contraindications include severe edema, poor skin quality, and poor vascular status.

Positioning

- The patient is placed in the lateral decubitus position with the operative extremity draped free. Padding is placed between the lower extremities, as well as under the contralateral extremity to protect the peroneal nerve.
- A thigh tourniquet is recommended.
Approach

Lateral Approach
- Three standard portals are recommended for visualization and instrumentation of the subtalar joint (FIG 4). The anatomic landmarks for lateral portal placement are the lateral malleolus, the sinus tarsi, and the Achilles tendon.
- Careful dissection and portal placement help avoid the superficial peroneal nerve branches (anterior portal) and the sural nerve and peroneal tendons (posterior portal).
- The anterior portal is established approximately 1 cm distal to the fibular tip and 2 cm anterior to it (FIG 5).
- The middle portal is just anterior to the tip of the fibula, directly over the sinus tarsi.
- The posterior portal is at or approximately one finger width proximal to the fibular tip and 2 cm posterior to the lateral malleolus.
- The posterior portal is usually safe when placed behind the saphenous vein and sural nerve and anterior to the Achilles tendon. With placement of the posterior portal, care must be taken to avoid the sural nerve.

Posterior Approach
- Posterior subtalar arthroscopy can be performed using a posterolateral and a posteromedial portal. This two-portal endoscopic approach to the hindfoot with the patient in the prone position has been credited with offering better access to the medial and anterolateral aspects of the posterior subtalar joint (FIG 6).
- The main difference between the two techniques is that the lateral approach for posterior subtalar arthroscopy is a true arthroscopy technique in which the arthroscope and the instruments are placed within the joint, whereas the two-portal posterior technique (using posterolateral and posteromedial portals) starts as an extra-articular approach.
- With the two-portal posterior technique, a working space is first created adjacent to the posterior subtalar joint by removing the fatty tissue overlying the joint capsule and the posterior part of the ankle joint.
- The joint capsule is then partially removed to enable inspection of the joint from the outside in, with the arthroscope positioned at the edge of the joint without actually entering the joint space.
- The maximum size of the intra-articular instruments depends on the available joint space.

FIG 3 • The patient is placed into the lateral decubitus position with the operative limb draped free.

FIG 4 • Standard portals and their positions.

FIG 5 • A. Standard subtalar arthroscopic portals demonstrated on a cadaver. B. Anterior and posterior portals with the skin stripped away. Note the proximity of the sural nerve to the posterior portal.

FIG 6 • A. Lateral portal for posterior subtalar arthroscopy. B. Posterolateral portal for posterior subtalar arthroscopy.
FIG 6 • Posterior endoscopic technique with the use of two portals.
PORTAL PLACEMENT

- Local, general, spinal, or epidural anesthesia can be used for this procedure.
- The anterior portal is identified first with an 18-gauge spinal needle, and the joint is inflated with a 20-mL syringe (TECH FIG 1).
- A small skin incision is made and the subcutaneous tissue is gently spread using a straight mosquito clamp.
- A cannula with a semi-blunt trocar is then placed, followed by a 2.7-mm 30-degree oblique arthroscope.
- The middle portal is placed under direct visualization using an 18-gauge spinal needle and outside-in technique.
- The posterior portal can be placed at this time using the same direct visualization technique. The trocar is placed in an upward and slightly anterior manner.

Inspection From the Anterior Portal

- Diagnostic subtalar arthroscopy examination begins with the arthroscope viewing from the anterior portal (TECH FIG 2A,B). The ligaments that insert on the floor of the sinus tarsi are visualized. It is easy to get disoriented, as the ligaments are closely packed and cross over one another in the sinus tarsi.
- More medially, the deep interosseous ligament (TECH FIG 2C) is observed to fill the tarsal canal.
- The arthroscope should now be slowly withdrawn and the arthroscopic lens rotated to view the anterior process of the calcaneus (TECH FIG 3A,B).
- The arthroscopic lens is then rotated in the opposite direction to view the anterior aspect of the posterior talocalcaneal articulation (TECH FIG 3C).

TECH FIG 1 • The subtalar joint is entered using an 18-gauge spinal needle. The joint is inflated (A) and an incision is made (B), followed by blunt dissection (C) and entry into the subtalar joint (D). The middle portal is made using direct visualization techniques.

TECH FIG 2 • With the arthroscope in the anterior portal, the ligaments that insert on the floor of the sinus tarsi can be visualized. It is often difficult to tell one from the other, especially if they are injured. A,B. Examples of a torn interosseous ligament that is impinging into the anterior aspect of the posterior facet of the subtalar joint. This impingement lesion is referred to as the subtalar impingement lesion. C. The interosseous ligament of the tarsal canal fills the canal and can be seen with the scope in the anterior portal. The anterior (left) and the posterior (right) facets are well seen.
Next, the anterolateral corner of the posterior joint is examined, and reflections of the lateral talocalcaneal ligament and the calcaneofibular ligament are observed (TECH FIG 3D). The lateral talocalcaneal ligament is noted anterior to the calcaneofibular ligament.

The arthroscopic lens may then be rotated medially and the central articulation observed between the talus and the calcaneus (TECH FIG 3E). The posterolateral gutter may be seen from the anterior portal.

It is often possible to advance the scope along the lateral and posterolateral gutter and visualize the posterior pouch and Stieda’s process (or os trigonum; TECH FIG 3F).

The arthroscope is then switched to the posterior portal. From this view, the interosseous ligament may be seen anteriorly in the joint. As the arthroscopic lens is rotated laterally, the lateral talocalcaneal ligament and calcaneofibular ligament reflections again may be seen.

The central talocalcaneal joint may then be seen from this posterior view and the posterolateral gutter examined (TECH FIG 4A).

The posterolateral recess, posterior gutter, and posterolateral corner of the talocalcaneal joint are visualized (TECH FIG 4B). The posteromedial recess and posteromedial corner of the talocalcaneal joint can also be seen from the posterior portal.
**SINUS Tarsi PATHOLOGY**

- The best portal combination for the evaluation and débridement of pathology in the sinus tarsi is the arthroscope in the anterior portal and the instruments in the middle portal.
- One can débride torn interosseous ligaments, remove loose bodies, and perform lysis of adhesions. A radiofrequency wand is a useful tool to access the hard-to-get-to spots in the sinus tarsi and subtalar joint.

**OS TRIGNONUM PATHOLOGY**

- The best portal combination for evaluation and removal of the os trigonum is the arthroscope in the anterior portal and the instrumentation in the posterior portal.
- Rarely, it is necessary to enlarge the portal for delivery of the os trigonum.

**ARThROSCOPIC SUBTALAR ARTHRODESIS**

- Both the anterior and posterior portals are used in an alternating fashion during the procedure for viewing and instrumentation.
- It is important to obtain a fusion of the posterior facet. The anterior facet is generally not fused. A primary synovec-tomy and débridement are necessary for visualization.
- Débridement and complete removal of the articular surface of the posterior facet of the subtalar joint down to subchondral bone is the next phase of the procedure.
- Once the articular cartilage has been resected, approximately 1 to 2 mm of subchondral bone is removed to expose bleeding cancellous bone.
- Spot-weld holes measuring approximately 2 mm in depth are created on the surfaces of the calcaneus and talus to create vascular channels.
- The posteromedial corner is inspected to insure adequate débridement.
- The guidewire for a large cannulated screw (6.5 to 7 mm) can be visualized as it enters the posterior facet.
- The foot is then put in about 0 to 5 degrees of valgus, the guidewire is advanced, and the screw is placed.
- Screw position and length are confirmed with fluoroscopy.
- Postoperative care is similar to open techniques.
- In general, no autogenous bone graft or bone substitute is needed.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>The subtalar joint can be difficult to distract, especially the posterior joint.</th>
<th>Use of a distraction device is not necessary or very useful for improving visualization of the subtalar joint. A high-flow system and an arthroscopic pump will improve visualization.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rarely, invasive joint distraction, using talocalcaneal distraction with pins inserted from laterally, or tibiocalcaneal distraction can be used in a patient with a tight posterior subtalar joint. The disadvantage of using an invasive distractor is the potential damage to soft tissues (especially the lateral calcaneal branch of the sural nerve) and ligamentous structures and the risk of infection and fracturing the talar neck or body.</td>
<td></td>
</tr>
<tr>
<td>Visualization of the anterior joint and sinus tarsi can be difficult. It is easy to get disoriented, as the ligaments are closely packed and cross over one another in the sinus tarsi.</td>
<td>The structures in the sinus tarsi, the anterior process of the calcaneus, and occasionally the anterior joint can be visualized best by placing the arthroscope through the anterior portal and instrumentation through the middle portal. This portal combination is recommended for visualization and instrumentation of the sinus tarsi and anterior aspects of the posterior subtalar joint. If the ligaments that insert on the floor of the sinus tarsi are torn or damaged or need débridement, the anterior joint can be visualized and accessed with this portal combination. Furthermore, this portal combination allows excellent visualization and access to the anterior process of the calcaneus.</td>
</tr>
</tbody>
</table>
Visualization of the posterior joint and lateral capsule and access to Stieda’s process (os trigonum)

**POSTOPERATIVE CARE**

- After completing the procedure, the portals are closed with sutures.
- A compression dressing is applied from the toes to the mid-calf. Ice and elevation are recommended until the inflammatory phase has passed.
- The patient is allowed to ambulate with the use of crutches, and weightbearing is permitted as tolerated.
- The sutures are removed approximately 10 days after the procedure.
- The patient should begin gentle active range-of-motion exercises of the foot and ankle immediately after surgery. Once the sutures are removed, if indicated, the patient is referred to a physical therapist for supervised rehabilitation.
- The patient should be able to return to full activities at 6 to 12 weeks postoperatively.

**OUTCOMES**

- Compared with open techniques, arthroscopy of the subtalar joint has advantages for the patient, including a faster postoperative recovery period, decreased postoperative pain, and fewer complications.
- Frey et al. demonstrated a success rate of 94% good and excellent results in the treatment of various types of subtalar pathology using arthroscopic techniques.
- All of 14 preoperative diagnoses of sinus tarsi syndrome were changed at the time of arthroscopy.
- The most common finding in these cases was a tear of the interosseous ligaments.
- In a more recent study of 126 cases followed for more than 2 years, a significant improvement (61 to 84) was noted using both the AOFAS and Karslon scores. Williams and Ferkel demonstrated a success rate of 94% good and excellent results in the treatment of various types of subtalar pathology using arthroscopic techniques.
- Preoperative diagnoses included degenerative joint disease, sinus tarsi dysfunction, and os trigonum.
- Good to excellent results were noted in 86% of the patients.
- Overall, less favorable results were noted with associated ankle pathology, degenerative joint disease, increased age, and activity level of the patient.
- No operative complications were reported.
- Goldberger and Conti retrospectively reviewed 12 patients who underwent subtalar arthroscopy for symptomatic subtalar pathology with nonspecific radiographic findings.
- The preoperative diagnoses were subtalar chondrosis in nine patients and subtalar synovitis in three patients.
- At 17.5 months (average) of follow-up, the postoperative AOFAS hindfoot score was 71 (range 51 to 85) compared with a preoperative score of 66 (range 54 to 79). All patients stated that they would have the surgery again.
- Surgical removal of the contents of the lateral half of the sinus tarsi improves or eradicates symptoms in roughly 90% of cases of patients with sinus tarsi pain or dysfunction.

**COMPlications**

- Although rare, the most likely complication to occur after subtalar arthroscopy is injury to any of the neurovascular structures in the proximity of the portals, including the sural nerve and superficial peroneal nerve.
- Other possible complications following subtalar joint arthroscopy include infection, instrument breakage, and damage to the articular cartilage.

**REFERENCES**

DEFINITION
- Medium-sized osteochondral defects of the talar dome
  - May approach the talar shoulder (transition of superior dome cartilage to the medial or lateral talar cartilage)
  - Often associated with subchondral cysts
- Osteochondral defect is reconstructed with a cylindrical osteochondral graft. To provide stability to this graft, the osteochondral defect in the native talus must be contained (have circumferential cartilage and subchondral bone).

ANATOMY
- Sixty percent of the talus’ surface area is covered by articular cartilage.
- The talus is contained within the ankle mortise.
  - Superior talar dome articulates with the tibial plafond.
  - Medial dome articulates with the medial malleolus.
  - Lateral dome articulates with the lateral malleolus.
- Talar blood supply
  - Posterior tibial artery
  - Artery of the tarsal canal
  - Deltoid ligament branch
  - Peroneal artery
  - Artery of the tarsal sinus
  - Dorsalis pedis artery

PATHOGENESIS
- The pathogenesis for osteochondral lesions of the talus (OLTs) is not fully understood.
- Theories include:
  - Trauma
  - Idiopathic focal avascular necrosis

NATURAL HISTORY
- In general, OLTs do not progress to diffuse ankle arthritis.
- However, large-volume OLTs may lead to subchondral collapse of a substantial portion of the talus and thus create deformity, higher contact stresses, and a greater concern for eventual ankle arthritis if left untreated.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients may or may not report a history of trauma.
- Ankle pain, typically on the anterior aspect of the ankle, is a common complaint.
- Pain is usually experienced on the side of the ankle that corresponds with the OLT, but it may be poorly localized to the site of the OLT. In fact, sometimes medial OLTs produce lateral ankle pain and vice versa.
- Pain is rarely sharp, unless a fragment of the OLT should act as an impinging loose body in the joint.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs
  - Obtain weight-bearing, three views of the ankle
  - Small OLTs may be missed.
  - Large OLTs are usually identified on plain radiographs (FIG 1).
- Often limited in characterizing OLT since the two-dimensional study cannot define the three-dimensional OLT
- Particularly useful in assessing lower leg, ankle, or foot malalignment that needs to be considered in the management of OLTs
  - May detect incidental OLTs (patient has a radiograph for a different problem and an OLT is incidentally identified on plain radiographs)
- MRI
  - Excellent screening tool when OLT or other foot–ankle pathology is suspected
  - Will identify incidental OLT, but defines other potential soft tissue pathology
  - Demonstrates associated marrow edema that may lead to overestimation of the OLT’s size
- CT (FIG 2)
  - Ideal for characterizing OLT, particularly large-volume defects
  - Defines OLT size without distraction of associated marrow edema
  - Defines the character of the OLT and extent of its involvement in the talar dome
- Diagnostic injection
  - Intra-articular
  - An anesthetic versus anesthetic plus corticosteroid
  - May have some therapeutic effect, even for several months
  - If the source of pain is the OLT, then intra-articular injection should relieve symptoms from OLT. If the pain is not relieved, then other diagnoses should be considered.

DIFFERENTIAL DIAGNOSIS
- Loose body in ankle joint
- Ankle impingement (anterior or posterior)
- Chronic ankle instability (medial, lateral, or syndesmotic)
Ankle synovitis or adjacent tendinopathy
■ Early ankle degenerative change

NONOPERATIVE MANAGEMENT
■ Activity modification
■ Bracing
■ Physical therapy if associated ankle instability
■ Nonsteroidal anti-inflammatories or COX-2 inhibitors
■ Corticosteroid injection
■ Viscosupplementation?

SURGICAL MANAGEMENT
Preoperative Planning
■ Indications for this surgery include:
  ■ Medium-sized OLTs not amenable to other joint-sparing procedures. If associated with a large subchondral cyst, then arthroscopic débridement and microfracture may not be effective, and some surgeons recommend osteochondral transfer as a primary procedure.
  ■ Failed arthroscopic (débridement and microfracture) management
  ■ Potential sites for graft harvest
    ■ Patient’s ipsilateral knee (superolateral femoral condyle, intracondylar notch)
    ■ Allograft talus
  ■ Ipsilateral knee versus talar allograft
    ■ Knee is autograft; however, knee cartilage is thicker than ankle cartilage and may have different biomechanical properties.
    ■ Allograft talus offers nearly the same cartilage thickness and harvest from the exact location of the native talus’ defect; however, it is not the patient’s own tissue.
  ■ The surgeon should check for associated pathology that may need to be addressed at the time of allograft talar reconstruction:
    ■ Osteophyte removal
    ■ Ligament reconstruction
    ■ Corrective osteotomies (calcaneal, supramalleolar)

FIG 1 • Radiographs. A. AP radiograph of the ankle suggests symmetric alignment and a medial talar dome defect. B. Mortise view also suggests medial osteochondral lesion of the talus. C. Lateral view shows anatomic alignment, with osteochondral lesion of the talus less obvious.

FIG 2 • CT. A. Coronal view with medial osteochondral lesion of the talus that approaches talar shoulder but appears contained. B. Sagittal view demonstrating rather medial osteochondral lesion of the talus. C. Axial view with posteromedial osteochondral lesion of the talus.
Patient education
- This is a complex procedure.
- The patient must understand that the intent is to transfer cartilage and bone from one location to another and expect it to incorporate into the native talus.
- If allograft is used, there is a negligible but real risk of disease transmission and possible graft rejection by the host.
- There is no guarantee that the procedure will work, and a revision procedure may be required, such as structural allograft reconstruction or potentially ankle arthrodesis.

Positioning
- The patient is positioned supine (FIG 3).
- For a lateral OLT, a bolster under the ipsilateral hip typically affords better access to the lateral talar dome.
- We routinely use a thigh tourniquet.

Approach
- The surgeon must determine the optimal surgical approach:
  - Medial talar dome (usually centromedial or posteromedial) typically warrants a medial malleolar osteotomy.

MEDIAL APPROACH FOR A MEDIAL OSTEOCHONDRAL LESION OF THE TALUS
- Make a longitudinal incision centered over the medial malleolus (TECH FIG 1A).
- Anterior ankle arthrotomy
  - Identify the joint line (TECH FIG 1B).
  - Visualize the anterior talus and possibly anterior OLT (TECH FIG 1C).
- Open the flexor retinaculum (TECH FIG 1D).
  - Identify and protect the posterior tibial tendon (PTT) (TECH FIG 1E).
- Predrill the intended screw holes for fixation of the osteotomy.
- Two parallel drill holes in the same orientation are typically used for open reduction and internal fixation (ORIF) of a medial malleolar fracture (TECH FIG 1F).
- Consider tapping the screw holes as well (traditional malleolar screws are not self-tapping) (TECH FIG 1G).

Trajectory of the oblique osteotomy
- Should target tibial plafond at lateral extent of OLT
- Allows perpendicular access to the OLT with the dedicated instrumentation
We routinely use a Kirschner wire to determine the trajectory for the osteotomy.
- Place the wire slightly proximal and lateral to the planned osteotomy so as not to interfere with the saw blade and chisel (TECH FIG 2A).
- Confirm desired Kirschner wire trajectory with fluoroscopy.
- Mark the osteotomy.
  - Across the periosteum and with minimal periosteal stripping (TECH FIG 2B)
  - Perpendicular to the tibial shaft axis
- Protect the soft tissues:
  - Tibialis anterior retracted
  - PTT retracted. Do not mistake the flexor digitorum longus for the PTT (PTT rests in a groove directly on the posterior aspect of tibia).
- Performing the osteotomy
  - Microsagittal saw (TECH FIG 2C)
    - To the subchondral bone
    - Use cool saline irrigation to limit risk of heat necrosis to the bone.
  - Chisel (TECH FIG 2D)
    - Complete the osteotomy with a chisel.
- Periodically check the progress of the osteotomy fluoroscopically to confirm trajectory and to avoid injury to the talar dome.
- Reflect medial malleolus on the deltoid ligament (TECH FIG 2E).
  - The PTT sheath must be released from the malleolus to allow full reflection of the malleolus.

**Lateral Approach for a Lateral Osteochondral Lesion of the Talus**

- Ideal for lateral OLT associated with lateral ankle instability.
- Lateral ligaments may be released even without ligament instability.
- Make a longitudinal incision over the distal lateral fibula and curve it slightly anteriorly at the distal margin.
  - Protect the sural nerve and lateral branch of the superficial peroneal nerve.
- Identify the inferior extensor retinaculum and mobilize it to be used as augmentation to lateral ligament repair at the conclusion of the cartilage procedure.
- Identify the peroneal tendons and protect them throughout the procedure.
- Release the joint capsule, with anterior talofibular and calcaneofibular ligaments, from the distal fibula.
- In many patients, plantarflexion and inversion allows sufficient anterior subluxation of the talus to perform osteochondral transfer with the dedicated instruments perpendicular to the osteochondral defect.
- If the exposure is not sufficient with soft tissue release alone, a fibular osteotomy may be performed to gain access to the more posteriorly situated lateral OLT.
- **Fibular osteotomy**
  - We routinely perform an oblique fibular osteotomy, similar to the pattern of a Weber B ankle fracture.
When performed with the ligament release described above, exposure is markedly enhanced.

Before performing the osteotomy, we place a small fragment plate on the lateral fibula that spans the proposed osteotomy and predrill the holes.

With the peroneal tendons and superficial peroneal nerve protected, perform the osteotomy obliquely using a microsagittal saw.

Cool saline irrigation to limit bony heat necrosis

Avoid injuring intact articular cartilage on talus.

 Syndesmotic ligaments remain intact.

### Osteochondral Transfer

- Single-stage operation
- Donor options:
  - Autograft from ipsilateral knee
  - Arthroscopy versus arthroscopic
  - Superolateral femoral condyle versus intracondylar notch
  - Moderate amount of donor graft available
  - Autograft from ipsilateral talus
  - Limited donor graft available
  - Allograft talus
    - Fresh allograft ideal
    - Ideally same side as the native talus to replace the deficient cartilage with cartilage from the exact same location
  - Maximum donor graft available
  - Advantage over knee or talar autograft if the OLT proves not to be contained

- Recipient site preparation
  - Débride the OLT sharply to stable circumferential rim of articular cartilage (TECH FIG 3A).
  - Be sure that the defect is contained.
  - Bony rim circumferentially
  - Interference fit will be compromised if medial talar dome at the defect lacks integrity.
  - If not, then a structural allograft reconstruction should be considered.

- Assess defect size and orientation with the sizing guide and with reference to preoperative CT scan (TECH FIG 3B). Larger defects may warrant two or even three grafts.

- Recipient site chisel
  - Assistant will need to position foot in maximal inversion or eversion for medial and lateral OLTs, respectively (TECH FIG 4A).
  - Select appropriate chisel size.
  - Orient chisel perpendicular to defect (TECH FIG 4B).

- We routinely advance the chisel 11 to 12 mm into the talus (TECH FIG 4C).
  - Maintain proper chisel orientation to the desired depth.
TECH FIG 3 • A. The surgeon probes and débrides the osteochondral lesion of the talus to define its superficial dimensions. B. The defect is sized to determine optimal recipient chisel size.

- Do not attempt to change orientation of the chisel once the chisel has been advanced into the subchondral bone.
- Once at the desired depth, twist the chisel forcefully 90 degrees and then 90 degrees again (TECH FIG 4D).
- Gently toggle the chisel to free the diseased cartilage from the surrounding healthy cartilage.
- Extract the diseased osteochondral cylinder (TECH FIG 4E).
- If the subchondral bone is sclerotic, a reamer of corresponding size from an anterior cruciate ligament set may be used to create the recipient site.
- Use cool saline irrigation to limit the risk of heat necrosis to surrounding native talus.
- Predrill the guide pin to ensure that the reamer maintains position and proper orientation.

Donor site preparation and graft harvest (superior lateral femoral condyle)

TECH FIG 4 • Preparing the recipient site. A. Assistant everts the ankle to permit vertical axis of the recipient chisel. B. Recipient chisel is oriented properly on the osteochondral lesion of the talus, approaching without violating the medial talar dome subchondral bone (essential so the defect remains contained). C. Mallet to advance the chisel. D. Once fully seated, the chisel is aggressively twisted to free the diseased cartilage cylinder. E. The recipient site is prepared. Note the slight medial cartilage defect, but the recipient site is still contained.
Superolateral arthrotomy
- Knee extended
- Longitudinal approach immediately lateral to patella (TECH FIG 5A,B), about 5 cm long
- Avoid injuring cartilage.

Chose optimal site for graft harvest (TECH FIG 5C).
- Use the same sizing guide as you did for the recipient site to determine the proper trajectory for the harvesting chisel and to determine the ideal location for graft harvest.

If multiple grafts are needed, be sure to leave an adequate bridge between harvest sites.
- Avoid fracturing one harvest site into another, thereby creating a large defect.

Select the corresponding donor chisel.
- This chisel is 1 mm larger in diameter than the recipient chisel. This allows for interference fit of the graft into the recipient site.

The chisel must be perpendicular to the harvest site (TECH FIG 5D).
- Be sure not to contact the cartilage surface with the chisel until proper position has been obtained. The chisel is sharp and will cut into the cartilage, even with light pressure.

Impact the chisel to a depth of 10 mm (TECH FIG 5E).
- Do not change the orientation of the chisel once it has been advanced into the subchondral bone.

Once desired depth has been achieved
- Rotate the chisel 90 degrees and then 90 degrees again (TECH FIG 5F).
- Toggle the chisel lightly to release the graft.
- Extract the graft from the knee.
- A fenestration in the chisel allows for visualization of the graft to ensure it is free and advancing from the harvest site with the chisel (TECH FIG 5G,H).

TECH FIG 5 • A–C. Exposure of superolateral femoral condyle.
A. Superolateral approach to knee. B. Knee arthrotomy. C. Superolateral femoral condyle exposed with patella retracted medially. D–H. Harvesting donor graft. D. Donor chisel oriented to allow optimal graft harvest. E. Harvesting chisel impacted without changing trajectory once chisel introduced. F. Once chisel is fully seated, it is aggressively twisted to free the cylindrical graft. (continued)
The graft does not leave the chisel until it is secured in the recipient site.

Graft transfer to the recipient site
- Properly orient the donor chisel over the recipient site, maintaining contact with the chisel directly over the defect (TECH FIG 6A,B).
- Advance the graft into the recipient site by advancing the tamp in the donor chisel (TECH FIG 6C). Fenestrations in the chisel permit visualization of the graft being advanced.
- Remove the chisel when the graft is nearly fully seated (TECH FIG 6D,E).
- The goal is to place the graft flush with the surrounding native articular cartilage.
- A corresponding tamp or sizing guide may then be used to carefully achieve the final position of the graft (TECH FIG 6F,G).

We routinely harvest a 10-mm osteochondral cylinder but prepare an 11- to 12-mm recipient site. While countersinking the graft is a risk, the interference fit typically limits this from occurring. In our opinion it is safer than creating a recipient site that is too shallow, thus potentially leading to forceful tamping of the graft that may lead to shearing of the graft cartilage from its osseous cylinder.

Osteochondral Transfer Incorporating a Small Portion of Medial or Lateral Talar Dome Cartilage
- This technique is used when the OLT involves some of the cartilage on the medial or lateral sides of the talar dome while still being contained.
- Recipient site
  - The recipient site chisel approaches the talar shoulder but is not advanced beyond the subchondral border of the medial or lateral talus.
  - This will extract the dorsal shoulder of the talus, leaving the medial or lateral talar subchondral bone and cartilage intact (still contained).
- Donor site
  - As for the recipient site and chisel, the donor chisel approaches the superolateral femoral condyle’s shoulder but is not advanced beyond its border.
  - The dorsal shoulder of the graft will be included in the harvest without violating the lateral femoral condyle’s subchondral bone on its lateral margin.
- Transfer
  - Medial OLT
    - The chisel will need to be rotated 180 degrees to fill the articular cartilage defect that extends over the shoulder from the dorsal talar dome.
TECH FIG 6 • (continued) D. Chisel typically releases graft before it is fully seated (in our hands, preferred so we can control the final graft position). E. Graft sitting slightly proud relative to the adjacent native cartilage. F. Dedicated smooth tamp used to perform final seating of graft. Inset shows that the tamp is tapped lightly to advance graft in a graduated manner. G. Graft seated flush with surrounding native cartilage. (Note medial articular defect not fully resurfaced, but majority of osteochondral lesion of the talus is resurfaced with stable graft.)

- Mark the donor chisel during graft harvest to avoid malrotation of the graft in the recipient site.
- For a lateral OLT this rotation is not necessary when transferring from the ipsilateral knee.

Closure
- Medial closure
  - Reduction of the medial osteotomy after cartilage reconstruction
- Temporarily place a drill bit in one of the predrilled holes to orient the reduction.
- Confirm reduction by visualizing the anterior and posterior aspects of the osteotomy at the joint line.
- We routinely use two partially threaded small fragment cancellous screws to fix the osteotomy under compression (TECH FIG 7A,B).
  - If fixation is suboptimal, two fully threaded cortical screws may be used to engage the opposite cortex.

TECH FIG 7 • Reducing medial malleolar osteotomy. A. Reduced osteotomy is secured with two malleolar screws placed in the predrilled holes. B. View through arthroscopy confirms reduction of anterior tibial plafond. (continued)
It may be necessary to use longer cortical screws from a pelvic set to reach the opposite cortex.

- A buttress plate placed at the superior aspect of the osteotomy provides an antiglide effect (TECH FIG 7C).
- Confirm fluoroscopically that the osteotomy is anatomically reduced at the plafond.
- A minimal gap will be present at the osteotomy site despite anatomic reduction, due to the thickness of the saw blade.
- Reapproximate the flexor retinaculum with the PTT in its anatomic position (TECH FIG 7D).
- Close the anterior arthrotomy (TECH FIG 7E).
- The periosteum over the osteotomy may be reapproximated but must be coordinated with the antiglide plate.
- Lateral closure
- Fibular osteotomy reduction, ligament repair, and closure after cartilage procedure
POSTOPERATIVE CARE
- We routinely observe these patients overnight for pain control.
- Follow-up is done in about 10 to 14 days.
- Provided the wound and osteotomy (if one was performed) are stable, the patient is transferred into a touch-down weight-bearing cam boot. If not, a touch-down weight-bearing short-leg cast is continued until the wound and osteotomy are stable.
- Intermittent minimal, gentle ankle range of motion (ROM) is encouraged, three or four times a day. If financially feasible, we arrange for an ankle continuous passive motion (CPM) device.
- Touch-down weight bearing is maintained for 8 to 10 weeks, with progressively increasing ankle ROM exercise.
- We routinely obtain simulated weight-bearing radiographs at 6 weeks and 10 weeks, and again at 14 to 16 weeks, depending on the progression of healing. If there was a concern about fixation of the graft or osteotomy, then radiographs are also obtained at the first postoperative visit (FIG 4).
- Knee cartilage has a different thickness than ankle cartilage; therefore, an appropriately placed osteochondral graft from the knee may appear resected on the postoperative radiograph (FIG 5).

OUTCOMES
- Good to excellent results with osteochondral autografting at short to intermediate follow-up can be obtained in 90% to 94% of patients.
- Excellent functional outcomes
- Improvement in ROM
- Improved pain scores
- Best results for smaller defects (those that can be managed with a single graft)
- Good to excellent results for OLTs associated with subchondral cysts
- Donor site morbidity was found to be minimal except in a single study, which found poor knee functional scores in 36%.
- No reported complications from malleolar osteotomy
- Results are not worse for osteochondral transfer performed as a secondary procedure after failed arthroscopic treatment compared to osteochondral transfer as a primary procedure. Additionally, there may be no benefit of osteochondral autograft transplantation over chondroplasty or microfracture in the management of primary lesions without subchondral cysts, as demonstrated in a recent randomized prospective trial comparing the three procedures.9

COMPLICATIONS
- Infection
- Wound complication
- Failure of graft incorporation
- Graft failure and potential risk of developing degenerative change
- Articular cartilage delamination or fissuring of the graft
- Malleolar osteotomy nonunion
- Persistent pain despite radiographic suggestion of graft incorporation
- Disease transmission with allograft, but with the current screening practices of tissue banks, this risk is negligible
- Donor site morbidity at the knee

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Perpendicular access</th>
<th>The dedicated chisel must be oriented perpendicular to the articular cartilage. Thus, the exposure (osteotomy) must be adequate to accommodate the perpendicular position of the chisel.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do not reorient the chisel once it has been advanced into the subchondral bone.</td>
<td>Carefully obtain the proper orientation of the chisel before advancing it. If orientation is changed during impaction, you may not be able to extract an intact osteochondral graft.</td>
</tr>
<tr>
<td>Graft height and recipient site depth</td>
<td>The graft must not be longer than the recipient site. Impaction may lead to shear of the graft’s articular cartilage from its osseous cylinder.</td>
</tr>
<tr>
<td>Using multiple grafts</td>
<td>Do not allow one graft harvest site to fracture into an adjacent harvest site. However, grafts may be overlapped (intersecting circles) to fill the recipient site optimally.</td>
</tr>
<tr>
<td>Malleolar osteotomy</td>
<td>The medial malleolar osteotomy must have perfect congruency at the tibial plafond when reduced.</td>
</tr>
</tbody>
</table>
REFERENCES


SURGICAL MANAGEMENT

Patient Positioning
- The patient is positioned supine under appropriate anesthesia, with thigh tourniquet control and a bolster beneath the ipsilateral buttck. The leg, ankle, and foot are prepared and draped from below the knee distally.

Approach
- For a medial lesion a 7-cm anteromedial longitudinal incision is made over the ankle joint parallel to the medial talar facet.
- The soft tissue is dissected to the ankle joint and a capsulotony performed.
- Enough capsule is stripped from the tibia to expose the medial half of the joint.
- A synovectomy is performed if needed.

TIBIAL OSTEOTOMY USING THE TRAP DOOR

Opening the Tibial Trap Door
- Strip the periosteum proximally along the distal tibial metaphysis to the upper limit of the wound.
  - Make a 1-cm mark on the medial tibial plafond beginning at the angle of Hardy (TECH FIG 1).
  - Make a second mark 3 cm above the joint line.
- Drill two transverse parallel holes across the tibial metaphysis beneath the cortex where the tibial trap door is to be removed. Absorbable pins will be inserted into these predrilled holes when the trap door is replaced after the graft has been inserted in the talar dome.
- Make two vertical parallel saw cuts with a Hall micro-oscillating saw using a no. 64 saw blade (Zimmer, Warsaw, IN) to a depth of 2 cm at the joint surface (TECH FIG 2).
  - Taper these cuts proximally and upward to the anterior tibial metaphysis 3 cm above the joint.
  - To protect the talar surface, insert a Freer elevator between the tibia and talus.
- Make a third horizontal saw cut connecting these cuts at their upper limit.
  - Angle the saw inferiorly and 22 degrees posteriorly from the anterior metaphysis toward the joint surface.
- Use a thin 10-mm osteotome to mobilize the trap door. Remove the trap door and place it aside (TECH FIG 3).

Coring Out the Lesion
- Plantarflex the ankle to deliver the osteochondral lesion into view (TECH FIG 4).
- Probe the lesion to determine its exact location.
- Select the appropriate-size coring instrument (Arthrex, MA): 6, 8, or 10 mm.
- Place the coring instrument at right angles to the talar dome and extract the lesion.
- The removed bone is to be used later.

TECH FIG 1  •  A 7-cm anteromedial incision exposing the medial half of the ankle joint, showing the angle of Hardy (arrow).
TECH FIG 2  •  Saw cuts are made 1 cm wide, 3 cm high, and 2 cm deep (not seen), creating a trap door (arrow).
Harvesting the Graft

- Expose the medial facet of the talar body using a mini-Hohmann retractor with the ankle in plantarflexion.
- Position the harvesting instrument on the medial facet 4 mm beneath the talar dome.
- Harvest the graft in such a way that when inserted into the recipient site, the slightly elevated inferior margin of the graft from the medial facet will be oriented toward the medial border of the talar dome, approximating the shape of the normal talar weight-bearing surface (TECH FIG 5).

Inserting the Graft

- Débride the talar recipient site and tap the osteochondral graft into place with the inferior medial facet portion oriented toward the medial border of the talus (TECH FIG 6).

Filling the Donor Site

- Insert the material that was removed, including the osteochondral lesion, in the donor site.
- This can be augmented with cancellous bone taken from the distal tibia.

Closing the Trap Door

- Insert the tibial bone block back into its bed and insert bioabsorbable pins (Biosorb, Johnson & Johnson, Princeton, NJ) into the predrilled holes to secure the bone block in place (TECH FIG 7).

Wound Closure and Postoperative Care

- Approximate the deep tissues with 3-0 absorbable suture and close the skin with 3-0 monofilament nylon.
- Apply a compression dressing and posterior splint; they are changed at the first follow-up visit.
- Sutures are removed at 2 weeks and a non–weight-bearing short-leg cast is used for 1 month.
- A range-of-motion boot is then prescribed with 50% weight bearing for 3 weeks, after which physical therapy is instituted.
Chapter 94  ANTHERIOR TIBIAL OSTEOTOMY FOR OSTEOCHONDRAL LESIONS OF THE TALUS

TECHNIQUES

- If the bone at the base of recipient site is excessively sclerotic, it may be drilled using a 0.045 Kirschner wire before inserting the graft in order to encourage vascular ingrowth.

- For lesions on the lateral talar dome, use the same technique but make the most lateral vertical saw cut 2 mm away from the distal tibiofibular syndesmosis to avoid violating the joint.

ADDITIONAL TECHNIQUE

PEARLS AND PITFALLS

- This technique avoids the need for a medial malleolar osteotomy. It provides excellent visualization of and access to the lesion through a single incision while avoiding a second procedure on an asymptomatic knee to harvest the graft.

- The procedure is best suited for lesions up to 10 mm in diameter and up to 10 mm deep located in the anterior two thirds of the medial or lateral talar dome margins.

- The graft can be placed just beneath the subchondral bone of the medial or lateral facet since these surfaces bear minimal weight, and no complications have been noted in the medial or lateral gutters.

- The surgeon should avoid making the vertical saw cuts more than 3 cm deep at the joint surface or 4 cm in height since this increases the risk of a medial malleolar stress fracture.

- In harvesting the osteochondral graft, the surgeon should avoid taking the graft too near the talar surface or too near the recipient site in order to avoid a stress fracture of the talar dome.

- Patients with arthritis can have progression of the condition even though the graft becomes incorporated and survives.

- The most common minor complaint is occasional aching at the anteromedial joint line with activity.

REFERENCE

DEFINITION
- Large osteochondral defects of the talar dome, typically involving the talar shoulder (transition of superior dome cartilage to the medial or lateral talar cartilage), and also often associated with large-volume subchondral cysts.

ANATOMY
- Sixty percent of the talus’ surface area is covered by articular cartilage.
- The talus is contained within the ankle mortise.
  - Superior talar dome articulates with the tibial plafond.
  - Medial dome articulates with the medial malleolus.
  - Lateral dome articulates with the lateral malleolus.
- Talar blood supply:
  - Posterior tibial artery
  - Artery of the tarsal canal
  - Deltoid ligament branch
  - Peroneal artery
  - Artery of the tarsal sinus
  - Dorsalis pedis artery

PATHOGENESIS
- The pathogenesis for osteochondral lesions of the talus (OLTs) is not fully understood.
- Theories include:
  - Trauma
  - Idiopathic focal avascular necrosis

NATURAL HISTORY
- In general, OLTs do not progress to diffuse ankle arthritis.
- However, large-volume OLTs may lead to subchondral collapse of a substantial portion of the talus and thus create deformity, higher contact stresses, and a greater concern for eventual ankle arthritis if left untreated.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients may or may not report a history of trauma.
- Ankle pain, typically on the anterior aspect of the ankle, is a common complaint.
  - Pain is usually experienced on the side of the ankle that corresponds with the OLT, but it may be poorly localized to the site of the OLT. In fact, sometimes medial OLTs produce lateral ankle pain and vice versa.
  - Pain is rarely sharp, unless a fragment of the OLT should act as an impinging loose body in the joint.
  - It is typically a deep ache, with and after activity, and is usually relieved with rest.
- Antalgic gait
- May be associated with malalignment or ankle instability
- Typically tenderness on side of ankle that corresponds with OLT, but not always

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs
  - Small OLTs may be missed.
  - Large OLTs are usually identified on plain radiographs, three views of the ankle, weight-bearing.
  - Radiographs are often limited in characterizing OLTs since the two-dimensional study cannot define the three-dimensional OLT.
  - Particularly useful in assessing lower leg, ankle, or foot malalignment, which needs to be considered in the management of OLTs
  - May detect incidental OLTs (patient has radiograph for a different problem and an OLT is incidentally identified on plain radiographs)
- MRI
  - Excellent screening tool when OLT or other foot–ankle pathology is suspected
  - Will identify incidental OLT, but defines other potential soft tissue pathology
  - Demonstrates associated marrow edema that may lead to overestimation of the OLT’s size
- CT
  - Ideal for characterizing OLTs, particularly large-volume defects
  - Defines OLT size without distraction of associated marrow edema
  - Defines the character of the OLT and extent of its involvement in the talar dome
- Diagnostic injection
  - Intra-articular
    - An anesthetic versus anesthetic plus corticosteroid
    - May have some therapeutic effect, even for several months
    - If the source of pain is the OLT, then intra-articular injection should relieve symptoms from OLT (and any intra-articular pathology). If the pain is not relieved, then extra-articular diagnoses should be considered.

DIFFERENTIAL DIAGNOSIS
- Loose body in ankle joint
- Ankle impingement (anterior or posterior)
- Chronic ankle instability (lateral or syndesmosis)
- Ankle synovitis or adjacent tendinopathy
- Early ankle degenerative change

NONOPERATIVE MANAGEMENT
- Activity modification
- Bracing
- Physical therapy if associated ankle instability
Nonsteroidal anti-inflammator{}ies or COX-2 inhibitors
Corticosteroid injection
Viscosupplementation?

SURGICAL MANAGEMENT

Preoperative Planning

- Indications for this surgery include:
  - Large-volume OLTs not amenable to other joint-sparing procedures
  - Failed arthroscopic surgery (débridement and microfracture)
  - Failed open procedures (cylindrical osteochondral transfer)
  - Large-volume OLTs typically are not amenable to autologous osteochondral transfer (talus or knee).
- We favor reconstruction of the large talar defect with an allograft talus. While we prefer fresh allograft tissue, we have on occasion used fresh-frozen tissue.
- Scheduling of this procedure with fresh allograft tissue is similar to organ transplantation but with a wider window for implantation after procurement.
- Multiple tissue banks have the ability to obtain fresh allograft tali.
- Once a donor talus is identified, the tissue bank performs appropriate screening.
- If the talus is deemed safe for implantation and represents a match based on radiographic size, on average 14 to 21 days of reasonable chondrocyte viability remains for the talar allograft to be used.
- While fresh structural talar allograft reconstruction for large-volume OLTs has gained a foothold as an accepted treatment among reconstructive foot and ankle surgeons, not all third-party payers cover this procedure. We do not seek an allograft talus for our patients from the tissue banks until our third-party payers cover this procedure. We do not seek an allograft tissue.
- The patient must understand that the intent is to implant allograft tissue.
- There is no guarantee that the procedure will work, and a revision procedure may be required, such as arthrodesis, which will eliminate joint motion.

Positioning

- Before anesthesia and moving the patient into the operating room, the surgeon should inspect the allograft to be sure it is the correct side (right or left) and for cartilage defects that may be present directly at the site that the graft is to be harvested.
- The patient is positioned supine.
- For a lateral OLT, a bolster under the ipsilateral hip typically affords better access to the lateral talar dome.
- We routinely use a thigh tourniquet.

Approach

- As noted above, the approach depends on the size and location of the OLT.
- For medial OLTs amenable to reconstruction of only a portion of the medial talar dome: direct medial approach, similar to that for open reduction and internal fixation (ORIF) of a medial malleolar fracture, with a medial malleolar osteotomy
- For lateral OLTs amenable to reconstruction of only a portion of the lateral talar dome: lateral approach, combining typical approaches for ORIF of a fibular fracture and the extensive exposure for a modified Brostrom procedure
- For large medial or lateral OLTs, involving the majority of the medial or lateral talar shoulder: anterior approach, similar to that for ankle arthrodesis or total ankle arthroplasty; typically no malleolar osteotomy is required.

### TECHNIQUES

#### TECH FIG 1A

- Defines anterior joint margin for safe performance of medial malleolar osteotomy
- Allows partial visualization of the OLT and allows confirmation that there is not diffuse articular cartilage degeneration
- Open the posterior tibial tendon sheath–flexor retinaculum, directly on the posterior margin of the tibia and

### APPROACH AND OBLIQUE MEDIAL MALLEOlar OSTEOTOMY

- Make a curvilinear incision over the medial malleolus, similar to that for ORIF of a medial malleolar fracture.
- Protect the saphenous vein and accompanying saphenous nerves.
- Anterior ankle arthroscopy (TECH FIG 1A)
TECH FIG 1 • A. Medial incision and anterior ankle arthrotomy. B. Opening of the posterior tibial tendon sheath. C. Predrilling of medial malleolus. Kirschner wire for trajectory of medial malleolar osteotomy has already been inserted and its position confirmed with fluoroscopy. D. Fluoroscopic image demonstrating Kirschner wire being used as a guide to direct the saw. E. The periosteum is scored perpendicular to the tibial shaft, at the level of the osteotomy. F. Medial malleolar osteotomy. Care must be taken to protect the posterior tibial tendon. G. Fluoroscopic image showing near-complete bone cut. H. Release of posterior tibial tendon sheath from distal medial malleolus to allow mobilization.

- Obtain fluoroscopic confirmation that the drill bits are in the proper trajectory.
- Consider passing a tap as well.
- Place a Kirschner wire obliquely to define the trajectory of the medial malleolar osteotomy (TECH FIG 1C).
- Place it slightly proximal to the desired osteotomy so it can function as a guide but not interfere with the saw (TECH FIG 1D).

■ Predrill the medial malleolus across the proposed osteotomy site (TECH FIG 1C).
■ We routinely use two small fragment malleolar screws and predrill with the corresponding drill.
Confirm the optimal Kirschner wire trajectory with intraoperative fluoroscopy.

Ideally, the Kirschner wire will extend to the lateral margin of the OLT, but with large-volume OLTs that may be too much and unnecessary. However, in our experience, making the osteotomy only to the axilla of the tibial plafond where it meets the medial malleolus will not allow adequate access to perform ideal recipient-site preparation.

Determine a plane for the osteotomy in the AP plane that is perpendicular to the longitudinal axis of the tibia. We find it helpful to score the osteotomy in the periosteum from anterior to posterior to determine this level (TECH FIG 1E).

Periosteal stripping is unnecessary; it may be limited to the osteotomy site.

With a microsagittal saw oriented correctly in both planes, the osteotomy is initiated (TECH FIG 1F).

Use cool saline to limit the risk of heat necrosis to the bone.

Obtain intraoperative fluoroscopy shortly after initiating the osteotomy; leave the saw blade in place to confirm proper trajectory. If incorrect, a subtle adjustment is still possible (TECH FIG 1G).

Continue the osteotomy with the saw to the subchondral bone and then complete the osteotomy with a chisel.

A fluoroscopic spot view allows the surgeon to confirm that the osteotomy is appropriate and is not violating the talar cartilage.

There may be some irregularity to the osteotomy at the posterior margin; this is typical as the osteotomy is mobilized. It may be advantageous as it allows for an interference fit during reduction of the osteotomy and perhaps greater stability.

Reflect the medial malleolus.

The posterior tibial tendon sheath must be released to the distal aspect of the posterior medial malleolus to allow the malleolus to reflect adequately and to gain optimal exposure of the medial talus dome (TECH FIG 1H). Protect the deltoid ligament fibers.

Preparing the Recipient Site

Define the extent of the OLT (TECH FIG 2A,B).

Clinical inspection

Review of CT scan

If the talar defect appears amenable to structural allograft reconstruction, have the donor talus placed on the back table and protected in a saline-soaked sponge.

Excise the diseased portion of the talus (TECH FIG 2C-F).

Reciprocating and microsagittal saw (use cool saline to limit risk of heat necrosis)

May need a small curette and rasp as well

**TECH FIG 2** • A, B. Identifying the extent of the talar shoulder lesion. C–E. Excision of the talar shoulder lesion using the microsagittal and oscillating saws. F. Talar shoulder lesion removed.
Define the dimensions of the recipient site. Use a caliper and a ruler and double-check the measurements.

**Harvesting Graft from Donor Talus**

- Handle the allograft talus with bone forceps.
- Properly orient the talus (compare to native talus) to ensure that the cuts will be congruent and in the same plane as those for the recipient site.
- Carefully mark the dimensions for graft harvest on the allograft (**TECH FIG 3A**).
  - Same location on the allograft talus as the recipient site on the native talus
  - If you err, err to have the graft slightly too large. Be sure to account for saw blade thickness.
- “Measure twice and cut once.”
  - You have only one opportunity, so be sure the measurements and orientation of the saw blade for each cut are optimal.
  - The allograft can be stabilized with two large pointed reduction clamps (**TECH FIG 3B**).
- Extract the graft from the donor talus (**TECH FIG 3C**).
- Reduce the immunogenic load from the graft by washing the graft’s cancellous surfaces with saline.

**Implanting and Securing the Graft into the Recipient Site**

- Only once have we had a graft match perfectly on the first attempt. The graft and recipient site will almost always need to be tailored slightly to allow optimal graft fit.
- It is unlikely that a perfect clinical and fluoroscopic match will be achieved. Attempt to achieve the best clinical match of the graft’s articular surface with the surrounding native cartilage (**TECH FIG 4A**).
- If the clinical match is appropriate, then the fluoroscopic match is not important.
  - There is a lot of variability in cartilage thickness and talar architecture in the human talus.
  - It is difficult to get four surfaces to congruently match.
- **Graft fixation**
  - Ideally, the graft will have some interference fit.
  - We routinely secure the graft with one or two small-diameter solid screws (1.5 or 2.0 mm in diameter). One is typically placed from dorsal to plantar, the other from medial to lateral (if the depth of the graft will allow) (**TECH FIG 4B, C**).
Place the screws in lag fashion.
- Countersink the screw heads below the articular surface (TECH FIG 4D,E).
- Using fluoroscopy, confirm that the graft and hardware are in optimal position (TECH FIG 4F–H).
- The graft will not look perfect fluoroscopically, but as long as the clinical appearance is acceptable, the outcome has a good chance to be favorable.
- The hardware may appear slightly proud fluoroscopically despite being countersunk. The talar dome is not a flat plane, and therefore the screw may seem to be protruding. Moreover, the articular cartilage is rather thick compared to such a low-profile screw head.

**Medial Malleolar Osteotomy Reduction and Closure**
- Irrigate the joint.
- Reduce the medial malleolus. Confirm the reduction through the anteromedial arthrotomy and posteriorly behind the posterior tibial tendon.
- Place the two screws in the predrilled holes and tighten the screws.
- While not essential for healing, we favor placing an antiglide plate over the proximal aspect of the osteotomy.
- Using fluoroscopy, confirm reduction of the graft and medial malleolus (see Tech Fig 4).
HEMI-TALUS RECONSTRUCTION OF MEDIAL OSTEOCHONDRAL LESION OF THE TALUS

Preoperative Evaluation

- Anticipate some incongruencies of the graft-native talus bony interfaces. It is difficult to achieve perfectly congruent apposition.
- There will be a slight gap at the medial malleolar osteotomy site despite anatomic reduction of the medial malleolus. This is due to the thickness of the saw blade. However, it is not acceptable to see a step-off at the osteotomy site where it enters the tibial plafond; this must be anatomic.
- The slight gaps at the graft and medial malleolus do not typically impair healing and should obliterate with eventual remodeling.
- Closure
  - Posterior tibial tendon sheath and flexor retinaculum
  - Anterior arthrotomy
  - Subcutaneous layer
  - Skin to a tensionless closure
  - We routinely use a drain.
  - Dressings, padding, and a posterior-sugar-tong splint with the ankle in neutral position

Approach

- Anterior approach (TECH FIG 6)
- Similar to anterior approach for ankle arthrodesis and total ankle arthroplasty
- Protect the superficial peroneal nerve.
- Divide the extensor retinaculum over the extensor hallucis longus tendon.
- Protect the deep neurovascular bundle.
- Anterior capsulotomy. Unlike ankle arthrodesis and total ankle arthroplasty, must protect ankle cartilage.
- Expose OLT with plantarflexion. Assess mediolateral dimensions and attempt to assess AP dimensions.

Preoperative Evaluation

- Patient is a 40-year-old man with chronic ankle pain failing prior arthroscopic débridement and microfracture. Feels he is overloading lateral border of foot.
- Preoperative weight-bearing radiographs suggest large medial OLT and varus malalignment with some varus talar tilt (TECH FIG 5A,B).
- CT demonstrates large-volume medial OLT (TECH FIG 5C–E).
- Before proceeding to the operating room, confirm that the allograft talus is the one intended for this patient, is available, and has not expired.
If the talus appears appropriate for an allograft talus, ask to have the donor talus opened and soaking in a warm saline-soaked sponge on the back table. At this point, though, this only expedites the procedure; it is not as though the talus may be returned. . .that patient now owns that talus.

Preparing the Recipient Site
- Joint distraction, preferably with an extra-articular distraction device
- Determine dimensions of diseased talus:
  - Clinical assessment
  - Review and correlate with CT.

Determine exact lateral sagittal border of OLT.
Make a vertical (sagittal) cut in the talus 1 mm lateral to the lateral extent of the OLT. The depth of this cut should be conservative until the exact superior-to-inferior dimensions of the OLT can be mapped out on the talus (TECH FIG 7A).
Horizontal (axial) resection in the talus (TECH FIG 7B)
- To maintain the proper axis, we routinely use a Kirschner wire placed from anterior to posterior, with its trajectory and depth confirmed on intraoperative fluoroscopy, to avoid misdirection of the axial resection.
- We use a thin oscillating saw for this cut, also with cold saline irrigation to cool the blade in an attempt to avoid heat necrosis to the bone.
- Protect the medial malleolar cartilage. Consider using a malleable ribbon retractor in the medial gutter.
- Extract the resected bone (TECH FIG 7C,D).
- Revisit the vertical and horizontal resections with the saw, a rasp, or both. If there is residual OLT in either or both of the prepared surfaces, then consider curetting these and bone grafting, or resecting more native talus (TECH FIG 7E).
- Fluoroscopic evaluation sometimes affords a useful appreciation of the recipient site.
- Determining the exact dimensions of the recipient site:
  - Calipers (TECH FIG 7F)
  - Ruler (TECH FIG 7G)
  - We routinely sketch the dimensions on a drawing of the recipient site on a surgical glove envelope or a sterile label on the back table.

Harvesting Graft from the Donor Talus
- Secure the allograft that has been placed on the back table with a bone-holding forceps.
- Mark the dimensions of the recipient site talus on the donor talus. One challenge is to orient the talus properly

TECH FIG 6 • Anterior approach, similar to that performed for total ankle arthroplasty. Since the entire medial one third to one half of the talar dome will be restructured, a medial malleolar osteotomy is typically not necessary.

TECH FIG 7 • A–D. Preparing the recipient site. A. Sagittal cut with reciprocating saw. B. Axial cut also with reciprocating saw. C. Elevating diseased portion of talus with osteotome. (continued)
to ensure that the two cuts will be in the optimal planes to congruently match the recipient site.

- Double-check the measurements.
- You have only one chance to harvest this graft.
- “Measure twice, cut once.”

- Make the cuts to harvest the talus (TECH FIG 8).
- Attempt to match the recipient site dimensions exactly, taking into account the thickness of the saw blade.
- If you have to err, then err on the side of harvesting a graft that is too large. Fine-tuning the graft is
 sometimes difficult, but it is still possible to downsize it or increase the size of the recipient site; it is not possible to augment the graft or reduce the size of the recipient site once the graft has been harvested.

- We routinely wash the graft’s cancellous surfaces with saline in an attempt to decrease the immunogenic load before implantation. However, we have no evidence to support this practice and perform this purely on an empiric basis.

**Implanting and Securing Graft into Recipient Site**

- Place the graft in the recipient site (TECH FIG 9A,B).
- We have never had a perfect match on the first attempt at seating the graft in the recipient site.
- Tailoring the graft to match the recipient site is often challenging.
  - In our hands this requires a slight deepening of the recipient site and a slight thinning of the graft.
  - Making the corresponding sagittal and axial talar cuts congruently is the most important step in achieving an optimal fit of the graft.
- Only once have we achieved a perfect graft match clinically and fluoroscopically.
  - The human talus is quite variable and regardless of the match, some inconsistencies will be present.
  - While the clinical appearance may suggest a near-perfect match, we routinely see slight incongruencies in the sagittal and axial preparations and what appears to be a slight mismatch to the native subchondral bone.
  - In our experience, however, these are not clinically relevant and some degree of remodeling during graft incorporation is anticipated.
- Fixation of the graft to the native talus (TECH FIG 9C–G)
  - We routinely use two solid small-diameter screws (1.5 or 2.0 mm) placed in lag fashion to secure the graft to the native talus.
  - These are placed anteriorly and countersunk below the articular surface, typically anterior to the tibial plafond with the ankle in neutral position.
  - While we would prefer to avoid violating the cartilage surface, to date we are not aware of any compromised outcome related to the articular defect created by placing the screws.
  - Because the talus is contained within the ankle mortise, in our experience posterior screw fixation is unnecessary.
  - We routinely assess graft position after screw placement fluoroscopically. Since the articular cartilage is not visible and the physiologic talar dome is not in a single plane, the countersunk screws may appear proud fluoroscopically.

**Axial Realignment**

- Based on the preoperative plan and intraoperative reassessment, consider correction of axial malalignment. This improves the weight-bearing axis of the lower extremity and potentially unloads and protects the graft (eccentric load on the talus may have contributed to development of OLT). The preoperative plan dictates the amount of desired correction. As a rule, 1 mm of medial opening equals 1 degree of correction.
  - Through the same incision, perform supramalleolar osteotomy for varus malalignment.
  - Medial opening wedge (TECH FIG 10)
    - Greenstick principle: leave lateral cortical hinge if possible
    - With or without fibular osteotomy, depending on degree of deformity
    - Minimal periosteal stripping
    - Attempt to limit to osteotomy site
    - Protect soft tissues
    - Judicious osteotomy
    - Consider a slightly oblique trajectory to increase surface area.
    - Careful medial opening
    - Protect lateral hinge.
    - If hinge is weak, maintain proper contact; control rotation of two fragments; consider using two plates in two planes for fixation.

---

**TECH FIG 9 • A, B.** Optimizing graft position in native talus. **A.** After further “touch-ups” to the graft and recipient site, optimal graft position. **B.** Stabilizing graft to native talus (blunt retractor superiorly and bone reduction clamp for coronal compression). (continued)
TECH FIG 9 • (continued) C–G. Graft fixation to native talus. C. Countersink used after drilling for screw to be placed in lag technique. D. First screw being inserted. E. First screw with compression and countersunk. F. Second screw being inserted. G. Both screws countersunk.

TECH FIG 10 • Realignment medial opening supramalleolar osteotomy. A. Osteotomy being carefully opened with an osteotome while preserving the lateral cortical hinge. B. Plate fixation.
We routinely bone graft the opening wedge osteotomy site. However, this is not recommended by all who perform these osteotomies.

**Closure**
- Perform thorough irrigation.
- Close the capsule.
- Release the tourniquet.

- Reapproximate the extensor retinaculum while protecting the deep neurovascular bundle, extensor tendons, and the superficial peroneal nerve.
- We routinely use a drain for 24 hours.
- Perform subcutaneous closure and tensionless skin reapproximation.
- Dressings, adequate padding, and posterior–sugar-tong splint with the ankle in neutral or even a slightly dorsiflexed position

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Procuring a talar allograft</th>
<th>Be sure it is the correct side (right or left). Be sure the tissue bank leaves the cartilage on the talus (we have had tali delivered from tissue banks that routinely remove the cartilage from the allograft talus!)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvesting the graft from the donor talus</td>
<td>“Measure twice and cut once.” You have only one opportunity to harvest the graft. Use a caliper and a ruler and double-check the measurements.</td>
</tr>
<tr>
<td>Orienting the donor talus during graft harvest</td>
<td>Take care to orient the donor talus properly, as it should rest in the ankle mortise (compare to the native talus). The sagittal and axial cuts must be congruent for the graft to have an optimal match.</td>
</tr>
<tr>
<td>Reducing the immunogenic load of the graft</td>
<td>Wash the graft’s cancellous surfaces with saline before implantation.</td>
</tr>
<tr>
<td>Graft position relative to the native talus</td>
<td>Rarely, if ever, is the graft a perfect clinical and fluoroscopic match; there is too much variability in the human talus. Anticipate some remodeling, provided the graft congruency is satisfactory to allow graft incorporation.</td>
</tr>
<tr>
<td>Screw fixation</td>
<td>Countersink the screws below the articular surface.</td>
</tr>
<tr>
<td>Malleolar osteotomy</td>
<td>Predrill the position for the screws to fix the malleolus at the conclusion of the surgery. Take into account the thickness of the saw blade; a perfect reduction clinically will demonstrate a slight gap due to bone loss from the saw blade. In our experience, the malleolus heals despite this narrow gap.</td>
</tr>
</tbody>
</table>

**POSTOPERATIVE CARE**
- We routinely observe these patients overnight for pain control.
- Follow-up is done in about 10 to 14 days.
- Provided the wound and osteotomy (if one was performed) are stable, the patient is transferred into a touch-down weight-bearing cam boot. If not, a touch-down weight-bearing cast is continued until the wound and osteotomy are stable.
- Intermittent minimal, gentle ankle range of motion (ROM) encouraged, three or four times a day. If financially feasible, we arrange for an ankle continuous passive motion device.

Touch-down weight bearing is maintained for 10 to 12 weeks, with progressively increasing ankle ROM exercise.

We routinely obtain simulated weight-bearing radiographs at 6 weeks and 10 weeks, and again at 14 to 16 weeks, depending on the progression of healing. If there was a concern about fixation of the graft or osteotomy, then radiographs are also obtained at the first postoperative visit (FIGS 1–3).

OUTCOMES

Gross et al² reported on nine patients who underwent fresh osteochondral allograft transplantation. At a mean follow-up of 11 years, six grafts remained in situ. The three failed allografts demonstrated radiographic and intraoperative evidence of fragmentation or resorption, and these patients went on to ankle fusion. Standardized outcomes measures for comparison were not used in that study.

Raikin³ recently reported on 15 patients who underwent bulk fresh osteochondral allografting for large-volume cystic lesions of the talus. The mean volume of the cystic lesions was 6059 mm³. At a mean follow-up of 4.5 years, the mean AOFAS ankle–hindfoot score was 83 points. Only two grafts failed and went on to have an ankle arthrodesis. Some form of graft collapse, graft resorption, or joint space narrowing was seen in all patients.

A retrospective review by Adams et al¹ showed significant improvement in pain and the Lower Extremity Functional Score (LEFS) at a mean follow-up of 48 months in eight patients who underwent osteochondral allograft transplantation of the talus. The mean postoperative AOFAS ankle–hindfoot score was 84 points. Three grafts were found to have graft-host lucencies in one plane on plain radiography. These patients were doing well and no further imaging was obtained. One patient continued to be symptomatic and was thought to have a nonunion of the graft due to circumferential lucency. Second-look arthroscopy demonstrated partial graft cartilage delamination but a stable graft. The patient did not wish to have any further treatment.

COMPLICATIONS

- Infection
- Wound complications
  - Particularly for anterior approach (as is performed for total ankle replacement)
  - Deep retraction only, avoiding direct tension on wound margins, reduces this risk.
- Failure of graft incorporation
- With large structural grafts, graft failure and development of degenerative change
- Articular cartilage delamination or fissuring of the graft
- Malleolar osteotomy nonunion
- Persistent pain despite radiographic suggestion of graft incorporation
- Disease transmission, although with the current screening practices of tissue banks, this risk is negligible.
REFERENCES


DEFINITION
- There are several reasons for cartilaginous defects of the ankle:
  - Traumatic injury
  - Osteochondritis dissecans (OCD)
  - Degenerative changes
- The necessity to treat a cartilage defect of the ankle depends on the clinical presentation. Osteochondral lesions of the talus (OLTs) are often found incidentally on screening MRIs obtained for reasons other than suspected intra-articular pathology.
- Autologous chondrocyte transplantation (ACT), also known as autologous chondrocyte implantation (ACI), is one of several surgical treatment options for symptomatic cartilage defects. In my opinion, ACI is best suited for patients between 18 and 50 years of age.
- ACI is indicated for management of symptomatic OLTs failing to respond to débridement, drilling, or microfracture.1,8,27
- Primary ACI can be considered in lesions larger than 2 cm 2 and in osteochondral lesions associated with expansive subchondral cysts (stage V lesion).48
- Advantages of ACI include:
  - ACI provides a stable cartilage rim that can be maintained at the site of the OLT.
  - Large defects can be readily addressed with this technique.
  - The periosteal flap can be harvested from the adjacent medial tibia.
  - With carefully executed suture technique or with matrix-based chondrocytes, shoulder lesions can be managed.
- Disadvantages of the ACI for the talar dome are:
  - ACI has Food and Drug Administration (FDA) approval only for the knee (as of October 2006).
  - The cost from industry for chondrocyte culture is considerable.
  - The procedure requires two stages to allow time for chondrocyte culture.
- Reports of the traditional technique that requires a periosteal flap under which the transplanted chondrocytes are positioned suggested limitations of the technique for the talus.47 Many OLTs involve, at least in part, the talar shoulder, an anatomic region poorly suited for anatomic coverage with a periosteal flap. Recently introduced matrix-based autologous chondrocyte transplantation (MACI) may afford advantages since it does not require coverage of the defect with a periosteal flap. Histologic investigations have shown that MACI may offer an improved alternative to traditional treatments for cartilage injury by regenerating hyaline-like cartilage.48
- Informed consent and patient education are imperative for ACI. ACI for the ankle lacks FDA approval. However, for larger OLTs, OLTs failing to respond to prior surgical management, or OLT with subchondral cysts, ACI provides patients and their surgeons with a potentially successful treatment avenue that did not exist before ACI. Early favorable outcomes with ACI applied to difficult OLTs justify the extra effort, education, and communication between physician, patients, and third-party payers that may be required to proceed with ACI in the ankle.
- In Europe, harvesting cells for culturing is considered part of a drug-producing process. Therefore, special permission must be sought from the local healthcare administration. Standard operating procedures for harvesting and transportation of the cartilage cells are mandatory for the accreditation process.

ANATOMY
- A slight majority of OLTs are on the medial shoulder of the talus.42
  - 62% of lesions are located at the medial talar shoulder; many of these are thought to be a result of OCD rather than posttraumatic.
  - 34% of the lesions are located at the lateral talar shoulder; most are thought to be of traumatic origin.
  - Central OLTs are rare (less than 5%).
  - In the AP direction, the midtalar dome (equator) is much more frequently involved (80%) than the anterior (6%) or posterior (14%) thirds of the talar dome.
- Classification of osteochondral lesions is based on arthroscopic findings21
  - Grade I: Intact lesions
  - Grade II: Lesions showing signs of early separation
  - Grade III: Partially detached lesions
  - Grade IV: Craters with loose bodies
- ACI is performed for symptomatic grade II-plus lesions (full-thickness cartilage defects).

PATHOGENESIS
- Traumatic cartilage injuries are caused by short, intensive, greater-than-physiologic strain on the joint resulting in partial detachment of the talar dome cartilage. The depth of these lesions varies from superficial chondral abrasions to full-thickness osteochondral defects.32,45
- OCD is a condition most frequently found in adolescents or young adults. While the cause remains poorly defined, theories include:
  - Chronic overload
  - Local disturbance of blood supply to the subchondral bone associated with the affected cartilage.25
- Degenerative cartilage defects (degenerative osteoarthritis) develop from wear and tear of the cartilage surface as part of the aging process. An individual’s risk of developing primary osteoarthritis most likely depends on a genetically determined quality of the cartilage. Ankle instability and other conditions that impart eccentric or nonphysiologic loads to the cartilage may accelerate the process of degeneration. In exceptional cases, when such a degenerative process is limited to a focal portion of the talar dome, ACI may be considered for degenerative
cartilage defects, provided the underlying cause leading to focal degeneration (ie, malalignment or chronic instability) is corrected.

**NATURAL HISTORY**

- The natural history of a focal cartilage injury has not been linked to diffuse ankle arthritis.
- Posttraumatic arthritis, which differs from an OLT, develops from diffuse injury to the cartilage surface that results in cartilage fibrillation and eventual eburnation. ACI is contraindicated for diffuse ankle arthritis.
- Injury to a focal portion of the talar dome spans the spectrum from a bone bruise to a detached focal osteochondral fragment. Although an osteochondral fragment may be created at the time of injury, the focal talar dome pathology probably evolves. Many OLTs are probably asymptomatic; we know this from numerous OLTs that are found incidentally on imaging studies of the ankle obtained for reasons other than suspected intra-articular pathology. However, with persistent eccentric stresses, greater-than-physiologic loads, inadequate local blood supply, or inadequate healing time, a stable OLT may progress to an unstable one.
- The difficulty is also in the symptomatology. While some apparently unstable lesions may be asymptomatic, other OLTs that are clearly stable result in considerable symptoms directly related to the OLT.28

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- While many patients report a specific ankle injury to account for the OLT, many do not present until months after ankle injury. A symptomatic OLT is in the differential diagnosis for an ankle sprain that does not heal. However, many patients with symptomatic OLTs do not recall a specific traumatic event leading to the OLT.40
- In my experience, most patients presenting with symptomatic OLTs are between 20 and 40 years of age.
- Men are more commonly affected than women (ratio 1.6:1).40
- Patients typically describe an ache in the ankle with activity or with the first steps after a period of rest. Occasionally, sharp ankle pain is noted with weight bearing. In our experience, mechanical symptoms of locking or catching are noted only with a completely detached osteochondral fragment. Paradoxically, OLTs may produce symptoms on the opposite side of the joint from the location of the cartilage defect.
- Our preferred physical examination methods are listed here. Occasionally, symptoms may not be elicited on clinical examination.
- Locking or catching: found when something interrupts the normal movement of the joint. However, it says nothing about the cause of this condition (eg, scar, joint body, osteochondral fragment and synovitis).
- Inversion test (calcaneofibular ligament [CFL]): strongly dependent on the cooperation of the patient. If positive, it is highly specific for a ruptured CFL.
- Medial stability: strongly dependent on the cooperation of the patient. If positive, it is highly specific for a ruptured deltoid ligament.
- Anterior drawer test (anterior talofibular ligament [ATFL]): strongly dependent on the cooperation of the patient. If positive, it is highly specific for a ruptured ATFL.
- The medial and lateral corner of the talar dome should be palpated with the ankle maximally flexed to identify anterior or central OLTs; posteroomedial palpation immediately posterior to the posterior tibial tendon (PTT) with the ankle maximally dorsiflexed may reproduce symptoms for posteroomedial OLTs. While anterolateral OLTs are relatively easy to palpate, posteroomedial lesions are difficult to access adequately on physical examination.
- We find it useful to compare the symptomatic ankle to the uninvolved contralateral ankle.
- The medial and lateral corner of the talar dome should be palpated with the ankle maximally flexed to identify anterior or central OLTs; posteroomedial palpation immediately posterior to the PTT with the ankle maximally dorsiflexed may reproduce symptoms for posteroomedial OLTs. While anterolateral OLTs are relatively easy to palpate, posteroomedial lesions are difficult to access adequately on physical examination.
- We typically dorsiflex and plantarflex the ankles with axial pressure while simultaneously applying eversion and inversion stresses to reproduce symptoms at the talar defect.
- Despite appropriate provocative maneuvers, our experience has been that posterior OLTs rarely exhibit obvious clinical findings.
- Associated injuries and other considerations in the differential diagnosis of chronic ankle pain should be evaluated, particularly because OLTs may be incidental findings. These include:
  - Ankle instability: Positive anterior drawer test and inversion testing
  - Chondromatosis of the ankle: Recurrent locking of the joint and persistent effusions are typical physical findings.
  - Intra-articular scaring with load-dependent pain, mostly at the anterior, lateral aspect of the ankle joint
  - Inflammatory arthropathy: While effusion and deep joint pain with weight bearing are commonly present, pain at rest and persistent joint warmth are also common features of inflammatory disease.
  - Pigmented villonodular synovitis (PVNS): Organized nodules of synovitis can mimic loose bodies with locking and effusion. Synovial swelling is not typical for osteochondral defects. MRI with contrast typically confirms the diagnosis of PVNS.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs of the ankle joint, including AP, mortise, and lateral views, are obtained to rule out late-stage degenerative arthritis.
- MRI with contrast is highly sensitive and specific in diagnosing osteochondral lesions, as well as associated injuries.23,34
- Osteochondral lesions were first classified by Berndt and Harty, based on plain radiographs:7
  - Stage I: Compression lesion; no visible fragment
  - Stage II: Beginning avulsion of a chip
  - Stage III: Chip, completely detached but in place
  - Stage IV: Displaced chip
- Plain films typically offer limited information on the size and extent of the lesion and may even miss the OLT. MRI, CT, and arthroscopic evaluation provide greater detail of OLTs than plain radiographs.
DiPaolo classification of osteochondral lesions based on MRI

- Stage I: Thickening of articular cartilage and low signal changes
- Stage II: Articular cartilage breached, low-signal rim behind fragment indicating fibrous attachment
- Stage III: Articular cartilage breached, high-signal changes behind fragment indicating synovial fluid between fragment and underlying subchondral bone (Fig 1)
- Stage IV: Loose body

Based on the greater detail of pathologic anatomy, Hepple et al.²³ revised the classification and included a type V (subchondral cyst formation)

- Stage I: Articular cartilage damage only
- Stage IIA: Cartilage injury with underlying fracture and surrounding bony edema
- Stage IIb: Stage IIA without surrounding bony edema
- Stage III: Detached but undisplaced fragment
- Stage IV: Detached and displaced fragment
- Stage V: Subchondral cyst formation

The Ferkel and Sgaglione CT classification is used for preoperative planning purposes and to learn the size of the subchondral defect.¹⁵

- Stage I: Cystic lesion of the talar dome with an intact roof
- Stage IIA: Cystic lesion with communication to the talar dome surface
- Stage IIb: Open articular surface lesion with an overlying, nondisplaced fragment
- Stage III: Nondisplaced lesion with lucency
- Stage IV: Displaced osteochondral fragment

DIFFERENTIAL DIAGNOSIS

- Syndesmosis injury
- Intra-articular scarring
- Subluxation or tear of peroneal tendons
- Fracture or disruption of the os trigonum
- Malleolar avulsion fracture
- Interosseous ligament injury
- Anterior process fracture of the calcaneus
- Lateral shoulder fracture of the calcaneus
- Chondromatosis
- Inflammatory joint disease
- PVNS

NONOPERATIVE MANAGEMENT

- In young patients with open physes, OCD can be managed conservatively with a high rate of complete remission (Fig 2).⁶,⁴⁶
- Acute osteochondral lesions may be treated conservatively. Acute lesions (stage I and II) require 3 weeks of immobilization. Stage III and IV lesions should be treated with a walker and partial weight bearing of 20 kg for 6 weeks.⁴⁰ However, unstable osteochondral lesions, particularly those with detached fragments, should be managed operatively.
- Incidentally discovered OLTs and OCD cases in adults are generally treated expectantly with regular follow-up.¹³,⁴⁶

Fig 1 • A. Arthroscopic view of a full-thickness osteochondral defect at the talar dome. B. Corresponding MRI.

Fig 2 • A. Osteochondritis dissecans in a child with open physis. B. 6 months later, the lesion is healed with conservative treatment.
The literature suggests that chronic OLTs, even larger lesions, may be treated nonoperatively as well. Nonoperative treatment comprises nonsteroidal anti-inflammatory agents, ankle bracing, physiotherapy, corticosteroid injection, and viscosupplementation. Currently, no conservative treatment of OLTs allows resurfacing or healing of the cartilage defect.

**Surgical Management**

- **Microfracture**
  - Arthroscopic débridement and microfracture generally represent the initial surgical management for the vast majority of OLTs, with satisfactory results in 65% to 90% of patients. After arthroscopic débridement of the OLT, the defect’s subchondral bone is penetrated with multiple noncontiguous passes of a specialized awl to permit the débrided defect to be populated with undifferentiated stem cells from the deeper tissues.
  - Over the next few months, these cells reorganize into (type II) fibrocartilage.
  - The biomechanical properties of fibrocartilage are different from those of hyaline cartilage; the fibrocartilage does not function in concert with the surrounding physiologic hyaline cartilage. The literature suggests that microfracture is successful in a majority of relatively small OLTs (up to 2 cm²).
  - Autologous osteochondral transfer (OATS or mosaicplasty) and ACI are typically secondary surgical procedures when arthroscopic débridement and microfracture and drilling fail.
  - Autologous osteochondral cylinder transplantation (OATS or mosaicplasty)
    - In the OATS or mosaicplasty technique osteochondral cylinders or plugs are harvested either from a low-load-bearing area of the knee or from the medial or lateral facet of the talus. These plugs are transplanted into the defect area, which has been prepared to the appropriate size.
    - This procedure fills large portions of the defect surface with high-quality hyaline cartilage. The results of this technique are satisfactory, but donor-site morbidity occurs in up to 50% of cases. To limit these harvesting symptoms, OCT can be successfully applied for cartilage defects of up to only about 3 cm². Matching defects on the talar shoulder are difficult with this technique, despite technique modifications described by Hangody et al. Moreover, the characteristics of talar cartilage differ from those of cartilage from the knee.
    - Allograft osteochondral cylinder transplantation
      - If available, osteochondral cylinders can be taken from a fresh or fresh-frozen cadaver talus.
      - Immunologic reactions have posed little problem to date.

**Preoperative Planning**

- All imaging studies are reviewed, with MRI providing detail of the cartilage defect and CT providing detail of subchondral bone involvement. Pure cartilage defects or shallow osteochondral defects can be managed with the conventional ACI procedure; deeper osteochondral defects require a “sandwich technique.”
- The sandwich technique involves two layers of periosteum. The defect is prepared and bone grafted to recreate the subchondral bone architecture. On this the first layer of periosteum is placed cambium layer up. Then the defect can be treated in the conventional manner: the second layer of periosteum is placed cambium side down. The cultured cartilage cells are injected between these two layers. Alternatively, the cartilage defect may be bone grafted in a first stage, with a conventional ACI procedure being performed in a second stage. This is feasible in the knee but more challenging in the ankle, which may require ligament release or osteotomy for adequate exposure, procedures that should not be performed more than once if not necessary.
- Matrix-based chondrocytes that do not require a periosteal flap can be placed directly on a bone graft, which makes the management of stage V lesions less demanding.
- Ankle malalignment and instability should be identified and corrected in conjunction with ACI if possible.

**Positioning**

- Harvesting chondrocytes: standard arthroscopy of the ankle or the knee
- Giannini et al. have demonstrated that the detached OLT fragment at the time of index arthroscopy may be an acceptable source of chondrocytes in ACL. Another possible source is the anterior aspect of the talus.
- Transplantation of chondrocytes: Depending on the location of the defect, the patient is positioned supine with a slightly internally or externally rotated leg. If iliac crest graft is to be obtained, the pelvis needs to be prepared and draped as well and the ipsilateral pelvis supported with a bump. Alternatively, bone graft may be harvested from the calcaneus, distal tibia, or proximal tibia, all locations within the surgical field typically prepared for ACI. A vacuum mattress can be helpful to adjust the patient’s position during the procedure (FIG 3).

**Approach**

- Harvesting chondrocytes: Medial and lateral anterior portals and a posterior, lateral portal give an adequate overview of the joint and allow the harvesting of chondrocytes.
- Transplantation: Depending on the location of the OLT, a medial approach between the medial malleolus and the PTT, a medial transmalleolar approach with osteotomy, or a lateral approach (with or without osteotomy) can be considered. ACI demands adequate exposure to properly suture a periosteal patch circumferentially around the OLT. Except for OLTs at the anterior or posterior margins of the talar dome, ACI cannot be performed properly without

---

**FIG 3** Standard positioning in a supine position.
medial malleolar osteotomy for extensive medial OLTs and ATFL–CFL release, lateral malleolar osteotomy, or both for extensive lateral OLTs.

A major advantage compared to mosaicplasty or OATS is that a perpendicular access is not required. Muir et al. demonstrated that the majority of the talar dome can be accessed without osteotomy, but acknowledged that osteotomies are required to adequately expose extensive OLTs.

Medial OLT: Occasionally, the ACI procedure can be performed for medial OLTs with an anteromedial or posterosomedical arthrotomy. In our experience, these are exceptional cases, often requiring extreme intraoperative ankle plantarfexion and dorsiflexion for anteromedial and posterosomedical lesions, respectively. An intact deltoid ligament permits little if any translation of the talus relative to the tibia. Access to an anterior defect can be enhanced with a groove created in the anteromedial tibia, but leaves a permanent defect in the anterior weight-bearing surface of the plafond. We appreciate that extreme dorsiflexion allows visualization of some posterosomedical OLTs; however, we caution against extreme dorsiflexion that tensions the posteromedial neurovascular bundle to allow proper access to the lesion. One author suggested that a medial malleolar window can be created, obviating the need for osteotomy. We have no experience with this approach.

Oblique medial malleolar osteotomy

- A longitudinal incision is centered over the medial malleolus, similar to that performed for open reduction and internal fixation of medial malleolar fractures.
- An anterior arthrotomy serves to identify the junction between the medial malleolar and tibial plafond articular surfaces and may allow visualization of the anterior aspect of the OLT.
- Posteriorly, the flexor retinaculum is opened, and the PTT is identified directly on the posterior tibia. The PTT rests in a groove in the posterior aspect of the medial tibia in its own sheath; the flexor digitorum longus tendon lies directly posterior to the PTT and should not be mistaken for the PTT.
- With the PTT properly retracted, the posterosomedical neurovascular bundle will also be protected.
- The medial malleolar osteotomy requires minimal periosteal stripping; in fact, we advise leaving as much of the periosteum as possible on the medial malleolar fragment to maintain blood supply for healing.
- To optimize reduction of the medial malleolar osteotomy after the cartilage repair procedure, we recommend predrilling the medial malleolus. Two parallel drill holes are placed extraarticularly perpendicular across the desired osteotomy, in the same orientation as screws placed for conventional open reduction and internal fixation for medial malleolar fractures. The proper course for these drill holes is confirmed fluoroscopically, both in the AP and lateral planes.
- Under fluoroscopic guidance a Kirschner wire pin is introduced obliquely to dictate the desired plane of the osteotomy. Typically, we introduce this guide pin slightly more proximal and medial than the intended course of the osteotomy to allow access for the saw blade, chisel, or both without having to remove the pin that guides our osteotomy.
- The osteotomy can be planned more conservatively as in mosaicplasty, because a perpendicular access to the OLT is not needed. As a rule, we plan to have the osteotomy enter the tibial plafond at the medial extent of the OLT.

With the plan for the osteotomy determined, the periosteum is divided transversely, again leaving the majority of the periosteum intact. With cold saline or sterile water irrigation to reduce the risk of osseous heat necrosis, a microsagittal saw is used to perform the oblique osteotomy to the level of the tibial plafond subchondral bone.

The joint is penetrated with an osteotome or a chisel. Intermittent fluoroscopic guidance is recommended to confirm proper saw blade or chisel orientation and that the talar dome is not injured during the final stages of the osteotomy.

The medial malleolus is then reflected, suspended by the deltoid ligament.

Even with careful technique, the osteotomy rarely separates in a uniform plane. Particularly posteriorly, a slight irregularity is observed. This is of little concern, however, as these irregularities will provide greater stability when the osteotomy is reduced.

To fully displace the medial malleolar fragment, the PTT sheath must be released from the medial malleolus.

At the conclusion of the cartilage resurfacing procedure, the medial malleolus is reduced and secured with two malleolar screws placed in the predrilled tracks with compression.

To limit a vertical shear effect, an antiglide screw or plate may be placed at the proximal aspect of the osteotomy. Alternatively, a third screw can be carefully placed from medial to lateral eccentrically across the osteotomy in addition to the two predrilled compression screws.

Anatomic reduction is confirmed clinically by visualizing the anterior and posterior aspects of the osteotomy and fluoroscopically in the AP and oblique planes. Fluoroscopy in all three routine views of the ankle confirms proper extraarticular position of the screws.

Due to the thickness of the saw blade, a slight, incomplete gap may be visualized at the osteotomy site in select cases; despite this immediate postoperative finding, our anecdotal experience has been that the oblique medial malleolar osteotomy heals in its anatomic position with few complications.

Lateral OLT

ATFL and CFL release: Some lateral OLTs are associated with lateral ankle instability. This combination of pathology is well suited to surgical management, since a modified Brostrom procedure is required to stabilize the ankle. If a lateral OLT is identified without lateral ankle instability, lateral ligament release to allow access to the OLT is readily repaired with a modified Brostrom technique, particularly since the lateral ankle ligaments are not attenuated.

The fibula is exposed through a longitudinal incision. If ligament release is inadequate, the extensile longitudinal incision facilitates the addition of a lateral malleolar osteotomy. Moreover, if associated pathology involves the peroneal tendons, the extensile longitudinal approach is necessary.

With the sural nerve protected posteriorly and inferiorly and the lateral branch of the superficial peroneal nerve protected anteriorly, the inferior flexor retinaculum is identified and isolated.

Deep to the retinaculum and at the distal and posterior margin of the fibula, the peroneal tendons are identified and protected throughout the procedure.
The ATFL and CFL lie within the lateral ankle capsular complex. Leaving a 1-mm cuff of capsule on the distal fibula, the capsule and the ATFL and CFL are released. The ankle is plantarflexed and inverted; the talus is subluxated anteriorly out of the ankle mortise to expose the OLT.

After the cartilage resurfacing, the talus is reduced in the ankle mortise and a modified Brostrom procedure is performed. This can be done with suture anchors in the distal fibula, placed to secure the ATFL and CFL components of the lateral ankle capsule in particular or with transosseous sutures.

During tensioning of the ligament repair, the talus is maintained posteriorly (avoiding anterior translation), with the ankle in a neutral sagittal plane position and the hindfoot in slight eversion. As described by Gould, the inferior extensor retinaculum is advanced to the distal fibula to lend greater stability to the repair.

Lateral malleolar osteotomy: Several different patterns for lateral malleolar osteotomies exist; surprisingly, few have been described in detail. We typically employ an oblique fibular osteotomy, similar to the pattern created by a simple Weber B ankle fracture. The approach is as described for the ligament release above. As for a medial malleolar osteotomy, periosteal stripping is kept to a minimum, predrilling is preferred, and cold saline or sterile water irrigation is applied to the osteotomy site to limit osseous heat necrosis.

Before performing the osteotomy, we position a small fragment plate in the desired position and predrill the holes. With the soft tissues protected, in particular the superficial peroneal nerve and the peroneal tendons, the oblique osteotomy is created from anterior to posterior using a microsaggittal saw. The syndesmotic ligaments are not disrupted. Release of the ATFL and CFL in combination with the fibular osteotomy can be considered to improve exposure of larger posterolateral OLTs with medial extension.

At the conclusion of the cartilage repair procedure, the fibula is reduced and secured with the predrilled lateral fibular plate. Reduction is confirmed with intraoperative fluoroscopy. Before placing the plate, a lag screw may be placed across the osteotomy, but we do not routinely do so.

As for the medial malleolar osteotomy, the thickness of the saw blade may lead to a slight, incomplete gap at the fibular osteotomy site in select cases. Again, despite this immediate postoperative finding, our anecdotal experience has been that the oblique medial malleolar osteotomy heals in its anatomic position with few complications.

Central defects

As observed in the cadaver model of Muir et al., perpendicular access to the central talar dome is not possible via medial and lateral osteotomies. Tochigi et al. described a Chaput lateral tibial osteotomy, similar to a Tilleaux fracture, to allow greater medial exposure to extensive lateral OLTs; however, Muir et al. noted that this osteotomy still fails to allow access to the central talar dome.

The trap door osteotomy described by Sammarco et al., in which an anterior osteochondral wedge is removed from the distal tibia, may permit access to select anterior central OLTs. Although attractive, the osteotomy must be carefully planned to accommodate the instrumentation at the ideal location for sufficient access, as coronal plane translation of the talus is not possible. Moreover, access to relatively rare posterocentral lesions is still not possible despite this novel approach.

HARVESTING OF CHONDROCYTES

Complete diagnostic arthroscopy and identify all pathology.

Using a curette, harvest two or three full-thickness articular grafts that include the superficial layer of subchondral bone (TECH FIG 1). The grafts are transferred to a sterile container and transported to the laboratory. Using a patented procedure, the articular cartilage matrix is enzymatically disrupted to isolate the chondrocytes. Culturing of chondrocytes requires about 2 to 6 weeks, depending on the company and the preferred culturing process.

Ensure that the cells are sent to the company immediately, the “cool chain” is sustained, and the required documents are included in the box.

TECH FIG 1 • A. Harvesting cartilage with a curette from the ventral aspect of the talus. B. Grasping the small piece of cartilage for culturing.
AUTOLOGOUS CHONDROCYTE TRANSPLANTATION

- To avoid compromising chondrocyte viability, use a tourniquet to maintain a bloodless field.
- We typically use a thigh tourniquet; although a calf tourniquet is possible, compression of the lower leg musculature may restrict exposure and manipulation of the ankle, thereby compromising exposure.
- Expose the transplantation site. Despite adequate exposure with appropriate osteotomies or ligament releases, performing the second ACI stage for the ankle, in particular suturing the periosteal flap, may prove tedious. Matrix-based transplants, where the chondrocytes for transplantation are already grown in a collagen matrix, provide a significant advantage. These membranes can be fixed with fibrous glue; sutures are optional. For the knee, both techniques have proven to have similar clinical outcomes. At the talus, there is still a lack of scientific evidence, but our extended anecdotal experience has shown similar results in both techniques.
- Débride all unstable cartilage with a curette to create a healthy, stable cartilage rim. The subchondral bone in the defect should be intact.
- If a shallow bony defect exists, remove the sclerotic bone. Despite tourniquet use, some bleeding may be encountered; it should be controlled with an epinephrine sponge or a minimal amount of fibrin glue.
- In the event of a deeper defect, use the “sandwich technique” described above to recreate subchondral support for the transplanted chondrocytes. Any bony cyst has to be filled with autologous bone graft, preferably from the iliac crest or the proximal tibia.
- Impact the graft to provide a smooth surface for the transplantation site.
- Measure the defect and create a template using a small piece of paper (from a sterile glove pack) or aluminum foil (from a suture pack).
- Technique with periosteal flap
  - By exposing the distal tibia just proximal to the ankle, identify an appropriate area for periosteal flap harvest; exposure is to the level of the periosteum without violating it.
  - Place the template on the periosteum and mark an outline 1 to 2 mm greater than the template on the periosteum. The periosteal harvest should be slightly larger than the template as periosteum tends to recoil or shrink slightly after harvest.
  - Perform sharp dissection to bone on the marked periosteum circumferentially. With a sharp periosteal elevator, elevate the periosteum, with its cambium layer, directly off the underlying tibia without creating defects in the periosteal graft. We routinely place a mark on the superficial layer of periosteum before detaching the periosteal flap from the tibia to be certain we can identify the cambium layer at the time of transfer to the talus.
  - Carefully separate overlying fibrous tissue or fat from the periosteal graft.
  - After ensuring that the OLT is bloodless, transfer the periosteal flap to the OLT, with the cambium layer facing the defect.
- Suture it using interrupted 6-0 Vicryl to the surrounding articular cartilage, with sutures spaced at intervals of about 3 mm. To optimize tensioning, the corners can be anchored first. Place the knots on the articular cartilage rather than the periosteal flap. The final suture is omitted at this point, with the residual defect being at the area of easiest access for chondrocyte transplantation.
- Apply fibrin glue around the periphery of the periosteal flap’s junction with the healthy articular cartilage, particularly between the sutures.
- Using a flexible angiocatheter, inject sterile saline into the residual opening to confirm a watertight seal; any leakage of saline should emanate only from the residual opening. Add sutures, fibrin glue, or both as needed.
- The chondrocytes are delivered in a vial that is sterile internally but not externally. The vial can be placed on a separate back table while the surgeon maintains sterile technique while resuspending and extracting the chondrocytes from the vial into a sterile angiocatheter.
- Through the residual opening under the periosteal flap, introduce the angiocatheter into the defect. The chondrocytes are evenly distributed with the surgeon gently injecting the suspension.
- Remove the angiocatheter and seal the residual aperture with a final suture and more fibrin glue.
- After the fibrin glue has cured, ankle range of motion confirms that the periosteal flap is stable.
- Stabilize the ankle joint with repair of the ligaments or osteotomy, depending on the particular approach.
- ACI has not been perfected for shoulder lesions of the talus. However, as for the femoral trochlea, a carefully executed suture pattern can allow the periosteum to be draped over a shoulder lesion to recreate, at least to some degree, the physiologic contour of the talus. With the periosteum first tensioned at the shoulder and secondarily on the dorsal and mediolateral aspects of the talus, ACI can be effective for select talar shoulder OLTS.
- Technique with matrix-based chondrocytes (MACI)
  - The technique with matrix-based chondrocytes requires no further preparation after the size of the defect is measured. The matrix is stable and can be fixed directly to the OLT.
  - Take care when removing the transplant from the transport container. In particular, avoid squeezing the transplant (TECH FIG 2A,B).
  - Cut the transplant according to the size of the defect. Some companies provide special punches for this step. The size of the transplant should meet exactly the size of the defect. Preparing the transplant 2 mm larger, as recommended for the periosteal flap, can lead to overlaying edges and a lack of stability.
  - Place the transplant into the defect. A first fixation happens due to adhesion forces. The edge can then be stabilized with 6-0 sutures and fibrin glue (TECH FIG 2C,D).
Check the transplant for stability by carefully moving the ankle joint into dorsiflexion and plantarflexion. We recommend that postoperative mobilization be limited so that the transplant is always covered at least partially by the tibial plafond to prevent shear forces. The optimal postoperative rage of motion can be checked in this step.

Insert one intra-articular tube before closing the wound. Stabilize the ankle joint with repair of the ligaments or osteotomy, depending on the particular approach.

**PEARLS AND PITFALLS**

**Indications and planning**
- Address associated pathology.
- Generalized osteoarthritis is a contraindication.
- Absence of clinical instability
- Intact cartilage at the corresponding tibial side
- The extent of cartilaginous detachment is often underestimated on MR, whereas the bony reaction tends to be overestimated.
- OLTs with subchondral cysts respond poorly to drilling or microfracturing. In these cases ACI or MACI can be considered as a primary procedure.
- ACI and MACI are not indicated in the face of diffuse ankle arthritis; these procedures are intended for focal defects only.

**Harvesting**
- Take extreme care when harvesting the chondrocytes from the ankle or ipsilateral knee joint.
- If not completely destroyed, the detached cartilage can be harvested.
- Ensure that the cool chain for transport is appropriate.

**Cultivation**
- This service is provided by several companies. They provide the medium for harvesting the chondrocytes and in some cases special tools for harvesting and transplantation.

**Transplantation**
- Be careful to prepare the transplant large enough.
- Adequate exposure is mandatory for ACI or MACI. This often requires a malleolar osteotomy.
- Intraoperative radiographs should be taken before performing an osteotomy and after the osteosynthesis. The osteotomy should be adequate to gain sufficient access to the OLT.
- Do not squeeze the transplant (MACI).
- Be sure that the periosteal flap is watertight before injecting the chondrocytes (ACI).

**Rehabilitation**
- Follow the rehabilitation plan; it takes time for the graft to gain its final stability and strength.
- “Too much, too fast” is the most common reason for failures.
POSTOPERATIVE CARE

- After covering the wounds with sterile dressings, the ankle joint is stabilized with a dorsal splint.
- Immediately postoperatively, the patient should have 48 hours of bed rest. The ankle should not be moved and is fixed with a brace.
- 48 hours postoperatively, drainage tubes are removed and the joint is mobilized with continuous passive motion. Limitations can occur in large defects or extended ligament repair.
- During the first 6 weeks postoperatively, the patients are allowed partial weight bearing (10 kg) and mobilization without weight bearing including accompanying physiotherapy (similar to the postoperative scheme in complex ankle fractures with open reduction and internal fixation).
- After 6 weeks, a gradual increase in joint loading is allowed (20 to 30 kg every 2 weeks) up to full body weight.
- After 12 weeks, full weight bearing in activities of daily life is allowed, including cycling with moderate resistance and swimming.
- After 6 months, increased athletic activities (e.g., jogging and skating) can be considered. However, there is little experience in bringing patients with an ACI or MACI back to professional sports. In our anecdotal experience we have seen most patients able to return to recreational sports.
- It is unclear whether patients can return to contact sports and sports that place high physical demands on the ankle joint. So far there are no data available.

OUTCOMES

- There are only limited data on this new treatment concept, and no long-term studies.
- Peterson et al.\(^9\) reported the results of his first 14 consecutive patients managed with ACI for the ankle. At an average follow-up of 45 months, 12 were considered improved, with 11 having good to excellent outcomes.
- Baums et al.\(^4\) found an improvement in the AOFAS ankle score from 43.5 to 88.4 in a prospective study of 12 patients.
- Giannini et al.\(^1\) reported an average AOFAS hindfoot–ankle score improvement from 26 points to 91 points at an average follow-up of 26 months. Histologic analysis of biopsies obtained at 12 months suggested hyaline cartilage in all eight specimens.
- In another series Giannini et al.\(^1\) demonstrated no statistically significant difference in 16 patients undergoing ACI with chondrocytes cultured from the detached OLT fragment compared to 7 patients undergoing ACI with chondrocytes harvested from the patient’s ipsilateral knee. In both groups, the average AOFAS hindfoot–ankle score improved from 54 points to about 89 or 90 points. Histologic appearance, expression of specific cartilage markers, cell viability, cell proliferation in culture, and redifferentiation were favorable, and the morphologic and molecular characters of the cultured chondrocytes from the detached fragment were similar to those of physiologic hyaline cartilage.\(^1\)
- By culturing the chondrocytes from the detached chondral fragment, donor site morbidity can be avoided.\(^1\) However, by taking small chips of cartilage from an unloaded area of the knee, the risk of donor site problems should be significantly lower, as reported for harvesting osteochondral grafts from the ipsilateral knee joint.\(^37\)

COMPlications

- In rare cases, the harvested chondrocytes are not suitable for culture. Typical causes are avital cells or contamination. In this case, the physician is informed by the laboratory that cultures the cartilage cells. One possibility is to do another arthroscopy to get cartilage cells; however, other treatment options like OATS or allograft can be considered.
- Delayed union in the malleolar osteotomy: Provided progression toward healing, even if very gradual, is observed on serial radiographs, our experience has been that the osteotomies eventually heal without complications. However, prompt revision open reduction and internal fixation with bone grafting is warranted if progression toward healing is not noted, to limit the risk of displacement of the osteotomy.
- Failure of the transplanted tissue includes detachment of the transplant, delamination, or ossification. Especially in the periosteal flap technique, ossification is a common cause of failure.\(^31\) Ossification in the MACI technique has not yet been reported.
- Resorption of the subchondral bone graft in stage V lesions treated using the sandwich technique can lead to a graft failure.
- Hypertrophy: Fibrous tissue may form at the graft–host articular junction or within the ankle, causing impingement, and can be effectively debrided to relieve symptoms. ACI in particular is subject to fibrillation or hypertrophy, and arthroscopic débridement, in select cases, is essential to remove mechanical symptoms and avoid delamination of the graft.\(^8\)
- The source of pain from an OLT remains ill defined, and the success of cartilage resurfacing procedures is certainly not 100%. Therefore, even without any obvious complication, pain may persist.
- If the clinical outcome is not satisfactory and follow-up imaging studies suggest graft compromise, ankle arthroscopy is warranted. While failure of graft incorporation or delamination of the resurfaced articular segment is perhaps irreversible, not all persistent symptoms are necessarily due to such phenomena. Second-look arthroscopy may demonstrate that the cartilage resurfacing procedure was successful but was inadequate to resurface what proved to be a larger area of diseased talus than originally identified.
- In ACI for which the cartilage cells are harvested from the knee, there is a risk of persistent knee symptoms. The reported prevalence of persistent knee symptoms ranges from less than 10% \(^18,22,41\) to 50%.\(^37\) It is important to educate patients about this risk preoperatively. Since Giannini et al.\(^1\) has demonstrated no statistically significant difference between chondrocytes cultured from the detached OLT fragment versus chondrocytes harvested from the patient’s ipsilateral knee, we always harvest chondrocytes from the ankle joint to minimize the risk of donor site problems.\(^4\) Based on our extended anecdotal experience doing so, we have seen no disadvantage with this concept.
- General surgical complications such as deep venous thrombosis, wound healing problems, or infection are also possible.

references


DEFINITION
- Lesions of the medial talar dome can be very challenging to manage operatively, particularly as they tend to be located in the central or posteromedial aspect of the ankle and are often difficult to access or visualize.
- Various techniques have been described to provide adequate or improved exposure for posteromedial talar dome lesions. Options include arthroscopic techniques, standard arthrotomy, tibial grooving, or medial malleolar osteotomy.
- With the recent interest in new techniques for the treatment of osteochondral lesions of the talar dome, appropriate exposure of both medial and lateral talar dome lesions has become very important.
- Osteochondral allograft insertion and other cartilage replacement techniques are moving to the forefront of orthopaedic foot and ankle care and rely on adequate exposure of the lesion itself. The chevron-type medial malleolar osteotomy is a very stable, reproducible osteotomy that allows excellent exposure to the tibiotalar joint.

ANATOMY
- Pertinent anatomy related to osteotomies of the medial malleolus includes the adjacent structures such as the posterior tibialis tendon and the adjacent neurovascular bundle. The medial malleolus is subcutaneous and convex on its medial border and slightly concave on its lateral surface. The posterior surface includes the malleolar sulcus, which contains the posterior tibialis tendon and the flexor digitorum longus tendon. The distal portion contains the attachment of the deltoid ligament.

PATHOGENESIS
- Lesions of the medial talar dome that require treatment by adjunctive osteotomy include talar body fractures, osteochondral lesions of the talar dome, and other intra-articular lesions.

NATURAL HISTORY
- Advantages proposed for the use of a medial malleolar osteotomy include excellent visualization and wide exposure for débridement or fixation of fragments. Possible disadvantages include the need for prolonged postoperative immobilization and the risk of degenerative ankle arthrosis or nonunion, as well as prominent hardware. No previous study has specifically addressed the results and the morbidity of a medial malleolar osteotomy.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standard ankle radiographs are mandatory. Intra-articular lesions, including talar fractures and osteochondral lesions of the talus, can be evaluated with MRI or CT scans.

SURGICAL MANAGEMENT
Preoperative Planning
- Preoperative planning primarily focuses on the planning required for the talar lesion, or fracture, that is being addressed. For comminuted talar body fractures, preoperative CT scans are essential not only for planning the potential fixation but also for evaluating the extent of the articular injury.
- In planning for the treatment of osteochondral lesions, MRI techniques can be helpful in evaluating the size and location of the lesion and the extent of articular involvement and screening for other articular abnormalities.
- CT scans can be helpful in determining the presence of cystic lesions and especially determining whether the lesion is “contained” and appropriate for consideration of osteochondral transplantation.

Positioning
- The patient is positioned supine.

Approach
- A standard medial approach is used, with the incision centered on the medial malleolus and slightly curved distally. Care is taken to avoid injury to the saphenous vein and nerve.

CHEVRON-TYPE MEDIAL MALLEOLAR OSTEOTOMY
- A chevron-type transmalleolar osteotomy is performed in the following manner.
- After standard exposure of the medial malleolus, open the posterior tibialis tendon sheath at the level of the ankle mortise.
- Retract the posterior tibialis tendon itself and protect it posteriorly.
- Predrill and tap the medial malleolus with a 2.5-mm drill.
- Make the chevron-shaped osteotomy with a microsagittal saw. The apex is directed proximally and the limbs of the chevron are extended from the mortise level. In the AP plane, the osteotomy is angulated toward the junction of the medial malleolus and tibial plafond articular surface.
- Complete the osteotomy with a fine hand osteotome, avoiding a “Kerf” effect within the joint.
Retract the osteotomized medial malleolus, releasing anterior and posterior soft tissues as necessary for exposure of the talar dome while maintaining the superficial and deep attachments of the deltoid ligament (TECH FIG 2).

At the conclusion of the procedure, stabilize the osteotomy using two 4.0-mm partially threaded cancellous screws (Synthes, USA) (TECH FIG 3).
PEARLS AND PITFALLS

Avoid laceration to posterior tibial tendon.  ■  Deep Hohmann retractor is placed after small incision is made in posterior tibial tendon sheath.

Inaccurate reduction.  ■  Must predrill before osteotomy.

Poor visualization.  ■  Avoid making the exiting areas of the arms of the osteotomy too distal.

POSTOPERATIVE CARE

The patient is placed in a plaster splint for 10 to 14 days postoperatively. Active range of motion is begun after 10 to 14 days (or when the wound has healed) and the patient is placed in a removable short-leg cast brace. Non-weight-bearing ambulation is maintained until radiographs, repeated at about 6 weeks, confirm maintenance of reduction.

OUTCOMES

A retrospective review was performed on 19 patients who underwent medial malleolar osteotomy for the treatment of pathology of the talar dome.6 Chart review, radiographic examination, and clinical examination were performed in all patients. Fifteen patients had osteochondral lesions of the medial talar dome. All patients failed conservative treatment of these lesions, including a period of immobilization and anti-inflammatory medication. The location of the lesion was in the posterior or central portion of the talar dome in all patients.

Three patients had medial malleolar osteotomy performed for exposure during internal fixation of displaced talar dome fractures. One additional patient had curettage and bone grafting of a large medial talar cyst.

About 50% of the patients had undergone prior surgery on the affected ankle. Six patients had a total of nine prior arthroscopic procedures. The average age of the patients was 32 years (range 14 to 51). The length of follow-up was 12 months (range 6 to 43).

All patients achieved union of the osteotomy both clinically and radiographically. The average time to radiographic union was 7 weeks (range 5 to 12). No failures of fixation were noted.

Preoperative and postoperative tibiotalar range of motion was measured. At the last follow-up, only 2 of 19 patients had any loss of motion compared to their preoperative evaluation. This decreased range of motion was about 10 degrees of total arc of motion.

Four patients had slight (less than 2 mm) displacement at the osteotomy site. This displacement was noted immediately postoperatively and was felt to be due to technical errors during the bone cuts for the osteotomy. No progressive displacement was noted in these patients. All four patients were asymptomatic at the osteotomy site and no progressive ankle arthrosis was noted. Three patients had symptomatic prominent screws that resulted in hardware removal. All the screws were removed as an outpatient procedure under a local anesthetic without complications. No postoperative complications, including infection, nonunion, or delayed wound healing, were noted in the study population.

COMPLICATIONS

Nonunion rates for medial malleolar osteotomy are reported as high as 12%. Theoretically the chevron-type provides excellent stability for fixation.

Other complications include saphenous nerve injury, with resulting medial ankle numbness or painful subcutaneous neuroma, or posterior tibial tendon laceration, resulting in displacement of the osteotomy and development of progressive arthrosis.

REFERENCES


DEFINITION
- Lateral ankle injuries are among the most common musculoskeletal injuries in the athletic population.
- Rates as high as 7 per 1000 person-years have been reported in the general population.
- From 10% to 20% of sprains progress to some kind of chronic symptoms.
- Determining whether the patient’s instability is functional (ie, subjective giving way) or mechanical (ie, motion beyond the normal physiologic limits) is important for formulating treatment recommendations.

ANATOMY
- The lateral ankle ligament complex consists of the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL).
- The ATFL originates from the anterior aspect of the distal fibula and inserts on the lateral aspect of the talar neck. It is often ill defined and, in the chronically sprained ankle, may be manifest as a capsular expansion.
- The ATFL limits anterior translation of the talus with the ankle in neutral and becomes the primary restraint to inversion when the ankle is plantarflexed.
- The CFL originates from the distal tip of the fibula and inserts on the lateral wall of the calcaneus (FIG 1AB).
  - The CFL measures 4 to 6 mm in diameter and 13 mm in length, and is directed posteriorly 10 to 45 degrees from the tip of the fibula.
  - The CFL functions to resist inversion with the ankle in neutral.
  - The anterior margin of the talus is wider than the posterior margin, which makes the ankle more susceptible to inversion injuries while in plantarflexion.
  - The peroneal tendons provide dynamic stability to the ankle joint.

PATHOGENESIS
- An inversion force with the ankle in plantarflexion is the most common mechanism of injury.
- The ATFL typically is the first ligament injured, followed by the CFL.
- Ligament ruptures are most commonly midsubstance tears or avulsions off of the talus.

NATURAL HISTORY
- Despite a relatively high incidence of lateral ankle injuries, most patients do well with nonoperative management.
- Patients are at increased risk for recurrent lateral ankle sprains after sustaining the initial injury and failing to rehabilitate completely.
- Chronic lateral instability may lead to progressive loss of function and osteoarthritic changes of the ankle.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Patients with chronic ankle instability frequently present with pain as well as complaints of multiple sprains caused by minor provocation.
- Duration of symptoms, the type of incidents that cause sprains, the need for functional bracing, and previous treatments are important for determining treatment recommendations.
- If pain is present between episodes of instability, other lesions about the ankle should also be considered.
- An anterior drawer test with a bony endpoint that is distinctly different from that of the contralateral ankle is considered markedly positive.
- Physical examination techniques include the following:
  - Palpation. Palpate the ATFL, CFL, syndesmosis, medial and lateral malleoli, peroneal tendons, base of the fifth metatarsal, and anterior process of the calcaneus.
Grading ATFL injuries. I, stretching; II, partial tearing; III, complete rupture. This is most useful in the acute setting to determine which structures are injured.

**Anterior drawer test (FIG 2AB).** The ankle is held in planatarflexion, and the talus is translated forward relative to the tibia. With intact medial structures, the displacement is rotatory. Translation of 5 mm more than the contralateral ankle or absolute translation of 9 to 10 mm is a positive test and suggests an incompetent ATFL. Grading ATFL injuries: I, stretching; II, partial tearing; III, complete rupture; most useful in the acute setting to determine which structures are injured.

**Talar tilt.** The heel is inverted with the ankle in neutral. Range of motion is compared to the contralateral ankle. Increased inversion is suggestive of a CFL injury.

**Alignment.** Assess the standing alignment of the hindfoot. Varus hindfoot alignment predisposes the ankle to inversion injury.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standard radiographs should include standing anteroposterior (AP), lateral, and mortise views to evaluate for anterior tibial marginal osteophytes, talar exostoses, osteochondral lesions of the talus, or intra-articular loose bodies.
- Talar tilt can be assessed with inversion stress mortise views of the ankle (FIG 3A).
  - Comparison views of the contralateral ankle should also be obtained.
  - A talar tilt angle greater than 10 degrees, or 5 degrees greater than the contralateral ankle, is considered pathologic laxity.

- Anterior translation stress radiographs can be obtained by performing the anterior drawer test and shooting a lateral radiograph (FIG 3B).
  - Comparison stress views of the contralateral ankle should also be obtained.
  - Anterior translation 5 mm greater than the contralateral ankle, or an absolute value of greater than 9 mm is suggestive of instability.
  - Stress radiographs may be helpful, but physical examination remains the gold standard for evaluation of instability.
  - MRI can be useful to evaluate the ligamentous injury, as well as peroneal tendon pathology and suspected osteochondral injuries.

**DIFFERENTIAL DIAGNOSIS**

- Lateral process talar fracture
- Anterior process calcaneus fracture
- Base of the fifth metatarsal fracture
- Tarsal coalition
- Osteochondral lesion of the talus or tibia
- Subtalar instability
- Syndesmosis injury
- Neurapraxia of the superficial peroneal or sural nerve
- Peroneal tendon tear
- Peroneal instability
- Sinus tarsi syndrome
- Anterolateral ankle soft tissue impingement

**NONOPERATIVE MANAGEMENT**

- Physical therapy should be the initial treatment for patients with chronic instability.
  - Proprioceptive training and peroneal tendon strengthening are the most important features.
The duration of therapy varies based on strength deficiencies and the intensity of the program.

External stabilization of the ankle with taping or bracing can be effective.

- Taping provides tibiotalar stability, but quickly deteriorates with activity.
- Reusable braces provide similar stability, but do not lose effectiveness with activity.
- Orthotic devices and shoe wear modification can also be used when foot or ankle malalignment contributes to the instability.

**SURGICAL MANAGEMENT**

- If the patient fails 3 to 6 months of conservative treatment and has persistent signs and symptoms of functional and mechanical instability, he or she becomes a candidate for surgery.

**Preoperative Planning**

- The history must be considered. A relative contraindication for this anatomic repair is generalized ligamentous laxity as might be encountered in Ehlers-Danlos syndrome.
- Carefully review the physical examination. If a varus heel exists, a Dwyer type calcaneal osteotomy should be considered.
- If an osteochondral lesion is present, the ligamentous reconstruction should be done in conjunction with arthroscopic or open treatment of the osteochondral defect.

**Positioning**

- The patient is placed in the lateral decubitus position with appropriate padding at bony prominences to avoid damage to subcutaneous structures (FIG 4AB).
- An operative platform is created using bolsters or blankets.
- A “bump” made of four or five towels is used either proximal to the ankle to create a varus or inverted position for better exposure or distal to the ankle to create a valgus or everted position to approximate the edges of the repair (FIG 4C).

**Approach**

- Two commonly used approaches
  - J incision (FIG 5A)
    - The incision is made from the distal tip of the fibula along its anterior margin proximally to the level of the ankle mortise.
  - Does not afford optimal access to the peroneal tendons
  - Curvilinear extensile exposure (FIG 5B)
    - Curvilinear incision over posterior tip of fibular, extending to sinus tarsi area
    - Affords comprehensive exposure to anterior ankle, ATFL, CFL, and peroneal tendons

**FIG 4** • With the patient in the lateral decubitus position, the nonoperated extremity should be well padded. A. Nonoperated leg in a gel pad. B. With the nonoperated leg protected, a platform may be used to facilitate positioning of the operated leg. C. Alternatively: positioning in the lateral decubitus position, using a stack of folded sheets to serve as a rest for the operated leg.

**FIG 5** • A. A traditional J approach on the anterior distal fibula. B. An extensile curvilinear exposure to the lateral ankle. This approach facilitates access to the peroneal tendons should there be associated peroneal tendon pathology.
MODIFIED BROSTROM ANATOMIC LATERAL ANKLE LIGAMENT REPAIR WITH SUTURE ANCHORS

- Perioperative antibiotics are given.
- The patient is positioned as described, a thigh tourniquet is placed, and a standard orthopaedic prep and drape is carried out. The tourniquet is inflated.
- The incision is made as described under Approach in the Surgical Management section (TECH FIG 1A).
- With the bump placed proximal to the ankle, a dissection is carried out to isolate the inferior extensor retinaculum.
- The joint capsule is then incised in line with the skin incision and just distal to the leading edge of the fibula. The anterior talofibular (ATF) ligament may or may not be visible as a capsular expansion.
- The CFL is inspected. This inspection, along with the preoperative evaluation, is used to decide whether or not a repair of this ligament is needed.
- The joint is inspected for chondral injury.
- A subperiosteal dissection is carried out at the anterior and lateral aspect of the fibula, raising a flap 3 to 6 mm wide.
- Using curettes and rongeurs, a trough is made in the anterior and lateral aspect of the fibula at its leading edge, about 3 mm deep and 3 mm wide.
- If no CFL repair is needed, a single corkscrew anchor double-armed with no. 2 FiberWire (Arthrex, Inc., Naples, FL) suture is inserted centrally in the trough. If a CFL repair is performed, a second anchor, with no. 2 Fiberwire, is used (TECH FIG 1B).
- The joint is thoroughly irrigated, and the actual repair begins. Move the bump so it sits under the lateral border of the foot, placing the subtalar and ankle joints into an everted position before repairing the CFL if necessary.
- The capsular and ATF ligament repair is now performed by bringing the sutures from deep to superficial in a horizontal mattress pattern. The “ligament” is shortened by creating the trough at the fibula. If further shortening is needed, the capsule may be trimmed from the distal cut edge.
- A second reinforcing layer of repair is created by suturing the inferior extensor retinaculum to the periosteal flap with absorbable 2-0 figure 8 sutures.
- The skin is closed in layers with 3-0 absorbable suture in the subcutaneous suture and staples or subcuticular suture used in the skin.

Modified Brostrom Anatomic Lateral Ankle Ligament Repair with Suture Anchor(s) (Courtesy of Mark E. Easley)

- Confirm ankle instability with exam under anesthesia.
- Approach and exposure
  - Curvilinear incision over posterior tip of the fibula and extending to the sinus tarsi (TECH FIG 2)
  - Protect sural nerve posteriorly and superficial peroneal nerve anteriorly.
- Prepare the inferior extensor retinaculum.
- Identify and mobilize the inferior extensor retinaculum (TECH FIG 3AB).
- Relatively thin superficial structure
- Identify, inspect, and protect the peroneal tendons (TECH FIG 3CD).
- Anterior arthrotomy
  - Detach the capsule, including the ATFL and CFL (TECH FIG 4AB).
  - Protect the peroneal tendons (TECH FIG 4C).
  - Excise the anterior inferior tibiofibular ligament (Bassett’s ligament) (TECH FIG 4D).
  - Usually present in patients after ankle sprain.
  - Potential for anterolateral soft-tissue ankle impingement.
  - Inspect the lateral talar dome for cartilage defect.

TECH FIG 1 • A. Traditional approach to perform the modified Brostrom repair. B. Suture anchors placed in the distal fibula.
Identify the ATFL and CFL (TECH FIG 5A–D); these are condensations within the capsular sleeve.

Develop a distal fibular periosteal flap (TECH FIG 6AB) to use as an additional reinforcement of the repair.

Prepare anterior distal fibula for reattachment of capsule and ligaments.
- Create a trough using a rongeur (TECH FIG 6C).
- Predrill anatomic footprints for ATFL and CFL suture anchor placement (TECH FIG 6DE).

Place suture anchors (TECH FIG 7AB).
- Orient them so that they do not:
  - Interfere with one another
  - Violate the joint
  - Violate the posterior cortex of the fibula and irritate the peroneus brevis
  - Test the stability of the suture anchors (TECH FIG 7C).
  - Lift the limb by the anchors; if the anchors are going to fail, we want them to do so now so the problem can be rectified.
  - Pass the respective sutures through the CFL, the adjacent capsule, and the ATFL (TECH FIG 7D–F).
  - Test the sutures to ensure that they indeed advance the appropriate portion of the capsule to the desired location on the distal fibula (TECH FIG 7G)
  - Position the ankle properly for securing the sutures (TECH FIG 8A).
  - Reduce the talus within the ankle mortise
  - Avoid anterior translation of the talus within the mortise
  - Dorsiflex the ankle to neutral
  - Maintain slight hindfoot valgus
  - Tie the sutures (TECH FIG 8B–D).
  - Check the stability of the repair after the anchor sutures have been tied (TECH FIG 8E).
  - Pass the anchor sutures through the distal fibular periosteal flap (TECH FIG 9A–C).
  - This reinforces the repair
  - Place additional sutures from the periosteum to the capsule that has been advanced to the distal fibula (TECH FIG 9D,E)
  - Augment the repair further with the inferior extensor retinaculum

TECH FIG 2 • Curvilinear extensile exposure to the lateral ankle ligaments.

- Identify the ATFL and CFL (TECH FIG 5A–D); these are condensations within the capsular sleeve.
- Develop a distal fibular periosteal flap (TECH FIG 6AB) to use as an additional reinforcement of the repair.
- Prepare anterior distal fibula for reattachment of capsule and ligaments.
  - Create a trough using a rongeur (TECH FIG 6C).
  - Predrill anatomic footprints for ATFL and CFL suture anchor placement (TECH FIG 6DE).
- Place suture anchors (TECH FIG 7AB).
  - Orient them so that they do not:
    - Interfere with one another
    - Violate the joint
    - Violate the posterior cortex of the fibula and irritate the peroneus brevis
    - Test the stability of the suture anchors (TECH FIG 7C).
    - Lift the limb by the anchors; if the anchors are going to fail, we want them to do so now so the problem can be rectified.
    - Pass the respective sutures through the CFL, the adjacent capsule, and the ATFL (TECH FIG 7D–F).
    - Test the sutures to ensure that they indeed advance the appropriate portion of the capsule to the desired location on the distal fibula (TECH FIG 7G)
    - Position the ankle properly for securing the sutures (TECH FIG 8A).
      - Reduce the talus within the ankle mortise
      - Avoid anterior translation of the talus within the mortise
      - Dorsiflex the ankle to neutral
      - Maintain slight hindfoot valgus
      - Tie the sutures (TECH FIG 8B–D).
      - Check the stability of the repair after the anchor sutures have been tied (TECH FIG 8E).
      - Pass the anchor sutures through the distal fibular periosteal flap (TECH FIG 9A–C).
      - This reinforces the repair
      - Place additional sutures from the periosteum to the capsule that has been advanced to the distal fibula (TECH FIG 9D,E)
      - Augment the repair further with the inferior extensor retinaculum

TECH FIG 3 • A,B. Mobilize the inferior extensor retinaculum to be used to augment the repair (Gould modification of the Brostrom procedure). A. Identify the inferior extensor retinaculum. B. Demonstrate that the retinaculum can be advanced. C,D. Identify, inspect, and protect the peroneal tendons. C. Identify the tendons. D. Inspect the tendons.

Text continues on page 4310
TECH FIG 4 • Anterior arthrotomy. A–C. The anterolateral capsule is elevated from the distal fibula. D. With the anterolateral tibiotalar joint exposed, the talar articular cartilage may be inspected and the hypertrophied anterior inferior tibiofibular ligament (Basset’s ligament) may be excised. (Following multiple ankle sprains, anterolateral soft tissue ankle impingement frequently develops).

TECH FIG 5 • Identify the ATFL and CFL within the lateral capsule; these structures represent condensations within the lateral capsule. A,B. ATFL and its anatomic location on the fibula identified. C,D. CFL identified and its competency tested with ankle/hindfoot inversion.
**TECH FIG 6** • Distal fibular periosteal flap. This flap may be developed to create another layer for repair. **A,B.** Mobilizing distal fibular flap. **C.** Using a rongeur to prepare the distal fibula for reattachment of the capsule. **D,E.** Predrill holes for suture anchors. **D.** First, drill hole in anatomic footprint of ATFL. **E.** Second, drill hole in anatomic footprint of CFL.

**TECH FIG 7** • Suture anchors. **A.** First anchor in anatomic footprint of ATFL. **B.** Second anchor in anatomic footprint of CFL. **C.** Stability of suture anchors tested by lifting limb from the operating room table by the anchor sutures. (continued)
TECH FIG 7 • (continued) D–G. Anchor sutures passed through respective capsular condensations. D. Suture through CFL. E. Suture through posterior aspect of capsule adjacent to CFL. F,G. Suture through ATFL.

TECH FIG 8 • A. Reduce the talus within the ankle mortise before reattaching the ligaments and capsule. The ankle is held in dorsiflexion, with a posterior force maintaining the talus within the ankle mortise. Although covered, a bump has been placed under the distal tibia to allow the heel to translate posteriorly without interfering with the operating table. The heel is maintained in slight valgus. B–D. Secure the sutures while ankle is maintained in optimal position. B. Protect the peroneal tendons. C. Secure the CFL and more posterior capsule. (continued)
TECH FIG 8 • (continued) D. Secure the ATFL. E. Recheck the anterior drawer test to determine if the primary sutures are securely maintaining ankle stability.

TECH FIG 9 • Anchor sutures passed through the periosteal flap to reinforce the repair. A. Sutures through the periosteal flap. B. Check the stability. C. Secure the sutures. D,E. Reinforce the repair with additional sutures. D. Pass sutures from the capsule through the periosteal flap. E. Secure these sutures.
Protect the peroneal tendons because they are in close proximity to the inferior extensor retinaculum (TECH FIG 10A).

Advancing the inferior retinaculum to the distal fibula over the capsular advancement is the (Nathaniel) Gould modification of the Brostrom lateral ankle ligament reconstruction (TECH FIG 10B–D).

If possible, advance the inferior retinaculum so that the tissue covers the sometimes prominent permanent anchors suture knots. Final check of the anterior drawer and talar tilt to ensure that ankle stability has been reestablished (TECH FIG 11A).

Closure (TECH FIG 11B).

### TECHNIQUES

#### MODIFIED BROSTROM BROSTROM-EVANS PROCEDURE

**Definition**
- This is a combination of the modified Brostrom procedure described above and the Evans procedure, tenodesing the anterior 50% of the peroneus brevis to the fibula

**Indications**
- Athlete or patient in whom greater restraint against inversion is desired
- For example, a football lineman who does not need as much hindfoot flexibility as a running back
- Anatomic repair planned but greater than anticipated instability, particularly with inversion stress, and an intra-operative determination that more restraint to inversion is needed than can be afforded by the modified Brostrom procedure alone.
- Lateral ankle instability in a patient with pre-existing longitudinal split tear of the peroneus brevis.

**Technique**

- Same positioning and approach as for a modified Brostrom procedure
- The ATFL and CFL are released with the capsular sleeve from the fibula the same way as for the modified Brostrom procedure (**TECH FIG 12A**)
- Preparing the peroneus brevis tendon
  - The peroneus brevis (PR) is isolated distal and proximal to the superior peroneal retinaculum (SPR) that is left intact
  - The peroneus brevis is split longitudinally and the anterior 50% is released proximally (**TECH FIG 12B**)
    - While keeping the SPR intact, the PR is split using a suture that is passed beneath the SPR that is used to separate the PR into anterior and posterior limbs, acting as a “saw” to divide the tendon along its longitudinal fibers.
    - After being released proximally the anterior limb of the PR is passed beneath the SPR distally
  - Passing the anterior limb of the PR through the fibula
  - Drill an oblique tunnel in the distal fibula (**TECH FIG 13A**)
  - Pass the anterior 50% of the PR through the tunnel from distal to proximal (**TECH FIG 13B**)
  - Complete the modified Brostrom procedure (**TECH FIG 13C,D**)
    - The ankle is held in neutral position
    - The talus is maintained in the ankle mortise

**TECH FIG 12** • A. Prepare the lateral ankle ligament complex as is done for the isolated modified Brostrom procedure. B. Isolate the anterior 50% of the peroneus brevis tendon.

**TECH FIG 13** • A. Transect the anterior 50% of the tendon proximally and pass this half of the peroneus brevis tendon beneath the intact superficial peroneal retinaculum. Drill a fibular tunnel from distal to proximal. B. Pass the anterior slip of the peroneus brevis through the tunnel from distal to proximal. C, D. Complete the modified Brostrom procedure. (continued)
Slight valgus is maintained in the hindfoot

Augment the modified Brostrom with the Evans modification

The anterior slip of the PR is secured to the fibular periosteum, both at the anterior and posterior aspects of the tunnel

Avoid excessive valgus or excessive tensioning as overtightening could occur; the goal is to have a restraint to inversion, not a complete lack of inversion

Typically, the anterior slip of the PR can be sewn over the fibula after being passed through the tunnel to further augment the repair (TECH FIG 13E,F)

Check ankle stability with anterior drawer and particularly inversion stress (TECH FIG 13G,H)

Postoperative Protocol

Same as for modified Brostrom
## PEARLS AND PITFALLS

| Incision | When making the traditional J incision, be sure it is positioned over the distal fibula and not the lateral process of the talus. Palpate the landmarks carefully. |
|———|———|
| Use a bump/bolster | Position is everything. A bolster under the ipsilateral hip ensures that the leg is maintained in the optimal position, thereby maintaining adequate exposure to the lateral ankle. A bolster under the operated ankle is also useful and improves access to the lateral ankle. |
| Ankle position when securing the sutures | Reduce the talus within the ankle mortise. Dorsiflex the ankle, push the talus posteriorly within the mortise, and maintain slight hindfoot valgus. It is useful to use a bump under the distal tibia so that the foot can be pushed posteriorly. |
| Protect the superficial peroneal nerve | The SPN crosses the anterior aspect of the surgical approach for the classic J incision and potentially for the extensile exposure as well. Be careful not to injure the nerve. |

## POSTOPERATIVE CARE
- The patient is to remain non-weight-bearing until seen in the clinic for the first cast change in 10 to 14 days.
- At this first postoperative visit, the splint is removed and wound evaluated. If no problems are seen, the skin closure is removed and the patient is placed in a short-leg weight-bearing cast for the subsequent 4 to 5 weeks.
- At the next visit the cast is removed and a physical therapy program is initiated for range of motion, proprioceptive training, and progressive resistive exercise.
- Gradual return to sport is possible at 12 to 16 weeks following surgery.

## COMPLICATIONS
- Minimal; avoid injury to the superficial peroneal and sural nerves
- Infection
- Wound dehiscence
- Failure of repair
- Peroneal weakness (postoperative physical therapy program important)

- If the talus was not reduced within the ankle mortise when the sutures were secured, then the repair may prove inadequate.
- With an anatomic repair, overtightening is unlikely.

## REFERENCES
DEFINITION
- Ankle sprains are the most common athletic-associated injury: they represent up to 40% of all sports-related injuries. The incidence of this inversion type of ankle sprain is around 10,000 people per day.
- Literature has cited that about 50% of patients with ankle sprains have some long-term sequelae of their injury. Many of these people develop ankle instability.
- Ankle instability can be divided into two categories, functional and mechanical.
  - Functional instability refers to the subjective feeling of the ankle giving way during activity.
  - Mechanical instability is the term used when patients show excessive ankle motion, beyond the normal physiologic barriers.

ANATOMY
- The lateral ankle is supported by both dynamic and static structures (FIG 1).
- Static structures include the bony architecture of the joints and the ligaments. This bony configuration contributes about 30% of the stability, whereas the remaining 70% of stability comes from the soft tissues.
- The dynamic structures that aid in the stability of the ankle include the peroneus longus and peroneus brevis tendons. These tendons run posterior to the fibula in the peroneal groove. They are kept in this groove by the superior peroneal retinaculum.
- Once the tendons pass the distal tip of the fibula, they alter their course and run along the lateral border of the calcaneus, under the inferior peroneal retinaculum, with the peroneus brevis inserting on the base of the fifth metatarsal and the peroneus longus making another turn at the cuboid tunnel and inserting on the first metatarsal.
- These two tendons act as the primary evertors of the ankle and also participate in plantarflexion of the ankle. As a result of their course and function, they work in a dynamic fashion to provide stability to the ankle and subtalar joints.
- In addition to the bony configuration of the joint, the static restraints for the lateral aspect of the ankle include the anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL), and the posterior talofibular ligament (PTFL).
  - The ATFL is the most frequently injured ligament and the weakest of the three ligaments. It is flat and broad and originates from the anterior border of the lateral malleolus and continues anteromedially to insert on the talar body, anterior to the articular surface.
  - The CFL originates just inferiorly from the ATFL on the anterior border of the lateral malleolus and runs deep to the peroneal tendons, and in a posterior, inferior, and medial direction to insert on the posterior aspect of the lateral calcaneus.
  - The PTFL is the strongest of this lateral ankle complex and is rarely injured. It originates from the posterior aspect of the fibula, deep to the peroneals, and inserts on the lateral tubercle of the talus, laterally to the flexor hallucis longus groove.
  - With the ankle plantarflexed, the ATFL is taut and becomes vertical, acting as a collateral ligament. In dorsiflexion, the same is true for the CFL.
  - The ATFL has been shown to be the primary restraint to inversion in the ankle.

PATHOGENESIS
- Injury to the lateral ligamentous complex of the ankle is common. These inversion ankle injuries often result in attenuation or rupture to one or more of these ligaments.
- With the loss of these static restraints, the ankle becomes mechanically unstable, moving past the normal physiologic restraints for the ankle joint (FIG 2).

NATURAL HISTORY
- Once injury to the lateral stabilizers of the ankle has occurred, the patient should undergo immobilization followed by progressive rehabilitation.
- If this approach fails, it is usually related to peroneal weakness, proprioceptive defects, subtalar instability, and mechanical or functional instability.
- Chronic ankle instability can lead to repetitive inversion injuries, with the potential for fracture, osteochondral lesions of the talus, peroneal tendon injury and dislocation, and significant posttraumatic arthritis.
PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with chronic lateral ankle instability will describe an inversion injury in the past. As a result, they will report that they have problems with consistent repetitive ankle sprains, a feeling of looseness in the ankle with or without pain.
- The physician should inquire whether the patient is experiencing pain between intervals of repetitive injury. This would point toward the possibility of a secondary problem from instability (i.e., osteochondritis dissecans, impingement lesion, synovitis).
- The examination for chronic lateral ankle instability includes evaluation of the joint above (knee) and below (subtalar). Assessment should include overall alignment, range of motion, point of maximal tenderness, anterior drawer testing, evaluation of the peroneal tendons for pathology, ankle proprioception, and evaluation for associated injuries.
- Alignment should be evaluated for both the overall lower limb and the hindfoot. Patients with hindfoot varus alignment are predisposed to ankle inversion injuries and instability. The alignment is assessed in both the seated and standing positions. The flexibility of the hindfoot should be checked.
- Patients whose malalignment cannot be corrected with orthoses should have the alignment addressed at the time of operative ligament repair.
- Tibiotalar as well as subtalar joint motion should be evaluated. Ankle motion has been described as ranging from 13 to 33 degrees of dorsiflexion and 23 to 56 degrees of plantarflexion.
  - The variability is dependent on the operator and the mode of measurement.
  - Accepted values for functional range of motion are 10 degrees of dorsiflexion and 25 degrees of plantarflexion.
  - Range-of-motion testing can always be compared to the uninjured side for comparison.
- Subtalar motion occurs about an oblique axis running from the medial side of the talar neck to the posterolateral wall of the calcaneus. Total motion for inversion and eversion is an arc of 20 degrees, but this is extremely difficult to assess accurately. The predominance of this motion is inversion.
- The anterior drawer test is designed to test the competency of the ATFL.
  - The test is performed with the patient seated and the knee flexed to 90 degrees. The tibia is stabilized with one hand while the ankle rests in relaxed plantarflexion. The contralateral hand is used to draw the talus anteriorly.
  - If the medial restraints are intact, then the movement has a rotatory component. Increased talar displacement when compared to the contralateral limb indicates a positive test. In addition, excessive motion alone can signify incompetence of the ATFL.
  - Most resources cite an absolute value of 10 mm for a positive test. A firm endpoint should also be noted when testing for ATFL competency.
  - Proper examination of the ankle for chronic instability includes the evaluation of the peroneal tendons. These tendons can easily be injured at the time of the varus stress that tears the ATFL as well as with the recurrent instability that follows.
  - Evaluation for swelling in the retrofibular space is performed.
  - Simple palpation of the tendons (for tenderness) and strength testing are mandatory.
  - Peroneal weakness mandates a search for peroneal pathology.
  - The peroneal compression test can be helpful as well. The patient should be examined in a dynamic way to elicit peroneal subluxation or dislocation if it is present.
- Proprioception testing is an essential part of evaluating chronic ankle instability. Defects in proprioception following ankle sprains are well documented in the literature.
  - The modified Romberg test or stabilimetry is the best way to assess proprioception. A modified Romberg test is performed by having the patient stand first on the uninjured limb, with eyes open and then closed; this is then repeated on the injured side.
  - The difference in balance is related to the proprioception pathways of each limb.
  - The limitation of this test is that, to be accurate, there should be a full range of motion of the ankle and the subtalar joint and no pain with full weight bearing.
  - The advantage of the Romberg test is that it requires no special equipment.
  - Stabilimetry measures postural equilibrium and correlates with functional instability, but data generated on total sway in the vertical and horizontal planes require a force plate and computer analysis.
- Finally, the examiner must rule out other possibilities on the differential diagnosis and determine whether there is more than one source of pathology.
  - Point tenderness in the area of the fifth metatarsal base, the anterior calcaneal process, and the lateral talar process could represent fracture.
  - Full evaluation of the ankle joint for loose bodies, osteochondritis dissecans lesions, and impingement lesions should be performed.
IMAGING AND OTHER DIAGNOSTIC STUDIES

- The use of imaging in the patient with the symptoms of ankle instability should begin with three plain radiographic views of the ankle.
- These films should be evaluated for fractures of the fifth metatarsal, lateral talocrural process, and anterior process of the calcaneus, as well as fractures to the malleoli.
- In addition, the examiner should be looking for exostoses of the tibia and talus, osteochondral lesions of the talus, and tarsal coalitions.
- Stress radiography can be used to evaluate anterior talocrural translation and talocrural tilt. A standardized apparatus would improve reliability and consistency in this measure. The use of the contralateral limb as a control should be included when using this measure for a surgical indication.
- Further studies to evaluate the lateral aspect of the ankle include the use of MRI. MRI can delineate peroneal tendon pathology as well as provide needed information about osteochondral lesions of the talus (FIG 3).

DIFFERENTIAL DIAGNOSIS

- Bone
  - Anterior process of calcaneus fracture
  - Lateral–posterior talocrural process fracture
  - Lateral malleolar fracture
  - Base of fifth metatarsal fracture
  - Tibiotalar bony impingement
  - Tarsal coalition
- Cartilage
  - Osteochondral lesions of talus or tibia
  - Subtalar cartilage flap tear
- Ligamentous
  - Functional lateral ankle instability
  - Mechanical lateral ankle instability
  - Subtalar instability
  - Syndesmosis injury
- Neural
  - Neuropraxia of the superficial peroneal nerve
  - Neuropraxia of the sural nerve, reflex sympathetic dystrophy
- Tendons
  - Peroneus brevis tendon tear
  - Peroneus longus tendon tear
- Soft tissue
- Anterolateral ankle impingement lesion
- Sinus tarsi syndrome
- Peroneal subluxation or dislocation
- Painful os peroneum syndrome
- Peroneal synovitis
- Anterolateral ankle impingement lesion
- Sinus tarsi syndrome

NONOPERATIVE MANAGEMENT

- Nonsurgical treatment of lateral ankle instability begins with restricted activity and physical therapy.
- Physical therapy should focus on stretching, proprioception, and peroneal tendon strengthening.
- In addition, braces and shoe wear modification can be used. The use of a lateral heel wedge, a flared sole, and a reinforced counter can assist patients with instability.
- External stabilization of the ankle joint with taping or wrap dressings can provide some stabilization. Studies have shown superior initial resistance to inversion with taping, but taping has been shown to lose 50% of this initial effectiveness after 10 minutes of exercise.
- As a result, the use of over-the-counter reusable braces is recommended for nonoperative stabilization of the ankle joint. A University of California Berkeley orthosis, an ankle–foot orthosis (AFO), or a hinged AFO may also be used to help patients avoid surgery.
- In more sedentary patients, these modalities may provide adequate treatment, but for most athletes, they are unacceptable for long-term care.

SURGICAL MANAGEMENT

- Surgery for chronic ankle instability is indicated following a trial of failed nonoperative management.
- Patients with persistent, symptomatic mechanical instability will benefit from ligament reconstruction. This is often the case for athletes as well as patients who cannot tolerate bracing on a long-term basis.
- Relative contraindications for surgery include pain with no instability, peripheral vascular disease, peripheral neuropathy, and inability to comply with postoperative restrictions.
- Many procedures have been described for the management of ankle instability. They can be subdivided into anatomic and nonanatomic reconstruction techniques.
- The authors’ choice for lateral ankle ligament reconstruction is influenced and based on the patient’s body habitus, activity pattern, and physical demands.
- In patients with the need for full ankle range of motion, such as dancers, an anatomic procedure is recommended.
- In patients who are obese, are at risk for repetitive external varus stresses, have connective tissue disorders (Ehlers–Danlos), or are undergoing revision surgery, a nonanatomic reconstruction such as the Chrisman-Snook is preferred.
- In patients with attenuated tissue, the advent of bioengineered tissue has allowed us to augment the anatomic repair.
- Arthroscopy of the ankle is indicated for patients who have osteochondral lesions of the talus, tibial and talocrural exostoses, and anterior impingement lesions. We have had excellent results in treating chronic lateral ankle instability with arthroscopic techniques.
- Radiofrequency to provide thermal energy to the ATFL has been used with moderate success to treat patients who require arthroscopy, with the benefits best realized in the functionally unstable ankle.
Preoperative Planning
- Preoperative planning in the case of chronic ankle instability is based on the cause of the instability.
- Patients should be thoroughly evaluated for the possibility of a tarsal coalition.
- Hind foot alignment should be addressed. Patients with a varus hind foot are predisposed to suffer inversion injuries, and the possibility of a Dwyer calcaneal osteotomy in addition to the ligament repair should be considered.
- The presence of intra-articular pathology should also be addressed. Patients with clear pathology should have this addressed at the time of surgery.
- Peroneal tendon injuries often accompany ankle instability and should be evaluated and treated at this setting.

Positioning
- Positioning patients for lateral ankle ligament repair and reconstruction should be based on the chosen procedure.
- For anatomic ligament repair, we prefer to place the patient in the lateral decubitus position. This allows direct access to the lateral aspect of the ankle and the ability to address peroneal pathology and perform a calcaneal osteotomy if necessary.
- Patients who are undergoing arthroscopy should be placed in the supine position for arthroscopy. If the surgeon then chooses open ligament repair techniques, a bump can be placed under the ipsilateral hip after the arthroscopic portion of the surgery is complete.

Approach
- The incision for the Brostrom-Gould procedure was originally described as a J-shaped incision, just anterior to the fibula (FIG 4A). This allows easy exposure to the anterolateral capsule and ATFL and CFL.

MODIFIED BROSTROM ANATOMIC LATERAL LIGAMENT RECONSTRUCTION
- In 1966, Brostrom reported a series of 60 patients on whom he performed a direct lateral repair of the lateral ligaments of the ankle. The ligaments of the ATFL and the CFL were found to be disrupted but present, and the torn ends were shortened and repaired directly by mid-substance suturing.
- In 1980, Gould modified this procedure by advancing the lateral aspect of the inferior extensor retinaculum to the fibula, reinforcing the repair of the ATFL.
- In addition to reinforcement, the modification limits subtalar instability and provides a checkrein to inversion.
- In this technique the patient is placed in the lateral decubitus position. All bony prominences are padded and an axillary roll is placed to protect the upper extremity. A well-padded thigh tourniquet is placed.
- The choice of an anterior incision or a posterior incision is up to the surgeon.
- The curvilinear incision (FIG 4B) extends from 4 to 5 cm proximal to the tip of the fibula and follows the course of the peroneal tendons.
- Distally, carry the incision toward the base of the fifth metatarsal.
- Take care to avoid the superficial peroneal and the sural nerves.
- An alternative to the J incision is a posterior curvilinear incision that allows the surgeon to repair the peroneal tendons and repair the lateral ligament complex (FIG 4B). We prefer this curvilinear incision.
This arthrotomy will divide both the ATFL and the CFL in their midsubstance. At this time the surgeon can evaluate the tibiotalar joint.

- Resect scar tissue; up to 5 mm of tissue can be excised.
- Imbricate the ligaments in a pants-over-vest fashion with 0 Vicryl stitches (TECH FIG 1B–D).
- Place the sutures but do not tie them until the ankle is held in dorsiflexion and eversion. Be sure to prevent anterior subluxation of the talus at this time.

After the repair, take the ankle through a range of motion to ensure that the sutures hold.

Once repair of the arthrotomy has been performed, advance the extensor retinaculum and secure it to the periosteum of the fibula, covering the ligament and capsular repair.

Perform irrigation and then subcutaneous and skin closure.

Apply a dressing and splint, placing the ankle in a slightly everted position.

In patients who have suffered from chronic lateral ankle instability with repeated inversion injuries, often the tissue at the time of surgery is attenuated and of poor quality. In the past, this might have caused failure of the anatomic repair, or caused the surgeon to consider a using an autologous tendon augmentation.

With the growing orthobiologic market, we have found that these bioengineered tissue augments can provide the surgeon with another option in the case of poor tissue quality, without the morbidity of autogenous tendon harvest.

The approach is the same as for the standard modified Brostrom repair.

After performing the arthrotomy, select the preferred tissue graft and prepare it as recommended by the manufacturer.

Secure the graft distally to the capsule with 0 Vicryl suture.

After attaching the graft to the distal aspect of the capsule, perform the standard Brostrom repair.

After tying the sutures through the ATFL and CFL, but before taking the ankle through a range of motion, tension the tissue implant to the fibula through bone tunnels, bone anchors, or suture to the periosteum, with the foot in an everted position.

Tension the implant to ensure there is no redundancy (TECH FIG 2).

Reef the inferior extensor retinaculum over the implant as well as the anatomic repair and secure it to the fibula.

Close the subcutaneous tissue and skin and apply a splint in slight eversion.
The presence of intra-articular pathology after chronic lateral ankle instability is well documented. The need to address this pathology as well as the lateral ligament instability inspired us to develop an arthroscopic protocol to address both at the same time.

The patient is placed supine on the operating table.

A well-padded tourniquet is placed on the upper thigh of the operative leg.

The operative extremity is then placed into a thigh–knee holder. The holder is padded to ensure there is no pressure on the peroneal nerve and the popliteal space.

The operative extremity then undergoes sterile preparation and draping.

A noninvasive ankle distractor strap is applied and the ankle is distracted.

Introduce a spinal needle into the ankle joint through the area of the standard anteromedial portal and insufflate the joint with 1% lidocaine with epinephrine. This distends the joint and aids in preventing the need for tourniquet use.

Incise only the skin and carry blunt dissection down to the capsule.

Use a blunt trocar for a 3.5-mm arthroscope.

Introduce the arthroscope into the joint and visualize the articular cartilage.

Once you have confirmed the arthroscopic placement, inflow is started to prevent extracapsular extravasation.

The area of the anterolateral portal is transilluminated, and the surgeon can avoid the dorsal veins of the ankle as well as the branches of the superficial peroneal nerve.

Use a spinal needle to confirm ankle portal placement and make the skin incision. Again, carry blunt dissection down to the capsule and penetrate the capsule with a blunt trocar.

Perform a standard 21-point arthroscopic examination. Note any intra-articular pathology (synovitis, osteochondral defects, impingement lesions) and treat it accordingly.

In this procedure, we have found that aggressive treatment of the anterolateral impingement lesion is necessary to allow improved visualization of the anterolateral gutter and the ATFL (TECH FIG 3A).
After treating the intra-articular pathology, introduce the probe for thermal energy delivery.

Once the wand is in the joint and placed in the posterior recess of the lateral gutter, remove the distraction device from the foot (TECH FIG 3B).

This is necessary to allow for contraction of the tissues when the thermal energy is delivered.

Use a painting technique, starting in the area of the CFL and working anteriorly.

Deliver the treatment only below the “equator” of the lateral ankle portal so as not to cause an impingement lesion (TECH FIG 3C).

Avoid repetitive painting of any one area to prevent injury.

After adequate exposure to the thermal effects, remove the probe, close the portals, and apply a dressing.

The patient is placed into a well-padded splint in slight dorsiflexion and eversion.

PEARLS AND PITFALLS

| Negative anterior drawer test with history consistent with instability | Beware the restraint of anterior tibial osteophytes. They can cause an abnormally negative drawer test despite a clinical picture of instability. |
| Failed primary Brostrom procedure | Be sure to evaluate hindfoot anatomy. If the hindfoot is in varus, combine lateral closing-wedge and lateral slide osteotomy with a revision procedure. |
| Patient activity level | Larger patients (more than 115 kg) and high-demand patients (football players) may require augmentation to the simple Brostrom-Gould procedure. |
| Anterolateral ankle joint pain, no chronic instability pattern, history of previous ankle sprain | An ankle impingement lesion can act as a primary pain generator. |

Global pain in lateral ankle region | Look carefully for secondary pathology. Recurrent instability can result in osteochondritis dissecans of the talus, subluxing or dislocating peroneal tendons, subtalar instability, and other intra-articular lesions of the ankle. |

POSTOPERATIVE CARE

- Postoperatively, the patient course is divided into 3-week increments.
  - The first 3 weeks is non–weight-bearing in a cast, the second 3 weeks is weight bearing to tolerance in a cast, and the third 3 weeks is weight bearing in a boot-walker.
  - At the 9-week mark, the patient is weaned into an ankle stirrup brace and placed into a physical therapy program to begin range of motion, strengthening, and proprioceptive training.
  - Patients are then progressed as tolerated until physical therapy goals are met.
  - Patients are allowed to discontinue the brace for daily activities but are asked to brace in situations at risk for 1 year after reconstruction.

OUTCOMES

- The clinical and functional outcome from anatomic repair for chronic lateral ankle instability is good.
  - In 1988 Karlsson et al.6 reported on 152 ankles with a follow-up of 6 years. Good to excellent results were found in 87% of patients. In this study, 86% of athletes reported no deterioration in function. Predictors of poor outcome included more than 10 years of instability, generalized ligamentous laxity, and osteoarthritis of the ankle.
  - A prospective outcome comparison study of the Chrisman-Snook and modified Brostrom procedure by Hennrikus et al.5 demonstrated that both operations provided good or excellent stability in more than 80% of patients, but the Brostrom procedure resulted in higher Sefton scores and a statistically significant decrease in complications when compared to the Chrisman-Snook.
  - Recently, a case series on 31 patients by Bell et al.1 showed 91% good or excellent results 26 years after undergoing the Brostrom procedure.
  - Outcome assessment for thermal-assisted capsular modification for ankle instability has shown promise.
  - The senior author has pioneered the use of this technology for the treatment of ankle instability.
  - Initial early-term follow-up studies show clear improvement in patients, with an average increase in AOFAS hindfoot scores of greater than 25 points.
  - We have previously reported on 16 patients with average follow-up of 14.5 months. Good to excellent results were achieved by 80% of the patients.
  - Subsequent publications and presentations have mirrored these results.
  - Most recently Maiotti et al.7 reported on 22 patients with 32 months of follow-up. Nineteen of these 22 patients had good to excellent results and 21 of 22 returned to sporting activity.

COMPLICATIONS

- The most common complications after repair of the lateral ligament complex are nerve-related. The incidence of nerve complaints after surgery ranges from 7% to 19%.
  - In addition to nerve complications, wound complications and infection, stiffness, and deep venous thrombosis have been reported. These complications are of course present with all surgeries.
The possibility of recurrent instability is also a possible complication of surgery. This is most often a result of inadequate rehabilitation but can also result if the patient is not appropriately evaluated for hindfoot varus or connective tissue disease.

REFERENCES

DEFINITION
- Lateral ligament instability occurs in some patients after an inversion injury. Although an inversion injury is common, only a few patients have ongoing ankle instability severe enough to require surgery. Persistent instability may occur in 15% to 48% of patients.
- Lateral ligament disruption may occur in combination with osteochondral defects, hindfoot varus, peroneal tendon tears, anterior lateral joint impingement, or a tight heel cord. Any of these concomitant pathologies needs to be sought during the clinical examination and treated if it represents a significant component of the ongoing symptoms.
- Medial ankle instability may occur in combination with lateral ankle instability. In these cases the medial ligament instability may need to be addressed at the same time.

ANATOMY
- The lateral collateral ligaments include the calcaneofibular (CFL) and anterior talofibular ligaments (ATFL). These are condensations within the lateral capsule.
- The CFL runs from the anterior tip of the fibula to the lateral wall of the calcaneus. The ligament passes superficial to the lateral margin of the posterior facet of the subtalar joint and courses deep to the peroneal tendons to insert via a broad base onto the lateral side of the calcaneus.
- The ATFL arises from the anterior portion of the distal fibula and inserts onto the lateral side of the talar neck.

PATHOGENESIS
- Lateral ankle instability occurs after an inversion injury to the lateral ligament complex. The injury typically occurs in plantarflexion. Traditionally the ATFL ruptures first and the CFL second. A cavus foot may predispose the ankle to recurrent instability. Osteochondral defects of the talus and peroneal tendon tears are known associated pathologies.

NATURAL HISTORY
- Most ankle sprains resolve without the need for surgery. However, a recurrently unstable ankle treated with appropriate physical therapy protocols may benefit from lateral ankle ligament repair or reconstructions. Left untreated, persistent lateral ankle instability may result in fixed varus tilt to the talus within the ankle mortise and eventual ankle arthritis. Most patients present because of the disability associated with the recurrent sprains. Physiotherapy and bracing will improve symptoms in some patients with recurrent instability. There does not appear to be a role for immediate surgery on ruptures of the lateral ligaments.
The area of maximum discomfort and instability should be elicited. We take the ankle and hindfoot through a range of motion independent of one another to determine the joint of maximum discomfort.

Peroneal tendon pathology may accompany lateral ankle instability. A resisted contraction of ankle eversion should be performed and the tendons palpated for pain and fullness (suggestive of tenosynovitis). The peroneal tendons, which are flexors, are best isolated with the ankle in plantarflexion and testing eversion against resistance. Peroneal tendon weakness accompanies most peroneal pathology due to pain; marked weakness may signify a peroneal tendon tear. In our experience, the combination of chronic ankle instability, varus hindfoot, and marked peroneal tendon weakness should raise the suspicion for a peroneal tendon tear. Occasionally, an equinus contracture may be associated with lateral ankle instability. A Silfverskiold test (ankle dorsiflexion with the knee flexed contrasted with ankle dorsiflexion with the knee extended) allows the examiner to determine whether the contracture is isolated to the gastrocnemius or involves both the gastrocnemius and soleus components of the Achilles complex.

The ATFL resists anterior translation and medial rotation of the talus on the tibia. A direct anterior draw (pulling the talus anteriorly without plantarflexion and internal rotation) may fail to elicit instability in an unstable ankle as an intact deltoid ligament medially will prevent translation. Instead, the examiner should hold the tibia posteriorly with the left hand while translating the calcaneus anteriorly and internally rotating the foot at the same time. Side-to-side comparison to the contralateral, physiologically stable ankle assists in identifying ankle instability.

An inversion stress test determines the integrity of the CFL. An injury to the syndesmosis (ie, “high ankle sprain”) may be elicited with a squeeze test and by rotating and translating the talus in the ankle mortise in dorsiflexion. A syndesmotic injury must be distinguished from lateral ankle instability since treatment is different.

We also routinely examine the medial ankle for deltoid instability, since medial and lateral instability may coexist.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- We routinely obtain weight-bearing AP and lateral ankle radiographs; if more information is required, we add a mortise view. Osteochondral defects, anterior osteophytes, and tibiotalar arthritis associated with recurrent instability are generally visualized on standard radiographs of the ankle (FIG 2).
- On occasion we add a calcaneal axial view, Saltzman view, or tibial views if we need additional information on limb alignment. Recurrent ankle instability may be secondary to tarsal coalition; if the hindfoot is stiff on clinical examination, then calcaneal axial view and standard foot radiographs may identify the coalition. CT provides greater detail of osteochondral defects, osteophytes, arthritis, and tarsal coalition and should be obtained if these associated findings are suggested on plain radiographs.
- An MRI, particularly an MRI arthrogram, may provide detail of the deficient ligaments. Associated chondral and osteochondral defects as well as soft tissue impingement lesions may also be visualized by an MRI examination (FIG 3).
- Selective, diagnostic local anesthetic blocks of the ankle, subtalar, or talonavicular joints may be required to determine localized joint pain.
- When the diagnosis of ankle instability is suspected but remains in question, an inversion stress test done under fluoroscopy, compared to the physiologically stable contralateral ankle, may be useful. Bone scans can assist in determining associated pathology.

**DIFFERENTIAL DIAGNOSIS**

- Loose body in ankle
- Osteochondral defect
- Syndesmotic instability
- Peroneal tendinopathy or rupture
- Medial ankle instability
- Cavus foot
- Tarsal coalition

**NONOPERATIVE MANAGEMENT**

- Nonoperative treatment includes bracing and physiotherapy. Patients with recurrent ankle instability may develop peroneal tendon weakness and loss of proprioception.\(^{33,37}\) Physiotherapy via proprioceptive training and strengthening can resolve the ankle instability. Bracing may help a patient to recover from a sprain and prevent future sprains by strengthening the dynamic, stabilizing peroneal tendons. Nonoperative treatment is less effective if ankle instability is associated with fixed hindfoot varus. Flexible hindfoot varus may be compensated for with a

---

**FIG 2 • Radiologic finding of osteochondral lesion of talar dome.**

**FIG 3 • MRI finding of osteochondral lesion of posteromedial talar dome.**
lateral wedge orthotic. If hindfoot varus is driven by a planatarflexed first ray (as determined by the Coleman block test), then the orthotic should be “welled out” under the first metatarsal head, permitting further progression of the hindfoot into physiologic valgus.

**SURGICAL MANAGEMENT**

- The indication for surgical management of lateral ligament instability is chronic symptoms despite appropriate nonoperative management, including physiotherapy and bracing.
- Surgical management of lateral ankle ligament instability includes repair (anatomic tightening of the lateral ankle ligaments) and reconstruction (reconstitution of the lateral ankle ligaments using more than the local physiologic tissue in the lateral ankle ligamentous complex).
- Lateral ankle ligament reconstruction may be anatomic or nonanatomic. Anatomic reconstruction implies that the ligaments are rebuilt in the physiologically occurring orientation. Nonanatomic reconstruction suggests that lateral ankle support is reconstituted with tissue (typically tendon transfer to substitute for ligament deficiency) that does not follow a physiologic orientation of the ATFL and CFL.
- In our opinion, the literature on this topic favors anatomic over nonanatomic reconstruction; examples of nonanatomic reconstruction include the Evans and Watson-Jones procedures. We recommend repairing the lateral ankle ligaments when possible. However, if the ligaments are not repairable or require an augmentation, we perform an anatomic reconstruction. Graft options for reconstruction include autograft (peroneus brevis, plantaris, gracilis) or allograft tendon.

**Preoperative Planning**

- Plain radiographs, and if further detail is needed other imaging studies of the ankle, must be evaluated for associated conditions, such as malalignment, osteochondral defects, tendon pathology, and arthritis. Adjuvant procedures must be planned so that they may be safely performed in concert with ligament reconstruction.
- We recommend performing stress testing with the patient under anesthesia. In our opinion, the gold standard tests to determine lateral collateral ligament integrity are (a) open anterior drawer and (b) inversion stress test on the table to determine the integrity of the lateral collateral ligaments.

**Positioning**

- We routinely use a bean bag or large bump under the ipsilateral hip to rotate the operated extremity and allow full access to the lateral ankle (FIG 4).
- A full lateral position is avoided, as it limits access to the proximal medial tibia, making harvest of the gracilis tendon autograft more challenging.

**Approach**

- We recommend an extensile approach (ie, a longitudinal curvilinear approach) in lieu of the traditional J-shaped incision popularized by Brostrom. The extensile approach affords access to not only the lateral ankle ligaments but also the distal tibia, peroneal tendons, sinus tarsi, and lateral calcaneus for adjuvant procedures that may be warranted.

**GRACILIS RECONSTRUCTION THROUGH DRILL HOLES**

- We prefer a gracilis autograft tendon, anchored via drill holes, for the anatomic lateral ankle reconstruction and aim to obtain (a) immediate stable fixation, (b) biologic ingrowth to bone in time, and (c) an anatomic reconstruction. The technique is a modification of the plantaris reconstruction described by Anderson (TECH FIG 1).
- Place the patient on the operating table with the operative hip as described above. Apply a wide thigh tourniquet. Prepare and drape the leg to just above the knee. Perform anterior drawer and inversion stress tests on the table to confirm the diagnosis.
- Use regional anesthetic blocks if possible to ensure appropriate postoperative pain relief.
- If intra-articular pathology has been preoperatively identified or is suspected, we routinely address this with ankle arthroscopy before lateral ankle reconstruction (TECH FIG 2).
- Start the extensile longitudinal lateral incision on the distal fibula, continue it over the lateral malleolus, and curve it anteriorly toward the sinus tarsi (TECH FIG 3).
- Expose the superior extensor retinaculum anterior to the fibula while protecting the deep branch of the peroneal nerve, which has variable anatomy. Strip the extensor
Chapter 100  HAMSTRING AUTOGRAPHING/AUGMENTATION FOR LATERAL ANKLE INSTABILITY 4325

TECH FIG 1 • Free gracilis lateral ligament reconstruction.

TECH FIG 2 • Osteochondral defect of the talus found on arthroscopy before ligament reconstruction.

TECH FIG 3 • Lateral incision (solid line) with course of sural and superficial peroneal nerves marked (dotted lines).

TECH FIG 4 • Lateral dissection anterior to the fibula, sparing the anterior talofibular ligament.

TECH FIG 5 • Open anterior drawer test. Talus is anterior and internally rotated relative to fibula, indicating a positive test and insufficiency of the anterior talofibular ligament.

Retinaculum off the fibula so that the extensor compartment is exposed. Carry the dissection distally toward the ankle joint to the junction between the tibia, talus, and fibula. Open the joint at this level. This dissection will ensure that no ligaments are damaged during the exposure (TECH FIG 4).

- Remove anterior osteophytes using an osteotome.
- Perform an open anterior drawer and inversion stress test (TECH FIG 5) to assess the integrity of the lateral collateral ligaments as a final check before proceeding with reconstruction. I will perform a repair if the ligaments are clearly torn off bone, if they are not obviously scarred or thickened, if there is enough length to bridge the gap, or if they have been avulsed with a bone fragment.
- If the ligaments are not considered repairable, then reconstruction is warranted. We favor an autograft gracilis reconstruction, and therefore optimal patient positioning and preparation and draping of the operated extremity are important.
- Perform a standard gracilis tendon harvest with an incision over the medial aspect of the tibial tubercle at the pes anserinus insertion. Carry dissection down through the sartorius fascia and onto the gracilis tendon. Isolate the gracilis with the knee flexed, and use a tendon stripper to release it from its muscle proximally. Reef the tendon using a baseball whipstitch.
Divide the tendon at its insertion into bone and measure it. Select a drill bit matching the size of the tendon (typically a 3.5-, 4.5-, or 6-mm drill bit). Alternatively, a tendon-anchoring interference screw system may be used, size-matched to the harvested tendon’s diameter.

Expose the fibula first by removing part of the peroneal fascia so that the peroneal tendons and the posterior fibula are exposed (TECH FIG 6). We typically examine the peroneal tendons at this time to rule out or treat associated peroneal tendon pathology. If needed the peroneal retinaculum is incised with a step cut to allow complete exposure of the peroneal tendons for débridement or repair.29

Incise the collateral ligaments and expose the insertions of the CFL and ATFL. Dissect to the origin of both ligaments on the calcaneus and talus. Both areas are dissected clear onto bone (TECH FIG 7). Use a curette to clear the area of the junction of the body and neck of the talus.

Make a medial incision at the anterior border of the Achilles tendon, and carry dissection down to the bone and tendon at this level (TECH FIG 8).

Drill through the calcaneus from medial to lateral, adjacent to the Achilles tendon, with the appropriately sized drill bit (depending on harvest tendon diameter), exiting laterally at the origin of the CFL (TECH FIG 9). A cannulated drill or a combined aiming device can be used to target this drill to the calcaneofibular footprint on the calcaneus.

Make a fibular drill hole starting at the insertion of the CFL and exiting the posterior fibula. Make another fibular drill hole starting at the insertion of the talofibular ligament and exiting in the posterior fibula about 1 cm above the exit point of the previous fibular drill hole (TECH FIG 10).

Then, make a 2.5-mm drill hole in the center of the junction between the talar body and neck (TECH FIG 11). Measure its depth. A fully threaded cancellous small-fragment screw with a small- and large-fragment washer is readied on the back table.

With a no. 2 braided nonabsorbable polyester suture, suture the tendon onto the edge of the Achilles medially,
using a Kessler stitch on the nonbraided end of the gracilis tendon. Leave 1 cm of loop between the Achilles and the end of the gracilis to prevent buildup of suture and ligament medially, which may cause irritation. Place the knot in the middle of this segment.

- Use a tendon passer to pass the tendon graft through the calcaneal tunnel to the lateral calcaneus.
- Cycle the tendon a few times to make it tight.
- Pass the tendon through to the posterior aspect of the fibula and pull it tight with the ankle in eversion. Suture the tendon to any remaining tissue on the fibula (TECH FIG 12).
- Bring the tendon back through the fibula so that it exits anteriorly at the second drill hole.
- Cycle the tendon in tension and suture it to the cuff of tissue on the fibula at the insertion of the talofibular ligament.
- Start the selected small-fragment screw with the large and small washer into the 2.5-mm hole in the talar neck.

- Place the split tendon end over the washer (right side) and under the washer (left side) and secure it around the washer in a clockwise direction. Hold the foot in dorsiflexion and eversion.
- Hold the tendon tight around the washer and screw and tighten the screw home. The tendon will tighten as the screw is placed home (TECH FIG 13). Although interference screw systems are effective, our method using standard screws and a simple ligament washer is cost-effective and consistently affords immediate ankle stability.
- Suture the free end of the tendon back onto the tendon segment between the fibula and washer.
- Suture the remainder of the tendon back onto the lateral side of the fibula, and trim the residual tendon end.
- To confirm stability and proper ligament tension of the reconstruction, place the ankle through repeat open anterior drawer and inversion stress tests. Close the wounds using nylon or staples. Use of a drain is at the surgeon’s discretion.
COUGHLIN DRILL HOLES IN BONE

- An alternative technique is to use drill holes through the bone made on the lateral side only.\textsuperscript{14} This is a variation of the Emslie technique (TECH FIG 14).
- Use a similar exposure, with no medial incision.
- Make two drill holes on the lateral wall of the calcaneus on each side of the origin of the CFL.
- Pass the tendon through the drill holes and suture it back onto itself.
- Make a single drill hole on the tip of the fibula joining the insertion of both lateral collateral ligaments.
- Make two drill holes on each side of the insertion of the talofibular ligament.
- Pass the tendon through the fibula and through the drill holes on the talus, and tension it and suture it back onto itself.
- We consider this variation more challenging than our described technique, specifically in passing the tendon through bone without fracturing the bone bridges. Moreover, we find it more difficult to ensure anatomic location of the ligaments and optimal tendon tensioning. In our opinion, prolonged postoperative immobilization may be required, depending on the strength of the bone bridges.

BIOTENODESIS SCREW TECHNIQUE

- With this technique a similar exposure and tendon harvest are used (TECH FIG 15). No medial exposure is required.
- Make a drill hole on the lateral side of the calcaneus at the CFL origin. Place the tendon over the tip of a tenodesis screw and secure it to the lateral wall of the calcaneus.
- Pass the tendon through two fibular tunnels at the anatomic locations of the CFL and talofibular ligament, exiting over a posterior fibular bone bridge as described in our technique.
- Make a second drill hole on the lateral side of the talus at the junction of the body and neck to accommodate the tendon and a second biotenodesis screw.
- Our concerns with this alternative are (a) quality of fixation via interference screw in the relatively weak cancellous bone of the calcaneus and (b) the relatively large talar drill hole, which may serve as a stress riser and cause of talar neck fracture.

MYERSON MINIMAL INCISION TECHNIQUE

- This technique (TECH FIG 16) is similar to the Coughlin technique but is performed through two small incisions.
- Make one incision over the calcaneal drill holes and a second over the region of the talar drill holes. Carry dissection down to bone. Make two connecting drill holes in each location. Tunnel a drill bit and guide subcutaneously to drill the pathway through the fibula.
- Harvest the graft and route it in the same fashion as in the Coughlin technique described earlier.
- While this is a reasonable alternative, as for the Coughlin technique, we have difficulty passing and tensioning the tendon using this technique.
PEARLS AND PITFALLS

**Exposure**
- Ensure that the exposure goes through the anterior compartment and down into the ankle. This will avoid damage to the ligaments before the open anterior drawer test.

**Positioning**
- Use a bean bag to ensure that the ankle is internally rotated to allow access to the lateral side of the ankle. Different patients have different amounts of internal rotation, and this needs to be accommodated. However, avoid a full lateral position if you plan a gracilis tendon harvest.

**Drill holes**
- Drill the calcaneal hole from medial to lateral. The vector guide can be used to ensure correct positioning of the exit hole and the CFL footprint on the lateral calcaneus.

**Drill hole size**
- The drill hole should closely match the size of the graft to ensure osseous integration. The drills and taps from the anterior cruciate ligament set can be used. The drill hole should be large enough to pass the tendon.

**Graft preparation**
- The graft should be prepared with a whipstitch to ensure that it passes easily through the bone tunnels.

**Graft tensioning**
- Avoid anterior translation of the talus within the ankle mortise when the tendon reconstruction is tensioned. In particular, place a bump under the distal tibia and avoid placing a bump under the heel, which tends to translate the foot and talus anteriorly. Also, after each pass of the tendon through a tunnel, cycle the ankle with the tendon under tension to gain optimal final tension.

POSTOPERATIVE CARE
- With our preferred technique, patients are placed in a walker boot at the time of surgery. At 1 week they are allowed to bear weight as tolerated. The sutures are removed at 2 weeks. Ankle range of motion, supervised by physiotherapy, is initiated at this time. Patients are kept in the walker boot until 10 weeks after surgery during weight bearing. Gait training is started 8 weeks after surgery. Proprioception and single toe raises are started 12 weeks out. Patients may return to sports after 4 months.

OUTCOMES
- There are few retrospective reviews of anatomic reconstructions using various autografts. Despite the paucity of literature all studies have reported good results, with 88% to 100% of patients reporting good outcomes.\(^1,12,15,46\)
- Few studies have specifically looked at the outcome of a gracilis ligament reconstruction. A review of 29 ankles in 28 patients by Coughlin reported a successful outcome in terms of AOFAS and Karlsson scores in all patients. Postoperative follow-up averaged 23 months.\(^15\)
- Sammarco and DiRaimondo used a portion of peroneus brevis through drill holes; 91% good and excellent results were seen in 43 ankles.\(^44\)
- One study looked at the outcome of a semitendinosus graft reconstructing the ATFL; 81% of 23 patients reported an improved outcome.\(^41\)
- There are sufficient studies with poor outcomes in the literature to recommend against nonanatomic reconstruction of the lateral ankle ligaments. Eleven papers in a recent review of lateral ligament reconstructions argued against nonanatomic reconstruction, including the Evans and Watson-Jones procedures.\(^6,8,22,24,25,28,33,36,37,40,47\)

COMPLICATIONS
- Wound healing
- Recurrent instability
- Nerve injury
- Loss of range of motion
REFERENCES

DEFINITION
- Lateral ankle sprains are the most common injury in sports, accounting for 15% to 20% of all athletic injuries in some parts of the world. These injuries result in compromise or complete disruption of the lateral ankle, and, often subtalar, ligamentous complexes.\textsuperscript{12,15}
- Ankle sprains range in severity from mild stretching to complete disruption of the ligamentous structures. Often, the injuries of moderate or medium severity are the most difficult to accurately diagnose and, therefore, manage properly.
- Most acute ankle sprains respond well to a course of nonoperative therapy, including standard rest-ice-compression-elevation (RICE) methods, functional bracing, and even immobilization followed by physical therapy.
- From 30% to 40% of patients will have persistent problems related to pain and swelling for up to 6 months after the injury, and 10% to 20% will have difficulties with recurrent sprains, leading to chronic ankle instability.\textsuperscript{10}
- Chronic ankle instability usually manifests itself in one of two ways: (1) recurring symptoms after an acute episode of ankle sprain, or (2) a pervasive feeling of looseness or “giving way” without warning.

ANATOMY
- The lateral ankle ligamentous complex is made up of three distinct ligaments: the anterior talofibular, the calcaneofibular, and the posterior talofibular ligaments. Other structures contributing to overall lateral ankle stability are the inferior extensor retinaculum and subtalar ligamentous complex.
- The anterior talofibular ligament (ATFL), which blends with the anterolateral joint capsule, is 15 to 20 mm long, 6 to 8 mm wide, and 2 mm thick.
- The ATFL originates from the anterior and distal fibula to insert on the lateral body of the talus, forming an angle of about 75 degrees to the floor.
- The calcaneofibular ligament (CFL) is 20 to 30 mm long, 4 to 8 mm wide, and 3 to 5 mm thick. It originates from the posteromedial portion of the inferior fibula to travel within the peroneal tendon sheath, under the tendons, and attaches to the lateral wall of the calcaneus. The orientation is 10 to 45 degrees posterior to the longitudinal axis of the fibula. The angle formed between the ATFL and CFL is 100 to 105 degrees.
- The posterior talofibular ligament (PTFL) is the largest of the lateral ankle ligaments, at 30 mm in length, 5 mm in width, and 5 to 8 mm in thickness. It has a broad insertion on nearly the entire posterior lip of the talus.
- The ATFL has the lowest load to failure of the three ligaments. Conversely, it has a much higher capacity to withstand strain than the CFL or PTFL, thereby allowing the greatest deformation before failure of all three structures.\textsuperscript{16}
- The ATFL is taut with the ankle in plantarflexion, whereas the CFL is relatively loose. The reverse is true for the dorsiflexed ankle. The strength of the CFL and the stability afforded by the bony mortise at the malleoli in a neutral or dorsiflexed ankle make maximal plantarflexion the position of vulnerability for lateral ankle ligament injuries.\textsuperscript{1,2}
- The subtaligamentous structures include the lateral talocalcaneal ligament, cervical ligament, interosseous talocalcaneal ligament—thought to provide the greatest contribution to stability of the subtalar joint, and the calcaneofibular ligament. These provide some measure of stability to the lateral ankle.

PATHOGENESIS
- Ankle instability is thought to be either acquired, as a result of repetitive trauma, or inherited due to ligamentous laxity, biomechanical abnormality (eg, heel varus, cavus foot position), or a combination of both.
- The ATFL is most commonly injured, accounting for about 75% of injuries to the ligaments of the ankle, followed by the CFL, which accounts for about 20% to 25% of these injuries. Injury to the ligaments occurs when they are either stretched or completely torn, either by avulsion from bone, or, more commonly, from midsubstance tearing.
- Neuromuscular deficits also result from these inversion injuries, leading to slower firing of the peroneal muscles in response to inversion stress, decreased responsiveness in the peronal nerve branches, weakness, and restricted dorsiflexion range of motion due to inadequate muscle forces.
- Repetitive injury can result in accumulated scarring leading to anterolateral mechanical impingement or even sinus tarsi involvement.\textsuperscript{5,14}
- Subtaligamentous ligaments may also be injured, although usually to a lesser extent.

NATURAL HISTORY
- Even though most ankle sprains and instability receive some form of treatment, there is little consistency in treatment regimens. The natural history is sketchy as to what would happen in the truly untreated situation.
- In one long-term study, one third of patients treated functionally for ankle sprains had continued complaints of pain, swelling, or instability in the form of recurrent sprains.\textsuperscript{10}
- Nearly three fourths had some level of impairment on return to sporting activity, with almost 20% incurring repeated sprains and 4% with pain at rest or severe disability.
- Dysfunction after an acute sprain will persist for 6 months in 40% of injured athletes.\textsuperscript{5}
- While it has been suggested that long-term lateral ankle instability and repeated traumatic events to the ankle can lead to advanced stages of degenerative disease, there is no actual proof of this theory.
- Nevertheless, it is presumed that continued ankle injuries as a result of lateral ankle instability can, and often will, lead to osteochondral injuries, abnormal joint mechanics, and neuromuscular dysfunction, predisposing the individual to risk of...
more severe injury to the extremity or disabling degenerative arthritis of the ankle and, possibly, the subtalar joints.

**PATIENT HISTORY AND PHYSICAL FINDINGS**
- Patients experiencing acute ankle sprains often describe a painful tearing or pop after sustaining an inversion type injury. Longer-standing instabilities will cause complaints of lack of confidence in the joint under high demands or frequent giving way; pain and swelling often are less severe and are of secondary concern to the patient.
- Findings on examination in the acute situation are reliably present and include anterolateral ankle pain, swelling, and pain on passive plantarflexion or inversion. In the patient with a chronically unstable ankle, the examination focuses more on the anterior drawer and talar tilt tests and the “suction sign.”
- Assessment for structural abnormalities also is important. Heel position should be examined in every patient, by looking at the patient from behind while he or she is standing, to determine the possible presence of varus malalignment.
- Neuromuscular function is another important part of the examination. Peroneal muscle group function, specifically, is critical. Strength and stability of the peroneals should be assessed by resistive muscle grading against plantarflexion and eversion. Provocative maneuvers such as the plantarflexion eversion stress test also should be performed to ensure that the peroneal tendons do not subluxate from the retrofibular groove.
- Sensory nerves should always be inspected to ensure no neurapraxia has taken place as a result of the traction from the injury.
- Syndesmotic integrity should be tested with palpation, the “squeeze” test, and dorsiflexion–external rotation provocative manipulations.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- According to the Ottawa Ankle Rules,^^1^ nearly 100% sensitivity is approached if the following criteria are used in the acute setting:
  - Tenderness at the posteroanterior edge or tip of the medial or lateral malleolus
  - Inability to bear weight (4 steps) right after the injury or in the emergency room
  - Pain at the base of the fifth metatarsal
- If radiographs are required, anteroposterior, lateral, and mortise views, preferably weight bearing, should be performed, looking for avulsion fractures of the tip of either malleolus, or, less frequently, the lateral calcaneus. One also should inspect for osteochondral fractures, joint malposition, and other fractures that may mimic lateral ankle sprains (see Differential Diagnosis).
- Stress views can be obtained in either the AP (talar tilt) or lateral (anterior drawer) position. Performing the study while stressing the ankle (as described in the section on examination of the patient) can give meaningful information regarding the stability of the joint. Significant controversy exists on what constitutes an abnormal study, but on the basis of the cumulative review of literature on this topic, more than 15 degrees of varus tilt and 5 mm of anterior translation are reasonably considered abnormal.
- MRI is valuable for determining whether the ligamentous structures have been injured and in what stage frame. Attenuation, wavy fibers, or disruption in the face of fluid accumulation suggests recent injury, whereas thickening or intrasubstance signal change gives rise to suspicion for a more remote injury. Infrequently, an absence of ligament tissue is noted, reflecting repeated injuries leading to degeneration of the complex.

**DIFFERENTIAL DIAGNOSIS**
- Acute
  - Lateral malleolar fracture
  - Fifth metatarsal fracture
  - Lateral talar process or “snowboarder’s” fracture
  - Peroneal tendon dislocation
  - Osteochondral defect
  - Superficial peroneal neurapraxia
- Chronic
  - Peroneal instability
  - Peroneal split tears
  - Subtalar instability
  - Osteochondral defect
  - Tibiotaral or subtalar arthritis

**NONOPERATIVE MANAGEMENT**
- Nonoperative management is the mainstay of treatment for both acute and chronic instabilities. Most patients will respond to conservative management; consequently, it is essential that appropriate conservative treatment be tried for all patients before surgery is suggested.
- Acute swelling and pain, whether from a new injury or recent repeat injury, is best managed with RICE. Immobilization in a walking cast or boot should be considered for anyone demonstrating a positive drawer or talar tilt after an acute episode or recurrence.
- Once the acute symptoms have subsided, functional strapping, taping, or bracing should be instituted along with an exercise regimen emphasizing peroneal strengthening, proprioceptive training, and Achilles tendon stretching.
- In the patient with a chronically unstable ankle, shoe wear modifications can be added as the individual returns to sports or activities. Orthoses with lateral heel and sole wedges or flare on the lateral sole of the shoe can promote a valgus moment and help avoid injury in the vulnerable patient. Reducing heel height and stiffening the sole of the shoe also can be helpful.
- Prophylactic brace wear or taping has been shown to have some benefit in prevention of injury. It also has a positive effect on reduction in severity of sprains if reinjury occurs while these measures are in effect.

**SURGICAL MANAGEMENT**
- Surgery rarely is indicated for an initial acute injury.
- Acute injuries failing appropriate conservative care, in our opinion, are best treated with an anatomic repair and reinforcement using a modified Brostrom procedure.
- Chronic instability failing appropriate conservative measures is more complex.
  - In a previously unoperated patient with MRI evidence of tissue remnants, an anatomic repair (modified Brostrom procedure) is very effective.
In patients who have repeated injuries and are left without evidence of ATFL or CFL remnant by MRI, or in patients who have previously undergone an attempt at surgical correction, reconstruction with free tendon graft is our preferred method.3,4,7,13,17

Preoperative Planning

- All imaging studies, including MRI, are reviewed, and any adjunctive pathology that may need to be addressed at the time of surgery, such as fragments of bone, OCLs, or peroneal tendon pathology, is noted.
- The joint (and the contralateral joint) is examined under anesthesia to determine the true nature of instability and also to gauge the effect of the repair (FIGS 1 AND 2).
- Graft choice also is an important preoperative consideration. An autogenous hamstring graft can be chosen and harvested in similar fashion to that of ACL graft harvests.3,4,7,13,17

Positioning

- The patient is placed in the supine position, typically with an ipsilateral hip roll to allow access to the posterolateral corner of the ankle.
- Arthroscopic examination is performed to identify any unseen intra-articular pathology.9 A thigh holder and soft tissue ankle joint distractor often are necessary for the initial portion of the procedure.

Approach

- One of two approaches may be chosen, depending on the degree of pathology that is to be addressed.
  - For ankle ligament reconstruction alone, an anterior curvilinear incision bordering the distal inferior tip of the fibula is preferred.
  - If it is necessary to address peroneal pathology or anterior osteophytes, a more extensile lateral malleolar incision, curving distally after the tip of the fibula, is useful (FIG 3).
- An oblique incision over the calcaneus usually can be added to either approach without great concern for increased wound morbidity.

TALAR TUNNEL PLACEMENT

- The lateral ankle is exposed by one of two incisions, as previously described.
- The origin sites of both ATFL and CFL are identified (TECH FIG 1A).
Dissection proceeds to expose the insertion of the ATFL on the lateral talus just at the corner of the lateral process as it blends from the body to the neck (TECH FIG 1B,C).

A 15- to 20-mm tunnel is drilled horizontally at this point with a 4.5- to 6-mm drill to accept the first limb of the tendon graft (TECH FIG 1D,E).

FIBULAR TUNNEL PLACEMENT

The fibula is exposed and a 4.5- to 6-mm tunnel is drilled from the insertion of the ATFL through the posterior fibular cortex (TECH FIG 2A–C).

A second tunnel is made more distally from the CFL insertion to a point about 3 to 4 mm distal to the previous exit point on the posterior fibular cortex. This allows for graft passage over a cortical bridge, and, in addition, the graft can be sutured to periosteum to prevent sliding (TECH FIGS 2D–F AND 3).

An alternative method uses a single tunnel from a point between the ATFL and CFL insertions, not violating the posterior cortex, that would accept a folded or doubled graft fixed with a single interference screw within this single tunnel.
C. Reaming of the first tunnel is done with a size-matched reamer based on screw size and graft diameter. D. A second guide pin is inserted from the CFL origin, aiming superior and posterior, but 3 to 4 mm below the previously created tunnel. Care must be taken to avoid tunnel blowout. E. Reaming the second fibular tunnel. F. A bony bridge is preserved between fibular tunnels.

TECH FIG 3 • Postoperative non-weight-bearing radiograph after reconstruction of lateral ligaments with allograft.

CALCANEAL TUNNEL PLACEMENT

A tunnel of similar size is then drilled bicortically through the lateral calcaneal wall at the level of the CFL insertion (TECH FIG 4).

TECH FIG 4 • A. The guide pin for the calcaneal tunnel is placed with the peroneal muscle group swept posterior. The tunnel is placed just inferior to the insertion point of the CFL. B. Verification of tunnel position. (continued)
TECH FIG 4 • (continued) C. Reaming the calcaneal tunnel. D. Note the relation between the calcaneal insertion of CFL and the reamed tunnel.

**GRAFT PASSAGE**

- The sutured tendon is inserted first into the talar tunnel and fixed with an interference screw (TECH FIGS 5 AND 6).
- It is then woven through the fibular tunnel from the ATFL insertion, through the more proximal posterior exit tunnel, back through the more inferior fibular hole and out the CFL origin. This gives the most anatomic origin and insertion points (TECH FIG 7 A–C).
- Lastly, the graft is passed through the calcaneal tunnel.
- The foot is held neutral to slightly everted, and a roll of towels is placed under the calf to allow a slight posterior drawer effect. The graft is held taut as it is brought through the skin on the medial side (TECH FIG 8).
- A second interference screw is placed in the calcaneus (TECH FIG 9).
- Range of motion and stability are assessed. If tension does not feel appropriate, the calcaneal screw can be removed, the graft retensioned, and the screw replaced.
- The tendon can receive a few sutures at the fibular tunnels to maintain tension of the individual limbs representing ATFL and CFL (TECH FIGS 10 A,B AND 11).
- If the surgeon prefers the single fibular tunnel technique, the interference screw is placed in the fibula with one limb of the graft directed toward the talus (ATFL) and one to the calcaneus (CFL). These are then similarly tensioned and fixed with individual interference screw fixation. This method is more exacting, as the limbs of tendon must be cut to exact length and fit into the proper depths of their respective tunnels.

TECH FIG 5 • A. All tunnel holes are reamed in advance of graft passage. B. Allograft tendon is mounted for insertion into the tibia tunnel with the first interference screw. C. The graft is inserted into the talar tunnel and fixed by interference screw.
TECH FIG 6 • Schematic of interference fit tenodesis screw.

TECH FIG 7 • A. The graft is pulled through the first fibular tunnel by a previously placed pull-through suture weave. B. The graft is then pulled through the second fibular tunnel and tension maintained. A stay suture can be placed in the graft and the fibular periosteum to maintain the ATFL tension. C. Graft pulled through both tunnels.

TECH FIG 8 • A Beath pin is used to pull the suture through the medial side of the tunnel and then out through the skin for final tensioning.

TECH FIG 9 • After appropriate positioning of the ankle and tensioning of the graft, the calcaneal interference screw is inserted.
WOUND CLOSURE

- Layered closure is performed, usually with a subcutaneous layer of 2-0 Vicryl or monocryl followed by skin sutures with 3-0 nylon.

CALCANEAL OSTEOTOMY

- If heel varus is present, a laterally based closing wedge calcaneal osteotomy may be performed.
- An oblique incision is carried out directly over the area of the planned osteotomy (usually about 2 cm posterior to any other concurrent incision).
- Periosteum is raised in each direction.
- A 1- to 1.5-cm width is marked on the lateral wall of the calcaneal tuberosity verifying that the osteotomy will not breach the bone tunnel.
- Saw cuts are made convergently to meet just before violating medial cortex.
- The wedge is removed and the osteotomy closed.
- Fixation can be achieved through either a large axially directed screw or staples.

PEARLS AND PITFALLS

| Graft handling | Great care must be taken in harvesting autograft so as to get enough length on the native gracilis. |
|               | If allograft is used, it must be ordered properly, with enough length to span the distance of the tendon weave (25 cm is plenty). |
|               | Once the allograft is thawed, it should be bathed in antibiotic solution until ready for use. |

| Tunnel placement | Avoid tunnel breakout. |
|                 | Consider making two separate tunnels on the posterior fibula divided by a cortical bridge between them. This will help resist the chance of graft migration on cancellous bone within the V-shaped tunnel. |
POSTOPERATIVE CARE

- Bulky, padded splinting in neutral positions are maintained for 10 to 14 days postoperatively.
- Once wounds are healed satisfactorily, the patient may begin protected weight bearing in a cast, as tolerated, for another 4 weeks.
- Gradual transition from cast to boot and introduction of range of motion begin 5 to 6 weeks after surgery.
- Rehabilitation is then instituted focusing on restoration of motion, Achilles stretching, proprioceptive training, and peroneal strengthening.
- Athletic activity usually is withheld for 4 to 6 months.

OUTCOMES

- Anatomic reconstruction for failed acute and chronic instability patterns continues to be our preferred method of lateral ankle ligament reconstruction. This has been shown in the literature to be extremely successful for return to function and reduction or elimination of symptoms in appropriately selected patients.
- When a patient has lost reliable lateral soft tissue structures by virtue of repetitive injury or previous failed procedures, an anatomic free graft lateral ligament reconstruction provides a very good alternative.
- Reconstruction using this method reconstitutes the ATFL and CFL, thus providing restoration of both ankle and subtalar stability.
- Anatomic reconstruction coupled with the preservation of native peroneal tendon function provides an optimum environment for return to function.
- Paterson et al13 showed 81% complete or substantial symptom resolution in 26 patients at 2-year follow-up by performing reconstruction of the ATFL alone. No significant differences were noted between operated and contralateral ankles with respect to range of motion or uniaxial balancing.
- Coughlin et al14 reported on 2-year follow-up in 28 patients. All patients were rated to have good or excellent outcomes with objective improvement in talar tilt measurements (13 degrees pre- vs 3 degrees postoperatively) and anterior drawer testing (on average, 10 mm pre- vs 5 mm postoperatively).
- Addition of tenodesis or interference screw fixation adds the advantage of being able to promote range of motion earlier with less concern for graft loosening.8,17

COMPLICATIONS

- Nerve injury
- Wound problems
- Infection
- Joint stiffness
- Deep venous thrombosis
- Subjective under- or over-tightening

REFERENCES

DEFINITION

- Lateral ligament injuries of the ankle are treated conservatively with good results in most cases. However, several factors may lead to chronic ankle instability with recurring ankle sprains:
  - Inadequate primary treatment
  - Incomplete healing of the ligaments
  - Repetitive trauma with deteriorated tissue quality
- Patients with chronic ankle instability can be divided into two groups:
  - Patients with sufficient tissue quality to perform a local repair
  - Patients with inadequate tissue quality for a local repair
- A Broström procedure for lateral ankle reconstruction is possible, as long as there is sufficient tissue.
- In patients with insufficient local tissue, an augmentation is needed to rebuild or reinforce the lateral ligaments. There are different options of tendon grafts, each with certain advantages and disadvantages:
  - Tenodesis
  - Semitendinosus tendon or gracilis tendon
  - Plantaris longus tendon

ANATOMY

- Laterally, the ankle is stabilized by the anterior (ATFL) and posterior (PTFL) fibulotalar ligament and the calcaneofibular ligament (CFL) (FIG 1).5
- Additional stability is provided by the bony structures. Especially in dorsal extension, the talus is locked between the medial and lateral malleolus.

PATHOGENESIS

- Torn lateral ligaments are the result of an ankle sprain. Depending on the severity of the sprain, one to three of the lateral ligaments are injured. A rupture of the ATFL is involved in most cases.
  - Anatomic classification
    - Grade I: ATFL sprain
    - Grade II: ATFL and CFL sprain
    - Grade III: ATFL, CFL, and PTFL sprain
  - AMA (American Medical Association) standard nomenclature system by severity
    - Grade I: Ligament stretched
    - Grade II: Ligament partially torn
    - Grade III: Ligament completely torn
  - Grading by clinical presentation symptoms
    - Mild sprain: minimal functional loss, no limp, minimal or no swelling, point tenderness, pain with reproduction of mechanism of injury
    - Moderate sprain: moderate functional loss, unable to toe rise or hop on injured ankle, limp when walking, localized swelling, point tenderness
    - Severe sprain: diffuse tenderness and swelling, crutches preferred by patient for ambulation
- With each ankle sprain, proprioception of the ankle joint is compromised.
- The risk for another ankle sprain increases after each injury. In an uninjured person, an ankle sprain will occur in 1:1,000,000 steps. This risk increases to 1:1000 steps after a severe ankle sprain.11
Chronic ankle instability is the combination of insufficient active and ligament stabilization mechanisms. There is some evidence that special anatomic variations increase the risk of developing chronic ankle instability after an injury. The healing of the ligaments can be compromised by synovial fluid between ligament and bone (Fig 2).

**Natural History**

Chronic instability is a risk factor for degenerative arthritis of the ankle joint. Valderrabano et al. have shown an increased prevalence of arthritis in patients with chronic ankle instability. Recurrent ankle sprains are likely in the future, but this is strongly dependent upon lifestyle and sports activities.

**Patient History and Physical Findings**

The patient history includes sustained injuries, frequency of ankle sprains, and causes of pain, as well as restrictions in daily living and sports. The degree of disability experienced by the patient depends upon the degree of instability and the physical demands. Many tests for ankle instability are strongly dependent on patient cooperation. If positive, however, they can be highly specific.

- The examiner should check the range of motion of the ankle joint with a stretched and a bent knee to rule out a shortening of the gastrocnemius or soleus muscle (or both). Restricted dorsiflexion with a stretched knee joint that is not found with a flexed knee is specific for a shortening of the gastrocnemius muscle (Silfverskiöld test).
- The inversion test is used to assess for a ruptured CFL.
- Medial ankle stability is checked in a plantarflexed position of the ankle to avoid a locking of the talus in the joint, which can mimic ligamentous stability. If positive, it is highly specific for a ruptured deltoid ligament.
- Insufficiency of the fibulocalcaneus ligament often affects the stability of the subtalar joint. The stability is checked in dorsiflexion of the ankle to lock the talus in the upper ankle joint. If positive, it is highly specific for a ruptured CFL in combination with subtalar instability.
- Effusion can be palpated ventral, but smaller amounts of fluid are difficult to detect.
- The ankle drawer test strains the ATFL and is highly specific for rupture of this ligament.

**Imaging and Other Diagnostic Studies**

- Plain radiographs should be obtained to evaluate potential bony pathology.
- Stress radiographs: The AP view shows the lateral opening of the joint. An anterior talar shift can be seen on the lateral stress view (Fig 3).
- MRI gives valuable information on the lateral ligaments and other pathology. In chronic instability scarring is often found. However, it is impossible to judge functional stability in an MRI. Frequent additional pathologies visible on MRI are tears of the peroneal tendons, osteochondral lesions, and bone edema.

**Differential Diagnosis**

- Articular injury (chondral or osteochondral fractures)
- Nerve injuries (sural, superficial peroneal, posterior tibial)
- Tendon injury (peroneal tendon tear or dislocation, tibialis posterior)
- Other ligamentous injuries (syndesmosis, subtalar, bifurcate, calcaneocuboid)
- Impingement (anterior osteophyte, anteroinferior tibiofibular ligament, scars)
- Unrelated pathology, masked by routine sprain (undetected rheumatoid condition, diabetic neuroarthropathy, tumor)

**Nonoperative Management**

The goals of nonoperative treatment are improving proprioception and strength. This can be achieved by physiotherapy and exercises.

- Shoe modifications include a lateral wedge or a flare.
- Means of external fixation are orthoses, braces, or taping. However, these methods are limited.
- Tape loses 30% of its stability after 200 steps. Skin problems are reported in up to 28%.
- Within the group of orthoses, semirigid, warped types provide the highest degree of stability.
- For many patients with symptomatic instability or pain, nonsurgical measures are not acceptable as a long-term solution. Usually these patients require a lateral ligament repair.

**Surgical Management**

In patients with no previous surgery and good tissue quality, the Broström procedure is a good option, reinserting the original ligaments in place. Especially with modern anchor techniques, this procedure has regained a great deal of popularity.
Broström showed in his work that even after a longer period of chronic instability, a reconstruction of the original ligaments is possible, providing sufficient stability and function of the ankle joint.4

- However, most patients with a history of recurrent inversion trauma do not have adequate tissue quality to perform a Broström procedure.5,10,16
- Insufficient local tissue can be augmented or replaced by a tendon graft.
- There are different options of tendon grafts, each with certain advantages and disadvantages.
  - Tenodesis: The major disadvantage of tenodesis procedures (eg, Evans or Watson-Jones) is that they often end up in persistent pain14,15 in combination with an increasing lack of stability over time.12,17
  - Autologous or homologous semitendinosus tendon or gracilis tendon can be used as graft. Although in general tolerated well, there is some risk of donor site morbidity after harvesting those tendons.1 If a homologous graft is used, there is a small risk of infection.
  - A local tendon that can easily be harvested with a minimum of donor site morbidity is the plantaris longus tendon.7

Preoperative Planning
- In about 3% of the patients, no plantaris longus tendon can be found or it is not long enough for transplantation. A strategy has to be discussed with the patient as to how to proceed in this case. An option is to change to a technique using another transplant (eg, the gracilis or semitendinosus tendon).

Examinations performed under anesthesia include range of motion of the ankle joint and the ankle stress tests to confirm the previous results, without an active stabilization of the ankle joint by the patient.

Additional intra-articular pathology is a common finding. In most cases, it is advisable to do an arthroscopy of the ankle joint before the final reconstruction.9

Positioning
- The patient is positioned supine with a sand sack under the injured side.
- The procedure is performed with a tourniquet (FIG 4).

Approach
- The plantaris longus tendon is harvested using a medial cut between the soleus and gastrocnemius muscle (FIG 5A).
- The procedure is performed with a standard lateral approach, straight, from the fibula directed to the base of the fifth metatarsal (FIG 5B).

FIG 4 • The patient is positioned supine with a sand sack under the injured side.

FIG 5 • A. Medial approach to harvest the plantaris longus tendon. B. Lateral approach with a 6- to 8-cm cut from the fibula toward the base of the fifth metatarsal.
HARVESTING OF PLANTARIS LONGUS

- Make a 3-cm cut at the medial aspect of the calf where the muscle has its highest volume (TECH FIG 1).
- When the muscular fascia is split, the soleus and the gastrocnemius can be bluntly separated.
- The tendon structure found medially between the two muscles is the plantaris longus tendon, which can easily be harvested with a tendon stripper. The plantaris longus tendon often is much easier to identify at this location than at the medial aspect of the calcaneus.
- If it is not possible to mobilize the plantaris longus tendon distally with the tendon stripper, the tendon can be cut through a small longitudinal incision (about 1 cm).
- Free the tendon from any muscular or fatty tissue.
- Reinforce one end of the tendon with a 0 nonabsorbable suture.
- Store the tendon in a moist compress.

TECH FIG 1 • Harvesting of the plantaris longus tendon. A. Medial incision between the soleus and gastrocnemius muscle. The fascia is directly under the fatty tissue. B. After a longitudinal incision of the fascia, the plantaris longus tendon is found right between the soleus and gastrocnemius muscle. C. The tendon is mobilized with a tendon stripper. D. The end of the plantaris longus is reinforced with a 0 nonabsorbable suture and stored in a moist compress.

ANATOMIC RECONSTRUCTION OF THE LATERAL LIGAMENTS WITH THE PLANTARIS LONGUS TENDON

- Expose the lateral ligaments and the distal fibula via a lateral approach.
- The tissue of the sinus tarsi can be reamed, especially if there is any evidence of inflammation.
- Inspect the quality of ligaments and local tissue.
- Drill two holes at the ventral aspect of the fibula with a diameter of 3.2 mm and a distance of 7 and 13 mm from the tip of the fibula (TECH FIG 2).
- Drill a third hole on the lateral side.
- With a small Weber forceps, connect the ventral holes and flatten the sharp edges surrounding them.
- Drill another two holes at the lateral aspect of the neck of the talus with a diameter of 3.2 mm and a distance of about 8 mm. The holes are located just at the border of the cartilage. In quite a few cases, remnants of the original ligaments can be found at this location.
- Again, create a canal with the Weber forceps.
- Retract the peroneal tendons, and have the assistant position the hindfoot in maximum pronation. Drill two holes and connect them, 13 mm from the joint line of the subtalar joint, similar to the technique mentioned before.
TECH FIG 2 • Anatomic reconstruction with the plantaris longus tendon. A. Drilling a hole at the anatomic insertion of the anterior talofibular ligament. B. Creating a canal between the drill holes with a Weber forceps. C. Routing the tendon through the drill holes. D. Any spare tissue of the tendon can be used for a further reinforcement. E–O. Routing the tendon through the drill holes. (continued)
Indications
- A complete history and physical examination should be performed.
- Care must be taken to address associated pathology.
- Graft augmentation is always indicated when the local tissue is insufficient.

Graft management
- A strategy has to be discussed with the patient if the plantaris longus tendon cannot be identified or is not suitable for transplantation.
- Extreme care should be taken when harvesting and preparing grafts.
- Graft should be secured at all times and handled carefully.

Fixation problems
- If the tendon does not go through the holes, try again to smooth the edges with a Weber forceps.
- If the plantaris longus tendon is too short for the whole routing, use a single layer, where the local tissue is best.
- Fracture of the bony bridges between the drill holes can be managed with anchors or with a transosseous suture of the graft.

PEARLS AND PITFALLS

POSTOPERATIVE CARE
- All patients are kept in a walking boot or walking cast for 2 weeks, and weight bearing is limited to 10 kg. After 2 weeks they get an ankle brace for another 4 weeks with full weight bearing in normal shoes. The ankle brace should be used day and night. In addition, physiotherapy with active stabilization is started in the third week. Cycling is normally possible after 4 to 6 weeks, running after 8 to 10 weeks. The patient should avoid contact sports, including soccer, for 3 to 5 months.

OUTCOMES
- Hintermann and Renggli\(^8\) published a series on this technique and found 78% excellent, 18% good, and 4% satisfying results in the AOFAS hindfoot score. Those good results match our experience.
- Especially athletic patients benefit from anatomic repair of the ligaments, which seems to produce more reliable and much better results than tenodesis.
COMPICATIONS
- Intraoperative graft mishandling
- Graft failure or rupture
- Fracture of the fibula
- Deep venous thrombosis
- Infection
- Loss of motion

REFERENCES
DEFINITION

- Deltoid ligament deficiency is present when both the deep and superficial components of the medial collateral ligament complex of the ankle are ruptured or are insufficient.
- Deltoid ligament deficiency may result from degenerative (eg, late-stage adult acquired flatfoot deformity), postoperative, 6–8 or traumatic or athletic 4 causes.

ANATOMY

- The deltoid ligament complex is a multiunit structure that provides support and restraint for the tibiotalar joint, subtalar joint, spring ligament, and talonavicular joint.
- There is wide agreement that the deltoid ligament complex is made up of both deep and superficial components.
- The deep portion of the complex originates from the intercollicular groove and posterior colliculus of the medial malleolus and inserts on the medial face of the talar body near the center of rotation of the tibiotalar joint. These short and stout fibers are intra-articular but extrasynovial. It is made up of anterior and posterior fascicles.
- There has not been agreement over the superficial components of the complex. In one of the more detailed anatomic studies Pankovich and Shivaram 5 described the superficial layer as being made up of the tibionavicular, tibiocalcaneal, and tibiotalar ligaments. These fibers represent a triangular array originating on the distal medial malleolus and extending in a fan shape to their respective insertions. The relative contribution of these components to both ankle and foot biomechanics is still a topic of investigation.

PATHOGENESIS

- The most common cause of deltoid ligament disruption is supination–external rotation ankle (SER) fractures. The most severe form of these fractures has either a medial malleolus fracture or a deltoid ligament rupture, in conjunction with a lateral malleolus fracture. The variant with an intact medial malleolus and disrupted medial collateral ligaments is termed SER IV-deltoid. This latter form is the most common form of deltoid ligament disruption.
- It has been very well established that deltoid reconstruction is not indicated for disruptions that occur in conjunction with ankle fractures. Reduction and fixation of the fracture component with re-establishment of the mortise morphology leads to healing of the deltoid ligament in the vast majority of those with these combined injuries. 9
- A smaller proportion of patients with deltoid ligament insufficiency will have developed this as a component of stage IV adult acquired flatfoot disorder (AAFD). 2
- Deltoid ligament insufficiency without concomitant ankle fractures resulting from the acute injury has been described but will not be discussed here. This chapter will concentrate on deltoid ligament insufficiency arising from degenerative causes.

NATURAL HISTORY

- As the posterior tibial tendon becomes deficient, the ability to bring the hindfoot into varus actively is lost.
- As the mechanical axis of the leg is shifted medially (relative to the foot) and the hindfoot deformity becomes more severe and eventually stiff, tension is progressively increased on the soft tissues of the medial ankle. The medial collateral ligament complex becomes unable to resist the loads placed upon it, with eventual insufficiency and lengthening. 7, 8
- Progression to stage IV AAFD occurs when the deltoid ligament becomes incompetent and the valgus force from the pre-existing hindfoot deformity causes the talus to tilt within the mortise.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Aspects of the history and physical examination of stage IV AAFD will be similar to those found in the earlier stages of this AAFD.
- There will be hindfoot valgus.
- Because of the chronic nature of posterior tibial tendon involvement, strength will be greatly diminished and likely absent because of rupture. The patient will neither be able to resist hindfoot eversion nor actively bring the forefoot across midline.
- Because of the decreased working length of the triceps surae resulting from chronic hindfoot valgus, there will be contracture of these muscles. A fixed hindfoot deformity may give a falsely optimistic impression of tibiotalar dorsiflexion. Re-establishment of ankle and hindfoot alignment without an appropriate lengthening of the heel cord will create or exacerbate an equinus deformity.
- There may be significant forefoot supination.
- Lateral pain may represent sinus tarsi or subfibular impingement, lateral ankle joint arthritis, or in severe cases distal fibular stress fracture.
- Pain in the sinus tarsi is frequently unrecognized or underestimated before palpation by the clinician.
- Callosity and pain below the talar head may be present if substantial dorsolateral peritalar subluxation has caused a prominence in the medial plantar midfoot.
- It is essential to determine whether the tibiotalar valgus deformity that is a hallmark of stage IV AAFD is rigid or reducible. This is further explained under surgical management.
- Clinical determination of the presence of valgus tibiotalar deformity is greatly enhanced with radiologic examination.
- The integrity of the lateral collateral ligament complex needs to be determined. A severe valgus deformity may lead to erosion and incompetence of these structures.
- The surgeon must also evaluate for the presence of ipsilateral knee valgus. If this is significant, consideration should be given to correcting the proximal deformity before the foot and
ankle surgery. Correction of the leg–ankle–foot axis without attention to knee deformity may not adequately relieve valgus stress through the reconstructed lower limb and result in recurrence of deformity.

- Methods for examining the deltoid ligament include:
  - Palpating the area inferior to the medial malleolus. Tenderness may represent incipient or recent deltoid rupture and may only be present early in stage IV disease.
  - Joint line palpation. The presence of valgus tilt indicates insufficiency of the deltoid ligament.
  - Weight-bearing AP ankle radiographs. Valgus tilt greater than 4 degrees indicates deltoid ligament insufficiency.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- The preferred radiologic views include the three-view weight-bearing series. The AP standing view will provide the most information. Patients with deltoid ligament insufficiency will demonstrate tibiotalar valgus tilting (FIG 1).
- Cross-sectional imaging is required only when plans are made for performing reconstruction using native peroneus longus tendon (discussed later). In this case MRI is used to confirm the integrity of the peroneus brevis before the longus is harvested.
- Selective intra-articular blocks often help the clinician localize the exact source of pain.

**DIFFERENTIAL DIAGNOSIS**

- Stage II or III AAFD
- Medial malleolus fracture nonunion
- Tibiotalar arthritis (with eccentric lateral joint erosion)
- Osteonecrosis of the talus with lateral collapse
- Distal tibial supramalleolar valgus malalignment (resulting from distal tibiofibular fracture or pilon fracture)
- Valgus malunion of pronation abduction-type ankle fracture with lateral plafond impaction or comminution

**NONOPERATIVE MANAGEMENT**

- In contrast to acute deltoid deficiency presenting in conjunction with an ankle fracture, we believe that nonoperative care has a very limited place in patients with chronic deltoid ligament insufficiency resulting from degenerative causes (eg, stage IV AAFD). All but patients with medical comorbidities contraindicating surgery should undergo surgical reconstruction.
- Conservative therapy may also be needed to relieve pain and temporize deformity while related orthopaedic conditions are corrected.
- Although halting the progression of the disease may be possible with conservative therapy, the deformities of stage IV cannot be corrected with bracing alone.

**SURGICAL MANAGEMENT**

- Healing of a chronically insufficient deltoid ligament to a functional structure does not occur in AAFD. Reefing and other surgical techniques attempting to incorporate this diseased tissue into the repair do not produce reliable results. Allograft or autograft reconstructions of the deltoid ligament give the best chances for success.
- Once a diagnosis of stage IV AAFD is made, an operative plan to correct all components of the deformity is needed.
- Evaluation of the ability to passively correct the tibiotalar deformity is central to whether the deltoid ligament may be reconstructed for salvage of the ankle joint.
- Tibiotalar valgus deformity that can be corrected passively may benefit from deltoid reconstruction in conjunction with bony and tendon work. Rigid tibiotalar deformity of stage IV AAFD should be reconstructed with tibiotalocalcaneal or pantalar fusion.
- It is essential to correct all components of the foot deformity along with deltoid reconstruction so that the forces that resulted in the native deltoid ligament insufficiency are neutralized and do not cause failure of the reconstructed ligament.
- If lateral collateral ligament insufficiency is found on examination, the surgical plan should include reconstruction of these structures.

**Preoperative Planning**

- Imaging studies are reviewed.
- Examination under anesthesia (EUA) should be accomplished before positioning the patient. Intraoperative fluoroscopy may be very useful during the EUA.
- It is also important to re-evaluate the lateral collateral ligaments during the EUA.
- All foot reconstructive procedures needed to restore plantigrade alignment should be done at the same surgical sitting if possible. These procedures should be done immediately before deltoid ligament reconstruction.

**Positioning**

- The patient should be positioned supine on the operating table.
- Retrograde application of an Esmarch bandage followed by inflation of an upper thigh tourniquet may be used to create a relatively bloodless field.
- Access to the medial ankle may be improved by placing a soft support under the contralateral hip.
The surgeon should ensure that the lower extremity is prepared and draped to a level above the knee so that limb–foot alignment may be evaluated intraoperatively.

**Approach**

- The approach for the minimally invasive deltoid ligament reconstruction (MIDLR) requires a longitudinal incision from the tip of the medial malleolus to just inferior to the prominence of the sustentaculum tali. This incision may need to be carried through incompetent fibers of the superficial deltoid ligament (FIG 2).
- The approach for the peroneal grafting method uses a straight longitudinal incision over the peroneal tendons to harvest the peroneus longus tendon and then a medial incision through which the tendon is brought before threading it through and securing it to the tibia. The patient should be initially positioned with a bump under the ipsilateral hip, which may be removed when increased access to the medial ankle is required.

**MINIMALLY INVASIVE DELTOID LIGAMENT RECONSTRUCTION**

- This technique\(^1\)\(^2\) reconstructs components of both the superficial and deep layers of the deltoid ligament without sacrificing any host tissue for graft.

**Forked Allograft Preparation**

- Cadaveric allograft from the posterior tibial tendon or the peroneal tendon provides a graft of good size. Larger grafts (eg, Achilles tendon) may be used but should be cut to appropriate thickness. Do not use grafts smaller than the posterior tibial tendon or peroneals.
- The graft should be about 20 cm in length and 6 to 7 mm in diameter. Split one end longitudinally, leaving about 5 cm of the opposite end unsplit.
- Place Krackow stitches of no. 00 nonabsorbable woven suture in all three limbs of the tendon (TECH FIG 1).
- After preparation, wrap the graft in moistened gauze and set it aside.

**Tibial Limb Placement**

- Above the medial malleolus, in the midcoronal plane, choose a level about 1 cm above the plafond at which the tibial limb of the graft will be anchored. This is approximated well by the level of the distal tibial physeal scar. Intraoperative fluoroscopy is very helpful in locating a proper site. The saphenous vein and nerve should be anterior to the entry site chosen.
- At the level for insertion, make a 1-cm longitudinal incision down to medial tibial cortex. Advance a guidewire from medial to lateral parallel to the plafond (TECH FIG 2). Make a 6.0-mm blind tunnel over the guidewire for a distance of 25 mm. Remove the guidewire.
- Secure the tibial limb (unsplit end) of the forked graft in the blind tibial tunnel using a 6.25-mm soft tissue interference screw (TECH FIG 3). Use manual testing to ensure that the graft is adequately anchored in the tunnel.

**Talar Limb Placement**

- The path of the tunnel through the talus starts at the medial center of tibiotalar rotation. This is most easily approximated by drilling the insertion point for the native deep deltoid ligament. The lateral exit of the tunnel is located at the lateral junction of the talar dome and neck. This lateral exit point is located by palpation. If this junction cannot be palpated, a small incision may need to be made to locate the lateral neck body junction. Advance a guidewire for a cannulated 5.0-mm drill along this axis. Confirm the position of the guidewire with AP and lateral fluoroscopic views.
- Drill a 5.0-mm tunnel over the guidewire. Pass one end of the sutured tendon through the tunnel from medial to lateral using a suture passer. Place appropriate tension on the graft and place a 5.0-mm soft tissue interference screw in the medial aspect of the tunnel to secure the graft. Advance the interference screw so that it is countersunk 1 to 2 mm into the tunnel.
Calcanéal Limb Placement

- Using palpation, locate the medial border of the sustentaculum tali. Once it is found, carefully dissect the posterior tibial tendon sheath away from the bone and retract it inferiorly. Insert the guidewire for the cannulated drill along an axis from the midportion of the sustentaculum tali to a point about 1 cm superior to the peroneal tubercle on the lateral side of the calcaneus (TECH FIG 4A). Placing the guidewire in this location allows for centralization in the sustentaculum and minimizes the chances of breaching the subtalar joint. Check the position of the guidewire using fluoroscopy.
- Create a 5.0-mm tunnel over this guidewire.
- Pass the free end of the remaining limb of the tendon graft through the sustentacular tunnel and out the skin overlying the lateral calcaneus. A small slit may need to be made to allow the graft to be pulled fully through. Perform tensioning and tibiotalar joint position manually and check it under fluoroscopy.
- When appropriate tension is achieved, insert a 5.0-mm interference screw from medial to lateral into the sustentacular tunnel.
- The appearance of the final construct in situ is illustrated in TECH FIG 4B. An illustration of the position of the graft after insertion and fixation is shown in TECH FIG 4C.
- Close the wounds in a layered fashion.
Chapter 103  DELTOID LIGAMENT RECONSTRUCTION

TECH FIG 4 • Calcaneal limb placement. A. Starting point for the calcaneal limb with guidewire advanced so as to avoid the subtalar joint and exit out the lateral calcaneal cortex. B. Completed minimally invasive deltoid ligament reconstruction in situ from the medial aspect. C. Completed minimally invasive deltoid ligament reconstruction from the medial aspect and from a posteroanterior view.

PERONEUS LONGUS GRAFT TENDON HARVESTING

- Harvest the peroneus longus tendon through a lateral incision that extends from the fourth metatarsal base to about midway up the calf.³
- Tenodese the proximal stump of the transected peroneus longus tendon to the peroneus brevis.
- After securing a Krackow locking suture to the free end of the peroneus longus tendon, wrap it in a piece of moist gauze.

Talar Tunnel Construction

- Make a medial incision centered over the medial malleolus, extending distally over the fibers of the superficial deltoid.
- Divide the fibers of the attenuated deltoid ligament, exposing the medial aspect of the talus.
- Pass an intraosseous guidewire from the lateral talar neck-body junction to the estimated center of rotation on the medial aspect of the talus inferior to the tip of the medial malleolus.
- Verify guidewire position fluoroscopically and clinically by dorsiflexing and plantarflexing the ankle to determine if the center of rotation has been localized.
- Create a tunnel using a cannulated reamer about 4 to 5 mm in diameter.

Tibial Tunnel Construction

- Create a second bony tunnel from the tip of the medial malleolus to a point in the lateral distal tibia. The exit point is about 5 to 6 cm proximal to the tibial plafond and anterior to the fibula. We recommend saving the shavings from the reamer to be used later as bone graft.

Graft Passage and Fixation

- Pass the tendon through the tibial tunnel from distal-medial to proximal-lateral.
- Tension the tendon first at the medial talar tunnel and then at the lateral tibial exit site, with correction of valgus talar tilt.
- Secure the tendon to the lateral tibia under maximal tension with a soft tissue washer or staple. Pack bone graft obtained from reaming in the bony tunnels. A schematic of the final construct is depicted in TECH FIG 5.
- Close the wounds.
POSTOPERATIVE CARE
- In the immediate period after tibiotalar joint-sparing reconstruction of stage IV posterior tibial tendon rupture, a plaster splint is applied in neutral position. Physiotherapy starts after the incisions have healed, usually about 2 weeks postoperatively. Therapy consists of passive and active mobilization of the ankle joint as well as intrinsic muscle exercises. Weight bearing is started progressively but is not full until 12 weeks postoperatively. Gait training is instituted as needed after weight bearing is commenced.

OUTCOMES
- There are no long-term results for these methods because both were recently developed. Studies on outcomes are made difficult by the small number of patients who present with stage IV AAFD. Ongoing studies are evaluating the ability to maintain the correction and stability obtained with these methods.
- Two-year clinical results for the forked graft method are just becoming available at the time of the writing of this chapter. Initial short-term results are promising, with maintenance of tibiotalar joint motion and stability in those who have undergone the procedure.
- Short-term follow-up data are available for the peroneus longus graft method. In the five patients evaluated after undergoing this procedure, four had tibiotalar valgus correction to 4 degrees or less that was maintained 2 years after the procedure.
COMPLICATIONS

- Breaching tibiotalar joint with misplaced tibial or talar tunnel
- Breaching subtalar joint with misplaced calcaneal tunnel (forked graft method)
- Damage to superficial peroneal nerve
- Damage to deep peroneal nerve (peroneal graft method)
- Damage to the sural nerve on calcaneal limb pull-through (forked graft method)
- Infection
- Graft failure or rupture

REFERENCES

DEFINITION

- Pronation injuries of the ankle joint complex may result in a partial or complete disruption of the superficial anterior bundles of the deltoid ligament.
- Chronic medial ankle instability may cause a secondary posterior tibial dysfunction over time, as the tendon may become elongated, ruptured, or both.
- Medial ankle instability may also be the result of a posterior tibial dysfunction with chronic overload of the deltoid ligaments and consecutive step-by-step disruption.
- Medial ankle instability must be suspected if the patient complains of “giving way,” especially medially, when walking on even ground, downhill, or downstairs, pain at the anteromedial aspect of the ankle, and sometimes pain on the lateral ankle, especially during dorsiflexion of the foot.

ANATOMY

- The deltoid ligament is a multibanded complex with superficial and deep components.
- It may be wise to differentiate the superficial and deep portions of the deltoid complex with respect to the joints they are spanning. The superficial ligaments cross two (the ankle and the subtalar joints) and the deep ligaments cross one joint (only the ankle joint), although differentiation is not always absolutely clear.10
- The three superficial and more anterior bands are the tibionavicular, tibiospring, and tibiocalcaneal ligaments; the three deep bands are the anterior, intermediate, and posterior tibiotalar ligaments (Fig 1).1
- As the tibioligamentous portion of the superficial deltoid has a broad insertion on the “spring ligament,” this ligament complex may interplay with the deltoid ligament in the stabilization of the medial ankle joint, and thus functionally not be separated from it (Fig 1).3

PATHOGENESIS

- Acute injuries to the medial ankle ligaments can occur during running downstairs, landing on an uneven surface, and dancing while the body is simultaneously rotated in the opposite direction. A key feature of the history is whether the patient has sustained a pronation (eversion) trauma—for instance, an outward rotation of the foot during simultaneous inward rotation of the tibia.
- Complete deltoid ligament ruptures are sometimes seen in association with lateral malleolar fractures, or in specific bimalleolar fractures.
- Chronic deltoid ligament insufficiency can be seen in a number of conditions, including posterior tibial tendon disorder, traumatic and sports-related deltoid disruptions, as well as valgus talar tilting in patients with previous triple arthrodesis or total ankle arthroplasty.

NATURAL HISTORY

- There is evidence that the medial ankle ligaments are more often injured than generally believed.4,5,7,8
- Several structures contribute to the stabilization of the medial ankle, and in the case of injury they are not involved in a uniform way. Medial ankle instability is thus not a single entity, and this has most important consequences for treatment.
- The findings of an exploratory, prospective study on 51 patients (53 ankles) have supported our belief that medial ankle instability without posterior tibial tendon dysfunction does exist as an entity.7 It is, however, not clear yet whether, or to what extent, such a medial ankle instability may cause a secondary posterior tibial dysfunction over time, as the tendon may become elongated, ruptured, or both.
- What is clear from the literature is that a coexisting pronation deformity of the foot will lead to further deterioration over time, as the medial ankle ligaments are chronically overstretched.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The diagnosis of medial ankle instability is made on the basis of the history and the results of physical examination, including special maneuvers, and plain roentgenography.
- Medial instability is suspected if the patient complains of “giving way,” especially medially, when walking on even ground, downhill, or downstairs, pain at the anteromedial aspect of the ankle, and sometimes pain on the lateral ankle, especially during dorsiflexion of the foot.
- A history of chronic instability, manifested by recurrent injuries with pain, tenderness, and sometimes bruising over the medial and lateral ligaments, is considered to indicate combined medial and lateral instability that is thought to result in rotational instability of the talus in the ankle mortise.
- Acute injuries may present with tenderness and hematoma at the side of the deltoid ligament.

FIG 1 • Anatomic situs of medial ankle. The superficial and deep deltoid consists of three distinct bundles each.
Physical examination methods for chronic medial ankle instability should include:
- Standing test. Inspect for malalignment, deformity, asymmetry, and swelling. Asymmetric planus and pronation deformity of the affected foot may indicate medial ankle instability: distinct, moderate, important.
- Palpation of anteromedial ankle. Pain in the medial gutter is typically provoked by palpation of the anterior border of the medial malleolus. It is the result of underlying synovitis due to chronic shifting of the talus within the ankle mortise.
- Anterior drawer test is a highly sensitive test for medial ankle instability.

A complete examination of the hindfoot should also include evaluating associated injuries and ruling out other possible causes. These include, among others:
- Fracture of medial malleolus: After an acute injury, radiographic analysis must be performed routinely to exclude a fracture of the medial malleolus (e.g., bony avulsion of the deltoid ligament) or fibula fracture with or without syndesmotic disruption.
- Loss of posterior tibial function after partial or complete rupture: The patient cannot correct the deformity while standing or create supination power to the foot.
- Talonavicular coalition: The subtalar joint is not mobile; so there is no varusization of the heel while going into the tiptoe position.
- Neurologic disorder: There is partial or complete palsy of one or more muscles due to deficient neurologic control.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Acute injury: Plain radiographs, including AP and lateral views, should be obtained to rule out bony avulsion fractures or associated injuries.
- Chronic injury: Plain weight-bearing radiographs, including AP views of the foot and ankle and a lateral view of the foot, should be obtained to rule out old bony avulsion fractures, secondary deformity of the foot (e.g., valgus malalignment of the heel, dislocation at the talonavicular joint), and tibiotalar alignment (e.g., medial gapping of the joint due to incompetence of the deltoid ligament) (FIG 2).

**DIFFERENTIAL DIAGNOSIS**
- Bony avulsion fracture of the medial malleolus (with or without fracture of the fibula or syndesmotic disruption)
- Fixed flatfoot deformity (e.g., acquired flatfoot deformity in adults after posterior tibial dysfunction)
- Osteochondral injury
- Talocalcaneal coalition

**NONOPERATIVE MANAGEMENT**
- Although nonoperative management is controversial, patients with less instability, particularly those who have less of a “giving-way” feeling, and those who are less involved with high-level pronation sports activities, may be treated nonoperatively.
- Nonoperative treatment consists of three components:
  - Medial foot arch supports
  - Physiotherapy for strengthening the invertor muscles
  - A neuromuscular rehabilitation program

**SURGICAL MANAGEMENT**

**Preoperative Planning**
- All imaging studies are reviewed.
- Plain films should be reviewed for fractures, cartilage lesions, hindfoot and midfoot malalignment, and the presence of any hardware (from previous procedures) or foreign bodies.
- Associated fractures, cartilage lesions, foot malalignment, and tendon disruption should be addressed concurrently.
- Examination under anesthesia should be performed to compare with the contralateral ankle.

**Positioning**
- The patient is in the supine position with the feet at the edge of the table.
- A commercially available knee holder is used to support the distal femur and to place the foot into a hanging position (FIG 4).
- This allows the surgeon to move the foot freely while arthroscopy is done before open reconstruction.
- After the arthroscopy, the knee holder is removed, leaving the foot on the table.
Approach
- An anteromedial approach is used for ankle arthroscopy.  
- A gently curved incision of 3 to 5 cm is made, starting 1 cm cranially of the tip of the medial malleolus and running toward the medial aspect of the navicular bone.

ANKLE ARTHROSCOPY
- Arthroscopy is done to visualize the internal structures and to assess medial and lateral ankle stability.  
- After visual evaluation of the ligaments, test lateral and medial ligament stability by applying gentle varus, valgus, and anterior pull stress to the ankle joint under arthroscopic control.  
- Ligament lesions are graded as distended if the ligament is thinned or elongated, and as ruptured if continuity is lost. Because most ligament tears are located on the proximal insertion, this is usually best seen by a completely free insertion area of the ligament on the malleoli (TECH FIG 1).

- As the foot is everted and pronated, the deltoid ligament is considered incompetent when it is tensioned, but obviously no strong medial buttress is created with this maneuver (TECH FIG 2). An excessive lifting away of the talus from the medial malleolus by pulling the foot anteriorly is also considered an indicator of stretching of this ligament.

- If there is additional instability of the lateral ankle ligaments, as found on the clinical examination and confirmed by arthroscopy, a lateral approach to the ankle is also performed to explore the anterior talofibular and calcaneofibular ligaments.

- Lateral instability is considered to be present when talar tilting occurs by supination stress of the foot.
- As evaluated for both the medial and lateral side, the ankle joint is graded as stable when there is some translocation of the talus, but not enough to open the tibiotalar joint by more than 2 mm (as measured by the 2-mm hook) and not enough to introduce the 5-mm arthroscope into the tibiotalar space; as moderately unstable when the talus moves to some extent out of the ankle mortise, allowing introduction of the 5-mm arthroscope into the tibiotalar space, but not enough to open the tibiotalar joint by more than 5 mm; and as severely unstable when the talus moves easily out of the ankle mortise, Typically allowing free insight into the posterior aspect of the ankle joint without significant pulling stress on the heel.  

TECH FIG 1 • Avulsion of anterior superficial layers from medial malleolus. Arthroscopy typically reveals a completely free insertion area of the ligament on the medial malleolus.

TECH FIG 2 • Incompetent deltoid ligament. A. As the foot is everted and pronated, the deltoid ligament is considered incompetent when it is tensioned, but obviously no strong medial buttress is created with this maneuver. B. An excessive lifting away of the talus from the medial malleolus by pulling the foot anteriorly is also considered an indicator of stretching of this ligament.
MEDIAL ANKLE LIGAMENT RECONSTRUCTION

- Complete acute rupture: Because the rupture is mostly situated proximally of the deltoid ligament (TECH FIG 3), reattachment to the medial malleolus is achieved by interosseous sutures; a bony anchor can also be used for refixation to the bone.8
- Chronic ruptures of the superficial deltoid ligament are classified as shown in Table 1.7,8
- Chronic rupture of the superficial deltoid ligament (type I lesion): Expose the anterior border of the medial malleolus by making a short longitudinal incision between the tibionavicular and tibiospring ligaments, where there is usually a small fibrous septum without adherent connective fibers between the two ligaments (TECH FIG 4A). After roughening the medial aspect of the medial malleolus, place an anchor (Panalock®) 6 mm above the tip of the malleolus (TECH FIG 4B); this serves for refixation of

**TECH FIG 3** - Acute deltoid rupture. This 28-year-old soccer player sustained a valgus trauma, causing an acute “giving way” of the foot. A. MR imaging reveals complete disruption of the ligament close to its proximal insertion to the medial malleolus. B. Surgical exploration confirms complete disruption of the deltoid ligament, although the posterior tibial tendon remained intact.

**Table 1** Classification of Chronic Superficial Lesions of Deltoid Ligament

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Location of Tear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I lesion</td>
<td>Proximal tear/avulsion of deltoid ligament</td>
</tr>
<tr>
<td>Type II lesion</td>
<td>Intermediate tear of deltoid ligament</td>
</tr>
<tr>
<td>Type III lesion</td>
<td>Distal tear/avulsion of deltoid and spring ligaments</td>
</tr>
</tbody>
</table>
Part 8 FOOT AND ANKLE • Section V SPORTS-RELATED PROCEDURES FOR ANKLE AND HINDFOOT

The second superior anchor on the medial malleolus serves for reattachment of the tibionavicular ligament (TECH FIG 5G). Use additional no. 0 resorbable sutures to further stabilize the reconstructed tibionavicular and tibiospring ligaments (TECH FIG 5H,I).

- Chronic rupture of the superficial deltoid ligament (type II lesion): If necessary, débride the tear (TECH FIG 6A). Then place two nonresorbable sutures in the spring ligament (TECH FIG 6B). If the tibionavicular ligament is completely detached from its insertion, place an anchor (Panalock®) at the superior edge of the navicular tuberosity. After tightening the sutures (TECH FIG 6C,D), use additional no. 0 resorbable sutures to further stabilize the reconstructed tibionavicular and spring ligaments.

- Chronic rupture of the deep deltoid ligament: Because this condition usually includes an extended tear of the superficial anterior bundles of the deltoid ligament, any

 TECH FIG 4 • Chronic rupture of the superficial deltoid ligament (type I lesion). A. The rupture is located between the tibionavicular and tibiospring ligaments, where a small fibrous septum without adherent connective fibers between the two ligaments is usually present. B. After roughening the medial aspect of the medial malleolus, an anchor (Panalock®) is placed 6 mm above the tip of the malleolus. C. It serves for refixation of the tibionavicular and tibiospring ligaments to the medial malleolus, and to shorten both ligaments. D. Final reconstruction after some additional no. 0 resorbable sutures. E. Principle of reconstruction.

 TECH FIG 5 • Chronic rupture of the superficial deltoid ligament (type II lesion). A. The superficial deltoid ligament is scarred and incompetent. B. Two anchors (Panalock®) are placed 6 and 9 mm above the tip of the medial malleolus. (continued)
**TECH FIG 5 (continued)**

C. Another anchor (Panalock®) is placed into the tuberosity of the navicular bone.

D. The deep flap is reattached to the medial malleolus using the distal anchor suture.

E. The superficial flap is reattached to the tuberosity of the navicular bone using the anchor suture.

F. A strong and well-tightened ligament reconstruction is thus obtained.

G. The second superior anchor on the medial malleolus serves for reattachment of the tibionavicular ligament.

H. Additional no. 0 resorbable sutures are used to further stabilize the reconstructed tibionavicular and tibiospring ligaments.

I. Principle of reconstruction.

**TECH FIG 6**

Chronic rupture of the superficial deltoid ligament (type III lesion).

A. The distal tear in the spring ligament is exposed and débrided.

B. Two nonresorbable sutures are placed in the spring ligament.

C. The sutures are tightened.

D. Principles of reconstruction.
TECH FIG 7 • Chronic rupture of the deep deltoid ligament. After the posterior tibial tendon has been split into two bundles, both bundles are inserted into a drill hole at the tip of the medial malleolus (arrow). One bundle is conducted through the anterior tunnel at the anterior aspect of the medial malleolus, and the posterior bundle is conducted through the posterior tunnel at the posterior aspect of the medial malleolus.

TECH FIG 8 • Chronic rupture of the deep deltoid ligament. A. Exposure of the posterior tibial tendon reveals a tear. B. Exposure of the deltoid ligament reveals an extended disruption and incompetence of the superficial and deep layers. C. A bone–tendon–bone transplant is fixed by screws distally into the navicular bone and, after tightening, proximally to the posterior aspect of the medial malleolus. D. Multiple nonabsorbable and absorbable sutures are used for further reconstruction of the ligament.

Reconstructive surgery should attempt to address the whole deltoid ligament. The posterior tibial tendon can be used as a graft for augmentation of the reconstructed deltoid ligament by passing it through a drill hole from the tip of the medial malleolus to the medial aspect of the distal tibia (TECH FIG 7). This technique was found to be disappointing, however, as it does not sufficiently reinforce the deep tibiotalar ligaments (Hintermann, unpublished data). Most recently, the use of a bone–tendon–bone transplant has been proposed for reconstruction of the deltoid ligament (TECH FIG 8). In this in vitro study, two limbs were created on a distal transplant; one was fixed to the medial aspect of the talus and the other to the sustentaculum tali. The proximal end was fixed to the distal tibia, the medial malleolus, or the lateral tibia. Less than 2.0 degrees of angulation was found while applying valgus stress of 5 daN for all fixation methods. However, the authors advised against fixation of the proximal limb in the medial malleolus.
LATERAL ANKLE LIGAMENT RECONSTRUCTION

- About 75% of patients with chronic medial ankle instability were found to have an associated avulsion of the anterior talofibular ligament that resulted in a complex rotational instability of the talus within the ankle mortise.7
- If the condition of the anterior talofibular ligament and the calcaneofibular ligament allows an adequate primary repair, these ligaments can be reconstructed by shortening and reinsertion (TECH FIG 9).
- When no substantial ligamentous material is present, augmentation with a free plantaris tendon graft is performed (TECH FIG 10).12

Posterior Tibial Débridement and Reconstruction

- Inspect the posterior tibial tendon meticulously during surgery, especially in the case of a type II or type III lesion of the anterior deltoid ligament.
- If there is degeneration of the tendon, débride the tendon.
- If there is elongation of the tendon, consider shortening the tendon.
- If there is an accessory bone (os tibiale externum), consider reattaching the bone with the tendon insertion; the posterior tibial tendon can also be tightened if the bone is reattached more distally to the navicular bone (TECH FIG 11).9

Lateral Lengthening Calcaneal Osteotomy

- This procedure is considered in the case of a pre-existing valgus and pronation deformity of the foot (eg, when a valgus and pronation deformity is also present on the contralateral, asymptomatic foot) or in the case of a severe attenuation or defect of the tibionavicular, tibiospring, or spring ligaments.
- A calcaneal osteotomy is performed along and parallel to the posterior facet of the subtalar joint, from lateral to medial, preserving the medial cortex intact (TECH FIG 12A–D).6
- As the osteotomy is widened, the pronation deformity of the foot is seen to disappear (TECH FIG 12E).
- Fashion a tricortical graft from the iliac crest to the length required and place it into the osteotomy site (TECH FIG F–H).

TECH FIG 9 • Primary anatomic repair of lateral ankle ligaments. A. Exposure of lateral ligaments and arthrotomy of ankle and subtalar joints that are débrided. The scarred anterior portion of the lateral ligaments is widely disconnected from the anterior border of the fibula. B. The anterior border of the fibula is roughened. C. An anchor or transosseous sutures are used to reattach the avulsed lateral ligaments (eg, the anterior tibiofibular and calcaneofibular ligaments at their common insertion 8 to 10 mm above the tip of lateral malleolus). D. A strong and well-tightened ligament reconstruction is thus obtained.
TECH FIG 11 • Unstable os tibiale externum. A. An unstable accessory bone (os tibiale externum) is found to weaken the pull of posterior tibial tendon. B. The accessory bone is mobilized and 3 to 5 mm of bone is removed on both sides of the pseudarthrosis. C. This allows for reattachment of the accessory bone more distally to the navicular bone, using screws and nonabsorbable sutures.

TECH FIG 10 • Reconstruction of lateral ankle ligaments with a free plantaris tendon graft. A. The remaining scarred ligaments do not allow primary repair of lateral ankle ligaments. B. A free plantaris tendon graft is used for reconstruction of the anterior talofibular and the calcaneofibular ligaments. C. A strong and well-tightened ligament reconstruction is thus obtained.

Double Arthrodesis
- This procedure is considered when the medial ankle instability is so excessive that a valgus tilt of the talus within the mortise is seen on a standard AP view of the ankle while the foot is loaded (Fig 2).11
- Be sure to fully correct the whole deformity (eg, valgus malalignment of the heel, and the peritalar dislocation of talus).
- Expose the talonavicular joint from medially through the same incision (TECH FIG 13A,B).
- Use a distraction spreader (Hintermann spreader) to open the joint; this allows for cartilage removal and debridement (TECH FIG 13C,D).
- Expose the subtalar joint from medially through the same incision.
TECH FIG 12 • Calcaneal lengthening osteotomy. **A.** The neck of the calcaneus is exposed using a lateral incision. **B.** The osteotomy is marked by a cisel to be directed through the sinus tarsi along the anterior border of the posterior facet of the subtalar joint. Two Kirschner wires for the Hintermann retractor are inserted. **C.** Osteotomy is performed using a saw. **D.** The osteotomy is opened using the retractor. **E.** As the osteotomy is widened, the pronation deformity of the foot is seen to disappear. **F.** A tricortical graft from the iliac crest or an allograft is fashioned to the length required and placed into the osteotomy site. **G.** The border of the inserted graft is smoothed. **H.** A regular bony contour on the bottom of the sinus tarsi is thus obtained.
Use the distraction spreader to open the joint; this allows for cartilage removal and débridement (TECH FIG E–G).
Correct the deformity first by reducing the former talonavicular joint, making sure to correct the frontal plane position of the navicular (eg, to achieve full correction of any forefoot supination deformity) (TECH FIG 13H–L).

Stable fixation is achieved by triple screw fixation at the talonavicular and double screw fixation at the subtalar joint (TECH FIG 13M–O).

Wound Closure
- Close the wounds in layers.
- Close the subcutaneous tissue and skin in standard fashion.

**TECH FIG 13** • Double arthrodesis. 
- A. Skin incision just above the posterior tibial tendon; the surgeon should stop proximally at a perpendicular line through the medial malleolus (eg, so as not to damage the deep bundles of the deltoid ligament). 
- B. Incision of skin and dissection of the medial ankle ligaments by sharp incision along the spring ligament. 
- C. The talonavicular joint is exposed first. The Hintermann retractor serves to expose the joint. 
- D. Cartilage is removed and the joint is cleaned to subchondral bone. 
- E. A third Kirschner wire is inserted into the sustentaculum tali of the calcaneus. This allows the surgeon to open the subtalar joint using the Hintermann distractor. 
- F. The cartilage is removed. 
- G. Final inspection shows complete débridement of the subtalar joint, including the sinus tarsi. (continued)
TECH FIG 13  * (continued)  

**H.** The Kirschner wires in the navicular and talar bones are kept in place and serve to reduce the talonavicular joint properly.  

**I.** Frontal view showing the frontal realignment at the talonavicular joint using both Kirschner wires as joysticks.  

**J.** A first guiding Kirschner wire is inserted through the tuberosity of the navicular into the talus. Afterwards, two other guidewires will be used to properly stabilize the talonavicular joint in the frontal plane.  

**K.** After inserting two additional guidewires from the bottom through the subtalar joint, fluoroscopy is used to insert the cannulated screws (QUIX, Newdeal/Integra).  

**L.** The deltoid ligament is reattached to the spring ligament using nonabsorbable sutures. The foot looks properly positioned at the end of surgery. Note the short incision that is used for this procedure. At 2 months, weight-bearing radiographs are obtained.  

**M.** Lateral view.  

**N.** AP view of the ankle.  

**O.** AP view of the foot.
### POSTOPERATIVE CARE

- The foot is protected by a plaster cast for 6 weeks, and full weight bearing is allowed as soon as pain-free loading is possible. In the case of double arthrodesis, initial plaster immobilization for 8 weeks is recommended.
- The rehabilitation program starts after cast removal. It includes passive and active mobilization of the ankle joint, training of the muscular strength, and protection with a walker or stabilizing shoe when walking.
- A walker or stabilizing shoe can be used for 4 to 6 weeks after cast removal, depending on regained muscular balance of the hindfoot.
- We recommend continued use for walks on uneven ground, for high-risk sports activities, and for professional work outside.

### OUTCOMES

- With appropriate surgical technique, success rates for ligament reconstruction of the medial ankle are on the order of 85% to 90% in terms of return to former sports and professional activities.\(^7\)
- As associated malalignment has been addressed more aggressively in the last years, the success rate has further increased.
- The most troubling problem remains a chronic incompetence of the deep deltoid ligament, which results in valgus tilt of the talus while loading the foot. Despite the use of tendon augmentation, most attempts at isolated ligament reconstruction have failed; the main step is probably a double arthrodesis in getting a stable and well-aligned hindfoot. An alternative may be a tibiocalcaneal arthrodesis.

### COMPLICATIONS

- Deficient stability because of inappropriate ligament reconstruction
- Recurrent instability because valgus deformity was not addressed
- Suture granuloma at the anterior margin of the medial malleolus when using nonresorbable sutures and placing the suture knot onto a bony surface
- Deep venous thrombosis
- Infection
- Scarring in the anteromedial ankle causing soft tissue impingement

### REFERENCES

DEFINITION
- The Achilles tendon is the strongest tendon in the body and is the primary plantarflexor of the ankle joint.\textsuperscript{15}
- Sudden stretch of the tendon tissue can result in complete or partial rupture, with an estimated incidence of 18 per 100,000 persons.\textsuperscript{3}
- With complete rupture, the ruptured ends of the tendon may pull apart, leading to a significant plantarflexion weakness and to the creation of a gap that is palpated clinically.
- A common source of confusion is that patients may continue to have active ankle plantarflexion due to the action of other flexors of the ankle.
- As a result, the diagnosis is initially missed in an estimated 20\% to 25\% of cases.\textsuperscript{5}

ANATOMY
- Three calf muscles—the medial, lateral gastrocnemius, and soleus—converge together to form the “triceps surae” or the Achilles tendon (FIG 1).
- The plantaris muscle originates from the lateral femoral condyle and passes obliquely between the gastrocnemius and soleus to reside medial to the Achilles tendon and inserts into it or the calcaneus. In an anatomic study, the plantaris muscle was absent in 7.3\% of specimens.\textsuperscript{15}

- The Achilles tendon courses distally, rotates 90 degrees internally, the soleus contribution being medial to that of the gastrocnemius, and inserts into the middle third of the flat surface of the posterior calcaneal tuberosity.\textsuperscript{10}
- The middle section of the tendon, 2 to 6 cm proximal to its insertion site, is a hypovascular zone.
- This zone is the narrowest in cross-section and corresponds to the most common site of tendon pathology, including paratenonitis, tendinosis, and tendon rupture.\textsuperscript{10}
- The tendon is surrounded by a paratenon that has a single layer of cells with variable structure, not a true tenosynovium.
- Webb et al\textsuperscript{16} documented the highly variable position of the sural nerve in relation to the Achilles tendon.
- As measured from the calcaneal insertion, the sural nerve crossed the tendon from medial to lateral at a mean distance of 9.8 cm, then coursed distally to lie a mean of 18.8 mm lateral (FIG 2).

PATHOGENESIS
- Achilles ruptures are usually caused by noncontact injuries. Common injury mechanisms leading to Achilles rupture are forceful push-off with an extended knee, sudden unexpected ankle dorsiflexion, or violent dorsiflexion of a plantarflexed foot.\textsuperscript{13}
Achilles rupture can occur high, near the muscle-tendon juncture (9%), at the tendon midportion (72%), or at the calcaneal insertion (19%).

Concomitant injuries such as ankle ligament sprains or ankle or tarsal fractures should be ruled out.

NATURAL HISTORY

Most Achilles ruptures do not have any antecedent symptoms.

A study of histologic scores comparing ruptured tendons with unruptured tendons, however, showed that there were significant histopathologic changes in the ruptured group that were not present in the older, asymptomatic, unruptured group. Therefore, tendinosis may play a role, but the extent of this role remains unknown.

Achilles rupture is more common in men. Studies have shown a male/female ratio of up to 12:1.

From an epidemiologic standpoint, middle-aged men with white-collar professions and recreational athletic activity constitute most of the patients.

Other predisposing factors are leg muscle imbalance, training errors, foot pronation, and use of corticosteroids and fluoroquinolones.

The contralateral risk of rupture was estimated at 26% on return to the same level of sports activities.

PATIENT HISTORY AND PHYSICAL FINDINGS

Most ruptures occur during athletic activity. Patients usually describe a sudden painful snap or shooting pain followed by sudden weakness to foot push-off.

Athletes will be unable to bear weight and will report distal leg swelling and stiffness.

Examination for ruptured Achilles tendon can include:

- Palpable gap test. A gap present indicates complete Achilles rupture with separation of the ruptured ends. It is more reliable when done early after rupture. It is 73% sensitive.
- Calf squeeze test (Thompson test). With patient prone, squeeze the calf and observe foot movement. Compare with the contralateral side.

Knee flexion test. With patient prone, patient actively flexes knee. Observe foot position and compare with other.

Active plantarflexion. This is poorly sensitive and unreliable because powerful plantarflexion may still be possible due to the action of other ankle plantarflexors.

IMAGING AND OTHER DIAGNOSTIC STUDIES

AP, lateral, and mortise view plain radiographs of the ankle should be obtained to rule out concomitant fractures or calcific changes of the Achilles tendon.

On a lateral view, the examiner should look for a disruption of the normal triangular fat pad seen anterior to the Achilles tendon (Kager triangle; FIG 3).

Ultrasonography can provide a dynamic study of the tendon structure and accurately measure gapping of the ruptured tendon ends.

The quality of images is highly dependent on the equipment and operator (FIG 4).

MRI is highly sensitive and specific in diagnosing Achilles tendon rupture.

It provides valuable information about tendon degeneration or other associated injuries (FIG 5).

MRI was found to be superior to ultrasound in diagnostic specificity of chronic Achilles tendinopathy.
DIFFERENTIAL DIAGNOSIS
- Rupture of the medial gastrocnemius
- Plantaris tendon rupture
- Baker cyst rupture
- Acute deep venous thrombosis
- Leg or calf contusion
- Tibia distal shaft fracture
- Posterior ankle impingement or symptomatic os trigonum

NONOPERATIVE MANAGEMENT
- Nonoperative treatment usually entails casting the foot in plantarflexion to allow apposition of the tendon ends, followed by casting the foot in neutral. Treatment continues for 12 weeks.
  - In a recent retrospective review, early recognition and initiation of nonoperative management within 48 hours of injury resulted in a successful functional outcome that was comparable to surgical repairs. In a recent retrospective review, early recognition and initiation of nonoperative management within 48 hours of injury resulted in a successful functional outcome that was comparable to surgical repairs.17
  - Nonetheless, nonoperative treatment carries up to threefold increase in the rerupture rate and may result in weakness of push-off secondary to healing of the tendon in a lengthened position.
  - Nonoperative treatment is often reserved for elderly, sedentary patients and also for patients with diabetes, tobacco use, and steroid use who are at high risk for surgical wound healing.4

SURGICAL MANAGEMENT
- Operative repair and early mobilization is considered the treatment of choice for younger patients with active lifestyles. In most patients, it is established that operative repair results in a favorable functional outcome with a significantly lower rerupture rate.
  - Numerous surgical techniques have been described, including open repair, percutaneous repair, limited open repair, and open repair with augmentation.5
    - In a comprehensive review of the recent literature, Wong et al18 concluded that in terms of outcome and the complication rate, the best results could be achieved with open repair and early mobilization.

Preoperative Planning
- Plain radiographs are reviewed and any displaced fractures are treated at the same surgical sitting.
- MRIs are reviewed to evaluate the quality of tendon tissue and the level of rupture and to measure the tendon gap if present.
- Severe tendon degeneration or a large gap may require a larger incision or tendon lengthening or augmentation; the surgeon should take this into account during preoperative patient counseling.

Positioning
- Achilles tendon repair is performed with the patient prone (FIG 6). We prefer to use a Wilson frame and commercially available foam head rest.
  - A thigh tourniquet is used for intraoperative hemostasis. A leg tourniquet is not recommended because it may tether the calf muscles and prevent intraoperative tendon apposition.
  - Some surgeons prefer to drape both legs for intraoperative comparison and accurate restoration of the resting tendon length. The operated leg should be clearly marked.

Approach
- Open Achilles repair is usually performed through a longitudinal medial, midline, or lateral incision.
- Primary end-to-end repair is done with heavy nonabsorbable suture.
- Modified Bunnell, Kessler, Krackow, and triple-bundle techniques have been described.5
  - In a biomechanical study, Jaakkola et al6 showed that the triple-bundle technique (FIG 7) provided the strongest suture repair. They credited its superior strength to the use of multiple strands and to tying the knots away from the repair site. However, the authors expressed concern over the large amount of suture material used and its possible negative effect on the vascularity of the tendon.
  - At our institution, we have designed a modification of the Krackow technique in which the free ends of one suture are
passed peripherally to encircle the transverse limb of the opposite suture (FIG 8).
- We likened this scheme to wrapping a gift box and named it the gift box technique.
- We have performed biomechanical pull-out studies on 13 Achilles cadaveric pairs comparing the gift box technique to the standard Krackow suture and documented more than a twofold increase in suture pull-out strength.\(^\text{12}\)
- We believe that the modification is simple to perform, minimizes suture material use, and preserves the vasculature of the healing tendon.

**INCISION**

- A longitudinal incision over the medial border of the tendon provides excellent exposure and access to the plantaris tendon and avoids the sural nerve (TECH FIG 1).
- Mobilize the thick skin and subcutaneous layer laterally, and take great care to preserve the paratenon.
- Protect the sural nerve and lesser saphenous vein as they course lateral to the paratenon.
- Enter the paratenon through a midline incision (away from the skin incision).
- Limit dissection at the tendon–paratenon plane, especially anterior to the tendon, to preserve the vascular supply of the tendon.

**MODIFIED KRACKOW SUTURE (GIFT BOX) TECHNIQUE**

- Débride the ends of the ruptured tendon in a limited manner.
- Two no. 2 fortified polyester sutures (Herculine, Linvatec) are used.
- Four loop Krackow locking sutures\(^\text{9}\) are passed on the medial side and four on the lateral side, avoiding the middle third of the tendon width.
- Unlike the classic Krackow suture, we pass our transverse limb in the middle of the tendon as we transition from one side to the other (TECH FIG 2).
- Use straight Keith needles to pass the free suture ends across the rupture site into the opposite end of the tendon.
Chapter 105  OPEN ACHILLES TENDON REPAIR

TECH FIG 2 • The transverse limb of the gift box suture is passed through tendon midsubstance. (Copyright Sam Labib.)

TECH FIG 3 • A. The gift box suture completed and tied. Note the tension created on the transverse limb of the suture, which helps tendon apposition. B. Intraoperative photograph of the completed gift box suture. (A, Copyright Sam Labib.)

TECH FIG 4 • Intraoperative photo after closure of the Achilles paratenon.

TRIPLE-BUNDLE SUTURE TECHNIQUE

- Beskin et al popularized an open repair of the Achilles tendon using no. 1 nonabsorbable polyester suture (Ethibond, Ethicon).
- Three rows of sutures are placed, creating six strands of suture that are tied away from the rupture site (Fig 7).

- Sutures should emerge one superficial and one deep to the transverse limb of the opposite Krackow suture (Fig 8).
- Thus, four suture strands are passed across the rupture site.
- Tie the surgical knots away from the rupture site—in other words, proximal and distal to the Krackow suture.
- Excellent apposition is usually achieved as the knots push on the transverse limbs of opposing sutures and the desired tendon length is recreated (TECH FIG 3).
- Use epitendinous running Prolene no. 3-0 suture to oversew the tendon ends together.
- Meticulously repair the paratenon with no. 3-0 braided polyglycolic absorbable suture (Vicryl, Ethicon) (TECH FIG 4).
- This can be facilitated by placing the ankle in maximum plantarflexion to relax the tendon tissue.
- We believe that midline placement of the paratenon incision facilitates its repair and minimizes the chance of skin tethering to the repaired tendon.
- Perform subcuticular skin closure with no. 4-0 monofilament absorbable suture (Monocryl, Ethicon).

PRIMARY REPAIR WITH AUGMENTATION

- Multiple authors have advocated primary augmentation of Achilles repair, with some preferring plantaris tendon, flexor tendon (TECH FIG 5), or artificial tendon implants.13
- A study by Jessing and Hansen7 however, found no evidence that such augmentation was superior to a nonaugmented end-to-end repair.
PEARLS AND PITFALLS

Clinical evaluation
- Diagnosis of complete rupture can be missed due to other active ankle flexors.
- Ultrasonography or MRI may be needed to verify the diagnosis.
- Care is taken to evaluate concomitant bony or tendon injury.

Nonoperative treatment
- Should be initiated early, with cast application in plantarflexion preferably within 48 hours of injury.
- Tendon gapping should be looked for and corrected.
- Strongly considered for patients with poor skin or vascular compromise. Poorly controlled diabetes and tobacco or steroid use are relative contraindications for surgical treatment.

Approach
- Midline incisions may result in a painful scar.
- A lateral incision places the sural nerve at an added risk of injury.
- Poor tissue handling may result in wound slough or dehiscence.

Tendon tension
- Aggressive trimming of tendon ends may result in significant shortening and undue tension on the repair.
- Use the contralateral limb as your guide to appropriate restoration of resting tendon length.

Suture technique
- Avoid strangulating locking suture techniques, which may compromise tendon healing and promote scar formation.
- Paratenon preservation and repair is mandatory for tendon repair and healing.

POSTOPERATIVE CARE
- Early functional mobilization was shown to yield improved tendon healing.
- A posterior splint holding the site in mild plantarflexion is used for 14 days. Labib et al showed no significant difference in tension when the repaired tendon was positioned in 30, 20, and 10 degrees of plantarflexion.
- Wound inspection is done, a non–weight-bearing cast boot is applied with heel lifts, and daily active range of motion is started.
- The patient is kept non–weight-bearing for a total of 6 weeks, but recent evidence suggests that weight bearing can be started before 6 weeks with no added risk of rerupture or gap formation.
- The patient is allowed gradual return to full weight bearing over an additional 6 weeks.
- At 3 months, full weight bearing is permitted, with low-impact activities.
- At 6 months, full activities are permitted as tolerated.

OUTCOMES
- Based on a literature review, there is overwhelming support for open operative repair and early functional mobilization of Achilles tendon rupture in healthy active individuals. On average, a success rate of 85% to 95% is often quoted.

Wong et al conducted an extensive literature review and concluded that the best results with regard to outcome and complication rate could be achieved with open repair and early mobilization.
- Most authors agree that surgical repair provides a significantly lower rerupture rate and better functional outcome, but these advantages should be weighed against the possible risks of wound dehiscence or infection.
- Recent studies showed a significant temporal improvement in surgical outcome coupled with a net decrease in surgical complications.

COMPLICATIONS
- Delayed or missed diagnosis
- Intraoperative devitalization of tendon, leading to wound infection
- Failure to preserve and repair the paratenon, leading to scarring and skin tethering
- Sural nerve injury and neuroma formation
- Wound dehiscence
- Tendon rerupture
- Loss of ankle motion
- Calf weakness
REFERENCES

DEFINITION
- Achilles tendon ruptures usually occur 3 to 4 cm above the calcaneal tuberosity.
- Although most injuries are “complete” ruptures, “partial” injuries have been described.

ANATOMY
- The Achilles tendon is about 9 cm long and 0.9 cm in diameter.
- The proximal part is composed of the gastrocnemius and soleus tendons.
- The distal portion inserts onto the posterior aspect of the tuberosity of the calcaneus.
- The Achilles tendon is surrounded by the paratenon, a delicate envelope that contributes to tendon vascularization.
- There is an area of poor vascularity located between 2.5 cm and 5 cm above the calcaneal tuberosity.

PATHOGENESIS
- Rupture of the Achilles tendon is a common injury among high-level athletes, recreational sports enthusiasts, or even sedentary individuals.
- Rupture of the Achilles tendon usually occurs during forceful dorsiflexion of the ankle.
- Patients often describe hearing or feeling a “pop” in the back of their ankle.
- Intratendinous degeneration can be found histologically.
- Association with cortisone and fluoroquinolone use has been demonstrated.
- This is typically a lesion of middle age, with peak incidence during the third and fourth decades.

NATURAL HISTORY
- There is a great deal of controversy concerning the treatment of an acute rupture of the Achilles tendon.
- Conservative treatment is found to have a higher rate of tendon rerupture and loss of strength because the tendon heals in an elongated position.
- The major factor motivating surgeons to use a nonoperative approach appears to be avoiding the wound complications that occur with an operative repair.
- An increasing number of reports in the literature have tended to favor operative treatment of an acute rupture of the Achilles tendon.
- The exact type of operative procedure and the postoperative regimen remain controversial.1–9 Mini-invasive techniques are associated with a lower complication rate.10–13
- If soft tissue complications are avoided, excellent functional results and full return to previous activity can be expected.

PHYSICAL FINDINGS
- Physical examination reveals moderate swelling about the posterior aspect of the ankle.
- Patients are usually able to walk, although with moderate pain.
- With the patient prone, spontaneous excess dorsiflexion of the involved ankle is noted.
- In most cases a tender defect (“soft spot”) can be palpated in the Achilles tendon between 2.5 and 5 cm proximal to its insertion into the calcaneal tuberosity.
- The Thompson squeeze test is positive.
- Patients have difficulty walking on their toes or rising up on their heels.

IMAGING AND DIAGNOSTIC STUDIES
- History and physical examination are sufficient to confirm the diagnosis.
- Since these injuries occur in a traumatic setting, plain radiographs of the ankle are strongly advised.
- There have been many reports of associated ankle fractures (medial malleolus).14
- Calcaneal (tuberosity) avulsion will appear on the lateral view.
- Ultrasound and MRI are not required for the diagnosis of Achilles tendon rupture but may be of value when the diagnosis is questionable.

DIFFERENTIAL DIAGNOSES
- Ankle sprain
- Ankle fracture
- Tennis leg (gastrocnemius tear)
- Acute paratenonitis
- Calcaneal (tuberosity) avulsion
- Plantaris tendon rupture

NONOPERATIVE MANAGEMENT
- Nonoperative treatment of acute Achilles tendon ruptures involves prolonged immobilization.
- Prolonged immobilization is associated with musculoskeletal changes (atrophy), increased time necessary for rehabilitation, and delayed return to work and preinjury activities.
- In randomized studies the rerupture rate has been found to be much higher in the nonoperative group.
- However, nonoperative treatment avoids surgical complications.
- Nonoperative treatment should be considered in elderly patients with limited functional expectations, patients with significant tobacco or alcohol addictions, patients receiving chronic cortisone treatment, patients with vascular disease, and patients with severe comorbidities such as renal failure.
Indications and Contraindications

- The indication for this technique is an acute (less than 3 weeks) Achilles tendon rupture occurring between 2.0 and 7.0 cm above the tuberosity of the calcaneus.
- Greater than 90 percent of ruptures of the Achilles tendon occur in the area between 2 and 8 cm above the calcaneal tuberosity.15
  - We believe that ruptures occurring more than 8 cm above the tuberosity (muscular ruptures) can be treated nonoperatively, while ruptures occurring less than 2 cm from the tuberosity necessitate fixation directly to bone.
- Contraindications include chronic rupture greater than 3 weeks in duration, previous local surgery, steroid use, open ruptures and lacerations greater than 6 hours in duration, complex open ruptures with soft tissue defects, and ruptures not occurring between 2 and 8 cm above the tuberosity of the calcaneus.

SURGICAL MANAGEMENT

Preoperative Planning

- Plain films should be reviewed for fracture, avulsion, and calcific tendinopathy.
- All imaging studies are reviewed.
- An examination under anesthesia should be performed before positioning the patient to reconfirm the side of injury.

Positioning

- The patient is placed prone on the operating table.
- A tourniquet is applied around the upper thigh.
- Both legs are included in preparation and draping to compare Achilles tendon tension and spontaneous plantarflexion intraoperatively.
- Plastic draping is not used (the technique involves percutaneous steps).
- Patients receive antibiotic prophylaxis.

Instrumentation

- The Achillon (Newdeal, Integra Life Science) was designed by this author and is made of either a rigid polymer or stainless steel (FIG 1).
  - It is designed to guide the passage of the sutures.
  - It is composed of a pair of internal branches connected to a pair of external branches, with each branch having a line of apertures at the same level to allow easy and accurate passage of the sutures through all four branches.
  - The two internal branches are at an 8-degree angle to each other, following the V-shaped anatomic form of the tendon.
  - A micrometric screw allows for varying the opening of the branches according to tendon morphology.
  - A straight needle with its attached suture is used with a needle driver, designed to provide a larger support surface to push the needle through the soft tissues and at the same time protect the surgeon by preventing perforation of the glove from the end of the needle.

Techniques

- Palpate the site of injury, represented by the gap or soft spot (TECH FIG 1A).
- The incision is paratendinous and medial (TECH FIG 1B), beginning at the soft spot and extending about 2.0 cm proximally.
- Gently retract the skin and subcutaneous tissue with hooks and identify the paratenon (TECH FIG 2A).
- Carefully open the sheath and tag each edge with a stay suture (TECH FIG 2B).
- Identify both stumps of the ruptured tendon (TECH FIG 3A) and carefully note the exact site of rupture.
- Introduce the Achillon in the closed position under the paratenon in a proximal direction, holding the tendon stump with a small clamp under the instrument (TECH FIG 3B).
- The tendon stump is located between the two internal branches (TECH FIG 3C).
- As the instrument is introduced, progressively widen it, holding the tendon stump firmly with the clamp.
- Confirm the position of the guide by external palpation; you should feel the tendon between the central (internal) branches of the instrument.
- Pass three sutures from lateral to medial, usually beginning with the most proximal hole of the instrument (TECH FIG 4A,B).
- Hold the end of each suture with a small clamp to keep them separate from each other.
- Slowly withdraw the instrument while progressively closing the branches (TECH FIG 5A).
- This maneuver results in the sutures sliding from an extracutaneous position to a peritendinous position, and thus the tendon itself is the only tissue held by the sutures (TECH FIG 5B).
- Apply traction to the three suture pairs to ensure they are firmly anchored in the tendon, and individually clamp them to prevent any confusion.
- Perform the same sequence on the distal stump: introduce the instrument under the tendon sheath and push it until it touches the calcaneus (TECH FIG 6A).
**TECH FIG 1** Illustration showing the skin incision, begun at the gap or soft spot (A), paratendinous and medial, and extended one and one-half to two centimeters proximally (B).

**TECH FIG 2** Illustration showing the sheath opened longitudinally in the midline (A) and a stay suture in place (B).

**TECH FIG 3** Illustration showing the forceps grasping the proximal tendon stump (A), and introduction of the instrument proximally under the paratenon (B,C).
Chapter 106  LIMITED OPEN REPAIR OF ACHILLES TENDON RUPTURES: PERSPECTIVE 1

**TECH FIG 4** • Illustration showing introduction of the first needle (A), and illustration showing all three sutures in the proximal tendon (B).

**TECH FIG 5** • Illustration showing the instrument being withdrawn (A) bringing the sutures from an extra-cutaneous to a peritendinous position (B).

**TECH FIG 6** • Illustration showing the exact same sequence performed on the distal stump. (A) Introduce the instrument under the tendon sheath and push it until it touches the calcaneus. (B) Illustration showing the sutures organized for tightening. (C) Illustration showing the tendon reduction performed under direct vision, confirming apposition of the tendon ends. (continued)
TECH FIG 6 • (continued) (D) Illustration showing closure of the skin with intradermal sutures.

**TECHNIQUES**

- All the sutures are now organized for tightening (TECH FIG 6B), which is carried out with corresponding pairs, and the tendon reduction is under direct visual control (TECH FIG 6C).
- If it is difficult to ascertain tendon length and reduction because the ends are too frayed, compare the tendon tension to the opposite leg.
- Close the tendon sheath, and then the skin with intradermal sutures (TECH FIG 6D).
- No drain is used.
- Apply a splint holding the ankle in 30 degrees of flexion before moving or waking up the patient.

**PEARLS AND PITFALLS**

- Be sure to note the soft spot or gap in the tendon to accurately plan the site of incision.
- Carefully open the paratenon and tag with stay sutures.
- Note exact site of rupture.
- Hold tendon stump with clamp while introducing Achillon instrument under the paratenon.
- Progressively open the instrument as it is introduced.
- After suture insertion carefully withdraw instrument while branches are progressively closed.
- Carefully organize all sutures for tying with ankle placed in equinus.
- Tendon reduction must be carefully controlled under direct vision.
- Orthosis is applied prior to moving or waking the patient.
- Failure to accurately locate the exact site of rupture prior to making incision.
- Failure to tag the paratenon with stay sutures.
- Failure to hold tendon stump with clamp while introducing Achillon instrument.
- Failure to progressively open the Achillon instrument as it is being inserted.
- Failure to keep each of the three sutures separate from each other.
- Failure to apply traction to the three suture pairs to ensure that they are firmly anchored in the tendon.
- Failure to individually clamp each of the three suture pairs to avoid confusion.
- Failure to control tendon reduction under direct visual control.
- Failure to apply orthosis prior to moving or waking the patient.

**POSTOPERATIVE CARE**

- Low-molecular-weight heparin (subcutaneous administration) is used to prevent deep vein thrombosis for 3 weeks postoperatively.
- Our early functional rehabilitation program, carefully supervised by the physical therapist, is divided into four stages.
- For the first 2 weeks patients are allowed partial weight bearing (30 to 45 pounds) and maintained in the splint full time.
- Then gentle ankle range of motion (flexion and extension) is begun, as well as thigh muscle exercises and the use of a stationary bicycle.
- The goal is to reach a neutral ankle position by the end of the third week.
- After 3 weeks, full weight bearing is allowed with continuous use of the protective splint.
- At the end of 8 weeks the splint is discontinued and weight bearing is allowed without any external support.
- A more intensive program of ankle range of motion, stretching, and isometric and proprioceptive exercises is instituted.
- Jogging is allowed at 3 months, and more demanding sports at 5 months.

**OUTCOMES**

- This limited open procedure with use of the Achillon instrument provides the advantage of an open repair but avoids the soft tissue problems associated with open repair.
- We published a prospective multicenter study in 2002 including 82 patients. Results showed no wound healing problems and no infections. No patient noted a sensory disturbance in the sural nerve distribution. All patients returned to their previous professional or sporting activities. The mean AOFAS score was 96 points (range 85 to 100 points).
- Complications occurred in three patients. Two of them were noncompliant and removed the orthosis within the first
3 weeks postoperatively, thus disrupting the repair by a new injury. One patient fell 12 weeks after the surgery and sustained a rerupture. All three new injuries were repaired with an open surgical procedure.

- Isokinetic results: The concentric peak torque was performed with the ankle in plantarflexion at 30°/s and 60°/s of angular velocity, after correction for dominance. There was no significant difference between the injured and uninvolved sides (Table 1). Endurance testing at 120°/s also revealed no difference between sides.

- Three recent reports describe similar excellent results using the exact surgical technique and Achillon instrument, thus providing further confirmation of its important role in the repair of acute Achilles tendon ruptures.

### COMPLICATIONS

- Disruption of the repair related to the patient’s noncompliance with the rehabilitation protocol (before the third month postoperatively)
- Rerupture of the healed Achilles tendon (after the third month postoperatively)
- Sural nerve injury
- Infection
- Deep venous thrombosis

### REFERENCES

DEFINITION
- Achilles tendon ruptures usually occur 3 to 4 cm above the calcaneal tuberosity.
- Although most injuries are “complete” ruptures, “partial” injuries have been described.
- An increasing number of reports in the recent literature favor operative treatment of a fresh rupture of the Achilles tendon; mini-invasive techniques are associated with a lower complication rate.

ANATOMY
- The Achilles tendon is about 9 cm long and 0.9 cm in diameter.
- The proximal part is composed of the gastrocnemius and soleus tendons.
- The distal portion inserts onto the posterior aspect of the tuberosity of the calcaneus.
- The Achilles tendon is surrounded by the paratenon, a delicate envelope that contributes to tendon vascularization.
- There is an area of poor vascularity located between 2.5 cm and 5 cm above the calcaneal tuberosity.

PATHOGENESIS
- Rupture of the Achilles tendon is a common injury among high-level athletes, recreational sports enthusiasts, or even sedentary individuals.
- Rupture of the Achilles tendon usually occurs during forceful dorsiflexion of the ankle.
- Patients often describe hearing or feeling a “pop” in the back of their ankle.
- Intratendinous degeneration can be found histologically.
- Association with cortisone and fluoroquinolone use has been demonstrated.
- This is typically a middle-age lesion, with peak incidence during the third and fourth decades.

NATURAL HISTORY
- There is a great amount of controversy concerning the treatment of an acute rupture of the Achilles tendon.
- Conservative treatment is found to have a higher rate of tendon rerupture and loss of strength due to the tendon healing in an elongated position.
- The major factor motivating surgeons to use a nonoperative approach appears to be avoiding the wound complications that occur with an operative repair.
- An increasing number of reports in the literature have tended to favor operative treatment of an acute rupture of the Achilles tendon.
- The exact type of operative procedure and the postoperative regimen remain controversial.
- If soft tissue complications are avoided, excellent functional results and full return to previous activity can be expected.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Physical examination reveals moderate swelling about the posterior aspect of the ankle.
- Patients are usually able to walk, although with moderate pain.
- With the patient prone, spontaneous excess dorsiflexion of the involved ankle is noted.
- In most cases a tender defect (“soft spot”) can be palpated in the Achilles tendon between 2.5 and 5 cm proximal to its insertion into the calcaneal tuberosity.
- The Thompson squeeze test is positive.
- Patients have difficulty walking on their toes or rising up on their heels.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- History and physical examination are sufficient to confirm the diagnosis.
- Since these injuries occur in a traumatic setting, plain radiographs of the ankle are strongly advised.
- There have been many reports of associated ankle fractures (medial malleolus).
- Calcaneal (tuberosity) avulsion will appear on the lateral view.
- Ultrasound and MRI are not required for the diagnosis of Achilles tendon rupture but may be of value when the diagnosis is questionable.

DIFFERENTIAL DIAGNOSIS
- Ankle sprain
- Ankle fracture
- Tennis leg (gastrocnemius tear)
- Acute paratenonitis
- Calcaneal (tuberosity) avulsion
- Plantaris tendon rupture

NONOPERATIVE MANAGEMENT
- Nonoperative treatment of acute Achilles tendon ruptures involves prolonged immobilization.
- Prolonged immobilization is associated with musculoskeletal changes (atrophy), increased time necessary for rehabilitation, and delayed return to work and preinjury activities.
- In randomized studies the rerupture rate has been found to be much higher in the nonoperative group.
- However, nonoperative treatment avoids surgical complications.
- Nonoperative treatment should be considered in elderly patients with limited functional expectations, patients with significant tobacco/alcohol addictions, patients under chronic cortisone treatment, patients with vascular disease, and patients with severe comorbidities (eg, renal failure).
SURGICAL MANAGEMENT

Preoperative Planning
- Plain films should be reviewed for fracture, avulsion, and calcific tendinopathy.
- All imaging studies are reviewed.
- Examination under anesthesia should be performed before positioning the patient to reconfirm the side of injury.

Preoperative Planning
- The surgeon should have available the Achillon® (Integra Life Sciences, Plainsboro, NJ) Achilles tendon repair system and two sets each of no. 2 nonabsorbable suture.
- The surgeon should be prepared to convert to an open procedure should the mini-open procedure not be feasible (severe shear injury pattern to the tendon).

Positioning
- The patient is placed in the prone position.
- The patient’s brachial plexi and ulnar nerves at the elbow are well protected from tension and untoward pressure, respectively.
- The patient’s genitalia must be protected.
- We routinely use a thigh tourniquet applied with the patient still supine on the stretcher before placing the patient in the prone position on the operating table.
- This facilitates effective tourniquet placement and avoids hyperextension of the back during tourniquet placement with the patient already prone.
- The feet are suspended over the end of the bed, with firm padding under the ankles.
- Both lower extremities are prepared into the operative field to determine the appropriate tension of the repair.

APPROACH AND IDENTIFICATION OF RUPTURED TENDON ENDS

- Mini-open incision (TECH FIG 1A)
  - Make a longitudinal skin incision about 2 cm long at the level of the rupture.
  - The incision is longitudinal in the event the procedure has to be converted to a full open procedure.

- Divide the paratenon to gain control of the ruptured tendon ends (TECH FIG 1B).
  - The plantaris tendon may occasionally be intact despite complete Achilles tendon rupture (TECH FIG 1C).
  - Tag the two tendon ends with suture (TECH FIG 1D,E).

TECH FIG 1 • A. Mini-open longitudinal incision directly over tendon rupture. B. Paratenon is divided to gain access to tendon ends. C. The plantaris tendon may remain intact despite complete Achilles tendon rupture. D. Tag sutures are placed on the mobilized tendon ends. E. Tension is applied to tag sutures, approximating the tendon ends.
PLACING PERMANENT SUTURES IN PROXIMAL ASPECT OF THE RUPTURED TENDON

- Using the proximal tag sutures, apply tension to the proximal tendon stump.
- Place retractors within the paratenon to define the interval between the tendon and the paratenon.
- Advance the Achillon device within the paratenon on the medial and lateral aspects of the tensioned proximal tendon (TECH FIG 2A,B).
- Typically, the tendon is palpable between the arms of the Achillon device.
- In succession from closest to farthest from the rupture, pass three sutures through the tensioned proximal tendon (TECH FIG 2C–F).

By retracting the Achillon device distally back into the wound, secure the sutures in the tendon, within the paratenon, and exiting within the wound (TECH FIG 3A,B).

- Tension must be placed on the sutures before proceeding to the next step to ensure the sutures are properly anchored in the proximal tendon (TECH FIG 3C).
- If the sutures pull out, repeat the three aforementioned steps, with careful palpation to be sure that the tendon is indeed between the arms of the Achillon device.

TECH FIG 2 • A. The Achillon device is advanced within the paratenon. B. Longitudinal tension placed on the tag suture while advancing the Achillon device facilitates optimal positioning of the tendon between the two arms of the Achillon device. C. The suture closest to the rupture is inserted first. Tension is maintained on the tag suture. D. The second suture is passed through the tendon. E. The third suture is passed. Tension is still maintained on the tag suture, and the tendon is centered between the two arms of the Achillon device that are within the paratenon. F. All three sutures are passed through the proximal tendon and organized.
By retracting the device from the wound, the three sets of sutures remain in the tendon, are within the paratenon, and exit at the wound. C. Longitudinal traction is placed on the sutures to ensure that they are secure within the proximal tendon.

PLACING PERMANENT SUTURES IN DISTAL ASPECT OF THE RUPTURED TENDON

- This is essentially the mirror image of placing sutures in the proximal tendon.
- With distal ruptures, the Achillon device must be advanced as close to the Achilles insertion on the calcaneus as possible to optimize the sutures’ purchase in tendon.
- Advance the Achillon device’s inner arms on either side of the Achilles tendon, within the paratenon (TECH FIG 4A).
  - Palpate to be sure that the tendon is indeed between the two arms of the Achillon device.
- Place the three sutures (similar to those in the proximal tendon), from closest to farthest from the rupture, into the distal tendon, with tension applied to the tag sutures (TECH FIG 4B–E).
- Retract the Achillon device from the wound, thereby bringing the three sutures within the paratenon and into the wound, ready for repairing the rupture (TECH FIG 4F).
- To ensure that the purchase of the sutures in the distal tendon is satisfactory, apply forceful tension to the sutures.
  - Tension should plantarflex the ankle (TECH FIG 4G).
  - Should the sutures pull out, repeat the steps described above so that acceptable purchase of the sutures in the distal tendon is achieved. In our opinion, palpation of the tendon between the arms of the Achillon device is helpful.

The Achillon device is advanced within the paratenon on the medial and lateral aspects of the distal tendon. (continued)
TECH FIG 4 • (continued) B–E. The three sutures are placed in the distal tendon and organized. F. The Achillon device is retracted from the wound so that the three sutures remain within the tendon, are within the paratenon, and exit at the wound. G. Longitudinal traction ensures that the sutures are secure within the distal tendon. Note the plantarflexion of the ankle with tension on the sutures.

**TENDON REPAIR**

- Approximate the two tendon ends by tensioning the sutures (TECH FIG 5A).
- The sutures must be carefully organized so that corresponding sutures are secured to one another.
- Passive plantarflexion of the ankle with a bump placed under the dorsum of the foot or maintained by an assistant takes tension off the tendon during repair.
- Secure the two sets of sutures closest to the rupture to one another first.
  - With tension maintained on one side, secure the other side with a surgeon’s knot (TECH FIG 5B).
  - Then secure the other side, applying tension first to remove residual slack in the suture (TECH FIG 5C).
- Repeat the suture technique described for the initial set of sutures for the other sets (TECH FIG 5D).
- Secure the intermediate set of sutures to one another, followed by the sets farthest from the rupture.
- If the sutures more distant from the rupture are overtensioned during the repair, then the tension gained with the previously secured sutures is forfeited. Therefore, overtensioning of each successive set of sutures is unnecessary.
- With the opposite, uninjured extremity prepared into the operative field, the resting tension of the repair may be compared to what is deemed physiologic (TECH FIG 5E).
- Setting the resting tension of the repair slightly greater than that of the contralateral extremity is acceptable and, in our opinion, preferred.
- Avoid undertensioning of the repair.
- As for flexor tendon repairs for the hand, we recommend reinforcing the repair with additional sutures directly at the rupture (TECH FIG 5F).
- In our opinion, this is important because the mini-open technique described above only serves the function of an internal splint. When the repair site is directly palpated after repair with only the three sets of sutures, invariably there is mostly suture at the repair site and relatively little collagen.
- We routinely perform this reinforcement with a running, absorbable suture.
- This not only reinforces the tendon repair but tends to bring more tendon collagen directly to the repair site.
- Place the running or alternatively multiple interrupted sutures circumferentially at the repair site.
TECH FIG 5 • A. The ruptured tendon ends are approximated by tensioning both sets of sutures. B. One side of the corresponding sutures closest to the rupture is tied. Tension should be maintained on the other side of this set of sutures. C. After removing slack in the suture, the other side of this first set of sutures is tied. D. The second and third set of sutures are secured. Over-tensioning of each successive set of sutures should be avoided since this will cause the previous set to lose its tension. E. The resting tension of the repair should match that of the other uninjured extremity. Preferably, the tension should be slightly greater in the repair. F. The repair is reinforced with a single running or multiple interrupted sutures directly at the rupture.

CLOSURE

- Repair the paratenon and fascial layer over the tendon to a “water-tight” closure (TECH FIG 6A).
- Reapproximate the subcutaneous layer and skin to a tensionless closure (TECH FIG 6B,C).

TECH FIG 6 • A. The paratenon and fascial layer are reapproximated. (continued)
POSTOPERATIVE CARE

- Low-molecular-weight heparin (subcutaneous administration) is used for prophylactic anticoagulation for 3 weeks postoperatively.
- We institute an early functional rehabilitation program, carefully supervised by the physical therapist, which is divided into four distinct stages.
- For the first 2 weeks patients are allowed partial weight bearing (30 to 45 pounds) and maintained in the splint full time.
- Then gentle ankle range of motion (flexion and extension) is begun, as well as thigh muscle exercises and the use of a stationary bicycle.
- The goal is to reach a neutral ankle position by the end of the third week.
- After 3 weeks, full weight bearing is allowed with continuous use of the protective splint.
- At the end of 8 weeks the splint is discontinued and weight bearing is allowed without any external support.
- A more intensive program of ankle range of motion, stretching, and isometric and proprioceptive exercises is instituted.
- Jogging is allowed at 3 months, and more demanding sports at 5 months.

OUTCOMES

- This limited open procedure with use of the Achillon instrument provides the advantage of an open repair but avoids the soft tissue problems associated with open repair.
- Assal et al published a prospective multicenter study including 82 patients. Results showed no wound healing problems and no infections. No patient noted a sensory disturbance in the sural nerve distribution. All patients returned to their previous professional or sporting activities. The mean AOFAS score was 96 points (range 85 to 100 points).
- Complications occurred in three patients. Two of them were noncompliant and removed the orthosis within the first 3 weeks postoperatively, thus disrupting the repair by a new injury. One patient fell 12 weeks after the surgery and sustained a rerupture. All three new injuries were repaired with an open surgical procedure.
- Isokinetic results: The concentric peak torque was performed with the ankle in plantarflexion at 30°/sec and 60°/sec of angular velocity, after correction for dominance. There was no significant difference between the injured and uninvolved sides. The endurance testing at 120°/sec also revealed no difference between sides.
- Three recent reports describe similar excellent results using the exact surgical technique and Achillon instrument, thus providing further confirmation of its important role in the repair of acute Achilles tendon ruptures.

REFERENCE

DEFINITION

- Achilles tendon ruptures typically occur about 2 to 6 cm proximal to the tendon’s insertion site on the calcaneus.
- This injury is relatively common among both high-performance athletes and the recreational athlete, particularly the “weekend warrior.”
- Ruptures occur most often in men between 30 and 50 years of age.

ANATOMY

- Tendinous portions of the gastrocnemius and soleus muscles coalesce to form the Achilles tendon (FIG 1).
- The plantaris muscle is a distinct entity medial to the Achilles tendon.
- The soleus tendon originates as a band proximally on the posterior surface of its muscle, and the gastrocnemius tendon emerges from the distal margin of the muscle bellies.
- The length of the tendon formed from the gastrocnemius and soleus range from 11 to 26 cm and 3 to 11 cm, respectively.

PATHOGENESIS

- Ruptures occur most commonly during athletic activities.
- Both hyperpronation and cavus foot alignment are associated with Achilles tendon injuries. The cavus foot is thought to place more stress on the lateral side of the Achilles tendon and to absorb shock poorly.
- Inconsistent training, including sudden increases in training intensity; excessive training; training on hard surfaces; and running on sloping, hard, or slippery roads have been implicated in Achilles tendon problems.
- Mechanisms of injury, leading to eccentric loads on the Achilles tendon, include pushing off with the weight-bearing forefoot while extending the knee, unexpected dorsiflexion of the ankle, or violent dorsiflexion of a plantarflexed foot.
- With normal aging, the Achilles tendon decreases in cell density, collagen fibril diameter and density, and fiber waviness. These changes may make the aging athlete more susceptible to injury.
- Spontaneous rupture of the Achilles tendon has been associated with corticosteroid use, inflammatory or autoimmune conditions, collagen abnormalities, infectious diseases, neurologic conditions, and fluoroquinolone use.

NATURAL HISTORY

- Chronic Achilles tendon injuries typically result in the patient’s inability to complete everyday tasks such as climbing stairs.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient reports sudden pain in the affected leg.
- Some patients recall an audible pop or snap.
With Achilles tendon ruptures, patients occasionally experience a sensation as though they were “kicked” or “hit” in the injured calf. Patients report an inability to bear weight and weakness of the affected lower extremity.

Physical examination should include the following:
- Palpation of gap: Palpate along the posterior aspect of the lower leg, and a gap may be felt along the course of the tendon.
  - Positive: appreciable gap
- Thompson test: With the patient prone, squeeze the proximal portion of the calf.
  - Positive: no plantarflexion of the ankle
- False-positive results may be obtained with an intact plantaris tendon.
- Knee flexion test: With the patient prone, have him or her actively flex both knees to 90 degrees.
  - Positive: asymmetric resting tension of both ankles; the affected foot may even fall into neutral or dorsiflexion.
- Needle test: Insert a hypodermic needle into the calf medial to the midline and 10 cm proximal to the insertion of the tendon. The ankle is put through passive range of motion.
  - Positive: the needle points proximally on dorsiflexion.
  - This test is usually only performed if there remains a high index of suspicion with the other tests being equivocal.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs (rarely required in evaluation of Achilles tendon ruptures)
  - In a lateral radiograph, the fat-filled triangular space (ie, Kager’s triangle) anterior to the Achilles tendon and between the posterior aspect of the tibia and the superior aspect of the calcaneus loses its regular configuration.
- MRI (FIG 2) (rarely required in evaluation of Achilles tendon ruptures)
  - T1- and T2-weighted images in the axial and sagittal planes should be used to evaluate Achilles tendon ruptures.
  - T1-weighted: a complete rupture of the Achilles tendon is identified as a disruption of the signal within the tendon.
  - T2-weighted: a complete rupture is demonstrated as a generalized increase in signal intensity, and the edema and hemorrhage at the site of the rupture are seen as an area of high signal intensity.10
- Ultrasound (useful because it can be performed in the office setting)
  - Rupture seen as an acoustic vacuum with thick irregular edges
  - May also be used for postoperative evaluation to assess the structure of the tendon and integrity of repair14

**DIFFERENTIAL DIAGNOSIS**

- Typically, rupture of the Achilles tendon does not conjure up a differential diagnosis.
- Because four other muscles plantarflex the ankle, Achilles tendon ruptures may be initially mistaken for ankle sprains; although increasingly less common, it has been reported that up to 20% of Achilles tendon ruptures may be missed by the first doctor to examine the patient.9

**NONOPERATIVE MANAGEMENT**

- Equinus short-leg cast or plantarflexed cam boot for 6 to 8 weeks
- At 6 to 8 weeks, start gentle range-of-motion exercises.
- A heel lift is used in the transition to wearing normal shoes.
- The patient may return to running in 4 to 6 months.
- Considered for elderly or sedentary patients, poor surgical candidates (vascular compromise and/or poor skin quality), or patients favoring nonoperative treatment
- The rerupture rate after nonoperative management is about 12.1%, compared with the rerupture rate for surgical repair, which is only 2.2%.12

**SURGICAL MANAGEMENT**

- In our hands, percutaneous repair is reserved for acute tears, a minimal tendon gap, and compliant patients.
- Advantages of percutaneous repair are as follows:
  - Low risk of wound complications
  - Preservation of blood supply for tendon healing
  - Performed as outpatient procedure
  - Requires only local anesthetic
  - Maintenance of tendon length
  - Earlier return to function when compared to closed treatment
- Disadvantages include:
  - Potential sural nerve injury
  - Higher rerupture rate versus open repair
  - Limited patient population
  - Need for compliance postoperatively
- Percutaneous repair is contraindicated in chronic tears, tendon gap, noncompliant patients, and high-level athletes (relative).

**Positioning**

- Prone position
- No tourniquet
- Injured foot in about 25 degrees of plantarflexion

**Approach**

- Percutaneous
PERCUTANEOUS ACHILLES TENDON REPAIR

- The repair is performed under local anesthesia (TECH FIG 1).
- A size 0 monofilament polydioxanone suture with two Keith needles, one on either end, is used.
- Medial and lateral stab incisions are made on either side of the Achilles tendon using a no. 15 blade in the following locations: at the level of the rupture; 2.5 cm and 5 cm above the rupture; and 2.5 cm below the rupture. A total of eight stab incisions are made (TECH FIG 2).
- The subcutaneous tissues at each incision site are spread using a hemostat.
- Beginning at the most proximal lateral wound, the needle is passed transversely, and the suture is then manipulated until equal lengths are established on either side (TECH FIG 3).
- The suture is then advanced distally from both sides through the ipsilateral proximal incisions in a crisscross fashion through the tendon at 45-degree angles (TECH FIG 4).
- The previous step is repeated at both 5 cm and 2.5 cm proximal to the rupture (TECH FIG 5).
- The suture, now emerging at the level of the rupture, is then tensioned to ensure that it is secured in the proximal Achilles tendon stump.
- The suture is then advanced distally across the rupture site, in a fashion similar to the previous step (TECH FIG 6).
- The lateral suture is passed through the ipsilateral incision transversely, from lateral to medial, where the ends of the sutures are pulled simultaneously, and then tied; closing the tendon gap.
- A hemostat is used to bury the knot and to be sure there is no skin puckering at any of the incision sites.
- Staples are placed to approximate the skin.

TECH FIG 1 • Local anesthetic used for the procedure.

TECH FIG 2 • Incision locations: at the level of the tear, 2.5 cm and 5 cm above the tear, and 2.5 cm below the tear.

TECH FIG 3 • The needle is passed transversely, and the suture is manipulated until equal lengths are obtained.

TECH FIG 5 • Crisscross fashion to advance the suture distally through the tendon at 45 degree angles.

TECH FIG 6 • Suture is advanced distally across the rupture site.

PEARLS AND PITFALLS

- No need for antibiotic prophylaxis
- Perform technique with two Keith needles.
- To avoid sural nerve injury, use the “nick and spread” technique or lengthen the lateral incisions at the level of the rupture and at the musculotendinous junction to 1.0 to 1.5 cm. Use two small Langenbeck retractors to further visualize the location of the sural nerve lying superficial to the fascia.16

POSTOPERATIVE CARE

- Throughout the rehabilitation period: light active dorsiflexion, muscle strengthening, proprioception exercises, stationary cycling with heel push, soft tissue treatments
- For the first 2 weeks: immobilization and non–weight-bearing of the foot and ankle in an adjustable boot locked in 20 degrees of plantarflexion (FIG 3). Gentle plantigrade movement of the foot, straight leg raises, and knee range of motion are begun.
- Week 2: the boot is adjusted to 10 degrees of plantarflexion.
- Week 4: Orthosis is adjusted to neutral; partial weight bearing is initiated.
Week 6: Full weight bearing is permitted.
Week 8: The foot is placed in a shoe with a heel lift.
Month 3: The patient starts closed-chain exercises, cycling, and elliptical trainer.
Month 6: Running, jumping, and sports activities may be resumed.

OUTCOMES

- Retrospective review of 10 consecutive patients with acute Achilles tendon ruptures:
  - No reruptures
  - No major complications
  - One sural nerve injury
  - Mean return to full activity at 6.1 months
  - American Orthopaedic Foot and Ankle Society (AOFAS) ankle hindfoot rating: average score 94
  - Mean difference of 1.58 cm in calf circumference, with the involved leg having the smaller circumference
  - Mean plantarflexion peak torque of the uninvolved leg having the smaller circumference
  - Mean return to work a mean of 4 months after percutaneous repair.
  - 1 patient (out of 22) experienced a rerupture after percutaneous repair.

The open repair group had an 8.6% incidence of wound complications (no wound dehiscence occurred in the percutaneous repair group).

- Two patients out of 35 experienced rerupture after open repair; 1 patient (out of 22) experienced a rerupture after percutaneous repair.

- Patients returned to work a mean of 4 months after open repair and 3.75 months after the Webb-Bannister percutaneous repair.

- No sural nerve complications occurred.

COMPLICATIONS

- Sural nerve injury
- Palpable suture knot which may necessitate excision
- Rerupture
- Deep venous thrombosis

REFERENCES

DEFINITION
■ Rupture of the Achilles tendon is common.
■ More than 20% of acute injuries are misdiagnosed, leading to chronic or neglected ruptures.4

ANATOMY
■ The two heads of the gastrocnemius arise from the condyles of the femur, the fleshy part of the muscle extending to about the midcalf. As the muscle fibers descend they insert into a broad aponeurosis that contracts and receives the tendon of the soleus on its deep surface to form the Achilles tendon.9
■ The Achilles tendon is the thickest and strongest tendon in the body. About 15 cm long, it originates in the midcalf and extends distally to insert into the posterior surface of the calcaneus. It receives muscle fibers from the soleus on its anterior surface throughout its length.9

PATHOGENESIS
■ The most common mechanism of injury is pushing off with the weight-bearing forefoot while extending the knee. Sudden unexpected dorsiflexion of the ankle or violent dorsiflexion of a plantarflexed foot may also result in ruptures.5
■ Corticosteroids, fluoroquinolone use, tendon pathology, and poor vascularity of the Achilles tendon have been associated with rupture.5

NATURAL HISTORY
■ A delay in treatment of Achilles tendon rupture results in the formation of a discrete gap. The gap between ruptured tendon ends may fill with fibrous nonfunctional scar. Patients find walking and ascending stairs difficult, and standing on tiptoes on the affected limb impossible.

PATIENT HISTORY AND PHYSICAL FINDINGS
■ Patients often give a history of feeling a blow to the posterior aspect of the leg and may describe an audible snap followed by pain and inability to bear weight.
■ In acute tendon ruptures, a gap in the Achilles tendon is usually palpable. In delayed presentation, edema may fill this gap, making palpation unreliable.
■ Active plantarflexion of the foot is usually preserved due to the action of the tibialis posterior and the long toe flexors.
■ The calf squeeze test, first described by Simmonds in 19577 but often credited to Thompson, is performed with the patient prone and the ankles clear of the table. The examiner squeezes the fleshy part of the calf, causing deformation of the soleus, and resulting in plantarflexion of the foot if the Achilles tendon is intact. The affected leg should be compared to the contralateral leg.
■ The knee flexion test is performed with the patient prone and the ankles clear of the table. The patient is asked to actively flex the knee to 90 degrees. During this movement the foot on the affected side falls into neutral or dorsiflexion and a rupture of the Achilles tendon can be diagnosed.6

IMAGING AND OTHER DIAGNOSTIC STUDIES
■ The diagnosis of acute ruptures is usually a clinical one.
■ Plain lateral radiographs may reveal an irregular configuration of the fat-filled triangular space anterior to the Achilles tendon and between the posterior aspect of the tibia and the superior aspect of the calcaneus.

DIFFERENTIAL DIAGNOSIS
■ Ankle sprain

NONOPERATIVE MANAGEMENT
■ Acute ruptures may be managed conservatively in an equinus cast for 6 to 8 weeks before being converted to a functional brace.
■ Conservative management may result in tendon lengthening, thus altering function.1

SURGICAL MANAGEMENT
■ Percutaneous repair3 was originally described as a compromise between open surgery and conservative management. A percutaneous repair aims to provide the optimal functional outcome of open repair while decreasing the problems associated with it in terms of wound healing and skin breakdown.

Preoperative Planning
■ Once the diagnosis is made, an assessment of general health and comorbidities should be performed.
■ The preoperative functional status should be noted.
■ The skin quality and neurovascular status of the affected limb should be examined.
■ The status of the sural nerve should be documented.
■ We recommend that the patient be maintained on deep venous thrombosis prophylaxis.
■ The procedure can be performed under general anesthesia or a local anesthetic, with a 50:50 mixture of 10 mL of 2% lignocaine hydrochloride (Antigen Pharmaceuticals Ltd, Roscrea, Ireland) and 10 mL of 0.25% bupivacaine hydrochloride (Astra Pharmaceuticals Ltd, Kings Langley, England) instilled into an area of between 8 and 10 cm around the ruptured Achilles tendon.

Positioning
■ The patient is placed prone, and a pillow is placed beneath the anterior aspect of the ankles to allow the feet to hang free.
■ The operating table is angled down 20 degrees cranially to reduce venous pooling in the feet and ankles.
■ A tourniquet is not necessary for this procedure.
Approach

- Previous approaches such as those described by Ma and Griffith\(^3\) using three medial and three lateral stab incisions have been abandoned in light of the relatively increased incidence of sural nerve entrapment.
- We will present two techniques that we employ. The first is an approach similar to that described by Webb and Bannister.\(^8\) Three 3-cm transverse skin incisions are made. The middle one is made over the palpable gap, and the proximal and distal incisions are placed 4 cm proximal and distal to the middle incision respectively (FIG 1). The second is currently our favored technique: the results for acute ruptures are as good as the first technique, but it is even less invasive.
- In the first technique the proximal incision is made more medial to the others to avoid the sural nerve. The stab incisions used in the five-incision latter procedure do not usually give rise to sural nerve problems.

**MINIMALLY INVASIVE REPAIR OF ACUTE ACHILLES TENDON RUPTURE WITH MODIFIED KESSLER SUTURE PATTERN**

- Use a small hemostat to free the tendon sheath from the overlying subcutaneous tissue.
- Pass a 1 PDS II (Ethicon, Johnson & Johnson Intl, Brussels, Belgium) double-strand suture on a long curved needle transversely through the distal incision, passing through the substance of the tendon and out through the same incision (TECH FIG 1A).
- Reintroduce the needle medially into the distal incision through a different entry point in the tendon, and pass it longitudinally through the tendon to lock the tendon. Direct the needle toward the middle incision and out through the ruptured tendon end (TECH FIG 1B).
- Rethread the suture still protruding from the distal incision onto the needle and reintroduce it laterally into the distal incision stump of the tendon (TECH FIG 1C).
- The procedure is repeated in the proximal stump (TECH FIG 1D).
- The suture ends are then tied with the ankle in physiologic plantarflexion.
incision and into the tendon. Pass it proximally through the tendon to exit from the middle incision (TECH FIG 1C).
- Apply traction to the suture to ensure satisfactory grip of the tendon.
- Carry out the same procedure for the proximal stump of the ruptured tendon (TECH FIG 1D).
- A further 1 PDS II (Ethicon) double-stranded suture can be placed in the tendon ends as described above to produce an eight-strand repair.
- Tie the sutures with the ankle in physiologic plantarflexion (TECH FIG 1E).
- Assess the tension by observing the contralateral limb as the sutures are tied.
- Close the skin wounds with undyed subcuticular 3-0 Vicryl (Ethicon, Edinburgh, UK) suture and apply nonadherent dressings.
- Apply a full plaster-of-Paris cast in the operating room with the ankle in physiologic equinus.

PERCUTANEOUS REPAIR OF ACUTE ACHILLES TENDON RUPTURE USING FIVE STAB INCISIONS

- Local anesthetic infiltration is used. Instill a 50:50 mixture of 10 mL of 2% lignocaine hydrochloride (Antigen Pharmaceuticals) and 10 mL of 0.25% bupivacaine hydrochloride (Astra Pharmaceuticals) into an area 8 to 10 cm around the ruptured Achilles tendon.
- The patient is placed prone, and a pillow is placed beneath the anterior aspect of the ankles to allow the feet to hang free.
- Angle the operating table down about 20 degrees cranially to reduce venous pooling in the feet and ankles.
- The affected leg is prepared with antiseptic and sterile draped. We do not use a tourniquet.
- Make five stab incisions over the Achilles tendon (TECH FIG 2A). The first is directly over the palpable defect and measures about 2 cm in a transverse direction.
- The other incisions are about 4 cm proximal and 4 cm distal to the first incision and are vertical 1-cm stab incisions on the medial and lateral aspect of the Achilles tendon.
- We advocate blunt dissection with a small hemostat directly onto the Achilles tendon. This avoids damaging the sural nerve, which crosses the lateral border of the Achilles tendon about 10 cm proximal to its insertion into the calcaneus.
- Use a small hemostat to free the tendon sheath from the overlying subcutaneous tissue (Tech Fig 2A).
- Pass a 1 PDS II (Ethicon) double-stranded suture on a long curved needle transversely through the lateral proximal stab incision, passing it through the substance of the tendon and out through the medial proximal stab incision (TECH FIG 2B).
- Reintroduce the needle into the medial proximal stab incision through a different entry point in the tendon and pass it longitudinally and distally through the tendon to lock into the tendon. Direct the needle toward the middle incision and out through the ruptured tendon end (TECH FIG 2C).
- Retread the suture that is still protruding from the lateral proximal stab incision onto the needle and reintroduce it via the lateral proximal stab incision into the tendon substance. Also pass it longitudinally and distally through the tendon to exit from the middle incision. Apply traction to the suture to ensure a satisfactory grip within the tendon. If the suture pulls through, repeat the procedure. We sometimes use an eight-stranded method by doubling the sutures used for the Kessler-type technique we are describing.
- Carry out the same procedure for the distal half of the ruptured tendon.
- Tie the sutures with the ankle in physiologic plantarflexion and bury them into the tissues using a hemostat (TECH FIG 2E).
- Close the skin wounds with undyed subcuticular 3-0 Vicryl (Ethicon) suture and apply nonadherent dressings.
- Apply a full plaster-of-Paris cast in the operating room with the ankle in physiologic equinus. Split the cast on both medial and lateral sides to allow for swelling (TECH FIG 2F).
POSTOPERATIVE CARE

- The postoperative care regimen and rehabilitation are similar for both techniques.
- Patients are discharged on the same day of the operation.
- The neurovascular status of the limb is assessed.
- After assessment by a physiotherapist, making sure that the patient is safe and comfortable in the cast, the patient can be discharged.
- The full cast is retained for 2 weeks, and patients are allowed to bear weight as comfort allows. During the period in the cast, patients are advised to perform gentle isometric contractions of the gastroc–soleus complex.
- At 2 weeks, patients are reviewed as outpatients, the cast is split, and the wounds are inspected. An anterior splint is worn with the foot in plantarflexion for a further 4 weeks.
- Patients are advised to mobilize with partial weight bearing initially, increasing to weight bearing as able by 4 weeks.
- The splint is then removed, and physiotherapy follow-up for gentle mobilization is arranged. Light weight-bearing exercise can be started 2 weeks after cast removal, and the patient should be fully weight bearing by 10 weeks.

OUTCOMES

- Lim et al., in a randomized controlled trial, advocated percutaneous repair over open surgical techniques after finding no significant differences in functional results, a lower infection rate with the percutaneous repair, and a subjectively more acceptable cosmetic appearance of the percutaneous operative site.
- We reviewed 31 patients who underwent percutaneous repair in our tertiary referral center between 2001 and 2003. Eleven patients (35.5%) received general anesthesia and 20 (64.5%) had local anesthesia. The average length of cast time was 5.97 weeks. One (3.2%) patient sustained a...
major complication, a small pulmonary embolism, which was managed successfully with warfarin. There were no reruptures, and six (19.4%) patients had minor wound complications.

COMPLICATIONS

- Early complications include sural nerve damage and hematoma.
- Intermediate superficial and deep wound infections may occur.
- The most important late complication is rerupture.

REFERENCES


DEFINITION

- Achilles tendon rupture results in loss of plantarflexion function of the ankle through disruption of the gastrocnemius–soleus–Achilles (GSA) mechanism.
- Chronic rupture is usually defined as a rupture not appropriately treated within 8 weeks of injury.
- Chronic or neglected ruptures result in retraction of the proximal myotendinous portion and diastasis between the ruptured tendon ends.
- Functional deficits result from loss of plantarflexion strength and dorsiflexion; check reign of the GSA mechanism.

ANATOMY

- The triceps surae complex is composed of the two heads of the gastrocnemius and the soleus muscle combining to form a single tendon—the Achilles tendon, making up the GSA complex.
- The GSA complex originates from the distal femoral condyles and inserts into the posterior calcaneal tuberosity, making it one of the few muscle–tendon complexes to cross three joints (knee, ankle, and subtalar joints) in the human body.
- The tendon is loosely surrounded by a paratenon, which allows the tendon to slide about 1.5 cm.
- The blood supply to the tendon emanates from the muscle proximally and the calcaneal insertion distally, leaving a watershed area of relatively avascular tendon 4 to 5 cm from the calcaneal insertion.

PATHOGENESIS

- Seventy-five percent of Achilles tendon ruptures occur during sporting activities.
- A history of prior Achilles tendinitis is present in about 15% of ruptures.
- Ruptures occur most commonly in the 30- to 40-year age group, with a male predominance.
- Eighty percent of Achilles tendon ruptures occur in the watershed area 2 to 6 cm above the insertion.
- Mechanism of injury resulting in rupture can be forceful plantarflexion or hyperdorsiflexion of the ankle.
- Achilles tendon ruptures are frequently missed or misdiagnosed as ankle sprains on initial assessment.
- Failure of immobilization or repair will allow continued contracture of the gastrocnemius muscle, resulting in retraction of the proximal myotendinous portion of the GSA complex and subsequently in the development of a gap between the tendon ends.

NATURAL HISTORY

- Missed or neglected ruptures of the Achilles tendon result in plantarflexion weakness and loss of the dorsiflexion; check reign of the GSA complex.
- Without treatment patients develop gait dysfunction, particularly walking up stairs, inclines, or ladders, as well as balance difficulties, with a tendency to fall forward.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients frequently recall the primary event, and often describe feeling like they had been “shot” or “hit” on the back of the heel when the rupture occurred.
- Silent or spontaneous ruptures may occur in the presence of systemic inflammatory diseases, steroid use, or chronic underlying Achilles tendinosis.
- Patients are usually able to walk on the limb and plantarflex the ankle without significant pain despite the chronic rupture.
- Primary complaints are:
  - Weakness of plantarflexion (walking up inclines, stairs, ladders)
  - Gait and balance difficulties
- Clinical examination
  - Inability to walk on tiptoes
  - Inability to perform a single-leg toe raise (difficulty with double-leg raise)
- Direct evaluation should be performed with the patient lying prone with both knees flexed to 90 degrees (both sides are examined and compared):
  - Decreased resting tension of the Achilles tendon (normal resting tension of the unaffected side holds the ankle at 20 to 30 degrees of plantarflexion, while the ruptured side will usually be neutral [zero degrees plantarflexion]).
  - Hyperdorsiflexibility of the ankle compared to the unaffected side
  - Plantarflexion may be present (due to the effect of the posterior tibial tendon, flexor hallucis longus [FHL], and tibialis posterior) but is weaker than the unaffected side.
- A palpable gap may be present between the ruptured tendon ends (FIG 1) when the tendon is followed from the insertion proximally. Careful palpation can usually detect the proximal end, and the gap can be estimated, although it is difficult to measure clinically.
- The Thompson test (squeezing the calf) will not result in symmetrical ankle plantarflexion (compared to the unaffected side), although some degree of plantarflexion is usually present in chronic rupture cases.
IMAGING AND OTHER DIAGNOSTIC STUDIES
- The diagnosis of an Achilles tendon rupture (acute or chronic or neglected) can usually be made on careful clinical evaluation alone.
- If one is uncertain or wishes to better quantify the rupture gap, ultrasound or MRI can be performed.
- Both tests are highly reliable in confirming the diagnosis and in obtaining an accurate measurement of the gap.
- No difference in diagnostic accuracy has been shown, although the MRI may yield more information about the degree of atrophy and fibrosis within the gastrocsoleus muscle.
- This will not affect the treatment options but may help prognosticate the outcome of reconstruction.
- MRI evaluation is useful in neglected ruptures to quantify the gap between the tendon ends.

NONOPERATIVE MANAGEMENT
- Brace management can be used for patients who are not candidates for surgical reconstruction.
- These include patients with medical risk factors, poor distal circulation, and impaired wound healing potential (including patients on steroids or immunosuppressive medications, and those with diabetes mellitus).
- Patients with more moderate functional deficits, with low physical demands, may choose nonsurgical management.
- Management consists of a custom-molded ankle–foot orthosis (MAFO) made of polypropylene.
- An ankle hinge spring-loaded MAFO can be fashioned to add plantarflexion torque and further aid push-off.
- Long-term braces tend to be poorly tolerated in many patients with more active lifestyles.

SURGICAL MANAGEMENT
- The choice of surgical reconstruction depends on the size of the rupture gap. The ability to mobilize the retracted muscle tends to be the major limiting factor.
- Defects less than 1 cm can usually be mobilized and repaired with end-to-end anastomosis.
- For defects of 1 to 3 cm, direct end-to-end anastomosis can usually be obtained. Stretching of the retracted muscle is usually required via longitudinal traction over about a 10-minute time period to close the gap.
- Defects of 3 to 7 cm require an advancement procedure of the Achilles tendon, performed as a V-to-Y lengthening. Further augmentation with a FHL tendon transfer results in additional strength and function of the repair. This technique will be outlined in more detail below.
- For defects of more than 7 cm, reconstruction involves either an Achilles turndown procedure (if enough tendinous tissue is available proximally) or an allograft replacement of the Achilles tendon.

Preoperative Planning
- MRI or ultrasound should be reviewed to determine the gap size and to aid in the location of the ruptured ends.
- Examination under anesthesia should be performed as described above.
- General endotracheal or spinal anesthesia can be used for this procedure.
- Surgery is usually performed on an outpatient basis.

Positioning
- Once the patient is anesthetized, a well-padded thigh tourniquet should be applied.
- It is technically easier to apply the tourniquet while the patient is still in a supine position.
- The surgeon must ensure that the connection for the tubing is placed posteriorly or laterally to allow attachment after positioning, and to prevent pressure problems from the patient lying on the connection or tubing.
- A calf tourniquet should not be used because it may limit the surgeon’s exposure and puts squeeze on the gastrocsoleus muscle, preventing muscle mobilization.
- The patient is turned into a prone position.
- Chest rolls should be used if the patient is asleep for the procedure (this is usually not needed if the procedure is performed under spinal anesthesia).
- Both lower extremities should be prepared and draped. This allows the unaffected side to be used as a template against which the resting tension of the repair can be assessed.
- The legs should be prepared and draped to above the level of the knee joints.

FIG 1 • A large palpable gap can usually be felt between the ruptured ends.

FIG 2 • MRI shows a neglected Achilles tendon rupture. The white arrows indicate the proximal and distal stump ends, with a 5-cm gap.
INCISION

- After Esmarch exsanguination of the limb, the tourniquet is inflated and left inflated until a compressive dressing has been applied at the end of the procedure.
- The approach to the repair involves an extensile incision over the posterior calf (TECH FIG 1A).
- Place the distal incision, over the region of the rupture and gap, medial to the Achilles tendon.
  - This prevents injury to the sural nerve, which runs 5 mm lateral to the Achilles tendon, and keeps the incision away from the posterior aspect of the heel, where it could rub against a shoe counter, causing irritation.
  - This usually involves the most distal 10 cm of the incision.
- Continue the incision sharply full thickness down to and through the paratenon. Reflect the paratenon off the tendon and preserve it for later repair.
- Proximally, curve the incision centrally and continue it up the posterior midline of the calf to the proximal extent of the myotendinous junction.
- The sural nerve in the calf crosses from lateral to central over the myotendinous junction region and then passes under the medial head of the gastrocnemius muscle proximally.
  - The nerve must be identified (TECH FIG 1B) within the subcutaneous tissue, retracted, and protected throughout the rest of the procedure.
  - The nerve runs with the lesser saphenous vein, which aids in identifying its location, and the vein too should be preserved if possible.
- Expose the entire tendon up to a level proximal to the myotendinous junction.
- Carefully reflect the paratenon off the proximal tendon and preserve it for later repair.

MEASUREMENT OF THE GAP

- Once the ruptured region is identified, measure the gap. A scar pseudo-tendon is frequently identified within the rupture gap, and this should be resected together with the nonviable ends of the tendon.
- Measure the true tendon gap (TECH FIG 2) with the knee flexed to 30 degrees and the ankle plantarflexed to 20 degrees to match the resting tension of the unaffected side.

V-TO-Y LENGTHENING

- Make an inverted-V incision through the tendinous portion only of the myotendinous junction of the GSA complex.
- Leave the underlying muscle fibers intact and attached to the proximal muscle body.
- Place the apex of the V in the midline at the most proximal portion of the myotendinous junction.
- The limbs of the V then diverge to exit at the medial and lateral borders of the tendon, respectively. The V limbs should be at least one-and-a-half times longer than the length of the measured gap (TECH FIG 3A). In our experience with these more extensive gaps (greater than 5 cm), we recommend that the limbs of the V are at least twice the length of the rupture gap to allow adequate lengthening to be obtained.
- Use a heavy braided nonabsorbable suture (we use no. 2 Fiberwire [Arthrex Inc., Naples, FL], but no. 5 Ethibond [Ethicon-J&J, Piscataway, NJ] can also be used) for the end-to-end tendon anastomosis after the lengthening.
Chapter 110  CHRONIC ACHILLES TENDON RUPTURES USING V-Y ADVANCEMENT AND FHL TRANSFER

- Use a locking Krackow technique, placing at least five locking loops in a running style along the medial and lateral aspect of the tendon, on each end of the rupture (TECH FIG 3B).
- Insert the suture into the free end of the tendon and then loop it in a locking pattern up the side of the tendon. Attempt to capture about one third to one half of the tendon width with each loop of the suture. Once five loops have been thrown, pass the suture through the substance of the tendon, exiting at the same level on the opposite side of the tendon. Throw another five locking loops toward the end of the tendon, with the suture exiting again at the free end of the tendon.
- We have found that a single continuous suture is adequate for the repair.

- Apply traction to the suture material within the proximal tendon stump in a distally directed longitudinal direction (TECH FIG 3C). This is a firm continuous traction, allowing the muscle fibers to gently stretch out and slide. A weight can be hung over the end of the table to facilitate traction. While some force is required to create this advancement slide, take patience and great care not to detach the tendon from the muscle, which would devascularize the tendon.
- While this is being applied, gently tease the muscle fibers of the myotendinous junction longitudinally, allowing the myotendinous junction to slide distally.
- Continue traction until the tendon ends can be approximated with the ankle resting tension matching the unaffected side.
- Repair the V incision in the tendon, creating an inverted-Y configuration (TECH FIG 3D). The long arm of the inverted Y is the length that the tendon has been elongated—equal to the length of the measured gap.

FLEXOR HALLUCIS LONGUS AUGMENTATION

- Before repairing the ends of the tendon together, harvest the FHL tendon and transfer it to augment the repair.
- The FHL muscle lies in the deep posterior compartment of the leg immediately posterior to the Achilles tendon in this region. With the Achilles tendon and muscle belly reflected, the deep posterior compartment fascia can be incised and released, exposing the FHL muscle and tendon. The muscle of the FHL usually extends distally down to the level of the tibiotalar joint, making it easy to identify (it is frequently referred to as “beef at the heel”) (TECH FIG 4A). Identify the tendon at the distal end of the muscle and digitally retract it.
The hallux should be seen to flex on traction of the tendon, confirming that the correct tendon has been identified. Immediately medial to the FHL muscle and tendon is the medial neurovascular bundle (including the tibial nerve and posterior tibial artery); take care to avoid injury to these structures. Follow the FHL tendon around the medial malleolus (dissection should be performed along the lateral aspect of the tendon as the sheath is released behind the ankle to avoid inadvertent injury to the bundle) (TECH FIG 4B).

With the ankle and hallux held fully flexed and maximum traction placed on the FHL tendon, transect the tendon as distally as possible. In almost all cases, adequate length of tendon can be obtained using this technique (TECH FIG 4C).

Measure the tendon diameter (TECH FIG 4D); a corresponding-sized bone tunnel will be drilled into the posterior tubercle of the calcaneus directly anterior to the attachment of the distal stump of the Achilles tendon.

The hallux should be seen to flex on traction of the tendon within the deep posterior compartment of the leg. B. The FHL tendon is retracted and followed to the level of the medial malleolus. C. The FHL tendon is transected at the medial malleolar level, leaving adequate tendon length for the transfer. D. The FHL tendon diameter is measured, allowing accurate tunnel sizing. E. A Beath pin is drilled through the calcaneus immediately anterior to the Achilles tendon insertion. F. The Beath pin is overdrilled with an appropriately sized cannulated drill bit so as to create the bone tunnel for the FHL tendon. G. The FHL tendon is pulled into the bone tunnel via the attached suture material and pulled to an appropriate tension.
Place a Krackow locking suture in the distal portion of the FHL tendon and pull the tendon into the bone tunnel. This is done using a Beath pin (long pin with a suture eyelet), pulling the suture ends out of the plantar aspect of the foot (TECH FIG 4E). Create the bone tunnel with a size-specific cannulated drill bit over the Beath pin (TECH FIG 4F). Traction can be applied to the suture to hold the tendon within the bone tunnel at the appropriate tension.

**ALTERNATE TECHNIQUE FOR FLEXOR HALLUCIS LONGUS HARVEST**

- If additional length of the FHL tendon is required, the tendon can be harvested from the midfoot.
- This requires a separate incision to be made over the medial side of the foot from the plantar aspect of the talonavicular joint extending to the midshaft of the first metatarsal.
- Reflect the abductor hallucis and flexor hallucis brevis dorsally, exposing the long flexor tendons.
- Identify the FHL and flexor digitorum longus (FDL) tendons at the master knot of Henry (beware of the medial plantar nerve!) and cut the FHL tendon.
- The FHL stump can be tenodesed to the FDL tendon, but multiple communications exist between these two tendons and this is usually not necessary.
- Retract the FHL through the posterior calf incision.
- This technique allows the FHL tendon to be passed through a transverse bone tunnel in the posterior tuberosity of the calcaneus and looped back onto itself.
- The double strands of tendon are theoretically stronger than a single strand, but no advantage has been shown clinically with this technique.
- I prefer to use the first single-incision technique, limiting the risks of an additional incision and the risks to the structures dissected in the approach, including the medial plantar nerve and its branches.

**ACHILLES TENDON REPAIR**

- After the FHL transfer is completed, attention is moved back to the Achilles tendon.
- Oppose the proximal and distal ends of the tendon appropriately (via the V-Y slide) and tie them together with intratendinous knots, using the aforementioned nonabsorbable braided suture (TECH FIG 6A).
- Once again, confirm that the ankle resting tension remains equal to the contralateral side to avoid overtightening of the repair (TECH FIG 6B).
- Gently dorsiflex the ankle to ensure that no diastasis occurs between the tendon ends, confirming adequate integrity of the repair strength.
Suture the muscle belly of the FHL to the back of the Achilles tendon at the level of the repair with absorbable suture. This provides a vascular bed to the relatively disvascular level of the ruptured Achilles tendon, theoretically increasing the healing potential of the repair.

Repair the paratenon over the repaired Achilles tendon as a separate layer, using absorbable suture.

Close the skin in layers via routine closure.

Apply a well-padded posterior plaster splint with the ankle maintained at its resting level of plantarflexion (equal to the contralateral side), and release the tourniquet.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Indications</th>
<th>As with any Achilles tendon surgery, wound edge necrosis remains a major risk factor. Patients need to be adequately assessed for vascularity, skin quality, and healing potential.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical approach</td>
<td>The sural nerve may be trapped in scar tissue after the rupture and should be carefully dissected and protected.</td>
</tr>
<tr>
<td>V-Y lengthening</td>
<td>Ensure that adequate length is used for the limbs of the V. Twice the rupture gap length is recommended. Avoid excess traction of the proximal tendon, which may result in complete disruption of the myotendinous portion of the GSA complex.</td>
</tr>
<tr>
<td>FHL harvest</td>
<td>Beware of the deep neurovascular bundle immediately medial and adjacent to the FHL muscle and tendon at the distal tibial level. Dissect the FHL tendon to at least the level of the medial malleolus to ensure enough tendon length is available. When drilling the Beath pin, ensure that the ankle is dorsiflexed so that the bone tunnel direction is colinear with that of the Achilles tendon and the proposed tendon transfer. Ensure that adequate interference fit has been obtained with the screw in the bone tunnel by pulling on the tendon after insertion. Ensure that the FHL tendon is placed at adequate tension to match the unaffected side.</td>
</tr>
<tr>
<td>Closure</td>
<td>Care should be taken in repairing the paratenon. This has a rich vascular supply, which is important to the tendon repair, and aids in preventing adhesions to the tendon to the skin and subcutaneous tissue.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Postoperatively patients are splinted for 2 weeks in slight equinus (equal to the resting tension of the unaffected side).
- They are kept strictly non–weight-bearing for the first 6 postoperative weeks.
- At 2 weeks after surgery incisions are checked and sutures removed.
- Patients are placed into Achilles-type fracture boots (Bledsoe Inc., Grand Prairie, TX) with three heel wedges, and instructed to remove one wedge after 2 weeks.
- After 6 weeks patients are allowed to start bearing weight on the affected extremity as comfort allows in their protective Achilles boot braces (with two wedges in place at this point).

- Patients are then instructed to remove one wedge every 2 weeks thereafter.
- Physical therapy is performed two or three times a week for the subsequent 10 weeks and includes passive Achilles stretching, an Achilles strengthening program, and gait training. This is performed with the boot brace removed.
- Twelve weeks after surgery, if the ankle is in a neutral alignment, the boot brace is discontinued for ambulation, with the patient continuing the therapy program.
- Patients are instructed to slowly resume their activity as comfort allows, but to avoid sudden acceleration and cutting or jumping activities until at least 6 months after surgery.
OUTCOMES

- Outcomes of chronic or neglected Achilles tendon rupture repair are uniformly inferior to those of acute rupture repair.
- Using a V-Y advancement alone, Us et al\(^5\) reported up to 22% deficiency in peak torque compared to the unaffected side in 6 patients.
- Wapner et al\(^6\) reported on using the FHL tendon without V-Y advancement through a two-incision approach (with the second incision made in the medial longitudinal arch, where the FHL was harvested at the level of the master knot of Henry).
  - On Cybex testing they reported 29.5% average decrease in strength at 30°/s and decreases in torque and work generated by plantarflexion of the ankle as being 41.8% and 51% respectively compared to the nonoperated side.
  - In a recent study by Raikin et al\(^4\) using the combined V-Y lengthening and FHL augmentation described above on 15 patients with a minimum gap of 5 cm, a 7.7 N-m (−22.3%) loss of plantarflexion torque at 60°/s and a 3.5 N-m (−13.5%) loss of plantarflexion torque at 120°/s was seen on Cybex testing compared to the unaffected side.
  - Patients had an average 5-degree loss of active motion arc of the ankle joint in the sagittal plane. AOFAS ankle hind-foot scores improved from an average 58.4 out of 100 preoperatively to an average 94.1 out of 100 postoperatively.
  - Eight of 15 patients were able to perform more than 10 repetitions of a single-leg heel raise at 2-year follow-up.
  - All patients were satisfied with their outcome (rated good or very good).

COMPLICATIONS

- Wound edge necrosis
- Rerupture
- Plantarflexion weakness
- Sural neuritis or nerve injury
- Deep vein thrombosis

REFERENCES

DEFINITION
■ Rupture of the Achilles tendon is common.
■ More than 20% of acute injuries are misdiagnosed, leading to chronic or neglected ruptures.3
■ Most authors define chronic rupture as a rupture with a delay in diagnosis or treatment for more than 4 weeks.2,8,9

ANATOMY
■ The two heads of the gastrocnemius (medial and lateral) arise from the condyles of the femur, the fleshy part of the muscle extending to about the middle of the calf. As the muscle fibers descend they insert into a broad aponeurosis, which contracts and receives the tendon of the soleus on its deep surface to form the Achilles tendon.14
■ The Achilles tendon is the thickest and strongest tendon in the body. About 15 cm long, it originates in the middle of the calf and extends distally to insert into the posterior surface of the calcaneum. Throughout its length, it receives muscle fibers from the soleus on its anterior surface.14

PATHOGENESIS
■ The most common mechanism of injury is pushing off with the weight-bearing forefoot while extending the knee. However, sudden unexpected dorsiflexion of the ankle or violent dorsi-flexion of a plantarflexed foot may also result in ruptures.4
■ Corticosteroids, fluoroquinolones, previous tendon pathology, and poor vascularity of the Achilles tendon have been associated with rupture.4
■ Patients with chronic ruptures of the Achilles tendon recall either minimal trauma or an injury misdiagnosed as an ankle sprain. They commonly complain of a limp and difficulties with activities of daily living, particularly ascending stairs.5

PATIENT HISTORY AND PHYSICAL FINDINGS
■ Methods for examination include the following:
  ▪ Palpable gap. Gap is not always palpable in chronic ruptures.
  ▪ Calf squeeze test (Simmonds test or Thompson test)12: positive or negative. False positive may be possible if plantaris is present and intact.
  ▪ Knee flexion test (Matles test)6: A false positive may occur when there is neurologic weakness of the Achilles tendon.
  ▪ Patients may present with a limp.
  ▪ In acute tendon ruptures, a gap in the Achilles tendon is usually palpable. This gap may be absent in chronic ruptures, as the gap is usually bridged by scar tissue.
  ▪ Active plantarflexion of the foot is usually preserved due to the action of tibialis posterior, the peroneal tendons, and the long toe flexors.
  ▪ The calf squeeze test, first described by Simmonds in 1957,12 but often credited to Thompson, who redescribed it in 1962, is performed with the patient prone and ankles clear of the couch. The examiner squeezes the fleshy part of the calf, causing the deformation of the soleus and resulting in plantarflexion of the foot if the Achilles tendon is intact. The affected leg should be compared to the contralateral leg.
  ▪ The knee flexion test is performed with the patient prone and ankles clear of the table. The patient is asked to actively flex the knee to 90 degrees. During this movement the foot on the affected side falls into neutral or dorsiflexion and a rupture of the Achilles tendon can be diagnosed.6

IMAGING AND OTHER DIAGNOSTIC STUDIES
■ As clinical diagnosis of chronic ruptures can be problematic, imaging can be useful.
■ Plain lateral radiographs may reveal an irregular configuration of the fat-filled triangular space anterior to the Achilles tendon and between the posterior aspect of the tibia and superior aspect of the calcaneus (this space is known as the triangle of Kager).
■ Ultrasonography of a chronic rupture usually demonstrates an acoustic vacuum with thick irregular edges (FIG 1).
■ T1-weighted MR images will show disruption of signal within the tendon substance, while T2-weighted images show generalized high signal intensity.

DIFFERENTIAL DIAGNOSIS
■ Acute rupture of the Achilles tendon, rerupture of the Achilles tendon, tear of the musculotendinous junction of the gastrocnemius-soleus and the Achilles tendon.

NONOPERATIVE MANAGEMENT
■ Consensus is that the most appropriate treatment for chronic Achilles tendon ruptures is surgical.8

SURGICAL MANAGEMENT
■ A delay in presentation of Achilles tendon rupture results in filling of the gap between the ruptured tendon ends with fibrous nonfunctional scar, which needs excision. To re-establish tendon continuity, surgeons may consider the use of...
the following: (1) the residual Achilles tendon, (2) adjacent tendons, (3) autologous free tendon grafts, (4) allografts.

Preoperative Planning
- All imaging should be reviewed to estimate the tendon gap.
- If the gap in maximum plantarflexion is 5 to 9 cm, peroneus brevis transfer can be used.
- If the gap is 9 to 12 cm, we recommend a free autologous gracilis tendon graft.
- If these tendons have already been used for other reconstructive procedures, alternative surgical options will have to be considered.

Positioning
- Under general anesthesia, the patient is placed prone with the ankles clear of the operating table.
- A tourniquet is applied to the limb to be operated on. The limb is exsanguinated, and the tourniquet is inflated to 250 mm Hg.

Approach
- The traditional midline longitudinal approach over the Achilles tendon has been associated with wound healing problems and a risk of sural nerve injury when extended proximally.
- We do not use the lateral approach, given the high risk of sural nerve injury.
- We employ a 10- to 12-cm curvilinear approach medial to the medial border of the tendon with sharp dissection through the subcutaneous fat to the paratenon. This incision avoids the sural nerve.
- Maintaining thick skin flaps is vital to reduce the incidence of wound breakdown.

PERONEUS BREVIS TENDON TRANSFER FOR CHRONIC ACHILLES TENDON RUPTURE
- The Achilles tendon is exposed by longitudinal incision of the paratenon in the midline for the length of the skin incision.
- The ends of the Achilles tendon are freshened by sharp dissection, producing a defect between the freshened ends. The proximal stump is gently dissected out and mobilized distally (TECH FIG 1).
- Through the base of the wound, the deep fascia overlying the deep flexor compartment and the compartment containing the peronei muscles can be seen.
- The internervous plane lies between the peroneus brevis (supplied by the superficial peroneal nerve) and the flexor hallucis longus (supplied by the tibial nerve).
- The peroneus brevis tendon can be identified toward the medial side.
- The tendons of the peroneus longus and brevis can be distinguished from each other at this level by the fact that although both are tendinous in the distal third of the lower leg, the peroneus brevis is muscular more distally than the peroneus longus. The deep fascia overlying the peroneal tendons is incised and the peroneal tendons are mobilized.
- Make a 2.5-cm longitudinal incision over the base of the fifth metatarsal. Identify the peroneus brevis tendon, place a stay suture in the distal end of the peroneus brevis tendon, and detach the tendon from its insertion and mobilize it proximally.
- Deliver the tendon through the posteromedial wound using gentle continuous traction as it is pulled through the inferior peroneal retinaculum. In this fashion, the tendon of the peroneus brevis retains its blood supply from the intermuscular septum.
- Weave the peroneus brevis tendon through the Achilles tendon ends.

TECH FIG 1 • Repair of chronic Achilles tendon rupture with peroneus brevis. A. Tendon ends are débrided to demonstrate true defect. B. Proximal stump mobilized into wound. C. Incision made over insertion of peroneus brevis on the base of the fifth metatarsal. (continued)
First pass it from lateral to medial through the distal stump via coronal incisions medially and laterally in the Achilles tendon.

- Suture the edges of the coronal incisions in the Achilles tendon to the peroneus brevis tendon to prevent progression of the incision that would lead to the peroneal tendon cutting out through the Achilles tendon.

- Pass the tendon through the proximal stump from medial to lateral, with the foot maximally plantarflexed.

- Suture the peroneal tendon to the Achilles tendon stumps using 3-0 Vicryl. This is usually sufficient, but, if there is a very large defect, the tendon of the plantaris can be harvested, if present. This is then used to reinforce the reconstruction.

- In most cases of neglected ruptures of the Achilles tendon, the paratenon is either not present or not viable. If present, one can generally manage to close it over the proximal stump using 2-0 Vicryl.

- Close the skin with a continuous 2-0 subcuticular Vicryl suture. Steri-Strips are applied and the wound is dressed.

- The tourniquet is deflated and the time recorded.

---

**FREE GRACILIS TENDON GRAFT FOR CHRONIC RUPTURES OF THE ACHILLES TENDON**

- Make a 12- to 15-cm longitudinal, slightly curvilinear skin incision medial and anterior to the medial border of the Achilles tendon.

- The paratenon, if not disrupted, is incised longitudinally in the midline for the length of the skin incision.

- The Achilles tendon is thus exposed, and gentle continuous traction is applied to the proximal stump of the ruptured tendon to further deliver it into the wound (**TECH FIG 2**).

- Excise scar tissue in both the proximal and distal stumps to reach viable tendon.
If the remaining gap in the Achilles tendon is greater than 9 cm, we proceed to harvest the gracilis tendon.

Make a vertical 2- to 3-cm longitudinal incision on the medial aspect of the tibial tuberosity, centered over the distal insertion of the pes anserinus.

A venous plexus is often encountered at the distal end of the wound, and care should be taken to diathermy this.

Carry out dissection deep to the fat both medially and superiorly with a small swab on an artery forceps to expose the sartorius fascia.

Insert a curved retractor and make a curved incision, 1 cm long, along the superior margin of the pes anserinus into the sartorius fascia, taking care to avoid the saphenous nerve.

Use blunt dissection with Mackenrodt scissors to produce a window within the superior border of the sartorius allowing access to the tendon of gracilis.

The gracilis tendon lies more superiorly than the neighboring tendon of the semitendinosus and can be retrieved with a curved Moynihan clip.

As the tendon is brought into the wound, use of an arthroscopic probe helps to identify the possible tendon’s proximal vincular attachments. The vincula are sectioned to achieve distal traction on the tendon.

Before using a tendon stripper to harvest the tendon, all attachments to the tendon must be completely released. An assistant places his or her hand over the calf, and, by applying firm traction longitudinally, excludes the presence of remaining tendinous attachments by the absence of calf tethering.

Harvest the gracilis tendon with the tendon stripper by directing the instrument in line with the tendon fibers, parallel to the thigh.

Imaging can be useful in clinching the diagnosis and in preoperative planning. The tendon must be completely freed of its attachments before harvesting. Diagnosis is usually made on a clinical basis, but this can be difficult in cases of chronic rupture. For defects greater than 9 cm we recommend free gracilis graft. We recommend peroneus brevis transfer for Achilles tendon defects less than 9 cm.

A incision placed medial and anterior to the medial border of the Achilles tendon reduces the likelihood of sural nerve injury. Patients are encouraged to increase the frequency of their exercise. Cycling and swimming are started at 8 weeks postoperatively. Patients are allowed to return to their sport at the fifth postoperative month.

POSTOPERATIVE CARE

- Before the patient is taken off the operating table, a below-knee plaster-of-Paris cast is applied to the operated leg, with the patient prone and the ankle in maximal equinus.
- The operated leg is elevated until discharge.
- Patients are usually discharged on the day after surgery after having been taught to use crutches by an orthopaedic physiotherapist.
- Thromboprophylaxis is provided with Fragmin 2500 units (dalteparin sodium) subcutaneously once daily, or with 150 mg acetylsalicylic acid orally daily until removal of the cast.
- Patients are told to bear weight on the operated leg as able, but to keep it elevated as much as possible at home for the first 2 postoperative weeks.
- The cast is removed at the second postoperative week, and a synthetic anterior below-knee slab is applied with the foot in maximal equinus.
- The synthetic slab is secured to the leg with three or four removable Velcro straps for 4 weeks.
- Patients can graduate to full weight bearing as soon as comfort allows.
- A trained physiotherapist supervises the introduction of gentle mobilization exercises of the ankle, isometric contraction of the gastrocsoleus complex, and gentle concentric contraction of the calf muscles. Inversion and eversion of the ankle is also encouraged.
- At 6 weeks postoperatively, the patient is followed up and the anterior slab removed.
- Physiotherapists supervise gradual stretching and strengthening exercises.
- Patients are usually discharged on the day after surgery.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Diagnosis is usually made on a clinical basis, but this can be difficult in cases of chronic rupture. The imaging can be useful in clinching the diagnosis and in preoperative planning.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indications</td>
<td>We recommend peroneus brevis transfer for Achilles tendon defects less than 9 cm. For defects greater than 9 cm we recommend free gracilis graft.</td>
</tr>
<tr>
<td>Positioning</td>
<td>Prone position, with thigh tourniquet</td>
</tr>
<tr>
<td>Incision</td>
<td>An incision placed medial and anterior to the medial border of the Achilles tendon reduces the likelihood of sural nerve injury.</td>
</tr>
<tr>
<td>Gracilis harvesting</td>
<td>The tendon must be completely freed of its attachments before harvesting.</td>
</tr>
</tbody>
</table>

OUTCOMES

- We have reported on 22 patients with chronic Achilles tendon ruptures using peroneus brevis tendon transfer. All were satisfied with the procedure. Despite subjective patient satisfaction, however, objective evaluation demonstrated greater loss of isokinetic strength variables at high speeds, and greater loss of calf circumference when compared with patients undergoing open repair of fresh Achilles tendon ruptures. Gallant et al assessed eversion and plantarflexion strength after repair of Achilles tendon rupture using peroneus brevis tendon transfer and found mild objective eversion and plantar flexion weakness. However, subjective assessment revealed no functional compromise.
- In a study by Pintore et al, 21 patients treated with a free gracilis graft, 2 had excellent results, 15 had good results, and 4 had fair results. All returned to their preinjury occupation. Fifteen returned to leisure activities, including sports such as tennis, squash, and bowling.
- Maximum calf circumference was significantly decreased in the operated leg at both presentation and follow-up.
- The operated limb showed a lower peak torque than the nonoperated one, but patients did not perceive this as hampering their daily or leisure activities.

COMPLICATIONS

- Wound healing problems
- Infection
- Sural nerve injury
- Rerupture of Achilles tendon
- Deep vein thrombosis
REFERENCES

DEFINITION
- Chronic Achilles tendon ruptures are defined as those of greater than 3 months’ duration.
- There are three indications for this technique:
  - A defect between healthy ends of tendon of at least 5 cm. Procedures using local tissue or autograft tendon augmentation generally suffice for lesser defects.
  - An expectation of recovery of function that would not be provided by Achilles tendon direct repair or advancement or flexor hallucis longus transfer
  - Failed reconstruction using autologous tendon advancement or augmentation
- This technique may also be considered for patients with severe chronic Achilles tendinopathy that warrants resection of an extensive degenerated section of the tendon, leaving a gap similar to that observed in chronic Achilles tendon rupture.

ANATOMY
- The Achilles tendon is the condensation of the two heads of the gastrocnemius and soleus muscles. The musculotendinous junction is about 6 to 8 cm from its insertion into the central third of the posterior calcaneus.
- The enthesis is composed of cartilage and fibrocartilage, typically over an area of 6 cm². The posterior calcaneal tuberosity and retrotalar bursa lie anterosuperiorly.
- The tendon is surrounded by paratenon consisting of both parietal and visceral layers. These relatively pliable layers provide tendon blood supply, nutrition, and lubrication. The approximate physiologic excursion of the Achilles tendon is 1.5 cm.
- Blood supply, from vessels running the entire length of the paratenon, approach the tendon from its anterior surface via the mesotenon. The concentration and diameter of these vessels vary along the course of the paratenon, with the fewest being at the relatively hypovascular area 4 cm proximal to the insertion. The blood supply at the Achilles insertion on the calcaneus is also relatively avascular.¹

PATHOGENESIS
- Rupture occurs when the tendon is stressed beyond its yield point. The magnitude of this depends on the force and speed of loading, cross-sectional area of the tendon, and diminution of tendon quality by any pathologic process.
- Predisposing factors
  - Achilles tendinopathy
  - Corticosteroids (oral or locally infiltrated), anabolic steroids
  - Low normal level of exercise, aging
  - Gout, hyperthyroidism, renal insufficiency, arteriosclerosis
  - Fluoroquinolones
- Pathogenesis of tendinopathy and chronic tears
  - Chronic Achilles tendon tears most commonly occur with preexisting tendinopathy, tendinopathy that frequently was asymptomatic. Eighty percent of tears occur in the relatively hypovascular area 2 to 6 cm above the insertion; the second most common location for tendinopathy or chronic tears to develop is at the insertion on the calcaneus.
  - Tendinopathy is a result of microtrauma, hypovascularity, degeneration, and failure of healing. With progression, fibrovascular proliferation from the paratenon, accompanied by a marked lymphocytic and histiocytic response, develops in the degenerative tendon, leading to fibrinous and myxomatous degeneration of the Achilles tendon. These changes decrease the threshold for tendon rupture.
  - Pathologic changes in untreated ruptures
    - There is initial retraction of the tendon ends due to inherent muscle tension.
    - Within 2 weeks, fibrous organization of the tendon ends and hematoma occur.
    - There is a gradual transformation in shape of the tendon ends, with the distal and proximal portions respectively becoming more bulbous and conical. Moreover, the tendon ends tend to adhere to the investing fascia of the deep posterior compartment.
    - The hematoma in the gap between the tendon ends gradually organizes into fibrous scar tissue, which appears to reestablish tendon continuity but lacks contractile strength.
    - The fibroblasts remain disorganized rather than aligning in a physiologically correct longitudinal formation.
    - The resultant fibrous mass is rarely capable of withstanding the physiologic tensile forces of the gastrocnemius–soleus complex and thus develops further elongation and weakness.
- Rupture of the Achilles tendon may lead to (1) loss of plantarflexion power, (2) lack of control of the second rocker during the stance phase of gait, and (3) subjective and objective decrease in ankle stability.¹²,¹³

NATURAL HISTORY
- Most chronic ruptures present in older patients.
- Occasionally a prodrome of Achilles tendon symptoms is reported; however, there may have been only the typical palpable and visual changes that occur with tendinopathy.
- The patient will describe a sudden onset of pain of varying intensity either on stumbling (eccentric loading) or on push-off (concentric loading).
- The pain is usually associated with swelling and weakness, although if the tendon was previously dysfunctional due to tendinopathy, the difference may be small.
- Medical attention is often not sought because plantarflexion function, albeit weak, remains due to the contribution of the other ankle plantarflexors (flexor hallucis longus, flexor digitorum longus, peroneal tendons, and the posterior tibial tendon).
- The amount of disability with an untreated rupture is often determined by the patient’s premorbid status.
PATIENT HISTORY AND PHYSICAL FINDINGS

Physical examination methods include the following:

- Thompson–Simmond test: Abnormal result signifies a functional tear of Achilles tendon.
- Plantarflexion power: A score less than 4 indicates that a tear is likely; a score of 4 or 5 indicates that a tear is unlikely.
- Palpation of gap between tendon ends gives some indication of repair technique, should surgical reconstruction be considered.
- Gap in tendon: Mild = end-to-end repair; Moderate = V–Y advancement; severe = Achilles tendon allograft
- A complete history and physical examination should be done to determine associated injuries and predisposing factors.
- Inspection:
  - Gap in tendon
  - Calf atrophy
  - Resting tension of the foot with the patient prone and knee flexed, relative to the uninjured contralateral extremity
- Gait:
  - Antalgic
  - Vertical oscillation of pelvis with increased hip and knee flexion
  - Ankle instability
- Palpation of gap between tendon ends gives some indication of repair technique, should surgical reconstruction be considered.
  - 1 to 2 cm: usually end-to-end repair with or without tenodesis augmentation
  - 2 to 5 cm: usually V–Y advancement with or without tenodesis augmentation
  - More than 5 cm: autograft or allograft tendon transfer or reconstruction
- Range of motion: excessive dorsiflexion (FIG 1)
- Plantarflexion:
  - May still be present due to recruitment of tibialis posterior, flexor hallucis longus, flexor digitorum longus, and peroneal tendons
  - Decreased power
- Thompson–Simmond test
  - Premorbid conditions: skin quality, smoking, neurovascular status, diabetes mellitus

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Imaging studies for chronic Achilles tendon ruptures are typically not indicated.
- Plain radiographs may reveal calcification within the tendon, suggestive of a degenerative process leading to rupture.

NONOPERATIVE MANAGEMENT

- The extent of nonoperative treatment depends on level of symptoms and required level of functional improvement. Despite the seemingly devastating functional consequences of chronic Achilles tendon rupture, not all patients require a reconstructive procedure.

- Bracing:
  - The level of hindfoot and ankle stabilization required is determined by the power of plantarflexion power afforded by secondary muscles and to a lesser extent by the patient’s weight.
  - A relatively lightweight carbon-fiber ankle–foot orthosis (AFO) may enhance gait during push-off by transferring elastic recoil gained during dorsiflexion to plantarflexion to compensate for lack of Achilles tendon function. In our experience, this treatment is less suitable for heavier patients.
  - A clamshell AFO that encompasses the foot and ankle may be of greater benefit than a traditional AFO for patients with a combination of severe loss of plantarflexion function and poor ankle stability. The addition of an anterior component to the conventional AFO provides the advantage of resisting excessive ankle dorsiflexion.
  - In select patients, a double-upright brace attached to a stiffer-soled shoe and locked at the ankle may be as effective as a conventional or clamshell AFO.

- Physical therapy:
  - Physical therapy should focus on strengthening the secondary ankle plantarflexors (flexor hallucis longus, flexor digitorum longus, posterior tibial tendon, and peroneals)
  - Gait training, stabilization, and proprioception exercises

SURGICAL MANAGEMENT

- Advantages of allograft versus autograft:
  - No morbidity or loss of function and pain from donor site
  - Quality and amount of autogenous tendon may be insufficient
  - Shorter operative time as no harvesting is required
  - Satisfactory mechanical properties of allograft are proven

- Disadvantages:
  - Cost
  - Theoretical risk of transmission of host infectious diseases
Preoperative Planning
- Vascular status is assessed.
- The surgeon should ensure that the posterior lower leg skin is amenable to surgical intervention; if concern exists, the threshold for plastic surgery consultation should be low.
- The contralateral limb is assessed for natural resting tension of the gastrocnemius–soleus complex.
- Imaging studies, if obtained, may provide some understanding of the extent of degenerated Achilles tendon.

Positioning
- Before positioning, a well-padded tourniquet is applied. This should be on the thigh as to prevent tethering of the gastrocnemius–soleus complex and potential inaccuracies in allograft tensioning.
- We prefer a popliteal block for postoperative pain management in conjunction with general anesthesia to permit the patient to tolerate the thigh tourniquet. Depending on surgeon preference, a more proximal regional anesthetic, spinal, or epidural may be considered. The advantage to a popliteal block is improved leg function and potentially safer mobilization in the immediate postoperative period, since the proximal limb girdle muscle function is not forfeited.
- Prone positioning with adequate padding, maintenance of airway, avoidance of brachial plexus tension, and safe positioning of the patient’s genitalia are all important.

Approach
- A posterior approach to the distal lower leg is used with a midline incision of about 20 cm centered over the Achilles tendon and central posterior calcaneus. While this is our preferred technique, the surgical approach must respect prior surgical approaches to the Achilles tendon (FIG 2).

ALLOGRAFT RECONSTRUCTION OF CHRONIC ACHILLES TENDON RUPTURE
- The Achilles tendon allograft tissue, comprising the distal Achilles tendon with its insertion into a block of allograft calcaneus, is carefully inspected to ensure it has been properly screened, has not expired, and is appropriate for the proposed procedure.
- Make a longitudinal incision in the midline. If preexisting incisions are present, maintain a midline approach as best as possible while respecting the previous approach or approaches.
- Create full-thickness flaps and retract only the deeper tissues to minimize wound complications.
- Incise the tendon sheath longitudinally and reflect it.
- Define and mobilize the tendon ends.
- Débride the proximal tendon end, leaving only healthy tendon. With allograft Achilles tendon reconstruction, the distal Achilles tendon stump is resected completely (TECH FIG 1).
- Contour the block of allograft calcaneus attached to the Achilles allograft with a saw, rongeur, or both for insertion and fixation into the patient’s calcaneus.
- Use an oscillating saw to create a matching corticocancellous trough in the posterior aspect of the patient’s calcaneus. We prefer to use a flexible chisel to fine-tune this trough, which will accommodate the allograft bone (TECH FIG 2).
- After fully inserting the allograft’s bony portion into the patient’s calcaneal trough, secure the bony block using two fully threaded cancellous 4.0-mm titanium screws (DePuy ACE Screw System, Warsaw, IN) (TECH FIGS 3–5).
Insert a running nonabsorbable no. 2 whip suture (Ethibond, Ethicon, Somerville, NJ) on either side of the allograft tendon (TECH FIG 6).

By proximally tensioning the sutures, the ankle assumes a position of maximum equinus as the graft spans the defect. This tension is maintained until the allograft is adequately secured to the patient’s residual native Achilles tendon, with the no. 2 nonabsorbable suture being woven into the host tissue or secured to a symmetric no. 2 whip suture placed into the host tissue.

With healthy residual proximal host Achilles tendon, we recommend performing an end-to-end repair between allograft and host tendon. When the patient’s residual tendon is adequate but with suspect quality at the most distal portion of the host tissue, we routinely perform an overlapping, imbricated reconstruction.

Augment the repair or reconstruction with a running 2–0 Vicryl suture (Ethicon).

Close the paratenon with 4-0 Vicryl.

Reapproximate the subcutaneous layer with 4-0 Vicryl and close the skin with 4-0 nylon, while maintaining careful handling of the skin margins.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Indications</th>
<th>Careful assessment of soft tissues and cause of the chronic Achilles rupture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach</td>
<td>Delaminating of skin flaps must be avoided; full-thickness flaps must be created. Retractors are not to be placed on the skin margins; only deep retraction of full-thickness flaps should be performed.</td>
</tr>
<tr>
<td>Achilles tendon débridement</td>
<td>Débridement of diseased tendon must be adequate to leave only healthy host Achilles tendon.</td>
</tr>
<tr>
<td>Graft tensioning</td>
<td>Maximum equinus positioning during graft tensioning to optimize graft resting tension at follow-up</td>
</tr>
<tr>
<td>Skin coverage</td>
<td>Careful respect of soft tissue, meticulous closure, and appropriate immobilization typically lessen soft tissue complications.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

■ Immobilization in equinus in a bulky splint for 2 weeks
■ Suture removal at 2 weeks
■ Immobilization in a hinged cam walker (Bledsoe Platform Boot, Medical Technology Inc., Grand Prairie, TX) set to neutral dorsiflexion block and block at 20 degrees of plantarflexion. The foot is kept in equinus by inserting heel pads into the boot.
■ Partial weight bearing (25 kg) is commenced at 2 weeks. This is increased by increments of 25 kg per week until full weight bearing is achieved.
■ At 8 to 10 weeks the boot is swapped for a 1- to 2-cm heel raise inside a shoe.
■ Gentle passive and active range-of-motion exercises and isometric exercises are commenced at 4 weeks.
■ Gentle passive stretching is started at 4 weeks and effort is gradually increased until at 10 weeks, standing calf-stretching exercises are commenced.
■ Elastic band exercises are started upon removal of the boot. Stationary bike riding is started at 10 to 12 weeks, with gradual progression of exercise up to 18 weeks, when active push-off exercises are initiated.

OUTCOMES

■ In our hands, outcomes with this technique have been satisfactory and without wound complications (FIG 3).
■ Typically, at 20 weeks the patient can perform single-leg toe-raises and begin jogging and light sporting activities, if previously able (FIG 4).
■ In our experience, most patients return to their preoperative exercise level and return to their prior occupation.

COMPLICATIONS

■ Infection
■ Wound dehiscence
■ Rupture of repair
■ Incorrect tensioning
■ Aseptic necrosis of graft

REFERENCES

SURGICAL MANAGEMENT
- Indications include neglected ruptures requiring secondary repair or revision surgery.
- Soft tissue expansion over the Achilles tendon and subsequent repair of the tendon are performed as a staged, two-part procedure about 3 to 4 weeks apart.
- This can be particularly effective when performing augmented procedures that increase the girth at the distal tendon or when the local skin is contracted.

Preoperative Planning
- MRI studies are reviewed to determine the ideal placement of the expander and to plan second-stage repair.
- The patient is instructed on the rationale for the staged procedure and the importance of weekly follow-up visits between each stage.

IMPLANTATION OF EXPANDER
- The initial stage of treatment involves subcutaneous placement of a 70-mL, rectangular soft tissue expander (McGhan, Santa Barbara, CA) between the Achilles tendon and the skin (TECH FIG 1).
- After sterile preparation, make a longitudinal incision along the medial aspect of the ankle, adjacent to the course of the Achilles tendon.
- Perform superficial subcutaneous elevation until a pocket about 6 × 4 cm is created.
- Insert a McGhan tissue expander into this cavity and place the injection catheter away from the implant.
- Subcuticular closure is followed by reapproximation of the skin.
- 10 mL of normal saline is initially injected into the implant via the injection port.
- The patient is seen 1 week postoperatively for further inflation of the implant.
- Ten mL of normal saline is added to the expander weekly.

REMOVAL OF EXPANDER AND TENDON REPAIR
- The expander is removed 3 to 4 weeks postoperatively (TECH FIG 2). At that time, removal of the tissue expander and Achilles repair are performed.
- The previously created incision is accessed and extended as necessary. The expansion balloon is then easily removed from its subcutaneous pocket.
- Surgical repair of the injured tendon is carried out in the surgeon’s preferred fashion.

Positioning
- The prone position allows the best access when approaching the Achilles tendon.
- A well-padded pillow is placed underneath the knees and anterior tibia–ankle.
- This allows for free plantarflexion and dorsiflexion of the ankle.

Approach
- The preferred approach is a posteromedial incision adjacent to the Achilles tendon. This allows the surgeon to avoid injury to the short saphenous vein and sural nerve.
- Simple extension of the incision is performed for the second-stage definitive repair.
- The posteromedial incision may be extended into a lazy-S, L shape, or a direct medial approach.

TECH FIG 1 • McGhan 70-mL soft tissue expander.

TECH FIG 2 • Inflated soft tissue expander in place subcutaneously.
PEARLS AND PITFALLS

**Indications**
- This technique should be avoided in patients with diabetes, peripheral vascular disease, immunocompromise, or a history of tobacco use.

**Soft tissue expander inflation**
- Patients rarely tolerate more than 30 to 40 cc of total volume within the implant. The expansion rate may need adjustment (from 10 mL/week) depending on individual skin pliability.

POSTOPERATIVE CARE
- After the initial stage of insertion, the patient is followed weekly for subsequent expander inflation. The inflation rate is 10 mL per week for 3 to 4 weeks.
- After expander removal and second-stage reconstruction the operative limb is placed into a short-leg splint in 10 to 15 degrees of plantarflexion.
- Non-weight-bearing with immobilization in a short-leg cast is maintained for 3 weeks. Range-of-motion exercises are initiated at 3 to 4 weeks postoperatively. Finally, weight bearing is allowed at 6 weeks after surgical repair (FIG 1).

OUTCOMES
- This technique has been used successfully in our practice with no complications related directly to soft tissue expansion.

COMPICATIONS
- Infection
- Seroma
- Sural nerve injury
- Fibrotic reaction

REFERENCES
DEFINITION

- Patrick Haglund in 1928 described an enlarged posterior border of the os calcis.3
- This anatomy, Haglund deformity, becomes very important when external shoeing and repeated hyperdorsiflexion causes contact between the Achilles tendon, the retrocalcaneal bursa, and the posterior proximal border of the calcaneus.
- As a result, Haglund syndrome is commonly characterized by inflammation within the retrocalcaneal or Achilles tendon bursa and often secondarily presents as insertional Achilles tendinopathy.
- The posterior heel pain and swelling associated with Haglund syndrome is the result of mechanical irritation by the calcaneal prominence on the surrounding soft tissues and the Achilles tendon.
- After conservative measures have failed, Haglund deformity and retrocalcaneal bursitis can be treated surgically using either an open or an endoscopic technique.
- The endoscopic technique is an outpatient treatment that is associated with low morbidity and high outpatient satisfaction. There is a short recovery time and a short time to gain preprocedure activity level.
- Appropriate visualization of the Achilles tendon and removal of the calcaneal prominence and retrocalcaneal bursa can be effectively accomplished using an endoscopic technique.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Clinical evaluation may help differentiate between retrocalcaneal bursitis and Achilles tendinopathy, although the two often coexist.
- Pathology within the retrocalcaneal space is detected on clinical examination with point tenderness along the anteromedial and anterolateral aspects of the Achilles tendon and an associated prominence of the calcaneus.
- Palpation of the affected hindfoot often reveals tenderness at the distal portion of the Achilles tendon proximal to its insertion on the calcaneus. The pain can be reproduced with passive or active dorsiflexion.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Imaging can assist with documenting the presence or absence of tendinopathy (FIG 1A).
- It can be difficult to distinguish whether symptoms are caused by retrocalcaneal bursitis or insertional Achilles tendinitis or tenosynovitis, and the two conditions often coexist.
- MRI can be used preoperatively to better demonstrate the coexistence of the two diagnoses (FIG 1B).
- Normal-appearing and diseased tendons can be distinguished endoscopically.

NONOPERATIVE MANAGEMENT

- Nonoperative measures for the treatment of posterior heel pain include the use of nonsteroidal anti-inflammatory medication, shoe wear modification (such as avoiding backless shoes), physical therapy for icing, other modalities, stretching exercises, pressure-release inserts, and hands-on friction massage.
- Local injections can be given in the retrocalcaneal space, but the concomitant use of local anesthesia and corticosteroids may further weaken the substance of the Achilles tendon and risk weakness and further micro- or macro-rupture of the tendon.4

PATHOGENESIS

- The retrocalcaneal space has been described as a disc space bursa covering the posterior superior angle of the calcaneus.2 The bursa walls may become diseased and hypertrophied with repeat hindfoot movement.
- Achilles tendinopathy is a degenerative process within the tendon substance causing microtears, edema, and reactive fibrosis with scar formation. These changes cause secondary mechanical irritation of the surrounding tissues and can even stimulate an inflammatory process.
SURGICAL MANAGEMENT

- The goal of treatment of Haglund deformity and syndrome is to remove the calcaneal prominence and to decompress the inflamed surrounding soft tissues.
- Open surgical correction is an alternative for patients who have failed to respond to nonoperative measures, especially if augmentation is advisable.
- Open procedures include resection of the calcaneal prominence proximal to the Achilles tendon insertion with retrocalcaneal bursa removal.
- A dorsal closing wedge osteotomy can rotate the posterior calcaneus to less prominence.
- Achilles tenolysis and partial resection of the diseased portion of the tendon may be necessary, often with augmentation by the flexor hallucis longus or flexor digitorum.
- Complete Achilles removal at its insertion is occasionally necessary.
- Complications associated with these procedures include hematomas, tendon or skin breakdown, nonunion, Achilles tendon avulsion, tenderness around the operative scar, cosmetic problems, altered sensation around the heel, and stiffness. Rehabilitation can be prolonged.
- The endoscopic technique of decompressing the retrocalcaneal space was developed to reduce morbidity and decrease the functional time to recovery for patients with retrocalcaneal bursitis.

Positioning

- The operation is performed with the patient in the supine position and under either general or regional anesthesia.
- A high thigh tourniquet is inflated to 300 mm Hg after Esmarch ischemia.
- The foot is positioned at the edge of the operating table. This enables the surgeon to place the foot against his or her body while using both hands to operate the arthroscopic instruments.
- The leg rests on a firm padded 12-inch-long and 4-inch-diameter cylindrical bump that allows the surgeon ample room to work and to control ankle dorsiflexion and plantarflexion.
- Alternatively, the prone position can be used.
- Both positions allow the patient’s foot to be controlled against the chest of the surgeon, who can then have both hands free for the instruments.

PORTAL PLACEMENT AND EXPOSURE

- Make a lateral portal through a vertical incision at the level of the superior aspect of the calcaneus (TECH FIG 1A).
- The incision is slightly anterior to the Achilles tendon and posterior to the sural nerve. It is important to bluntly dissect and spread the soft tissues when making the lateral portal to minimize the risk of injury to the sural nerve.
- Enter the retrocalcaneal space with a blunt trocar to develop working space.
- Place a 4.0-mm arthroscope into the retrocalcaneal space.
- Establish the medial portal similarly just anterior to the Achilles tendon, using the light of the arthroscope as a guide (TECH FIG 1B).

RESECTION AND DECOMPRESSION

- Introduce a 3.5-mm arthroscopic shaver (for larger hindfeet, a 4.5-mm arthroscope can be used) into the medial portal and remove the bursal tissue. This expanded working space creates visualization and access to the posterior calcaneus and the Achilles tendon attachment.
Depending on the quality of the bone, use either the arthroscopic shaver or a 4-mm arthroscopic burr to resect the posterior superior calcaneal prominence (TECH FIG 2).

- Keep the hooded portions of the instruments toward the anterior direction.
- Take special care to stop the rotating or oscillating shaver or burr usage when the instrumentation enters or exits the portal.
- Carry out the resection both medially and laterally into the sulcus of the calcaneal tendon (retrocalcaneal bursa) and distally to the attachment of the Achilles tendon.
- Visually confirm adequate exposure and resection of the osseous prominence until there are no areas of Achilles tendon impingement.
  - In a few cases, the use of the mini C-arm (Mini 6600 series; GE OEC Medical Systems, Salt Lake City, UT) is needed to determine, document, and confirm adequate resection.
- Damaged or diseased Achilles tendon can be selectively exposed and with a nerve hook or probe identified.
- Limited bone or tendinopathy can be removed with the arthroscopic shaver.
- An 18-gauge needle can be inserted several times into the tendon to promote blood ingress and collagen scar where there is myxoid or degenerative change.
- The rationale for this is to initiate a vascular response within the tendons for healing; it is performed with or without débridement.
- Insert an arthroscopic probe into the retrocalcaneal space to confirm continuing effective attachment of the Achilles tendon.

**COMPLETION AND WOUND CLOSURE**

- Hyper-plantarflex and dorsiflex the foot with the anterior chest and abdomen to verify any last areas of impingement.
- Irrigate and suction the retrocalcaneal space to remove any loose tissue.
- Close the portal sites with two 4-0 nylon skin horizontal mattress sutures.
- Inject local anesthetic (0.25% Marcaine without epinephrine) into the portal sites.
- Apply a compression dressing and splint the foot into slight equinus with the posterior splint and sugar-tong "trilaminar splint."

**PEARLS AND PITFALLS**

- Set up with heels directly at the end of operating room table so can manage position of ankle/foot in dorsiflexion and plantarflexion with chest/abdomen.
- Develop entire operative field from posteromedial to posterolateral corner so panoramic view of Achilles tuberosity attachment.
- MRI is necessary preoperatively to document insertional tendinopathy. If more than 25% of the cross-sectional area of the tendon is involved, open repair may be necessary (author’s opinion).
- Experience enables removal of paratenon and further removal of small ruptures and/or ossification in selected cases and situations.
- Postoperative routine is (a) non-weight-bearing for 2 to 3 weeks, (b) partial weight-bearing for 2 to 3 weeks, and (c) to maximize strength of posterior tibial and peroneals as soon as mobilization permits.
POSTOPERATIVE CARE
- The average time until full weight bearing is 4 weeks.
- Patients wear shoes with a heel counter and return to normal daily function in 8 weeks.
- All athletes returned to their previous level of activity in an average of 12 weeks.
- Patients may need a longer period of cast immobilization after débridement of the Achilles tendon or significant Achilles tendinopathy.

OUTCOMES
- In our study of endoscopic bony and soft tissue decompression of the retrocalcaneal space for the treatment of Haglund deformity and retrocalcaneal bursitis,9 32 heels in 30 consecutive patients underwent endoscopic decompression. The time of surgery after diagnosis of retrocalcaneal bursitis averaged 20 months. All patients had failed to respond to nonoperative measures, and none had undergone previous surgery.
- Indications for operative intervention included failed nonoperative measures, history and physical examinations consistent with retrocalcaneal bursitis, and Haglund deformity causing mechanical impingement or Achilles tendinopathy.
- Patients were prospectively followed from 1997 to 2003, with a mean follow-up of 35 months (range 3 to 62 months).
- Thirty heels completed subjective and objective measures using the American Orthopaedic Foot and Ankle Society (AOFAS) ankle–hindfoot scale.5
  - Twenty-eight patients had an average preoperative AOFAS score of 62 points. Postoperative AOFAS scores averaged 97 points.
  - Twenty-six patients had excellent results and three had good results. There was one poor result and one major complication. An excellent result was defined as pain-free activity with complete return to activity, and a poor result was defined as having persistent symptoms and inability to return to activity.
  - The cohort was stratified into “daily athletic activity” and “athletic” groups and the groups were compared. No statistical differences in outcome between the two groups existed.
  - All patients reported satisfaction with the cosmetic appearance of their portal sites.
- These results compared with those published by van Dijk et al13: their 20 patients resumed participating in sports at an average of 12 weeks.

COMPLICATIONS
- One major complication occurred among the 30 heels: a patient sustained a proximal Achilles tendon rupture (of an unprotected tendon) 19 days after having undergone endoscopic decompression while ambulating without a prescribed protected walker boot.9
- There were no intraoperative or skin or soft tissue complications (ie, wound dehiscence and postoperative infection).
- No patients reported a painful scar or neuroma-type symptoms.

REFERENCES
DEFINITION
- Insertional Achilles tendinopathy is posterior heel pain at the insertion of the Achilles tendon.
- The clinical diagnosis is acute and chronic pathology of the Achilles tendon insertion and its surrounding tissues.

ANATOMY
- The Achilles tendon, the condensation of the gastrocnemius and soleus tendons, inserts on the posterior calcaneal tuberosity.
- The insertion is not only posterior but also on the medial and lateral aspects of the calcaneus.
- A dorsal-posterior calcaneal prominence is most obvious on a lateral radiograph. The Achilles tendon inserts distal to this, directly posterior on the calcaneus.
- Between the distal Achilles tendon and the dorsal-posterior calcaneal prominence, immediately proximal to the Achilles insertion, is the retrocalcaneal bursa.
- A pre-Achilles bursa is superficial to the distal Achilles tendon.

PATHOGENESIS
- While not fully understood, repetitive microtrauma to the Achilles tendon insertion is thought to be the cause.
- Most likely some initial injury occurs, followed by multiple minor reinjuries that lead to chronic symptoms.
- In the acute phase, the process may have some inflammatory characteristics; however, the chronic process is degenerative, with a relative paucity of inflammatory tissue.
- Without histologic confirmation, the diagnosis of Achilles tendinitis or tendinosis cannot be made; therefore, the pathologic process at the Achilles tendon insertion is viewed as “tendinopathy” without tissue confirmation.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The patient may recall an inciting event but typically reports chronic activity-related aching or even sharp pain at the posterior heel.
- In addition, the patient notes a progressively enlarging prominence on the posterior heel.
- This ache is usually accompanied by exquisite tenderness directly posteriorly on the calcaneus, at the Achilles tendon insertion, with manual pressure, on contact from the shoe’s heel counter, or when the posterior heel is rested on a hard surface.
- Putting the Achilles tendon on stretch aggravates the symptoms, such as when the patient walks uphill.
- Physical examination reveals the following:
  - A prominence is evident on the posterior heel, at the Achilles tendon insertion (FIG 1).
  - Tenderness is felt directly on the posterior calcaneal prominence.
  - No tenderness is found in the Achilles tendon proximal to its insertion on the calcaneus.
  - Thompson’s test is negative.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- A lateral weight-bearing radiograph of the foot often demonstrates irregularities and calcifications at the Achilles tendon insertion on the posterior calcaneus (FIG 2A).
- While unnecessary to make the diagnosis, magnetic resonance imaging (MRI) defines the extent of tendon involvement at the insertion and the presence of retrocalcaneal and perhaps even pre-Achilles bursitis (FIG 2B).

DIFFERENTIAL DIAGNOSIS
- Pre-Achilles bursitis
- Retrocalcaneal bursitis
- Calcaneal stress fracture
- Haglund’s deformity (prominent dorsal-posterior calcaneal tuberosity impinging on the Achilles tendon)
- Calcaneal stress fracture
- Posterior ankle impingement
- Plantar fasciitis
- Noninsertional Achilles tendinopathy

NONOPERATIVE MANAGEMENT
- Activity modification (avoidance of activities that place the Achilles tendon on stretch)
- Nonsteroidal anti-inflammatory agents
- Heel lift or a shoe with a heel to unload the Achilles tendon
- Open-backed shoe or a shoe with a soft heel counter

FIG 1 • Example of posterior calcaneal prominence characteristic of insertional Achilles tendinopathy.
Physical therapy
- Focus on eccentric strengthening exercises
- In our experience the common practice of aggressive Achilles stretching must be avoided as it will aggravate the symptoms.
- Modalities: ultrasound, iontophoresis
- Extracorporeal shockwave therapy may have some benefit but is largely unproven.
- Corticosteroid injection may lead to Achilles rupture and is contraindicated unless the process is isolated to retrocalcaneal bursitis, in which case a judicious injection of only the retrocalcaneal bursa can be performed.

SURGICAL MANAGEMENT
- The primary surgical indication is nonoperative management.
- Up to 50% of insertional Achilles tendinopathy can be successfully managed without surgery, even when there is a large posterior calcaneal prominence.
- Insertional Achilles tendinopathy with central calcific tendinosis may be less amenable to nonoperative management.

Preoperative Planning
- Preoperative medical clearance
- Even in healthy patients, the thin skin on the posterior heel is at risk. Carefully inspect skin to be sure that the patient is a reasonable candidate for a posterior approach to the Achilles tendon insertion.
- With extensive Achilles tendon degeneration (confirmed with preoperative MRI), an augmentation of the insertion may be warranted. Therefore, preoperative planning should include the anticipation that the flexor hallucis longus (FHL) tendon may need to be harvested and transferred to the posterior calcaneus. The FHL tendon lies immediately deep to the deep compartment fascia that is anterior to the Achilles tendon and can readily be harvested through the same approach.
- As a rough estimate, we perform an FHL augmentation in less than 10% of cases but routinely have our preferred anchoring system available should the transfer be warranted.
- We educate all of our patients undergoing surgical management for insertional Achilles tendinopathy that, based on our intraoperative findings, an FHL tendon transfer may be necessary.
- The recovery following surgical management for insertional Achilles tendinopathy is prolonged and may take a full year before the patient returns to full activity. We educate our patients that the recovery is not rapid.

Positioning
- The patient is placed prone on the operating table.
- We routinely inflate the thigh tourniquet with the patient supine on the stretcher, then flip the patient to the prone position on the operating room table. This facilitates proper tourniquet position and avoids stressing the patient’s lumbar spine, which may be stressed when placing the tourniquet with the patient in the prone position.
- The chest and pelvis are well padded.
- The brachial plexi and ulnar nerves at the elbows are protected and relaxed.
- The genitalia are protected.

APPROACH AND REFLECTION OF THE ACHILLES TENDON INSERTION
- A central approach is undertaken, directly over Achilles tendon and posterior calcaneus (TECH FIG 1A).
- The scalpel is moved through skin and into central portion of distal Achilles tendon. Deep incision is continued distally, directly to bone.
- The goal is to avoid unnecessary delamination of the soft tissues and to elevate full-thickness flaps.
- We then elevate medial and lateral slips of Achilles tendon from the calcaneus (TECH FIG 1B,C).
- More than half of the Achilles tendon insertion can be elevated without compromising the integrity of the insertion. One study suggests that up to 75% can be released.
- We elevate the Achilles tendon until all the diseased portion of tendon can be excised.
Another study suggests that the entire insertion of the Achilles tendon should be routinely elevated and excised to ensure that all diseased tissue is removed. Reattachment is facilitated by a proximal Achilles tendon lengthening that also serves to unload the Achilles tendon.

We do not routinely elevate the entire Achilles tendon, but should one or both of the Achilles tendon slips become detached, we have uniformly been able to reattach the tendon to the calcaneus with a successful outcome.

**DÉBRIDEMENT OF THE DISEASED PORTION OF ACHILLES TENDON**

- The diseased portion of tendon is gradually pared from the Achilles insertion, until only healthy fibers remain (**TECH FIG 2A–C**).
- Healthy Achilles fibers have an organized, longitudinal pattern.
- Degenerated Achilles tendon substance is unorganized and may be likened to crab meat (**TECH FIG 2D,E**).
- Calcific tendinosis may be present, and all calcifications within the residual Achilles tendon must be excised (**TECH FIG 2F**).
CALCANEAL EXOSTECTOMY

- Retractors are used to protect the medial and lateral Achilles tendon slips.
- We routinely use a microsagittal saw to perform the exostectomy.
- We first define the exit point on the dorsal calcaneus in order to avoid the tendency to take unnecessary calcaneal bone (TECH FIG 3A).
  - If necessary, a single fluoroscopy spot image may be used to define the trajectory of the saw blade.
  - As a general rule, it is steeper (more vertical) than anticipated (TECH FIG 3B).
- The bony prominence is mobilized with a chisel and removed with a rongeur (TECH FIG 3C,D).
- Commonly, the exostectomy must be “touched up” to remove all of the prominence (TECH FIG 3E).
- With the Achilles tendon slips still protected, the medial and lateral chamfers are removed (TECH FIG 3F,G).
- This helps narrow the heel and reduce the bulk of the residual calcaneus, medial, and lateral prominences that may lead to persistent pressure and impingement experienced by the patient.
- While these chamfers are near the medial and lateral insertion points of the Achilles tendon, typically they can be excised without compromising the residual tendon attachment.
TECH FIG 3 • (continued) D. A rongeur is used to remove the resected bone. E. Touch-up to ensure an appropriate amount of bone was removed and an adequate “healing” cancellous surface is exposed. Chamfer preparation to decompress the lateral (F) and medial (G) dimensions of the prominent calcaneus.

REATTACHMENT OF RESIDUAL HEALTHY ACHILLES TENDON

Primary Sutures

- With only healthy Achilles tendon fibers remaining and the calcaneus decompressed posteriorly, medially, and laterally, the Achilles tendon should be reattached to the calcaneus.
- While one study suggested that up to 75% of the tendon attachment can be released without compromising the integrity of the insertion, we routinely reattach the elevated portion of tendon to the exposed cancellous calcaneal surface.
- In our opinion, reattachment not only strengthens the repair but also facilitates direct tendon healing to the calcaneus.
- We routinely use two or three suture anchors:
  - One anchor for each tendon slip
  - Occasionally, an additional anchor to augment the reattachment of both tendon slips
- The anchors are positioned relatively symmetrically on the exposed cancellous surface, in a position that will allow for each respective tendon slip to be reapproximated to the calcaneus in a balanced fashion (TECH FIG 4A,B).
- The anchors must be strong enough to lift the foot from the bed (TECH FIG 4C–E). If they should fail, we would prefer for them to fail now so we can rectify the problem.

TECH FIG 4 • A. Anchor being started into bone. B. Anchor secured to bone. (continued)
Balancing and Securing the Sutures

- The anchor sutures are then passed in through their respective tendon slip, also in a balanced manner to ensure that the tendon slips have near equal tension once the sutures are secured (TECH FIG 5A–C).
- We routinely check the anticipated tension by pushing the tendon slip to bone while tensioning the sutures after they have been passed through the tendon.
- If the tension does not appear to be equal in the two slips, we readjust the position of the sutures.
- The sutures must not only be tensioned appropriately in the longitudinal plane but must also be balanced well in the medial-to-lateral plane, so that the two tendon slips may also be reapproximated side to side and reconfigure the physiologic Achilles attachment.
- The sutures are then secured (TECH FIG 5D,E). Have the assistant hold the ankle in plantarflexion so that the tendon slips fully contact the calcaneus.
Additional Sutures

- We have a low threshold to place a third suture anchor to further stabilize both Achilles slips distally on the calcaneus (TECH FIG 6A–C).
- Finally, the most distal Achilles fibers are reapproximated to the fascial tissue immediately distal to the calcaneus (TECH FIG 6D,E).
- Avoid trapping fat in this portion of the repair as it may lead to fat necrosis.
- The two Achilles slips are then reapproximated to one another with an absorbable suture (TECH FIG 6F).
- Gently test dorsiflexion. The ankle should typically still reach neutral without compromising the repair. If it does not, however, it is not a problem.
- Patients rarely if ever develop equinus contracture.
- Once the Achilles tendon insertion is again healthy and asymptomatic, it has been our experience that the gastrocnemius and soleus muscles accommodate.
FOOT AND ANKLE • Section V  SPORTS-RELATED PROCEDURES FOR ANKLE AND HINDFOOT

TECH FIG 6 • (continued) F. Reapproximating two tendon slips proximal to the reattachment.

CLOSURE

- Close the paratenon (TECH FIG 7A).
- Reapproximate the subcutaneous tissues (TECH FIG 7B).
- Perform a tensionless closure. We routinely use staples in the proximal wound but favor suture in the distal wound, where the skin does not evert as readily (TECH FIG 7C).
- Sterile dressings, abundant padding, and a posterior splint with the ankle in its resting tension complete the closure.

TECH FIG 7 • Closure. A. Paratenon. B. Subcutaneous tissue. C. Skin (sutures are used distally to ensure that skin margins did not invert).

FLEXOR HALLUCIS TENDON AUGMENTATION

- Only rare patients present with a combination of insertional and noninsertional Achilles tendinopathy.
- Extensive débridement of diseased tendon is required (TECH FIG 8A,B).
- After fasciotomy of the deep compartment, the FHL tendon is identified, the tibial nerve is protected, and the FHL is harvested from its medial fibroosseous tunnel with the ankle and hallux interphalangeal joint in maximum plantarflexion (TECH FIG 8C).
- With this local (short) harvest of the FHL, in contrast to a long harvest from the plantar foot via a separate incision, the tendon length is ample for augmentation of the Achilles reattachment (TECH FIG 8D).
- The FHL tendon is anchored via an interference screw in the central calcaneus, within the exposed cancellous surface created after exostectomy (TECH FIG 8E).
- A suture goes through the plantar calcaneus to allow optimal tensioning of the FHL tendon (TECH FIG 8F).
- Suture anchors for reattachment of the Achilles slips are balanced on either side of the FHL anchor point (TECH FIG 8G).
**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Category</th>
<th>Pearl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcific tendinosis</td>
<td>Be sure not only to débride the unhealthy tendon fibers but also to remove all calcifications within the tendon.</td>
</tr>
</tbody>
</table>
| Reattachment of the healthy Achilles tendon to the calcaneus | The two Achilles tendon slips should be reattached in a balanced manner on the exposed cancellous surface of the calcaneus.  
Before tying the sutures of the suture anchors, check that the tension appears nearly equal for the two tendon slips. |
| Paratenon                        | As for repair of acute Achilles tendon ruptures, be sure to close the paratenon over the tendon. |
| FHL tendon augmentation          | This is an intraoperative decision and, in our experience, rarely necessary. If augmentation is needed, perform an FHL harvest through the same incision via a deep compartment fasciotomy. Be sure to identify and protect the tibial nerve that will be immediately adjacent to the FHL tendon. Transfer the tendon as far posteriorly on the exposed cancellous surface of the calcaneus as possible for the greatest mechanical advantage. |
POSTOPERATIVE CARE

■ Weeks 0 to 2: Posterior splint with the ankle in resting tension of plantarflexion
■ At 2 weeks: Return to clinic for suture removal and casting
■ Weeks 2 to 5: Short leg, plantarflexed (5 to 10 degrees) weight-bearing cast, with weight bearing permitted but use of an assistive device encouraged
■ At 5 weeks: Return to clinic for cast removal and transfer to a cam boot
■ Weeks 5 to 8: Cam walker boot with a 5- to 10-degree heel lift; initiate a physical therapy program, with a gradual progression to careful resistance exercises
■ Weeks 8 to 12: Progression to a regular shoe with a heel lift or an open-back shoe with a slight heel; physical therapy with a progressive eccentric strengthening exercises
■ Between 3 and 6 months: return to full activities; home program for physical therapy
■ It may take a full year before patients “can forget about this Achilles tendon.”
■ Maintain independent basic physical therapy exercises for a lifetime.

OUTCOMES

■ Most patients undergoing surgical management of insertional Achilles tendinopathy have good to excellent results, albeit without returning to full activity for 6 to 12 months.
■ However, most studies note that there are patients that do not return to full activity and while they are improved, they are not pain-free.
■ Johnson et al5 reported a mean improvement in the AOFAS ankle outcomes score from 53 to 89 points for 22 patients at 34 months’ average follow-up.
■ McGarvey et al9 noted an 82% satisfaction rate in 22 patients at mean follow-up of 33 months. Thirteen of 22 patients were pain-free and and an equal number could return to full activities.

COMPLICATIONS

■ Wound dehiscence
■ Infection
■ Avulsion of Achilles tendon from anchors on calcaneus
■ Persistent pain despite apparent successful procedure
■ Suture reaction or irritation

REFERENCES

DEFINITION
- Calcific Achilles tendinopathy is the most common cause of posterior heel pain.
- Intratendinous degeneration results in ectopic calcification and ossification at the Achilles tendon insertion to the calcaneus.

ANATOMY
- The Achilles tendon inserts over the inferior half of the posterior calcaneal tuberosity (FIG 1).
- The insertion expands over the tuberosity to become the calcaneal periosteum.
- The inferior half of the posterior calcaneal tuberosity has a rough surface with an extensive Sharpey fiber network.
- The superior half of the posterior calcaneal tuberosity has a smooth, almost articular surface.
- The retrocalcaneal bursa occupies the interval between the Achilles tendon and the superior half of the posterior calcaneal tuberosity. The bursa also extends superiorly over the posterosuperior process of the calcaneus.
- The ossification–calcification typically develops at the insertion, extends proximally into the tendon, and may comprise several segments within the more proximal tendon.

PATHOGENESIS
- The pathogenesis is not well understood.
- Two patient groups are typically affected: athletically active individuals in their 30s and 40s and overweight women in their 50s and 60s.
- Biochemical and histologic findings include:
  - Degenerative changes
  - An anaerobic environment
  - Longitudinal tears of the Achilles tendon
  - Chondral metaplasia and endochondral ossification without insertional fibers from the tendon
- Peritendinous swelling is rare, but increased caliber of the Achilles tendon may be present.
- Weakness is rare, but Achilles tendon contracture is common.
- Achilles tightness should be addressed with stretching before considering nonoperative treatment a failure.
- Pain with resisted plantarflexion suggests more extensive tendinosis.

NATURAL HISTORY
- Symptoms compromise the patient’s ability to wear shoes with a heel counter and participate in activity ranging from walking to intense athletic activity.
- Symptoms may improve in at least 50% of cases with activity modification, physical therapy, or shoe modifications.
- Disabling symptoms that do not improve with nonoperative treatment may benefit from surgery.
- Achilles tendon rupture in the presence of insertional calcification is extremely rare, even without any form of treatment.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The typical patient complaint is posterior heel pain aggravated by activity or shoe wear.
- Symptoms develop insidiously over time.
- Inflammatory enthesopathies such as psoriasis, Reiter syndrome, and inflammatory bowel disease may be present.
- Tenderness localized to the Achilles insertion on palpation (the examiner should press directly posteriorly on the heel where the Achilles tendon inserts) confirms the diagnosis.
- Tenderness may also be present in the Achilles tendon itself or over the retrocalcaneal bursa. The examiner should lightly squeeze the tendon between the index finger and thumb; squeezing hard on the tendon can result in a false-positive result. A thickened or painful tendon will require MRI to determine whether tendon transfer reconstruction is necessary.

FIG 1 • Anatomy of insertional calcification of the Achilles tendon. Note expansion of Achilles tendon fibers over posterior calcaneal tuberosity and intratendinous location of calcification.
Pain with maximum passive plantarflexion suggests inflammation of the paratenon.

Palpation of the retrocalcaneal bursa will differentiate retrocalcaneal bursitis from insertional tendinosis because a tender retrocalcaneal bursa may benefit from bursectomy.

Pain with toe walking supports the diagnosis. Inability to do either suggests the need for rehabilitation before considering surgery.

The surgeon must accurately assess the neurovascular status of the foot and the presence and appearance of any previous incisional scars.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Lateral radiograph of heel (FIG 2)
  - The examiner should identify insertional ossification, characterize the size of the posterosuperior process of the calcaneus, and identify intratendinous calcification more proximally.
  - Parallel pitch lines and the Fowler angle provide no diagnostic, therapeutic, or prognostic information.
  - MRI is indicated when the tendon is thickened, tender, or calcified to determine whether greater than 50% of the cross-sectional area of the tendon is involved (FIG 3).

**DIFFERENTIAL DIAGNOSIS**

- Retrocalcaneal bursitis
- Calcaneal stress fracture
- Plantar fasciitis
- Calcaneal periostitis
- Achilles tendinosis without insertional calcification

**NONOPERATIVE MANAGEMENT**

- Nonoperative management is helpful in at least 50% of cases.
- Initial treatment is with a removable walker boot with removable wedges.
- Two or three wedges are used for 2 weeks, and then a wedge is removed every 2 weeks.
- Use of the boot is continued for 2 weeks after removal of the last wedge.
- Weight bearing as tolerated is permitted in the boot.

- Physical therapy is started upon completion of removable walker boot immobilization and should include eccentric closed-chain strengthening exercises.\(^6\)
- Corticosteroid injection is contraindicated.

**SURGICAL MANAGEMENT**

- Surgical treatment is indicated for disabling symptoms that do not improve with thorough nonoperative treatment.
- Patients should be counseled that recovery can be a lengthy and sometimes frustrating process, as it is often 12 to 18 months before maximum improvement occurs, especially in nonathletic patients.\(^4\,7\)
- Recurrent prominence occurs in 50% of cases but is rarely symptomatic.\(^7\)

**Preoperative Planning**

- It may be helpful to have patients undergo crutch training preoperatively.
- A flexor hallucis longus tendon transfer reconstruction of the Achilles tendon will be necessary if an MRI demonstrates that greater than 50% of the cross-sectional area of the Achilles tendon is involved with degenerative tendinosis.

**Positioning**

- The lateral or prone position is necessary. The heel is more accessible in older or heavier patients when positioned prone. Anesthesia concerns may require lateral positioning.

**Approach**

- Lateral, medial, posterior, and combined approaches have all been described. The lateral approach will be described here.
- Advantages of the lateral approach are:
  - Direct exposure of the insertional calcification
  - Less compromise of the Achilles insertion expansion than other approaches because the strongest insertion is medial
  - The scar is less likely to be irritated by shoes, as with the posterior approach.

**FIG 2 • Lateral radiograph of heel with insertional calcification of the Achilles tendon.**

**FIG 3 • Axial T1-weighted MRI showing intratendinous degeneration comprising greater than 50% of the cross-sectional area of the Achilles tendon (white arrow).**
After administration of anesthesia, position the patient lateral decubitus or prone.
- Apply a thigh tourniquet.
- Prepare and drape the leg, exsanguinate the leg, and inflate the tourniquet.
- Make a longitudinal incision along the lateral heel anterior to the anterior margin of the Achilles tendon. The incision should extend distally to nearly the plantar surface and proximally superior to the retrocalcaneal bursa (TECH FIG 1).
- Carefully perform sharp dissection to create full-thickness flaps, taking care to identify and protect any branches of the sural nerve.

**TECH FIG 1** • Location of incision.

- Make a longitudinal periosteal incision and extend it proximally through the retrocalcaneal bursa, and excise the retrocalcaneal bursa.
- Elevate the periosteum anteriorly, then elevate it posteriorly.
- Continue sharp elevation of the calcaneal periosteum and Achilles tendon insertion expansion medially along the posterior calcaneal tuberosity all the way to the medial aspect of the tuberosity.
- Subperiosteal exposure of the insertional ossification requires careful dissection to preserve the Achilles sleeve.
- Resect any degenerative tendinosis of the Achilles tendon. If preoperative MRI showed tendinosis affecting greater than 50% of the cross-sectional area of the Achilles tendon, a flexor hallucis longus tendon transfer, described elsewhere, will be necessary.
- Resect the posterior calcaneus along a line from inferior to the insertional ossification to anterior to the posterosuperior process of the calcaneus using a saw or osteotome (TECH FIG 2).
- Round over the sharp edges medially and laterally with a rasp or rongeur.
- Place two suture anchors in the cancellous bone left after ostectomy and repair the Achilles tendon to the calcaneus (TECH FIG 3).
- Repair the periosteum laterally.
- Close the incision.
- Apply a sterile dressing and plaster posterior mold splint with the ankle in resting plantarflexion.

**TECH FIG 2** • Location of ostectomy to include the posterosuperior process of the calcaneus and the insertional calcification.

**TECH FIG 3** • Location of suture anchors and repair of Achilles tendon to ostectomy surface of calcaneus.
PEARLS AND PITFALLS

**Exposure**
- Do not be afraid to lengthen the incision to avoid tension from retraction.
- The incision is posterior to the sural nerve, but there may be a branch to the calcaneus in the field, which should be protected.
- Creating full-thickness tissue flaps and avoiding blunt dissection minimize the risk of wound dehiscence.

**Decompression**
- Elevating the periosteum anterior to the ostectomy will facilitate later repair of the Achilles to the calcaneus.
- Be sure to perform ostectomy anterior to the posterosuperior process of the calcaneus, but be careful to avoid the posterior facet of the subtalar joint.
- A secure repair of the Achilles to the calcaneus permits early motion with minimal risk of early avulsion.

POSTOPERATIVE CARE
- Non-weight-bearing is continued for 4 weeks postoperatively.
- Two weeks after surgery, the postoperative splint is changed to a removable walker boot with an Achilles wedge like that used for nonoperative care.
- The removable walker boot is continued for 6 weeks, for a total of 8 weeks of immobilization.
- Active, nonresistive ankle and hindfoot range-of-motion exercises are begun once the incision has healed.
- Physical therapy begins 8 weeks after surgery.

OUTCOMES
- Fifty to 85% of patients report good or excellent results 2 years after surgery.4,7
- The percentage of good or excellent results is higher in athletic than nonathletic patients.4
- Radiographically recurrent insertional calcification occurs in 50% of patients, but symptoms do not always recur with radiographic recurrence.7
- Some patients have recurrent symptoms without radiographic recurrence.7
- Maximum symptomatic relief may not occur until 12 to 18 months after surgery.
- A 1- to 2-month period of temporary symptomatic recurrence often occurs 7 to 10 months after the surgery.7

COMPLICATIONS
- Superficial or deep infection is especially common in diabetic and overweight patients.
- Delayed wound healing is also especially common in diabetic and overweight patients.
- Paresthesias and hypoesthesias can be avoided by identifying and protecting the sural nerve and its calcaneal branch.
- Achilles avulsion
- Deep venous thrombosis
- Recurrence

REFERENCES
DEFINITION

- The term *insertional Achilles tendinitis* (IAT) is actually a misnomer. The condition is more typically a degenerative process, and the nomenclature should reflect this condition, more appropriately, as a tendinosis or tendinopathy.\(^5,7,8,9,14\)
- As the name suggests, insertional Achilles tendinopathy is identified by a painful condition at the musculotendinous insertion of the tendon Achilles on the posterior calcaneus.
  - It represents about 10% to 20% of all Achilles pathology.\(^2\)
  - It is most commonly seen as an overuse injury in athletes, eg., runners and “push-off” athletes such as basketball or volleyball players, or in more sedentary patients as a degenerative process.

ANATOMY

- The Achilles tendon (TA) is the largest tendon in the body. Its chief function is plantarflexion of the foot and ankle.
- It is viscoelastic and strong, elongating up to 15% under loads and bearing up to 10 times body weight in single-legged stance during running.\(^5,9\)
- The Achilles insertion is a broad expanse that envelopes the entire tuberosity of the os calcis and sends Sharpey’s fibers to the medial, lateral, and plantar borders of the bone.\(^1\)
- Immediately anterior to the Achilles tendon lie the retrocalcaneal bursa and a variably sized posterolateral prominence of calcaneus, often known as Haglund’s deformity.
- More anteriorly lies the deep posterior compartment musculature, which includes the flexor hallucis longus (FHL), the neurovascular bundle, including the tibial nerve, and vessels.
- The FHL originates from the fibula and interosseous membrane, travelling obliquely and distally to pass under the sustentaculum tali, through a fibro-osseous tunnel, and on to the master knot of Henry to attach to the hallux.

PATHOGENESIS

- Repetitive stress can lead to a combination of inflammatory and degenerative changes.
- Degeneration or tendinosis occurs as the already compromised vascularity of the tendon is further reduced by age and injury.\(^5,9\)
  - Microscopic and macroscopic changes occur, leading to scarring and slow regeneration or repair.
  - Tenocytes are reduced in number and quality, contributing to poor repair potential.
- Inflammatory changes are manifested as paratenonitis involving the investing layer surrounding the TA, but not the tendon itself. This leads to thickening and adherence of the paratenon to the TA.
- Additionally, the continuum of injury and inadequate repair capacity create a cycle of collagen and calcium deposition in an effort to stabilize the musculotendinous enthesis, leading to enlargement of the insertion site; generation of abundant, poor quality tissue; and irritation of the surrounding tissues, causing a painful thickening of the insertion of the TA.

NATURAL HISTORY

- Untreated IAT has not been studied extensively. However, surgical findings and histologic analyses have provided some information.
- Persistent IAT leads to continued pain and swelling of the retrocalcaneal heel.
- A vicious cycle occurs in which further injury induces more attempts at repair and scar formation, leading to more irritation of surrounding tissues, decreased vascularity, and further microscopic injury.
- The posterior heel is more difficult to accommodate in a shoe.
- Range of motion is reduced, leading to increased susceptibility to injury with any activity that places the TA under strain.
- Calcific debris is generated, both as reactive tissue response to injury and intratendinous hematoma formation as a result of injury. This compromises the viscoelasticity and, therefore, the integrity of the tendon, making it more apt to tear, either partially or completely.\(^4,14\)
- A less pliable, less resilient TA is the end product. Insertional avulsion or rupture may occur, presenting a difficult treatment dilemma.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients provide fairly accurate descriptions and complain of pain at the bone–tendon interface on the retrocalcaneal heel.
- Pain may be worse after activity, but gradually becomes more pervasive.
- Athletes may note an increase in symptoms with increases in training intensity or duration or changes in surface or shoes.
- Examination demonstrates tenderness directly posteriorly on the heel or, often, posterolaterally.
- In advanced cases, thickening, nodularity, or hardening may be palpated.
- Dorsiflexion of the ankle may be reduced compared with the contralateral leg.
- Methods for examining the Achilles tendon and its insertion include:
  - Direct palpation
  - The posterior heel and TA are inspected for visual or palpable swelling, tenderness, nodularity, or gapping, all of which are suggestive of diseased tendon.
  - Thompson test
  - With the patient prone, squeeze the calf at the gastrocnemius–soleus junction to elicit plantarflexion of the foot.
Compare with the contralateral side. A positive test is identified when the excursion of the injured side is far less than its uninjured counterpart. This is evidence for complete rupture.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

**Radiographs**
- Radiographs often are not necessary for diagnosis, but they are helpful in determining the presence of calcific debris, which is a poor prognostic sign. (FIG 1).
- Plain lateral and axial radiographic views usually are sufficient.

**Ultrasonography**
- Ultrasonography is a relatively inexpensive and accurate way to determine tendon quality, integrity, and function.
  - It has the advantage of being used dynamically to watch active tendon excursion, if so desired. It also may be used to follow the course of healing.
  - It is a highly user-dependent tool.

**MRI**
- MRI probably is the most comprehensive study available for investigation and evaluation of a damaged Achilles tendon (FIG 2 A,B).
  - This study gives the most accurate information regarding degree of TA involvement, quality of surrounding tissue, presence or absence of rupture, and other concomitant pathology.

**DIFFERENTIAL DIAGNOSIS**
- Retrocalcaneal bursitis
- Haglund syndrome
- Inflammatory arthritides
- Seronegative spondyloarthropathies
- Gout
- Familial hyperlipidemia
- Sarcoidosis
- Diffuse idiopathic skeletal hyperostosis
- Pharmacologically induced pathology
  - Fluoroquinolone use
  - Chronic corticosteroid use

**NONOPERATIVE MANAGEMENT**
- Nonoperative treatment is successful in over 90% of patients with this process.\(^5^,8\)
  - Success rates decline in the face of greater age at time of presentation, longstanding symptoms, and evidence of calcific tendinosis.\(^8\)
  - Initial phases of treatment include NSAID use, heel lifts, eccentric stretching, and shoe modifications to widen and soften the heel counter.
  - More advanced situations may call for formal orthoses to correct any biomechanical abnormality, night splinting to apply continual stretch to the TA, and therapy modalities such as ice, contrast baths, and iontophoresis.
  - Severe cases may require immobilization in a cast or boot, followed by gradual reintroduction to cross-training before return to regular sports or activities.

**SURGICAL MANAGEMENT**
- Surgical decision making should reflect failed conservative efforts and continued symptoms and functional impairments.
- Younger, more athletic patients often respond to a simple débridement of damaged TA, which usually accounts for less than 50% of the total tendon. A midline tendon-splitting approach to this débridement is our preferred procedure for these patients.

**Preoperative Planning**
- Tendon integrity becomes more questionable with involvement of more than 50%, so augmentation is entertained at
this point. This extensive involvement may become evident on preoperative testing or, alternatively, on intraoperative evaluation.

- Ideally, the surgeon will already have a good idea before beginning the procedure as to whether an augmentation is necessary.
  - This is readily apparent on imaging.
  - One must be ready to add this procedure if it is found to be necessary intraoperatively.

### Positioning

- The patient is placed in the prone position (Fig 3).
- Both feet are prepped into the surgical field, up to the level of the knees.

### Approach

- A midline incision currently is preferred (Fig 4), beginning about 2 to 3 cm proximal to the insertion and extending distally to expose the entire insertion of the TA.

---

**RETROCALCANEAL DÉBRIDEMENT**

- Full-thickness flaps should be developed medially and laterally, including the substance of the Achilles tendon (Tech Fig 1A).
- All nonviable or suspect-appearing tissue should be removed (Tech Fig 1B).

---

**Tech Fig 1**

- A. A midline tendon-splitting incision is made with full-thickness flaps through the TA.
- B. The retrocalcaneal bursa is visualized through the tendon.

- Once adequate débridement takes place, the retrocalcaneal bursa also can be excised.
- Any enlarged or impinging posterolateral prominence of calcaneus should be aggressively removed with a ronguer, oscillating saw, or osteotome.
FLEXOR HALLUCIS LONGUS HARVEST

- The FHL muscle belly usually is easily visible after the débridement is complete (TECH FIG 2A).
- Trace the FHL into its fibro-osseous tunnel (TECH FIG 2B,C).
- Plantarflex the ankle and hallux maximally.
- With a no. 15 blade, transect the tendon as distally as possible while an assistant pulls posteriorly on the proximal portion of the tendon (TECH FIG 2D).
- An interlocking suture of 2-0 braided nonabsorbable material is sewn into the tendon stump.

ATTACHING THE GRAFT

- A 6.5-mm vertical tunnel is created in the posterior calcaneus about 1 cm anterior to the previous Achilles insertion (TECH FIG 3A).
- The FHL suture is passed through the tunnel and through the plantar skin with a Beath pin, bringing the FHL tendon into the tunnel (TECH FIG 3B).
- Tensioning is ensured by using the other foot as a reference at about 15 to 20 degrees of resting equinus. If the most medial and lateral remnants of native Achilles are maintained, they will also serve as reference for proper tensioning.
- An absorbable interference screw is introduced for graft fixation (TECH FIG 3C).
- Tension and range of motion are assessed and should be roughly equal to that of the uninjured limb (TECH FIG 3D).
- The FHL muscle belly is then sewn in a side-to-side tenodesis fashion to the remaining TA to promote vascularity and help restore power to push-off (TECH FIG 3E).
WOUND CLOSURE

- Layered closure is performed with a 2-0 absorbable monofilament in the paratenon, if any is left.
- 2-0 monocryl suture is used for subcutaneous fat.
- Skin is closed with 3-0 nylon suture.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Decision to augment</th>
<th>All studies must be evaluated thoroughly and the tendon inspected carefully at the time of surgery to ensure TA insertional integrity. Any question regarding stability of insertion should prompt consideration for augmentation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incision</td>
<td>Full-thickness flaps are essential for reliable healing. Avoid undermining the skin. Perform the débridement through the tendon. A midline incision appears to have better angiosomal blood supply than either medial or lateral incisions.</td>
</tr>
<tr>
<td>FHL harvest</td>
<td>The muscle belly is easy to identify, but the tendon and tibial nerve are similar in appearance, consistency, and location as they course into the foot. Follow the FHL from muscle to tendon and stay within the fibro-osseous tunnel under the sustentaculum.</td>
</tr>
<tr>
<td>Insertional débridement</td>
<td>Be aggressive in removal of injured TA tissue and inflamed bursa. Be generous in resecting the calcaneal prominence.</td>
</tr>
<tr>
<td>Bone tunnel</td>
<td>Do not wallow out the tunnel while drilling. The calcaneus is predominantly cancellous, and this is easy to do.</td>
</tr>
<tr>
<td>Tensioning</td>
<td>Leaving a few TA fibers attached medially and laterally can demonstrate the patient’s natural resting tension to help with this step.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- Immediately postoperatively, the foot is splinted in 15 to 20 degrees of equinus for 2 weeks.
- The patient is then placed in a walking boot with a 2-inch heel lift for another 2 weeks and allowed to gently touch down to the floor. (Noncompliant patients receive a walking cast.)
- At 1 month, patients are instructed on gentle active-assisted range of motion and permitted to progress to full weight bearing as tolerated.
- Over the next 2 months, the heel lift is gradually reduced in height until a painless plantigrade foot is achieved.
- Physical therapy is begun at 6 to 8 weeks after surgery.

OUTCOMES

- Treatment of IAT by simple débridement is useful in younger patients, but more unpredictable as the extent of disease or patient age increases.5
- Several studies have shown substantial healing times after débridement alone, and even further compromise and poor predictability with evidence of intratendinous calcific debris.14
- The success of the procedure depends on how thoroughly débridement of involved tissue is performed; however, beyond 50% tendon compromise, the stability of the insertion comes into question.
- Augmentation with the FHL tendon has been shown to be technically reproducible and statistically successful.6,12,13,15
  - In one series, 20 patients undergoing this procedure for chronic Achilles tendon insufficiency revealed no postoperative reruptures, tendinopathy recurrences, or wound complications.13
  - Despite presumed and reported differences in calf circumference and push-off strength, these differences seem well tolerated and acceptable to patients when compared to the substantial amount of pain relief and restoration of function they receive.15
- The technique, as described, modifies classic descriptions in several ways:
  - Deviation from the classic two-incision technique,6,12,13 thus reducing morbidity of another surgical site
  - Maintaining more native FHL bulk and function by preserving distal vincular tendon11 attachments at the master knot of Henry. Theoretically, this will reduce the push-off strength morbidity associated with this procedure.
  - Decision regarding augmentation can be made after Achilles débridement determines insertional integrity, because the FHL harvest may be performed through the same incision as the débridement of the TA.
- Less tendon is needed because tendon transfer fixation is equal to or better than the side-to-side single-looped method because of interference screw fixation of the tendon directly to bone.3,10

COMPLICATIONS

- Wound complications
- Inadequate tendon débridement
- Inadequate bone resection
- Tibial nerve injury
- Fracture through bone tunnel
- Over- or under-tensioning the tendon transfer

REFERENCES

DEFINITION

- Tendinopathy of the Achilles tendon involves clinical conditions in and around the tendon arising from overuse.\(^1\)
- Tendinopathy of the Achilles tendon is common both in athletic and nonathletic individuals. It can affect several regions of the tendon.
- One particularly common site is the main body of the tendon, 2 to 4 cm from its insertion on the calcaneus.\(^2\)

ANATOMY

- The two heads of gastrocnemius (medial and lateral) arise from the condyles of the femur. As the muscle fibers descend, they insert into a broad aponeurosis that contracts and receives the tendon of the soleus on its deep surface to form the Achilles tendon.\(^3\)
- The Achilles tendon is the thickest and strongest tendon in the body. About 15 cm long, it originates in the midcalf and extends distally to insert into the posterior surface of the calcaneus. Throughout its length, it receives muscle fibers from the soleus on its anterior surface.\(^4\)

PATHOGENESIS

- To date, the etiopathogenesis of Achilles tendinopathy remains unclear.
- Tendinopathy has been attributed to a variety of intrinsic and extrinsic factors.\(^6\)
- It has been linked to overuse vascularity, dysfunction of the gastrocnemius-soleus, age, gender, body weight and height, endocrine or metabolic factors, deformity of the pes cavus, lateral instability of the ankle, the use of quinolone antibiotics, excessive movement of the hindfoot in the frontal plane, marked forefoot varus, changes in training pattern, poor technique, previous injuries, footwear, and environmental factors such as training on hard, slippery, or slanting surfaces.\(^1\)–\(^6\)
- Most of the above factors should be considered associative, not causative, evidence, and their role in the cause of the condition is therefore still debatable.\(^7\)

NATURAL HISTORY

- Although Achilles tendinopathy has been extensively studied, there is a clear lack of properly conducted scientific research to clarify its cause, pathology, natural history, and optimal management.\(^8\)
- The management of Achilles tendinopathy lacks evidence-based support, and tendinopathy sufferers are at risk of long-term morbidity with unpredictable clinical outcome.\(^9\)
- Most patients respond to conservative measures, and the symptoms can be controlled, especially if the patients accept that a decreased level of activities may be necessary.\(^9\)
- In 24% to 45.5% of patients with Achilles tendinopathy, conservative management is unsuccessful, and surgery is recommended after exhausting conservative methods of management, often tried for 3 to 6 months. However, longstanding Achilles tendinopathy is associated with poor postoperative results, with a greater rate of reoperation before reaching an acceptable outcome.\(^10\),\(^11\)
- As the biology of tendinopathy is being clarified, more effective management regimens may come to light, improving the success rate of both conservative and operative management.\(^12\)

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients typically present with pain located 2 to 6 cm proximal to the insertion of the tendon and felt after exercise.
- As the pathologic process progresses, pain may occur during exercise, and, when severe, may interfere with activities of daily living.
- Runners experience pain at the beginning and at the end of a training session, with a period of diminished discomfort in between.
- The foot and the heel should be inspected for malalignment, deformity, obvious asymmetry in the size of the tendon, localized thickening, a Haglund heel, and any previous scars.\(^11\)–\(^13\)
- The tendon should be palpated to detect tenderness, heat, thickening, nodularity, and crepitation.
- The “painful arc” sign helps to distinguish between lesions of the tendon and paratenon. In paratendinopathy, the area of maximum thickening and tenderness remains fixed in relation to the malleoli from full dorsiflexion to plantarflexion, whereas lesions within the tendon move with movement of the ankle.\(^14\)

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Plain soft tissue radiography is useful in diagnosing associated or incidental bony abnormalities.\(^9\)
- Ultrasound is the primary imaging method, since it correlates well with the histopathologic findings despite being operator-dependent.\(^12\)
- Ultrasound promptly identifies hypoechoic areas, which have been shown at surgery to consist of degenerated tissue, and increased thickness of the tendon.
- MRI studies should be performed only if the ultrasound scan remains unclear.
- MRI provides extensive information on the internal morphology of the tendon and the surrounding structures and is useful in evaluating the various stages of chronic degeneration and in differentiating between peritendinitis and tendinosis. Areas of mucoid degeneration are shown on MRI as a zone of high signal intensity on T1- and T2-weighted images.\(^13\)

DIFFERENTIAL DIAGNOSIS

- Paratendinopathy of the Achilles tendon, acute or chronic rupture of the Achilles tendon, rerupture of the Achilles tendon.
tendon, tear of the musculotendinous junction of the gastrocnemius-soleus and the Achilles tendon.

NONOPERATIVE MANAGEMENT

- There is weak evidence of a modest benefit of nonsteroidal anti-inflammatory drugs (NSAIDs) for the alleviation of acute symptoms.
- Low-dose heparin, heel pads, topical laser therapy, and peritendinous steroid injection produced no difference in outcome when compared with no treatment.
- Medications shown to be effective in randomized controlled trials include peritendinous injection of aprotinin, topical application of glyceryl trinitrate, and the use of ultrasound-guided sclerosing injections in the area of neovascularization.
- Painful eccentric calf-muscle training can be an effective treatment for noninsertional Achilles tendinopathy.
- Eccentric loading and low-energy shock-wave therapy show comparable results.

SURGICAL MANAGEMENT

- Conservative management is unsuccessful in 24% to 45.5% of patients with tendinopathy of tendo Achilles.
- Surgery is recommended after at least 6 months of conservative management.
- The objective is to excise fibrotic adhesions, remove degenerated nodules, and make multiple longitudinal incisions in the tendon to detect intratendinous lesions and to restore vascularity, possibly stimulating the remaining viable cells to initiate a response in the cell matrix and healing.
- The defect can be sutured in a side-to-side fashion or left open.
- Reconstruction procedures may be required if large lesions are excised.

Preoperative Planning

- Preoperative imaging studies can guide the surgeon in the placement of the incision and in incising the tendon sharply in line with the tendon fiber bundles.

Positioning

- Under locoregional anesthesia, the patient is placed prone with the ankles clear of the operating table.
- The prone position allows excellent access to the affected area.
- Alternatively, the patient can be positioned supine with a sandbag under the opposite hip and the affected leg positioned in a figure 4 position.
- A tourniquet is applied to the limb to be operated on. The limb is exsanguinated, and the tourniquet is inflated to 250 mm Hg.

Approach

- The incision is made on the medial side of the tendon to avoid injury to the sural nerve and short saphenous vein (TECH FIG 1).
- A straight posterior incision may also be more bothersome with the edge of the heel counter pressing directly on the incision.
- Maintaining thick skin flaps is vital to reduce the incidence of wound breakdown.

Expose the paratenon and the Achilles tendon (TECH FIG 1).
Identify and incise the paratenon (TECH FIG 2).
In patients with evidence of coexisting paratendinopathy, the scarred and thickened tissue is generally excised.
Based on preoperative imaging studies, the tendon is incised sharply in line with the tendon fiber bundles (TECH FIG 3).

The tendinopathic tissue can be identified as it generally has lost its shiny appearance and it frequently contains disorganized fiber bundles that have more of a “crab-meat” appearance (TECH FIG 4).
Sharply excise this tissue (TECH FIG 5).
The remaining gap can be repaired using a side-to-side repair, but we leave it unsutured (TECH FIG 6).
Suture the subcutaneous tissues with absorbable material (TECH FIG 7).

The skin edges are juxtaposed with Steri-Strips (TECH FIG 8) and then a routine compressive bandage. The limb is immobilized in a below-knee synthetic weight-bearing cast with the foot plantigrade.

If significant loss of tendon tissue occurs during the débridement, consider a tendon augmentation or transfer.

A tendon turndown flap has been described for this purpose. With a turndown procedure, one or two strips of tendon tissue from the gastrocnemius tendon are dissected out proximally while leaving the strip attached to the main tendon distally. It is then flipped 180 degrees and sewn in to cover and bridge the weakened defect in the distal tendon.

A plantaris weave has also been reported for this purpose. The plantaris tendon can be found on the medial edge of the Achilles tendon. It can be traced proximally as far as possible and detached as close as possible to the muscle tendon junction to gain as much length as possible.

It can be left attached distally to the calcaneus, looped and woven through the proximal Achilles tendon, and sewn back onto the distal part to the tendon.

Alternatively, the plantaris can be detached distally as well and used as a free graft.

The tourniquet is deflated and the time recorded. 

---

**TECH FIG 3** - Longitudinal tenotomy along the tendon fibers. Note that as the tendon fibers rotate 90 degrees, the longitudinal tenotomy has to follow them.

**TECH FIG 4** - The macroscopic appearance of the tendinopathic area is visualized.

**TECH FIG 5** - The tendinopathic tissue is excised.

**TECH FIG 6** - Appearance at the end of the procedure.

**TECH FIG 7** - The skin wound after suture of the deep tissues.

**TECH FIG 8** - Steri-Strips are applied to the surgical wound before a routine compressive bandage. The limb is then immobilized in a below-knee synthetic weight-bearing cast with the foot plantigrade.
FOOT AND ANKLE • Section V  SPORTS-RELATED PROCEDURES FOR ANKLE AND HINDFOOT

PEAKS AND PITFALLS

**Diagnosis**
- Diagnosis is usually made on a clinical basis, including a careful history and physical examination.
- Ultrasound can identify hypoechoic areas, which have been shown at surgery to consist of degenerated tissue, and increased thickness of the tendon.
- MRI studies should be performed only if the ultrasound scan remains unclear.

**Positioning**
- Prone position, with thigh tourniquet.

**Incision**
- An incision placed medial and anterior to the medial border of the Achilles tendon reduces the likelihood of injury to the sural nerve and short saphenous vein.

**POSTOPERATIVE CARE**

- A period of initial splinting and crutch walking is generally used to allow pain and swelling to subside. In addition, wound healing complications are difficult to manage and an initial period of immobilization may promote skin healing.
- After 14 days, the wound is inspected and motion exercises are initiated. The patient is encouraged to start daily active and passive ankle range-of-motion exercises. The use of a removable walker boot can be helpful during this phase. Weight bearing is not limited according to the degree of débridement needed at surgery, and early weight bearing is encouraged. However, extensive débridements and tendon transfers may require protected weight bearing for 4 to 6 weeks postoperatively.
- After 6 to 8 weeks of mostly range-of-motion and light resistive exercises, initial tendon healing will have been completed. More intensive strengthening exercises are started, gradually progressing to plyometrics and eventually running and jumping.13,14

**OUTCOMES**

- The surgical procedure is commonly successful, but patients should be informed of the potential failure of the procedure, risk of wound complications, and at times prolonged recovery time.6
- Rehabilitation is focused on early motion and avoidance of overloading the tendon in the initial healing phase.

**COMPLICATIONS**

- Wound healing problems
- Infection
- Sural nerve injury
- Rupture of Achilles tendon
- Deep vein thrombosis

**REFERENCES**

DEFINITION
- Insertional and midsubstance Achilles tendinosis is a painful degenerative process that arises due to mechanical and vascular factors and affects the paratenon and collagen fibers.
- It is most commonly seen in patients in their mid-40s and older.

ANATOMY
- The Achilles tendon, the largest tendon in the body, connects the gastroc–soleus complex to the calcaneus (FIG 1).
- It is covered by a paratenon without a definite tendon sheath.
- The blood supply of the tendon arises distally from calcaneal arterioles and proximally from intramuscular branches. There is a relatively hypovascular, or watershed, area 2 to 4 cm proximal to the tendon insertion.

PATHOGENESIS
- Mechanical and vascular factors contribute to the development of tendinosis. The process begins with mechanical pressure on the insertion of the Achilles tendon from internal factors, a Haglund’s deformity, or external factors, such as a firm heel counter. Retrocalcaneal bursitis develops initially without Achilles tendon involvement. Increasing prominence of the posterolateral calcaneal tuberosity or hindfoot malalignment (ie, varus heel), can cause tendon collagen fiber injury and further inflammation of the retrocalcaneal bursa.
- Progressive thickening of the retrocalcaneal bursa and peritendinous tissue increases mechanical pressure on the tendon, impeding blood flow and hampering the normal repair process, leading to a thickened, degenerative tendon.

With dysvascular changes associated with aging, the tendon becomes increasingly thick and painful. Radiographs at this point may show a spur or calcification at the Achilles insertion.

NATURAL HISTORY
- The natural history of the pathologic process most likely is a continuum that begins with retrocalcaneal bursitis and ends in chronic Achilles tendinosis.
- Patient activity becomes more restricted due to increased pain and weakness.
- Age-dependent changes in collagen quality and decreased vascularity contribute to the development of tendinosis.
- As the degenerative process becomes chronic, the tendon becomes mechanically deficient and more susceptible to rupture.
- Symptoms become unremitting as the disease progresses.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Achilles tendinosis causes pain and swelling of the diseased segment of tendon.
- Pain increases with physical activity and with direct pressure on the affected tendon.
- Patients with seronegative arthropathies, spondyloarthropathies, hypercholesterolemia, sarcoidosis, and renal transplant have an increased incidence of Achilles tendinopathy.
- The patient should be assessed for hyperpronation or heel varus deformities, which can cause eccentric Achilles tendon loading. If either is present, an orthosis to keep the hindfoot in neutral may be necessary.
- Ankle dorsiflexion is measured with the knee flexed and extended to assess for gastrocnemius or Achilles tendon tightness. If excessive tightness is present, a gastrocnemius recession should be considered along with the flexor hallucis longus (FHL) transfer.
- With the patient prone on the examining table, the Achilles tendon is palpated to localize the area of thickening and tenderness (either insertional or noninsertional). Assess the size of the calcaneal tuberosity; if it is enlarged, excision of this prominence should be considered to reduce mechanical pressure on the diseased Achilles tendon.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Radiographs are useful in evaluating the extent of tendon calcification and presence of a Haglund’s deformity (FIG 2).
- Although MRI scanning is not essential for preoperative planning, it can be beneficial in estimating the amount of degenerative tendon to be excised (FIG 3).

DIFFERENTIAL DIAGNOSIS
- Haglund’s deformity
- Os trigonum

FIG 1 • The Achilles tendon and its relationship to the flexor hallucis longus tendon.
Part 8 FOOT AND ANKLE • Section V SPORTS-RELATED PROCEDURES FOR ANKLE AND HINDFOOT

Retrocalcaneal bursitis
Peritendinitis
Seronegative spondyloarthropathy
Insertional tendinopathy
Achilles tendinosis

NONOPERATIVE MANAGEMENT

- Nonsurgical treatment of insertional or noninsertional Achilles tendinosis includes rest, immobilization, and rehabilitation.
- Immobilization can include casting, a cast brace, and a custom molded ankle foot orthosis (AFO).
- Structural abnormalities such as heel varus are addressed with wedges or orthotics, or both.
- Training regimens are modified to reduce stress on the affected tendon.
- Physical therapy for heavy-load eccentric strengthening exercises has been found to be effective for Achilles tendinopathy and may be superior to conventional treatment regimens and comparable to open débridement of the tendon.

SURGICAL MANAGEMENT

- Surgery is performed only on those patients who have intractable pain and impaired function or those who have failed previous tendon débridement or Haglund’s resection alone. Most people in this patient group have a chronic Achilles tendon deficiency, and are sedentary, overweight, and have radiographic or MRI evidence of a thickened, calcific Achilles insertion.
- Most treatments that have been described focus on removing mechanical pressure from the diseased tendon (eg, excising the posterosuperior calcaneal tuberosity), débridement of the diseased tendon, or augmentation of the remaining, débrided tendon (ie, FHL, peroneus brevis, plantaris).
- The bulk of surgical treatment is discussed in the following sections and in the Techniques section.

Preoperative Planning

- The extent and location of diseased tendon must be identified. The area of tendon degeneration most often is the distal 2 to 4 cm. The degeneration also may be isolated at the mid-substance.
- The patient must understand preoperatively that the time to maximum improvement could be prolonged (average 8.2 months).
- If the surgeon wants to loop the transferred FHL through the calcaneus at the time of the transfer and more tendon length consequently will be needed, the FHL should be harvested from the midmost at Henry’s knot and pulled out the posterior incision.

Positioning

- The patient is placed prone on the operating table with a soft bump anterior to the ankle (FIG 4).

Approach

- Various incisions have been used to approach the diseased tendon.
  - Incisions that have been recommended include central splitting, medial and/or lateral longitudinal pretentious, or medial with a transverse L-shaped extension distally.
  - All of these incisions can be used successfully to expose and débride diseased tissue, but if augmentation of the Achilles tendon is anticipated, a medial incision will give the best access to the FHL.
  - Whatever incision is selected, it should be done sharply through the subcutaneous tissue to the paratenon, taking care not to dissect horizontally, thus reducing the risk of vascular compromise of the soft tissues overlying the tendon.

FIG 2 • Lateral radiograph of the heel revealing a prominent calcaneal tuberosity and calcification of the Achilles insertion.

FIG 3 • A. This sagittal MRI scan demonstrates increased signal in the Achilles insertion. B. This axial MRI scan of the Achilles insertion reveals diseased fibers.

FIG 4 • The patient is positioned prone on the operating table.
FLEXOR HALLUCIS LONGUS TRANSFER OR AUGMENTATION FOR ACHILLES TENDINOSIS

A 10-cm posteromedial incision is made starting near the junction of the proximal and middle thirds of the Achilles tendon and stopping distally at the tendinous insertion into the calcaneal tuberosity. The incision is made sharply through the subcutaneous tissue to the paratenon, taking care not to dissect horizontally, thereby reducing the risk of vascular compromise of the soft tissue overlying the Achilles tendon. An L-shaped extension of the incision distally is performed if extensive débridement of the Achilles tendon is anticipated and better exposure of the lateral tendon insertion is needed (TECH FIG 1).

The substance of the tendon is carefully inspected. Any amorphous (codfish-flesh appearing), calcified, or ossified tissue of the tendon is excised, leaving only relatively healthy, normally striated tissue. Usually, more than 50% of the cross-section is removed. The degenerative, calcified area of tendon is best excised by removing a wedge-shaped piece of tissue from the insertion of the Achilles tendon (TECH FIG 2).

In all cases, a partial calcaneal ostectomy is performed at the superoposterior aspect to decompress the Achilles tendon insertion (TECH FIG 3). This also improves exposure to the anterior aspect of the tendon, aiding in tendon inspection and débridement.

With the degenerative tissue removed, the triangular fat pad anterior to the Achilles tendon is excised, exposing the deep posterior fascia (TECH FIG 4). The fascia overlying the posterior compartment of the leg is incised longitudinally to the proximal extent of the FHL muscle body. The FHL tendon is identified (TECH FIG 5). The flexor retinaculum is released along the medial aspect of the hindfoot to further expose the FHL.

Gentle retraction of the neurovascular bundle with a blunt retractor allows safe visualization of the tendon distally (TECH FIG 6). The FHL is transected as far distal as possible with the ankle and hallux in maximum plantarflexion. Transection of the tendon is done medial to lateral to avoid accidental injury to the neurovascular structures.

The tendon is brought posteriorly and positioned at the calcaneus between the two limbs of the remaining débrided Achilles insertion (TECH FIG 7). If more length of the FHL is needed, the origin of the more distal muscle fibers of the FHL can be detached bluntly from the fibula and interosseous ligament to increase the excursion of the FHL. Proper tensioning of the FHL transfer is determined by dorsiflexing the ankle to place the Achilles tendon at maximal stretch. With the FHL appropriately tensioned, any excess length of the tendon is removed to allow optimal pull of the transferred tendon to the calcaneus.

TECH FIG 1 • Full-thickness, L-shaped incision to increase exposure of the diseased Achilles tendon.

TECH FIG 2 • A. Drawing of typical location of diseased Achilles. B. Area of wedge resection of the Achilles insertion in preparation for repair.
TECH FIG 3 • A. Drawing of area of bone resection. 
B. Partial ostectomy performed through the resected tendon. C. Drawing of resected bone and decompressed tendon insertion.

TECH FIG 4 • The triangular fat pad is excised, and the deep posterior fascia is exposed.

TECH FIG 5 • The flexor hallucis longus (FHL) tendon is exposed after the deep fascia is split.
**Chapter 119**

**FLEXOR HALLUCIS LONGUS TRANSFER FOR ACHILLES TENDINOSIS**

**TECH FIG 6**
- A. The flexor retinaculum is split to expose the FHL distally.
- B. The neurovascular bundle is protected with a deep retractor.

**TECH FIG 7**
- A. The FHL is pulled posteriorly and checked for length.
- B. Drawing of FHL placement between the limbs of the remaining Achilles tendon.
- C. The FHL is tightly positioned against the Achilles tendon.
The transferred tendon is held with a two-strand suture anchor (TECH FIG 8). The first strand of suture is used in modified Kessler fashion to secure the FHL to the calcaneus at the proper tension (TECH FIG 9). The second strand is used as a whipstitch to add pullout strength (TECH FIG 10). The FHL tendon is sutured to the Achilles tendon in side-to-side fashion with nonabsorbable braided suture (TECH FIG 11).

- A careful, layered closure of the paratenon, subcutaneous tissue, and skin is performed.
## PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Skin incision</th>
<th>■ Care must be taken to make a full-thickness incision from the skin to the paratenon without undermining the soft tissue layer, to avoid skin slough.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achilles tendon débridement</td>
<td>■ Make sure to excise all diseased Achilles tendon to reduce the risk of persistent pain postoperatively.</td>
</tr>
</tbody>
</table>
| FHL harvest | ■ Protect the neurovascular bundle with a deep retractor through the medial incision while exposing the FHL for transfer to avoid injuring adjacent vital structures.  
■ Cut the tendon with a no.15 blade medial to lateral to avoid injury to the neurovascular bundle.  
■ Maximally plantarflex the ankle and great toe, and pull on the FHL before cutting the tendon to obtain adequate length of the transferred tendon. |
| FHL transfer | ■ Dorsiflex the foot while placing the FHL transfer at maximal stretch to determine the proper insertion point and tensioning of the transferred tendon.  
■ Make sure there is good apposition between the FHL and remaining Achilles tendon by excising all interposed fat and using nonabsorbable sutures to hold the repair. |
| Skin closure | ■ Perform careful, separate layer closure, starting with the paratenon, to avoid excessive scarring. |

## POSTOPERATIVE CARE

- A compressive dressing with splints is applied in the operating room with the ankle in neutral position. The initial dressing is kept in place for 10 to 14 days. At that time, if the incision is well healed and the reconstruction was deemed stable at the time of operation, the patient is placed in a controlled ankle motion (CAM)-soled walker, and weight bearing as tolerated is allowed.

- If more than 75% of the Achilles tendon has been débrided, a weight-bearing cast is applied for 4 weeks to provide extra support for the healing tendon.

- Range-of-motion and strengthening exercises are begun 6 to 8 weeks postoperatively if clinical improvement (decreased pain and swelling) is evident.

- The patient is weaned from the CAM-soled walker at 10 to 12 weeks as symptoms of pain and swelling allow.

## OUTCOMES

- Hansen reported a proximal FHL transfer technique with good or excellent results. Emphasis was placed on thoroughly excising the diseased tendon.

- Wapner reported good to excellent pain relief and improved function in seven patients with Achilles débridement and FHL transfer harvested from the midfoot for tendinosis.

- Wilcox et al., using the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score and the SF-36 Health Survey, reported overall good results with FHL transfer in 20 patients with recalcitrant Achilles tendinosis but found that patient function may not improve.

- Den Hartog reported significant improvement in the postoperative AOFAS hindfoot scores in 29 patients who underwent FHL transfer for severe Achilles tendinosis.

## COMPLICATIONS

- Rerupture of the augmented Achilles

- Wound necrosis secondary to undermining of soft tissues

- Infection

- Scarring secondary to inadequate repair of the paratenon

- Persistent pain and swelling

## REFERENCES


DEFINITION

- The plantaris tendon is an ideal source for soft tissue augmentation for ligament reconstructions or tendon repair.\(^1\),\(^14\)
- The plantaris tendon has high tensile strength with the structured collagen characteristic of physiologic tendons.
- Harvest of the plantaris tendon rarely creates appreciable donor site morbidity.
- The goal of this chapter is to provide the foot and ankle surgeon with a simple and reliable method to harvest readily available local tissue for plantaris tendon grafting even if its harvest was not originally planned.

ANATOMY

- The plantaris muscle originates from the lateral femoral condyle, courses along the lower leg’s superficial posterior compartment, and has its musculotendinous junction just distal to the level of the knee joint.
- The proximal plantaris tendon is situated between the gastrocnemius and the soleus muscle. Distally, it lies immediately adjacent to the Achilles tendon in the distal third of the lower leg and typically inserts in the calcaneal tuberosity (FIG 1A).
- The length of the plantaris tendon ranges from 30 to 45 cm.\(^11\)
- The plantaris tendon insertion is variable.\(^3\),\(^4\),\(^11\)
  - In addition to inserting on the calcaneal tuberosity, it may insert at the bursa calcanei, retinaculum flexorum, ankle capsule, plantar aponeurosis, or blend with the Achilles tendon or intermuscular septum (FIG 1B).
  - Because of this variability, distal harvesting procedures are unsuccessful in about 12% to 20% of cases.\(^4\),\(^9\),\(^12\)
  - In about 6% to 7% of individuals, the plantaris tendon is absent. In humans, the plantaris muscle and tendon serve little function; however, early in evolution, it was far more developed in monkeys.\(^3\),\(^8\),\(^10\),\(^11\) Therefore, harvesting the plantaris tendon in humans causes no appreciable donor site morbidity.\(^2\),\(^7\)–\(^9\)
- Bohnsack et al\(^1\) compared highest tensile strength per cubic millimeter (N/mm\(^3\)) of commonly used autografts:
  - Peroneus longus, 61 N/mm\(^3\)
  - Peroneus brevis, 41 N/mm\(^3\)
  - Plantaris, 94 N/mm\(^3\)
  - Achilles split, 36 N/mm\(^3\)
  - Fascia lata, 27 N/mm\(^3\)
  - Periosteal flap, 2 N/mm\(^3\)
  - Corium, 12 N/mm\(^3\)
  - Anterior talofibular ligament, 8 N/mm\(^3\)
- They found the plantaris tendon to have the highest N/mm\(^3\).

PATHOGENESIS

- Chronic joint instability and chronic tendon ruptures develop over months to years.
- In joint instability, acutely torn ligaments eventually scar in an elongated state.

FIG 1 • Anatomy of the plantaris tendon. A. The only tubular structure between the soleus and the gastrocnemius muscles is the plantaris tendon. Therefore, blind dissection between these muscles does not risk nerves and vessels. Major vessels run underneath the soleus muscle. B. Insertions of the plantaris tendon are variable and may complicate the successful harvesting procedure.
Acute untreated tendon ruptures, similarly, eventually demonstrate degeneration and elongation.

Both chronic ligament and tendon injuries eventually may become so degenerated that surgical reconstruction is not possible with residual local tissue, especially in the case of chronically attenuated ligaments or tendons that have been subjected to repeated trauma or microtrauma. These situations lend themselves well to plantaris autografting.

PATIENT HISTORY AND PHYSICAL FINDINGS

Although isolated plantaris tendon ruptures have been reported, no specific physical examination technique has been developed that can isolate the plantaris tendon to confirm in advance that it is present when plantaris tendon harvest is being considered.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Ultrasound is useful in identifying the presence of a plantaris tendon and has a high specificity.10

When MRI is used to evaluate an injury to the ankle ligament or tendon, the imaging study also may prove useful in identifying the presence of an ipsilateral plantaris tendon that may be used for tissue augmentation.7,8,13

SURGICAL MANAGEMENT

The plantaris tendon is ideal tissue for most ligament or tendon augmentations in the foot and ankle, especially because it typically is in the sterile field for virtually every foot and ankle procedure.

Preoperative Planning

If an MRI scan was obtained to determine the initial pathology, it can be used to identify the existence of the plantaris tendon before surgery.8,13

If not, a preoperative ultrasound examination is helpful.10,13

Positioning

Harvest of the plantaris tendon is relatively simple, regardless of which patient position is dictated by the particular foot and ankle procedure.

No tourniquet is needed for plantaris tendon harvesting.

Approach

The proximal approach is a 2-cm longitudinal incision about 30 cm proximal to the medial malleolus (FIG 2).

The distal approach is a 2-cm longitudinal incision at the medial Achilles insertion on the medial calcaneal tuberosity (FIG 3).

The plantaris may be harvested from a proximal or distal approach; for both approaches, only a minimally invasive, 2-cm incision is required.

AUTHORS’ PREFERRED TECHNIQUE FOR PROXIMAL PLANTARIS HARVESTING6,7

Subcutaneous blunt dissection to the fascia is performed with care taken to protect the saphenous nerve and vein (TECH FIG 1A). A 2-cm longitudinal incision is made in the fascia to enable the surgeon’s finger to enter the intermuscular space (TECH FIG 1B). The only tubular structure that runs between the gastrocnemius and the soleus muscle bellies is the plantaris tendon. No nerves or vessels are at risk.13

The tendon is mobilized with the finger or a nerve retractor (TECH FIG 1C).

The plantaris tendon is isolated in a distal direction using a blunt tendon stripper. The tendon stripper is ad-
TECH FIG 1 • A. Blunt spreading of the subcutaneous fat down to the fascia without damage to the saphenous nerve or vein. B. A 2-cm fascial incision is made, and blunt dissection is carried out further down between the gastrocnemius and soleus muscles with the surgeon’s finger. C. The plantaris tendon is developed with a nerve retractor. D. Introduction of the tendon stripper. E. The harvested autograft usually is about 30 cm long.

DISTAL PLANTARIS HARVEST

A 2-cm skin incision is made at the medial border of the Achilles tendon insertion at the calcaneal tuberosity (see Fig 3).

Blunt dissection is carried down to the Achilles tendon and the plantaris tendon. The variability of the plantaris insertions may necessitate a slightly more involved dissection to identify the distal extent of the plantaris tendon (see Fig 1B).

The tendon is mobilized and harvested with a blunt tendon stripper from distal to proximal (TECH FIG 2A).

At the level of the popliteal fossa, the inner cylinder of the stripper is rotated to transect the tendon (TECH FIG 2B). The tendon is stored in a wet sponge until it is needed for ligament or tendon augmentation.

The skin is closed with interrupted sutures and adhesive strips.
Chapter 120  PROXIMAL MINI-INVASIVE GRAFTING OF PLANTARIS TENDON

POSTOPERATIVE CARE

- Adhesive wound strips can reduce skin tension and broadening of the scar.
- After wound healing the patient may use scar massage to reduce subcutaneous adhesions.

OUTCOMES

- The proximal harvesting procedure of the plantaris tendon was reported in a clinical study of plantaris tendon autograft for lateral ligament reconstruction of chronic ankle instability. In 52 cases (93%), a strong 25- to 35-cm tendon graft was harvested. In one case (2%) the plantaris tendon was deemed too weak to serve as appropriate donor material. In three (5%) of 56 ankle reconstructions the plantaris tendon could not be located during surgery without preoperative imaging or ultrasound. This observation was consistent with incidence studies of the plantaris tendon in cadavers (absence ranged between 6% and 7%).

- Use of the distal approach to harvest the plantaris tendon also has been reported. Investigators failed to locate the plantaris tendon distally in 12% to 20% of cases in these studies.

COMPLICATIONS

- We have performed proximal plantaris harvesting in 102 cases with only one case of mild dysesthesia at a broadened scar. This did not create any functional deficits for the patient.
- Despite the close proximity of the saphenous nerve and vein, we have not observed any saphenous nerve or vein injuries.
- In 36 patients we have performed a distal approach plantaris harvest. Four of these patients (11% of cases) developed a hypertrophic or hypersensitive scar that created shoe irritation.

PEARLS AND PITFALLS

Indication

- We prefer the plantaris tendon over the peroneal tendons when grafting for chronic lateral ankle reconstruction. Use of this tendon will not further decrease dynamic control of lateral ankle instability.

Technique

- A proximal approach to a plantaris autograft will increase the success of the grafting procedure, because the distal tendon course is variable and may be difficult to find.
- A proximal approach to the plantaris tendon will reduce complications—making the incision at the calcaneal tuberosity could cause hypertrophic scarring and resultant shoe wear irritation.
- If the plantaris tendon cannot be located with distal harvesting technique, a small, medial, split Achilles tendon graft can be harvested with the tendon stripper advanced from distally to proximally.

REFERENCES

DEFINITION
- Peroneal tendon tears are a disruption of the fibers, most commonly of the peroneal brevis tendon.
- Acute tears rarely may be the result of an ankle fracture or severe sprain.
- The most common type of tear, an attrition tear, is the result of multiple subluxations or peroneal tendinitis.

ANATOMY
- The peroneus longus and peroneus brevis tendons both originate in the lateral compartment of the leg.
- The peroneus brevis inserts into the base of the fifth metatarsal and the longus into the proximal plantar first metatarsal and the first cuneiform.
- Both muscles are innervated by the superficial peroneal nerve.
- The peroneus longus courses posterior to the peroneus brevis tendon as they pass through the common peroneal synovial sheath proximal to the lateral malleolus.
- The superior peroneal retinaculum prevents subluxation of the peroneal tendons, forming a 1- to 2-cm fibrous sling from the posterolateral aspect of the distal fibula to the anterior Achilles sheath and lateral wall of the calcaneus.
- The inferior peroneal retinaculum covers the tendons 2 to 3 cm distal to the lateral malleolus.
- The peroneal tubercle of the calcaneus separates the peroneus longus and brevis into separate sheaths.

PATHOGENESIS
- Traumatic rupture may occur with ankle fractures or severe sprains but is rare.
- Partial longitudinal tears are commonly associated with peroneal tenosynovitis.
- Peroneus longus tears often are seen with a painful os peroneum, an enlarged peroneal tubercle, or pathology at the cuboid or calcaneus.
- Instability of peroneal tendons at the level of the superior peroneal retinaculum may be a cause of tendinitis leading to tears.
- Brevis tendon tears can be caused by compression between the lateral ridge of the malleolus and the peroneus longus tendon.
- Brevis tears are commonly at the level of the distal lateral malleolus.

NATURAL HISTORY
- Injury to the peroneal tendons is a frequently overlooked cause of persistent lateral ankle pain.
- There have been two mechanisms described by Munk and Davis leading to a tear of the peroneus brevis tendon.
  - Subluxation of the peroneus brevis tendon may occur as a result of chronic ankle instability, and the tearing of the superior peroneal retinaculum. The tendon may split as it subluxes over the sharp posterolateral edge of the fibula.
  - The second mechanism described is tearing of the brevis tendon caused by compression between the posterior fibula and the peroneus longus tendon.
- Peroneus longus tears, unlike peroneus brevis tears, are commonly seen at the level of the peroneal tubercle.

PATIENT HISTORY AND PHYSICAL FINDINGS
- The evaluation of a patient with suspected peroneal pathology should start with a thorough history from the patient. Pain, swelling, and warmth may be caused by an acute injury or prolonged repetitive activity.
- The patient should be asked to pinpoint the area of pain to the examiner.
- Peroneus brevis tendon tears cause pain and persistent swelling along the peroneal tendon sheath and commonly behind the fibula.
- Peroneus longus tendon tears present with pain in the cuboid groove, in the plantar aspect of the foot, or at the level of the peroneal tubercle.
- Patients should be asked about other existing conditions. Rheumatoid arthritis, psoriasis, hyperparathyroidism, diabetic neuropathy, calcaneal fractures, and local injections have been associated with an increased risk of peroneal tendon tears.
- A history of subluxation or dislocation (FIG 1) can also give rise to peroneal tendon pathology.
- Physical examination of the peroneal tendons should include:
  - Assessment for posterolateral hindfoot swelling. Swelling indicates pathology; swelling about the lateral or posterolateral side of the ankle could represent tendinitis, tenosynovitis, repetitive subluxation, or tear.
  - Inspection for hindfoot alignment. Any varus position from neutral is a positive finding. Varus position is associated with an increased rate of peroneal tendon disorders.

FIG 1 • Dislocation of peroneal tendons.
Palpation along the course of the peroneal tendons should be performed to identify areas of tenderness. Any tenderness along tendons is a positive finding. Tenderness along the peroneal tendons may represent tendinitis, tenosynovitis, or tear.

Strength: ankle and foot eversion strength against resistance. Weakness in eversion is probably pathology, but near-normal eversion strength may not rule out peroneal pathology due to recruitment of other muscle groups. Strength may be decreased due to pain or tendon rupture.

Neurovascular assessment: sensory examination along the sural nerve distribution. Pain along the sural nerve distribution is assessed to rule out sural nerve neuritis.

Peroneal tunnel compression test. The foot is dorsiflexed and everted while manual pressure is applied along the retrofibular region. A positive finding (pain) indicates possible tendinitis, tenosynovitis, or tear.

Plantarflexion of the first ray. With the foot in neutral, active plantarflexion of the first ray is tested. Loss of plantarflexion of the first ray compared to the unaffected side is a positive sign. Loss or limitation of plantarflexion of the first ray is consistent with dysfunction of the peroneus longus tendon.

Testing for peroneal tendon dislocation or subluxation involves active rotation of the ankle, with subluxation or dislocation on palpation and visualization noted. Dislocation or subluxation gives rise to tendinitis or tears.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Plain radiographs and weight-bearing views of the ankle and foot are obtained. An axillary heel view will allow evaluation of the peroneal tubercle and the retromalleolar groove. Radiographs are important in ruling out fractures, arthrosis, tumors, and impingement.
- MRI is the study of choice when evaluating the peroneal tendons. Heterogeneity or discontinuity of the tendon, a fluid-filled tendon sheath, marrow edema along the lateral calcaneal wall, and a hypertrophied peroneal tubercle are all indications of peroneal tendon tears (FIG 2).
- Often the MRI underestimates the extent of pathology with regard to tears of the peroneus longus tendon. Peroneal tenography allows indirect visualization of the tendons by injecting contrast into the sheaths. Tenography may be useful to test for external compression, dislocation, and complete rupture.
- Ultrasound is noninvasive and does not expose the patient to radiation. Complete ruptures are seen as discontinuities in the tendon and partial tears are represented by focal lucencies. However, ultrasound has limited usefulness in imaging disorders of the peroneal tendons and is very dependent on the quality of the ultrasonographer.

**DIFFERENTIAL DIAGNOSIS**

- Sural nerve neuritis
- Calcaneus fractures
- Os peroneum fracture
- Lateral malleolar avulsion fractures
- Lateral ankle impingement
- Hypertrophic peroneal tubercle
- Bony spurring at the posterior lateral fibular groove of the calcaneus
- Prominent exostoses
- Hindfoot arthritis
- Tumor

**NONOPERATIVE MANAGEMENT**

- Nonoperative management consists of nonsteroidal anti-inflammatory medication, rest, activity modification, a lateral heel wedge, rarely use of an ankle-foot orthosis, and in difficult cases immobilization in a short-leg cast or walking boot for 6 weeks.
- Use of corticosteroid injections have been reported, but tendon splitting and rupture should be considered as possible complications of injection.

**SURGICAL MANAGEMENT**

- Redfern and Myerson describe an algorithm for surgical treatment, evaluating functional tendons, mobility of the remaining peroneal musculature, ankle stability, and position of the heel.
- After an MRI and clinical examination indicate a tear or rupture and the patient has failed to respond to conservative treatment, surgery is indicated.
- The procedure is finalized when intraoperative examination is performed.
- Upon gross examination three types of tears or ruptures are evaluated:
  - Type I: Both tendons are grossly intact.
  - Type II: One tendon is torn, the other usable.
  - Type III: Both tendons are torn and unusable.

**Preoperative Planning**

- All imaging studies are reviewed.
- MRI has been reported to both underestimate and overestimate the degree of tendon pathology.
- Operative planning should rest on the clinical evaluation, failure of conservative treatment, and occasionally injection of local anesthetic into the tendon sheath.
- Deformity of the hindfoot or laxity of the ankle ligaments that could cause recurrent tendon tears should be noted preoperatively and addressed in a single procedure with any peroneal tendon pathology.
Positioning
- The patient is positioned supine with a bump under the ipsilateral hip.
- A well-padded tourniquet is placed on the ipsilateral thigh.
- Blankets are used under the operative ankle to elevate the operative extremity.
- The contralateral leg is secured to the table with tape.

Approach
- Following the course of the peroneal tendons, a slightly curved 10-cm incision is made posterior to the lateral malleolus and carried distally along the course of the tendons.
- Blunt dissection is taken to the peroneal sheath, while protecting the sural nerve (FIG 3).

FIG 3 • Sural nerve position during approach.

TYPE I: BOTH TENDONS GROSSLY INTACT
- Perform the standard approach.
- Open the peroneal sheath in line with the tendons.
- Perform an intraoperative examination of the peroneal tendons to evaluate the amount of degeneration or tears (TECH FIG 1A).
- Perform a synovectomy, followed by removal of any degenerated tendon (TECH FIG 1B).
- If the remaining usable tendon is 50% or more of the original diameter, then a repair is indicated.
- Use a running 3-0 absorbable Vicryl suture to tubularize the tendon and return it to a smooth surface (TECH FIG 1C).
- Obtain hemostasis.
- Repair the sheath using 2-0 suture, followed by subcutaneous closure, and use nonabsorbable suture for the skin.

TYPE II: ONE TENDON TORN AND THE OTHER USABLE
- Perform the standard approach.
- Open the peroneal sheath in line with the tendons.
- Perform an intraoperative examination of the peroneal tendons to evaluate the amount of degeneration or tears.
- If one tendon is found to be more than 50% unusable, then a tenodesis is indicated.
- Perform the tenodesis side to side to the usable tendon proximal.7
- The sheath should remain open.
- Obtain hemostasis.
- Subcutaneous closure and use nonabsorbable suture for the skin.
Chapter 121 REPAIR OF PERONEAL TENDON TEARS

TYPE III: BOTH TENDONS TORN OR UNUSABLE
- Perform the standard approach.
- Open the peroneal sheath in line with the tendons.
- Perform an intraoperative examination of the peroneal tendons to evaluate the amount of degeneration or tears.
- In type III, both peroneal tendons are more than 50% degenerated or torn.
- Examine for excursion of the proximal muscle.
- If no excursion is present due to scarring and fibrosis, a tendon transfer is indicated.
- If excursion is present and the tissue bed is scarred, then a staged allograft with silicone rod is considered.
- If excursion is present and the tissue bed is free from scarring, then an onstage allograft or tendon transfer is considered.

PEARLS AND PITFALLS

| MRI | MRI has been shown to underestimate and overestimate the degree of peroneal tendon pathology compared with the intraoperative findings. It must be correlated with the clinical examination findings. |
| Intraoperative | The surgeon should be ready to evaluate the peroneal tendons during the procedure and proceed with the proper repair or reconstruction, as physical examination and current imaging findings have been described to both overestimate and underestimate the degree of pathology. |
| Intraoperative | The surgeon may need to resect a portion of the distal muscle belly of the peroneus brevis to make room in the peroneal sheath behind the fibula. |
| Intraoperative | The surgeon must evaluate the posterior fibula for an exostosis, which may be the cause of a peroneus brevis tear. |

POSTOPERATIVE CARE
- A posterior splint is applied in the operating room.
- At 1 week the splint is changed to a partial weight-bearing cast.
- At 3 weeks a wound check with suture removal is done, followed by a walking boot for 3 more weeks.
- At 6 weeks a prefabricated ankle brace is applied and active range-of-motion exercises are started.
- Physical therapy for calf strength is initiated at 6 weeks.
- Return to activities is considered at 3 months, with an orthotic containing lateral posting.

OUTCOMES
- A study by Redfern and Myerson assessed 29 feet with peroneus longus and brevis tears.
  - 31% had normal peroneal strength postoperatively, and
  - 59% had moderate peroneal strength.
  - 9% had postoperative complications.
  - 50% continued to experience some painful symptoms postoperatively; in all but three patients, pain was mild.

COMPLICATIONS
- Complex regional pain syndrome
- Adhesive tenosynovitis
- Failed repair

REFERENCES
Pathology of the peroneal tendons may cause chronic lateral ankle pain. Chronic lateral ankle pain can have many causes. Isolated tears of the peroneus brevis and longus are rare, but fissuring and longitudinal splitting of the brevis and longus tendons have been reported as a cause of chronic ankle pain and functional instability. Histologic evaluation of these splits has shown chronic wear with cystic and myxoid degeneration of the tendon. When recognized early, direct repair is possible with good results.

ANATOMY
- The peroneus brevis tendon can be identified at the level of the lateral malleolus since it is closest to the malleolus.
- The peroneus longus tendon is directly posterior to the brevis tendon.
- Both the longus and brevis tendons are tethered at the level of the lateral malleolus by the superior peroneal retinaculum, which is a band of deep fascia that extends from the tip of the lateral malleolus to the calcaneus.
- The tendons lie within the fibular groove; the most common location for longitudinal peroneus brevis tendon tears is at the fibular groove.
- The flexor hallucis longus tendon (FHL) has a strength percentage of 3.6 and can substitute for the peroneus brevis muscle–tendon unit, which has a strength percentage of 2.6.
- The FHL is an in-phase muscle with an axis of contracture similar to the peroneal muscle–tendon unit as it arises off the posterior fibula.
- This technique inserts the FHL into the residual stump of the peroneus brevis tendon.
- Our technique does not restore function of both peroneal tendons, since the distal portion of the peroneus longus tendon is too enmeshed in scar to serve as a viable insertion point for the FHL tendon.

PATHOGENESIS
- The pathogenesis of chronic peroneal tendon ruptures is unclear. Many theories have been suggested, including a zone of critical hypovascularity, mechanical impingement from the fibular groove, incompetence of the peroneal retinaculum, the presence of a sharp posterior fibular ridge, dynamic compression between the peroneus longus and brevis tendons, or the presence of a peroneus quartus muscle.

NATURAL HISTORY
- Patients typically present with advanced pathology of both tendons, such that neither can be salvaged in their entirety.

These patients tend to be middle-aged individuals who were active, working adults before their injuries. They will not wear bracing full-time or accept a surgical fusion of their hindfoot.
- Most patients have a history of at least one failed surgical procedure to attempt a primary repair or anastomosis of the peroneus brevis and longus tendons.
- The goal of this procedure is to provide dynamic stabilization of the ankle and restore the function of the peroneal tendons.

PATIENT HISTORY AND PHYSICAL FINDINGS
- These patients present with chronic lateral ankle pain and tenderness, swelling, and lateral ankle instability.
- Patients have considerable weakness and painful inversion and eversion compared with the contralateral limb.
- A fully functional FHL tendon must be demonstrated.
- Alignment of the affected lower extremity, including the hip, knee, ankle, hindfoot, and forefoot, must be assessed. A fixed hindfoot varus deformity may need to be corrected at the time of surgery.
- If mechanical instability of the ankle is present, a ligament reconstruction at the time of the first stage can be included.
- Muscle strength and balance should be evaluated, particularly inversion and eversion.
- The single heel rise is helpful to evaluate the normal inversion–varus alignment of the hindfoot.
- Manual muscle testing for FHL is helpful to evaluate the functionality and strength of the FHL motor unit.
- The anterior drawer test is used in evaluating the integrity of the anterior talofibular ligament and the calcaneofibular ligament.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Weight-bearing ankle and foot radiographs must be obtained.
- MRI of the involved ankle demonstrates chronic thickening, fissuring, scarring, and stenosis of the remaining peroneal structures. Tears in the substance of the tendon and fluid in the sheaths may also be visualized. Associated pathology of the ankle can be identified as well.

DIFFERENTIAL DIAGNOSIS
- Fibular fracture, stress fracture
- Peroneal tendon tear
- Ankle instability, involving the anterior talofibular ligament or calcaneofibular ligament
- Lateral process fracture of the talus
- Syndesmosis or subtalar sprains
- Impingement lesions
- Osteochondral lesions of the talus
- Tarsal coalition
NONOPERATIVE MANAGEMENT
- Functional rehabilitation includes range of motion for the ankle and hindfoot, concentric and eccentric muscle strengthening, endurance training with particular attention to the peroneal musculature, and proprioceptive training.
- Proprioceptive exercises improve dynamic stability and are an essential part of the rehabilitation program.
- Functional bracing or taping may be useful to help prevent recurrent injury during “at-risk” activities.

SURGICAL MANAGEMENT
- The technique is staged in two parts. During each stage, the patient is positioned in the same manner. Perioperative antibiotics are given. A pneumatic thigh tourniquet is applied as needed.

Preoperative Planning
- All imaging studies must be reviewed.
- Plain films must be reviewed for degenerative changes, malalignment, fractures, and the presence of hardware from previous surgeries.

Positioning
- The patient is placed supine on the operating table. Some prefer to place the patient on a beanbag and approach the lateral aspect of the ankle in a lazy lateral or lateral decubitus
position. We place saline bags under the ipsilateral hip to achieve this lazy lateral position.

**Approach**

- A longitudinal incision is centered over the course of the peroneal tendons, beginning 1 cm posterior and proximal to the tip of the fibula.

- The incision is extended to the base of the fifth metatarsal (FIG 4).
- Care must be taken to protect the sural nerve in the distal aspect of the incision, which is subcutaneous and just posterior to the incision.
- The surgeon carefully dissects through the extensive scar tissue (FIG 5).

**FIG 2** • Intraoperative photograph of a longitudinal peroneus brevis tear located in the fibular groove.

**FIG 3** • Axial T2 MRI image demonstrating (A) a tear in the peroneal tendon and (B) fluid around the sheath of the tendon.

**FIG 4** • Intraoperative photograph demonstrating the peroneal incision, from over the peroneals to the base of the fifth metatarsal.

**FIG 5** • Extensive scar tissue is evident overlying the peroneal tendons in this multiply operated patient.

**STAGE 1: DÉBRIDING THE PERONEAL TENDON AND SHEATH REMNANTS**

- If present, identify the peroneal sheath. Incise the sheath proximally through the superior peroneal retinaculum to the musculotendinous junction. Distally, open the sheath as far as needed.
- The first stage of reconstruction consists of débriding the remaining peroneal tendon tissue and the tendon sheath (TECH FIG 1).

**TECH FIG 1** • The peroneal tendon sheath and tendon are débrided.
STAGE 1: INSERTING THE HUNTER ROD

- Insert a 6-mm Hunter rod into the bed of the peroneal sheath. Suture the Hunter rod to the remaining stump of the peroneus brevis tendon distally with nonabsorbable suture. Proximally, the rod remains free in the sheath (TECH FIG 2).
- Trim the sheath of any redundancy and close it over the Hunter rod (TECH FIG 3).

TECH FIG 2 • A 6-mm Hunter rod is placed into the bed of the peroneal sheath. The Hunter rod is sutured into the remaining stump of the peroneus brevis tendon distally with nonabsorbable suture. Proximally, the rod remains free in the sheath.

TECH FIG 3 • The sheath is trimmed of any redundancy and closed over the Hunter rod.

STAGE 2: EXCHANGING THE HUNTER ROD FOR THE FHL TENDON

- With the FHL harvested, make a small incision at the proximal aspect of the previously made lateral incision overlying the proximal aspect of the Hunter rod, staying proximal to the lateral malleolus.
- Identify the FHL in the deep posterior compartment at its origin on the posterior fibula. Pull it into the lateral incision (TECH FIG 4).

TECH FIG 4 • After the flexor hallucis longus is released from the plantar surface of the foot, it is identified in the deep posterior compartment at its origin on the posterior fibula. It is then pulled into the lateral incision.
POSTOPERATIVE CARE

- Identify the proximal portion of the Hunter rod and attach the FHL to the proximal aspect of the Hunter rod.
- Make a small distal incision over the distal suture site of the Hunter rod and the remaining portion of the peroneus brevis (TECH FIG 5).

- Release the Hunter rod from this suture site and pull it distally, allowing the FHL tendon to slide into the newly formed tendon sheath.
- Attach the FHL to the remaining stump of the peroneus brevis tendon using a Pulvertaft weave (TECH FIG 6).

TECH FIG 5 • A small distal incision is made over the distal suture site of the Hunter rod and the remaining portion of the peroneus brevis.

TECH FIG 6 • The flexor hallucis longus is attached to the remaining stump of the peroneus brevis tendon using a Pulvertaft weave.

PEARLS AND PITFALLS

| Indication | Complete history and physical examination
| Address associated malalignment and pathology.
| For patients with chronic tendinosis of both peroneal tendons that have failed previous surgical repair
| Address additional pathology such as ligament instability or heel varus at the first stage of reconstruction.

| Incision | Avoid injury to the sural nerve. Preoperative testing is necessary to assess whether there is preexisting damage from the patient’s previous surgeries. By staying over the course of the peroneal tendons the surgeon can generally avoid the sural nerve as it sits about 1 cm posterior.

| Hunter rod placement | Use a nonabsorbable suture to attach the Hunter rod distally to avoid displacing the rod from the distal peroneus brevis stump.
| Perform adequate débridement on the peroneal tendons and surrounding scar.

| FHL harvest | Do not harvest the FDL.
| During exposure, be careful of the neurovascular structures.
| Tenodese the distal stump of the FHL to the FDL tendon with all five toes held in a neutral position.

POSTOPERATIVE CARE

- Postoperatively, after the insertion of the Hunter rod, patients are initially placed in a bulky Jones dressing for the first 2 weeks. Thereafter, they are allowed to bear weight as tolerated in a removable short-leg walking boot. They are instructed to remove the boot four times a day and perform active and passive range-of-motion exercises of the ankle and hindfoot in all planes of motion.
- Three months after the Hunter rod placement, the patient is brought back to the operating room for a transfer of the FHL tendon. Postoperatively, again, he or she is placed in a bulky Jones-type dressing for 2 weeks. Thereafter, the patient is advanced to a removable short-leg cast walker and maintained non-weight-bearing until 4 weeks. From week 4 to week 8, the patient is advanced to partial weight bearing in a removable cast walker. The patient is instructed to begin active and passive range-of-motion exercises of the ankle and hindfoot in all planes of motion. Home strengthening exercises are begun at 8 weeks, and the patient is advanced to an ankle stirrup at 12 to 14 weeks based on his or her strength. All patients are enrolled in formal physical therapy for functional rehabilitation of the ankle starting at 8 weeks.

OUTCOMES

- Data on the 8-year follow-up of seven patients has been published by the senior author (KLW). All wounds healed without complications. One workers’ compensation patient had continued pain and ambulates with a molded ankle-foot orthosis. The remaining six patients report complete relief of preoperative symptoms and a return to preinjury levels of activity. There were five excellent results, one good result, and one fair result.\textsuperscript{15,16}

COMPlications

- Wound complications
- Sural nerve injury
- Chronic pain
REFERENCES
DEFINITION
- Subluxation or dislocation of the peroneal tendon is a relatively uncommon injury, with the majority of the cases attributed to a traumatic event. Chronic subluxation has also been reported without any history of a specific event. Numerous surgical procedures have been described for the treatment of peroneal tendon subluxation, which may be classified into three categories: primary repair, soft tissue augmentation, and bony reconstruction. Primary repair of the superior peroneal retinaculum (SPR) is a commonly used surgical procedure. However, the effectiveness of primary repair depends upon the quality of the retinaculum and its ability to contain the peroneal tendons. When the SPR tissue is deficient or insufficient, then other procedures are necessary.

- Soft tissue procedures other than primary repair involve the augmentation of tissue already present or the rerouting of tissue from other structures to recreate the SPR.
- Bony procedures attempt to recreate a more stable fibular sulcus by deepening the fibular groove or extending the fibular rim. In this chapter we present a soft tissue augmentation procedure using a periosteal-based flap of the retrofibular sulcus.

ANATOMY
- Along the lateral aspect of the lower leg there are two muscles in the lateral compartment, the peroneus longus (PL) and peroneus brevis (PB). These two muscles arise at the proximal fibula and become tendinous before crossing the ankle.
- The peroneal tendons are contained in a single sheath located posterior and immediately distal to the fibula. Roughly at the level of the peroneal tubercle on the lateral calcaneus, the tendons separate into separate sheaths. The PB muscle belly extends more distal than the PL, and it becomes tendinous about 1.5 cm before the tip of the fibula. The PB tendon lies directly posterior to the fibula and anteromedial to the PL tendon as the two tendons course behind the fibula.
- The peroneal tendon sheath comprises the SPR, the calcaneofibular ligament (CFL), and the fibular sulcus. Respectively, the fibular sulcus represents the anterior border, the SPR the lateral border, portions of the SPR and CFL the posterior border, and portions of the CFL and posterior talofibular ligament the medial border of the peroneal tendon sheath. The PB inserts on the dorsal base of the fifth metatarsal, while the PL courses lateral to medial on the plantar aspect of the foot and inserts on the lateral sides of the base of the first metatarsal and medial cuneiform bones.
- The SPR is the primary restraint against subluxation of the peroneal tendons within the fibular groove. The SPR can have an extremely varied anatomy, with differences in width, thickness, and insertional patterns. Most commonly, the SPR inserts into both the Achilles tendon and the calcaneus. There is no distinct insertion point of the SPR; instead, it blends into the periosteum of the fibula.
- The anatomy of the fibula is varied as well. About 50% of fibulae have a bony ridge about 2 to 4 mm that augments the fibular sulcus. A cadaveric study by Edwards found that 82% of the time a sulcus was present at the posterior edge of the distal fibula. The average sulcus dimension was 3 mm deep and 6 mm wide. He found that 11% of the cadavers had no groove and that 7% of the cadavers had a convex fibula. A fibrocartilaginous rim was deficient in 48% of all cadavers and was absent in 30%.

PATHOGENESIS
- According to Zoellner and Clancy, in acute injury, the peroneal tendons tend to dislocate anteriorly over the lateral malleolus in people who have an anatomic predisposition. The fibular groove that serves as the pulley for the tendons can be shallow or convex, and the SPR may be absent or lax. A low-lying PB muscle belly can also cause subluxation (FIG 1). In a study of the effect of a low-lying PB muscle belly, Geller et al measured the location of the musculotendinous junction (MTJ) in 30 cadaveric specimens with respect to the fibula tip and peroneal tubercle, and also the width of the PB tendon.

FIG 1 • A, B. Anatomic dissection of a peroneus muscle belly that is too distal. Note the distance to the fibular tip.
The PB MTJ was significantly more distal and the tendons had a significantly greater diameter in torn (4/30) versus untorn (26/30) specimens (Table 1). The authors suggested that the location of the peroneus brevis MTJ may have an influence on the development of degenerative tears.

■ Recurrent dislocations are the result of an inciting acute traumatic episode of forceful ankle dorsiflexion with a simultaneous powerful contraction of the peroneal muscles that causes failure of the SPR. The dorsiflexion causes the SPR to tighten, thereby decreasing its diameter. This force is theorized to cause the retinaculum to be avulsed from its periosteal attachment. Eckert and Davis4 stated that the SPR’s attachment on the edge of the fibula does not adhere to a strong band of collagen, but instead blends into the periosteum of the lateral malleolus. They proposed that this weak insertion point is responsible for tendon dislocation secondary to avulsion of the fibular fibrocartilaginous lip and stripping of the SPR from the fibula.

■ The prototypical mechanism is in skiers as they forcefully contract the peroneal muscles to grab the ski edge into the snow.

■ Eckert and Davis4 classified SPR injury into three different grades according to severity:
  - Normally, the peroneal tendons are contained within the fibular sulcus by the SPR.
  - Grade 1 injury: Separation of the retinaculum from the cartilaginous lip and the lateral malleolus
  - Grade 2 injury: The distal 1- to 2-cm dense fibrous lip is elevated along with the SPR.
  - Grade 3 injury: Avulsion of a thin fragment of bone along with the collagenous lip attached to the deep surface of the SPR and deep fascia. (Radiographically, this may be represented by a “fleck sign.”)
  - In grade 1 injuries the peroneal tendons are easily reducible and are unstable under tension only.
  - In grade 2 and 3 injuries the peroneal tendons fail to remain reduced even without tension.

NATURAL HISTORY

■ Based on our experience, symptomatic recurrent subluxation does not resolve spontaneously.

■ Often, peroneal tendon dislocation continues to be misdiagnosed as a chronic ankle sprain. As the tendons dislocate and relocate, direct tendon injury occurs due to repetitive trauma.

■ Zone 1 tendon injuries occur at the fibular groove and usually involve the PB tendon. The action of the PB tendon snapping over the sharp ridge of the fibula leads to a longitudinal tear within the tendon substance (FIG 2).

■ Zone 2 injuries occur distal to the fibular tip, usually affecting the PL tendon. These injuries are caused by the PL coursing over the lateral wall of the calcaneus and turning 45 degrees at the cuboid facet. As the tears propagate, an inflammatory response may lead to tenosynovitis, tendinopathy, and potential tendon rupture. Peroneal tendon subluxation and dislocation is thought to accentuate the symptoms.

PATIENT HISTORY AND PHYSICAL FINDINGS

■ The patient may not be able to recall a traumatic event preceding the usual complaints of lateral ankle swelling and pain posterior to the lateral malleolus. Most patients report that the pain radiates proximally. Patients complain of persistent lateral ankle pain and swelling with a sensation of snapping or popping and may note a “pop” laterally before the tendon gives way.

■ On physical examination, the lateral ankle will be swollen and tender and may be ecchymotic in the acute setting. This can easily be confused with a lateral ankle sprain (Table 2), but the location of the pain may be used to differentiate between the two. Tenderness posterior to the fibula is indicative of peroneal tendinopathy; in contrast, tenderness at the anterior distal fibula suggests an anterior talofibular ligament injury (ankle sprain). However, since the CFL is the floor of the

![FIG 2 • The split peroneus brevis tendon, with the peroneus longus running more posterior.](image_url)

Table 1: Low-lying Muscle Belly of PB and its Relationship to PB Tears

<table>
<thead>
<tr>
<th>Specimen Data</th>
<th>Average Distance To Fibula Tip (cm)</th>
<th>Average Distance Peroneal Tuberosity (cm)</th>
<th>Average Width (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No tear (n = 26)</td>
<td>1.62 ± 1.38</td>
<td>3.39 ± 1.3</td>
<td>1.19 ± 0.37</td>
</tr>
<tr>
<td>Tear (n = 4)</td>
<td>0.04 ± 1.51</td>
<td>2.13 ± 0.83</td>
<td>1.44 ± 0.39</td>
</tr>
</tbody>
</table>

Table 2: Clinical Differentiation of Ankle Subluxation from Ankle Sprain

<table>
<thead>
<tr>
<th>Signs and Symptoms</th>
<th>Subluxation</th>
<th>Sprain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenderness</td>
<td>Proximal to tip of fibula</td>
<td>Distal to tip of fibula</td>
</tr>
<tr>
<td>Swelling</td>
<td>Posterolateral</td>
<td>Anteroinferior</td>
</tr>
<tr>
<td>History</td>
<td>Snapping</td>
<td>Giving way</td>
</tr>
<tr>
<td>Worse on uneven ground?</td>
<td>Possible</td>
<td>Probable</td>
</tr>
<tr>
<td>Worse on circumduction?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Worse on flexion–inversion?</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
peroneal tendon sheath, there may still be some confusion with more severe ankle sprains. A negative anterior drawer test and pain experienced when the foot is stressed against resisted eversion are more indicative of an injury to the SPR.

- Peroneal tendon subluxation test: In the prone position, with the knee flexed to 90 degrees, ankle dorsiflexion and forced hindfoot eversion against resistance is performed. Apprehension and peroneal tendon subluxation or dislocation with this provocative maneuver typically confirms the diagnosis.8

- Acutely dislocated peroneal tendons are occasionally seen on physical examination, but more commonly the tendons are reduced upon presentation and are dislocated only with the peroneal tendon subluxation test.

- Likewise, chronic peroneal tendon subluxation or dislocation may not present with the tendons frankly dislocated. Chronic subluxation and dislocation are generally best diagnosed by testing the ankle through a range of motion of inversion and plantarflexion to maximum eversion and dorsiflexion with resistance.

- Peroneal compression test: Direct compression of the peroneal tendon sheath to identify peroneal tendon injury

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Standard weight-bearing ankle radiographs (AP, lateral, and mortise) define the bony ankle anatomy alignment. In cases of peroneal tendon subluxation, radiographs are usually negative. In a grade 3 injury a "fleck" of bone can be seen off the posterior distal fibula and is considered pathognomonic of an SPR injury (FIG 3).

- MRI affords detail of the soft tissues. Injury to the SPR, the peroneal tendons, or other supporting tissues may be identified: anomalous structures such as the peroneus quartus or a low-lying PB muscle belly may be suggested (FIG 4). A MRI is useful for preoperative planning, as other pathology (PB tear, low-lying MJT, fibular sulcus) may also need to be surgically addressed concomitant with repair of the subluxation or dislocating peroneal tendons. We also use MRI to define the morphology of the fibular sulcus. While MRI may identify dislocated or subluxated peroneal tendons, the tendons are often reduced while the patient is relaxed in the MRI scanner; however, occasionally dislocated tendons may be identified on axial MRI views.

**DIFFERENTIAL DIAGNOSIS**

- Injury to the lateral ligament complex
- Fracture of lateral malleolus, lateral process of the talus, anterior process of the calcaneus, or fracture at the base of the fifth metatarsal
- Osteochondral defect on the talar dome
- Peroneal tendon pathology

**NONOPERATIVE MANAGEMENT**

- Initial treatment of an acute injury consists of a well-molded, short-leg cast for 6 weeks. Successful outcomes of nonoperative management range from 14% in a study by Eckert and Davis4 to up to 56% as reported by McClennan,9 while other investigators have also reported variable outcomes in small case series.6,10,11,14 At best, only half of all patients become better. Therefore, as part of initial injury counseling, it is necessary to inform the patient that an operation will still be necessary, in most instances, despite conservative treatment. For patients with chronic subluxation, nonoperative treatment has not been shown to help; usually pain and symptoms recur once the short-leg cast is removed. In addition, more athletic, higher-demand patients tend to demand more reliable treatment and wish to proceed with operative repair.

**SURGICAL MANAGEMENT**

- Illustrated here is a modified surgical technique for soft tissue augmentation representing an alternative procedure for the treatment of peroneal tendon subluxation. No absolute contraindications exist for the procedure, but relative contraindications include:

  - The presence of a previous fracture or surgery that alters the local morphology and tissue quality
  - An Eckert and Davis grade 3 fracture, with a thin fragment of bone along the cartilaginous lip attached to the deep surface of the peroneal retinaculum; the anterior portion of
the SPR is already compromised and would not make a good surgical candidate.

- Patients with collagen disorders (Marfan, Ehlers-Danlos), where the strength and integrity of the periosteal flap could be suspect.

**Preoperative Planning**

- Routine ankle radiographs are essential to identify or rule out a rim fracture of the distal fibula, which occurs in 15% to 50% of all cases of peroneal subluxation.1

- Typically, the ankle radiographs appear normal. We routinely obtain an MRI to identify potential peroneal tendon tears, other soft tissue anomalies such as a peroneus quartus, or other causes of lateral ankle pain and instability that need to be addressed concomitant to SPR augmentation.13

- MRI axial cuts define the morphology of the fibular sulcus and are helpful in staging a bony procedure if necessary during the superior retinaculoplasty.

**Positioning**

- Either general or regional anesthesia is acceptable for this procedure, and the surgeon’s preference determines which anesthetic method to use.

- The patient is placed in an oblique lateral position using a beanbag or large support under the ipsilateral hip. Adequate rotation of the limb facilitates access to the posterior fibula.

- We routinely use a thigh tourniquet and carefully pad all bony prominences.

- An examination under anesthesia with provocative maneuvers such as the anterior drawer and rotary subluxation test may identify associated instability and locking or popping of the unstable peroneal tendons.

**Approach**

- The standard lateral approach is used.

- Care should be taken not to injure the sural nerve.

---

**SUPERIOR PERONEAL RETINACULOPLASTY**

- We use a standard lateral incision along the course of the peroneal tendons, taking care not to injure the sural nerve.

- Carry the incision down to the level of the peroneal tendon sheath (TECH FIG 1A).

- Inspect the SPR. Usually, it is attenuated and deficient, especially along its anterior border. The retinaculum often is lifted off its fibular attachment, thus allowing the peroneal tendons to subluxate.

- Make an incision in the peroneal sheath along the posterior border of the fibula.

**TECH FIG 1 • A.** Intraoperative photograph of a left ankle (lateral approach) shows the peroneal tendons subluxing anteriorly (brevis is the gray arrow, longus is the white arrow, superior peroneal retinaculum [SPR] is the black arrow). **B.** The peroneal tendons have been retracted anteriorly by the Penrose drain. Elevation of an anterior-based periosteal flap (outlined by dots) from the fibular groove has been completed. The black arrow shows the remnant of the SPR posteriorly. **C.** The tendons are relocated, after a groove-deepening procedure, into the recreated groove. The white dots outline the anteriorly based periosteal flap. It is then brought over to the posterior remnant of the SPR (black arrow). **D.** The flap is sutured to the remnant SPR with nonabsorbable sutures, completing the superior peroneal retinaculoplasty.
■ Retract the peroneal tendons anteriorly (TECH FIG 1B).
■ Occasionally, a small tear may be noticed in the PB tendon, warranting débridement or repair.
■ If a shallow or convex fibular groove is present, we typically perform a groove-deepening procedure.
■ We routinely reinforce the SPR with a soft tissue periosteal flap elevated from the fibular groove from a posterior to anterior direction.
■ Raise the periosteal flap, measuring about 1.0 × 3.0 cm, sharply, from posterior to anterior. After the flap is raised, a groove-deepening procedure may be performed when indicated.
■ Use a burr to deepen the groove 6 to 9 mm with all raw bony edges. The groove should extend from the fibular tip to 5 cm proximal. We use bone wax to smooth the groove.
■ Reduce the peroneal tendons and use the periosteal flap to contain the tendons, with the visceral side of the periosteum facing the tendons (TECH FIG 1C).
■ Suture the flap to the posterior remnant of the SPR with a series of 3-0 polybraided nonabsorbable sutures (TECH FIG 1D).
■ Range the ankle to evaluate the soft tissue repair, being sure that the tendons are free to move within the reconstructed peroneal tendon sheath.
■ Close the skin in usual fashion, and place the leg into appropriate dressings and splints with compressive bandages.

**DETAILED SURGICAL TECHNIQUE (COURTESY OF MARK E. EASLEY, MD, AND JAMES K. DEORIO, MD)**

**Positioning and Approach**
- Patient positioned in lateral decubitus position
- Regional anesthesia
- Thigh tourniquet
- Posterolateral approach
  - Immediately posterior to posterior margin of the distal fibula
  - Expose SPR.
  - Protect sural nerve.
  - Release SPR 1 to 2 mm posterior from posterior fibular margin.
  - Peroneal tendons will be dislocated, so determining exactly where to release SPR will be distorted.
  - Chronically dislocated tendon may be located in a “pocket” lateral to the distal fibula (TECH FIG 2).
  - Inspect the tendons, particularly the more anterior peroneus brevis, for a tear.
  - Peroneal tendon dislocations predispose the tendons to longitudinal split tears as the tendon repeatedly subluxates around the posterolateral fibula.

**TECH FIG 2** • Chronically dislocated peroneal tendons. **A.** Tendons in a pseudogroove on the lateral fibula. **B.** With peroneal tendons reduced, a “new gliding surface” and pocket of displaced superior peroneal retinaculum is evident.

**TRADITIONAL GROOVE-DEEPENING PROCEDURE (“TRAP DOOR TECHNIQUE”)**
- Creating the “trap door” in the posterior distal fibula
  - Maintain the peroneal tendons dislocated anteriorly to protect them during the fibular groove deepening.
  - Using a microsagittal saw, weaken the posterior cortex within the fibular groove (TECH FIG 3A).
  - While the fibula may be weakened only on the posterolateral margin, it is often necessary to weaken the “hinge” on the posteromedial margin as well (TECH FIG 3B).
  - The fibular groove also needs to be weakened transversely, at the proximal margin of the trap door (TECH FIG 3C).
  - Next, the trap door is completed at its distal margin, where the fibular groove rounds the distal fibula (TECH FIG 3D).
Elevate the trap door and reflect it posteriorly on its hinge (TECH FIG 3E,F). If the hinge should be separated completely, it is not a problem.

- Decancellate the distal fibula. We typically use a high-speed burr to evacuate the cancellous bone from the distal fibula (TECH FIG 4), but a curette may also be used.
- Replace the “trap door” into the deepened fibular groove.

- Impact the posterior fibular bone that was elevated, but try to preserve the smooth surface so that the peroneal tendons have a smooth gliding surface with little risk of impingement or creation of adhesions (TECH FIG 5A).
- The groove should be deep enough to keep the peroneal tendons reduced without manually restricting them (TECH FIG 5B). If it is not, then further decancellation may be necessary.

- Repair the SPR.
  - With the tendons reduced, repair the SPR by advancing the intact leading edge of the SPR from its posterior position to the posterolateral rim of the distal fibula from which the SPR was displaced by the tendon dislocation and elevated for the surgical exposure (TECH FIG 6A).
  - We routinely create drill holes in the distal posterolateral fibula to anchor the SPR (TECH FIG 6B).
  - Be sure that the tendons glide well within the new fibular groove and are not stenosed by the repair (TECH FIG 6C,D).

- Standard closure

**TECH FIG 3** • A. Weakening the posterolateral aspect of the fibula to create the “trap door.” B. Weakening the hinge of the trap door. C. Transverse osteotomy to ensure that the trap door can open. D–F. Elevating the trap door. D. Osteotome introduced into distal posterior fibula. E. Posterior fibula elevated at its posteromedial hinge. F. Trap door completely open.

**TECH FIG 4** • High-speed burr is used to remove cancellous bone from distal fibula.
MODIFIED TECHNIQUE USING A LARGE-DIAMETER DRILL BIT  (AS DESCRIBED BY ROBERT B. ANDERSON, MD)

- Chronically dislocated peroneal tendons may create a new pocket and even gliding surface on the lateral fibula (TECH FIG 7).
- Protect the dislocated tendons and adjacent soft tissues from the drill bit.
- From the distal fibular tip, introduce progressively larger-diameter drill bits to weaken the distal fibula and ream away the distal fibular cancellous bone (TECH FIG 8).
- While simple impaction of the posterior fibula to deepen the groove is possible at this point, we prefer to first weaken the cortex with a microsagittal saw as described for the traditional fibular groove-deepening procedure (TECH FIG 9A).
- To protect the smooth surface on the posterior fibula, a tamp can be placed longitudinally in the groove and impacted so as to avoid disruption of the smooth gliding surface for the peroneal tendons (TECH FIG 9B).
- The peroneal tendons should remain reduced without manually restraining them (TECH FIG 10A). If not, then deepen the groove further with a larger-diameter drill bit and perform further impaction of the posterior fibular surface.
- Reattach the SPR to the posterolateral fibular margin via drill holes.
- Be sure the peroneal tendons glide well without restriction in the deeper fibular groove (TECH FIG 10B).
- Standard closure
**TECH FIG 7** • Pseudogroove created on lateral fibula. **A.** Peroneal tendons lateral to fibula. **B.** With tendons reduced, the pseudogroove is visible, with the displaced and attenuated superior peroneal retinaculum.

**TECH FIG 8** • **A.** Drill bit introduced to decancellate the distal fibula. **B, C.** Fluoroscopic confirmation of proper drill bit position in distal fibula. **B.** AP view. **C.** Lateral view.

**TECH FIG 9** • Impaction of the posterior fibula to deepen the fibular groove. **A.** Weakening the posterolateral margin of the fibula to facilitate impaction. **B.** Using a tamp longitudinally to protect the gliding surface of the posterior fibula during its impaction.

**TECH FIG 10** • **A.** Peroneal tendons remaining reduced in the deepened fibular groove, even without superior peroneal retinaculum (SPR) repair. **B.** SPR repaired without stenosis of the peroneal tendons.
The peroneal tendons must be retracted anteriorly to allow visualization of the flap donor site to ensure sufficient harvest and to avoid damage to the peroneal tendons.
- The flap should maintain its continuity, anteriorly, with the fibrocartilage ridge. Use of a no. 69 Beaver blade is critical for flap elevation.
- The flap should be elevated before any groove-deepening procedure. If the groove is deepened before this, the periosteum will be destroyed.

<table>
<thead>
<tr>
<th>PEARLS AND PITFALLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvest of periosteal flap</td>
</tr>
<tr>
<td>- The peroneal tendons must be retracted anteriorly to allow visualization of the flap donor site to ensure sufficient harvest and to avoid damage to the peroneal tendons.</td>
</tr>
<tr>
<td>- The flap should maintain its continuity, anteriorly, with the fibrocartilage ridge. Use of a no. 69 Beaver blade is critical for flap elevation.</td>
</tr>
<tr>
<td>- The flap should be elevated before any groove-deepening procedure. If the groove is deepened before this, the periosteum will be destroyed.</td>
</tr>
<tr>
<td>Flap-to-tendon adhesions</td>
</tr>
<tr>
<td>- No issues with tendon-to-flap adhesions have been reported; nonetheless, early range of motion starting at 4 weeks minimizes any chance of adhesions developing.</td>
</tr>
<tr>
<td>Peroneal tendon tears</td>
</tr>
<tr>
<td>- Tears in the tendons need to be débrided and repaired or reconstructed. Successful peroneal tendon reduction with persistent symptoms secondary to peroneal tendon tears may lead to a poor outcome.</td>
</tr>
<tr>
<td>Avoid overtightening the peroneal tendon sheath reconstruction</td>
</tr>
<tr>
<td>- This will lead to stenosing flexor tenosynovitis. Overtightening is unnecessary; the tendons simply need to remain reduced.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- Postoperatively, the patient is immobilized in a short-leg cast and is kept non–weight-bearing for a total of 6 weeks.
- After 4 weeks the cast is removed and the patient is given a removable stiff-ankle rocker-bottom boot and remains non–weight-bearing for an additional 2 weeks while beginning physical therapy with ankle range-of-motion exercises.
- At the end of 6 weeks the patient is progressed to weight bearing as tolerated in the brace, after which the patient is weaned from the stiff-ankle boot and is started with ankle strengthening with inversion and eversion exercises.

OUTCOMES

- A favorable outcome of the procedure depends not only on how well the surgical procedure is performed but also on the appropriate treatment of other associated conditions. Often tendon injuries coexist with subluxation and dislocation and must be treated simultaneously. If tendon pathology such as a tear or degeneration is present and left untreated, pain may persist after surgery no matter how well the surgery was performed.
- In a preliminary study by Tan et al.\(^\text{15}\) conducted at two centers (University of Pennsylvania and University of Medicine and Dentistry of New Jersey), 10 patients with subluxation or dislocation of the peroneal tendons were treated with this technique. Nine of 10 patients had good to excellent results. One patient required a groove-deepening procedure.

COMPLICATIONS

- Peroneal tendon adhesions: Early range-of-motion exercises starting at 4 weeks can minimize this complication.
- Stenosing flexor tenosynovitis: Overtightening of the peroneal tendon sheath is unnecessary; the tendons simply need to remain reduced posterior to the fibula.
- Sural and superficial peroneal nerve injury

The editor and coauthors of this chapter wish to acknowledge the contribution of Dr. Enyi Okereke. Dr. Okereke passed away while on a medical mission to Enugu, Nigeria.

REFERENCES

DEFINITION
- Peroneal tendon subluxation or dislocation from the retrofibular groove is a rare cause of ankle pain and disability. The acute injury often remains unrecognized or is misdiagnosed as an ankle sprain.
- Untreated or misdiagnosed acute injury predisposes a patient to recurrent peroneal dislocation, potential peroneal tendon tear, or chronic dislocation.

ANATOMY
- The peroneus longus and brevis muscles are the two major structures within the lateral compartment of the leg, both arising from the proximal fibula (FIG 1).
- Both structures become tendinous before crossing the ankle joint and remain in a common sheath. As they course distally the tendon of the peroneus brevis lies against the posterior surface of the distal fibula, anterior and medial to the tendon of the peroneus longus.
- Distal to the fibula each tendon enters a distinct tendon sheath, separated by the peroneal tubercle.
- Posterior to the distal fibula both tendons are stabilized in the retrofibular groove by the superior peroneal retinaculum (SPR) (FIG 2).
- The posterior surface of the distal fibula is covered by a layer of fibrocartilage to allow smooth gliding of the peroneal tendons. The depth and width of the retrofibular (peroneal) groove is highly variable. A definite groove is present in about 80%. In the remaining cases the posterior surface of the fibula is flat or convex. A fibrocartilage rim on the lateral border of the fibula that adds an additional 2 to 4 mm to the depth of the sulcus is often present.
- The SPR, the primary restraint to peroneal instability, is composed of a band of the deep fascia that is continuous with the periosteum of the distal fibula but does not attach to the fibrocartilage rim or the posterolateral edge of the bone. It is extremely variable in width and thickness, and five distinct insertion patterns have been described, the most common being a band to both the Achilles tendon and the calcaneus. The fiber orientation of the SPR is parallel to those of the calcaneofibular ligament, and therefore inversion injuries of the calcaneofibular ligament may also cause injury to the SPR.

PATHOGENESIS
- Acute subluxation or dislocation of the peroneal tendons usually occurs while the foot is forcefully dorsiflexed with the peroneal muscles strongly contracted; it commonly occurs during a forward fall in Alpine skiing or in springboard diving.
- Resisted plantarflexion and inversion while the peroneals contract may also cause subluxation or dislocation of the peroneal tendons, and in this case it is commonly associated with lateral instability of the ankle.
Peroneal dislocation may also occur as a sequela to severe calcaneal fractures with lateral displacement of the calcaneus.\(^5,7\)

Peroneal dislocations can be classified into three grades depending on the pathoanatomy of the injury (FIG 3).

As a result of subluxation or dislocation, inherent injuries to the tendons can occur. Depending on the location of the tendon injury they are divided into zone I, II, and III.

- **Zone I** injuries are defined as those involving the fibular groove and most often affect the peroneus brevis tendon. As the tendons sublux in the groove, the brevis is forced onto the sharp posterolateral bony ridge of the distal fibula, causing a longitudinal split in the tendon from the strain of a 45-degree course change as well as compression by the overlying longus tendon.
- **Zone II** injuries are located between the tip of the fibula and the cuboid tunnel.
- **Zone III** injuries are located in the cuboid tunnel and primarily involve the peroneus longus tendon and possibly a painful os peroneum.

**NATURAL HISTORY**

- If diagnosed early, in acute peroneal dislocation the tendons can be manually reduced and held in a reduced position for a 4- to 6-week period of immobilization. In this situation, functional rehabilitation leads to maintenance of tendon reduction and complete recovery in about 50% of cases.\(^1\)
- With delayed diagnosis and treatment, recurrent subluxation and chronic dislocation is common and may lead to degeneration and tearing of the peroneal tendons.\(^9\)

**PATIENT HISTORY AND PHYSICAL FINDINGS**

- Most patients present well beyond the acute phase complaining of vague posterolateral ankle pain that radiates proximally with or without a popping sensation during activity.\(^12\)
- There may be a history of forced dorsiflexion trauma associated with a pop on the lateral aspect of the ankle.
- Often a history of an inversion–supination sprain and possible lateral ankle instability is reported.\(^10\)
- On physical examination peroneal tendinopathy is characterized as fullness along the tendons with diffuse tenderness. Localized tenderness over the posterior ridge of the fibula should raise suspicion for progression of the injury to a peroneal tendon split tear.
- Pain may be elicited with inversion stretch or active resisted eversion.
- Tendon subluxation typically presents as snapping or popping and pain with eversion against resistance. The peroneal tunnel compression test consists of having the patient perform this motion while palpating the posterior border of the fibula. Circumduction of the ankle may demonstrate dislocation of the tendons with eversion and dorsiflexion and spontaneous relocation with plantarflexion and inversion (FIG 4).
- Chronic dislocation of the tendons is characterized by a palpable ridge over the lateral distal fibula often associated with chronic swelling.
- Eversion strength may be limited by pain. Significant weakness of active eversion without much pain should raise suspicion for a complete tear of the peroneal tendons.

**FIG 2** • Superior view of the ankle region shows the relationship of the fibular groove, superior peroneal retinaculum, peroneal tendons, and cartilaginous ridge. (From Coughlin MJ, Mann RA, eds. Surgery of the Foot and Ankle, 7th ed. St. Louis, MO: Mosby, 1999, p. 819.)

A complete examination of the ankle should also include evaluation of associated injuries ruling out differential diagnoses. This includes (but is not limited to) the following:
- Lateral ankle instability: history of frequent sprains, cavovarus foot, increased laxity with anterior drawer or inversion stress test compared to the contralateral side
- High ankle sprain (syndesmotic sprain): pain over anterior ankle syndesmosis, pain with provocative maneuvers (calf squeeze test, external rotation stress test)
- Painful os trigonum or posterior talar process fracture: pain with forced plantarflexion, pain with resisted plantarflexion of the great toe

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs including AP, mortise, and lateral views of the ankle should be obtained to rule out fracture or large osteochondral defects of the talus.
- Occasionally a “fleck” sign, an avulsion fracture off the posterior distal fibula, can be seen on AP or mortise views. If present this is considered pathognomonic for a grade III injury to the SPR with peroneal dislocation.4 As shown in FIGURE 5A, this may be difficult to see without the use of a “hot lamp.”
- Stress views may be helpful to rule out lateral ankle instability.
- CT may be helpful in uncertain diagnosis to evaluate the anatomy of the fibular groove and detect small avulsion fractures, which may be difficult to see on plain films. Axial CT scan images may also confirm peroneal tendon dislocation.
- MRI can identify injury to the SPR, subluxated or dislocated tendons, and intrasubstance degeneration and split tears of the tendons (FIG 6).
- Ultrasound, while operator-dependent, allows a dynamic, real-time examination to evaluate subluxation during provocative maneuvers.

DIFFERENTIAL DIAGNOSIS
- Peroneal tendinopathy or tears
- Lateral ankle instability
- High ankle sprain
- Osteochondral defect of the talus
- Painful os trigonum or posterior talar process fracture
- Retrocalcaneal bursitis

NONOPERATIVE MANAGEMENT
- Acute peroneal subluxation or dislocation can be treated nonoperatively if the peroneal tendons can be reduced and held in a reduced position.
- In this case treatment consists of short-leg cast immobilization in slight plantarflexion and inversion for 4 to 6 weeks, followed by functional rehabilitation. U- or J-shaped foam or felt pads can be placed in the cast to apply pressure around the distal fibula and maintain the position of the peroneal tendons.
- In our opinion, there is no role for nonoperative treatment for symptomatic chronic peroneal dislocation or recurrent subluxation.

SURGICAL MANAGEMENT
- All irreducible peroneal tendon dislocations and those associated with a rim avulsion fibular fracture should be considered for acute surgical reduction and repair.
- Operative treatment is also indicated for all chronic injuries in patients with pain or functional limitations.
- Five basic categories of repair have been described: (1) anatomic reattachment of the retinaculum, (2) bone block procedures, (3) reinforcement of the superior peroneal retinaculum with local tissue transfers, (4) rerouting of the tendons behind the calcaneofibular ligament, and (5) groove-deepening procedures.8
- The goal of groove-deepening procedures is to increase the height of the posterolateral fibular rim to prevent the peroneal tendons from subluxating.
General contraindications to surgical intervention include peripheral vascular disease, skin breakdown or vasculitis, and patients who are “voluntary” subluxators. These are usually patients with generalized ligamentous laxity. Physical examination usually shows the peroneal tendons to subluxate to the lateral rim of the fibular on both ankles, but not over it.

Preoperative Planning

- We recommend reviewing all imaging studies preoperatively to plan for not only fibular groove deepening but also any procedures to address associated pathology. Plain films should be reviewed for fractures, loose bodies, ankle and foot alignment, and the presence of any hardware (from previous procedures).
- Associated fractures, osteochondral lesions, and lateral ankle instability should be addressed concurrently.
- We routinely perform an examination under anesthesia on the operating table before making an incision to assess the ankle and subtalar joint. The peroneal tendons may also be assessed under anesthesia, but without the patient being able to evert against resistance, this is of limited value.

Positioning

- The procedure is performed with the patient in the semilateral position (FIG 7). A bean bag is used to maintain the position of the body with a 10-lb sandbag underneath the ipsilateral hip. This allows the physician to readily access the posterior fibula and obtain fluoroscopic AP and lateral ankle views of the ankle without moving the C-arm from the standard AP position. Regional or general anesthesia may be used and a thigh tourniquet is applied.

Approach

- The standard surgical approach is through a longitudinal, curvilinear incision on the posterior aspect of the fibular following the course of the peroneal tendons to roughly the level of the peroneal tubercle (FIG 7).
- This allows excellent visualization of the SPR, the peroneal tendons, and the posterior aspect of the distal fibula and also provides sufficient access to the lateral tibiotalar joint in cases where concomitant lateral ligament reconstruction is indicated.
- If lateral ankle instability and injury to the peroneal tendons distally have been ruled out preoperatively or with the examination under anesthesia, the approach can be limited to a longitudinal incision just posterior to the fibula.

FIG 6 • T1-weighted (A) and T2-weighted (B) axial MRI images showing dislocated peroneal tendons (arrow) with abundant tenosynovitis. Note the shallow retrofibular groove and the torn superior peroneal retinaculum.

FIG 7 • Utilitarian posterolateral approach for peroneal repair and indirect fibular groove deepening.

INDIRECT FIBULAR GROOVE DEEPENING

- Make a curvilinear incision along the posterior aspect of the distal fibula. It extends toward the base of the fifth metatarsal but usually ends at the level of the peroneal tubercle.
- Develop full-thickness skin flaps to avoid skin necrosis.
- Protect the sural nerve and branches of the superficial peroneal nerve.
- Incise the peroneal sheath distal to the fibula. If the SPR is still intact, incise it over the bone and then sharply elevate it off the fibula, leaving a cuff of tissue on the distal fibula. Retract the edges of the SPR posteriorly with two small hemostats to facilitate later repair.
- Inspect the peroneal tendons, excise inflamed tenosynovium, and débride and repair split tears in the tendons with buried nonabsorbable suture (TECH FIG 1A,B).
- Excise any low-lying peroneus brevis muscle from the tendon. Also excise a normal anatomic variant, the peroneus quartus, a supernumerary muscle of the lateral compartment of the leg, if present. These additional procedures tend to make room in the groove for the peroneal tendons (TECH FIG 1C).
- Expose the distal fibular tip, avoiding injury to the calcaneofibular ligament.
Place an intramedullary guide pin from distal to proximal inside the fibula, in line with the posterior cortex (TECH FIG 2A). Thin the posterior cortex by sequential reaming over the guidewire (usually 7 to 8 mm) (TECH FIGS 2B AND 3). We routinely use suitably sized reamers from the biotenodesis screw system (Arthrex, Naples, FL) or any anterior cruciate ligament instrument set. Alternatively, consider using progressively larger drill bits from a standard trauma set or cannulated drills from a dedicated fifth metatarsal (Jones fracture) set (Wright Medical, Memphis, TN).

**TECH FIG 1** • **A.** The superior peroneal retinaculum is incised longitudinally and retracted with two hemostats. A longitudinal split tear of the peroneus brevis tendon (PBT) is often identified in chronic dislocations. **PLT,** peroneus longus tendon. **B.** Split tears of the PBT are débrided or repaired. **C.** The low-lying peroneus brevis muscle and if present the peroneus quartus (PQT) are excised to create room for the peroneal tendons.

**TECH FIG 2** • **A.** An intramedullary guide pin is placed into the distal fibula parallel to the posterior cortex. **B.** The posterior cortex of the fibula is thinned by intramedullary reaming with cannulated reamers over the guide pin. **C.** To avoid fracture of the edge of the fibula during impaction the posterolateral cortex is perforated with an osteotome (this is necessary only in very hard bone). **D.** The posterior cortex of the fibula is impacted into the void created by the reamers with an appropriate-size tamp.
Once the posterior cortex is sufficiently thinned, impact it into the void created by the reamers using an appropriately sized bone tamp (TECH FIGS 2D AND 3). This preserves the physiologic gliding surface covering the groove, making it a smooth bed for tendon excursion. If the bone is very hard and impaction cannot be performed easily, the posterolateral cortex of the fibula can be perforated with an osteotome or microsagittal saw to facilitate impaction of the posterior cortex (TECH FIG 2C).

- Also tamp the very distal tip of the fibula inward to avoid a sharp edge that would otherwise impinge on the peroneal tendon as it courses into the foot.
- When done correctly the entire peroneus brevis and at least 50% of the peroneus longus tendon should be covered by the fibular rim with the tendons in a resting position.
- After completing groove deepening, tendon débridement, and tendon repair, repair the SPR.
- Sharply elevate the remainder of the cuff on the fibula off bone, exposing the lateral cortex, which is then roughened to bleeding bone with a rasp or rongeur.
- Excise any redundant SPR tissue and advance the remaining SPR to the previously prepared cortical bed; secure it through either drill holes or suture anchors.
- Place three or four drill holes or suture anchors about 1 cm apart proximally from the tip of the fibula (TECH FIG 4A). Reattach the posterior flap of the SPR to the prepared bone with 2-0 suture in a “pants-over-vest” technique, making sure that the space between the bony surface of the lateral malleolus and the SPR is obliterated. Suture the anterior portion of the retinaculum over the repair with interrupted 2-0 suture (TECH FIG 4B,C).

- Test the stability of the repair by ranging the ankle through a full range of motion. Verify free excursion of reduced tendons; the tendons should not be trapped by the repair. Overtightening of the SPR repair is not necessary; the goal is to keep the peroneal tendons reduced posterior to the fibula.
PEARLS AND PITFALLS

- Avoid surgery on voluntary dislocators.
- Maintain the operated limb in a semilateral position (use a large bump under the ipsilateral hip or a bean bag).
- Incise the SPR on the posterior margin of the fibula, not too far posteriorly.
- Create adequate room for the peroneal tendons.
- Inspect both peroneal tendons for tears.
- Avoid fibular stress fracture.
- Avoid creating stenosis of the peroneal tendons when repairing the SPR.

- High risk of recurrence
- It is difficult to gain access to the posterior aspect of the fibula with the patient in a supine position.
- This allows excision of redundant tissue and a secure SPR repair to bone.
- Excise all low-lying peroneus brevis muscle and the entire peroneus quartus if present.
- Débride and repair as necessary.
- Reaming the fibula may not weaken the posterior fibula adequately, particularly in young, healthy patients with good bone quality.
- Observe satisfactory tendon excursion with ankle and hindfoot range of motion after SPR repair.

POSTOPERATIVE CARE

- Immediately postoperatively the leg and ankle are placed into a posterior and U-splint in neutral position and the patient is kept non-weight-bearing for 2 weeks.
- Sutures are removed at 2 weeks. A short-leg walking cast is applied and the patient is allowed to bear weight as tolerated.
- At 6 weeks the cast is removed and a cam walker boot is applied to avoid ankle inversion, while allowing plantarflexion and dorsiflexion. Active range-of-motion exercises are initiated at that time.
- Peroneal strengthening is started at about 8 to 10 weeks after surgery.
- Full return to activities is expected between 4 and 6 months postoperatively.
- In elite athletes, given a stable reconstruction, we have been more aggressive with the rehabilitation, to include biking and pool activities by 4 weeks.

OUTCOMES

- As many variations of fibular groove-deepening techniques have been described, all reported results in the literature are derived from small retrospective series. There are no published prospective randomized studies comparing different surgical techniques.
- In general, results of fibular groove-deepening techniques have been good, as long as the underlying pathology is correctly addressed.8
- In our hands, indirect grooving has provided excellent overall results while minimizing the surgical dissection and morbidity. We have not had recurrent dislocations using this technique.
- We recommend that fibular groove deepening should be performed with every SPR reconstruction for chronic peroneal dislocation.

COMPLICATIONS

- Infection
- Delayed wound healing
- Sural nerve injury
- Recurrent dislocation
- Loss of motion

REFERENCES

Tibialis anterior rupture may present as an acute injury or as a chronic painless foot drop. The diagnosis is often delayed. Recommended treatment is surgical for active patients and nonsurgical for low-demand patients. Surgical options include direct repair and reconstruction.

**ANATOMY**
- The tibialis anterior muscle originates from the lateral tibial condyle and interosseous membrane.
- Its insertion is the medial side of the medial cuneiform and the inferomedial base of the first metatarsal.
- The musculotendinous junction is at the junction of the middle and distal thirds of the tibia.
- The tendon courses within a synovial sheath from the musculotendinous junction to its insertion, deep to the extensor retinaculum of the ankle and foot.
- Innervation is the deep peroneal nerve.
- The tibialis anterior muscle controls deceleration of the foot after heel strike and dorsiflexes the ankle.

**PATHOGENESIS**
- Younger individuals with healthy tibialis anterior tendons rarely suffer spontaneous rupture; instead, their mechanism of injury is laceration from penetrating trauma or distal tibia fracture.
- Spontaneous ruptures typically occur in older individuals with degenerative tendinopathy of the tibialis anterior tendon. Minor trauma may be associated with these ruptures, with a mechanism of plantarflexion–eversion. Ruptures typically occur within 3 cm of the tendon’s insertion on the medial cuneiform.

**NATURAL HISTORY**
- The natural history of tibialis anterior rupture is inferred from studies documenting the results of nonoperatively treated patients. These patients will ambulate with a slap-foot gait and sometimes have difficulty negotiating uneven terrain. Most patients are functional; however, they may require a brace.
- Nonoperatively treated patients tend to be older and lower-demand. The natural history for younger, more active patients may indicate less desirable results.
- Definite conclusions regarding the natural history of tibialis anterior ruptures are limited due to the low number of reported cases in the literature and lack of natural history studies.

**PATIENT HISTORY AND PHYSICAL FINDINGS**
- Physical examination methods include:
  - Examining for swelling. The examiner should palpate along the course of the tibialis anterior muscle–tendon. Swelling with discontinuity of the tendon indicates a tendon rupture. An anterior ankle mass may be the presenting complaint.
  - Gait disturbance. The examiner should observe the patient ambulating, looking for slap-foot gait or foot drop. Chronic ruptures may present with minimal gait disturbance; the patient may have difficulty ambulating only when on uneven surfaces. Inability to heel-walk indicates tibialis anterior dysfunction. The patient may need to hyperflex the hip and knee to clear the foot during the swing phase of gait, since the ankle does not dorsiflex adequately.
  - Muscle strength is evaluated with manual motor testing. No contraction or weak ankle dorsiflexion suggests tibialis anterior dysfunction. Patients will substitute the toe extendors for the tibialis anterior during ankle dorsiflexion, exhibiting toe hyperextension when asked to dorsiflex the ankle.
  - The examiner should note any heel cord tightness. Subacute and chronic injuries often present with heel cord contractures, since the major antagonist to ankle plantarflexion is forfeited with tibialis anterior tendon rupture. As a rule, at least 10 degrees of ankle dorsiflexion must be present for a tibialis anterior repair or reconstruction, and thus surgical management may require adding Achilles tendon or gastrocnemius lengthening.
  - The examiner should completely assess the involved extremity to rule out other diagnoses. The most common errors in diagnosis are:
    - Lumbar radiculopathy: presents with diminished sensation, positive straight-leg raise test
    - Peroneal nerve palsy: affects the toe extendors and peroneal musculature in addition to the tibialis anterior. Preservation of extensor hallucis longus and toe extensor function will distinguish tibialis anterior rupture from peroneal nerve palsy.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Imaging studies are generally not required in the evaluation of tibialis anterior tendon ruptures, since the diagnosis is usually simple to make on clinical examination alone.
- Radiographs are nondiagnostic and rarely required in the evaluation of tibialis anterior tendon ruptures. Radiographs are, however, useful to assess associated injuries (tibia fractures).
- MRI may be useful in chronic cases where patients do not recall a history of trauma. MRI demonstrates lack of continuity in the tibialis anterior and signal change in the tendon, particularly with pre-existing tendinopathy. Because the tibialis anterior tendon courses from lateral to medial across the anterior ankle and retracts with rupture, occasionally it is difficult to assess.
- If there is uncertainty in the diagnosis, electrodiagnostic studies may identify common peroneal palsy or lumbar radiculopathy.

**DIFFERENTIAL DIAGNOSIS**
- Peroneal nerve palsy
- Lumbar radiculopathy
- Rarely, a peripheral neuropathy may present as isolated tibialis anterior tendon dysfunction.
NONOPERATIVE MANAGEMENT

- Low-demand patients may be treated with an ankle–foot orthosis (AFO).

SURGICAL MANAGEMENT

- Direct repair of the tendon is occasionally possible, but delay in diagnosis may preclude direct repair due to muscle contracture.
- A sliding tibialis anterior tendon grafting technique has been described to gain tendon length to allow repair, and allograft tendon transfers have been proposed in the absence of tibialis anterior myofibrosis.
- Our preferred reconstruction for tendons that cannot be directly repaired is to augment the repair with the adjacent, native extensor hallucis longus (EHL) tendon (FIG 1).

Preoperative Planning

- Imaging studies are reviewed when available to appreciate the extent of pre-existing tendinopathy and to potentially identify the approximate site of the rupture.
- The surgeon should prepare for Achilles tendon lengthening or gastrocnemius–soleus recession to achieve adequate (at least 10 degrees) dorsiflexion.

Positioning

- The patient is positioned supine. A bump may be placed under the ipsilateral hip, but this is typically not necessary since access is required only to the anteromedial ankle.

Approach

- An anterior approach is made directly over the course of the tibialis anterior tendon.
- As has been learned from total ankle arthroplasty and open reduction and internal fixation of tibial pilon fractures, careful soft tissue handling is essential.

EXTENSOR HALLUCIS LONGUS TRANSFER TO MEDIAL CUNEIFORM

- Perform gastrocnemius recession or Achilles tendon lengthening if indicated.
- Use an anterior approach with an incision over the course of the tibialis anterior tendon (TECH FIG 1A,B).
- Divide the superior and inferior extensor retinaculum and tibialis anterior sheath.
- Isolate the remnant of the tibialis anterior tendon. Occasionally direct repair is possible, rarely by advancing the residual tendon to bone, but instead to the residual tendon stump on the medial cuneiform. If inadequate tendon is available or muscle excursion is poor, then proceed with EHL transfer.
- Expose the EHL tendon. Proximally the EHL is in a separate sheath adjacent to the tibialis anterior.
- Through a separate 3- to 5-cm incision over the distal EHL immediately proximal to the first metatarsophalangeal joint, divide the EHL tendon distally. Leave enough distal stump to suture to the adjacent tendon of the extensor hallucis brevis. Place a whipstitch consisting of no. 2 non-absorbable suture in the free end of the EHL.
- Pass the EHL under the skin bridge and through the tibialis anterior sheath proximally. The EHL will now occupy the previous sheath for the tibialis anterior (TECH FIG 1C,D).
- Drill a vertical hole in the medial cuneiform for attachment of the EHL. Sequentially drill using 2.5-mm, 3.5-mm, and 4.5-mm drill bits. Enlarge the hole with a
The tendon sheath is opened, exposing the torn retracted end of the tibialis anterior. The sheath is carefully preserved for later repair. The extensor hallucis longus (EHL) tendon is harvested by dividing it at the level of the metatarsophalangeal joint. The EHL tendon sheath is entered proximally. The EHL tendon is passed into the tibialis anterior sheath and pulled distally. A drill hole is placed from dorsal to plantar at the midpoint of the medial cuneiform. The drill hole is sequentially enlarged. Fixation using a biotenodesis screw (Arthrex, Naples, FL). The graft is also looped around the medial cuneiform and sutured to itself and surrounding soft tissue. Proximally, the EHL is tenodesed to the tibialis anterior stump. The EHL stump is sutured to the extensor hallucis brevis. The tibialis anterior sheath is closed.
curette as needed to allow graft passage. Leave enough periosteum to provide additional points of attachment for suturing the graft in place.

- Secure the graft with the ankle in 10 degrees of dorsiflexion (TECH FIG 1E–H).
- Pass the EHL graft from dorsal to plantar. Fixation may be accomplished with an interference screw or by looping the graft around the medial cuneiform and suturing it to surrounding periosteum and back on itself. The EHL tendon may be further anchored to the residual distal fibers of the torn tibialis anterior tendon.
- The transferred EHL tendon serves to bridge the gap created by the tibialis tendon rupture. However, the relative strength of the EHL muscle is far less than that of the tibialis anterior muscle. Therefore, in the absence of myofibrosis of the tibialis anterior, we recommend sewing the residual tibialis anterior tendon stump to the transferred EHL tendon under some tension.
- Attach the distal EHL stump to the extensor hallucis brevis, and we recommend dorsiflexing the hallux about 10 to 15 degrees to compensate for anticipated stretching of this tendon transfer postoperatively (TECH FIG 1I).
- Close the tibialis anterior tendon sheath, superior extensor retinaculum, and wound in layers (TECH FIG 1J).
- Place a splint or bivalved cast with the ankle in 10 degrees of dorsiflexion. Avoid plantarflexion as this places tension on the wound edges and tendon transfer.

### Pearls and Pitfalls

<table>
<thead>
<tr>
<th>Misdiagnosis</th>
<th>Perform a complete history and physical examination to rule out conditions that may mimic tibialis anterior rupture.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure to address heel cord tightness</td>
<td>Note ankle dorsiflexion as part of the preoperative evaluation and perform Achilles tendon lengthening or gastrocnemius recession as indicated.</td>
</tr>
<tr>
<td>Inadequate EHL graft length</td>
<td>Expose and divide the distal end of the EHL at the metatarsophalangeal joint level.</td>
</tr>
<tr>
<td>Wound breakdown</td>
<td>Carefully close the tibialis anterior sheath, superior extensor retinaculum, and subcutaneous tissue before skin closure. Immobilization in at least 5 degrees of dorsiflexion is important to avoid tension on the wound edges.</td>
</tr>
<tr>
<td>Graft failure</td>
<td>Secure fixation with proper use of an interference screw and adequate graft length to suture back on itself and surrounding tissues. Postoperative immobilization. Avoidance of early aggressive rehabilitation.</td>
</tr>
</tbody>
</table>

### Postoperative Care

- A short-leg cast is worn for 6 weeks, followed by an ankle-foot orthosis (AFO) for an additional 6 weeks.

### Outcomes

- Sammarco et al. presented a series of 18 patients with acute and chronic tibialis anterior tendon ruptures managed with direct repair or interpositional graft. There was significant improvement in the average hindfoot score. The authors concluded that surgical repair of a ruptured tibialis anterior tendon can be beneficial regardless of age, sex, medical comorbidities, or delay in diagnosis.
- Ouzounian et al. reported on seven patients with tibialis anterior rupture treated with a variety of surgical reconstructive techniques. All patients had an increase in strength and function.
- Markarian et al. failed to show a significant difference between operative and nonoperatively treated groups. The lack of statistical significance was possibly due to the bimodal age distribution in the study, with older, more sedentary patients receiving nonoperative treatment.
- The literature is scarce regarding the results and complications of surgical reconstruction of the tibialis anterior tendon due to the rarity of this injury.

### Complications

- Intraoperative graft complications
- Neuroma
- Wound dehiscence
- Infection
- Graft failure

### References

DEFINITION
- Pathology leading to a spectrum of motor function loss that includes loss of ankle dorsiflexion
  - Common peroneal nerve palsy, L5 radiculopathy, cerebrovascular accident
  - Loss of ankle dorsiflexion and hindfoot eversion
  - Retained posterior tibial tendon (PTT) function
- Hereditary sensory motor neuropathy
  - A constellation of motor function deficits and associated deformity
  - Includes loss of dorsiflexion and hindfoot eversion
  - Retained PTT function
- Flaccid paralysis
  - Global loss of motor function to the ankle and foot

ANATOMY
- Posterior tibialis
  - Muscle originates on the posterior tibia, interosseous membrane, and fibula.
  - Muscle and then tendon course in the deep posterior compartment.
  - Tendon travels directly posterior to the medial malleolus.
  - Tendon has numerous insertions on bones of plantar midfoot, spring ligament, and medial aspect of navicular.
- Interosseous membrane (IOM) and distal tibia–fibula syndesmosis
  - Thick fibrous bands between tibia and fibula
  - Distal tibia–fibula syndesmosis is narrow, with little space for tendon transfer even when a generous window is created in the distal IOM.
- Inferior extensor retinaculum
  - On the dorsum of the foot to prevent bowstringing of the extensor tendons as they transition across the anterior ankle to the dorsal foot
- Sciatic nerve
  - Comprises tibial and common peroneal nerves that separate immediately proximal to the popliteal fossa
  - Common peroneal nerve often affected in these neuropathies
- Superficial peroneal nerve
  - Motor function to anterior and lateral compartment muscles
    - Dorsiflexion and eversion, respectively
  - Sensory distribution to dorsum of the foot
- Deep peroneal nerve
  - Courses between tibialis anterior and extensor hallucis longus tendons proximal to the ankle
  - Located directly on the dorsum of midfoot
  - Immediately deep to extensor hallucis brevis muscle belly
  - Motor function to intrinsic muscles of foot
  - Sensory distribution to first web space
- Tibial nerve function typically spared
- Tibial nerve must be intact to create a dynamic tendon transfer
- If tibial nerve is not intact, then transfer can only be a tenodesis
- Anterior ankle and dorsal midfoot neurovascular structures at risk
  - Superficial peroneal nerve (may be insensate as part of the neuropathy)
  - Deep neurovascular bundle
    - Anterior tibial artery
    - Deep peroneal nerve (may also be insensate as part of the neuropathy)
    - Peroneal artery branch
    - Situated directly on anterior distal IOM

PATHOGENESIS
- Loss of common peroneal nerve function
- Loss of ankle dorsiflexion and hindfoot eversion
- Loss of major antagonists
  - Eventual equinus contracture
    - Imbalance of hindfoot inverter (PTT) and everters (peroneus brevis) and usually, but not always, peroneus longus
  - Eventual hindfoot varus deformity
    - Imbalance of hindfoot inverters (PTT) and everter (peroneus longus)
- Flaccid paralysis
  - Tibial and common peroneal nerve palsies
  - No motor function distal to knee
  - Since both sets of major antagonists lost, typically no contractures

NATURAL HISTORY
- Foot drop may eventually recover.
  - Tendon transfers should not be considered until a chance for recovery has been ruled out.
- Common peroneal nerve palsy may lead to progressively worsening equinocavovarus foot deformity due to overpull of plantarflexors and inverters powered by intact tibial nerve and loss of dorsiflexors and everters powered by compromised common peroneal nerve.
- Flaccid paralysis remains relatively stable since both sets of antagonists are compromised.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Gait abnormality
  - “Slap foot gait”
    - Inability to dorsiflex ankle and control tibialis anterior from heel strike to stance phase
  - Exaggerated hip and knee flexion
  - Inability to dorsiflex ankle or great toe from push-off through swing phase
  - Compensation to allow toes to clear during swing phase
- Hindfoot inversion
  - Patient walks on lateral border of foot.
- Inability to dorsiflex ankle
  - May check by asking patient to walk on heels
  - Manual muscle testing with patient seated on examining table with knee flexed
- Lack of eversion
  - Varus hindfoot
  - Over time, may become a fixed inversion contracture
- In some disease processes (eg, Charcot-Marie-Tooth disease) toe dorsiflexion is spared, creating claw toe deformities.
  - Patient attempts to compensate for lack of ankle dorsiflexion with toe extensors, worsening claw toe deformities.
  - Even when toe extensors are involved in the palsy, flexor tendons may become contracted.
  - Passive dorsiflexion of the ankle will reveal this.
  - With equinocavovarus foot contracture, calluses may form under metatarsal heads, particularly the fifth.
  - Sensation may be diminished on the dorsal and lateral aspects of the foot.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- Imaging is typically unnecessary for patients with foot drop except in the following situations:
  - Consideration should be given to MRI:
    - If there is concern for mass effect creating a compressive neuropathy: lumbar spine, common peroneal nerve at fibular head
    - To rule out tibialis anterior tendon rupture (should be evident on clinical examination alone)
  - Consideration should be given to radiographs of foot or ankle:
    - To rule out stress fracture
    - To better define bony deformity (fixed deformity, associated ankle or foot arthritis; important because arthrodesis may need to be considered in lieu of or in combination with tendon transfer)
- Electrodiagnostic studies
  - Absence of recovery at 1 year and particularly at 18 months is highly suggestive that recovery of nerve function will not occur.
  - Nerve conduction studies and electromyography
  - Baseline and follow-up studies to determine if any recovery evident
  - Important to determine if tendon transfer is warranted
  - Tendon transfer should not be performed if nerve function may recover!
  - Absence of recovery at 1 year and particularly at 18 months is highly suggestive of no recovery.
  - We recommend consultation with a neurologist to confirm interpretation of electrodiagnostic studies.
  - Studies may also define function of PTT.
    - Important when considering dynamic PTT transfer versus PTT tenodesis
    - A tendon transfer of a healthy tendon immediately reduces its strength on manual muscle testing from 5/5 to 4/5, so if it is already compromised, then the tendon transfer will do little more than create a tenodesis.
    - Useful in determining if a more proximal compressive neuropathy exists

**DIFFERENTIAL DIAGNOSIS**

- Tibialis anterior tendon rupture
- Cerebrovascular accident
- Lumbar spine radiculopathy
- Hereditary sensorimotor neuropathy
- Leprosy
- Poliomyelitis
- Cerebral palsy (spastic)

**NONOPERATIVE MANAGEMENT**

**Bracing with an ankle–foot orthosis (AFO)**

- Requires a fixed AFO in flaccid paralysis
- May be a flexible AFO with common peroneal palsy
    - Requires plantarflexion stop
- Equinus contracture may need to be corrected to facilitate brace wear.
  - Achilles stretching
  - Botulinum toxin injection
  - Tendo Achilles lengthening (TAL)
- Varus deformity
  - If flexible may be corrected with bracing
  - If fixed, bracing is difficult.

**SURGICAL MANAGEMENT**

**Preoperative Planning**

- The surgeon must confirm that motor function will not recover before proceeding with tendon transfer.
  - Serial clinical examination
  - Serial electrodiagnostic studies (at least one compared to baseline)
- The surgeon must determine what motor function persists:
  - Tibial nerve
  - PTT (inversion)
  - Gastrocnemius–soleus (plantarflexion)
  - None (flaccid paralysis)
- The surgeon must evaluate for equinus contracture.
  - The surgeon should be prepared to perform TAL if necessary (see Tech Fig 1A–D).
- Flexible versus fixed deformities
  - Flexible deformity typically corrects with tendon transfer alone.
  - Fixed deformity
    - May require capsular release or even arthrodesis
- Toe contractures
  - Although claw toe deformity may not be evident with the ankle plantarflexed, once the deformity is corrected, toe contractures may become obvious.
  - Dorsiflexing the ankle will put the contracted flexor hallucis and digitorum on stretch, thereby revealing the toe contractures.
  - The surgeon should be prepared to address toe contractures as part of the procedure.
- Tendon transfer anchoring
  - We routinely use interference screws to anchor tendon transfers to bone.
  - Need to have an anchoring system available
  - Alternatively, anchoring to existing distal tendon or existing soft tissues in the foot may be possible.
  - In our experience, anesthesia should maintain complete muscle relaxation and paralysis during the procedure; otherwise, the success of the tendon transfer may be compromised.
At the conclusion of the procedure we often perform botulinum toxin injections into the gastrocnemius–soleus complex to further protect the tendon transfer postoperatively.

**Positioning**

- **Supine**
- If the PTT will be transferred through the IOM or if a peroneal tendon will be used for correction of flaccid paralysis, we routinely place a bolster under the ipsilateral hip to afford optimal lateral exposure. Once the lateral tendon is harvested or the PTT transferred through the IOM, the bolster may be removed.
- We routinely use a thigh tourniquet.

**Approach**

- Multiple relatively small incisions are needed; extensile exposures are unnecessary.

---

**ACHILLES LENGTHENING**

**Indications**

- Not always necessary, but typically required when foot drop occurs
- Without active dorsiflexion the gastrocnemius–soleus’ antagonist is lost, often leading to an Achilles contracture.
- Occasionally patients maintain an active stretching program, thereby avoiding an Achilles contracture.
- Weakening of the gastrocnemius–soleus complex may be beneficial since a transfer of a healthy muscle–tendon unit is subject to an automatic one-grade loss of power (5/5 manual muscle testing drops to 4/5 with transfer).
- Occasionally we use botulinum toxin in the gastrocnemius–soleus complex when performing a PTT transfer for foot drop.

**Technique**

- Determined by the Silfverskiold test
- Equinus contracture with the knee in extension and flexion *(TECH FIG 1A)*

---

**TECH FIG 1** • Tendo Achilles lengthening. **A.** Equinus with knee in flexion and extension suggests tight gastrocnemius and soleus. **B.** Initial Achilles hemisection. **C.** Second Achilles hemisection (opposite direction from first), to be followed by third and final hemisection in same direction as first. **D.** Dorsiflexion re-established after Achilles lengthening.
Triple hemisection (Hoke procedure) because both the gastrocnemius and soleus are contracted (TECH FIG 1B–D).
- Equinus contracture only with the knee in extension: gastrocnemius–soleus recession (Strayer procedure) because only the gastrocnemius is contracted.

**Posterior Tibial Tendon Transfer Through the Interosseous Membrane**

- **Advantages**
  - PTT in direct line from its muscle through the IOM to the lateral cuneiform (our preferred site for tendon anchoring)
  - Anchor point slightly lateral of midline to promote dorsiflexion and eversion
- **Disadvantage**
  - PTT may be constricted and stenosed within narrow window created in distal IOM.

**Posterior Tibial Tendon Harvest**

- Make a 4-cm longitudinal incision over the medial navicular and PTT on the medial foot.
- Open the PTT sheath to expose the tendon.
- Release the PTT insertion on the medial navicular.
- Alternatively, use a chisel to elevate some medial navicular bone with the PTT release from the medial navicular (may allow for another centimeter of tendon for transfer) (TECH FIG 2A).
- Isolate the PTT attachment on the medial navicular and the tendon fibers that begin to course to the plantar midfoot (TECH FIG 2B).
- With the PTT fibers isolated, transect them to release the PTT distally.
  - Be sure to fully isolate the PTT fibers; the medial plantar nerve and the plantar medial complex of veins is in close proximity.
  - Accidentally transecting the nerve leads to loss of sensation in the plantar medial forefoot.
  - Violating the veins may make it difficult to achieve satisfactory hemostasis as these veins may then retract under the foot.
- Thin the distal stump of the PTT to facilitate its transfer into an osseous tunnel that will be created in the foot (TECH FIG 2C).

**TECH FIG 2 • Posterior tibial tendon (PTT) harvest**

A. Elevating PTT with a sliver of medial navicular may allow longer tendon harvest. B. Isolating PTT. C. Distal PTT needs to be trimmed to allow it to pass into dorsal foot osseous tunnel. D, E. Tag suture in distal PTT. F. Transfer of PTT to proximal medial wound. A 3-cm incision is made over PTT musculotendinous junction. (continued)
■ Place tag sutures in the distal PTT (TECH FIG 2D,E).
■ Make a more proximal medial incision at the PTT musculotendinous junction on the posterior tibia.
  ▪ 3-cm incision (TECH FIG 2F)
    ▪ Flexor digitorum tendon is usually encountered first.
    ▪ Deep to the FDL, directly on the posteromedial tibia, the PTT is identified.
    ▪ Place a blunt retractor around the PTT through this more proximal wound to isolate it.
■ Mobilize the distal PTT.
    ▪ Alternate tension on the proximal tendon through the proximal wound and the distal tag sutures (TECH FIG 2G), then apply tension proximally only.
    ▪ This may not work.
    ▪ The medial incision may need to be extended proximally to allow access to the posterior medial malleolus, a common location where the tendon may bind.
    ▪ Once mobilized, the distal aspect of the PTT may be transferred to the proximal wound (TECH FIG 2H).
■ Tendon will desiccate rapidly, so we keep it tucked in the proximal medial wound.

### Posterior Tibial Tendon Transfer Through the Interosseous Membrane
■ Lateral incision on anterior aspect of distal fibula, at distal tibiofibular syndesmosis
■ Careful exposure of anterior IOM
■ Elevate the anterior compartment soft tissues.
■ A branch of the peroneal artery courses on the anterior IOM and is at risk.
■ Create a generous window in the distal IOM (TECH FIG 3A).
■ From tibia to fibula
■ About 3 to 4 cm long
■ Pass a tonsil clamp through the IOM directly on the posterior aspect of the tibia to exit in the proximal medial wound (TECH FIG 3B).
■ The posterior neurovascular structures (tibial nerve and posterior tibial artery) are at risk, so be sure the clamp is directly on the posterior tibia.
Use the tonsil clamp to grasp the tag sutures of the PTT (TECH FIG 3C).
- Pull the tag sutures and PTT from the medial wound to the lateral wound, keeping the tendon directly on the posterior aspect of the tibia (TECH FIG 3D,E).
- Be sure that the window in the IOM does not impinge on the transferred tendon.
  - If there is stenosis, then further enlarge the window so that the tendon easily glides between the tibia and fibula.
- Keep the tendon end in the wound to limit desiccation.

**Preparation of the Dorsal Foot Anchor Site**

- Fluoroscopically identify the center of the lateral cuneiform.
  - Oblique foot views usually best define the lateral cuneiform (TECH FIG 4A).
- Center a 3- to 4-cm longitudinal skin incision directly over the lateral cuneiform.
- Dissect to the lateral cuneiform.
  - Protect the superficial peroneal nerve and extensor tendons.
  - Deep neurovascular bundle is usually medial to this approach.
- Expose and define the cuneiform.
  - We routinely use small-gauge hypodermic needles or Kirschner wires to mark the joints surrounding the lateral cuneiform and fluoroscopically confirm that the lateral cuneiform is defined by these markers (TECH FIG 4B).
  - Periosteum and capsular tissue are left intact.
  - Create an osseous tunnel in the center of the lateral cuneiform.
  - We routinely predrill the center with a Kirschner wire and confirm the starting point and trajectory of the wire fluoroscopically.
  - Remove the wire and introduce sequentially larger drill bits to enlarge the tunnel (TECH FIG 4C).

**TECH FIG 4** • Preparing dorsal foot osseous tunnel. A. Lateral cuneiform is identified fluoroscopically. B. Borders of lateral cuneiform are exposed and marked. C. Drill hole is created in lateral cuneiform and proper position is confirmed fluoroscopically. D. Osseous tunnel is gradually enlarged, first with drill bits, then dedicated reamer system for interference screw. E. Prepared osseous tunnel in lateral cuneiform.
Posterior Tibial Tendon Transfer to Dorsum of Foot

- Transferring the PTT deep to the extensor retinaculum with the extensor tendons diminishes the power of the transfer (which is by definition already weakened by one grade with transfer).
- Create a subcutaneous soft tissue tunnel from the dorsal foot incision to the more proximal and lateral lower leg incision using a curved Kelly or tonsil clamp (TECH FIG 5A).

Use the clamp to grasp the tag sutures and pull the tendon through the subcutaneous tunnel to the dorsal foot incision (TECH FIG 5B).

Before anchoring the tendon in the osseous tunnel, pull the tendon via the tag sutures into the tunnel to be sure that the tunnel diameter is appropriate.
- Pass a Beath pin or drill bit (has an eye to place suture) through the tunnel and the plantar skin (TECH FIG 5C).
  - Because of the midfoot arch and the drill hole centered in the lateral cuneiform foot this pin or the drill bit will exit in the medial arch (TECH FIG 5D).
- Dorsiflex the ankle.
- With the tag sutures secured, pull the pin or drill bit through the plantar skin, thereby pulling the distal tendon end into the tunnel (TECH FIG 5E).
  - If the tunnel does not accommodate the tendon, then the tendon and tag sutures must be withdrawn and the tunnel enlarged.
  - Because of the angle at which the tendon enters the tunnel, we often need to guide the tendon into the tunnel with a forceps.
- Anchoring the tendon to bone
  - Some degree of stretching or accommodation is anticipated, so we routinely anchor the tendon with the ankle maintained in 10 degrees of dorsi-
### TECH FIG 5 (continued)

**G.** Tension applied on plantar tag sutures.
**H.** Augmenting anchoring. Suture anchor being placed within osseous tunnel.
**I.** Two anchors secured in tunnel (note separate tag suture of PTT).
**J.** Final fixation of tendon transfer in dorsal foot. Tendon fully tensioned with ankle dorsiflexed.

- **K, L.** Securing tendon to anchors and adjacent periosteum.
- **M.** Interference screw positioned.
- **N.** Screw advanced.
- **O.** Screw fully seated.

Have the assistant maintain full ankle dorsiflexion and tension on the tag sutures on the plantar foot.
We usually cut the tag sutures so they retract beneath the skin.
Rarely, we have used a well-padded button on the plantar foot to further augment the tendon’s anchor point. We do not routinely do so because of the risk for plantar skin necrosis from the button despite adequate padding.
In select patients, the dorsiflexed ankle will unmask claw toes due to flexor hallucis longus and flexor digitorum longus contractures. Consider flexor hallucis longus and flexor digitorum longus lengthenings, posterior to the ankle and tibia via the more proximal medial approach, or percutaneous tenotomies at the plantar toes.

- A properly sized isolated interference screw is probably adequate.
- However, we typically augment the anchor point with several nonabsorbable sutures from the periosteum surrounding the tunnel to the tendon directly at the entrance to the tunnel.
- To further augment the anchor point: before advancing the tendon and tag suture into the tunnel, place one or two suture anchors within the tunnel. Then advance the tendon into the tunnel and secure the tendon with the anchors. By tightening these sutures, the tendon may be pulled even further into the tunnel. An interference screw and periosteal sutures may still be used.
POSTERIOR TIBIAL TENDON TRANSFER ANTERIOR TO THE TIBIA

Advantages
- PTT has no opportunity to stenose in the IOM.
- Glides smoothly around anteromedial tibia
- Anchor point slightly lateral of midline to promote dorsiflexion and eversion

Disadvantage
- PTT is not in direct line from its origin to anchor point in the foot; it must travel around medial tibia.
- Anchor point is in the middle (second) cuneiform.
- Central location so it cannot provide an eversion moment
- However, typically unimportant since with PTT transfer the agonist–antagonist balance between PTT and peroneus brevis is again re-established by being neutralized.

Achilles Lengthening
- Same as for PTT transfer through IOM described earlier (TECH FIG 6)

Posterior Tibial Tendon Harvest
- Same as for PTT transfer through IOM described earlier (TECH FIG 7)

Preparation of the Dorsal Foot Anchor Site
- Similar to preparation of dorsal foot anchor site described earlier for PTT transfer through IOM

TECH FIG 6 • Adequate dorsiflexion (essential for successful tendon transfer to re-establish dorsiflexion).

TECH FIG 7 • Approach to posterior tibial tendon (PTT) harvest. A. The two planned medial incisions. B. Planned dorsal foot incision. C–E. Harvesting PTT. C. PTT is isolated. D. Distal tendon is trimmed (contoured). E. Tag suture in distal end of tendon. (continued)
However, when transferring the PTT through the IOM we typically anchor the tendon to the lateral (third) cuneiform.

In contrast, when we transfer the PTT anterior to the medial tibia, we typically anchor the tendon in the middle (second) cuneiform.

Middle cuneiform is smaller than the lateral cuneiform.

In our experience, greater risk of fracture with drill hole, tendon transfer, and interference screw

Fluoroscopically identify the center of the middle cuneiform.

AP and sometimes oblique foot views best define the middle cuneiform.

Center a 3- to 4-cm longitudinal skin incision directly over the middle cuneiform.

Dissect to the middle cuneiform.

Protect the superficial peroneal nerve and extensor tendons (TECH FIG 8A).

Protect the deep neurovascular bundle, usually encountered in this approach; it is directly deep to the muscle of the extensor hallucis brevis.

Expose and define the cuneiform.

We routinely use small-gauge hypodermic needles or Kirschner wires to mark the joints surrounding the medial cuneiform and fluoroscopically confirm that the medial cuneiform is defined by these markers (TECH FIG 8B).

Leave the periosteum and capsular tissue intact.

Create an osseous tunnel in the center of the medial cuneiform.

We routinely predrill the center with a Kirschner wire and confirm the starting point and trajectory of the wire fluoroscopically.

Remove the wire and introduce sequentially larger drill bits to enlarge the tunnel (TECH FIG 8C).

We use drill bits to a diameter of 4.5 mm.

With fluoroscopic confirmation, slight adjustments may be made with each successive drill bit to center the tunnel optimally in the cuneiform.

TECH FIG 7 • (continued) PTT is mobilized. F. PTT is identified at its musculotendinous junction. G. PTT is mobilized to allow transfer to proximal wound. H, I. Transferring PTT to proximal medial wound. H. Tendon is pulled into proximal wound. I. Proposed course for transfer to dorsum of foot.

TECH FIG 8 • Preparation of dorsal foot osseous tunnel. A. Dorsal incision over middle cuneiform. B. Middle cuneiform is identified and marked. (continued)
Use the reamer from the interference screw system to enlarge the tunnel to the desired diameter (TECH FIG 8D).

Typically, we enlarge the tunnel to 5.5 to 6.0 mm in the medial cuneiform.

**Posterior Tibial Tendon Transfer to Dorsum of Foot**

- Transferring the PTT deep to the extensor retinaculum with the extensor tendons diminishes the power of the transfer (which is by definition already weakened by one grade with transfer).
- Create a subcutaneous soft tissue tunnel from the dorsal foot incision to the more proximal and medial lower leg incision using a curved Kelly or tonsil clamp (TECH FIG 9A,B).

Use the clamp to grasp the tag sutures and pull the tendon through the subcutaneous tunnel to the dorsal foot incision.

Before anchoring the tendon in the osseous tunnel, pull the tendon via the tag sutures into the tunnel to be sure that the tunnel diameter is appropriate.

Pass a Beath pin or drill bit (has an eye to place suture) through the tunnel and the plantar skin (TECH FIG 9C,D). Because of the midfoot arch, this pin or drill bit will exit in the medial arch (TECH FIG 9E).

Dorsiflex the ankle.

With the tag sutures secured, pull the pin or drill bit through the plantar skin, thereby pulling the distal tendon end into the tunnel (TECH FIG 9F).

If the tunnel does not accommodate the tendon, then the tendon and tag sutures must be withdrawn and the tunnel enlarged.
Because of the angle at which the tendon enters the tunnel, we often need to guide the tendon into the tunnel with a forceps.

- Anchoring the tendon to bone
- Some degree of stretching or accommodation is anticipated in the posterior tibial muscle and tendon, so we routinely anchor the tendon with the ankle maintained in 10 degrees of dorsiflexion.
- A properly sized isolated interference screw is probably adequate.
- However, we typically augment the anchor point with several nonabsorbable sutures from the periosteum surrounding the tunnel to the tendon directly at the entrance to the tunnel.
- To further augment the anchor point
  - Before advancing the tendon and tag suture into the tunnel, place one or two suture anchors within the tunnel (TECH FIG 9G).

- Then advance the tendon into the tunnel and secure the tendon with the anchors. By tightening these sutures, the tendon may be pulled even further into the tunnel. An interference screw and periosteal sutures may still be used (TECH FIG 9H).
- Have the assistant maintain full ankle dorsiflexion and tension on the tag sutures on the plantar foot.
- We usually cut the tag sutures so they retract beneath the skin.
- Rarely, we have used a well-padded button on the plantar foot to further augment the tendon’s anchor point (TECH FIG 9I). We do not routinely do so because of the risk for plantar skin necrosis from the button despite adequate padding.
**BRIDLE PROCEDURE**

- **Advantages**
  - The "bridle" creates a balance to the foot and ankle.
  - Potentially can make the patient with flaccid paralysis brace-free

- **Disadvantage**
  - With flaccid paralysis, the tendon transfer is static, not dynamic.
  - Functions as a tenodesis
    - If procedure is successful, foot and ankle remain in neutral position at all times.

**Achilles Lengthening**

- Same as for PTT transfer through IOM described earlier

**Posterior Tibial Tendon Harvest**

- Same as for PTT transfer through IOM described earlier (TECH FIG 10)

**Harvest of the Peroneus Longus**

- With an adequate skin bridge from the anterior ankle distal tibial incision, make a 2- to 3-cm incision immediately posterior to the fibula, about 8 cm proximal to the tip of the fibula at the level of the peroneus longus' musculotendinous junction (TECH FIG 11A).
  - Protect the superficial peroneal nerve. However, with common peroneal nerve palsy, an injury to this terminal sensory branch will probably be inconsequential.
  - Sharply divide the peroneal retinaculum 2 to 3 cm longitudinally over the musculotendinous junction of the peroneus longus.
  - Divide the peroneus longus tendon at its musculotendinous junction (TECH FIG 11B).
  - Place a tag suture in the transected distal end of the tendon.
  - Make another 2- to 3-cm incision over the lateral cuboid (TECH FIG 11A).
  - Protect the sural nerve.
  - Isolate the peroneus longus tendon and pull its released proximal portion through this lateral foot wound (TECH FIG 11C,D).
  - Tuck the peroneus longus tendon in the distal lateral foot wound to keep it from desiccating.
  - The peroneus longus tendon will be passed to the anterior ankle wound (see below).

**TECH FIG 10** • Harvest of posterior tibial tendon for bridle procedure.

**TECH FIG 11** • A–C. Harvest of peroneus longus for bridle procedure. A, B. Two small incisions, the first at the musculotendinous junction of peroneus longus and the second where the tendon courses around the cuboid. C. Peroneus longus transferred to distal lateral incision. D. Anticipated course for peroneus longus in bridle procedure (note also approximate course of posterior tibial tendon transfer).
Posterior Tibial Tendon Transfer Through the Interosseous Membrane

- Make an incision over the lateral aspect of the distal anterior tibia.
- Carefully expose the anterior IOM (TECH FIG 12A).
- Protect the superficial peroneal nerve.
  - Divide the extensor retinaculum over the tibialis anterior and extensor hallucis longus tendons.
- Protect the deep neurovascular bundle (TECH FIG 12B).
- Protect the peroneal artery branch that courses on the anterior IOM.
- Create a generous window in the distal IOM (TECH FIG 12C).
  - From tibia to fibula
  - About 4 cm long
- Pass a curved Kelly or tonsil clamp through the IOM directly on the posterior aspect of the tibia to exit in the proximal medial wound (TECH FIG 12D).
  - The posterior neurovascular structures (tibial nerve and posterior tibial artery) are at risk, so be sure the clamp is directly on the posterior tibia.
- Use the tonsil clamp to grasp the tag sutures of the PTT.
- Pull the tag sutures and PTT from the medial wound to the lateral wound, keeping the tendon directly on the posterior aspect of the tibia (TECH FIG 12E).

- Be sure that the window in the IOM does not impinge on the transferred tendon. If there is stenosis, then further enlarge the window so that the tendon easily glides between the tibia and fibula.
- Keep the tendon end in the wound to limit desiccation.

Transfer of the Peroneus Longus

- Using a Kelly clamp, create a subcutaneous tunnel from the anterior distal tibial wound to the lateral foot wound (TECH FIG 13A).
- Spread this tissue carefully with the clamp to avoid any soft tissue impingement within the tunnel.
- Grasp the tag suture in the peroneus longus and pull the tendon from the lateral foot wound to the anterior distal tibial wound (TECH FIG 13B).

Transfer of Posterior Tibial Tendon Through the Tibialis Anterior Tendon

- Make a stab incision in the tibialis anterior tendon with proximal tension placed on the tibialis anterior tendon while the ankle is held in dorsiflexion.
- This will tension the distal extent of the tibialis anterior tendon before it is secured to the PTT.
- Avoid simply creating an incision in the tibialis anterior tendon in situ; this will render the tension in the medial aspect of the “bridle” ineffective.
Create an osseous tunnel in the middle cuneiform (TECH FIG 15A).

Create a subcutaneous soft tissue tunnel from the dorsal foot incision to the more proximal and anterior lower leg incision using a curved Kelly clamp.

Use the clamp to grasp the tag sutures and pull the tendon through the subcutaneous tunnel to the dorsal foot incision (TECH FIG 15B).

Before anchoring the tendon in the osseous tunnel, pull the tendon via the tag sutures into the tunnel to be sure that the tunnel diameter is appropriate.

Pass a Beath pin or drill bit (has an eye to place suture) through the tunnel and the plantar skin (TECH FIG 15C). Because of the midfoot arch, this pin or drill bit will exit in the medial arch (TECH FIG 15D).

Dorsiflex the ankle.

With the tag sutures secured, pull the pin or drill bit through the plantar skin, thereby pulling the distal tendon end into the tunnel (TECH FIG 15E).

### Preparation of the Dorsum of the Foot and Anchoring the Posterior Tibial Tendon

- Similar to that described for PTT transfer anterior to the tibia (see earlier)
- Transfer to the middle cuneiform
- A separate incision may be made (two limited incisions anteriorly) or the anterior distal tibial approach may be extended to the dorsum of the foot (single extensile anterior incision).

Pass the PTT through this stab incision in the tibialis anterior (TECH FIG 14).

If a more secure fixation between the tibialis anterior and PTT is desired, then consider a Pulvertaft weave.

While more weaving of the PTT through the tibialis anterior may afford greater fixation, it may in turn diminish the excursion of the PTT, thereby limiting the amount of distal PTT that will rest within the middle cuneiform’s osseous tunnel.

### TECH FIG 13 • Transferring peroneus longus tendon from distal lateral foot wound to anterior lower leg wound.

A. Subcutaneous tunnel to grasp free end of peroneus longus. B. Tendon transferred.

### TECH FIG 14 • Posterior tibial tendon is transferred through the tibialis anterior. Note the pretensioning of the tibialis anterior to optimize tension in the bridle.

### TECH FIG 15 • A. Creating the osseous tunnel in middle cuneiform. B–G. Transferring posterior tibial tendon (PTT) from anterior lower leg wound to dorsum of foot. B. Tendon passed through subcutaneous tunnel to dorsum of foot. C. Beath needle with tag sutures from PTT passed through osseous tunnel. (continued)
Chapter 126  TENDON TRANSFER FOR FOOT DROP

TECH FIG 16 • With the foot balanced, tibialis anterior and peroneus longus are secured to posterior tibial tendon transfer to create the bridle.

TECH FIG 15 • (continued) D. Tension on tag sutures on plantar foot. E. Tendon passed into middle cuneiform osseous tunnel. F. Positioning interference screw. G. Interference screw fully seated with appropriate PTT tension achieved.

- With the PTT properly tensioned in the second cuneiform’s osseous tunnel, the PTT is anchored in a manner similar to that described earlier for the other techniques (interference screw with or without suture anchor in tunnel) (TECH FIG 15F,G).

Securing and Tensioning Tibialis Anterior and Peroneus Longus to the Posterior Tibial Tendon

- Maintain the ankle in 10 degrees of dorsiflexion.
- Balance the foot with respect to varus or valgus; it should have a neutral to slight valgus heel.
- Tibialis anterior
  - Tension the tibialis anterior proximally and suture the tibialis anterior and PTT to one another at the point where the PTT passes through the tibialis anterior.
  - Reinforce this connection with several more side-to-side sutures between the two tendons, both proximal and distal to where the PTT passes through the tibialis anterior.
- Peroneus longus
  - Approximate the peroneus longus to the PTT where it passes anterior to the distal tibia and ankle, with maximum tension applied (TECH FIG 16).
  - Without support, the ankle should maintain dorsiflexed ankle and neutral hindfoot positions.
POSTOPERATIVE CARE

- We routinely place a well-padded short-leg cast in the operating room to protect the transfer, with the ankle in maximum dorsiflexion.
- At first follow-up (2 to 3 weeks), we remove the cast while maintaining ankle dorsiflexion.
- To protect the transfer, the ankle should not be allowed to plantarflex.
- A new short-leg cast is applied, one that allows touch-down weight bearing.
- Follow up at 5 to 6 weeks from surgery.
- The short-leg cast is removed, again protecting dorsiflexion.
- Wound inspection
  - Without allowing the ankle to plantarflex, the cast is removed.
  - Consideration may be given to creating a temporary AFO.
- We typically place the patient in a short-leg walking cast at this point, with the ankle in near-maximum dorsiflexion. The patient is encouraged to walk.
- At 8 to 10 weeks
  - The patient can typically discontinue use of the cast.
  - AFO for ambulation is typically worn until 4 to 5 months after surgery. During the final month of brace wear, the surgeon can consider hinging the AFO and placing a plantarflexion stop at neutral.
  - A cam boot is used for sleeping; it is typically worn until 4 to 5 months after surgery.
  - A physical therapy program is initiated to train the PTT to function as an ankle dorsiflexor.
- Return to brace-free full function is not recommended before 6 months.

OUTCOMES

- Select case series of PTT transfers for foot drop and bridle procedures suggest a satisfactory outcome in a majority of cases.

COMPLICATIONS

- Infection
- Wound dehiscence. The wound must be healed before initiating active dorsiflexion (usually not a problem because cast is maintained for at least 8 weeks).
- Failure of the tendon transfer anchoring point; less common with newer anchoring system
- Imbalance of bridle procedure: tibialis anterior and peroneus longus must be properly tensioned intraoperatively

REFERENCES

Chapter 10
**Posterior Cervical Fusion With Instrumentation** 4576

Chapter 11
**Occipitocervical and C1–2 Fusion and Instrumentation** 4586

Chapter 12
**Lumbar Discectomy** 4595

Chapter 13
**Lumbar Decompression** 4603

Chapter 14
**Posterolateral Thoracolumbar Fusion With Instrumentation** 4609

Chapter 15
**Transforaminal and Posterior Lumbar Interbody Fusion** 4616

Chapter 16
**Anterior Thoracic Corpectomy** 4628

Chapter 17
**Anterior Lumbar Interbody Fusion, Disc Replacement, and Corpectomy** 4634

Chapter 18
**Adult Scoliosis** 4646

Chapter 19
**Iliac Crest Bone Graft Harvesting** 4659
GENERAL CONSIDERATIONS

Anterior Approach (Smith-Robinson)

- The approach chosen depends on a number of factors, including the spinal segments that must be exposed, the nature of the procedure to be performed, and the patient’s body habitus.
- In general, the Smith-Robinson approach allows access from C2 down to T1 in most patients. However, local variations in patient morphology may either limit or increase the extent of available exposure.
- Ease of access to the C2-3 disc depends on the location of the mandible and can be assessed on the preoperative lateral radiograph.
- Nasal intubation is preferable when approaching this level as it allows the mandible to be maximally closed, away from the line of sight of the disc.
  - Depending on the location of the mandible with respect to C3-4, nasal intubation may be preferable in certain instances of C3-4 access as well.
  - For pathology at C7-T1 or distal, careful scrutiny of the disc space with respect to the sternal notch on lateral radiographs will help to assess whether a sternal-splitting approach may be necessary.
  - In some patients with long necks, access to T2 or even T3 may be possible with a standard Smith-Robinson approach.
  - In those with short or stocky necks, even getting to C7 may be a challenge (Fig 1).
- Imaging studies should be evaluated for anatomic variations such as medial aberrancy of the vertebral artery.

- Considerable debate exists as to whether the “sidedness” of approach affects the rate of postoperative superior laryngeal nerve palsy. The literature is not conclusive but suggests higher rates with right-sided approaches.
  - If a patient has had prior neck surgery and it is desirable to approach the spine from the opposite side to avoid scar, a preoperative indirect laryngoscopy should be performed by ear, nose, and throat (ENT) consultation to rule out a recurrent laryngeal nerve palsy.
  - If one exists, the spine must be approached from the side of the injury to avoid the possibility of bilateral vocal cord palsy. If one does not exist, the spine can be approached from either side.

Lateral Retropharyngeal Approach (Whitesides)

- This approach can be used for anterior access to the upper cervical spine but not the basiocciput.
- It is often used for high cervical bony lesions, including tumors or infections for which a posterior approach is not possible, unstable fractures or dislocations with deficient or incompetent posterior elements, or posterior nonunions (particularly for fusions of C1 to C2).
- It is also useful for access to high cervical ventral or ventrolateral intradural lesions such as neurofibromas or meningiomas.
- It allows unilateral access to C1 to C3. Access to the far contralateral side requires a second approach.
- Potential complications include injury to the spinal accessory nerve and the vertebral artery. The jugular vein also lies within the operative field and can be a site of significant bleeding if inadvertently injured.
- Significant retropharyngeal swelling has occurred and can result in prolongation of intubation if the patient’s airway becomes obstructed.

Anterior Approach to the Cervicothoracic Junction (Transmanubrial-Transclavicular Approach)

- There are several different approaches for exposing the cervicothoracic junction, including the transmanubrial-transclavicular and the sternal-splitting (median sternotomy) approaches.
  - The sternal-splitting (median sternotomy) approach may be useful in providing improved distal access to the upper thoracic spine.
  - Deep dissection is essentially the same for the two approaches.
  - Cranial to caudal dissection is recommended to avoid injury to the major crossing vessels distally (eg, the left brachiophical vein).
  - With a left-sided approach, the thoracic duct is at greater risk. It passes into the left venous angle between the subclavian artery and the common carotid artery.
With a right-sided approach, the recurrent laryngeal nerve is at greater risk because of its greater variability versus the left side, where the nerve is more constant in its location in the tracheoesophageal groove.

**POSITIONING**

**Anterior Approach (Smith-Robinson)**
- The patient is positioned supine with the neck slightly extended.
- The amount of extension tolerated by the patient without developing neurologic symptoms should be assessed preoperatively and not exceeded during positioning (FIG 2).
- A bump (eg, rolled sheets) under the shoulders facilitates gentle extension of the spine.
- A halter or Garner-Wells tong is optional but not routinely necessary for anterior cervical discectomy and fusion (ACDF) surgery.

A foam doughnut is placed behind the occiput to prevent pressure necrosis.
- The head is placed in neutral rotation. Doing so provides landmarks (the nose and the sternal notch) that are in line with the longitudinal axis of the spine for orientation during decompression and instrumentation.
- Depending on the relationship of the mandible to the upper cervical spine, proximal approaches to C2-3 may be easier if the head is gently rotated away from the side of the approach.
- The amount of rotation should be kept in mind to prevent disorientation during surgery.
- The shoulders are gently taped down to facilitate intraoperative radiographic visualization.
- Excessive force should be avoided when taping down the shoulders to avoid brachial plexus injuries.
- Spinal cord monitoring (eg, somatosensory evoked potentials [SSEP] and motor evoked potentials [MEP]) can be used to help prevent positioning-related nerve injuries, but it is not completely sensitive in detecting injury.

**Lateral Retropharyngeal Approach (Whitesides)**
- The patient is placed supine with the head turned away from the side from which the approach will be performed unless the patient is constrained in a halo for instability reasons.
  - If this is the case, the exposure will be more challenging but still possible.
  - Nasotracheal intubation opposite the side of the approach is desirable as it allows the jaw to be fully closed, offering the least inhibited exposure.
- The pinna (earlobe) can be retracted forward and sewn anteriorly to allow better access to the styloid process and posterior ear area.
- The entire cervical region and lower face is prepared and draped.

**ANTERIOR APPROACH (SMITH-ROBINSON)**

**Incision and Superficial Dissection**
- A transverse incision placed in a skin crease is more cosmetic and suffices for accessing up to three disc levels in most instances.
  - A longitudinal incision, although less cosmetic, allows for a more extensile approach (C2-thoracic spine) and should be considered when three or more discs require access, or if the patient has a very thick, muscular neck.
- The incision is made using palpable anterior structures as a guide (ie, C3 hyoid bone, C4-5 thyroid cartilage, C6 carotid tubercle, C7 cricoid cartilage) (TECH FIG 1A).
  - The preoperative lateral radiograph can also be used to determine roughly where to make the incision to allow optimal access to the desired disc(s).
  - The surgeon should try to make the incision such that it will be in line with the “line of sight” of the intended disc space (TECH FIG 1B).
  - Transverse incisions may extend from the anterior two thirds of the sternocleidomastoid (SCM) to beyond the midline.
- Longer incisions and greater tissue mobilization facilitate multilevel procedures and will heal with a nearly imperceptible scar if placed within a natural skin crease.
- Vertical incisions, if used, are placed along the medial border of the SCM.
- The incision is continued through the subcutaneous fat to the platysma (TECH FIG 1C).
- The platysma is divided in line with the skin incision using electrocautery.
- Blunt dissection with scissors undermines the edges of the platysma.
- This allows for greater mobilization of the soft tissues, which is helpful in accessing multiple disc levels and getting enough exposure to place plates and screws.
- Superficial veins crossing the field of dissection may need to be ligated to facilitate exposure (TECH FIG 1D).
Deep Dissection

- The anterior border of the SCM is identified.
- Blunt dissection is then carried through the deep cervical fascia directly medial to the SCM.
- The SCM is retracted laterally to allow palpation and identification of the carotid artery (TECH FIG 2A).
- The carotid artery should be visualized and will form the lateral border of the approach; the esophagus will define the medial border of the approach.

Once the carotid is identified, a plane through the pretracheal fascia lying between the carotid sheath and the medial structures (thyroid gland, trachea, and esophagus) is created (TECH FIG 2B).
- Finger dissection in this plane is useful in allowing extensible exposure.
Extending the Exposure

- If surgery involves one level, minimal mobilization may be necessary. If the surgery involves multiple levels or the skin incision is not collinear with the desired disc space, greater mobilization is helpful.
- In general, crossing structures should be preserved if possible to avoid potential injury to neural structures (e.g., laryngeal nerves). Blunt dissection with scissors, Kittners, or fingers works best.
  - The superior thyroid vessels typically overlie C3-4, and the inferior thyroid vessels generally overlie C6-7.
  - The omohyoid is encountered crossing distal-lateral to cephalad-medial in the interval medial to the sternomastoid at roughly the C6 level. It can be divided with electrocautery or left intact.
  - Dividing the omohyoid will allow for a more extensile cephalad-caudal exposure and less tension on the wound for easier placement of plates and screws in multilevel or very distal constructs.

Elevation of Longus Colli and Identification of Levels

- Using bipolar electrocautery, subperiosteal elevation of the longus colli should be done to the level of the uncinate processes bilaterally, and at least from the midportion of the vertebral body above to the midportion of the body below the level for which discectomy is planned (TECH FIG 3A).
- Time and care spent on carefully elevating the longus colli facilitates proper, stable placement of self-retaining retractors, which in turn facilitates decompression and accurate placement of hardware.
- Retractor blades are then placed beneath the elevated longus colli (TECH FIG 3B).
- Careful placement of retractors will help avoid injury to the esophagus and sympathetic chain (which runs along the ventral surface of the longus colli).
- TECHNIQUES FIGURE 3C represents a cross-sectional view at the C5 level demonstrating the plane of dissection for the Smith-Robinson approach.
- Location of the appropriate level should be ensured by intraoperative radiographs before disruption of the disc.
**Chapter 1**

**ANTERIOR CERVICAL APPROACHES**

---

**Incision and Superficial Dissection**

- A transverse incision is extended from the mastoid tip, posterior to the ear, and is carried along the inferior border of the mandible, preferably in a natural skin crease.
- The incision is then directed caudally along the anterior border of the SCM (TECH FIG 4A).
- This incision can be extended as needed according to the amount of distal cervical spine exposure required. It can be carried as far as the sternal notch.

---

**LATERAL RETROPHARYNGEAL APPROACH (WHITESIDES)**

**Incision and Superficial Dissection**

- The incision is then carried through the subcutaneous tissues and platysma muscle using electrocautery.
- Dissection is carried out using blunt dissection techniques in the subplatysmal plane, allowing the creation of superior-anterior and inferior-posterior musculocutaneous flaps (TECH FIG 4B).
- The superior-anterior flap is elevated to the inferior border of the parotid gland.
- The greater auricular nerve is identified and dissected out of the subcutaneous tissue both caudally

---

**TECH FIG 3** (continued) B. Self-retaining retractors can be placed beneath the elevated longus colli to allow an unimpeded view of the anterior spine. Care should be taken to avoid injuring the esophagus and sympathetic chain during placement of the retractors. The use of cephalad/caudal retractors is optimal but not necessary in most cases. C. A cross-sectional view through the neck at C5 demonstrating the plane of dissection.

**TECH FIG 4** A. A transverse incision is extended from the mastoid tip and is carried along the inferior border of the mandible, turning caudally and continuing along the anterior border of the sternocleidomastoid muscle. B. The incision is carried through the subcutaneous tissues and platysma muscle using electrocautery in line with the incision. Subplatysmal flaps are developed with blunt dissection techniques to allow adequate mobilization of tissue. (continued)
C. The greater auricular nerve is identified and mobilized from the subcutaneous tissues to allow adequate retraction. It is sometimes necessary to sacrifice the greater auricular nerve. This will result in a small area of insensate skin but otherwise has no functional significance. D. The external jugular vein and collaterals are mobilized or ligated as needed. The sternocleidomastoid is mobilized anteriorly with the carotid sheath. For additional exposure the sternocleidomastoid can be taken down from the mastoid prominence through the tendinous insertion.

- It is occasionally necessary to sacrifice the greater auricular nerve; this will leave the patient with a small insensate patch of skin but no long-term functional deficit.
- The external jugular vein is identified and then mobilized or ligated as needed.
- The SCM is mobilized and retracted medially and anteriorly with the carotid sheath.

**Mobilization of Sternocleidomastoid**

- Depending on the amount of exposure required, the SCM may be detached partially or entirely from its tendinous insertion at the mastoid prominence.
  - Be sure to leave enough tissue cuff to allow reapproximation of the muscle on closure.
- Take care to identify and protect the spinal accessory nerve, which enters the SCM about 3 cm distal to the tip of the mastoid process.
  - For limited exposure, the spinal accessory nerve can be retracted anteromedially with the SCM (TECH FIG 5).
  - For more extensive exposure, it can be dissected off the jugular foramen in a cephalad direction and retracted posterolaterally while the SCM is everted.

**Deep Dissection**

- Lymph nodes found in the field of dissection and around the spinal accessory nerve can be excised.
- The lateral process of C1 is now easily palpable about 1 cm distal to the mastoid process.
- The interval between the jugular vein and the longus capitis muscles is then created, allowing access to the retropharyngeal space.
- The retropharyngeal space can be opened further with blunt dissection techniques employing scissors, Kittners, or fingers.
- A sharp elevator or bipolar electrocautery can then be used to elevate the longus capitis and longus colli muscles from the transverse processes and lateral masses of C1 and C2 (TECH FIG 6A).
- Retraction is best accomplished by bending a malleable retractor so that it can be used as a lever against the contralateral transverse process, thus elevating the soft tissues anteriorly and medially (TECH FIG 6B).

**TECH FIG 4 (continued)**

- External jugular vein
- Parotid gland
- Great auricular nerve
- Sternocleidomastoid

**TECH FIG 5**

- The spinal accessory nerve is identified as it enters the sternocleidomastoid about 3 cm distal to the tip of the mastoid process and retracted anteriorly with the sternocleidomastoid. The lateral process of C1 will lie essentially in the middle of the field of dissection, about 1 cm distal to the mastoid process.
Bipolar electrocautery can be used to elevate the longus capitis and longus colli muscles subperiosteally from the transverse processes and lateral masses of C1 and C2. Plane of dissection for the retropharyngeal approach. For deep retraction, a malleable retractor can be used as a lever against the contralateral transverse process, allowing elevation of the soft tissues anteriorly and medially.

ANTERIOR APPROACH TO THE CERVICOTHORACIC JUNCTION (TRANSMANUBRIAL-TRANSCLAVICULAR APPROACH)

Incision and Superficial Dissection
- A standard Smith-Robinson approach is taken, with the incision extended distally over the manubrium (TECH FIG 7A).
- The sternal and clavicular heads of the SCM are released at the tendinous attachments and retracted proximally and laterally. Be sure to leave enough tissue cuff to allow reapproximation of the muscle on closure.
- Likewise, the sternohyoid and sternothyroid are sectioned and retracted proximally and medially (TECH FIG 7B).
- The omohyoid is also generally sectioned for better exposure. It does not need to be repaired.

Mobilization of Clavicle
- The medial third of the clavicle and the left side of the manubrium is then cleared of any remaining soft tissue.
- The clavicle is then divided (typically with a Gigli saw) at the junction of the medial and middle thirds (TECH FIG 8A).
- Care must be taken to avoid injuring the left subclavian vein, which is normally closely apposed to the undersurface of the clavicle.
- At this point, the medial third of the clavicle can be disarticulated from the manubrium (TECH FIG 8B).
- If more exposure is needed, the left side of the manubrium can be removed in a piecemeal fashion by a rongeur.
- Alternatively, the medial third of the clavicle and a section of the manubrium can be removed together by careful sectioning. This will allow plate or wire reconstruction of the clavicle and manubrium if desired.
- If the manubrium and medial third of the clavicle are removed in this manner, the sternal head of the SCM can be left in continuity with the manubrium and reflected en bloc (TECH FIG 8C).

Deep Dissection
- The inferior thyroid vein and artery are often encountered with deeper dissection and may need to be ligated for better exposure.
- Careful blunt dissection proceeds in the same interval as for the standard Smith-Robinson approach (ie, between the carotid sheath laterally and the trachea and esophagus medially).
- The recurrent laryngeal nerve is almost always found between the esophagus and trachea on the left side of the neck within this plane.
- Blunt retractors are then placed and the carotid sheath, left brachiocephalic artery, and innominate vein are retracted inferolaterally (TECH FIG 9A).
- Likewise, a blunt retractor is used to retract the trachea, esophagus, left recurrent laryngeal nerve, and right brachiocephalic vessels inferolaterally to the patient’s right.
- The prevertebral fascia is then identified and incised to expose the vertebral bodies. Once adequately dissected, the surgeon can visualize and access as far distally as T3 or T4.
- TECHNIQUES FIGURE 9B represents a cross-sectional view at the cervicothoracic junction demonstrating the plane of dissection for the transmanubrial-transclavicular approach.
- At the completion of the procedure, the clavicle is replaced and plated.
TECH FIG 7 • A. The incision for a low Smith-Robinson approach can be extended along the anterior border of the sternocleidomastoid to the midsagittal plane at roughly the sternal notch and then extended vertically to just beyond the manubrial–sternal junction. B. The sternal and clavicular heads of the sternocleidomastoid are released and reflected laterally while the sternohyoid and sternothyroid muscles are sectioned and reflected medially. The omohyoid is usually released during the exposure. It does not need to be repaired.

TECH FIG 8 • A. The clavicle is divided at the junction of the medial and middle thirds, taking care to avoid injuring the left subclavian vein, which is normally closely apposed to the undersurface of the clavicle. B. The medial third of the clavicle can be disarticulated from the manubrium at the manubrioclavicular joint. This will generally provide adequate exposure to the C7-T1 level. C. For additional exposure, the left side of the manubrium can be removed piecemeal using a rongeur. A second option involves careful sectioning of the manubrium, which will allow lateral reflection of both the manubrium and medial third of the clavicle without disarticulation of the manubrioclavicular joint.
TECH FIG 9 • A. Blunt retractors are used to carefully retract the carotid sheath, left brachiocephalic artery, and innominate vein inferolaterally, while the trachea, esophagus, left recurrent laryngeal nerve, and right brachiocephalic vessels are retracted inferomedially. B. Cross-sectional view through the cervicothoracic junction demonstrating the plane of dissection for the transmanubrial-transclavicular approach.
ANATOMY

Posterior Cervical Musculature
- The muscles covering the posterior aspect of the cervical spine are arranged in three layers (FIG 1).
- Superficial layer: The trapezius muscle originates from the superior nuchal line of the occiput, the ligamentum nuchae, and the spinous processes of the upper thoracic spine. It inserts into the spine of the scapula and the acromion.
- Intermediate layer: The splenius capitis arises from the lower half of the ligamentum nuchae and upper six thoracic vertebrae, inserting onto the mastoid process and the lateral half of the superficial nuchal line under the sternocleidomastoid.
- The deep layer consists of the semispinalis capitis, the semispinalis cervicis, the multifidus, and the rotators, arranged from superficial to deep layers respectively.
  - The semispinalis capitis arises from the transverse processes of the upper six thoracic vertebrae and the articular processes of the midcervical vertebrae and inserts onto the occiput between the superior and inferior nuchal lines.
  - The semispinalis cervicis arises from the transverse processes of the upper six thoracic vertebrae and inserts onto the spinous processes of C2 to C5.
  - The multifidus muscle lies deep to the semispinalis cervicis. It originates from the articular processes of the lower cervical vertebrae and inserts onto the spinous processes of the upper cervical vertebrae.
  - The rotators lie deep to the multifidus. They originate from the transverse process of one vertebral and ascend obliquely to insert on the spinous process of the vertebra one or two levels cranial to their origin.

Suboccipital Musculature
- The rectus capitis posterior minor originates from the posterior tubercle of the atlas and inserts onto the medial half of the inferior nuchal line.
- The rectus capitis posterior major originates from the spinous process of the axis and inserts onto the lateral half of the inferior nuchal line.
- The obliquus capitis superior originates from the transverse process of the atlas and inserts onto the occiput laterally between the superior and inferior nuchal lines.
- The obliquus capitis inferior muscle originates from the spinous process of the axis and inserts onto the transverse process of the atlas.
- The suboccipital triangle lies between the rectus capitis posterior major and the superior and the inferior obliquus.
- The greater occipital nerve is the medial branch of the posterior division of the second cervical nerve at the medial angle of the suboccipital triangle. It runs cephalad between the semispinalis capitis and the obliquus inferior, toward the occiput, where it pierces the semispinalis capitis and the trapezius. It is responsible for cutaneous innervation of the back of the scalp (FIG 2).

Osteoligamentous Anatomy
- The external occipital protuberance or inion is an easily palpable bony landmark in the midportion of the occiput. The superior nuchal line extends as a bony ridge on either side of this prominence. A small ridge or crest, called the median nuchal line, descends in the medial plane from the external occipital protuberance to the foramen magnum. The inferior nuchal line runs parallel to the superior nuchal line, midway between the inion and foramen magnum (FIG 3).
- The atlas does not have a spinous process but has a posterior tubercle marking the center of the posterior arch.
- The spinous process of the axis is tall, bifid, and broadest in the cervical spine.
- A broad sheet of thick fibrous tissue called the posterior atlanto-occipital membrane extends from the posterior border of the foramen magnum to the superior border of the posterior arch of the atlas.
- The posterioratlantoaxial membrane is a broad, thin membrane extending from the inferior border of the posterior arch of the atlas to the superior border of the lamina of the axis.
- The tectorial membrane is the cranial extension of the posterior longitudinal ligament, running posterior to the transverse ligament to attach onto the anterior border of the foramen magnum.
- The anterior atlantoaxial ligament is the continuation of the anterior longitudinal ligament, extending from the inferior border of the anterior arch of the atlas to the front of the body of the axis (FIG 4).
- The pars interarticularis or isthmus of C2 is the waist of the posterior arch of C2, connecting the superior and inferior articular processes. The medial margin of the pars interarticularis along the superior border of the C2 lamina is a guide to the medial margin of the C2 pedicle.
- The C1–2 facet joint is oriented largely in the axial plane, while the C2–3 and remaining subaxial cervical facet joints are coronally oriented 45 degrees to the plane of the spine.
- The spinous processes from C3 to C6 are small and bifid. The C7 spinous process tends to be straight and long and terminates in a single tubercle. It is usually the longest of the cervical spinous processes.
- The lateral mass of the cervical spine refers to the lateral column of each vertebral body that includes the superior and inferior articular processes and the transverse foramen on either side.
  - It offers a secure fixation anchor for screw insertion from C3 to C6, particularly when the spinous process and lamina are fractured or removed.
  - A faint longitudinal groove marks the separation between the laminae and lateral masses.
  - The exiting nerve root and posterior portion of the transverse process lie anterior to the lateral mass.
  - The anteroposterior depth of the lateral mass reduces gradually from C3 (about 8.9 mm) to C7 (about 6.4 mm).
Superficial layer
- Trapezius

Intermediate layer
- Splenius capitis

Deep layer
- Semispinalis capitis
- Rectus capitis posterior minor
- Rectus capitis posterior major
- Obliquus capitis inferior
- Semispinalis capitis

Superficial, intermediate, and deep layers of the posterior cervical musculature are shown on the left. The suboccipital muscles lie deep to these muscles and are shown on the right.

FIG 2 • Anatomy of the suboccipital triangle. The suboccipital triangle lies between the rectus capitis posterior major, the obliquus superior, and the obliquus inferior. The greater occipital nerve is seen crossing the suboccipital triangle along its medial angle. The posterior arch of the atlas with the vertebral artery is seen in the floor of the suboccipital triangle.
FIG 3 • A. Bony anatomy of the occiput with muscular insertions. Superior, inferior, and median nuchal lines are the prominent bony ridges on the posterior occipital surface. The major posterior cervical muscles and muscles of the suboccipital triangle insert on these bony ridges and on the posterior occipital surface between these ridges. B. Sagittal cross-section showing the ligamentous architecture of the proximal cervical spine. Anterior and posterior atlanto-occipital as well as atlantoaxial ligaments and the ligaments stabilizing the odontoid process are depicted: the apical ligament of the dens and the transverse ligament of the atlas.
The lateral mass of C7 is elongated superoinferiorly but is thinner in the anterior posterior plane than the other cervical vertebrae.
The pedicles of the cervical vertebrae are smaller than those in the lumbar spine. The dimensions are generally appropriate for pedicle screw insertion at C2 and C7.
Computed tomography should be obtained in all patients before screw fixation to verify pedicle width and morphology, particularly between C3 and C6.

**Nerve Root Anatomy**
- The dorsal and ventral nerve roots formed from the respective rootlets enter a common sleeve of the arachnoid and dura mater.
- The nerve root runs 45 degrees anterolaterally and 10 degrees inferiorly to enter the intervertebral foramen by passing over the top of the corresponding pedicle.
- The dorsal nerve root lies anterior to the superior articular process, positioned at the tip of the superior articular facet medially and then coursing inferiorly to lie on top of the pedicle laterally.
- The ventral root lies anteroinferiorly adjacent to the uncovertebral joint.
- The cervical nerve roots occupy the lower third of the intervertebral foramen, while the upper two thirds of the foramen is filled with fat.
- In the lateral part of the intervertebral foramen, the dorsal nerve root is enlarged to form the dorsal root ganglion, which lies between the vertebral artery and a groove on the anterolateral aspect of the superior articular process (Fig 4).
- The dorsal and the ventral nerve roots join distal to the dorsal root ganglion outside the intervertebral foramen to form the spinal nerve.

**Vertebral Artery**
- The vertebral artery is a branch of the first part of the subclavian artery, lying anterior to the transverse process of the seventh cervical vertebra at its origin.
- The vertebral artery courses medially and posteriorly through the subaxial cervical spine within the transverse foramina of the sixth through the first cervical vertebrae.
- It is at risk of injury where it lies unprotected between the transverse foramina and during anterior procedures lateral to the disc space, particularly at the upper cervical levels (FIG 5).
- Anatomic variations in the course of the vertebral artery are not infrequent. Following its origin off the subclavian artery, the vertebral artery typically enters the C6 transverse foramen. Bruneau et al reported entry into the C3, C4, C5, or C7 transverse foramina in 0.2%, 1.0%, 5.0%, and 0.8% of patients, respectively.
- A 2% incidence of tortuosity of the vertebral artery has been reported, leading to a potentially dangerous medial course of the vessel within the vertebral body.
- More cephalad, after emerging from the transverse foramen of C2, the artery lies lateral to the C1–2 facet joint before it enters the transverse foramen of the atlas.
- The artery exits the transverse foramen of the atlas and continues posteromedially in a groove on the superior surface of the posterior arch of the atlas.
- It enters the foramen magnum by piercing the atlanto-occipital membrane about 10 mm from the midline.
- In approaches to the posterior cervical spine, the vertebral artery is at risk of injury during exposure of the posterior arch of the atlas and in the transverse foramina of C1 and C2 during screw insertion for occipitocervical or atlantoaxial fusion procedures.
- To protect the vertebral artery during these procedures, dissection should be limited to within 12 mm of the midline on the posterior aspect of C1 and within 8 mm of the midline on the superior surface of the posterior arch of the atlas.
- Further lateral dissection can be performed on the inferior surface of the C1 arch versus the superior surface because the vertebral artery runs on the superior surface of the C1 arch.
- The width of the lateral mass of the atlas averages 11.6 ± 1.4 mm. The height of the portion of the lateral mass of the atlas inferior to its posterior arch averages 4.1 ± 0.7 mm.
- The lateral mass of C1 thus can generally safely accommodate a 3.5-mm screw below its attachment to the posterior arch.
SURGICAL MANAGEMENT

Indications
- Posterior spinal cord decompression via laminoplasty or laminectomy
- Nerve root decompression via foraminotomy
- Occipitocervical or atlantoaxial decompression, fusion, and instrumentation
- Posterior cervical fusion
- Cervical pedicle or lateral mass instrumentation

Positioning
- The patient's cervical spine should be ranged in flexion and extension in the preoperative area to determine a safe range that does not produce symptoms. Movements of the neck during intubation should be minimized, particularly in myelopathic patients.
- Awake intubation and positioning should be considered in myelopathic patients with markedly reduced canal dimensions.
- In patients undergoing occipitocervical and atlantoaxial procedures, the chin should be tucked to facilitate exposure of the occipitocervical region. For subaxial procedures, slight flexion of the neck reduces overlap of the laminae and facet joints, making deep dissection easier and facilitating decompression of the central and lateral canal. The neck should be brought back into neutral position for fusion or instrumentation procedures.
- Hyperextended or hyperflexed positions under anesthesia, particularly when held for prolonged periods of time, may contribute to spinal cord injury.
- We recommend use of the Mayfield three-point clamp to hold the cranium during posterior occipitocervical and posterior cervical surgery. The clamp is secured to the operating table with an adaptor.
- We infrequently use intraoperative tong traction because we believe the amount of traction transmitted to the operative site is variable.
- The shoulders are pulled down and taped to the distal end of the bed to facilitate intraoperative radiographic visualization (FIG 6). Excessive traction on the shoulders should be avoided to minimize the risk of brachial plexus injury.
- The reverse Trendelenburg position reduces epidural venous congestion and intraoperative bleeding. We avoid the sitting position to minimize the risk of intraoperative air embolism.
- Bony prominences and peripheral nerves in the upper and lower extremities should be well padded to protect against intraoperative decubiti or neurapraxia.
- Allowing the abdomen to hang free facilitates venous return to the heart, maintains cardiac output, and decreases the required peak inspiratory pressure.
- Radiographs are obtained after positioning to verify cervical alignment. Placement of a radiopaque marker before obtaining these radiographs facilitates planning of the incision.

FIG 6 • Positioning of the patient for posterior cervical surgery. In the prone position, the patient's head is stabilized with a Mayfield three-point clamp while traction is applied through the shoulders by taping them down. The patient is in the reverse Trendelenburg position with the abdomen allowed to hang free.
POSTERIOR APPROACH TO SUBAXIAL SPINE

- A midline skin incision is used for most surgical procedures to the subaxial spine. Palpation of the prominent spinous processes of C2 and C7 beneath the skin or the use of intraoperative radiographs can help restrict the incision to the area that requires exposure.
- The incision is deepened through the relatively avascular median raphe, which is a condensation of the deep fascia. This appears as a “white line” in the midline.
- Electrocautery is then used to incise the ligamentum nuchae.
- Troublesome bleeding from the paraspinal muscles can be minimized by staying within the avascular median raphe.
- Intermittent palpation of the spinous processes helps the surgeon stay oriented to the midline. The posterior cervical paraspinal musculature generally originates laterally and caudally, passing obliquely cephalad.
- Reduction of intraoperative bleeding is facilitated by dissecting caudal to cephalad in a subperiosteal fashion.
- For laminoplasty or multilevel laminectomy, the interspinous tissues are cauterized to minimize bleeding and then stripped off the spinous processes.
- Deep retractors are inserted beneath the fascial layers directly on bone. Deep dissection is carried further laterally along the laminae.
- Localization of level is facilitated by identifying the large C2 and C7 spinous processes and the bifid spinous processes from C2 to C6.
- An intraoperative lateral radiograph should be obtained to confirm the operative levels.
- If facet fusion is not planned, the dissection should stop at the medial third of the facet joint and the facet joint capsule should be preserved.
- If facet fusion or instrumentation is required, the dissection is extended to the lateral border of the lateral mass.

POSTERIOR APPROACH TO OCCIPITOCERVICAL REGION

- The external occipital protuberance and the prominent bifid C2 spinous process can be palpated in most patients beneath the skin. A midline skin incision is made extending from just above the occipital protuberance to the cervical level required.
- The incision on the scalp is deepened down to bone, and the occiput is exposed in subperiosteal fashion from the inion down to the foramen magnum.
  - The dissection is carried laterally for a distance of 2.5 cm on either side of the median occipital crest. Excessive lateral dissection or retraction can injure the greater occipital nerve.
  - The incision is extended caudally through the ligamentum nuchae in the midline. Staying in the midline reduces blood loss.
  - Self-retaining retractors are applied at both ends of the incision.
  - The large bifid spinous process of C2 is easily identified. It is exposed subperiosteally by dissecting the attachments of the rectus capitis posterior major and obliquus capitis inferior from these structures.
  - The greater occipital nerve exits posteriorly along the inferior border of the obliquus capitis inferior muscle and can be preserved by keeping the dissection on the C2 posterior arch.
  - Preserving the soft tissue attachments to the distal and lateral aspects of C2 and the C2–facet joint helps maintain subaxial stability postoperatively.
  - The C1 ring lies deep in the space between the occiput and C2. The posterior arch of C1 has no muscular attachments.
- Soft tissue from the posterior arch of C1 is dissected subperiosteally, taking care to stay within 12 mm of the midline on the posterior aspect of the posterior ring of C1 and within 8 mm of the midline on the superior aspect of the posterior ring of C1 to avoid vertebral artery injury (TECH FIG 1).

TECH FIG 1 • The vertebral artery emerges from the transverse foramen of the atlas and courses medially in the groove on the superior surface of the posterior arch of the atlas. At the medial end of the groove it turns anteriorly and pierces the atlanto-occipital membrane about 10 mm from the midline.
EXPOSURE OF C1–2 FACET JOINT

- Exposure of the articulation between the lateral mass of C1 and the superior articular process of C2 is occasionally required for screw fixation of the lateral mass of C1 and fusion of this joint.
- After dissection and retraction of the muscles off the posterior aspects of C1 and C2 of the upper cervical spine, the lamina of C2 is identified.
- Soft tissue is carefully dissected off the lamina of C2 using a Freer elevator or dissector.
- Tracing the lamina of C2 proximally exposes the pars interarticularis of C2 and the superior medial corner of the C2 pedicle.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pitfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior vertebral arch fragments</td>
<td>Unstable or fractured fragments should be stabilized with a clamp during dissection to avoid inadvertent contusion of the spinal cord.</td>
</tr>
<tr>
<td>Stenotic canal</td>
<td>Excessive manipulation of the posterior elements in a patient with a stenotic canal should be avoided as it may inadvertently result in spinal cord injury.</td>
</tr>
<tr>
<td>Excessive bleeding</td>
<td>Venous bleeding from epidural veins can occasionally be profuse. The patient should be positioned in reverse Trendelenburg position to decrease the blood loss. Hemostatic agents and bipolar cautery are used to control bleeding from these veins.</td>
</tr>
<tr>
<td>Vertebral artery</td>
<td>The vertebral artery is endangered at lower cervical levels (C3 to C6) only if the transverse processes at these levels are destroyed by tumor or infection.</td>
</tr>
<tr>
<td>Spina bifida</td>
<td>Cervical spina bifida is a rare condition that can lead to cord damage during dissection if not recognized.</td>
</tr>
</tbody>
</table>

EXPOSURE OF C1–2 FACET JOINT (continued)

- Exposure of the C1 lateral mass can be obtained by following the inferior arch of C1 laterally until the lateral border of the spinal canal is identified by visualizing its corresponding location on C2.
- From this point on C1, ventral dissection with a Penfield or Freer will allow palpation of the C1 lateral mass. The greater occipital nerve is encountered and swept distally. A large venous plexus is present and must be controlled with Gelfoam and bipolar cautery.

REFERENCES

DEFINITION
- The anterior approach can be used to access the thoracic spine for decompression, deformity correction, and stabilization. This approach allows for access to treat conditions such as intervertebral disc herniation, infection, tumor, and trauma.

ANATOMY
- The thoracic spinal cord may have a tenuous blood supply, particularly in patients with congenital anomalies and kyphosis.
- The midthoracic cord represents a watershed zone for vascularity. The artery of Adamkiewicz supplies the thoracic cord but can have a variable origin. Its origin is usually (80%) from the left side at the T10 level but can vary from T5 to L5.1

SURGICAL MANAGEMENT
Preoperative Planning
- Radiographs of the thoracic spine and chest should be obtained to determine the level of surgery and help in “rib counting.”
  - It is often helpful to obtain lumbar radiographs also to determine the number of lumbar segments below the most distal thoracic rib. Knowing this information preoperatively helps in counting “up” from the sacrum intraoperatively if needed.
  - In the absence of obvious bony pathology such as fractures, infections, or tumors, it is very easy to inadvertently localize the wrong level in the thoracic spine. The surgeon should be sure to have a strategy for intraoperative level identification based on careful scrutiny of radiographs and MRI or CT scans before surgery, understanding that the quality of portable films obtained intraoperatively may not be optimal.
  - When obtaining an MRI to better understand the nature of the pathology in relation to the thoracic spinal cord, the surgeon should ask for a topogram to be performed so that there is no question as to the level or levels of involvement.
  - On CT scan or MRI, the surgeon should pay close attention to the position of the aorta and inferior vena cava, especially on the axial cuts, as this may affect the side from which the spine is approached, especially if a corpectomy will be performed.
- Anesthesia considerations include the use of an oral gastric tube and double-lumen endotracheal tube, which allows for collapse of the ipsilateral lung.
  - If the surgical site is T10 or distal, selective deflation of the ipsilateral lung is usually not necessary.
  - If the surgical site is proximal to T10, selective deflation is helpful in keeping the lung out of the field, but it may lead to more postoperative issues with atelectasis.
- Neurologic monitoring is frequently used when performing thoracic operations.

Positioning
- The patient should be in the lateral decubitus position with the arms in prayer position.
- The thorax vertex should be positioned over the break of the bed, all pressure points should be padded, pillows should be placed between legs and arms, and an axillary roll should be used to prevent compression of the axillary vessels (FIG 1).
- The operating surgeon typically stands behind the patient during the exposure. However, it may be helpful to stand in front of the patient when performing the decompression, as the line of sight into the spinal canal is better from that vantage point.

Approach (Right Versus Left)
- Considerations for thoracic approaches include:
  - Approach from the side of herniation in cases of postero-lateral or lateral herniation.
  - Look at the axial CT or MRI scans to determine the location of the heart and great vessels. In most thoracic cases, these structures are either on the left or central. Thus, all other factors being equal, a right-sided approach is favored in most cases.
  - In the distal thoracic spine (eg, T10–12), the liver may be in the way of a right-sided approach. Because it is a bit more difficult to retract the liver than the kidney or spleen, a left-sided approach may be favorable.
- Considerations for thoracolumbar approaches include:
  - The left-sided approach is generally favored, as it is easier to mobilize the great arteries (aorta, iliacs) from their left-central position to the right, rather than mobilizing the great veins (which tend to be further to the right) toward the left.

FIG 1 • Patient placed in the lateral decubitus position. It is important to ensure that all bony prominences are well padded.
ANTERIOR THORACIC APPROACH FROM T1 TO T4

- For upper thoracic exposures a right-sided approach is preferred to avoid the heart.
- The surgeon makes a curved skin incision below the tip of the scapula (TECH FIG 1A).
- This incision is carried down to the latissimus dorsi muscle and then the latissimus is incised, leaving a cuff of the muscle on the scapula for later closure (TECH FIG 1B).
- A large retractor (ie, Richardson retractor) can then be held by the assistant while the surgeon incises the periosteum over the appropriate rib and then resects the rib as far anteriorly and posteriorly as possible (TECH FIG 1C).
- At this point, the chest is entered through the rib bed and a Finochietto or Omni retractor can be placed, with one of the blades holding the scapula up and out of the way.
- Now the lung can be deflated and retracted anteriorly and inferiorly (TECH FIG 1D).
- The pleura overlying the spine is now sharply incised. Placing suture into the edges of the pleura makes subsequent closure easier.
- Segmental vessels are identified and ligated as needed and the vertebral bodies (the "valleys") and disc spaces (the "hills") are identified.

TECH FIG 1 • Anterior thoracic approach from T1 to T4. A. A curved incision should be made just under the tip of the scapula. B. The incision is carried down to the latissimus dorsi. A cuff of muscle is left attached to the scapula for repair upon closure. C. The surgeon incises the periosteum over the rib. D. The deflated lung is retracted anteriorly and inferiorly while protecting the esophagus and great vessels.
ANTERIOR THORACIC APPROACH FROM T5 TO T12

- The surgeon should plan the incision directly over the desired rib (ie, 10th rib for T9-10 disc). A curvilinear skin incision is made along the path of the rib from the anterior border of the latissimus dorsi to the costochondral junction anteriorly (TECH FIG 2A).
- Due to the downslope of the ribs, it is generally preferable to make an incision that is more proximal rather than distal. If the incision is too distal, the ribs may impede access to the more proximal segment, necessitating a second thoracotomy. In contrast, it is easier to access levels that are distal to the rib that is resected. Thus, if in doubt as to the exact rib to be resected, the incision should be made more proximal.
- Skin and subcutaneous fat are incised to expose the trapezius and latissimus dorsi.
- The trapezius and latissimus dorsi are divided in line with the incision using electrocautery. The rhomboids may need to be split to gain more exposure cephalad.
- Once the correct rib is identified, the surgeon divides the periosteum over the upper border of the rib to avoid injury to the intercostal nerve and vessels (TECH FIG 2B).
- The rib is stripped subperiosteally anteriorly to the costochondral angle and as far posteriorly as possible (TECH FIG 2C).
- The rib is removed with a rib cutter and passed off the field. The rib is cut at the midaxillary line anteriorly and as far posteriorly as possible. The rib can be used as a strut graft or autologous bone graft.
- The periosteal rib sleeve and parietal pleura are incised to enter the thorax. A rib spreader is placed to hold the ribs apart (TECH FIG 2D).
- The ipsilateral lung is deflated and retracted medially to expose the parietal pleura overlying the spine.
- The parietal pleura overlying the spine is incised and retracted medially. Stitches can be placed in the parietal

TECH FIG 2 • Anterior thoracic approach from T5 to T12. (In these images, the patient’s head is to the upper left and the patient’s back is toward the surgeon.) A. The incision in planned directly over the rib. Injecting the subcutaneous tissues with a combination of anesthetic and epinephrine aids in hemostasis. B. The skin and subcutaneous tissues have been divided, exposing the desired rib. C. Subperiosteal exposure of the rib before excision. Note the thin parietal pleura beneath the rib bed. D. After excision of the rib the parietal pleura is entered, exposing the ipsilateral lung. (continued)
E. The parietal pleura and the underlying segmental vessels. F. The vertebral bodies and intervertebral discs are exposed after segmental arteries are ligated and the overlying soft tissues are removed. Once the costotransverse and costovertebral articulations are excised (G), the rib head can be removed with a high-speed burr (H).
pleura to make closure easier. The underlying segmental vessels are visualized (TECH FIG 2E).

- The segmental arteries arising from the aorta can run in an ascending, recurrent, horizontal, or descending direction depending on the level of involvement.
- The surgeon carefully ligates as few segmental vessels as possible to gain adequate exposure to the spine. Ligating more segmental vessels than necessary places the spinal cord at increased risk for ischemia because the thoracic spinal cord has a tenuous blood supply (TECH FIG 2F).
- In cases of suspected vascular anomalies, such as congenital kyphosis, the surgeon should consider temporary occlusion of the segmental vessels and check evoked potentials before vessel ligation. If a patient has had a prior spine exposure on one side, the surgeon should be wary of ligating the contralateral segmental vessels. Instead, the surgery should be performed through the previously exposed side, or a preoperative angiogram should be obtained to identify the important arterial feeders to the spinal cord.

- The intrathoracic vertebral bodies and intervertebral discs are now exposed. To gain access to the posterior intervertebral disc, the rib head may need to be removed.
- The costotransverse and costovertebral articulations are removed to excise the rib head (TECH FIG 2G).
- The soft tissues overlying the transverse process, pedicle, and vertebral body are removed.
- The superior edge of the pedicle is identified and followed back to the intervertebral space.
- The superior edge of pedicle is burred to expose the posterior intervertebral disc and lateral margin of the dura (TECH FIG 2H).

### Detaching the Diaphragm

- Exposure of T12-L1 may require detaching the diaphragm.
  - The diaphragm inserts and originates from the xiphoid and the inferior six ribs.
  - The lateral arcuate ligament arises from the transverse process of L1.
  - The crura extend more distally on the right.
  - The diaphragm is innervated centrally by the phrenic nerves.

- The patient is positioned in the lateral decubitus position with the right side down. The approach should be made from the left side to avoid the liver and inferior vena cava.
- The crura of the diaphragm are detached as described above.
- An oblique incision is made from the quadratus lumborum to the lateral border of the rectus abdominis (TECH FIG 4).
  - This approach can be extended to L5 in most patients and even to S1 in those with low-riding iliac crests.
  - The subcutaneous tissue is incised and the fascia of the external oblique is divided.
  - The external and internal obliques, transverse abdominis, and transversalis fascia are incised.

- The surgeon starts at the costal angle and incises the costodiaphragmatic reflection until extraperitoneal fat is visualized.
- The diaphragm is divided off the anterior chest wall (TECH FIG 3). The surgeon should leave a 1- to 2-cm cuff of diaphragm on the anterior chest wall to allow for diaphragm repair at closure. To avoid diaphragm denervation, the diaphragm should be incised only at its periphery. The diaphragm is split up to the lateral arcuate ligament.
- The medial and lateral crura are detached, exposing the underlying peritoneum.
- The peritoneum is swept medially until the retroperitoneal space is visualized.
- The surgeon bluntly dissects and sweeps the fascia of Gerota medially to expose the spine and the overlying parietal pleura.
- The aorta and vena cava are identified.
- The surgeon can elevate the psoas muscle if needed.
- The parietal pleura is incised to expose the spine.

### THORACOABDOMINAL RETROPERITONEAL LUMBAR SPINE APPROACH FROM T10 TO L3

- The peritoneum is exposed and bluntly reflected anteriorly.
- The ureter is identified and reflected anteriorly with retroperitoneal fat.
- The vertebral bodies, psoas, and great vessels are identified.
- The genitofemoral nerve lies on anterior psoas muscle, and excessive traction should be avoided.
- The segmental vessels that lie over the middle of the vertebral bodies are identified and ligated.
- The psoas is bluntly dissected off the vertebrae and retracted laterally.
- The vertebral body, pedicle, and neuroforamen can be visualized.
**TECH FIG 4** • Thoracoabdominal approach. **A.** A curvilinear incision is made over the 10th rib and the muscle layers are identified. **B.** The retroperitoneal space is entered through the costal cartilage after removing the 10th rib. **C.** The light areolar tissue that signifies the retroperitoneal space is identified, and the peritoneum is mobilized from the undersurface of the diaphragm and abdominal wall as well as the aorta. **D.** Exposure of the spine is done after ligation of segmental vessels.
### PEARLS AND PITFALLS

| Neurologic compromise | ![The surgeon should consider preoperative angiography before left-sided approaches between T8 and T12 to identify the artery of Adamkiewicz and prevent spinal cord infarction.](image)
|                        | ![The surgeon should consider temporarily clamping the segmental arteries before ligation and assessing for changes in evoked potentials to avoid vascular catastrophe, because blood supply to the spinal cord is tenuous in the thoracic region, especially in the “critical zone” from T4 to T9.](image) |
| Avoiding wrong-level surgery | ![The surgeon should place a hand under the scapula and count rib spaces. The first rib is often difficult to feel, but the second rib space is the largest.](image)
|                          | ![Preoperative anteroposterior and lateral chest radiographs can aid in rib counting, especially in kyphotic patients.](image) |
| Exposure                | ![Using a double-lumen endotracheal tube will allow deflation of the ipsilateral lung and improve exposure.](image)
|                          | ![Detaching the psoas muscle off the transverse processes can improve exposure of the intervertebral disc space and neuroforamen. The transverse processes can also be removed to further increase exposure.](image)
|                          | ![Flexing the patient’s hips can decrease tension on the psoas and improve visualization of the lumbar spine.](image)
|                          | ![More ribs may need to be excised to gain better exposure, especially in older patients, in whom the ribs may not be as compliant to the rib spreader.](image)
|                          | ![From T2 to T5 it may help to detach the serratus anterior muscle from the anterior chest wall and reflect it cephalad to gain better exposure. The surgeon should avoid cutting the long thoracic nerve at this level.](image)
|                          | ![If scapular manipulation is needed to gain better exposure, the rhomboids, trapezius, and dorsal scapular muscles can be divided, allowing the scapula to be mobilized laterally.](image) |
| Visceral injury          | ![When approaching from the right side, the surgeon should dissect the soft tissues away from the spine as close as possible to the bone with a blunt gauze or finger to prevent injury to the cisterna chyli and thoracic duct.](image) |

### POSTOPERATIVE CARE
- Chest tubes are left in place until output is less than 150 mL over 24 hours.

### COMPLICATIONS
- The exiting nerve root can be injured while removing the pedicle.
- Vascular injury
- Intercostal neuralgia
- Atelectasis
- Neurologic injury
- Wrong-level surgery
- Significant bleeding can be encountered when entering the epidural space.
- Visceral injury

### REFERENCE
Anterior Lumbar Approach

P. Justin Tortolani, Samer Saiedy, and Ira L. Fedder

DEFINITION
- The anterior lumbar approach provides excellent access to the lumbar spine extending from the L2–3 disc to first segment of the sacrum (S1).

ANATOMY
- The anterior abdominal wall has a layered configuration that changes depending on whether the approach is proximal or distal to the arcuate line.
- Above the arcuate line, the layers in order are skin, subcutaneous fat (containing fascia of Camper and Scarpa), anterior rectus sheath (aponeurosis of the external and internal oblique muscles), rectus muscle, posterior rectus sheath (aponeurosis of the internal oblique and transversus abdominis muscles), transversalis fascia, and peritoneum (FIG 1).
- Below the arcuate line, the posterior rectus sheath is not present, and thus the rectus muscle lies directly on the transversalis fascia.
- For retroperitoneal exposures, the approach goes through the abdominal wall to the layer of the transversalis fascia and then progresses laterally until this fascia ends, exposing the retroperitoneal fat.
- For transperitoneal exposures, the transversalis fascia is divided in the midline, as is the peritoneum, and the exposure proceeds directly posteriorly to the level of the sacral prominence.
- The abdominal contents are retracted to expose the great vessels overlaying the anterior lumbar spine.
- Key anatomic structures with relationship to the spine are shown in FIGURE 2.
- Vascular
  - The abdominal aorta and the bifurcation into the left and right common iliac arteries lies anterior to the venous system, and the left iliac artery is typically encountered first (L4–5). In most people, the bifurcation occurs at L4–5.
  - Preoperative scrutiny of MRI or CT scans can help identify the location of the bifurcation, which can be important in planning.
  - The left renal artery and vein (L2) restrict exposure proximal to L2.
  - The inferior vena cava (IVC) lies posterior and to the right of the aorta. Because of this deep, right-sided position, the IVC should not be mobilized to the left.
  - The L5–S1 disc occupies a position between the bifurcation of the aorta and the IVC in most patients, so mobilization of the large vessels is rarely required for access. The middle sacral artery and vein branch off the left common iliac and should be ligated or cauterized if small.
  - Exposures above L5–S1, however, require mobilization of the great vessels to the right. To do this, the iliolumbar vein, which branches off the left common iliac, must be identified and ligated (see Techniques section).
- Genitourinary
  - Left kidney: rarely visualized, surrounded by perinephric fat (L1–2)
  - Left ureter: easily retracted anteriorly with peritoneal contents and can be identified by stimulated peristalsis
- Muscular
  - Psoas (paraspinal, L1–L5)
- Neurologic
  - Sympathetic chain (paraspinal, anterior and medial to psoas)
  - Presacral plexus (directly over sacrum)
  - Lumbosacral plexus (postero-medial to and within psoas muscle)
  - Genitofemoral nerve (lies on anterior aspect of psoas)
- Lymphatic
  - Paraspinal lymphatics and lymph nodes
  - Lymphatic drainage will appear as a milky white fluid, which is rarely of clinical consequence.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Previous abdominal surgery (eg, hysterectomy, hernia repair) can create challenges during this exposure. The presence of midline abdominal mesh, cellulitis or abscess, and a colostomy are relative contraindications to the anterior approach.
- Previous exposure of the anterior lumbar spine, particularly if it involved mobilization of the great veins, makes revision approaches much more risky due to the greater likelihood of vascular injury.
- Obesity (body mass index above 40) is a relative contraindication to anterior exposure of the lumbar spine due to the depth of the operative field.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Plain radiographs are used to assess the degree of aortic calcification and lumbopelvic deformity.
- Preoperative axial MRI or CT allows for estimation of the level of the bifurcation of the aorta and IVC (FIG 3).
- Routine angiography, CT-angiography, or MR-angiography is not necessary unless there is a concern for aberrant anatomy (eg, history of situs inversus).
- Preoperative arteriograms, venograms, and prophylactic IVC filters should be considered before any revision approaches to the anterior lumbar spine. Preoperative ureteral stents can also help prevent ureteral injury during revision exposure.

SURGICAL MANAGEMENT
- Indications for the anterior lumbar approach are as follows:
  - Anterior discectomy for interbody fusion, total disc replacement, disc débridement in cases of discitis and vertebral osteomyelitis, radical discectomy for deformity correction
Anterior corpectomy for tumor resection, radical deformity correction, and vertebral body osteomyelitis

Preoperative Planning

When exposure of the L5–S1 disc is required, the direct anterior lumbar approach should be used in most cases, as the ilium blocks satisfactory access from a lateral approach.

The direct anterior approach is less morbid than the lateral approach to the lumbar spine because the latter involves greater division of the abdominal wall musculature. For these reasons, we prefer the direct anterior approach (versus the lateral approach) even in cases of multilevel disc exposures (eg, lumbar scoliosis correction) unless the L1–2 disc or L2 vertebra requires exposure, or if anterior instrumentation in the form of screw–rod constructs is needed. Anterior plates can be used from a direct anterior approach at L5–S1 and in some cases L4–5, depending on the vascular anatomy. However, greater mobilization of the great vessels at the level of the bifurcation is needed from a direct anterior versus lateral approach. Thus, a lateral approach may provide better...
exposure to the spine if the great vessels are anticipated to be difficult to mobilize.

Positioning
- The patient is positioned supine over an inflatable pillow (FIG 4A).
- The operating room table should allow for free passage of the fluoroscopic C-arm (FIG 4B).
- Care should be taken to ensure that the pelvis is level so that true anteroposterior and lateral fluoroscopic images can be easily obtained.
- The patient’s arms can be tucked at the side, placed into a “cross” position, or crossed over the chest but must not restrict appropriate fluoroscopic imaging (FIG 4C).

Approach
- Various skin incisions can be used.
  - The Pfannenstiel can be used for L5–S1 exposures but is less extensile if additional proximal exposure is necessary.
  - The direct midline and paramedian incisions are useful for multilevel exposures as they are easily extended proximally or distally (FIG 5A–D).
  - Palpation of the sacral promontory allows more accurate placement of the skin incision (FIG 5E). Alternatively, a lateral C-arm view can be taken to mark the location of the incision, keeping in mind that the trajectory needed to access the disc, especially at L5–S1, may require that the incision be placed where the path of this trajectory meets the skin rather than directly over the disc space itself.
  - Retroperitoneal versus transperitoneal
    - The transperitoneal approach carries a higher risk of retrograde ejaculation due to the theoretically greater likelihood of injury to the presacral sympathetic nerve fibers.
    - This approach is useful, however, in revision approaches to L5–S1 in which the retroperitoneal exposure was used at the index procedure.
    - Transperitoneal approaches likely increase the risk of adhesion formation and possible small bowel obstruction. In addition, small or large bowel perforation and postoperative ileus are relatively more likely when the peritoneum is entered. Finally, extra time and care are required to retract the small intestines; this generally requires more retractors and large sponges to prevent interference during the remainder of the procedure.
  - Right versus left retroperitoneal
    - With certain failures of lumbar disc replacement, revision exposures of the lumbar spine are necessary. To preserve the left retroperitoneal exposure for a potential revision exposure, some surgeons advocate performing a right-sided retroperitoneal incision at the index surgery.
    - Because optimal placement of a lumbar disc correlates with improved functional outcomes for the patient, we advocate performing the exposure that provides the ideal set of circumstances for accurate device placement at the outset.5
    - Because the right common iliac artery and vein lie more vertical, crossing the L5–S1 disc space, whereas the left common iliac artery and vein traverse the disc diagonally, access to L5–S1 is easier and provides a more expansive exposure when performed from the left retroperitoneal approach.
Chapter 4  ANTERIOR LUMBAR APPROACH

ANTERIOR EXPOSURE OF LUMBAR SPINE (LEFT PARAMEDIAN INCISION AND RETROPERITONEAL APPROACH)

Dissection
- Once the skin is incised, the subcutaneous fat is divided in line with the skin incision to the level of the anterior rectus sheath.
- The anterior rectus sheath is identified and stripped clean of all fat to assist in identification of the fascial edges at the time of wound closure (TECH FIG 1A).
- The anterior rectus sheath is incised in line with the skin incision—centered over the disc of interest—and then retracted laterally, exposing the underlying rectus abdominis muscle (TECH FIG 1B).
- The rectus abdominis is then retracted laterally, exposing the underlying transversalis fascia (TECH FIG 1C).
- With the rectus abdominis retracted, the transversalis fascia is followed laterally to its insertion on the abdominal wall. A sponge on a stick can be used to gently strip the transversalis fascia off this insertion (TECH FIG 1D).
- Handheld retractors are then used to sweep the peritoneum and left ureter to the midline and beyond, to the patient’s right.

Further Exposure
- If exposure of L4–5 is required, the arcuate line is identified and a small, 1-inch incision is created to allow more freedom in mobilization of the peritoneum (TECH FIG 2A,B).
- For exposure of the L4–5 disc or above, the lateral border of the left common iliac artery and vein are first identified using blunt dissection. These vessels are then retracted toward the midline to expose the iliolumbar veins coursing posteriorly (TECH FIG 2C).
- There is often more than one iliolumbar vein, and retracting the common iliac too forcefully can result in avulsion and significant bleeding that can be difficult to control, especially if the wound is deep or the distal end of the vein retracts behind the psoas after avulsion.
- At L5–S1, blunt dissection with a Kittner exposes the disc space and defines the vascular anatomy. Palpation of the sacral promontory helps guide the blunt dissection.
TECH FIG 1 • A. The anterior rectus sheath can be clearly visualized. A small Richardson retractor has been placed at the top of the incision and a cerebellar retractor has been placed inferiorly. The blue arrow marks the center of the planned vertical fascial incision. B. The vertical fibers of the rectus abdominis muscle are visualized as the anterior rectus sheath is held to the patient’s left with two Kocher clamps. C. The rectus abdominis muscle is retracted laterally with a Kittner, exposing the underlying transversalis fascia. D. A sponge on a stick is used to bluntly dissect the transversalis fascia off the undersurface of the rectus.

TECH FIG 2 • A. For exposures at L4–5, the posterior rectus sheath (arcuate line) is identified and the peritoneum is retracted away. B. Once the arcuate line is identified, it can be cut vertically; this enables the surgeon to safely retract the abdominal contents to the patient’s right. C. In this cadaveric dissection, the iliolumbar veins can be visualized branching off the left common iliac vein, coursing posteriorly and laterally. By retracting the vein toward the midline and the psoas muscle laterally, the vein takes on a more transverse orientation and is easier to ligate. One of the lumbar nerve roots can be seen directly lateral to the iliolumbar vein. Excessive retraction pressure can injure these nerve roots. The arterial system has been removed.
Retractor Placement

- While a vascular surgeon or assistant retracts the great vessels with handheld retractors, sharp, narrow Hohmann retractors are placed directly into the vertebrae.
- Alternatively, blunt radiolucent retractors can be used. These retractors can be held by hand, can be fixed with transfixion pins, or can be clipped to an external frame (Omni) or ring (Endo-ring) for the remainder of the procedure.
- The optimal configuration of retractors for L5–S1 and L4–5 exposures is depicted in TECHNIQUES FIGURE 3A,B.
- At L5–S1, placing a malleable retractor against the sacrum keeps the peritoneal contents and bladder out of the operative field and also provides a safety barrier to inadvertent movements of surgical instruments.
- For L5–S1 exposures, we prefer to use a sharp Hohmann retractor, which penetrates the bone on the (patient’s) left side of the inferior vertebral body of L5. This ensures that the left common iliac vein will not slip under the retractor. Since this retractor is embedded in bone, there is no retraction on the lumbar nerve plexus.
- For L4–5 exposures, since there are no vascular structures to retract on the (patient’s) left side, a handheld retractor can be used to gently retract the psoas muscle. With a handheld retractor, it is critical that the blade does not extend too deep along the lateral edge of the vertebra, where it can impinge on the lumbar plexus. Surgical assistants need to pay attention to the force and location of their retraction effort.
- At L5–S1, retractors are positioned to retract the right and left common iliac artery and veins lateral to the superior margin of the disc.
- Before incising the disc, lateral fluoroscopic imaging should confirm the operative level and ensure that the retractors have not pierced the endplate (TECH FIG 3C).

**TECH FIG 3**

- **A.** Optimal configuration of retractors for exposure of the L5–S1 disc.
- **B.** Optimal configuration of retractors for exposure of the L4–5 disc. Thin Hohmann retractors with sharp tips can be used to pierce the vertebral body and keep the great vessels out of the operative field. Handheld radiolucent blade retractors can also be used to retract the great vessels. Some retractors are cannulated, allowing them to be fixed with a transfixion pin into the vertebral body.
- **C.** The lateral fluoroscopic image confirms that the teeth of the Hohmann retractors are not in the disc space and that they are surrounding the disc of interest.
**POSTOPERATIVE CARE**

- The patient is given 24 hours of antibiotics for wound infection prophylaxis.
- A perioperative nasogastric tube is used to reduce the incidence of postoperative ileus.
- The patient is mobilized on postoperative day 1 with a lumbar corset.
- Incentive spirometry is used.
- Skin staples are removed on postoperative day 10 to 14.
- Stool softeners and laxatives are used as needed to avoid fecal impaction.

**OUTCOMES**

- The prevalence of major vein lacerations was 1.4% and the prevalence of left iliac artery thrombosis was 0.45% in a series of 1315 consecutive retroperitoneal exposures.²
- Ureteral and nerve injuries (lumbosacral nerve root or sympathetic) occur less frequently than major vascular injuries.⁴
- Mortality after anterior lumbar exposures is less than 1%.⁴
- Anterior approaches to the spine likely result in reduced patient satisfaction in terms of self-image and appearance.³
- The possibility of retrograde ejaculation should be discussed preoperatively with all male patients, as the prevalence ranges from 0.1% to 13.3%.¹⁶ To preclude the need to harvest sperm from the bladder in affected men, donation before surgery is a viable option.

**COMPLICATIONS**

- Retrograde ejaculation
- Ureteral injury
- Abdominal or umbilical hernia
- Wound infection and dehiscence
- Bowel injury
- Bladder injury
- Lumbosacral plexus injury
- Deep venous thrombosis and pulmonary embolism
- Major vessel injury and massive blood loss
- Reflex sympathetic dystrophy

**REFERENCES**

ANATOMY

Superficial landmarks allow for gross determination of anatomic level. Proximally, C7 and T1 are the largest spinous processes and act as landmarks for determining anatomic level. Distally, the intercrestal line approximates the L4–5 interspace.

There are three layers to the posterior musculature of the spine (FIG 1, Table 1):

- Superficial layer: trapezius, latissimus dorsi, rhomboid major and minor, and levator scapulae
- Intermediate layer: serratus posterior superior and inferior, and levatores costarum
- Deep layer: erector spinae, transversospinalis, interspinalis, and intertransversarii

The superficial and intermediate layers receive their nervous supply from peripheral nerves, which are not encountered through the posterior approach (FIG 2). The deep layer receives its nervous supply segmentally from the posterior dorsal rami. There is a large amount of redundancy in the innervation of the deep layer.

The midline approach is a true internervous plane, and nerve injury occurs only with excessive lateral dissection.

The vascular supply to the deep layer is from segmental branches of the aorta. These vessels enter the operative field at the level of the intertransverse ligament and can be a source of significant bleeding.

The facet joint capsules have a shiny white appearance, with the individual fibers can be seen inserting onto the lateral edge of the laminar trough. Care should be taken to avoid violating the capsular fibers unless that segment is being fused.

The ligamentum flavum has a yellow appearance, with the fibers running in a cephalad-caudad direction. The cephalad end of the ligament has a broad insertion from the base of the spinous process to between 50 and 70 percent of the anterior surface of the lamina. The caudad end of the ligament inserts from the superior edge of the lamina to between 2 and 6 mm of the anterior surface of the lamina.

Particularly at the L5–S1 level, the interspace may be widened or the posterior bony anatomy only partly formed. Care should be exercised when exposing this level as inadvertent plunging into the canal may occur.

Laterally, the intertransverse membrane overlies the iliopsoas and protects the neural structures that lie beneath.

In children, the spinous process apophysis has not fused. During dissection, the apophysis is split down to the bone and then elevated with the paraspinal musculature.

FIG 1 • The superficial, intermediate, and deep musculature of the back.
Table 1  Musculature of the Back

<table>
<thead>
<tr>
<th>Muscle Superficial layer</th>
<th>Origin</th>
<th>Insertion</th>
<th>Innervation</th>
<th>Blood Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapezius</td>
<td>Medial third of superior nuchal line of occiput, external occipital protuberance, and ligamentum nuchae; spinous processes of C7–T12</td>
<td>Lateral third of clavicle, acromion, spine of scapula</td>
<td>Motor supply from spinal accessory nerve, sensory fibers from C3 and C4</td>
<td>Transverse cervical artery</td>
</tr>
<tr>
<td>Latissimus dorsi</td>
<td>Spinous processes of T7—sacrum, medial third of iliocostalis, ribs 9–12, inferior angle of scapula</td>
<td>Floor of bicipital groove</td>
<td>Thoracodorsal nerve (C7, C8)</td>
<td>Thoracodorsal artery</td>
</tr>
<tr>
<td>Levator scapulae</td>
<td>Transverse processes of C1–C4</td>
<td>Medial border of scapula</td>
<td>Dorsal scapular nerve (C5), with branches of C3–C4 innervating upper part of muscle</td>
<td>Dorsal scapular artery</td>
</tr>
<tr>
<td>Rhomboid major</td>
<td>Spinous processes of T2–T5</td>
<td>Medial border of scapula</td>
<td>Dorsal scapular nerve (C5)</td>
<td>Dorsal scapular artery</td>
</tr>
<tr>
<td>Rhomboid minor</td>
<td>Caudal end of ligamentum nuchae, spinous processes of C7–T1</td>
<td>Medial border of scapula</td>
<td>Dorsal scapular nerve (C5)</td>
<td>Dorsal scapular artery</td>
</tr>
<tr>
<td>Intermediate layer</td>
<td>Serratus posterior superior</td>
<td>Spinous processes of C7–T3</td>
<td>Ribs 1–4</td>
<td>Intercostal nerves</td>
</tr>
<tr>
<td>Serratus posterior inferior</td>
<td>Thoracolumbar fascia, spinous processes of T11–L2</td>
<td>Ribs 9–12</td>
<td>Intercostal nerves</td>
<td>Posterior intercostal arteries, subcostal artery, and L1–L2 lumbar arteries</td>
</tr>
<tr>
<td>Levatores costarum</td>
<td>Tip of transverse process of C7–T11 vertebrae</td>
<td>Rib below level of origin</td>
<td>Posterior rami of thoracic spinal nerves</td>
<td>Dorsal intercostal arteries</td>
</tr>
<tr>
<td>Deep layer</td>
<td>Erector spine (vertically oriented and superficial)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iliocostalis</td>
<td>Iliac crest, sacrum, transverse and spinous processes of vertebrae and supraspinous ligament</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longissimus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spinalis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transversospinalis (obliquely oriented and intermediate)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Semispinalis</td>
<td>Transverse processes T1–T12</td>
<td>Spinal processes of C2–T5</td>
<td>Dorsal rami of spinal nerves</td>
<td>Segmental arteries from aorta</td>
</tr>
<tr>
<td>Multifidus</td>
<td>Articular processes of cervical vertebrae, transverse processes of thoracic vertebrae, mammillary processes of lumbar vertebrae, posterior superior iliac spine</td>
<td>Spinal processes of C2–L5</td>
<td>Dorsal rami of spinal nerves</td>
<td>Segmental branches from aorta</td>
</tr>
<tr>
<td>Rotatores</td>
<td>Transverse processes</td>
<td>Spinal processes of C2–L5</td>
<td>Dorsal rami of spinal nerves</td>
<td>Segmental supply by deep cervical arteries, posterior intercostals, subcostal artery, and lumbar arteries</td>
</tr>
<tr>
<td>Deepest muscle</td>
<td>Deep layer (vertically oriented and superficial)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interspinales</td>
<td>Spinal processes</td>
<td>Spinal processes one level above</td>
<td>Dorsal rami of spinal nerves</td>
<td>Segmental branches from aorta</td>
</tr>
<tr>
<td>Intertransversarii</td>
<td>Anterior and posterior transverse processes of cervical vertebrae, transverse and mammillary processes of lumbar vertebrae</td>
<td>Anterior and posterior processes of cervical vertebrae one level above, transverse and accessory processes of lumbar vertebrae one level above</td>
<td>Dorsal rami of spinal nerves</td>
<td>Segmental branches from aorta</td>
</tr>
</tbody>
</table>

SURGICAL MANAGEMENT

Positioning

- Patients should be placed in the prone position on a radiolucent table (FIG 3A).
- Care is taken to ensure that the neck is in a neutral position with no hyperextension.
- The arms are positioned at 90 degrees or less of abduction to minimize the likelihood of rotator cuff impingement. The arms are allowed to slightly hang down in a forward-flexed position about 10 degrees. The axilla should be clear from any padding to prevent brachial plexus palsy.
- Elbow pads are placed along the medial epicondyle to protect the ulnar nerve.
- Pads are placed at the chest and iliac crests.
- The chest pad is placed just proximal to the level of the xiphoid process and distal to the axilla. In women, care is taken to tuck the breasts and ensure that the nipples are pressure-free.
- The iliac pads are placed two fingerbreadths distal to the anterior superior iliac spine, allowing the abdomen to hang free and reducing any unnecessary epidural bleeding.
- Proper placement of the chest and iliac pads allows for restoration of normal sagittal alignment via gravity.
- Alternatively, for lumbar decompressive procedures alone, the knees are positioned in a sling, allowing the hips to flex and eliminating lumbar lordosis and widening the laminar interspaces (FIG 3B). This position improves access to the lumbar spinal canal but should be avoided when instrumenting as lumbar lordosis is decreased.

**Approach**
- Two approaches are used: midline and paraspinal.
- The midline approach is used for most spinal procedures as it allows direct access to the spinal canal.
- The paraspinal approach, also known as the Wiltse approach, was initially described for spondylolisthesis but is now being used during far-lateral discectomies and minimally invasive muscle-sparing techniques.
- There is increased interest in the paraspinal approach, particularly in conjunction with transforaminal lumbar interbody fusion procedures.
MIDLINE POSTERIOR APPROACH

Incision and Dissection

- Anatomic landmarks are identified to center the skin incision appropriately (TECH FIG 1A).
- A midline incision is made over the spinous processes down to the level of the fascia.
- A Cobb elevator is used to create 2-mm full-thickness skin flaps with subcutaneous fat. This allows for better visualization of the fascia during closure (TECH FIG 1B,C).
- The location of the spinous processes is again verified, and electrocautery is used to reflect the fascia from the tips of the spinous processes.
- Electrocautery is used to subperiosteally elevate the paraspinal musculature laterally to the trough of the lamina. The surgeon should avoid going beyond this point to protect the insertion of the facet joint capsule.

Cautery

- Two venous bleeders are encountered that require electrocautery (TECH FIG 2A).
  - The first is located adjacent to the pars interarticularis (TECH FIG 2B,C).
  - The second is located just lateral to the facet joint.
- Electrocautery is used to elevate the paraspinal musculature off the transverse processes. Care should be taken to stay on the transverse process and not to violate the intertransverse membrane.
- Bipolar cautery should be used at the intertransverse ligament to avoid damage to the spinal nerves.
Paraspinal Resection

- In large and muscular patients, often it is necessary to excise a portion of the paraspinal muscles overlying the transverse processes to be fused.

- The muscle is resected beginning underneath the fascia and extending toward the lateral edge of the transverse processes. This creates a pocket over the transverse processes that serves as a bone graft cavity (TECH FIG 3).

**TECH FIG 2** • A. Venous bleeding sites are adjacent to the pars interarticularis and at the junction of the facet and the transverse process. B,C. Probes (arrows) indicate the location of venous bleeders adjacent to the pars interarticularis (B) and the facet joint (C).

**TECH FIG 3** • A,B. Electrocautery is used to excavate a muscular pocket for the fusion mass. C,D. Complete posterior exposure.
**PARASPINAL APPROACH**

- The approach is typically performed two fingerbreadths lateral to the spinous process.
- After the fascia has been exposed, the paraspinal muscles are palpated and the interval between the multifidus medially and longissimus laterally is identified.
- A sharp incision through the fascia is made at this interval (TECH FIG 4).
- The interval is defined with blunt dissection down to the lateral edge of the facet joint and transverse process junction.

**TECH FIG 4** • Cross-section of spine showing Wiltse interval.

**PEARLS AND PITFALLS**

<table>
<thead>
<tr>
<th>Complication</th>
<th>Pearls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pars interarticularis bleeder</td>
<td>Lateral to the pars; can be prophylactically identified and cauterized</td>
</tr>
<tr>
<td>Lateral facet bleeder</td>
<td>A ball-tipped probe can be placed along the undersurface of the lateral edge of the superior articular process where the facet bleeder originates. Electrocautery can then be used to coagulate this vessel, which hinders intertransverse exposures.</td>
</tr>
<tr>
<td>Facet capsule preservation</td>
<td>A sponge can be placed over the facet. Muscle stripping is then performed with a Cobb elevator as the sponge protects the capsular fibers from being disrupted and accidentally incised.</td>
</tr>
<tr>
<td>Widened lower lumbar interspace</td>
<td>An anteroposterior radiograph should be evaluated preoperatively to assess for spina bifida occulta and widened interlaminar windows. Extra caution should be employed when working in these areas to avoid inadvertent injury to the thecal sac.</td>
</tr>
</tbody>
</table>

**COMPLICATIONS**

- Major and minor complication rates of up to 80% have been reported in some series (Table 2).²
- Risk factors for complications include patient age, length of surgery, levels exposed, blood loss, and postoperative urinary incontinence. Diabetes and other medical comorbidities have not been shown to be independent risk factors for the development of postoperative complications.¹–³

**REFERENCES**


**Table 2 Complications Associated with the Posterior Approach²,³**

<table>
<thead>
<tr>
<th>Complications</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major</td>
<td></td>
</tr>
<tr>
<td>Wound infection</td>
<td>1–10%</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>5%</td>
</tr>
<tr>
<td>Renal failure</td>
<td>5%</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>3%</td>
</tr>
<tr>
<td>Respiratory distress</td>
<td>2%</td>
</tr>
<tr>
<td>Neurologic deficit</td>
<td>2%</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>2%</td>
</tr>
<tr>
<td>Cerebrovascular accident</td>
<td>1%</td>
</tr>
<tr>
<td>Minor</td>
<td></td>
</tr>
<tr>
<td>Urinary tract infections</td>
<td>34%</td>
</tr>
<tr>
<td>Anemia requiring transfusion</td>
<td>27%</td>
</tr>
<tr>
<td>Confusion</td>
<td>27%</td>
</tr>
<tr>
<td>Ileus</td>
<td>22%</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>7%</td>
</tr>
<tr>
<td>Transient hypoxia</td>
<td>7%</td>
</tr>
<tr>
<td>Wound seroma</td>
<td>5%</td>
</tr>
<tr>
<td>Leg dysesthesia</td>
<td>2%</td>
</tr>
</tbody>
</table>
DEFINITION
- Cervical spondylosis refers to degenerative conditions affecting the cervical spine, including disc degeneration, herniation, facet arthrosis, and osteophytic spur formation. Depending on the nature and location of the spondylotic changes, pathologic compression of neural structures in the cervical spine may occur.
- This chapter focuses on anterior cervical discectomy and fusion (ACDF) as a surgical treatment option for patients with cervical radiculopathy. Cervical myelopathy can also be treated with ACDF as long as the spinal cord compression occurs at the disc, rather than the retrovertebral, level.
- All techniques described in this chapter can apply to the decompression of the spinal cord in myelopathic patients as well as the nerve root in radiculopathic patients. However, for the purposes of organization, cervical myelopathy is discussed in the chapter on anterior cervical corpectomy (see Chap. SP-7).

ANATOMY
- The anterior longitudinal ligament is a wide band of ligaments stretching along the anterior surface of the vertebral bodies. Its dense longitudinal fibers widen as they travel caudally and are intimately associated with the intervertebral discs as well as the vertebral endplates.
- The posterior longitudinal ligament (PLL) is a smooth and shiny group of dense ligaments that course along the posterior surface of the vertebral bodies within the spinal canal. The PLL tends to be thicker centrally and thins out laterally as it attaches to the uncinate regions. Bulging or ossification of the PLL (OPLL) can cause spinal cord compression.
- The intervertebral disc comprises the outer annulus fibrosus and the central gelatinous nucleus pulposus. Each disc is attached to the subchondral bone of the adjacent vertebral bodies. The outermost rim of the vertebral endplate is not attached to the disc, leaving a ring of exposed bone that may be more prone to forming arthrotic spurs.
- The uncovertebral joints are critical bony landmarks for anterior cervical decompression (FIG 1). Spurs commonly arise from these articulations and cause impingement of the exiting roots as they enter the foramen.
- Depending on the cervical level, the vertebral artery may be as close as 5 mm away from the medial aspect of the uncinate process.
- Each cervical spinal nerve is composed of dorsal and ventral roots. The ventral root lies dorsal to the uncovertebral joint, while the dorsal root is ventral to the superior articulating facet.
- It is important to keep in mind when performing uncovertebral osteophyte resection that the nerve root leaves the spinal cord at roughly a 45-degree angle ventrolaterally in the

FIG 1 • Anterior foraminotomy anatomy: important anatomic relationships to consider when performing anterior cervical spine surgery. The exiting nerve root enters the foramen at a 45-degree ventrolateral angle. The posterior aspect of the uncinate joint marks the entry zone of the neuroforamen, and it is where osteophytes commonly arise to impinge the exiting root. Thus, the uncus should be decompressed when performing foraminotomy. It is critical to hug the posterior aspect of the uncinate during foraminotomy to avoid injuring the exiting root, which lies immediately dorsal. The vertebral artery is unlikely to be injured while working in the posterior disc space (eg, during decompression) because it is located at roughly the level of the middle third of the vertebra. The trajectory of discectomy should be bounded by the uncines at all times, but it can widen posteriorly at the level of the nerve root to thoroughly decompress the root while avoiding vertebral artery injury (dashed blue line). The posterior longitudinal ligament (dashed yellow line) tends to be thicker and better defined centrally; it thins out laterally.
axial plane. Thus, care must be taken to hug the posterior surface of the uncinate to avoid injury to the exiting root.4

**PATHOGENESIS**
- Neural impingement occurs in two main locations: within the spinal canal, affecting the spinal cord, the nerve root, or both; or within the foramen, where the exiting root can be affected.
- Depending on whether the involved structure is the spinal cord or the nerve root, patients can present with symptoms of myelopathy, radiculopathy, or both.

**NATURAL HISTORY**
- The natural history of cervical radiculopathy is generally favorable, with most patients having spontaneous resolution or considerable improvement of their symptoms over time.
- It is not common for radiculopathic patients to progress to myelopathy.9,10

**HISTORY AND PHYSICAL FINDINGS**
- Patients with radiculopathy typically present with radiating pain, paresthesia, or motor weakness (Table 1). However, the pattern of symptoms is not always dermatomal (FIG 2).
- On examination, patients with radiculopathy may have motor, sensory, or reflex changes along the affected nerve root distribution. However, the neurologic examination findings may be normal.
- Patients may express exacerbation of radicular pain with particular head positions (ie, head positions that narrow the size of the neural foramen, such as neck extension with rotation to the affected extremity).
- This can be elicited by performing the Spurling test. The Spurling sign is very helpful in differentiating cervical radiculopathy from extraspinal causes, such as cubital or carpal tunnel syndromes, as reproduction of symptoms should occur only with a cervical source of compression.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**
- Plain radiographs, although of limited value in evaluating neural compression, remain a commonly acquired initial study and can be used to evaluate overall alignment, spinal instability, or bony pathology, including spur formation.
- MRI is the modality of choice for evaluating neural compression.
- CT-myelography provides outstanding resolution of bony and neural anatomy, but it is less appealing as it requires an invasive procedure. It is typically recommended for patients with contraindications for MRI (eg, prosthetic heart valve, pacemaker) or when MRI fails to provide sufficient detail.

If a high-quality MRI is available but questions remain regarding bony anatomy for the purposes of surgical planning, a noncontrast CT scan provides complementary information (eg, differentiating OPLL from disc herniation) (FIG 3).

**DIFFERENTIAL DIAGNOSIS**
- Cervical radiculopathy
- Cervical myelopathy
- Brachial plexus injury
- Complex regional pain syndrome or reflex sympathetic dystrophy
- Thoracic outlet syndrome
- Inflammatory arthropathy
- Spinal cord tumor
- Angina

![FIG 2 • Dermatomes of the cervical nerve roots. Symptoms do not always follow the textbook distribution of dermatomes. In particular, radiculopathies involving various nerve roots, such as C5, C6, or C7, can all produce periscapular pain, not uncommonly in the absence of radiating pain down the arm. If in doubt as to the offending level, a selective nerve root block can be performed for diagnostic purposes.](image-url)
Shoulder pathology
- Peripheral nerve compression (eg, carpal or cubital tunnel syndrome)
- Diabetic neuropathy
- Multiple sclerosis
- Syringomyelia
- Stroke
- Guillain-Barré syndrome
- Normal-pressure hydrocephalus
- Spinal cord tumor

NONOPERATIVE MANAGEMENT
- Nonoperative management should be considered as the initial mode of treatment for most patients with radiculopathy.
- Nonsurgical treatment typically includes physical therapy, traction, pain medication, cervical collars, and epidural injections.

SURGICAL MANAGEMENT
- Surgical intervention is indicated for radiculopathy in patients with persistent symptoms resistant to nonoperative care, progressive weakness, or instability.
- Common surgical approaches to radiculopathy include ACDF versus posterior laminoforaminotomy.¹¹

Preoperative Planning
- The surgeon should evaluate imaging studies for anatomic variations, such as medial aberrancy of the vertebral artery.
- To perform a safe but complete and adequate neural decompression, high-quality illumination and magnification are essential.
- An operating microscope provides illumination and visualization superior to that of loupes and headlights, but either method can be used.
- Another advantage to the microscope is that the view obtained by the assistant is the same as that of the operating surgeon.
- If the surgeon chooses to use the microscope, given the smaller field of view, it is imperative to continuously adjust the viewing angle such that a line of sight parallel to the disc space is achieved (FIG 4). If this is not done, the surgeon may inadvertently stray away from the disc space, veer into one vertebral body or the other, and not proceed to the back of the disc space, where the decompression needs to occur.

Positioning
- The patient is positioned with a bump under the scapula and the occiput on a foam doughnut to prevent pressure necrosis.
- The amount of extension tolerated preoperatively without excessive pain or neurologic symptoms is recreated.

Approach
- A standard Smith-Robinson approach to the anterior cervical spine is used for most cases from C2 to T2.

FIG 3 • MRI and CT scans may provide complementary information in delineating bony versus soft tissue masses. A. On the axial MRI, the compressive lesion appears to be a soft disc. B. A CT scan through the same level, however, demonstrates the pathology to be an ossified disc. Similarly, CT scans can help differentiate disc herniations from ossification of the posterior longitudinal ligament.

FIG 4 • Line of sight. When using the microscope, it must be angled properly to provide a parallel view of the disc space to facilitate decompression and endplate preparation. Endplate preparation should proceed in a parallel fashion (dotted red lines) (A) centered on the disc space to achieve a rectangular space for graft insertion. Parallel, wide preparation of the disc space also makes decompression easier to perform and ensures that the decompression is centered on the disc space (C). (B,C)
- If the line of sight is not maintained, one may err into the vertebral bodies above and below rather than progressing toward the area at the disc level that requires decompression. To achieve parallel surfaces, the inferior endplate of the cephalad vertebra typically requires greater preparation because it is concave. In contrast, the superior endplate of the caudal vertebra is flatter and requires less preparation. (C) Proper line of sight is facilitated by removing the anterior lip (arrow, shaded yellow), which allows for better visualization of, and access to, the posterior disc space.
Initial Discectomy

- Once the disc is exposed, it is sharply incised with a no. 15 blade and removed with a combination of curettes and pituitary rongeurs.
- The disc and cartilaginous material should be removed until the PLL and both uncinate processes are visualized (TECH FIG 1A).
- An important maneuver to facilitate disc space visualization and neural decompression is to remove the anterior portion of the inferior endplate of the superior vertebral body (the anterior lip). Doing so provides a direct line of sight into the posterior disc space, which facilitates later foraminotomy and resection of the PLL, if necessary.
- This surface is almost always concave, with the anterior portion overhanging the disc space, thus preventing direct visualization of the posterior disc space.
- Removal can be done with either a Kerrison rongeur or a high-speed burr.
- Flattening this surface also facilitates optimal graft–endplate contact (TECH FIG 1B,C).
- Use of the burr to fashion the endplates, alternating with use of the curettes and pituitary rongeur to remove cartilage and disc material, is performed.

Use of Distraction: Pins, Tongs, and Spreaders

- Intervertebral body distraction pins can be placed to gently distract the disc space and improve visualization.
- Generally, this is done after an initial superficial discectomy, which allows greater disc space mobilization with the pins.
- Because greater preparation of the inferior endplate of the superior vertebra is usually needed, the Caspar pin should be placed more cephalad in the cephalad vertebral body (TECH FIG 2).
- Overdistraction of the disc space is not desired. If the disc space is fused in an overdistacted position, postoperative neck pain may result. If there is a significant compressive lesion on the spinal cord, distraction should

**TECH FIG 1 • A.** The discectomy should begin lateral (red lines) to the medial border of the uncinate. The upslope of the uncinate is clearly defined with curettes and Kerrison rongeurs until these borders are unquestionably identified. Having a wide discectomy allows for placement of larger grafts or supplemental grafts in the uncinate regions. **B,C.** Anterior cervical discectomy and fusion graft carpentry. Creating parallel disc spaces facilitates graft–host bone contact, securing an intimate fit, as well as allowing for wide decompression of spurs arising from the posterior disc space. Spurs are removed off the inferior vertebral of C5 and C6 (arrows). More bone than usual was removed from the inferior portion of C6 because of the extensive spondylotic bar causing spinal cord compression along the floor of the canal in this patient.

**TECH FIG 2 •** Caspar pin placement. Because greater preparation of the inferior endplate on the cephalad vertebra is necessary, the surgeon should place the upper Caspar pin (C5) further away from the endplate (eg, in the midbody of C5 or more cephalad), while being cognizant of not entering the adjacent disc space above. The Caspar pins are placed in the midline to avoid compromising later screw fixation during plating. To achieve parallel distraction, the pins should be placed parallel to the disc space. If the tips (ie, the leading ends) converge, relative kyphosis of the disc space occurs with placement of the Caspar pin spreader and distraction; if the tips diverge, relative segmental lordosis occurs with placement of the Caspar pin spreader and distraction.
be avoided until the compression has been relieved to prevent stretching or tenting of the cord over that lesion.

- An additional benefit of the Caspar pins is that they help to retract the soft tissues in a cephalad-caudal direction without the use of a secondary set of retractor blades.
- Alternatively, a small laminar spreader can be used in the contralateral disc space instead of Caspar pins to provide distraction.

**Endplate Preparation**

- The inferior endplate of the cephalad level is concave, whereas the superior endplate of the inferior level tends to be relatively flatter. Thus, to achieve intimate contact of bone graft with both endplates, a rectangular space is created by parallel decortication of the endplates.
  - This generally requires greater preparation of the inferior endplate of the cephalad level versus the superior endplate of the inferior level.
- It is important not to remove too much bone off the inferior endplate of the cephalad level, however, as doing so limits the bone available in the vertebra to accommodate a plate and screws. This is particularly the case in smaller patients who have smaller vertebrae.
- A high-speed burr is helpful in decorticating the endplates.
- The creation of a parallel rectangular space within the disc space allows insertion of a graft appropriately sized to match the larger height present at the center of the disc space.
- Both endplates should be thoroughly denuded of cartilage and decorticated to reveal bleeding bony surfaces to enhance the chance of successful fusion.\(^5\)
- Alternating use of the high-speed burr, curettes, and the pituitary rongeur will allow the surgeon to reach the posterior disc space and the PLL.
- During ACDF, we are more aggressive with endplate preparation than during corpectomy, because ACDF grafts tend to be more stable than corpectomy grafts.
  - If major endplate resection is performed during corpectomy, significant settling or pistoning of the graft may occur (see Chap. SP-7), which is less likely with ACDFs. Furthermore, in cases of extensive spondylosis, wide disc space preparation facilitates decompression along the floor of the canal in ACDF surgery.
  - When performing corpectomy, on the other hand, the additional room is not usually necessary because removing the vertebral body creates wide access for work at the disc level.

**Anterior Foraminotomy**

- The discectomy is performed to the level of the PLL, with complete removal of the posterior annulus. It is safer to leave the PLL intact during the initial foraminotomy or resection of posterior osteophytes when the burr is being used, because it acts as a protective layer to the neural elements. Once the bony removal is complete, the PLL can then be resected.\(^2\)
- The medial half of the posterior uncinate is thinned under direct visualization with a high-speed burr to unroof the entry zone of the foramen (TECH FIG 3).
  - The microscope is angled appropriately to visualize the uncinate.

**TECH FIG 3** • Anterior foraminotomy. **A.** The burr is used to thin down bone in the lateral aspect of the canal (arrow) until only a thin shell is left. The posterior longitudinal ligament (PLL) is left intact as a protective layer to the neural elements until burring is completed. **B.** A curette is used to outline the bony edges and ensure that they are thin enough for passage of a curette or Kerrison rongeur. The PLL does not necessarily need to be resected during foraminotomy if the pathology is due solely to uncinate bone spurs, although we routinely do so and do not consider the decompression complete until the lateral edge of the dura and the exiting root are clearly visualized and palpated to be free of compression. **C.** A 2-mm Kerrison is then used to remove bone spurs. It is critical to hug the posterior margin of the uncinate during this move to avoid injuring the root underneath, which exits the canal ventrolaterally at about a 45-degree angle.

- In general, it is easier to decompress the contralateral rather than the ipsilateral foramen, although decompression of both is certainly possible. Thus, in cases of unilateral radiculopathy, we prefer to approach the spine from the side opposite to the patient’s symptoms.
- It is important not to force a large instrument into a severely narrowed foramen if it does not fit easily. Instead, the surgeon should use the burr to thin the uncus until the instrument can easily be passed into the foramen.
- Constant irrigation is performed to prevent thermal injury and to clear away bone debris.
- If visualization is adequate, continued thinning of the osteophyte can progress until only a thin shell of bone is left.
- A microcurette or 2-mm Kerrison is then used to resect the thinned osteophytes.
Alternating between microcurettes or a Kerrison and the burr, the foramen can be gently and progressively carved out laterally.

- The nerve root exits the spinal canal at roughly a 45-degree angle, ventrolaterally. Thus, it is imperative to avoid blindly placing a burr, curette, or Kerrison deep to the uncinate to avoid root injury. Instead, one should closely hug the uncinate while entering and decompressing the foramen (see Fig 1).

- Foraminotomy is complete when a micro nerve hook or curette can easily be passed into the foramen anterior to the exiting root without resistance.

When and How to Resect the PLL

- With soft disc herniations, a defect in the PLL is often present through which the nuclear material extrudes (TECH FIG 4A,B).
- By delicately probing with a microcurette, the extruded fragment can be fished out from behind the PLL.
- If necessary, the defect in the PLL should be enlarged with a 2-mm Kerrison until a satisfactory portal is available to remove the herniation and ensure that all loose disc fragments have been removed.
- It is debatable whether the PLL needs to be resected in every case. In general, we prefer to do so, especially in cases of disc extrusion, and do not consider the decompression complete until the dural sac or exiting nerve root (depending on which is compressed based on preoperative imaging) is inspected for the absence of any further compression.

- If, however, the compressive lesion is an uncinate spur, with no evidence of subligamentous disc extrusion, satisfactory decompression can be achieved by removing the spurs without necessarily removing the PLL.

- If there is no rent in the PLL, one can be created by teasing a microcurette between the longitudinal fibers of the PLL until the curette is posterior to the PLL (TECH FIG 4C,D).

- Once the plane is identified between the PLL and dura, the fibers of the PLL can be resected with a curette or Kerrison rongeur.
- Placing tension on the PLL with gentle distraction will facilitate its removal.

**TECH FIG 4 A,B.** Removing herniated nucleus pulposus. A. With extruded herniations, a rent in the longitudinal fibers of the posterior longitudinal ligament (PLL) may be identified. A curette is then used to delineate the edges of the rent in the PLL. Once this is defined and the surgeon is certain of a plane between the PLL and underlying dura, a Kerrison is used to enlarge the edges of the rent. B. The rent has been enlarged to provide more room for finding the herniation. Curettes are then used to fish out the fragments and decompress the cord or root. C,D. Removing the PLL. C. If the PLL is intact, it can be removed by teasing in between the longitudinal fibers with a microcurette. Once a plane is established, a Kerrison can be used to remove the PLL. D. It is often easier to find this plane in the central portion of the PLL, where it is thicker, than laterally, where it is thinner and less defined.
We generally find it easier to define a plane in the PLL centrally, where it tends to be thicker, than laterally, where it is thinner and the plane with the dura is less distinct. Often, there are multiple layers of PLL, and usually in chronic cases there is a membranous layer between the PLL and the dural sac that can be confused with dura itself. In general, if it does not look like dura, it probably is not.

The portion of the PLL contralateral to the disc herniation or symptomatic foraminal stenosis does not routinely need to be removed.

**Avoiding Vertebral Artery and Neural Injury**

Before surgery, the surgeon should always scrutinize the position of the vertebral arteries on the preoperative scans to rule out the presence of aberrancies in their course (Tech Fig 5A,B,C).

Aberrations typically occur within the vertebral body. However, it is not uncommon for one vertebral artery to be closer to the uncinate on one side versus the other, which would mandate greater caution when approaching that side.

In the absence of vertebral artery aberrancy, laceration to the vertebral artery is most likely to occur from the surgeon’s loss of orientation to the uncinates. The uncinates define the safe zone for the vertebral artery and the effective zone for the decompression.

It is imperative to define and maintain orientation with both uncinates at all times during anterior cervical surgery.

The vertebral artery is typically in the anterior two thirds of the disc space. When curetting disc material in this area, a vertebral artery laceration might occur if the curette strays lateral to the lateral border of the uncinate.

If in doubt, a Penfield dissector can be used to identify the lateral border of the uncinate processes to avoid straying laterally and injuring the vertebral arteries, which are generally a few millimeters from the lateral edge of the uncinate (Tech Fig 5C).

**Graft Sizing and Placement**

Ultimate graft height can be estimated preoperatively from the preoperative lateral film. In many cases, a graft height of 2 to 3 mm more than that measured on the preoperative lateral film will be the optimal choice.

Ideally, the anteroposterior depth of the graft should be a few millimeters less than that of the disc space, such that the graft can be countersunk 2 mm without entering the spinal canal.

The final height of the graft can be determined after endplate preparation with sizers that accompany commercial grafts (Tech Fig 6).

The trials should be lightly malleted into position under gentle Caspar pin distraction.

A snug fit in the distracted position will ensure an excellent fit after removal of distraction pins.

If the trial does not fit but the next smaller trial seems too loose, the surgeon should identify the area of impingement and lightly decorticate that area. Then, the trial is reinserted.

**TECH FIG 5 A,B.** Vertebral artery anomalies. A. The right transverse foramen (arrow) courses somewhat more medially than the one on the left. This is a subtle but potentially important anomaly to observe preoperatively. B. The anomaly occurs within the vertebral body rather than at the disc space level, where the right transverse foramen is now more normally positioned (arrow). C. Penfield lateral to the uncinate. In certain cases, especially if there is a deformity, the location of the lateral border of the uncinate (ie, the safe zone for the vertebral artery) may not be obvious after elevation of the longus colli. Placing a Penfield 4 dissector gently underneath the longus colli, retracting it laterally, and then hooking the dissector lateral to the uncinate will allow for safe orientation to the vertebral artery.

**TECH FIG 6.** Commercially available sizers are used to determine optimal graft size. A trial that fits snugly under gentle Caspar distraction will suffice. If autograft is used, the appropriate trial is used as a template for cutting the autograft bone. The surgeon should try to place a graft that fills the space as much as possible without overdistracting, which can cause posterior neck pain, or entering the spinal canal.
For multilevel ACDF, we prefer to decompress and graft each segment before proceeding to the next level. One way to enhance fusion rates is to place as much bone into the interspace as possible. A wide decompression also provides greater room for bone graft. Space lateral to the structural bone graft in the uncinate regions can be packed with bone or bone graft substitutes. If the space is wide enough, two grafts can be placed side by side to fill the entire space. We generally prefer to use commercially prepared cortical allografts for ACDF, except in patients with poor healing potential. Alternatively, autograft iliac crest bone can be used.

Determining Plate Length
- Plating is optional for one-level ACDF with autograft. If allograft or multilevel surgery is performed, plating is recommended.
- Once the graft has been placed, the size of the plate is then determined.
- Optimal plate length is one that allows for the screws to be immediately adjacent to the endplates (TECH FIG 7).
- This plate length allows for screws that angle away from the disc space, which in turn allows for screws that are longer than ones directed parallel to the disc space, yet are short enough to avoid entry into the supra- and infra-adjacent disc spaces.
- This length also prevents impingement of the plate into the adjacent disc spaces.

Plating Techniques
- The plate should be contoured into lordosis to lie flush against the vertebral bodies.
- It should also be centered coronally within the margins of the uncinate processes.
- Screws should also be angled medially to decrease the chance of lateral injury to nerve roots or vertebral arteries.
- The screw length can be estimated preoperatively by measuring the depth of the vertebral body on CT or MRI scans. The majority of levels will accommodate 14- to 16-mm screws.
- Dynamic plates can be used if desired (TECH FIG 8). They have the theoretical benefit of improving load sharing on the graft. There are several types of dynamic plates.
  - Variable screw systems allow for toggling within a fixed screw hole with settling of the construct. A potential downside is that the screw can loosen within bone as toggling occurs.
  - Slotted plates have holes that allow screws to translate longitudinally as the construct shortens. The screws are rigidly fixed to bone and do not toggle, but excessive translation may lead to adjacent-level plate impingement.
  - Telescoping plates use fixed screws in nonslotted holes, but the ends of the plate telescope with respect to each other as settling occurs. Postoperative adjacent-level plate impingement will not occur with this design if the plate is properly positioned at the time of surgery, as the distance from the end of the

**TECH FIG 7** • Proper plate sizing. A. The length of an optimally sized plate is such that the screw holes at the top and bottom of the construct are immediately adjacent to their respective endplates. In this example, even though this was done, the plate is still closer to the cephalad adjacent disc space than ideal because the vertebral bodies in this patient are relatively short. Nevertheless, adjacent-level disc degeneration did not occur in this patient at 2-year follow-up. Bicortical screw purchase is not routinely needed, but estimates of screw length can be obtained by measuring MRI or CT scans preoperatively. Screws should be angled away from the disc space to provide greater length and divergent fixation, which may better resist pullout. B. This patient also has short vertebrae. However, this plate was placed too close to the adjacent disc, resulting in adjacent-level ossification disease (arrow). The cephalad screws are not immediately adjacent to the endplate but rather inserted at roughly the midpoint of the vertebral body. Similarly, the caudal screws begin in the midportion of the vertebral body. The plate is too long distally and comes close to the subjacent disc as well. As demonstrated by these examples, proper plate sizing is especially important in patients with shorter vertebrae, where the adjacent discs are closer together.
plate to the endplate does not change with construct shortening. However, these plates tend to be somewhat thicker.

- If dynamic plates are used, the surgeon must perform the plating procedure to accommodate the anticipated settling without overlapping uninvolved adjacent discs.\(^8\)

**ANTERIOR CERVICAL DISCECTOMY AND FUSION WITHOUT INSTRUMENTATION**

- **ACDFs** were traditionally performed without plating.
- Although plates may better preserve lordosis and achieve higher fusion rates in multilevel cases, avoiding plates may decrease operative time, decrease the amount of retraction on the soft tissue structures of the neck during surgery, and avoid plate-related complications such as screw backout or esophageal erosion.
- However, if one chooses not to use a plate, autograft should be used rather than allograft, and rigid postoperative immobilization in a cervical orthosis is mandatory.
- Up to three adjacent interbody cervical fusions can be safely performed without instrumentation.
  - The interspaces should be fused sequentially, meaning a decompression and fusion is completed at one interspace before the next is addressed.

**Measuring the Space**

- After appropriate decompression, the depth and height of the interspace are measured without distraction (TECH FIG 9A,B).
- A laminar spreader is then inserted to distract the interspace, and the height is again measured (TECH FIG 9C,D).
- Without distraction, the height is generally 6 mm; with distraction, it can be up to 12 mm.
- This distraction is important in shaping the tricortical graft. The height of the graft should be greater than the resting height but less than the distracting height so that the inherent compression of the vertebral bodies will hold the graft firmly in place.

**Inserting the Graft**

- After the appropriate size of cortical graft is obtained, it is inserted with the laminar spreader distracted (TECH FIG 10A,B).
- The graft should have at least a 2-mm offset anteriorly, and the posterior edge of the graft should be 4 mm anterior to the dura and PLL.
- After the distraction is released (Tech Fig 10C,D), the graft should be tested for stability by trying to dislodge it using a smooth right-angle probe.
- Postoperatively, if the graft is stable, a simple soft collar should be used for 4 to 6 weeks.
TECH FIG 9 • Measuring the interspace without (A,B) and with (C,D) distraction.

TECH FIG 10 • The cortical graft in place with (A,B) and without (C,D) distraction. Without distraction, the graft is compressed by the natural elasticity of the cervical spine. There is about 2 to 6 mm of free space between the posterior surface of the graft and the spinal cord.
The surgeon should create a rectangular space with parallel endplates. This will generally require removing the anterior portion of the inferior endplate to allow for better visualization of the posterior disc space, particularly in narrow spondylotic discs, and facilitates subsequent decompression.

**Foraminotomy**
- The uncinate is the guide to the foramen. The surgeon should maintain orientation to it at all times. When entering the foramen to remove bone spurs, the curette or Kerrison should hug the posterior aspect of the uncinate to avoid the nerve root, which exits ventrally at a 45-degree angle. The uncinate should be thinned first with a burr so that a small instrument can be inserted into the foramen to complete the foraminotomy without injuring the underlying root.

**Plate fixation**
- The surgeon should choose the shortest plate that will fit, such that the screw holes are immediately adjacent to the endplates, to avoid adjacent-level plate or screw impingement.

**Multiple fusions in ACDF without instrumentation**
- In cases of multiple fusions, each decompression and fusion must be completed before the next interspace is addressed. If all the interspaces to be fused are decompressed before the first graft is inserted, it will lead to unbalanced grafts, with one bone plug being significantly wider than the others because of the inherent elasticity of the vertebral bodies.

**POSTOPERATIVE CARE**
- The utility of bracing after plated ACDF is debatable.
- We typically place the patient in a cervical collar for 6 weeks.
- A deep drain is placed in the retropharyngeal space to prevent hematoma formation. It is typically removed the morning after surgery unless its output is greater than 30 cc in the last 8 hours.
- The postoperative diet may be rapidly advanced as tolerated. Cold beverages and ice cream may help with dysphagia and reduce swelling in the immediate perioperative period.

**OUTCOMES**
- Over 90% of patients experience excellent relief of radicular symptoms with ACDF.
- Midline axial neck pain may improve if it is associated with radicular pain, but patients should be counseled that the primary goal of treatment is neural decompression and relief of radicular or myelopathic symptoms.
- Similarly, unilateral neck pain can be a manifestation of radiculopathy and also generally improves.
- However, isolated axial neck pain without radicular complaints does not predictably improve with surgery, and we recommend nonoperative treatment in such patients.

**COMPLICATIONS**
- Complications potentially associated with ACDF include dysphagia, dysphonia, pseudarthrosis, implant failure, neurologic injury, esophageal injury, airway compromise from swelling or hematoma, and vertebral artery injury.
- Some degree of dysphagia is almost universal immediately after surgery. The majority of patients with dysphagia have only mild symptoms, with clinical improvement within 3 weeks. Long-term significant dysphagia is not common (about 4%).
- The superior laryngeal nerve innervates the cricothyroid muscle, which adjusts the tension on the vocal folds and also provides supraglottic sensation. Superior laryngeal nerve palsies therefore may lead to difficulty with singing high notes as well as aspiration.
- The recurrent laryngeal nerve innervates the muscles responsible for abducting the vocal folds. Recurrent laryngeal nerve palsy most commonly presents as hoarseness. Bilateral injuries can lead to airway obstruction and require tracheostomy.
- Even with modern surgical techniques, nonunions still occur. However, many cervical nonunions are asymptomatic and do not require further treatment. Symptomatic nonunions can be addressed with revision ACDF or posterior laminoforaminotomy and fusion.
- It is often argued that fusion accelerates adjacent-segment degeneration. Although biomechanical studies show increased disc pressures and mobility at discs adjacent to fusions, clinical series have not confirmed that adjacent-segment degeneration is truly accelerated by fusion versus simply being a manifestation of the patient’s propensity toward spondylosis. In fact, the available evidence suggests that about 3% of patients will have symptomatic adjacent-segment disease regardless of whether the index operation was ACDF, ACD without fusion, or posterior foraminotomy without fusion.

**REFERENCES**
Cervical myelopathy describes a constellation of signs and symptoms resulting from cervical spinal cord compression. Common symptoms include gait instability, clumsiness and loss of manual dexterity, and glovelike (rather than dermatomal) numbness of the hands. Because the presentation of myelopathy can be subtle, especially in its early manifestation, the diagnosis can be missed or wrongly attributed to “aging.” Surgical decompression is the mainstay of treatment and can be accomplished anteriorly (ie, corpectomy, discectomy and fusion, or both) or posteriorly (ie, laminectomy and fusion or laminoplasty).

Anterior corpectomy and fusion will be discussed in this chapter. Corpectomy is performed when retrovertebral compression of the spinal cord exists. If the compression is purely disc-based, corpectomy is not necessary, and an anterior cervical disectomy and fusion approach can be used instead.

**PATHOGENESIS**

- Spondylotic changes (eg, bone spurs, disc degeneration with annular bulging, disc herniations) are the most common causes of cervical cord compression.
- Ossification of the posterior longitudinal ligament (OPLL) is another not uncommon cause of cord compression. It may arise in discrete locations or be continuous (**FIG 1A,B**).
- Kyphosis, whether primary or occurring after laminectomy, can also cause cord compression and myelopathy.
- Cervical myelopathy often arises in the setting of a congenitally narrowed cervical canal (**FIG 1C,D**). In these patients, the cord may have escaped compression during relative youth but not after the accumulation of a threshold amount of space-occupying spondylotic changes.
- Although cervical spondylotic myelopathy tends to be a disorder seen in patients 50 years of age or older, depending on the degree of congenital stenosis and the magnitude of the accumulated spondylotic changes, it can be seen in patients who are much younger.

**NATURAL HISTORY**

- Patients with cervical myelopathy are generally thought to have a poor prognosis without surgical treatment, with a gradual stepwise progression of symptoms.\(^1\)

**HISTORY AND PHYSICAL FINDINGS**

- Patients with cervical myelopathy present with a spectrum of upper and lower extremity complaints.
- Upper extremity complaints include a generalized feeling of clumsiness of the arms and hands, “dropping things,” inability to manipulate fine objects such as coins or buttons, trouble with handwriting, and diffuse (nondermatomal) numbness.
- Lower extremity complaints include gait instability, a sense of imbalance when walking, and “bumping into walls” when walking. Family members may comment that the patient walks as if he or she is intoxicated.
- Patients with severe spinal cord compression may also complain of Lhermitte symptoms: electric shock-like sensations that radiate down the spine or into the extremities with certain offending positions of the neck (can occur with either flexion or extension).
- Many myelopathic patients deny any loss of motor strength. Similarly, bowel and bladder symptoms, if present, may arise in the later stages of disease. Despite advanced degrees of spondylotic, many myelopathic patients may have no neck pain.
- Symptomatic nerve root compression can coexist in patients with myelopathy and presents as a myeloradiculopathy.

**Physical examination should include:**

- Scapulohumeral reflex testing, which is positive with hyperactive elevation of the scapula or abduction of humerus
- Jaw jerk reflex, which is positive with hyperactive jerking of the jaw. Because cervical cord compression alone will not cause this reflex to be positive, its presence suggests that the origin of upper motor neuron findings in a given patient may arise from the brain rather than the spinal cord.
- Test for spasticity of the great toe, which is positive if the great toe extends while the remaining toes fan apart.
- Test for the Hoffman sign, which is positive with flexion of the index finger and thumb.
- Jaw jerk reflex, which is positive with hyperactive elevation of the jaw. Because cervical cord compression alone will not cause this reflex to be positive, its presence suggests that the origin of upper motor neuron findings in a given patient may arise from the brain rather than the spinal cord.
- Test for the Babinski sign, which is positive if the great toe extends while the remaining toes fan apart.
- Test for the Hoffman sign, which is positive with flexion of the index finger and thumb.
- Jaw jerk reflex, which is positive with hyperactive jerking of the jaw. Because cervical cord compression alone will not cause this reflex to be positive, its presence suggests that the origin of upper motor neuron findings in a given patient may arise from the brain rather than the spinal cord.
- Test for finger escape sign, which is positive if the little finger (also possibly the ring finger) cannot be held in this position without falling into abduction and flexion for more than 30 seconds. This is suggestive of cervical myelopathy.
- Tandem gait test, which is positive if the patient demonstrates significant instability. A positive result confirms gait imbalance, but in no way specifies the source of the imbalance as being the cervical spinal cord.

**IMAGING AND OTHER DIAGNOSTIC STUDIES**

- A lateral radiographic view can be helpful in showing the amount of congenital cervical stenosis as well as sagittal alignment.
- Lateral views are consistent with congenital stenosis when the ratio of the diameter of the canal to the diameter of the vertebral body is less than 0.8.
- Particularly if OPLL is suspected, CT scans (with or without myelograms, depending on whether a high-quality MRI is available) are helpful in delineating bony versus soft tissue pathology.
DIFFERENTIAL DIAGNOSIS

- Of cervical myelopathy:
  - Amyotrophic lateral sclerosis
  - Myopathies
  - Peripheral neuropathy
  - Syringomyelia
  - Multiple sclerosis
  - Diabetic neuropathy
  - Brachial plexopathy

NONOPERATIVE MANAGEMENT

- Surgery is the treatment of choice for symptomatic cervical myelopathy.
- Nonoperative treatment of cervical myelopathy is reserved for patients who cannot tolerate surgery.
- Controversy exists regarding the management of patients with asymptomatic spinal cord compression. In those with severe asymptomatic compression, consideration should be given to prophylactic surgery, particularly if cord signal changes are present, to prevent spinal cord injury with trauma (e.g., central cord syndrome) (FIG 2).

FIG 1 A, B. Ossification of the posterior longitudinal ligament (OPLL). A. Continuous OPLL causing severe spinal canal stenosis from C1 to C4. B. Axial CT scan in a different patient demonstrating a central stalk of OPLL. C, D. Congenital canal. Congenital stenosis is defined as a ratio of the canal to the vertebral body of 0.8 or less, and it can be measured on lateral radiographs (C) or advanced imaging such as CT-myelography (D) (different patients). The CT-myelogram shows superimposed spondylotic changes that further narrow the canal dimensions and cause cord compression.

FIG 2. Sagittal T2-weighted MRI demonstrating spinal cord signal changes.
SURGICAL MANAGEMENT

■ The most common surgical options include anterior decompression and fusion (discectomy versus corpectomy, depending on the absence or presence of retrovertebral cord compression, respectively), laminoplasty, and laminectomy with fusion.

■ In general, anterior surgery is preferred when cord compression arises from three or fewer disc segments, as the incidence of fusion and graft complications increases exponentially with greater number of segments fused. The presence of kyphosis or significant spondyloitic neck pain also favors an anterior approach.

■ Conversely, posterior approaches such as laminoplasty are favored when myelopathy arises from three or more motion segments and the cervical alignment is neutral or lordotic, particularly if the patient has minimal to no neck pain.

■ For posterior surgery to adequately decompress the cord, however, enough lordosis must be present to allow cord driftback after removal of the posterior tethers (lamina, flavum).

■ Combined anterior and posterior surgery should be considered in cases of severe or postlaminectomy kyphosis.

■ Multilevel corpectomy as a stand-alone operation is not recommended in patients with significant postlaminectomy kyphosis, as this creates a highly unstable construct that is prone to failure.

Preoperative Planning

■ Preoperative CT and MRI scans should be scrutinized to analyze the course of the vertebral arteries and the width of the spinal canal requiring decompression.

■ CT scans may provide additional information to MRI scans when it is unclear whether the compressive lesions are bony (OPLL, osteophytes) or soft disc material.

Positioning

■ For anterior cervical corpectomy and fusion, patients are positioned as described in Chapter SP-1.

■ However, greater caution is necessary in positioning the myelopathic versus radiculopathic patient. In particular, one must ensure that the patient is not excessively extended beyond the tolerance of the compressed cord. The amount of extension tolerated preoperatively should be assessed and not exceeded intraoperatively.

■ Gardner-Wells tongs may be used for multilevel corpectomy but are not generally needed for one-level corpectomy.

■ Weight, typically 30 to 40 lb, can be added to the tongs after decompression to allow for distraction during graft insertion. Significant distraction on the spine should be avoided until after the cord has been decompressed.

Approach

■ The approach is similar to that for anterior cervical discectomy and fusion but generally needs to be more extensile to access multiple levels. (Please see Chap. SP-1 for further details.)

■ The surgeon should ensure that wide exposure beyond the medial border of the uncinates is achieved, with appropriate elevation of the longus colli muscles bilaterally, to achieve a stable base for the self-retaining retractors as well as to provide orientation to the uncinates, which remain the critical landmarks for either corpectomy or discectomy surgery.

EVALUATING THE LIMITS FOR THE CORPECTOMY

■ The corpectomy is performed after the initial discectomies above and below the vertebra to be resected. The discectomies are performed from uncinate to uncinate as detailed in Chapter SP-1.1.

■ The width of the corpectomy required to decompress the cord should be based on preoperative imaging studies (TECH FIG 1).
The edges of the corpectomy are longitudinally delineated with a high-speed burr from uncinate to uncinate to define the safe limits of the decompression. Next, a Leksell rongeur can be used to quickly remove large fragments of vertebral body bone (TECH FIG 2). This bone should be saved for grafting. Once the cancellous bone is removed grossly, fine decompression then proceeds with a high-speed burr. Under direct visualization, a high-speed burr is used to remove bone until a thin shell of posterior cortex remains. Microcurettes and Kerrisons are then used to flake off the remaining bone. Attention should be paid to maintaining the width of the corpectomy as it proceeds posteriorly toward the canal, as the tendency is to cone the decompression narrowly as one proceeds posteriorly. Vertebral body bleeding often hinders visualization during bone removal. The surgeon should take time to achieve hemostasis using bone wax (gently applied when the remaining vertebra is still thick) or powdered Gelfoam–thrombin (when the remnant vertebral body is very thin). Significant dorsal pressure should be avoided during these maneuvers to avoid inadvertently plunging into the spinal canal. Epidural bleeding is best controlled with bipolar cautery as well as Gelfoam–thrombin.

**CERVICAL CORPECTOMY**

- Generally, sufficient decompression will occur if the width of the decompression spans from uncinate to uncinate.
- Wider decompressions beyond the medial border to the uncinates are typically performed at the disc level, where a combination of cord and root compression may occur, but are not necessary at the vertebral body level, where only the spinal cord is compressed.
- Staying within the uncinates will allow for thorough decompression while avoiding vertebral artery injury, unless a vertebral artery anomaly exists. Such anomalies are more likely to occur within the vertebral body rather than the disc spaces, and they should be recognized on preoperative imaging to avoid injury.

**TECH FIG 2** • Steps in bone removal. A. Leksell rongeur is used to remove large pieces of vertebral body bone after delineating the lateral edges of the corpectomy longitudinally along the medial border of the uncinates with a high-speed burr. B. After removing the bulk of the vertebra, a burr is used to sequentially remove bone in layers until only a thin remnant of bone remains. C. Finally, curettes and Kerrison rongeurs are used to remove the remaining bone. Adequate thinning of all bone to be removed allows the passage of smaller instruments that do not exert pressure on the spinal cord.

**TECHNIQUES**

**REMOVING THE POSTERIOR LONGITUDINAL LIGAMENT**

- If cord compression arises strictly from bony osteophytes or congenital narrowing of the spinal canal, the PLL does not necessarily need to be resected. In general, we favor removing the PLL to confirm adequate decompression.
- If, however, there is an extruded or sequestered herniated disc behind the vertebral body, or if OPLL is the cause of compression, the PLL should be resected.
- When resecting the PLL, a small curette is used to probe in between longitudinal fibers of the PLL until it can be passed dorsal to it. Once a plane is created, larger curettes or 2- or 3-mm Kerrisons can be used to complete the resection of the PLL (TECH FIG 3).
- If severe OPLL is present, the dura may be deficient or absent, and the surgeon should be prepared to perform a dural patch and possibly a subarachnoid lumbar drain.
- The presence of severe OPLL may favor a posterior approach, all other factors being equal, to avoid complications related to dural deficiencies.
- In severe OPLL, instead of removing the entire OPLL, an alternative technique is to allow it to float anteriorly by releasing its tethers at nonossified portions, then allowing the ossified portion to float anteriorly along with the underlying adherent dura. However, one downside to this approach can be the potential for regrowth of the OPLL.7
TECH FIG 3 • A curette is used to tease apart the longitudinal fibers and create a plane dorsal to the posterior longitudinal ligament (PLL). Once this plane is identified, a curette or pituitary rongeur is used to elevate the PLL while a small Kerrison removes it. The surgeon must be careful never to exert compression on the cord by passing large instruments.

GRAFTING OPTIONS

- Autograft, allograft, or cages can be used.
- Autograft options include structural iliac crest or autologous fibula. Both are excellent graft materials but can be associated with significant donor site morbidity. Because of its shape, iliac crest is generally suitable for one- or sometimes two-segment corpectomy reconstruction. Fibula is favored for two-segment or more corpectomy reconstruction.6
- Because of donor site morbidity issues, allograft fibula or cages filled with local autograft remain popular choices for corpectomy reconstruction.
- Local corpectomy bone can be used to provide the biologic stimulus for healing, allowing the allograft to serve both structural and osteoconductive roles. Local bone is packed in and around the allograft (TECH FIG 4).

TECH FIG 4 • Local morselized autograft is packed around the strut graft and into the cleared-out uncinate regions. An additional benefit of wide discectomy is the ability to fuse the uncinate regions.

ENDPLATE PREPARATION

- The endplates above and below the corpectomy should be thoroughly decorticated and denuded of all cartilaginous material.
- To prevent excessive subsidence, we prefer not to remove as much endplate when performing corpectomy reconstruction as is done when performing anterior cervical discectomy and fusion.
- Nevertheless, it is helpful to remove the anterior lip on the caudal surface of the cephalad vertebra to allow for better contact of the graft to the endplate. The anterior lip is flattened to be level with the central concavity of the endplate (TECH FIG 5A).
- The structural integrity of the endplate is maintained in the central third to allow a stable loading surface for the

Corpectomy autograft

Fibular autograft
If a total corpectomy is performed, care is taken to find a graft that will fill most of the depth of the vertebral body but will still be small enough to stay well clear of the decompressed cord when recessed by 2 to 3 mm from the front of the vertebral body.

If the posterior lip needs to be removed to decompress the cord, it can be done along the floor of the canal with a Kerrison after the corpectomy is completed.

Kickout is most likely to occur at the caudal end of the construct, where the compressive loads on the graft are translated into a shear force due to the relative lordosis of the caudal vertebra. To prevent kickout, the caudal endplate should be prepared parallel to the floor, such that the shear vector is minimized. The tradeoff is that doing so will result in a greater likelihood of subsidence (TECH FIG 5B,C).

GRAFT SIZING

If a total corpectomy is performed, care is taken to find a graft that will fill most of the depth of the vertebral body but will still be small enough to stay well clear of the decompressed cord when recessed by 2 to 3 mm from the front of the vertebral body.

A reasonable amount of distraction should be performed after the decompression. This can be done by the application of weights to cervical tongs or, in one- or some two-level situations, by Caspar pin distraction (the Caspar spreader is usually not long enough to span multilevel corpectomies).

Care should be taken not to distract the spine until all compressive lesions on the cord have been removed, to avoid tenting the cord over the compressive lesions.

In general, the amount of distraction should result in overall vertebral column length that is slightly longer than it was preoperatively. Excessive distraction is more likely to result in subsequent graft pistoning and subsidence, as the spine naturally recoils to its initial state once the patient is upright.

The wooden end of a cotton applicator can be whittled away until it just fits into the corpectomy. This can be used as a template for cutting the graft to appropriate length (TECH FIG 6).

TECH FIG 5 • A. Carpentry of the inferior endplate of the cephalad level: preparing the inferior endplate of the cephalad segment (eg, the inferior endplate of C5 during a C6 corpectomy). Flattening the anterior lip and the anterior third of the endplate allows for proper insertion of a strut graft. They are flattened to be level with the central concavity of the endplate. The central third of the endplate is left as structurally sound as possible to resist excessive subsidence. The posterior third may be left intact to act as a barrier to posterior migration of the graft into the canal. The posterior lip, which is often a source of spondylotic compression, can be removed with a Kerrison after the corpectomy is completed to decompress the floor of the spinal canal. B,C. Carpentry of the superior endplate of the distal level. B. When performing corpectomy reconstructions in which the distal level is lordotic, if the superior endplate of that vertebra is not level with the ground, the graft is likely to kick out anteriorly as the compressive loads on the graft are converted into shear at the graft–endplate interface. C. The solution is to flatten the superior endplate of the caudal vertebra. The graft is now less likely to kick out, but the tradeoff is that it is more likely to piston.

TECH FIG 6 • After applying distraction, a wooden applicator (Q-tip) serves as a useful device for measuring the length of the graft.
**GRAFT INSERTION**

- The graft is gently tamped into the distracted corpectomy site (**TECH FIG 7**).
- Distraction is then released, and the stability of the graft is tested by gently pulling on the graft with a clamp.
- Because bony union is desired not only at the ends of the graft but also side to side between the shaft of the strut graft and the remaining vertebral bodies, intimate contact of graft to host is desirable in all regions. Any open spaces can be grafted with the local bone from the corpectomy.
- If autograft is scarce, it is best to save it for the ends of the allograft strut and fill the middle portion of the marrow cavity with a bone graft substitute.
- The uncinate regions at each disc level are a good surface for fusion and can be grafted with local bone. The residual disc spaces lateral to the medial border of the uncinate can be packed with local bone to facilitate fusion.

**TECH FIG 7** • The graft is inserted under either tong traction or Caspar pin distraction. The superior end of the graft is inserted first, and then the inferior end is gently tamped into position.

**ANTERIOR CERVICAL PLATING**

- Plating is performed as noted during anterior cervical discectomy and fusion.
- Standalone plated multilevel corpectomies (three or more disc levels) have been reported to be associated with high failure rates. Consideration should be given in such cases to supplemental posterior fixation.5

**PEARLS AND PITFALLS**

| Limits of corpectomy | The uncinate should be used as boundaries to prevent injury to the vertebral arteries while achieving wide enough cord decompression. |
| Carpentry of the caudal endplate of the cephalad vertebra | The endplates should be thoroughly decorticated but preserved in the area of contact with the graft to avoid excessive subsidence. |
| Carpentry of the cephalad endplate of the caudal vertebra | If the inferior end of the construct is at a lordotic segment, the endplate should be flattened such that the graft will sit parallel to the ground. Doing so will help avoid kickout. |

**POSTOPERATIVE CARE**

- If retraction time on the soft tissues of the neck has been more than 3 hours, a cuff-leak test should be considered before extubation to rule out the presence of edema that may lead to airway obstruction upon extubation.
- This is performed by deflating the endotracheal tube while obstructing the lumen of the tube, and then determining if there is a leak around the deflated tube. If there is no leak, consideration should be given to keeping the patient intubated with the head elevated until a leak is detected. Steroids can also be given to decrease airway edema.
- The head of the bed should be elevated above 45 degrees in all patients postoperatively to diminish edema.
- Most patients are placed in a rigid cervical orthosis for 6 weeks.
- If a drain is placed, it should be followed closely and removed once the output is below an acceptable limit (ie, 30 cc per shift), typically on postoperative day 1.

**OUTCOMES**

- Although the primary goal of surgery in myelopathy is to prevent progression, most patients actually note neurologic improvement after successful corpectomy and fusion.2

**COMPLICATIONS**

- Complications encountered during the anterior approach to the cervical spine are similar to those discussed in Chapter 11. The incidence of airway obstruction may be higher due to soft tissue edema from longer surgical retraction times.
- Neurologic injury is rare (1% to 2%).
Most complications associated with cervical corpectomies are related to graft and plate problems.  
Dislodgement and pistoning of the graft into the adjacent vertebral bodies with loss of lordosis are potential postoperative complications. The risk increases as the number of levels corpectomized and the length of the strut graft increases. The rate of graft dislodgement ranged from 7% to 50% despite plating in one early series of multilevel corpectomy. To avoid such complications, hybrid corpectomy constructs can be used instead if the pattern of neural compression allows. Hybrid constructs combine corpectomies at levels with retrovertebral compression along with discectomies at levels demonstrating compression only at the level of the disc space (FIG 3).

For a three-disc-level problem, a single-level corpectomy can be combined with a single-level anterior cervical discectomy and fusion.

For a four-disc–level problem, two single-level corpectomies can be performed with an intervening intact vertebra, or a single-level corpectomy with two single-level anterior cervical discectomies and fusions.

Hybrid constructs avoid the negative biomechanical issues associated with long strut grafts and provide more points of segmental screw fixation, leading to constructs that are more stable and less likely to fail. If a posterior approach can be used instead in the patient with multilevel myelopathy, we prefer to do so. Ideal candidates for posterior surgery such as laminoplasty are those with multilevel cervical myelopathy, preserved lordosis, and little to no spondylotic neck pain. In patients like these, fusion and its attendant complications can be avoided altogether with laminoplasty.

Exacerbation of axial neck pain can occur after laminoplasty in those who have significant complaints preoperatively, although it rarely becomes of significance in those who have little to no axial pain preoperatively. Also, adequate decompression may not occur after laminoplasty in those with kyphosis, as cord drift back away from anterior compressive lesions is unreliable in this setting.

REFERENCES

DEFINITION
■ Cervical radiculopathy is a clinical diagnosis defined by the presence of motor or sensory changes or complaints in a specific dermatomal distribution.

ANATOMY
■ Cervical radiculopathy is largely due to mechanical compression of the exiting cervical nerve roots.
■ The intervertebral foramen is bounded by the following structures (FIG 1):
  ▪ The disc and uncovertebral joint ventrally
  ▪ The borders of the pedicles cranially and caudally
  ▪ The superior articular facet of the caudal segment (eg, the superior articular facet of C6 at the C5-6 foramen) dorsally
■ In the subaxial cervical spine, the foramen averages 9 to 12 mm in height and 4 to 6 mm in width, and in a young person, the cervical nerve root occupies approximately one third of the available space in the foramen.
■ With increasing age, degenerative changes (osteophyte formation), disc protrusion, or cervical instability, this proportion may increase and signs of radiculopathy may develop.

PATHOGENESIS
■ Any process that causes impingement of the exiting cervical nerve roots can lead to cervical radiculopathy.
■ Potential etiologies of cervical radiculopathy include cervical spondylosis leading to foraminal stenosis due to uncinate or facet hypertrophy, disc herniation, instability, and anterolisthesis or retrolisthesis.

NATURAL HISTORY
■ The natural history of cervical radiculopathy is not well studied, but about half of the adult population will have neck and radicular symptoms at some point during their lifetime.
■ In patients treated nonoperatively, up to 66% will have persistent symptoms and up to 23% of patients with persistent neck or radicular pain will be unable to return to their original occupation.

PATIENT HISTORY AND PHYSICAL FINDINGS
■ When a patient presents with radiculopathy, a complete history and physical examination is of paramount importance.
■ Questions about the duration of the symptoms, location and nature of the pain, distribution of altered sensation and numbness (axial or radicular), presence of weakness, and any associated manifestations must be asked to understand the underlying pathology and target the offending level of cervical pathology.
■ Since radiculopathy can be associated with myelopathy, the presence or absence of balance difficulties, loss of bowel or bladder control, presence of constitutional symptoms, trauma, signs of dysdiadochokinesia, or change in neurologic status must be elucidated.
■ The physical examination should include motor and sensory evaluation (both gross and pinprick), reflex testing, upper and lower motor neuron signs, and cerebellar functional testing.

IMAGING AND OTHER DIAGNOSTIC STUDIES
■ Plain radiographs of the cervical spine, including anteroposterior (AP), lateral, odontoid, oblique, and lateral flexion/extension views, are used initially to evaluate for the presence of cervical pathology.
■ If symptoms have been present for at least 6 weeks, additional imaging is indicated and usually includes cervical spine MRI.
■ If MRI is contraindicated, a cervical CT myelogram may be beneficial.
■ A CT scan with coronal and sagittal reconstructions may be helpful in operative planning.

DIFFERENTIAL DIAGNOSIS
■ Cervical radiculopathy
■ Myelopathy
■ Myeloradiculopathy
■ Entrapment syndromes (eg, pronator syndrome, carpal tunnel syndrome, cubital tunnel syndrome)
■ Thoracic outlet syndrome

NONOPERATIVE MANAGEMENT
■ Although cervical radiculopathy is common, only a few patients require surgical intervention, and despite a heightened clinical acumen for the diagnosis and treatment of cervical spondylosis, the mainstay of treatment remains nonsurgical.
■ Nonsurgical modalities that are initiated first include physical therapy, nonsteroidal anti-inflammatory drugs, and activity modification.
■ If these methods fail, a selective nerve root injection at a designated level can be attempted with a high degree of safety and efficacy.
■ The purpose of the nerve root injection is twofold: to provide pain relief by decreasing inflammation through the use of a corticosteroid, and to serve as a diagnostic tool to localize the offending pathology.

SURGICAL MANAGEMENT
■ Posterior cervical foraminotomy is indicated for foraminal stenosis or a foraminal disc herniation resulting in a neurologic deficit such as a sensory deficit, motor weakness, and/or progressive symptoms that fail to respond to an appropriate course of nonsurgical treatment.
As with any surgical intervention, a thorough discussion with the patient and family about the desired outcomes and risks and benefits of the procedure must be undertaken before surgery.

**Preoperative Planning**

- To perform an adequate foraminotomy, one must first understand the anatomy of the foramen.
- The basic principle of the procedure is to unroof the foramen, which then allows the nerve root to displace dorsally away from the compressive pathology, which is anterior in most cases.
  - Less commonly, a portion of the superior facet may itself be a source of compression, which can then be directly removed by the posterior foraminotomy.
  - Since the superior articular facet of the caudal cervical segment forms the roof of the foramen, resection of the medial portion of the superior articular facet is necessary to adequately decompress the neuroforamen.
  - Similarly, since the pedicles form the cranial and caudal borders of the neuroforamen, adequate decompression requires resection of the superior articular facet to the lateral margin of the pedicles, as any overhang of the superior articular facet over the caudal pedicle can lead to persistent compression.
  - In contrast, because resection of more than 50% of the facet joint can lead to facet instability, resection of the superior facet lateral to the pedicle is unnecessary.

**Positioning**

- Proper patient positioning is critical when performing posterior cervical foraminotomy to reduce blood loss and improve visualization of the operative field.
- Although there are a variety of ways to position a patient, we routinely place the patient in bivector Gardner-Wells tong traction and position the patient prone on an open Jackson frame (OSI, Orthopaedic Systems, Inc., Union City, CA).
  - This table is quite versatile and allows for intraoperative alterations in patient positioning throughout the operation.
  - Typically, the table is tilted into reverse Trendelenburg to distribute blood into the abdomen and legs, thereby creating a more physiologic state for the patient and providing better visualization in the operative field.
  - To facilitate this position, the head of the table is placed in the top rung and the foot of the bed is placed in the bottom rung.
  - The chest and abdomen are supported on bolsters that allow the abdomen to hang free, and the legs are supported in a sling with pillow support.
  - The shoulders are taped down on both sides to provide traction, thereby allowing better radiographic visualization of the lower cervical spine during intraoperative imaging.
  - Bivector traction is used with the aid of two separate ropes so the neck is maintained in proper alignment, depending on the procedure being performed (FIG 2).
  - One of the ropes is placed in-line and horizontal to the table through a pulley system, and the other is placed over a cross-bar on the Jackson frame to facilitate placement of the head into extension.
  - It is imperative to maintain good coordination and communication with the anesthesia providers during change of positioning of the head, as the endotracheal tube may become dislodged if not secured properly.

**FIG 1** Model showing the posterior element anatomy and boundaries of the foramen.

**FIG 2** Bivector traction technique using the open Jackson frame. Two separate ropes are used so the neck is maintained in proper alignment, depending on the procedure being performed: one of the ropes is placed in-line and horizontal to the table through a pulley system, and the other is placed over a cross-bar on the Jackson frame to facilitate placement of the head into extension. Although not necessary, a horseshoe may be used ventral to the face to catch the head if the tongs slip.
EXPOSURE

- For bilateral foraminotomies, typically a midline incision is used, whereas for a unilateral foraminotomy, an incision approximately 2 cm lateral to the midline can be made (TECH FIG 1A–C).
- With either approach, the lamina, the junction between the lamina and the facet joint, and the facet joint itself have to be exposed while preserving the facet capsule.
- After exposure, the intralaminar V is identified and the decompression is performed (TECH FIG 1D,E).

TECH FIG 1 • A. Dissection of the posterior cervical spine along the midline in the avascular plane. B. Continued dissection, showing midline splitting of the muscles. C. The posterior cervical spine after meticulous dissection of the posterior elements with lateral extension over the facet capsules. Bovie marks illustrate the lateral mass–laminar border. D. Model of the cervical spine showing the C5–6 interspace with the intralaminar V (yellow lines). This is the key anatomic landmark that must be recognized to perform an adequate foraminotomy. E. An intraoperative image showing the C5–6 interspace with the intralaminar V (yellow lines).

- If the neck is not adequately flexed during a foraminotomy, one must resect a large amount of the overhanging inferior articular facet to expose the underlying superior facet.
- This may weaken the lateral mass and lead to a fracture, or more commonly it makes placement of the lateral mass screw more difficult if a fusion is being performed in addition to a foraminotomy.

Approach

- A posterior cervical foraminotomy can be performed using open, endoscopic, or microscopically assisted approaches.
**RESECTION OF INFERIOR ARTICULAR FACET**

- A high-speed 2-mm acorn-shaped carbide-tip cutting burr is used to resect the overlying inferior articular facet and then the medial superior articular facet with the neck in neutral or flexed position (TECH FIG 2).
- Although the inferior articular facet does not cause impingement of the nerve root (the inferior articular facet lies dorsal to the superior articular facet), the overlying inferior articular facet must be resected to the lateral margin of the pedicles to expose the underlying superior articular facet.

**TECH FIG 2**  
A. Model of the cervical spine showing the C5-6 interspace with resection of the inferior facet, which must be resected to the lateral margin of the pedicles to expose the underlying superior articular facet. To determine whether enough of the inferior facet has been resected, a small angled microcurette can be used to palpate the pedicle. B. An intraoperative image showing the C5-6 interspace with resection of the inferior facet. The probe illustrates the cranial extent of the C6 superior articular facet.

**RESECTION OF SUPERIOR ARTICULAR FACET**

- Once the inferior articular facet is resected, the superior articular facet underneath is resected out to the lateral border of the pedicles, completing the decompression (TECH FIG 3).
- During the decompression, copious irrigation (20-mL syringe with a 2-inch-long 18-gauge angiocath) must be used to prevent thermal damage to the surrounding tissues. It also aids in visualization.
- Typically we recommend the use of a burr over Kerrison rongeurs because inserting instruments (such as Kerrison rongeur, which may have a relatively thick footplate) into the already stenotic canal and foramen can cause neurologic damage. However, once most of the roof of the foramen has been removed, it is usually safe to use a 1-mm Kerrison rongeur to clean up any overhanging bone.

**TECH FIG 3**  
A. An intraoperative image showing that once the inferior articular facet is resected, the superior articular facet underneath can be identified. B. The superior articular facet is resected out to the lateral border of the pedicles; this is best performed using an L-shaped resection, as shown in the intraoperative image, to ensure there is no iatrogenic impingement on the nerve root, which can occur if a keyhole or a C-shaped resection of the superior articular facet is performed (see E). C. An intraoperative image showing the completed resection of the superior articular facet. The remaining small ledge of bone can be removed using a small angled microcurette or 1-mm Kerrison rongeur. (continued)
DISCECTOMY

- If the patient has an intraforaminal disc herniation, then the nerve root must be manipulated to expose the herniated disc fragment that is ventral to the nerve root.
- If there is little room for the root to migrate cranially, the cranial 2 to 3 mm of the caudal pedicle may have to be burred down, and a microscopic right-angle probe can then be placed into this space and rotated ventrally to the root to sweep any herniated disc fragment out from under the root, and micro pituitary rongeurs can be used to remove the disc fragment.

CONFIRMATION OF ADEQUATE DECOMPRESSION

- After completing the decompression, a hemostatic agent such as FloSeal or Surgiflo is used to control any bleeding surfaces.
- Once the foraminotomy is completed, the lateral walls of the cranial and caudal pedicles should be readily palpable, and there should be no bone overhanging the medial and superior aspect of the caudal pedicle (TECH FIG 4).

WOUND CLOSURE

- The posterior wound is closed in multiple layers.
- If meticulous midline exposure was performed, the preserved interspinous ligaments with the muscular attachments are used as the first layer of closure. The amount of muscle incorporated into the suture is minimized, since all such muscle will necrose.
- With a well-exposed spine, one can find a thin fascial layer enveloping the muscle that can be used to close the layers.
- The closure progresses from deep to superficial with the placement of deep, middle, and superficial drains.
- The multiple drains prevent isolated pockets of hematoma, which can act as a nidus for infection.
PEARLS AND PITFALLS

Positioning
- Bivector traction with the neck placed in flexion when the foraminotomy is being performed is crucial, as neck flexion unshingles the facets and exposes the underlying superior articular facet.
- Reverse Trendelenburg position helps to decrease blood loss.
- Good coordination and communication with the anesthesia providers during change of positioning of the head is critical.

Exposure
- Meticulous midline dissection through avascular raphe decreases blood loss and allows better closure.
- Care must be taken not to detach the semispinalis cervicis from the spinous process of C2 if a C2-3 foraminotomy is required.
- Care must be taken to remain superficial to the facet capsules during dissection to preserve them, as they provide some protection against postoperative kyphosis.

Decompression
- Adequate decompression requires resection of the superior articular facet (the roof of the foramen) to the lateral margin of the pedicles.
- About 50% (medial-lateral) of the overlying inferior articular facet must be resected to expose the underlying superior articular facet.
- Any overhang of the superior facet over the caudal pedicle can result in persistent nerve root compression.

Closure
- The posterior wound is closed in multiple layers to more closely reapproximate the normal anatomy.

Postoperative course
- Postoperatively, patients do not have any range-of-motion restrictions, nor are they required to wear a brace.

POSTOPERATIVE CARE

- Postoperative pain regimen includes patient-controlled analgesia and ketorolac (Toradol) for 36 to 48 hours in patients under age 65 who have normal renal function and no history of congestive heart failure.
- Patients typically remain in the hospital for 24 to 48 hours, depending on drain output. Patients are discharged on oral pain medication and are instructed to return to the clinic for routine follow-up at 6 weeks postoperatively.
- Although a soft collar is given for comfort, patients are encouraged to discontinue using the collar as soon as they can.
- There are no range-of-motion restrictions, and therapy with immediate motion can begin.
- Rapid return to normal activities and aerobic exercise is encouraged.

OUTCOMES

- Results of posterior cervical foraminotomy are encouraging, with good or excellent outcomes reported in about 90% to 95% of patients.

COMPLICATIONS

- Neurologic injury or worsening radiculopathy
- Infection
- Inadequate decompression or failure to relieve symptoms
- Instability and deformity secondary to overly aggressive decompression
- Air embolism if the procedure is done in a sitting position

REFERENCES

Cervical laminoplasty is a surgical procedure designed to decompress the spinal cord from a posterior approach. The cervical laminae are reconstructed to create more available space for the spinal cord while at the same time preserving motion and normal alignment.

Cervical myelopathy is pathologic spinal cord dysfunction due to spinal cord compression. Compression of neural elements results in a spectrum of cord dysfunction ranging from mild to quite severe. Cervical laminoplasty is most often used to treat cervical myelopathy associated with multilevel cervical stenosis.

Multilevel cord compression is commonly due to cervical spondylotic stenosis. This is a degenerative process resulting in decreased space available for the spinal cord, with possible instability and loss of lordosis. Congenital stenosis of varying degrees is often associated with patients with symptomatic cervical spondylotic myelopathy.

Other conditions such as ossification of the posterior longitudinal ligament, trauma, infection, and neoplasm can result in stenosis that can be treated with laminoplasty.

The key to treating this condition is to achieve multilevel decompression that alleviates circumferential compression and allows the spinal cord to drift away from ventral compressive lesions.

ANATOMY

The cervical spine is composed of seven vertebrae normally arranged in an overall lordotic alignment. The occiput–C1 articulation is responsible for 50% of neck flexion and extension and the C1–C2 atlantoaxial articulation is responsible for 50% of total rotation. Lateral bending below the C2–C3 level is coupled with rotation due to the 45-degree inclination of the cervical facet joints.

The subaxial vertebral segments of C3–C7 are similar to each other and distinct from C1 ( atlas) and C2 (axis). The subaxial vertebrae articulate via zygapophyseal or facet joints posteriorly and laterally via the uncovertebral joints, or joints of Luschka.

Intervertebral discs are located between vertebral bodies of C2–C7. The discs are composed of an inner nucleus pulposus and outer annular fibrosus.

Anteriorly the spinal canal is bounded by the vertebral bodies, the intervertebral discs, and the posterior longitudinal ligaments; laterally and posteriorly by the vertebral arch; and posteriorly by the ligamentum flavum, which runs from the anterior surface of the superior lamina to the posterior surface of the inferior lamina (FIG 1).

PATHOGENESIS

Cervical spondylotic myelopathy is the most common indication for cervical laminoplasty. It is the most common cause of myelopathy in patients older than 50 years. By age 40, most people will have radiographic evidence of degenerative changes.1

The degenerative process typically begins in the intervertebral disc. The degenerated discs are more fibrotic as a result of proteoglycan loss within the nucleus pulposus. This is associated with lost water content from the nucleus pulposus and loss of normal shock-absorbing capacity.

With disc degeneration, the disc height decreases and the annulus fibrosus bulges radially, resulting in ventral spinal canal narrowing. Collapse and loss of lordotic curvature can lead to a cascade of compensatory changes, including osteophyte formation around the uncovertebral joints, the facet joints, and the insertion of the annulus fibrosus. In the dorsal spinal canal, there is thickening or buckling of the ligamentum flavum, which causes a decrease in canal and foraminal dimensions.

Protruded disc material, osteophytes, and thickened soft tissues within the canal or foramen result in extrinsic pressure on the nerve roots or spinal cord. Spondylotic changes and osteophyte compression may also impair the circulation within the cord, leading to cord ischemia and resultant myelopathy.

NATURAL HISTORY

The true natural history of cervical spondylotic myelopathy is difficult to discern. This is due partly to the fact that most cases now are treated surgically and early studies of the disease took place several decades ago. At that time modern diagnostics were unavailable; therefore, confounding variables due to other neurologic conditions cloud the picture.

What is known about the natural history is that the disease process progresses in a variable and unpredictable manner. Often there is stepwise deterioration of neurologic function, with periods of stable symptoms followed by decline.

The clinical course may wax and wane over a period of years. Sensory symptoms may be transient, but motor symptoms tend to persist and progress. While surgical intervention may relieve symptoms and halt progression, some neurologic deficits are permanent and do not respond to surgical treatment.4

PATIENT HISTORY AND PHYSICAL FINDINGS

The diagnosis of cervical myelopathy may be difficult to make due to the variability in clinical findings. Pain is frequently not a significant complaint in myelopathic patients unless associated with root compression or facet arthrosis. Patients may present with subtle findings or profound neurologic deficits.

The diagnosis requires a high index of suspicion and careful evaluation of the patient’s history, physical examination, and imaging studies.
Patients commonly present with insidious onset of gait disturbance, trouble with balance, and clumsiness in the hands and lower extremities. They may report burning pain in the upper extremities, difficulty in handwriting and fine motor control, diffuse numbness, and weakness of grasp. Advanced cases can present with flaccid weakness and bowel and bladder dysfunction.

The physical examination should begin with an assessment of gait, which may be wide-based, hesitant, stiff, or spastic. Patients may be unable to perform heel-toe walk or may have poor balance during toe raises. A careful neurologic examination should follow. Each dermatome should be tested.

Sensory findings may be variable. Pain, temperature, and vibratory and dermatomal sensation may all be decreased.

On the motor examination, depending on the level of cord compression as well as nerve root and peripheral nerve dysfunction, mixed upper and lower motor neuron findings may be present in the extremities. Patients may have weakness and atrophy as well as brisk reflexes.

The Lhermitte sign is said to be positive when extremes of neck flexion or extension result in paresthesias and weakness. This can be a sign of posterior column compression. Pathologic reflexes such as the scapulohumeral reflex (indicates compression above the C3 level), inverted radial reflex (indicates compression at the C5 to C6 levels), the Hoffman sign, clonus, the Babinski sign, and finger escape may be present.

IMAGING AND OTHER DIAGNOSTIC STUDIES

Plain AP and lateral radiographs are useful for initial evaluation of cervical spine sagittal alignment and the extent of spondylotic changes such as disc space narrowing, osteophytes, kyphosis, joint subluxation, and spinal canal stenosis (FIG 2A).

Flexion and extension views can provide information about possible spinal instability.

Magnetic resonance imaging (MRI) aids in determining accurate dimensions of the spinal cord and canal. MRI is also the technique of choice for visualization of soft tissues such as ligamentous hypertrophy, disc herniations, and changes within the cord parenchyma such as edema and myelomalacia (FIG 2B).

Computed tomography (CT) with and without contrast is superior to MRI for defining the bony anatomy and is the
study of choice for evaluating ossification of the posterior longitudinal ligament (FIG 2C,D).

DIFFERENTIAL DIAGNOSIS
- Cervical spondylosis
- Soft disc herniations
- Infectious discitis or epidural abscess
- Muscular dystrophy or dystonia
- Loss of normal sagittal alignment
- Neurogenic disorders (syringomyelia, multiple sclerosis, amyotrophic lateral sclerosis, cerebellar dysfunction)
- Instability of the cervical spine can cause myelopathic symptoms.
- Ossification of the posterior longitudinal ligament
- Peripheral neuropathy or nerve injury
- Drug intoxication
- Vascular disease
- Autoimmune disorders

SURGICAL MANAGEMENT
- Laminoplasty was specifically designed to prevent the kyphotic deformities seen with laminectomy alone and is associated with fewer complications than laminectomy and fusion.²
- Laminoplasty involves posterior decompression from C3 to C7, allowing for dorsal cord expansion and drift while preserving motion.
- Indications
  - Cervical spondylotic myelopathy involving three or more disc levels
  - Congenital stenosis of the spinal canal
  - Ossification of the posterior longitudinal ligament
  - Spinal cord tumors
- Contraindications
  - Kyphotic sagittal alignment of more than 10 to 14 degrees can lead to worsening of the kyphotic deformity and poor neurologic outcomes.
  - Significant segmental instability
- Relative contraindications
  - Ossification of the ligamentum flavum. This condition is associated with dural adhesions, which can make opening the posterior arch difficult.
  - Previous posterior cervical surgery such as foraminotomies. Scar formation can produce adhesions that can make opening the laminar arch difficult.
  - Primary axial neck pain in the setting of myelopathy. Laminoplasty preserves motion, and hence the procedure is not designed to address pain generation from facet arthrosis and disc degeneration. Fusion procedures provide greater benefit to patients with significant complaints of axial neck pain.

Preoperative Planning
- The patient’s history, clinical examination, and imaging studies should be thoroughly reviewed and documented before the case.
- Evaluation of the patient’s active range of motion in flexion and extension assists with head positioning. Passive flexion and extension outside of this range (eg, during positioning) can be dangerous in the setting of cord impingement.
- The presence of preoperative axial neck pain may be an indication for an alternative procedure, as listed above.
- Careful examination of CT scans to determine the bony anatomy of the dorsal cortices can be helpful. Special attention should be given to the lamina-to-lateral-mass junction.
- If concomitant fusion is planned, the midline splitting laminoplasty (“French door”) approach may be considered, but a unilateral open door technique can also be used with fusion and lateral mass instrumentation.

Positioning
- Intubation is preformed with caution to protect the cervical spine. This includes advanced notification to anesthesia personnel of spinal cord compression in severe cases. Care should be taken not to extend the neck more than the patient’s comfortable range of motion before sedation. The use of fiberoptic assistance should be considered in high-risk cases.
- Application of a Mayfield head holder reduces risks to soft tissues and provides a stable platform for the head during the procedure (FIG 3A).
- The patient is placed prone onto chest bolsters. The abdomen should be as free as possible to reduce venous bleeding and prevent ventilatory difficulty. Arms are tucked in at the patient’s side (FIG 3B).
- The head is positioned to allow for slight cervical flexion to tension skin on the posterior neck and decrease shingling (or overlap) of lamina. Intraoperative repositioning of the flexion–extension of the head is possible if necessary with the Mayfield tongs.
- The bed is then placed in reverse Trendelenburg to decrease venous bleeding and allow for horizontal positioning of the cervical spine.
- Spinal cord monitoring is routinely performed in myelopathic patients. This helps to monitor neurologic problems related to positioning as well as with the laminoplasty procedure itself.
- The surgical field should be prepared from the nuchal line to roughly T4 to allow for possible wound extension.

Approach
- A posterior midline incision is made over the spinous processes from C2 to T1. This can be extended to the occiput or further down the thoracic spine as necessary.

FIG 3 • A. The patient’s head is placed in a Mayfield head holder. B. The patient is placed prone onto chest bolsters with arms tucked in at the sides. The head is placed in slight flexion. Spinal cord monitoring equipment is also seen.
INCISION AND DISSECTION

- A posterior midline approach to the spinous processes is made, using a longitudinal incision from C2 to T1.
- Electrocautery is used to divide the subcutaneous fat in the midline to reach the tips of the spinous processes.
- Once the tips of the spinous processes have been found, a subperiosteal dissection is performed to expose the C3–C7 lamina. Careful attention should be taken to stay in the midline avascular plane to reduce bleeding.
  - The dissection should extend laterally to fully expose the junction of the lateral mass and the lamina.
  - Exposure should not extend beyond the midportion of the lateral masses.
- The extensor muscle attachment to the C2 spinous process is carefully preserved. The inferior C2 laminar margin is usually broad and should be exposed to aid in visualization of the C2–3 junction.
- The spinous processes can be amputated at their base. Spinous processes are useful for bone graft (either for strutting open the lamina or for local bone graft for the hinge side).
- Removing the spinous processes significantly improves exposure and reduces asymmetric posterior displacement of paraspinal musculature (TECH FIG 1A).
- The interlaminar ligamentum flavum between C2–3 and C7–T1 is removed. First, a rongeur is used to create a small opening in the interlaminar ligamentum flavum. Then a combination of curette and Kerrison rongeur is used to divide the rest of the interlaminar ligamentum flavum (TECH FIG 1B).

TROUGH PREPARATION

Open-Side Trough

- A 3.0- or 4.0-mm round or oval low-aggression high-speed burr is used to form the trough.
- The trough location is at the junction of the lamina and lateral mass.
- For the opening side, bony layers should be removed in sequence: the outer cortex, next the cancellous middle layer, followed by the ventral cortex (TECH FIG 2A).
- Troughs should be made no deeper than 4 mm. Once at that depth, the burr should be directed medially to avoid the facets. Switching to a 3.0-mm burr can be beneficial after the initial work with the 4.0-mm burr to aid in more precise burring.
- As the bone is thinned, the surgeon should use a delicate instrument such as a microcurette or Penfield elevator to palpate and identify any bone bridges still attaching the lamina to the lateral masses. Completion of the bone separation can be performed with a microcurette, a 1.0-mm Kerrison rongeur, or a diamond burr (TECH FIG 2B).
- Care should be used at this time to avoid the epidural veins, which create significant bleeding. Bipolar electrocautery can be used to control bleeding epidural veins.

French Door (Midline Splitting)

- The French door technique involves creation of a midline opening trough and two hinge troughs.
- The midline of the posterior arch can be split by a variety of methods. One method is to remove the spinous process as described above and use a 4.0-mm low-aggression burr to create a complete midline trough. The burr is carefully manipulated to remove the dorsal midline bone down to the ventral bone (TECH FIG 3).
- Completion of the opening is then performed as described earlier and shown in Techniques Figure 2B.
Hinge-Side Trough

- The hinge side is prepared opposite the opening side at the same anatomic junction of lamina and lateral mass.
- The hinge trough is prepared in a similar manner; however, it entails removal of only the dorsal cortex and cancellous layers. The ventral cortex can be thinned to open the hinge, but the surgeon should preserve as much as possible to preserve a mechanically sound hinge (TECH FIG 4).

- Stiffness of the hinge should be tested periodically during preparation. This is the rationale for performing the hinge after the open side has been completed. The goal is to create a pliable yet firm hinge that yields to moderate opening force without breaking the hinge inner cortex.
- Hinge troughs used for the French door technique are prepared in the same anatomic location as troughs created for the open door technique. Similar to the open door technique, ventral cortex should be preserved to create stable hinges.
OPENING THE LAMINOPLASTY

- Proceeding from caudal to cranial, a nerve hook or curved curette is used to elevate the lamina on the opening side. Division of the residual ligamentum flavum and epidural veins proceeds from C3 to C7. A Kerrison rongeur can be used to divide ligamentous attachments, and bipolar forceps are used for cauterization of epidural veins.
- The laminae are then opened sequentially. This can be done with the assistance of a curved microcurette to raise the opening side and gently bend open each lamina hinge. Care should be taken to identify and lyse any epidural adhesions (TECH FIG 5A).
- Starting from C3 and proceeding to C7 allows for blood to flow away from the working area and reduces the overhang of the inferior edge of the superior lamina due to lamina shingling.
- Completion of opening laminae is carried out carefully with small curettes (TECH FIG 5B).

POSTERIOR ARCH RECONSTRUCTION

- The laminoplasty door is held open using a variety of techniques.
- Plate reconstruction has become popular because of the immediate mechanical security that plates provide (TECH FIG 6A,B). However, eventual mechanical stability relies on hinge-side bony healing to permanently hold the posterior arch open.
- Bone struts can also be used; this was the most frequently used method for many decades. Autogenous spinous process grafts fashioned from the spinous processes of C6 and C7 can be used, as well as rib allograft or machined cortical grafts (TECH FIG 6C).
- Reconstruction with bone has the advantage of allowing for full bony reconstruction of the lamina arch, as the bone struts usually fully incorporate with time. Furthermore, placing bone is easier and faster to place than plate and screws, but bone provides less initial mechanical stability to the arch and may (rarely) dislodge before healing of the hinge.
- Hybrid reconstruction with alternating plate and bone graft can also be used (TECH FIG 6D).
- With the French door technique, midline plates can be applied. Other structures have been used, including autograft, allograft, or hydroxyapatite (TECH FIG 6E).
- Alternatively, the lamina can be held open with sutures that go from the lamina to the lateral mass or facet capsules. Suture anchors have also been used.
Part 9  SPINE • Section II  CERVICAL SPINE SURGERY

WOUND CLOSURE

- A deep drain is placed, followed by a layered fascial and subcutaneous closure.
- Skin is closed using a subcuticular stitch.

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Physical examination</th>
<th>The Hoffman reflex can indicate spinal cord compression but can be positive in normal individuals.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient position</td>
<td>Slight cervical flexion facilitates exposure and closure by eliminating redundant posterior skin folds and decreases overlap of lamina (laminar shingling) for improved identification of adjacent levels.</td>
</tr>
<tr>
<td>Opening side</td>
<td>If foraminotomies are planned, then the opening side should be made over the ipsilateral side of compression. If asymmetric compression is present, it may be beneficial to open the more affected side. While creating the opening hinge, a color change in the cortex can be appreciated. As the deep (ventral) cortex is thinned, yellow areas (which correspond to ligamentum flavum) and blue areas (which correspond to veins or dura) can be seen through the bone. Care should be taken at this point as the ventral bone is now very thin.</td>
</tr>
</tbody>
</table>
POSTOPERATIVE CARE

- Typically a soft cervical collar is worn for comfort.
- Most patients can begin immediate active range of motion.
- Drain output is monitored and drains are typically removed by 48 hours after surgery.
- The patient is weaned from the cervical collar over 2 to 4 weeks.

OUTCOMES

- Cervical laminoplasty is a valuable treatment option for myelopathic patients with multilevel stenosis. It provides cord decompression while preserving motion.
- With proper patient selection, neurologic outcomes are excellent, with few complications. In a meta-analysis of results on neurologic improvement, 80% of postoperative patients were reported to have excellent outcomes.²
- When compared with laminectomy with fusion, outcomes regarding neurologic improvement were similar. However, laminectomy with fusion had more frequent complications, such as progression of myelopathy, nonunion, instrumentation failure, development of a significant kyphotic alignment, persistent bone graft harvest site pain, subjacent degeneration requiring reoperation, and deep infection.¹

COMPLICATIONS

- Segmental nerve root palsy: This is most commonly a motor deficit affecting the C5 root that occurs a day or two after surgery. It usually resolves to a large degree with time.
- Axial neck pain has been reported. However, the pain is typically mild and often described as stiffness.
- Loss of cervical motion: Up to 50% loss of range of motion has been reported with some laminoplasty techniques.
- Dural tears are infrequent. They can be handled with either direct repair or with fibrin glue with the addition of a lumbar diverting cerebrospinal fluid drain.
- The infection rate is very low. Good hemostasis and irrigation is recommended.

REFERENCES

Surgical Management

Operative intervention in the posterior subaxial cervical spine is frequently carried out for decompression or stabilization.

Fusion and instrumentation of the posterior cervical spine may be required for unstable fractures or after extensive decompressive procedures.

Instrumentation reduces the need for postoperative immobilization and orthosis wear, augments fusion success, and allows better maintenance of sagittal alignment of the cervical spine.

Interspinous Wiring

Interspinous wiring can be an alternative to lateral mass or pedicle screw fixation in stabilization of the posterior cervical spine.

Although it resists flexion reasonably well, it is generally not as strong in resisting extension, axial load, rotation, and lateral bending.

The most commonly used implants are 18- or 20-gauge stainless steel wire or 1- to 1.2-mm titanium braided cable.

Alternatives include braided stainless steel or polyethylene cable. Multistrand braided steel, titanium, or polyethylene cables show superior fatigue resistance, greater flexibility, and improved stability on flexion-extension testing compared to a single-filament stainless steel wire.

In modern spine surgery, wiring techniques are generally limited to cases in which biomechanically superior techniques such as lateral mass fixation cannot be used, somewhat less invasive midline-only exposure is desired, or the additional rigidity of lateral mass fixation is not necessary (eg, for posterior repair of relatively stable pseudarthroses, or to provide a tension band effect as an adjunct to anterior instrumentation).

Techniques of wiring include simple interspinous wiring (eg, Rogers), Bohlman triple wiring (can be used also for occipitocervical fixation), and oblique wiring.

As a result of the direction of its stabilizing forces, oblique wiring may counter rotational instability better than simple interspinous wiring.

Lateral Mass Screw Fixation

The lateral mass of the subaxial cervical vertebra is a quadrangular column of bone formed by the complex of the superior and inferior articular processes and the intervening bone.

Lateral mass screws are the implants most commonly used at present for posterior fixation of the subaxial cervical spine.

They are versatile in that they can be used when the posterior elements are deficient (eg, from trauma, tumors, or surgical resection for decompression).

Lateral mass screw and rod-plate fixation provides superior flexion and torsional stiffness compared to posterior wiring.

The improved strength of fixation allows instrumentation to be limited to the levels of fusion. When wiring techniques are used, the construct occasionally needs to be extended proximally or distally to obtain additional points of fixation.

A lower incidence of postoperative kyphosis can be achieved with lateral mass screws versus wiring techniques.13

Lateral mass screws have a low incidence of complications and are much easier to insert than cervical pedicle screws.

The Magerl technique of lateral mass screw fixation has been shown to have superior pullout strength and higher load to failure when compared to screws inserted with the Roy-Camille technique.26

This may be related to the longer screw length generally obtained with the Magerl technique (18 mm with Magerl technique versus 14 mm with the Roy-Camille technique).6,16

Pullout strength is significantly greater with a bicortical screw than with a unicortical purchase.

Because bicortical purchase engenders potential risk to nerve roots and the vertebral artery, however, unicortical purchase is used in most cases.

Pedicle Screw Fixation of the Cervical Spine

Pedicle screw fixation allows superior, simultaneous stabilization of all three columns of the cervical spine.

The risk of neurovascular injury from penetration of the small cervical pedicle restricts the widespread use of this technique.

Pedicle screws are most commonly used at C2 and C7, where the pedicles are largest in the cervical spine.

They are often used at the cephalad or caudal ends of long instrumented constructs.

At C7, most patients do not have a vertebral artery in the foramen transversarium, making pedicle screw fixation feasible.

At C2, the vertebral artery is generally lateral to the insertion site and trajectory of the pedicle, making pedicle screw fixation feasible.

From C3 to C6, the proximity of the vertebral artery and the small diameter of the pedicles make pedicle screw fixation challenging and not feasible for routine use.

Whenever pedicle screw fixation in the cervical spine is contemplated, careful scrutiny of preoperative CT and MRI scans is essential.

The cervical pedicle is generally taller than it is wide, with the mean height of all cervical pedicles around 7 mm (range 6 to 11 mm).27

The width of the pedicle is the critical determinant for feasibility of pedicle screw placement.

Pedicle outer diameters less than 4 mm may preclude pedicle screw insertion.12

Multiple morphologic studies have found that the mean cervical pedicle outer width varies from 4 to 7 mm, with significant variation in width at different levels (Table 1).12,24,27
The pedicles of C2 and C7 are generally large enough to accommodate either 3.5- or 4-mm screws. The length of the pedicles from C3 to C6 ranges from 12 to 18 mm. Screw lengths are generally slightly longer to obtain purchase within the vertebral body. The axial angle of the pedicle (medial angle to the sagittal plane) is the least at C2 (25 to 30 degrees) and increases to a mean of 44 degrees (25 to 55 degrees) at C3. From C3 to C7 it gradually reduces to a mean of 37 degrees (33 to 55 degrees).

### Table 1

<table>
<thead>
<tr>
<th>Pedicle</th>
<th>Width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2</td>
<td>6.9 ± 1.6</td>
</tr>
<tr>
<td>C3</td>
<td>5.3 ± 0.8</td>
</tr>
<tr>
<td>C4</td>
<td>5.4 ± 0.8</td>
</tr>
<tr>
<td>C5</td>
<td>5.7 ± 0.8</td>
</tr>
<tr>
<td>C6</td>
<td>5.9 ± 0.9</td>
</tr>
<tr>
<td>C7</td>
<td>6.7 ± 1.0</td>
</tr>
</tbody>
</table>


### POSTERIOR CERVICAL FUSION

- Although it is tempting to focus on instrumentation techniques, performing a meticulous fusion technique is just as important, if not more so, to the success of surgery.
- In virtually all cases, posterior fusion is supplemented by some form of instrumentation.
- To maximize the surface area for fusion, all posterior bony surfaces that do not need to be resected for the decompression should be left intact for fusion.
  - The main priority, however, should always be to first achieve adequate neural decompression.
- After exposure, all soft tissues, including the interspinous ligaments and muscles, facet joint capsules, and paraspinal soft tissue, are meticulously resected so that the cortical surfaces lie exposed.
- Facet joint cartilage is removed with a curette or 3-mm burr within the facet joint.
- The posterior cortical surfaces of the laminae and spinous processes are decorticated with a 3-mm burr to expose bleeding subcortical bone (TECH FIG 1).
- Bone graft obtained from the iliac crest is morselized into small cancellous and corticocancellous chips and on-laid over the bleeding bone.
- Cancellous chips of bone are directly inserted into the facet joint.
- Bone placed between the spinous processes has the additional benefit of being readily visualized on postoperative lateral radiographs obtained to radiographically assess the presence of fusion.

### INTERSPINOUS WIRING

#### Simple Interspinous Wiring

- The spinous processes and laminae at the level to be instrumented should be confirmed to be intact and instrumentable on preoperative imaging studies.
- Closed or operative reduction of spinal fracture-dislocations should be carried out before instrumentation if possible.
- In some cases of flexion–distraction injury, sequential tightening of the wires can be done to reduce the spine.

- Two- to 3-mm drill holes are made through the cortex at the junction of the spinous process and laminae bilaterally, at the levels to be included in the fusion.
- Attention should be paid to the ventral location of the dural sac, and the drill should be directed coronally to minimize the risk of inadvertent spinal cord injury (TECH FIG 2A).
- The drill holes should be positioned at the proximal aspect of the cephalad spinous process and the distal aspect of the caudal spinous process to provide the widest margin of safety against the wire cutting through the spinous process.
The tips of a towel clip or a tenaculum clamp are placed in the cortical holes on either side of the base of the spinous process.
- A gentle side-to-side rocking movement is used to create a continuous tract in the cancellous bone at the base of the spinous process.
- The wire or cable selected for use is passed through and around the base of the cranial spinous process (TECH FIG 2B).
- One end of this wire is similarly passed through and around the base of the caudal spinous process so that both ends of the wire end up on the same side of the spine.
- A plate of corticocancellous bone graft is harvested from the iliac crest and divided into halves.

The graft should be long enough to extend from the superior edge of the cephalad lamina to the inferior edge of the caudal lamina within the fusion levels.
- The cancellous surface of this bone is placed on the decorticated laminae on either side of the spinous process.
- The free ends of the wire are then tightened over the graft (TECH FIG 2C).
- Additional cancellous bone graft is placed over the decorticated laminae and spinous processes and within the facet joint at the fusion levels.

**Triple Wire Technique**
- The wire or cable selected is passed through and around the spinous processes at the cephalad and caudal ends of the fusion levels, as with routine interspinous wiring.

**TECH FIG 2** - Simple interspinous wiring. 
**A.** Safe position of the drill hole for passage of spinous process wire is dorsal to the spinal laminar line. **B.** The wire or cable selected is passed through and around the base of the cranial and caudal spinous processes at the levels selected for fusion, so that both ends of the wire are on the same side of the spine. **C.** Ends of wire are twisted together after releasing any cervical traction.
A pair of corticocancellous plates of bone graft including the full thickness of the cancellous bone of the iliac crest but excluding the inner cortical table is harvested from the posterior iliac crest.

The length of the bone block should be adequate to span the fusion construct and wide enough to cover the decorticated laminae within the fusion levels.

- Two- to 3-mm drill holes are created in the proximal and distal portions of the harvested bone grafts.
- Two additional 22-gauge wires are passed through the holes in the proximal and distal spinous processes.
- These wires are then passed on either side through the holes made in the bone graft.
- The wires are tightened over the grafts on both sides to hold the bone graft rigidly against the decorticated lamina and spinous process (TECH FIG 3).

**Oblique Wiring**

- A periosteal elevator is carefully inserted into the facet joint to slightly distract and clearly identify the plane of the facet joint.
- A 2-mm drill bit is used to make a channel in the sagittal plane through the midportion of the inferior articular process, exiting through the articular surface into the joint.
- The periosteal elevator within the joint confirms penetration by the drill and prevents overpenetration by the drill (TECH FIG 4A).
- A 20-gauge wire or cable is passed through this drill hole and is guided distally through and out of the facet joint using a periosteal elevator in a “shoehorn” fashion.
- One end of the wire is then passed either around or through a hole in the intact spinous process of the vertebra one or two levels caudal to the level of injury.
- This procedure is done bilaterally, and the free ends of the ipsilateral wires are twisted together to the appropriate tension (TECH FIG 4B). The absence of

**TECH FIG 3** Triple wiring technique. After simple interspinous wiring, additional wires are passed through the cranial and caudal spinous processes at the levels selected for fusion. These wires are used to firmly hold corticocancellous plates of bone graft against the decorticated laminae at the fusion levels.

**TECH FIG 4** Facet wiring techniques. A. A channel is drilled in the sagittal plane through the midportion of the inferior articular process, exiting through the articular surface into the joint. A periosteal elevator held within the joint space prevents overpenetration by the drill and can be used to guide the wire out through the joint space. B. Facet wires may be obliquely looped around the spinous process when the lamina is deficient at a level.
laminae or spinous processes is often a reason to consider oblique wiring over interspinous wiring.

- Supplemental midline interspinous or triple wiring is frequently added when the bony anatomy permits.

**Multilevel Buttrress Facet Wiring**

- Posterior stabilization after multilevel laminectomy can also be obtained by posterolateral facet fusion with multilevel facet wiring.8
- Oblique facet wires are passed bilaterally through the inferior articular processes at all facet joints included in the fusion.
  - Two wires are passed through a hole in the spinous process of the most caudal vertebra.
- Rib grafts, iliac crest strut grafts, or metal rods have all been used with the multilevel facet wires (TECH FIG 5).8,14
  - The graft or rod is placed over the decorticated lateral masses and in between the free ends of the wires, and the wires are twisted together at each level to the appropriate tension.

**Postoperative Immobilization**

- Rigid external bracing is recommended in all posterior cervical wiring procedures until solid bony fusion is obtained. Six to 12 weeks of halo vest or rigid cervicothoracic bracing should be used after interspinous or oblique wiring, depending on the stability of the construct and the number of levels included in the fusion.

**LATERAL MASS SCREW FIXATION**

- The quadrilateral posterior surface of the lateral mass is clearly exposed.
  - A ridge between the lamina and lateral mass identifies the medial border.
  - The lateral edge of the lateral mass can be easily palpated.
  - The joint lines above and below delineate the superior and inferior borders.
  - The center of the quadrilateral posterior surface of the lateral mass is identified.
- Several techniques have been described for lateral mass screw insertion.
  - Roy-Camille et al30 proposed an entry point for the lateral mass screw at the center of the posterior surface of the lateral mass.
    - The screw is directed perpendicular to the posterior surface of the lateral mass, angled laterally 10 degrees to the sagittal plane.
    - This trajectory aims to exit lateral to the vertebral artery and inferior to the exiting nerve root (TECH FIG 6A–C).
  - Magerl et al25 proposed an entry point 1 mm medial to the center of the posterior surface of the lateral mass.
    - The screw is directed parallel to the plane of the facet joint with 25 degrees of lateral angulation in the axial plane.
    - This trajectory again aims to exit lateral to the vertebral artery and superior to the exiting nerve root at the junction of the transverse process and the lateral mass.
    - Lining up the screw heads for subsequent fixation to the rod is easier if the most proximal and distal screws are inserted initially, followed by the screws in between.
    - Most current instrumentation systems use a rod to connect the screws after they have been precisely positioned and inserted into the lateral mass.
  - We use lateral-plane fluoroscopy to determine the direction of the screw in the sagittal plane, aiming to keep the screw parallel to and between the articular surfaces of the lateral mass.
  - This trajectory aims to exit lateral to the vertebral artery and superior to the exiting nerve root (TECH FIG 6D,E).
  - A modification of the Magerl et al technique by An et al7 uses a similar starting point but recommends angling the screw 30 degrees laterally in the axial plane and 15 degrees cranially in the sagittal plane.
  - Magerl et al recommended inserting a needle into the facet joint to determine the plane of the joint.
  - Polyaxial screw heads compensate for minor variations in insertion or anatomy.
  - The rods can be contoured in multiple planes and allow for application of compressive, distractive, and rotatory forces for correction of deformity.
  - A rod–screw construct can easily be extended to the occipital and thoracic region.

- Radiographs should show a continuous fusion mass and absence of mobility in flexion and extension before immobilization is discontinued.
Bicortical screws should be considered in certain cases:
- Patients with rheumatoid arthritis or metastatic bone tumors in whom bone quality may be suboptimal.
- Longer fixation constructs extending to the occipital or thoracic regions, to reduce the chances of implant pullout.

## PEDICLE SCREW FIXATION OF THE CERVICAL SPINE

### Insertion of Pedicle Screws from C3 to C7

- Preoperative radiographs and CT images should be reviewed to assess pedicle dimensions and orientation and to confirm the feasibility of obtaining intraoperative radiographs; this is especially important in patients with short, stocky necks.
- Inserting pedicle screws before decompression allows better identification of morphologic landmarks and reduces the risk of inadvertent injury to an exposed spinal cord during the insertion process.
- The most commonly used technique relies on identification of topographic landmarks combined with fluoroscopy.¹
- The entry point to the pedicle is 1 to 2 mm inferior to the caudal edge of the inferior articular process and 2 to...
3 mm lateral to the midline or 2 to 3 mm medial to the lateral edge of the lateral mass.
- Occasionally, degenerative changes at the joint may obscure true landmarks.
- The dorsal cortex of the lateral mass is penetrated using a high-speed burr.
- The cancellous bone of the pedicle in many cases can be visualized in this pilot hole.
- A blunt, fine pedicle probe is advanced through this cancellous bone to find the medially angled pedicle (TECH FIG 7A).
- Fluoroscopy is used to guide the trajectory in the sagittal plane.
- In general, the screws should be parallel to the superior endplate of the vertebral body from C5 to C7 and angled slightly rostral to the endplate from C2 to C4.
- Some authors recommend that a keyhole laminoforaminotomy be performed after locating the entry point.4
- The superior and medial walls of the pedicle are directly palpated through this foraminotomy with a right-angled nerve hook to direct the trajectory of the pedicle probe (TECH FIG 7B).
- The pilot hole is tapped before inserting the screw.
- Size 3.5- or 4-mm screws are generally used, based on preoperative imaging of pedicle dimensions.
- Small pedicle diameters may require a 2.7-mm screw.19
- The length of the screw ranges from 18 to 26 mm, depending on the length of the pedicle as determined on preoperative CT scans.
- The screw should be inserted to a depth no longer than two thirds of the anteroposterior width of the vertebral body, as confirmed on the lateral fluoroscopy image.
- Since the C7 pedicle is longer, a screw up to 30 mm can usually be inserted at this level.

- Computer-assisted image guidance systems have been used for pedicle screw insertion in the cervical spine.
- Preoperative CT data are used by the computer-assisted system to prepare a three-dimensional model of the vertebra.
- After registration of surface landmarks during surgery, a registered probe or drill bit can be used to locate the entry point and guide a fine drill bit through the pedicle into the vertebral body.

C2 Pedicle Screw Insertion
- The entry point for the C2 pedicle is located on the superior medial quadrant of the posterior aspect of the lateral mass of C2, 3 mm lateral to the medial edge of the isthmus, and in line with or slightly distal to the superior margin of the C2 lamina.
- The cortex is penetrated with a 3-mm burr.
- The underlying cancellous bone is probed with a fine curette or pedicle probe to locate the pedicle channel.
- The entry point and trajectory for subsequent drilling are confirmed by palpating the medial and superior margins of the C2 pedicle with a Penfield probe, and with fluoroscopy to determine sagittal angulation.
- The drill is generally angled 15 to 25 degrees medially and 20 to 30 degrees cranially.
- The integrity of the drilled hole is verified with a blunt probe and tapped, and a 3.5- to 4.0-mm screw is inserted.
- Twenty- to 22-mm screw lengths are generally used. C2 pedicle screws longer than 24 mm are likely to penetrate the anterior surface of the vertebral body and may provide superior fixation in some situations.28
- Using a polyaxial screw head allows easier compensation for the difference in medial angulation between the C2 and other subaxial pedicles when connecting to a rod.
Chapter 10  POSTERIOR CERVICAL FUSION WITH INSTRUMENTATION

OUTCOMES

Posterior Wiring Techniques
- Long-term successful fusion rates of 94% to 96% have been reported with interspinous wiring techniques when used for trauma, degenerative conditions, and tumors of the cervical spine.²²,²⁹
- Weiland and McAfee³³ reported a fusion rate of 100% when a triple-wire technique was used for subaxial posterior cervical fusion in 60 patients. Two of the 60 patients required halo vest immobilization, while the rest fused with a two-poster orthosis.
- Cahill et al⁷ reported stable fusion and acceptable alignment in all 18 patients with facet dislocations treated using bilateral oblique wiring. Fusion generally occurred within 3 to 4 months. No patients developed neurologic deterioration after wiring.
- Callahan et al⁸ reported solid fusion in 50 of 52 cases with multilevel facet fusion done after, using iliac crests or rib graft for fixation along with facet wires. Two patients who failed to achieve solid fusion were followed up with regular assessments and did not require any further management.
- Fusion rates with interspinous wiring have been found to be comparable to those obtained from lateral mass plating.²³

Lateral Mass Screw Fixation
- Ebraheim et al¹¹ retrospectively reviewed the radiographic and clinical outcomes in 36 patients treated with lateral mass plate–screw fixation for traumatic instability, post-laminectomy instability, or metastatic disease. Fusion occurred at an average of 3 months in all patients. One patient demonstrated postoperative neurologic deterioration, but this resolved with subsequent decompression.
- Fehlings et al¹³ reported successful arthrodesis in 39 (93%) of 42 patients treated with lateral mass plate–screw fixation for cervical instability at a mean follow-up of 46 months. Revision of posterior plating was required in two patients for a screw pullout. Another patient required supplementary anterior plating for progressive postoperative kyphosis.

Cervical Pedicle Screws
- Screw loosening or pullout has not been an issue with cervical pedicle screw use.
- Abumi et al³ used pedicle screw–rod fixation after correction of cervical kyphosis in 30 patients and reported excellent correction and no adverse mechanical or neurovascular sequelae related to the pedicle screws.

COMPLICATIONS

Wiring
- The most common complication reported with interspinous wiring is loss of reduction and recurrence of the deformity.
- Loss of reduction is more common when posterior wiring is done across a level with fractured posterior elements by bypassing that level.²²
- Osteoporosis or excessive tensioning of the wires may result in intraoperative or postoperative fracture of a spinous process.
- Wire breakage can occur with use of a single-strand wire.
- Use of multistrand cable reduces the risk of wire breakage.¹⁸,³⁴
- Inadvertent passage of spinous process wire through the spinal canal can lead to spinal cord injury.
- Appropriate placement of drill holes at the spinolaminar line and avoiding a ventrally placed tract between the holes on either side should avoid this complication.

Lateral Mass Screw Fixation
- In a cadaveric comparison of different screw placement techniques, Xu et al³⁵ found that violation of either the dorsal or
ventral nerve root was least likely using the modification of the Magerl technique described by An et al. Clinical studies with lateral mass screw insertion have reported a 6% incidence of nerve root injury and a 6% incidence of screw malposition. Three percent of the patients required screw removal for radiculopathy.

Screw loosening is reported to occur with a incidence ranging from 2% to 6%.[1,13,15,17] In addition to direct contact of the nerve root by the screw, radiculopathy can also occur from foraminal stenosis as the lateral mass gets pulled up to the rod during final tightening of the construct. Precise screw length and placement and appropriate contouring of the rod should minimize the incidence of this problem. Vertebral artery injuries have not been reported after lateral mass plating.

Cervical Pedicle Screws

The medial pedicle wall is the thickest, making medial perforation and spinal cord injury less likely. The lateral pedicular wall is thin, increasing the risk of lateral perforation during pedicular screw insertion. There is little to no space between the superior border of the pedicle and the superior nerve root, while there is a mean gap of 1.4 to 1.6 mm between the inferior border of the pedicle and the inferior nerve root.[36] Thus, cortical perforations of the pedicle walls by the pedicular screws are more likely to damage the vertebral artery or superior nerve roots. Abumi et al. reported a 6.7% (45/669 pedicle screws) incidence of cortical perforation by the screw in 180 consecutive patients. Three of the 180 patients developed screw-associated neurovascular complications, with two patients developing radiculopathy that resolved with nonoperative management. One patient developed vertebral artery injury without neurologic sequelae.

Kast et al. reported lateral cortical perforation with more than 25% narrowing of the vertebral artery foramen in 4 of 94 pedicular screws implanted in 26 patients. No vascular or neurologic sequelae occurred with these breaches. Three screws encroached on the intervertebral foramen; one of these screws was revised for a sensory radiculopathy.

Kotani et al. reported reduced pedicle perforation when an image-guided system was used, while other authors have not shown significant improvement in safety or accuracy with these systems.

REFERENCES

DEFINITION

- The term atlantoaxial instability encompasses a number of varied conditions that compromise the normal function of the C1–2 joint, resulting in either pain, spinal cord dysfunction, or the threat thereof.
- Atlantoaxial instability can result from trauma, including rupture of the transverse ligament, odontoid fracture, or Jefferson fracture. Nontraumatic causes include inflammatory arthropathy, osteoarthritis, congenital anomalies, rotatory subluxation, tumor, and infection.
- Several methods have been described for stabilizing the atlantoaxial complex, including wiring techniques, transarticular screw fixation, and, more recently, articular mass screws.
- We describe our technique for transarticular screw fixation and articular mass screw and rod construct to achieve atlantoaxial arthrodesis.

ANATOMY

- The first cervical vertebra, or the atlas, is unlike any other in that it lacks a vertebral body and spinous process. It consists of an anterior and posterior arch connected by two articular masses, forming a ring that pivots about the odontoid process of C-2 (FIG 1A).
- On each side of the cranial surface of the C1 posterior arch there is a groove for the vertebral artery, the first cervical nerve, and their associated venous complex. In a small subset of the population, this groove is covered by an arch of bone, the ponticulus posticus. The resulting foramen is identified as the arcuate foramen
- The articular masses of C1 give rise to the superior and inferior articular facets, which are broad and articulate with the occipital condyles superiorly and the axis inferiorly. A synovial joint also is located between the posterior aspect of C-1 and the odontoid process of the axis.
- The axis (C2) has thicker laminae and a larger bifid spinous process than a typical cervical vertebra. It is characterized further by an odontoid process that projects upward from the vertebral body. Lateral to the odontoid process, or dens, are the sloping superior articular surfaces, which articulate with the inferior articular facets of C1, forming the atlantoaxial joint. The C2 pedicle can be identified in a zone between the lamina and vertebral body, projecting superomedially (FIG 1C,D).
- C1–2 articulation: The C1–2 complex is composed of three articulations, two laterally comprised of the inferior C1 and superior C2 articular facets, and one anteriorly between the dens and the posterior aspect of the anterior C1 arch.
- The C1–2 articulation allows for 47 degrees of rotation to either side, which is approximately 50% of the lateral rotation of the entire cervical spine. Panjabi and associates showed that in the healthy spine C1–2 flexion is 11.5 degrees, extension is 10.9 degrees, lateral bending 6.7 degrees, and axial rotation to each side 38.9 degrees.
- The vertebral artery, which is the first branch of the subclavian artery medial to the anterior scalene muscle, ascends behind the common carotid artery. It then ascends through the foramina transversaria from C6 to C1. After traversing through the foramina transversaria at C1, the artery takes a sharp turn medially and posteriorly to course behind the C1 articular mass along the groove in the posterior arch of C1. It then passes through the posterior atlanto-occipital membrane before ascending through the foramen magnum as it merges with its counterpart to form the basilar artery (FIG 1E,F).
- The C1 nerve root, or the suboccipital nerve, exits cranial to the posterior arch of C1 and innervates muscles of the suboccipital triangle. The C2 nerve root, or greater occipital nerve, exits between the posterior arches of C1 and C2, posterior to the superior C1–2 articulation. It does not exit through a true foramen like the remaining subaxial cervical nerve roots. It traverses inferior to the obliquus capitus inferior to ascend through the semispinalis capitus to lie superficial to the rectus capitis. Injury to the greater occipital nerve can lead to dysesthesia of the posterior scalp and be troublesome to patients.

PATHOGENESIS

- Stability of the C1–2 articulation relies heavily on its ligamentous restraints, including the transverse, alar, and apical ligaments, and the facet capsules. Trauma may disrupt these ligamentous restraints. Also, with the advanced degeneration found in arthritic conditions, these ligamentous structures may become incompetent.
- Up to 3 mm of anterior translation of C1 on C2, as measured by the anterior atlantodental interval (AADI) on a lateral cervical radiograph, is normal. An atlantodental interval of 3.5 to 5 mm in an adult indicates potential damage to the transverse ligament, whereas an interval greater than 5 mm indicates probable injury to the transverse ligament and accessory ligaments.
- In cases of trauma, an atlantodental interval greater than 3.5 mm probably is an indication for further evaluation, and most likely requires C1–2 arthrodesis.
- In patients with inflammatory arthropathy, including rheumatoid arthritis, a canal diameter identified as posterior atlantodental interval (PADI) smaller than 14 mm is associated with a worse outcome and is an indication for decompression and fusion. The exact anterior atlantodental interval measurement is not as relevant in these patients as with trauma patients.
- Fractures that involve the osseous structures of C1 and C2 also may result in atlantoaxial instability and require arthrodesis (FIG 2B).
NATURAL HISTORY

- In the event of C1–2 trauma, the potential need for surgery arises in the setting of ligamentous instability, fractures, or a combination of the two. Atlantoaxial instability due to rupture of the transverse ligament represents a threat to the cervical spinal cord with a low likelihood of successful healing. Thus C1–2 fusion is indicated.
- Transverse ligament disruption in association with a Jefferson fracture may represent an exception to this rule, in that successful nonoperative fracture treatment (halo-vest) can lead to a “stable” C1–2 segment on flexion–extension radiographs.
- Fractures of the odontoid process may represent a primary indication for C1–2 fusion if nonoperative means (eg, halo-vest immobilization) cannot obtain or maintain an appropriate reduction, or if a patient elects surgery to avoid the use of a halo. Displaced odontoid fractures have an increased likelihood of resulting in either non- or malunion in the cases of type II and III fractures, respectively (FIG 3A).
- Primary atlanto-axial osteoarthritis is quite painful and responds poorly to nonoperative means. C1–2 fusion affords a high likelihood of symptom relief (FIG 3B).
- Cervical myelopathy due to either rheumatoid pannus or pseudo-pannus formation, as seen in older individuals with extensive subaxial spondylosis and spontaneous fusion, is unlikely to improve without surgery (FIG 3C).
- C1–2 instability due to rheumatoid arthritis may be neither symptomatic nor a neurologic threat. Thus, in this case, an ADI exceeding 3.5 mm is not, by itself, an indication for surgery. A PADI of less than 14 mm or the presence of myelopathy is a poor prognostic sign and indicates the need
for fusion. Painful C1–2 rheumatoid involvement in the face of adequate medical therapy also indicates the need for fusion. Progressive C1–2 subluxation, especially with cranial settling, also has an unfavorable natural history. C1–2 fusion in this instance will obviate the need for a future occipitocervical fusion, which has a less favorable influence on the overall condition of the cervical spine (FIG 3D,E).

- The natural history of asymptomatic C1–2 instability associated with miscellaneous conditions such as os odontoideum (FIG 3F) and Down syndrome is less clear. When such patients have symptoms, myelopathic signs, or an insufficient PADI, the potential benefits of a C1–2 fusion probably outweigh the risks of the natural history. The patient’s age, lifestyle, and activity level also must be considered in determining the need for surgery.

HISTORY AND PHYSICAL FINDINGS

- A complete history and physical examination, including a thorough neurologic examination, should be performed when evaluating a patient with C1–2 pathology. The complaints offered will vary with the presentation (eg, trauma, inflammatory arthritis, developmental, congenital).

- Patients with a traumatic injury may complain of isolated pain but also may present with neurologic deficits. A low threshold of suspicion should be maintained for patients with blunt trauma to the head or face, or with known noncontiguous fractures of the spine.

FIG 2 • A. An anterior atlantodental interval greater than 5 mm indicates likely injury to the transverse ligament and, in the setting of trauma, necessitates operative stabilization. B. An avulsion (arrow) of the transverse ligament from the ring of C1 indicates instability and may require arthrodesis of C1–2.

FIG 3 • A. Displaced odontoid fractures (type 2) have a higher likelihood of a nonunion and may require a primary C1–2 fusion. B. Joint space narrowing is a sign of C1–2 osteoarthritis and responds poorly to nonoperative management. C. Pseudo-pannus formation behind the dens in patients with rheumatoid arthritis can lead to cervical stenosis and myelopathy. It rarely improves without surgery, but will dissolve after C1–2 fusion. Flexion (D) and extension (E) lateral radiographs demonstrate C1–2 instability in a patient with rheumatoid arthritis. F. Os odontoideum is another condition associated with instability in which part of the dens is not attached to the axis body.
Some patients with rheumatoid arthritis may complain only of axial neck pain, whereas others may present with deteriorating gait and bilateral hand numbness or clumsiness without significant neck pain.

Patients with primary atlantoaxial arthritis will complain of severe neck and head pain, most often unilateral, with varying degrees of refusal to rotate their head, especially ipsilaterally toward the pain. Locking or crepitation of the affected joint may be both audible and palpable.

Physical examination should include the following:
- Active self-limited rotation of the head, especially toward the side of the pain. Normal rotation is up to 50 degrees of rotation to either side. C1–2 pathology often causes pain that limits rotation.
- Palpation of the suboccipital area near the interval between the posterior arches of C1 and C2 will elicit pain. When asked, the patient often can point to the source of their pain.
- Response to traction vs. compression combined with passive C1–2 rotation. The patient is examined supine with his or her head resting comfortably on a pillow. Passive lateral head rotation is measured with slight manual traction. In cases of C1–2 arthritis, this maneuver should provide more motion and less pain than similar motion with an axial vertex load. With slight manual traction, head rotation is increased, whereas an axial vertex load will cause pain and result in decreased rotation.
- In the setting of potential traumatic instability, however, these examination maneuvers are not applicable. The cervical spine must be immobilized until the radiographic and CT findings are known.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- In the setting of blunt trauma, plain radiographs of the cervical spine, specifically the upper cervical spine, have been shown to be inadequate.
  - McCulloch et al\(^{12}\) reported that plain radiographs have a sensitivity of 52%, a specificity of 98%, a positive predictive value (PPV) of 81%, and a negative predictive value (NPV) of 93%, whereas helical CT had a sensitivity and specificity of 98%, PPV of 81%, and NPV of 93%.
  - They concluded that although helical CT has limited ability to detect pure ligamentous injury, it is superior to plain radiographs when evaluating patients with high-energy trauma for cervical spine fractures.
- Other means may be required to evaluate potential ligamentous instability, such as an MRI scan or lateral flexion-extension radiographs under certain circumstances.
- CT with sagittal and coronal reconstruction is done routinely for diagnostic purposes as well as for preoperative planning.
- Fractures of either C1 or C2 indicate a significant likelihood of additional cervical spine fractures. As many as 50% of C1 fractures may be associated with other fractures.
- A vertebral artery angiogram is recommended when there is any question of acute injury or history of injury to the vertebral arteries. A unilateral vertebral artery injury rarely is symptomatic because of sufficient collateral flow through the contralateral vertebral artery as well as the circle of Willis. A patient with a vertebral artery injury who presents with neurologic deficits due to a concomitant spinal cord injury may be especially difficult to diagnose clinically.

We recommend imaging with either an angiogram or an MRA in all patients presenting with a significant flexion-distraction injury, fracture that extends into the transverse foramen, or facet dislocation (FIG 4).
- When discovered, this should be treated with prompt anticoagulation to prevent thromboembolic complications. If a surgical procedure is necessary, anticoagulation is stopped before and restarted after surgery.\(^{3}\)

DIFFERENTIAL DIAGNOSIS
- Rheumatoid arthritis: instability, pannus accumulation, cranial settling.
- Degenerative osteoarthritis
- Trauma: odontoid fracture, Jefferson fracture, transverse ligament rupture
- Tumor
- Infection
- Atlantoaxial rotatory subluxation: recurring subluxation, irreducible and fixed subluxation
- Miscellaneous: Down syndrome, os odontoideum

NONOPERATIVE MANAGEMENT
- In most instances a hard collar is not adequate for immobilizing an unstable C1–2 articulation, but one may be considered in an elderly patient who is not a surgical candidate and otherwise cannot tolerate a halo or Minerva vest (Variteks, Istanbul, Turkey).
- For certain fractures, use of a halo-vest may be appropriate, and the patient is treated in the orthosis for 3 months. It is a time-tested “nonoperative” option with well-defined success/failure rates.
- Some patients may require a halo for postoperative immobilization, depending on the fixation quality, the anticipated level of patient compliance with a hard collar, and other unusual circumstances.

SURGICAL MANAGEMENT
- Several different techniques have been described for successful posterior C1–2 fixation and fusion.
  - Before Jeanneret and Magerl\(^{10}\) described the transarticular screw technique, posterior fixation was accomplished with Gallie’s sublaminar wiring and grafting\(^{6}\) or by the Brooks wiring method.\(^{2}\)
Some of the newer methods include the C1 articular mass and C2 pedicle screw and rod construct described by Goel and Laheri, and the use of a C2 interlaminar screw combined with C1 articular mass screw and rod construct.

Biomechanically, the Magerl technique of transarticular fixation provides the best stability compared with traditional wiring methods, but it may be technically more demanding than either the Brooks or Gallie method of fixation.

Malreduction of C1–2, anomalous position or size of the vertebral arteries, and collapse of the lateral masses of C2 are relative contraindications to the use of the transarticular screw method because of the risk for inadvertent penetration of the vertebral artery.

Preoperative Planning

All imaging studies should be reviewed with regard to osseous anatomy as well as the course of the vertebral artery. Preoperative CT scanning with reconstructed images in the sagittal plane or in the plane of the transarticular screw is necessary to view the pertinent anatomy and to avoid injury to the vertebral artery.

Confirmation of an anatomic reduction of C1–2 intraoperatively is preferable to avoid vertebral artery injury, neurologic injury, and inadequate bony purchase of the screw. However, mild anterior displacement of C1 on C2 is well tolerated and may facilitate fixing the C1 lateral mass, as long as the PADI remains large enough to accommodate the spinal cord.

C1–2 reduction in most trauma conditions can be achieved with longitudinal traction in the awake patient. After successful reduction, a halo vest may be applied to facilitate prone positioning of the patient under anesthesia.

Positioning

The patient is placed in the prone position on bolsters with the head rigidly held in place using Mayfield tongs, or previously placed halo. The shoulders and arms are tucked at the patient’s side.

The table is adjusted into a reverse Trendelenburg orientation, with the knees bent (FIG 5). The shoulders can be depressed with wide tape if necessary to obtain a true lateral view of the C1–2 complex.

After the patient is positioned, the proper alignment of an unstable C1–2 joint should be confirmed radiographically before proceeding further. It is important to confirm that the head is in neutral rotation, to avoid an iatrogenic torticollis.

EXPOSURE

A midline posterior skin and subcutaneous incision is made from the occiput to the spinous process of C7. The deep subperiosteal dissection is confined from the upper edge of C1 to the inferior margin of the C2 laminae (TECH FIG 1).

The longer skin incision permits the correct trajectory of the drill guides, which often are tunneled through the posterior cervical extensor muscles.

A shorter skin incision could be used, with the drills, guides, and other instruments passed through percutaneous stab wounds, but we have found the cosmetic results less desirable.

Muscular infiltration with local anesthetic and epinephrine will reduce bleeding.

MAGERL METHOD OF C1-2 TRANSARTICULAR SCREW FIXATION

Sagittal and axial CT images are scrutinized preoperatively. The isthmus of the C2 pars must measure at least 4.5 mm in height and width to accommodate a transarticular screw. An abnormally large or malpositioned vertebral artery might lead to increased risk of harm to this important structure.

C1–2 reduction and the ability to obtain a true lateral view of C1–2 with a fluoroscope are confirmed.
The starting point for the transarticular screw is at the posterior cortex of the C2 inferior articular process 2 mm cephalad and 2 to 3 mm lateral to the medial border of the C2–3 facet joint.

The starting point is confirmed with a direct lateral C-arm image and marked with a 2-mm burr to provide a secure starting point for the tip of the drill bit. Caudal–cranial angulation is determined via lateral C-arm fluoroscopic guidance. The sagittal plane orientation is confirmed visually with reference to the superior and medial surfaces of the C2 pars. A Penfield 4 dissector can be placed on the dorsal surface of the C2 pars to serve as a guide on the lateral fluoroscopy view.

The K-wire is directed superiorly along the C2 pars while aiming toward the anterior arch of C1 as seen on the lateral fluoroscopic images, with slight medial angulation of 0 to 10 degrees (TECH FIG 2A,B).

We recommend leaving the drill bit or K-wire in place on the initial side to transfix the C1–2 joint, then proceeding to the opposite side. The screw on the second side is inserted before returning to the initial side to remove the drill bit, then tap and insert the second screw. This avoids any problems with loss of reduction (TECH FIG 2C–F).

Bone grafting is performed with autologous iliac crest. After careful decortication of the posterior arches, a modified Gallie technique is employed using either heavy suture or braided titanium cable to secure the graft in place (as described under Gallie Method of Sublaminar Wiring and Grafting).

The extensors at C2 are repaired with drill holes placed through the spinous process.

TECH FIG 2 • A,B. The guidewire is placed superiorly through the pars, aiming toward the anterior arch of C1 on lateral fluoroscopic images. With the first guidewire in place, a second guidewire is placed on the other side. The K-wire is overdrilled with a drill bit (C,D) and tapped, and the screw is placed on the second side (E) before the same is done on the first side. F. Postoperative radiograph of transarticular screw fixation in a patient who sustained a C1–2 fracture-dislocation.

GOEL METHOD OF C1–2 ARTICULAR MASS FIXATION

The ponticulus posticus is a common anomaly that can easily be mistaken for a broad posterior arch of the atlas, and the lateral radiograph must be reviewed to check for the presence of an arcuate foramen to avoid injuring the vertebral artery.17

The starting point for the C1 screw is in the middle of the junction of the C1 posterior arch and the midpoint of the posterior inferior part of the C1 lateral mass. The entry point is marked with a 2-mm high-speed burr.

The C2 nerve root is retracted in a caudal direction for proper screw placement. If divided proximal to the dorsal root ganglia, the patient may experience troubling neuralgia and numbness postoperatively.

The initial drill hole is made in a straight or slightly convergent trajectory in the sagittal plane and parallel to the plane of the C1 posterior arch in the coronal plane, with the tip of the drill aimed toward the anterior arch of C1 (TECH FIG 3A).
The hole is tapped and measured, and a 3.5-mm polyaxial screw of appropriate length is placed so that the screw head stays above the bony surface of the lateral mass to avoid any irritation to the greater occipital nerve.

Care should be taken when dissecting around the C1–2 articulation to avoid excessive bleeding from the epidural venous plexus in this area. Hemostasis can be achieved using bipolar electrocautery, powdered Gelfoam with thrombin, and cotton pledgets.

The center of the lateral mass of C1 is the ideal exit point of the C1 lateral mass screw, and the proximity of the internal carotid artery (ICA) places it in danger when placing a bicortical screw. The ICA can vary in location from side to side and may be within 1 mm of the ideal exit point of a bicortical transarticular screw or a C1 lateral mass screw. Medial angulation of the screw in the lateral mass of C1 may increase the margin of safety for the ICA, but care should be taken to avoid penetrating the occipitocervical joint.

Brooks wiring is the most reliable of the traditional wire fixation methods. It does not provide as much stability as other screw options, however, and so must be used in conjunction with significant postoperative immobilization, often a halo-vest, for optimal likelihood of fusion. It also requires passing sublaminar wires at C2, which can be technically demanding.

Midline posterior subperiosteal exposure of C1 and C2 laminae is carried out with careful attention to dissect from midline laterally at C1 to prevent injury to the vertebral artery. The occipital nerves emerge through the interlaminar space between C1 and C2.

The ligamentum flavum between C1 and the occiput and also between C1 and C2 is sharply divided. A Woodson instrument is used to confirm that there are no dural adhesions in the sublaminar space.

Although Brooks originally described use of two doubled 20-gauge stainless steel wires passed under each side of the arch of C1 followed by C2 with the aid of a no. 2 Mersilene suture in a cephalad-to-caudal direction, we routinely use pairs of braided titanium cables rather than stainless steel wire.

The starting point of the C2 pedicle is in the midline of the C2–3 facet joint, 3 to 5 mm cranial to the C2–C3 articulation. The trajectory is 25 degrees of medial convergence and is aimed 25 degrees cephalad, while keeping in mind that individual anatomy will vary.

A no. 4 Penfield dissector is used to feel the medial border of the C2 pars interarticularis, and the superior and medial aspects of the isthmus are palpated during the drilling process.

The drilled hole is then palpated with a blunt ball-tipped probe. The hole is tapped, and a 3.5-mm polayxial screw is inserted bicortically.

The polyaxial screw heads are connected with two rods. If necessary, a reduction of the C1–2 articulation is performed before fixation with the rods.

The posterior elements of C1 and C2 are decorticated, and a corticocancellous H-graft is secured using a modified Gallie technique (TECH FIG 3B).

The extensors at C2 are repaired using drill holes through the spinous process.
GALLIE METHOD OF SUBLAMINAR WIRING AND GRAFTING

- The Gallie method is less stable than the Brooks method and is relatively contraindicated in the presence of any posterior C1–2 instability. It also requires significant postoperative immobilization.
- The sublaminar cable is passed under the laminae of C1 and C2. We use a suture for this technique when the Gallie graft is employed in conjunction with Magerl transarticular fixation, because the Gallie configuration is relied on for maintenance of graft position, not for mechanical stability.
- A corticocancellous bone graft from the iliac crest (TECH FIG 5A) is taken and placed with the cancellous side facing down on the cortical bone has been burred to reveal a nice bleeding cancellous bed (TECH FIG 5B). The small grooves are placed on the superior and inferior edges of the graft to hold the sutures in place.
- The cable is tightened, and the graft is secured (TECH FIG 5C).

TECH FIG 5 • A. The posterior arches of C1 and C2 are decorticated. B. A corticocancellous graft is taken from the iliac crest. This is fashioned into an H shape, and the cancellous side is placed facing down on the decorticated posterior elements of C1–2. C. A modified Gallie technique is used to secure the graft in place.

PEARLS AND PITFALLS

| Bone grafting | A Gallie H-graft is fashioned from the iliac crest and contoured to fit over the posterior arches of C1 and C2, with its cancellous surface applied directly opposing the decorticated surfaces of C-1 and 2. |
| Frameless stereotactic navigation | This method registers only one vertebra, and the relation of C1 and C2 obtained on the CT scan may differ from that resulting after positioning on the operating table, resulting in aberrant screw placement and possible injury to the vertebral artery, whereas intraoperative fluoroscopy yields real time information. Caution should be used in interpreting the information presented on the 'virtual' images during surgery. |
| Injury to the vertebral artery | Careful preoperative planning will guide selection of the appropriate procedure to reduce the risk of injury. In the event of injury to a vertebral artery during a Magerl procedure, a short screw may be placed to contain the bleeding. If this occurs while drilling or tapping the first side, it is unwise to attempt a C1–2 screw on the contralateral side. An alternative fixation technique should be employed, such as a Brooks or Gallie procedure. |
| Venous bleeding in the C1 lateral mass | Gentle tamponade of the venous sinuses, along with application of hemostatic agents, is recommended. Once the surgical instruments are removed along with the pressure from the retractors, the bleeding is usually is controlled with ease. Avoid indiscriminate use of cautery. |
| Supplemental wire/cable fixation | Supplemental wiring with the Magerl, Goel, and C2 laminar screw methods provides no significant mechanical advantage. However, a suture configuration of a similar nature will hold the graft surfaces in proper apposition to the decorticated host bone, possibly improving the fusion rates. |
| C1–2 facet fusion | Originally described as a component of the Magerl procedure, direct exposure, decortication, and grafting of the posterior aspect of the C1–2 facets is not routinely necessary. It may be indicated for revision procedures, patients with incompetent posterior C–1 arches, or certain fracture patterns, or for high-risk hosts. |
POSTOPERATIVE CARE
- Whereas patients undergoing the Brooks or Gallie procedure obtain a maximal fusion rate with postoperative halo-vest immobilization, the modern screw fixation methods yield fusion rates in excess of 90% with only cervical collars worn for 6–12 weeks.
- The type of collar used and duration of wear should be in accordance with surgeon judgment about host bone, security of fixation, anticipated patient compliance, etc.

OUTCOMES
- Jeanneret and Magerl achieved solid fusion in 13 patients stabilized with the transarticular screw technique.
- McGuire and Harkey showed solid fusion in 8 patients using a transfacet screw technique.
- Fielding and associates achieved fusion in 45 of 46 patients with fractures using the Gallie technique.
- Brooks and Jenkins used a C1–2 sublaminar wiring technique to achieve fusion in 14 out of 15 patients.
- Harms reported fusion in all 37 patients with C1 lateral mass and C2 pedicle minipolyaxial screw and rod construct.
- Cost-effectiveness: The Goel C1–2 articular mass method has been popularized by Harms, and is offered as less risky than the Magerl method with respect to the vertebral artery. However, in the right patient, the Magerl method has proved to be quite safe. The cost of two 4.0-mm cannulated bone screws is substantially less than four polyaxial screws and a pair of rods.

COMPLICATIONS
- Vertebral artery and internal carotid artery injuries
- Infection
- Malpositioned screw
- Nonunion
- C2 neuralgia
- C1–2 hyperextension with Brooks or Gallie procedure if the C1 and C2 arches are compressed together.

REFERENCES
DEFINITION

- Clinically significant lumbar disc herniations are characterized by a focal distortion of the normal anatomic configuration of discal material resulting in compression and subsequent dysfunction of the lumbar nerve roots.

ANATOMY

- The functional components of the intervertebral disc are the annulus fibrosus (fibrous concentric rings, type I collagen) enclosing the central nucleus pulposus (gelatinous, type II collagen, proteoglycans), and the vertebral endplates (hyaline cartilage).
- The anatomic unit of the lumbar spine is the vertebral body with its attached posterior elements and the disc below (FIG 1A).
- The nerve roots travel within the common dural sac (the cauda equina) and then exit at each level. They are numbered according to the pedicle beneath which they pass.
- The spinal canal is divided into zones from medial to lateral: central canal, subarticular zone, foraminal zone, and extraforaminal (far-lateral) zone (FIG 1B).
- Disc herniations are best classified based in the following ways:
  - Based on the integrity of the annulus fibrosus and whether there is a connection of herniated discal material with the disc space (FIG 2)
  - Based on the anatomic location of the herniated material relative to the disc space, the canal, and the compressed nerve root using the nomenclature above (FIG 3)
- Accurate anatomic classification of disc herniations facilitates preoperative planning and can minimize the risk of surgical complications such as missed pathology and iatrogenic nerve root injury.

- The importance of a complete knowledge of spinal anatomy and understanding of the particular patient’s pathoanatomy cannot be overstated.

PATHOGENESIS

- In the normal disc, the nucleus pulposus imbibes and releases water to balance mechanical loads. The annulus fibrosus converts these loads to hoop stresses, thereby containing the nuclear material. The endplates allow diffusion of nutrition into, and waste products out of, the nucleus.
- Together, they allow for the three basic spinal segmental functions: mobility, stability, and protection of the nearby neurologic structures.
- With early or intermediate disc degeneration (natural aging with or without minor repetitive trauma), the endplates fail to allow adequate diffusion, the nucleus fails to replace degraded proteoglycans, and annular support weakens (failure of cross-linking, development of clefts). Biomechanical dysfunction occurs, with possible herniation of nuclear material.
- Many disc herniations do not cause pain or neurologic symptoms. A combination of herniation, nerve root compression, and an inflammatory interface is required for nerve root dysfunction and associated radiculopathy and sciatica.

NATURAL HISTORY

- Many studies have shown that with time and nonoperative treatment, over 90% of patients with a first-time lumbar disc herniation will get better without surgery. Accordingly, to propose surgery requires clear indications.
- Absolute indications
  - Bladder or bowel involvement secondary to a massive disc herniation and cauda equina syndrome: immediate surgical intervention

FIG 1 • A. Anatomic unit. The first floor is the disc level, the second floor is the foraminal level, and the third floor is the pedicle level. B. Regions of the canal.
**Fig 3**. The patterns of disc migration can be characterized relative to the structures of the anatomic unit (e.g., at the disc level or at the pedicle level). The area of root compression can be described relative to the nerve root anatomy (e.g., at the shoulder of the traversing root, in the axilla of the exiting root).

**Differential Diagnosis**

- Intraspinal, extrinsic compression or irritation at the level of the nerve root: spinal stenosis, osteomyelitis or discitis, neoplasm, epidural fibrosis (scar)
- Intraspinal, extrinsic compression or irritation proximal to the nerve root: conus and cauda lesions such as neurofibroma or ependymoma
- Intraspinal, intrinsic nerve root dysfunction: neuropathy (diabetic, idiopathic, alcoholic, iatrogenic [chemotherapy]), herpes zoster, arachnoiditis, nerve root tumor
- Extraspinal sources distal to the nerve root: pelvic or more distal neoplasms with associated sciatic or femoral nerve compression, sacroiliac disease (e.g., infection, osteoarthrosis), osteoarthritis of the hip, peripheral vascular disease

**Nonoperative Management**

- The evidence base is still a bit unclear, but the following are commonly recommended.
- Rest: bed rest (no more than 2 or 3 days), activity or job modification, weight loss
- Medication: analgesics, nonsteroidal anti-inflammatories, tapered doses of oral steroids
- Exercise: physical therapy (McKenzie program)
- Injections: epidural or selective root blocks (may provide some temporary relief while the natural history takes over)
- Time: 6 weeks to 3 months (unless absolute indications for surgery exist as noted above)

**Surgical Management**

- The evidence base is clear: open discectomy and microdiscectomy are the operative techniques with the best-documented long-term outcomes and are the gold standards of surgery for lumbar disc herniations.

**Imaging and Other Diagnostic Studies**

- MRI is the imaging study of choice for the diagnosis and anatomic classification of lumbar disc herniations. It is highly sensitive and specific and provides, along with the clinical picture, adequate information for detailed preoperative planning.

- CT-myelography is invasive and less specific than MRI but provides excellent sensitivity when MRI is unavailable or contraindicated.

- Plain radiographs may show disc space narrowing, early formation of osteophytes, or a “sciatic scoliosis.” While providing no direct evidence of a herniated disc, they may be helpful to rule out unexpected destructive pathology (e.g., infection, tumor, fracture) in patients who have failed to respond to nonoperative intervention or those with red flags. They also allow excellent delineation of bony anomalies that may prove vital to preoperative planning and intraoperative localization, such as transitional lumbosacral articulations or spina bifida occulta.

**History and Physical Findings**

- The most common complaint is pain with or without associated paresthesias or weakness in a specific monoradicular anatomic distribution.

**Classification of Disc Herniations**

- **A** protrusion
- **B** subannular extrusion
- **C** transannular extrusion
- **D** sequestration
The skin incision is made directly midline posteriorly and extends from the top of the cephalad spinous process to the bottom of the caudal spinous process, about 1.5 inches for single-level pathology.

From here, one of two windows of approach will be undertaken based on the location of the disc herniation: the interlaminar window or the intertransverse window.
INTERLAMINAR WINDOW

- The dorsolumbar fascia is incised just off the midline in a gentle curvilinear fashion on the involved side at a length to match the skin incision.
- A Cobb elevator is used to gently elevate the muscle (multifidus) from the spinous processes to the midportion of the facet joint laterally.
  - The degree of muscle elevation should be limited to what is necessary to allow adequate laminar exposure for laminotomy.
- A retractor is then placed. We prefer a retractor with a medial hook for the interspinous ligament and a blade for gentle lateral muscular retraction (TECH FIG 1A).
  - An intraoperative C-arm image is then obtained to confirm the level. Alternatively, a lateral radiograph can be taken.

- A cylindrical retractor, placed transmuscularly using a sequential dilation technique, is a reasonable alternative as long as great care is taken to expose the correct portion of the interlaminar window (there is a tendency to be “pushed” too far laterally).
- At this point, illumination and magnification are gained by the use of the operative microscope (our preference) or a headlamp and loupes.
- Outcomes are similar for the two when used properly, and the surgeon should decide on his or her preference based on experience and comfort level.
- A laminotomy on the undersurface of the cephalad lamina and minimal medial facetectomy is then performed using a Kerrison rongeur (TECH FIG 1B).

**TECH FIG 1 • A. Muscle retractor. B. Laminotomy. C. Laminotomy and the ligamentum. Bony excision used for the “typical disc herniation” in the canal or subarticular zones. It may need to be extended cephalad for herniations extending upward into the second story or may need to include the upper portion of the caudal lamina for herniations extending downward into the third story of the level below. The ligamentum is either freed from its insertions on the undersurface of the lamina above and the undersurface of the facet capsule laterally using a sharp curette, creating a flap, or is incised and split as depicted. D. Identifying the lateral edge of the root. The traversing root is readily identified by vessels that travel along its lateral edge longitudinally, rise up onto its shoulder, and form a plexus in its axilla. Further caudally, the root is closely associated with the medial border of the pedicle.**
The degree of laminotomy and facetectomy should be enough to allow full visualization of the underlying nerve root at the area of compression and to allow access for excision of herniated disc material—no more and no less.

For small disc herniations in the canal or subarticular zones (the “typical disc herniation”), minimal bony excision is required at lower lumbar levels.

For larger disc herniations and those extending cephalad into the second story, a larger laminotomy or even hemilaminectomy may be required. The key in these situations is to preserve at least 5 mm of the lateral pars interarticularis and at least 50% of the medial facet.

Laminotomy of the upper surface of the caudal lamina is generally not needed unless the herniated material has migrated caudally to the third story of the level below adjacent to the pedicle.

The ligamentum flavum is then addressed. One of two techniques is used: the Rick Delamarter and John McCulloch flap or the Rob Fraser split (TECH FIG 1C). The former preserves the ligamentum flavum as a complete barrier to minimize scar formation from posterior, while the latter offers a little less coverage but preserves the ligament’s biomechanical integrity.

The lateral edge of the traversing nerve root is then identified.

This is readily identified by consistent lateral veins and the root’s association with the pedicle (TECH FIG 1D). These veins can then be gently mobilized to allow exposure of the underlying annulus. Occasionally, anomalous roots lateral to the traversing root may be present. Again, safety is ensured by identifying the veins directly overlying the annulus and using these to provide a window to access.

Herniation Exposure

For herniations within the canal or subarticular zones and in the first or second story (85% of encountered discs), the traversing nerve root is gently mobilized medially, allowing exposure of the herniated disc.

If the root is immobile, the surgeon should excise more bone within the subarticular region (medial facetectomy) to afford visualization and palpation of the medial border of the pedicle associated with the traversing root.

Access to the disc cephalad to this will be within a safe zone lateral to the traversing root and within the axilla of the exiting root.

Once larger fragments are teased out, the traversing root will become mobile, allowing greater access.

Retraction should be minimal at upper levels (L1–L3 due to presence of the conus) and limited to about 40%—that is, to less than half the width of the unilateral hemilaminotomy below this (TECH FIG 2).

Retraction should be relaxed during periods in which no active work is undertaken in or near the disc space: the nerve is rested while the pituitary rongeur is being cleaned, and gently re-retracted when it returns. This will minimize trauma to the root.

Hemostasis is then obtained by gently tucking small pieces of Gelfoam or thrombin cephalad and caudally to the exposed disc space. These are to be removed at the end of the case.

If bipolar cautery is used, it should be done with caution to avoid root injury.

Herniations extending caudally to the third story of the level below (uncommon, 5%) are most often within the “axilla” of the traversing root. Retraction of the root is not used; rather, the herniation (usually sequestered) is gently teased out.

Discectomy

Once visualized, any free disc material is removed with a pituitary rongeur. A ball-tipped probe is used to tease out any additional free fragments hiding further out in the subarticular zone or under the common dural sac or root.

The disc space is then entered (this will be the first step in “contained” herniations) by annulotomy. A long-handled no. 15 blade facing away from the traversing root is used, preferably with a longitudinal orientation.

Within the disc space, any loose fragments are removed with the pituitary rongeur (TECH FIG 3), and the disc space is irrigated.

More aggressive excision (“complete discectomy”) may slightly decrease the risk of recurrence, but at the price of increased back pain and a potential for accelerating the degenerative process.

Depth of work should be limited to avoid anterior perforation and potential vascular injury. The surgeon should respect the anterior portion of the annulus and avoid perforating it with an instrument.

Discectomy is complete when no additional loose fragments can be removed from the disc space and free mobility of the nerve root is confirmed.
The root retractor is then removed, along with the pieces of Gelfoam. The wound is thoroughly irrigated. This “washing,” coupled with removing the root retractor, is usually adequate to stop any epidural bleeding. If it persists, temporarily placing Gelfoam again is almost always adequate. Unless there is still a bit of oozing, drains are generally not indicated, and the wound is closed in three layers (fascia, subcutaneous tissue, and skin [absorbable, subcuticular]).

INTERTRANSVERSE WINDOW

- The dorsolumbar fascia is incised 1.5 fingerbreadths off the midline longitudinally (TECH FIG 4A).
- The plane between the multifidus medially and the longissimus laterally is freed by finger dissection, allowing palpation of the facet joint.
- A retractor is placed within this plane (TECH FIG 4B) and an intraoperative C-arm image is obtained to confirm the level.
- The tip of the superior articular process and the lateral pars interarticularis are exposed with electrocautery and partially resected (TECH FIG 4C,D).
- The intertransverse membrane is gently retracted laterally using a ball-tipped probe.
- Gentle blunt dissection is used to identify the exiting nerve root and the underlying herniated material.

Gentle technique, patience, and really good lighting and magnification are required here (again, we prefer the operative microscope, but outcomes are similar regardless). There is plenty of adipose tissue and a venous plexus surrounding the dorsal root ganglion of the root that must be identified before introducing the pituitary rongeur.

- A ball-tipped probe and pituitary rongeur are used to gently tease out the loose fragment, with minimal to no retraction applied to the root. This can be traced back into the disc space as necessary and any loose fragments removed.
- The wound is irrigated, hemostasis is obtained, and closure is performed as described above.

TECH FIG 3 • Discectomy. After annulotomy, the pituitary rongeur is used to remove the herniation and loose fragments within the disc space.

TECH FIG 4 • A. The fascial incision is made 1.5 fingerbreadths from the midline. B. Retraction. (continued)
POSTOPERATIVE CARE

- After surgery, patients may be fitted with a light lumbar corset if desired and are encouraged to walk once anesthesia has worn off and pain permits. About 85% are discharged as outpatients. Fifteen percent will be older (less mobile) or have nausea and vomiting requiring an overnight stay and 23-hour observation.

- Once home, patients engage in a program of progressive walking, stretching, and corset use for comfort. For those progressing slowly, physical therapy may be introduced. Heavy lifting and excessive bending and twisting should be avoided in the first few weeks.

- If all is well, they may drive in about a week and return to light work once they feel up to it. Heavy labor should be avoided for 6 to 12 weeks to ensure proper soft tissue healing (skin, muscle, annulotomy). Long-term activities are not restricted.
OUTCOMES
- There is an 85% likelihood of an excellent or good outcome 5 years postoperatively.
- Patients with significant medical or social comorbidities (eg, diabetes, heavy smoking), worker’s compensation or litigation, and psychological problems (depression) are less likely to do well.
  - Each factor is associated with a 15% reduction in the likelihood of an excellent or good outcome.
- Truly informed consent is recommended.

COMPLICATIONS
- Surgeon-dependent: wrong level, wrong side, missed pathology, iatrogenic instability, “battered root syndrome,” dural tear, hemorrhage, positioning (eg, eyes, ulnar nerve)
- Operative environment or patient-dependent: wound infection, disc space infection, urinary retention, thrombophlebitis or pulmonary embolism

REFERENCES
DEFINITION
- Degenerative changes that are part of the aging process may lead to compression of neurologic tissues within the spinal canal or subarticular zones (with or without the foraminal zone) of the lumbar spine.
- This spinal canal stenosis may lead to neurogenic claudication or a monoradiculopathy.

ANATOMY
- The functional vertebral unit is depicted in FIGURE 1. More details are given in the anatomy section of Chapter SP-12.
- Spinal canal stenosis is best classified based on vertical extent of compression, regions of the canal involved, and severity of the involvement.
- Accurate anatomic classification facilitates preoperative planning and can minimize the risk of surgical complications such as missed pathology and iatrogenic root injury.

PATHOGENESIS
- Degenerative changes can affect the disc, the soft tissues, and the facet joints of the spinal unit.
- Annular bulging of the disc, ligamentum flavum hypertrophy and infolding, and osteophyte formation on the facet joints can contribute to neurologic compression. Occasionally, epidural lipomatosis also contributes to spinal stenosis, especially in the presence of insulin-dependent diabetes mellitus (IDDM).
- This compression occurs slowly and gradually affects the blood supply (arterial inflow and venous outflow) of traversing nerve roots and the free flow of cerebrospinal fluid within the common dural sac. When increased demands are placed, as in walking, the nutritional needs of the nerve roots cannot be met and noxious byproducts of metabolism cannot be removed, resulting in neurophysiologic malfunction characterized clinically by paresthetic and cramping symptoms in the legs.
- As in lumbar disc herniations, many patients with spinal stenosis are asymptomatic, suggesting that other factors intrinsic to nerve root function and adaptability are equally important (eg, smoking, vascular disease, diabetes).

NATURAL HISTORY
- Patients with mild to moderate symptoms and mild to moderate neurologic compression may respond to conservative care. Unless the compression increases, symptoms generally remain stable, with minimal resolution and minimal worsening.
- The more severe the symptoms and the more severe the neurologic compression, the more likely symptoms will progress, the less likely they will respond to conservative measures, and the more likely patients will seek surgical intervention.

HISTORY AND PHYSICAL FINDINGS
- Symptomatic patients with spinal canal stenosis generally present with neurogenic claudication (70%), monoradiculopathy (15%), or a combination of the two.
- Foraminal stenosis (10% to 15% of cases) is best diagnosed clinically by a severe monoradiculopathy of an exiting nerve root, and radiographically on parasagittal MRI imaging or CT sagittal reconstruction (FIG 2).

IMAGING
- As described in Chapter SP-12, MRI is the imaging study of choice for the diagnosis and anatomic classification of spinal canal stenosis.
- CT myelography is invasive and can better resolve the bony component of stenosis compared to MRI. Myelograms taken in flexion-extension may demonstrate a dynamic component to the stenosis. CT myelograms may be particularly useful in patients who have had prior surgery (where MRI may be difficult to interpret due to scarring) and in those with associated spinal deformity (eg, scoliosis).
- Plain radiographs are useful in demonstrating instability in the coronal (lateral listhesis) or sagittal (spondylolisthesis) planes that may need to be addressed with fusion in addition to decompression. Upright anteroposterior, lateral, and flexion-extension views can be obtained.

DIFFERENTIAL DIAGNOSIS
- Vascular claudication, bilateral hip osteoarthritis, peripheral neuropathy, and “pump problems” such as congestive heart failure or coronary artery disease resulting in poor peripheral vascular flow.

NONOPERATIVE MANAGEMENT
- Patients with mild or moderate claudicant symptoms may respond to physical therapy, nonsteroidal anti-inflammatories, and epidural or root sleeve steroid injections. While some patients may relapse into symptoms, many in this group are content to repeat these efforts or to live with their symptoms.
- Patients with significant claudication generally do not respond to nonoperative measures, or they respond only temporarily. Most will elect to undergo operative decompression. Similar to disc herniations, absolute surgical indications include a cauda equina syndrome and progressive neurologic deficits.

SURGICAL MANAGEMENT
- The evidence base is clear: decompressive laminectomy or laminotomy is the operative technique with the best-documented long-term outcomes and is the gold standard of surgery for spinal canal stenosis.
Preoperative Planning
- Planning is vital and should aim to answer several questions:
  - What is the patient’s clinical syndrome?
  - What levels are involved?
  - Is the involvement “intersegmental”?
  - Are the foramina involved?
  - Is there associated pathology: disc herniation, synovial cyst, or degenerative spondylolisthesis or lateral listhesis?
- The answers to these questions will direct the surgical approach, with the goal being complete and safe decompression of compressed neurologic tissue while minimizing damage to tissues not directly involved in the pathologic process.

Positioning
- Prone positioning on a well-padded frame is used (generally the Andrew’s, Wilson, or Jackson; see Fig 4A in SP-12). The hips and knees are gently flexed to decrease lumbar lordosis and to facilitate the interlaminar approach. The abdomen is free to decrease intra-abdominal pressure and venous backflow into the canal.
- Shoulders should be gently flexed and abducted to less than 90 degrees; eyes, elbows, knees, and feet need to be well padded.
- A needle is passed between and lateral to the spinous processes at the involved level or levels and C-arm imaging used to confirm the level. The needle is removed and the level or levels are marked and labeled on the skin (see Fig 4B in SP-12).

Approach
- After initial dissection, one of two windows will be undertaken based on the location of stenosis: the interlaminar window or the intertransverse window.
- The traditional interlaminar approach of laminotomy or laminectomy is used in about 90% of cases of spinal canal stenosis requiring operative intervention.
  - It is used to decompress soft and bony tissues that compress the neurologic structures within the central canal and subarticular zones throughout the lumbar spine.
- Two less invasive approaches may also be used and have outcomes similar to those seen with the more traditional approach: microdecompression via a unilateral approach and microdecompression via spinous process osteotomies.
  - Both techniques afford bilateral decompression of spinal canal stenosis via a unilateral approach.
INCISION

- The skin incision is made directly midline posteriorly and extends from the top of the most cephalad involved spinous process to the bottom of the most caudally involved spinous process (about 1.5 inches for single-level pathology).
- The subcutaneous tissues are gently mobilized and retracted to allow visualization of the dorsolumbar fascia.

Traditional Interlaminar Window for Decompression

- The dorsolumbar fascia is incised in the midline along the length of the skin incision, allowing exposure of spinous processes at each level.
- A Cobb elevator is then used to gently elevate the muscles (multifidus) from the spinous processes and laminae to the midportion of the facet joints bilaterally.
- A retractor is then placed and an intraoperative fluoroscopic image obtained to confirm the levels.
- At this point, illumination or magnification, based upon surgeon preference and experience, is gained by the use of the operative microscope or headlamp or loupes.
- A midline laminotomy is performed on the undersurface of the cephalad lamina to above the level of the insertion of the ligamentum flavum.
  - This laminotomy is then continued into the subarticular zone laterally (medial facetectomy) and then to include the superior surface of the caudal lamina (TECH FIG 1).
  - This bony work allows for exposure and excision of soft and hard tissues compressing the common dural sac and nerve roots and should be enough to get the job done safely and completely while avoiding iatrogenic injury.
- In cases with concomitant congenital stenosis (involvement in the anatomic “third story” [see Chap. SP-12]; about 15% of cases), complete midline laminectomy may be needed because the lamina itself is part of the pathologic compressive process.
  - In the absence of congenital stenosis or deformity, a decompressive procedure that spans the distance from the top to the bottom of the facet joint will adequately decompress the central portion of the canal in most cases. This is because in most cases central stenosis occurs where the disc, ligamentum flavum, and facets converge to impinge upon neural structures.
- Soft and hard compressive tissue is then excised, allowing for decompression of the common dural sac and nerve roots.
  - Generally, no retraction of the underlying dura and roots is needed since most pathology is visible and accessible posteriorly.
  - Concomitant pathology will also need to be addressed if present.
  - Degenerative spondylolisthesis should be treated by spinal fusion with or without instrumentation, as discussed in following chapters.
  - Synovial cysts will need to be completely excised and the pseudocapsule gently peeled from the dura.
  - Disc herniation should be addressed as described in Chapter SP-12.
- The process is repeated at each clinically involved level. Generally, a residual laminar bridge is maintained at each level for routine decompression for degenerative stenosis (laminotomy). Cases of congenital stenosis require midline laminectomy given the compression within the “third story.”
- The wound is then irrigated and hemostasis obtained. The use of a drain is optional, depending on the degree of oozing. The wound is then closed in three layers (fascia, subcutaneous tissue, skin in running subarticular fashion).

TECH FIG 1 • Laminotomy or laminectomy is performed to allow access to the ligamentum flavum, which is excised in its entirety in a trumpeted fashion throughout the segment. Medial facetectomy is included to address any bony stenosis in the subarticular zones.
MICRODECOMPRESSIVE VIA THE INTERLAMINAR WINDOW

Unilateral Approach
- Microdecompression via a unilateral approach may be used for patients with a predominant monoradiculopathy with or without neurogenic claudication and degenerative stenosis with minimal to no spondylolisthesis.
  - In other words, it is a good option in any case that may be adequately decompressed via laminotomy.
  - A unilateral approach and decompression similar to that described above is undertaken on the ipsilateral side.
  - The contralateral side is decompressed via excision of the inferior half of the spinous process and laminar junction, allowing exposure and excision (by working underneath the interspinous ligament) of the contralateral ligamentum flavum via progressive angulation of the microscope, progressive resection of the contralateral laminae (covering the entire area where the ligamentum inserts), and ligamentum resection in its entirety (TECH FIG 2).
  - This operation is technically demanding but affords a recovery similar to that seen with microdiscectomy.

Spinous Process Osteotomy Approach
- Microdecompression via spinous process osteotomies may be used as a less invasive alternative for surgeons more comfortable with the traditional approach.
  - It affords the visualization of traditional midline approaches while preserving the spinous process and interspinous and supraspinous ligaments.
  - A unilateral approach is used, similar to typical discectomy.
  - The spinous processes are then osteotomized just posterior to their junction with the laminae.
  - When the retractor is placed, the typical bilateral interlaminar window is exposed and decompression as described above is undertaken (TECH FIG 3).
  - Once the retractor is removed, the spinous processes fall back into place and generally heal back to the residual laminar ring.

TECH FIG 2 • Microdecompression. A unilateral approach is used and a unilateral decompression performed. The contralateral side is decompressed by angulating under the interspinous ligament in a trumpeted fashion.

TECH FIG 3 • Spinous process osteotomies. A unilateral approach is used and the spinous processes are osteotomized near their base. The spines are then retracted, allowing exposure of the “usual” interlaminar window. After decompression, the spines fall back into place and generally heal to the residual laminar bridge.
Chapter 13 LUMBAR DECOMPRESSION

FORAMINAL DECOMPRESSION VIA THE INTERTRANSVERSE WINDOW

- Foraminal stenosis may be present with or without associated stenosis within the central canal and subarticular zone (addressed separately as above). With the exception of L5–S1, where it is accessible via an interlaminar window, it will need to be addressed via the intertransverse window.
- Adequate decompression of foraminal stenosis via an interlaminar approach requires resection of the lateral pars and results in potential instability at the level. The intertransverse window is a less morbid and easier approach to the foraminal zone and requires minimal resection of the lateral pars.
- The multifidus is taken medially and the longissimus is taken laterally by finger dissection, allowing placement of a retractor in this intermuscular–nervous plane.
- The tip of the superior articular process and the lateral pars interarticularis are exposed with electrocautery.
- Staying within the capsule of the facet joint to protect the underlying exiting root, the surgeon excises the tip of the superior articular process entirely, affording a bony decompression of the foramen (TECH FIG 4). Concomitant soft tissue stenosis (ligamentum flavum insertion in the subarticular zone or lateral disc herniation) can then be easily addressed if present.
- Irrigation, hemostasis, and closure are performed as described above.

TECH FIG 4 • Foraminal decompression. Excision of the tip of the superior articular process and part of the pars interarticularis via a paraspinal approach (A) affords decompression of the exiting root in the foramen (B).

PEARLS AND PITFALLS

<table>
<thead>
<tr>
<th>Wrong-level exposure, exploration, and surgery are always a concern.</th>
<th>The recommendations in Chapter SP-12 discuss how to limit these possibilities.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revision decompression is difficult due to significant midline scar formation.</td>
<td>The goals should be to find residual lamina and to excise this cephalad and laterally, allowing exposure of previously undisturbed dura and roots. The decompression can then be carried caudally and medially using this normal dura as a guide.</td>
</tr>
</tbody>
</table>

POSTOPERATIVE CARE

- After surgery, patients are fitted with a light lumbar corset and are encouraged to walk once anesthesia has worn off and pain permits. About 25% will be ready for discharge as 23-hour observation patients. The others (older patients and those with comorbidities) are discharged once they are medically stable and can mobilize adequately.
- Once home, patients engage in a program of progressive walking, stretching, and corset use for comfort. For those progressing slowly, physical therapy may be introduced.
- If all is well, they may drive in about a week and return to light work once they feel up to it. Heavy labor should be avoided for 6 to 12 weeks to ensure proper soft tissue healing. Long-term activities are not restricted.

OUTCOMES

- In most patients, there is an 80% likelihood of an excellent or good outcome 2 years after surgery.
- Patients with significant medical comorbidities (e.g., diabetes, heavy smoking, peripheral vessel disease, coronary artery
disease) are less likely to do well; these comorbidities reduce the likelihood of an excellent or good result by an estimated 15% to 20%.

- Truly informed consent is recommended, as these procedures are not benign in this population.

**COMPLICATIONS**

- Dependent on the surgeon: wrong level, wrong side, missed pathology, iatrogenic instability, root injury, dural tear, hemorrhage, positioning (eg, eyes, ulnar nerve)
- Dependent on the operative environment and patient: wound infection, urinary retention, thrombophlebitis or pulmonary embolism

**REFERENCES**

ANATOMY
- Pedicle morphology is detailed in Table 1.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- Standing posteroanterior and lateral radiographs should be obtained whenever possible.
- Additional flexion-extension views may provide insight into subtle instabilities (FIG 1).
- Full-length posteroanterior and lateral radiographs are obtained in cases of spinal deformity to assess for global balance (coronal or sagittal).
- Lateral bending views can help determine the flexibility of the curve and levels for fusion.
- Axial computed tomography (CT) images can provide invaluable information about pedicle morphology, particularly in the setting of deformity.

SURGICAL MANAGEMENT
Indications
- Degenerative
- Spondylolisthesis
- Iatrogenic instability
- Discogenic back pain
- Pseudarthroses
- Adult deformity
- Curve progression
- Neurologic deficit
- Back pain refractory to nonoperative care
- Pulmonary compromise secondary to deformity
- Coronal or sagittal imbalance
- Pediatric deformity
- Progressive scoliosis more than 50 degrees
- Kyphosis more than 75 degrees
- Curve progression despite bracing in a skeletally immature individual
- Isthmic spondylolisthesis more than 50%

Preoperative Planning
- Pedicle anatomy can be best assessed on CT (FIG 2).
- A general assessment as to whether a pedicle is instrumentable can be gained by examining its size on an anteroposterior radiograph of the pedicle.
- Pedicle width and length and starting points can be determined from the axial image.

Positioning
- Patients should be placed in the prone position on a radiolucent table (FIG 3).
- Care is taken to ensure that the neck is in a neutral position and is not hyperextended.
- The arms are positioned at 90 degrees or less of abduction to minimize the likelihood of rotator cuff impingement. The arms are allowed to hang down slightly in a forward-flexed position about 10 degrees. The axilla should be clear from any padding to prevent brachial plexus palsy.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Pedicle Morphology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>Thoracic</td>
</tr>
<tr>
<td>Size</td>
<td>Width increases cephalad and caudad to T5. T5 is the smallest pedicle (mean 4.5 mm).</td>
</tr>
<tr>
<td></td>
<td>T12 is angled laterally; T11 is neutral.</td>
</tr>
<tr>
<td></td>
<td>Vertical angulation</td>
</tr>
<tr>
<td></td>
<td>Length</td>
</tr>
</tbody>
</table>
### Table 2: Pedicle Screw Starting Points

<table>
<thead>
<tr>
<th>Region</th>
<th>Starting Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal thoracic (T1–T3)</td>
<td>Junction of the midpoint of the transverse process and the lateral pars</td>
</tr>
<tr>
<td>Midthoracic (T4–T9)</td>
<td>Junction of the proximal transverse process and the lateral third of the superior articular process</td>
</tr>
<tr>
<td>Distal thoracic (T10–T12)</td>
<td>Junction of the midpoint of the transverse process and the lateral pars</td>
</tr>
<tr>
<td>Lumbar</td>
<td>At the inferolateral aspect of the L5–S1 facet joint</td>
</tr>
<tr>
<td>Sacral</td>
<td></td>
</tr>
</tbody>
</table>

- Elbow pads are placed along the medial epicondyle to protect the ulnar nerve.
- The chest pad is placed just proximal to the level of the xiphoid process and distal to the axilla. In women, care is taken to tuck the breasts and ensure that the nipples are pressure-free.
- The iliac pads are placed two fingerbreadths distal to the anterior superior iliac spine, allowing the abdomen to hang free and reducing any unnecessary epidural bleeding.
- Proper placement of the chest and iliac pads allows for optimal restoration of sagittal alignment via gravity.

### Approach

- Two approaches are used: the midline approach and the paraspinal approach.
- The midline approach is used for most spinal procedures as it allows direct access to the spinal canal.
- The paraspinal approach, also known as the Wiltse approach, was initially described for spondylolisthesis but is also used for far-lateral discectomies and minimally invasive muscle-sparing techniques (eg, minimally invasive pedicle screw instrumentation or transforaminal lumbar interbody fusion).
- Specific screw entry points are detailed in Table 2.
Chapter 14  POSTEROLATERAL THORACOLUMBAR FUSION WITH INSTRUMENTATION 4611

THORACOLUMBAR PEDICLE SCREW PLACEMENT

Pedicle Start Point

- Once the bony anatomy of the dorsal elements is meticulously exposed, the proper position of the pedicle entry point is defined. Anatomic landmarks include the lateral edge of the facet joint, the pars interarticularis, and the transverse processes (TECH FIG 1A).
- The actual pedicle starting point may vary significantly from the commonly quoted “norms” in many patients. What follows are general guidelines. Preoperative imaging studies (such as CT scan, or even the relationship between the pedicle and the lateral aspect of the pars on an anteroposterior radiograph) can provide clues about anatomic variations in a given patient or level.
- In both the lower (T10–12) and upper (T1–3) thoracic spine, the entry point is at the junction of the bisected transverse process and the lateral edge of the pars interarticularis.
  - In the midthoracic region (T5–9), the starting point is more medial and cephalad. Here, it is at the junction of the superior margin of the transverse process and the lateral third of the superior articular process (TECH FIG 1B).
- In the lumbar spine, the entry point is at the midpoint of the transverse process and 2 mm lateral to the pars interarticularis.
  - The sacral entry point is at the inferolateral aspect of the L5–S1 facet joint.
  - Using a 4-mm high-speed burr, the posterior cortex is breached to a depth of about 5 mm (TECH FIG 1C).
  - Alternatively, the “bull’s-eye” technique with fluoroscopy can be used to correctly identify the starting point, particularly when patient anatomy is distorted (TECH FIG 1D).

Cannulating the Pedicle

- A 3.2-mm hand drill is placed into the starting hole and advanced along the axis of the pedicle (TECH FIG 2A,B).

The drill is advanced under fluoroscopic guidance into the vertebral body to an ultimate depth of 35 to 40 mm in the lumbosacral spine, 25 to 30 mm in the lower and upper thoracic spine, and 30 to 35 mm in the midthoracic spine.

- Measurements of pedicle length can be made on axial CT or MRI scans and used to guide screw length.
- The advantage of using a hand drill is that cortical violations are lessened. When resistance is met (cortex), the drill fails to advance, and consequently the angle is adjusted.
- Alternatively, a “gearshift” type of device can be used to sound the pedicle. The gearshift should be rotated or wiggled as it is advanced with only gentle pressure. This technique allows the instrument to seek the proper path within cancellous bone rather than being pushed forcefully through a cortical wall. The process is analogous to feeding a guidewire into a vein during central line placement: the idea is to provide guidance, not force, to the instrument as it navigates a path within the cortical margins of the bone.
- For the S1 pedicle, the drill is directed 25 degrees medially and 10 degrees inferiorly toward the sacral promontory. A lateral fluoroscopic image is used to identify the sacral promontory (TECH FIG 2C).
- Ideally, the screw tip should achieve tricortical purchase (engaging the anterior and posterior cortex and superior endplate of S1) (TECH FIG 2D).
- A flexible ball-tipped probe is then advanced down the pedicle tract. Bone should be encountered at the base of the tract as well as along all four walls of the pedicle.
- Medial and lateral cortical breaching is most common as the pedicle is narrowest in this plane.
- A medial pedicle breach is most likely to occur at a depth between 15 and 20 mm ventral to the transverse process, which is the depth at which the spinal canal is encountered in most levels.
If a proper start site is selected, lateral breaches are more likely to occur deeper than 20 mm due to failure to medialize and follow the proper trajectory as the pedicle transitions into the vertebral body. However, if the start site is too lateral, a lateral breach may occur more superficially.

Pedicle Screw Sizing

- With the ball-tipped probe advanced along the length of the pedicle tract, the surgeon measures the tract depth using a hemostat and a ruler (TECH FIG 3A).
- In general, pedicles are tapped 1 mm smaller than the diameter of the screw to be used to optimize screw purchase. If the pedicle is sclerotic, "line-to-line" tapping should be performed. If the patient is osteoporotic, tapping is not necessary.
- After tapping, the ball-tipped probe is again advanced through the pedicle tract to confirm that the pedicle cortices and anterior vertebral body are intact.

- A Kirschner wire is then placed into the pedicle while the remaining pedicle tracts are cannulated.
- All Kirschner wires are confirmed to be positioned properly via fluoroscopy. At this point, fusion bed preparation may occur (TECH FIG 3B,C).

Fusion Bed Preparation

- The wound is copiously irrigated before decortication to preserve the local bone graft generated with high-speed burring.
- Using a high-speed burr, the transverse process, the pars interarticularis, and the lateral wall of the facet joint of each level to be fused are decorticated.
- Bone graft is placed over the decorticated areas. The fusion bed can be prepared with any combination of autogenous iliac crest bone graft, autogenous local bone graft (from the spinous processes and lamina), allograft, demineralized bone matrix, or bone morphogenic protein (TECH FIG 4).
PELVIC FIXATION

- Sacropelvic fixation can be used in the setting of long-deformity reconstructions and tumor and in traumatic settings involving the lower lumbosacral spine.
- Modern pelvic fixation is most easily accomplished via modular iliac screw placement.
- After dissection of the posterior superior iliac spine, a starting point is identified 1.5 cm distal to the tubercle.
- A burr or rongeur is used to create a recessed defect such that the iliac screw head will lie recessed within the posterior superior iliac spine.
- A gearshift is then inserted into the starting point and advanced between the inner and outer tables of the pelvis, with the medial point of the probe scraping along the medial wall.
  - The trajectory should generally aim toward the hip joint.
  - The cortex of the medial wall is thicker than the lateral, and thus lateral violations are more likely than medial violations.
- A ball-tipped probe is used to assess the inner and outer tables.
- Depth is measured and the screw is inserted. The screw is typically 7.5 to 8.5 mm in diameter and roughly 60 to 80 mm long (TECH FIG 5).

CROSS-CONNECTORS

- Cross-connectors can significantly increase the rotational and bending stiffness of a multilevel construct.
- One, two, or three cross-links can be used, depending on the length of the construct. If multiple cross-connectors are used, they should be spread as far apart as possible from each other for maximal construct rigidity.

HOOK INSERTION

- Hooks can be placed about the pedicle, transverse process, or lamina.
- Fixation is increased with a claw configuration.
- A claw configuration is composed of two hooks directed toward each other, separated by one or two levels. Claws are primarily used at the ends of a construct (TECH FIG 6A).
- Pedicle hooks provide the strongest fixation of all hook constructs. Always oriented cephalad, the pedicle hook is placed between the lamina of the superior vertebra and the superior articular process of the inferior vertebra (TECH FIG 6B). The U-shaped tip fits around the pedicle and allows for increased stability.
- The inferior facet of the vertebra can be removed with an osteotome. It is helpful to resect enough of the facet so that the lateral edge of the spinal canal is identified so that it can be avoided during implant placement. The cartilage of the superior facet is removed with a curette. A pedicle hook developer is

TECH FIG 4 • After decortication, bone graft is placed over the decorticated areas.

TECH FIG 5 • Fusion to pelvis with iliac screws.

TECH FIG 6A

TECH FIG 6B
**TECH FIG 6** • A. Thoracic hooks oriented in the claw configuration. B. Placement of a thoracic pedicle hook. C. A pedicle hook developer developing a plane for the pedicle hook. D. Placement of an upgoing laminar hook. E. Upgoing and downgoing transverse process hooks.

**PEARLS AND PITFALLS**

- Careful assessment of preoperative imaging (CT) allows for more accurate pedicle screw placement.
- Breaching the medial or inferior pedicle cortex endangers the exiting nerve root. Medial pedicle breaches are typically identified at a depth of 15 to 20 mm.
- Fluoroscopy can be used to identify proper pedicle starting points when patient anatomy is distorted.
- Too medial a starting point for pedicle screw entry may injure the supra-adjacent facet joint.

**POSTOPERATIVE CARE**

- With secure multilevel pedicle screw fixation, it is probably not necessary to brace patients postoperatively, although that decision should be individualized based on the patient’s pathology.

**COMPLICATIONS**

- Infection
  - The incidence of infection for posterior spine surgery is increased with the addition of an instrumented fusion.
  - A 1% infection rate has been noted for discectomies, a 6% infection rate for discectomies and fusion.
Although there is a wide range reported for instrumented posterior fusions, the overall infection rate appears to be around 5% to 6%.

Pseudarthrosis (nonunion rates, particularly crossing the lumbosacral junction)

- The incidence of nonunion after posterior lateral intertransverse fusion ranges from 3% to 25%.
- Smoking has been shown to be a risk factor for nonunion.
- A wide range of fusion rates across the lumbosacral junction has been reported (22% to 89%).
- A 92.5% fusion rate is reported across the L5–S1 junction when using iliac screws.

Neurologic and vascular injury

- Although there is potential for severe vascular injury with pedicle screws in the thoracolumbar spine, vascular complications are rare, outside of a few reports.
- The risk of nerve root irritation has been reported to be very low (0.2%) from pedicle screw instrumentation.

REFERENCES

Several types of lumbar arthrodesis have been developed to address the various pathologic processes that occur.
Each of these fusion techniques offers certain advantages and disadvantages that provide the surgeon with a range of options for addressing each patient’s condition.

The standard lumbar arthrodesis techniques include:
- Anterior lumbar interbody fusion (ALIF)
- Posterior spinal fusion (PSF), which includes two subtypes: posterior interlaminar and facet fusion
- Posterior lateral intertransverse fusion
- Combined anterior and posterior fusion (AP fusion or 360-degree fusion)
- Posterior lumbar interbody fusion (PLIF) and its variant the transforaminal lumbar interbody fusion (TLIF)
- The PLIF procedure uses a posterior approach to the spine that involves radical discectomy and endplate preparation combined with an interbody fusion using a structural graft or cage with or without supplemental posterior instrumentation.
- The TLIF procedure is similar to PLIF with the modification that the interbody region is accessed unilaterally via a more lateral approach in conjunction with pedicle screw instrumentation.
- PLIF and TLIF are versatile techniques that offer several advantages over the other fusion methods.
  - They allow for pathology in all three columns of the spine to be addressed and for a circumferential fusion to be achieved through a single posterior approach.
  - They directly address the disc as a potential pain generator in patients with discogenic pain syndromes.
  - They have demonstrated a high rate of fusion that approximates the arthrodesis rate achieved with a more extensive combined anterior and posterior fusion procedure.
  - They allow for direct decompression of the spinal canal if necessary.
  - They permit some correction of spinal deformities, including asymmetric disc space collapse, spondylolisthesis, and mild kyphosis.
- PLIF and TLIF procedures also avoid some of the drawbacks inherent to anterior lumbar interbody fusion procedures, such as:
  - There is a reduced risk of the complications associated with an anterior approach, including vascular injury, higher rates of thromboembolic disease, and retrograde ejaculation in males.
  - They preserve a virgin anterior approach should revision surgery become necessary or should an adjacent segment arthroplasty become an option in the future.
- PLIF and TLIF have the disadvantage, however, of potential nerve root injury from preparation and instrumentation of the disc space through a posterior approach.

The major difference is that the PLIF procedure uses a bilateral and more-medial approach to access the interbody region, whereas the TLIF technique involves a unilateral approach with complete removal of one facet joint to allow more lateral access to the disc space (FIG 1).
- As a result, the exiting root is in greater danger when performing a TLIF, whereas the traversing root is in greater danger with a PLIF.
- Gaining access to the posterior annulus and interbody region during TLIF and PLIF procedures is a critical step that requires an understanding of the local neurologic anatomy and the triangular working window to the annulus. The triangular working window consists of the following:
  - The traversing nerve root and thecal sac form the medial border of the triangle.
  - The exiting nerve root from the proximal vertebral level forms the lateral border (eg, L4 for an L4–5 TLIF or PLIF).
  - The superior aspect of the pedicle of the distal vertebra forms the base of the triangle.
  - A confluence of epidural veins traveling longitudinally and transversely drapes the floor of the spinal canal and neuroforamen.
  - With careful exposure, a triangular working window measuring up to 1.5 cm wide and of slightly greater height can be created.
  - A noncollapsed disc space of an adult lumbar spine averages between 12 and 14 mm in height, with an anteroposterior diameter of about 35 mm.

The PLIF and TLIF procedures allow for fusion of the anterior column of the spine in the interbody region, which offers several biologic and biomechanical advantages over posterior spinal fusions:
- The anterior column of the spine is known to support 80% of the body’s compressive load; consequently, intervertebral structural grafts are subjected to compressive loading, which facilitates arthrodesis.
- Since interbody structural grafts are load-sharing, they significantly reduce the cantilever bending forces applied to posterior spinal implants, thus protecting them from failure.
- The interbody space has been shown to provide an optimal milieu for promoting arthrodesis for several reasons:
  - A large surface area of highly vascular cancellous bone is available.
The disc space represents a relatively shorter gap to span when compared to intertransverse fusion.

The outer annulus serves as a barrier that reduces fibrous tissue ingrowth into the fusion mass during healing of an interbody arthrodesis.

**INDICATIONS**

- Discogenic pain syndromes due to internal disc disruption or degeneration as well as postdiscectomy chronic low back pain are well suited to PLIF or TLIF for several reasons:
  - These procedures directly address the disc as the pain generator and have been shown to have superior clinical outcomes in treating discogenic pain compared to isolated posterior spinal fusions, which do not remove and fuse the painful disc.
  - They allow for restoration of interbody height and some correction of local kyphosis without putting undue stress on the posterior implants.
  - They permit decompression of the exiting and traversing nerve roots indirectly by restoring foraminal height and directly via open laminectomy and foraminotomy. Because of this, PLIF and TLIF are ideally suited to patients with discogenic pain syndromes occurring in conjunction with radicular symptoms caused by herniated disc pathology or stenosis (FIG 2).
  - Low-grade isthmic spondylolisthesis can also be treated successfully with PLIF and TLIF procedures as an alternative to performing a combined anterior and posterior fusion. PLIF and TLIF allow for direct decompression of the spinal canal and exiting nerve roots as well as indirect foraminal decompression through restoration of disc space height.
  - Addition of the interbody fusion raises the arthrodesis rate over stand-alone posterior fusion.
  - When clinically indicated and with proper instrumentation, PLIF and TLIF allow for reduction of the spondylolisthesis and slip angle, with some restoration of lordosis. In experienced hands and in conjunction with a wide decompression and intraoperative neurologic monitoring, some higher-grade spondylolistheses can be successfully reduced and stabilized with the PLIF and TLIF procedures.
  - PLIF and TLIF procedures can be a useful adjunct to adult deformity surgeries such as degenerative scoliosis and spondylolisthesis and offer several advantages:
    - They can be used to provide anterior column support at the caudal end of fusion constructs and the lumbosacral junction without requiring an additional anterior approach to the spine.
    - They improve the arthrodesis rate, which can be helpful when an interlaminar fusion is not possible because a midline decompression was necessary to address spinal stenosis.
They allow for some additional deformity correction by releasing asymmetrically collapsed disc spaces and providing interbody structural support.

Several recent presentations (not yet published) have found that routine cases of degenerative spondylolisthesis may not benefit from the addition of an interbody arthrodesis and may be best managed with standard posterior laminectomy and fusion procedures.

PLIF and TLIF can also help raise the fusion rate in arthrodesis procedures in which clinical conditions pose a challenge to spinal fusion, such as:

- Patients unwilling or unable to quit smoking
- Patients with diabetes mellitus or on systemic corticosteroids
- Patients on chemotherapy or with an irradiated fusion bed
- Revision spinal fusion procedures in which the posterolateral fusion bed is fibrotic and hypovascular
- Any other situations in which the clinician feels that the addition of an interbody arthrodesis is justified because conditions exist that may impede the formation of a posterior arthrodesis

**CONTRAINDICATIONS**

- PLIF should not usually be attempted at the level of the conus medullaris (typically L1–2) or above, and great caution must be taken using the TLIF procedure at the level of the cord or conus.
- Severe osteoporosis is a relative contraindication to these procedures as disc space preparation can result in major endplate violations with subsequent implant subsidence.
- Anomalous neural anatomy such as a conjoined nerve root can make the performance of a PLIF or TLIF procedure impossible.
- Even in some cases of “normal” nerve root anatomy, local variations in take-off angles of the exiting and traversing roots can place the roots at risk during interbody approaches. Caution should be exercised in such cases and interbody fusion abandoned if not felt to be safe.
- Severe focal kyphosis is poorly addressed with a PLIF or TLIF procedure and is usually better treated with an anterior procedure that allows for release of the anterior longitudinal ligament and annulus fibrosus.
- Irreducible higher-grade spondylolisthesis are not well treated with the PLIF and TLIF procedures as the surface area of the opposing vertebral endplates is minimized.

**NONOPERATIVE MANAGEMENT**

- Before considering PLIF and TLIF surgeries, standard nonoperative management options for the pathologic conditions being addressed should typically be exhausted.
- Nonsurgical treatment usually involves a combination of analgesic medications, physical therapy, and activity and lifestyle modification. When applicable, interventional pain management techniques such as trigger point injections, facet blocks, or epidural steroid injections should be considered.
- Surgical intervention is usually reserved for patients who remain symptomatic despite several months of nonoperative treatment and whose symptoms are severe enough to justify the risks associated with operative care.

**SURGICAL MANAGEMENT**

- As mentioned earlier, PLIF and TLIF procedures are capable of addressing a wide variety of pathologic conditions and in specific situations offer several compelling advantages.
- Given their versatility, the well-trained spinal surgeon needs to be aware of the indications for these procedures and must be capable of executing them properly.
- While the usefulness of the PLIF and TLIF procedures is clear, one must remain mindful that these procedures are technically demanding and should be undertaken only after careful training and preoperative planning and with meticulous surgical technique.

**Preoperative Planning**

- Preoperative imaging studies should be reviewed to determine the appropriate size and trajectories necessary for pedicle screw insertion as well as the anteroposterior diameter of the disc space.
- Disc space height as well as adjacent disc height and overall lumbar alignment should be measured to help determine optimal interbody implant size.
- An assessment should be made as to whether direct or indirect neurologic decompression will be necessary.
- When using the TLIF technique, the interbody approach should be performed on the patient’s symptomatic side if he or she has radicular complaints or from the side of maximal neurologic compression if the lower extremity symptoms are of equal severity.
- Although sometimes difficult to assess, the patient’s MRI needs to be studied carefully to identify anomalous neural anatomy such as a conjoined nerve root.
- If a conjoined nerve root is suspected, the TLIF should be performed from the opposite side and the patient should be counseled preoperatively that the interbody portion of the procedure may not be possible because the contralateral side may demonstrate intraoperative nerve root anomalies as well.
- For the PLIF procedure, the presence of a conjoined nerve root usually necessitates a unilateral PLIF. If identified preoperatively, conversion to a TLIF should be strongly considered.
- Deformity at the level of the planned fusion needs to be assessed so that intraoperative measures can be taken to provide for correction.

**Positioning**

- The patient should be positioned prone on an operating room table that allows for fluoroscopic imaging, such as a Jackson spine table (FIG 3).
- The abdomen should be free to decompress the vena cava. This maneuver has been found to reduce epidural venous engorgement and bleeding.
- A Foley catheter and lower extremity sequential compression devices should be used routinely.

**FIG 3** • Prone positioning with the abdomen free of compression, lower extremity compression devices in place, knees flexed, and all bony prominences padded. All tubes and wires are secured so that the area under the patient is free of obstruction, which facilitates later use of the fluoroscopy unit.
Distraction option 1: Use of rods and screws

Several methods of achieving interbody distraction exist, after screw placement, the next step is to provide posterior distraction to open the posterior portion of the disc space.

- Lumbar disc spaces are normally lordotic, which can make insertion of an appropriate-sized interbody cage through the narrow posterior portion of the disc space difficult.
- With distraction, the disc space alignment can be neutralized, thereby facilitating access to the interbody region with minimal bony resection.
- Several methods of achieving interbody distraction exist, and these can be combined as needed to achieve the desired alignment. The choice of distraction technique is largely based on surgeon preference, as all three methods have been found to be effective.

- Distraction option 1: Use of rods and screws
  - Rods are loaded bilaterally into the pedicle screws, followed by provisional placement of the system’s locking nuts.

- Distraction option 2: Spinous process distraction
  - Distracting off the spinous process can reduce the risk of screw loosening that might occur with excessive distraction on the pedicle screws.

- Distraction option 3: Interbody dilators
  - Another option available to facilitate interbody distraction is to use interbody dilators, which are placed into the disc space and rotated to restore disc space height (TECH FIG 1E).

This technique minimizes stress applied to the posterior implants and provides the most powerful method of vertebral body distraction.

**Approach**

The standard posterior approach to the lumbar spine is used, including exposure out to the tips of the transverse processes so that an adequate intertransverse fusion can be performed.

- Some surgeons choose to perform a more limited dissection and do not perform the posterolateral portion of the fusion, hoping that by preserving the blood supply and muscular attachments in the intertransverse region there will be reduced erector muscle dysfunction and fibrosis with improved outcomes.

**Disc Space Distraction**

- After screw placement, the next step is to provide posterior distraction to open the posterior portion of the disc space.
- True minimally invasive TLIF options have been developed. With these techniques, the procedure is modified so that it can be carried out through cannulas and with percutaneous instrumentations. These modifications will not be discussed in this chapter. The surgeon should be adept at open interbody fusions before considering minimally invasive approaches.
- For the standard TLIF procedure, the spinous processes and interspinous ligaments can usually be left intact. Preserving these structures minimizes epidural scarring and provides a larger surface area for the posterior fusion.
- If decompression of the contralateral side of the spinal canal is required, the TLIF procedure can be modified to include a central laminectomy.
- Two exposure options exist for the PLIF procedure, each of which will be discussed in more detail later in the chapter:
  - Extensive resection including wide laminectomy with bilateral facetectomies
  - Limited resection using bilateral laminotomies and medial facetectomies

**Pedicle Screw Insertion**

- After exposure, pedicle entry points are identified at the junction of the transverse process with the superior articular process of each vertebra.
- A high-speed burr or awl is then used to access each pedicle, followed by use of a pedicle probe and tap to create a proper path for the screws.
- Polyaxial pedicle screws are then placed bilaterally in the standard fashion.
- Fluoroscopy or image guidance systems, electromyographic responses, or both can be used to aid in proper screw positioning.
- If desired, the transverse processes can be decorticated using a high-speed burr or curette before screw insertion. This is recommended to facilitate the posterior arthrodesis as access to the transverse processes becomes somewhat limited once the pedicle screws are in place.

**Transforaminal Lumbar Interbody Fusion**

- Distraction is then carried out using the rods on both sides and a standard distractor (TECH FIG 1A–C).
- To allow for the distraction, the rods need to be slightly longer than will ultimately be necessary.
- The polyaxial screw heads should be angled as laterally as possible to maximize the volume of space medial to the rods. This maneuver facilitates later access to the disc space without requiring rod removal.
- Alternatively, several systems have pedicle screw distractor instruments that provide distraction off the screws without requiring rods to be inserted.
- Distraction instruments obviate the need to use longer rods and allow for unimpeded access to the facet and disc space during interbody preparation and implant insertion.
- Lateral fluoroscopy should be used to judge the amount of distraction obtained at the posterior margin of the disc space.
- Once adequate alignment is obtained, the system’s locking nuts are tightened to maintain the distraction.
- Care should be taken not to excessively distract off the screws in osteoporotic patients, as this could lead to screw loosening.

- Distraction option 2: Spinous process distraction
- Distraction can also be achieved by using a lamina spreader placed between the spinous processes (TECH FIG 1D).
- Distracting off the spinous process can reduce the risk of screw loosening that might occur with excessive distraction on the pedicle screws.

- Distraction option 3: Interbody dilators
- Another option available to facilitate interbody distraction is to use interbody dilators, which are placed into the disc space and rotated to restore disc space height (TECH FIG 1E).

This technique minimizes stress applied to the posterior implants and provides the most powerful method of vertebral body distraction.
Use of interbody distractors is not possible until access to the disc space has been achieved, so this technique is not an option until the disc space has been accessed.

**Complete Unilateral Facetectomy**

- The inferior articular process of the cephalad vertebra should be exposed and removed using an osteotome or rongeurs (TECH FIG 2A).
- The superior articular process of the caudal vertebra is then dissected free of the ligamentum flavum with curettes and removed using Kerrison rongeurs. To maximize access to the disc space, the entire superior articular process down to the cephalad aspect of the pedicle should be removed so that the top of the pedicle can be easily seen and palpated (TECH FIG 2B).
- The lateral aspect of the hemilamina and the caudal portion of the pars interarticularis are resected using Kerrison rongeurs to provide access to the neural foramen and posterolateral annulus.
- The triangular working zone between the exiting and traversing nerve roots and the superior aspect of the pedicle should be identified (TECH FIG 2C).
  - The exiting nerve root is present just below the pedicle of the cephalad vertebra.
  - The exiting nerve can be identified visually or palpated but should not be deliberately manipulated as the sensitive dorsal root ganglion is in this region.
  - While it is critical to identify the location of the exiting nerve root, care should be taken not to unnecessarily dissect the nerve out of its sleeve of fatty tissue; in some cases the nerve will be located and palpated but never fully visualized.
- The traversing nerve root and the lateral aspect of the thecal sac will be present in the medial portion of the triangle. Nerve root retractors can be used to mobilize the neurologic elements medially to provide additional access to the posterolateral annulus (TECH FIG 2D).
- As in all lumbar spinal surgical procedures, if trouble is encountered locating a nerve root, the surgeon should find or palpate the associated pedicle and look along the medial and inferior pedicle wall.
- With the neurologic elements accounted for, the posterolateral annulus can be accessed through the previously described triangular working zone by carefully coagulating and dividing the obstructing epidural veins using bipolar cautery (TECH FIG 2E).
- Significant bleeding can be encountered at this stage, and the use of cottonoids in conjunction with hemostatic agents such as Gelfoam, Floseal, or Surgiflo can be helpful.
- If the surgeon is not careful, the exiting or traversing nerve roots can be damaged while dealing with the bleeding arising from the epidural venous plexus. Working methodically while remaining constantly aware of the location of these neural structures is critical.

**Disc Space Preparation**

- A nerve root retractor is used to mobilize the thecal sac and traversing nerve root medially to improve exposure
of the posterolateral annulus. An advantage of the TLIF procedure is that minimal neural retraction is necessary to access the interbody region. Depending on the local nerve root anatomy, however, retraction of the traversing root may be necessary even with a TLIF.

- A scalpel is then used to incise a rectangular region of the annulus lateral to the traversing nerve root to create a window into the disc space (TECH FIG 3A).

- It is extremely important to have proper instruments available to facilitate the critical step of disc space preparation. These instruments are frequently provided by the vendor of the graft or implants to be used in the interbody region and should include (TECH FIG 3B):
  - Interbody paddle scrapers to dilate and prepare the endplates
  - Offset curettes to facilitate access to the contralateral side of the disc space
  - Rasps, ring curettes, and reverse curettes to assist in endplate preparation
  - Osteotomes or box chisels to improve access to the interbody region when the disc space is narrowed posteriorly
  - Long straight and upbiting pituitary rongeurs for débridement of the interbody region

- After creation of the annular window, typically shavers or dilators of increasing size are serially introduced into the disc space and rotated (TECH FIG 3C,D).

- Lateral fluoroscopy can be helpful in determining the proper depth of penetration into the disc space. The anterior and anterolateral annulus should be palpated by the instrument and never violated, or catastrophic vascular injury could occur.

- Instruments used within the disc space are typically marked so that they are not overinserted to avoid potentially catastrophic violation of the anterior annulus. It is helpful to preoperatively estimate disc space length (posterior to anterior) on MRI or CT scan to have an idea of how far the instruments can be inserted.

- After dilation and shaving, a combination of curettes and rongeurs is used to perform a thorough discectomy and endplate preparation down to bleeding bone (TECH FIG 3E,F).

- Care should be taken not to violate the endplates in regions expected to load share with the interbody implant as this can make implant placement difficult and lead to settling of the structural graft.

- Several TLIF techniques do call for perforation of the endplates to expose cancellous bleeding bone in
TECHNIQUES

non-load-sharing interbody regions, using osteotomes for the anterior portion of the disc space or curettes and awls for other areas.

Because of the concave nature of the endplates, it is sometimes necessary to use osteotomes or box chisels to remove a rim of bone from the posterior aspect of the vertebral bodies to improve access to the disc space and allow for placement of a properly sized graft (TECH FIG 3G). The surgeon should remember that aggressive removal of the posterior lip may lead to a greater risk of implant backout with root compression.

On completion of the discectomy and endplate preparation, exposed bony endplates should be visible on the cephalad and caudal vertebral bodies.

To minimize the risk of neurologic injury and postoperative dysesthetic pain, several recommendations should be followed during the disc space preparation and graft insertion:

- Retraction on the neurologic elements should be minimized, and it should be released intermittently throughout the procedure.
- The thecal sac should never be retracted across the midline of the spinal canal.
- Particularly in revision cases, the neurologic elements should be carefully mobilized off the floor of the canal and disc space before retraction.
- Implants should be selected that can be inserted without excessive neural retraction.
- This can be an issue with use of threaded cylindrical cages because the height and width of the device must be equal; consequently, a cage of the appropriate height might be too wide to be safely inserted.
Graft Placement

- A variety of interbody grafting techniques have been described for use in the TLIF procedure:
  - Placement of two vertical fibular allografts or vertical titanium mesh cages posteriorly in the disc space with cancellous graft packed anteriorly (TECH FIG 4A)
  - Use of an oblique threaded cylindrical cage or machined cortical allograft bone dowel (TECH FIG 4B)
  - Use of an obliquely placed rectangular PEEK cage or bullet-shaped cortical allograft
  - Placement of a curved titanium cage, PEEK cage, or machined cortical allograft anteriorly and as centrally as possible within the disc space, with cancellous graft placed behind the device (TECH FIG 4C)

- While it has been shown that anterior cage placement is biomechanically superior to posterior cage placement, studies comparing the clinical efficacy of these various techniques do not exist.

- When choosing an interbody graft and grafting technique, surgeons should consider several factors:
  - Ability to insert the device without requiring excessive neurologic retraction
  - Volume of cancellous graft that can be packed within and around the cage or allograft
  - The effect of the graft’s position and shape on the ability to restore lordosis with later compression of the posterior instrumentation

- The remainder of this section will describe the technique in which a single curved titanium or PEEK cage or allograft is placed anteriorly and centrally within the disc space.

- After endplate preparation, graft trials should be used to determine the proper size for the interbody spacer (TECH FIG 4D). Fluoroscopic imaging should be used to confirm proper sizing of the trial.

- The anterior and lateral aspects of the disc space should then be tightly packed with morselized graft material.

  - Several options are available for use as morselized graft material, including autogenous iliac crest bone graft, local bone graft from the removed facet and lamina, allograft corticocancellous bone, allograft demineralized bone matrix, ceramic bone graft extenders, and bone-inducing substances such as bone morphogenetic protein.

  - The choice of graft should depend on surgeon experience, host factors that may affect fusion, patient preference, cost, and availability.

  - Graft impactors should be used to maximize the amount of bone that can be placed into the interbody space. For the technique using a central and anteriorly placed cage, the anterior 25% of the disc space should be filled initially with tightly packed morselized graft material.

  - Before inserting the actual cage or graft, the trial should be reinserted to confirm that the morselized graft has not blocked the pathway for insertion of the structural graft.

  - The implant should then be inserted into the interbody space and placed anteriorly and as centrally as possible.

    - Implant position should be confirmed with AP and lateral fluoroscopy during insertion.

    - Straight and offset impactors can be used to facilitate proper cage positioning.

    - Additional morselized graft material should then be packed into the posterior aspect of the disc space behind the implant (TECH FIG 4E,F).

**TECH FIG 4** • A–C. Several of the TLIF options available for graft type and position. A. Vertical cages or grafts placed posteriorly within the disc space with cancellous graft packed anteriorly. B. A single oblique threaded cage or graft. C. An anteriorly and centrally placed cage with cancellous graft placed posteriorly. D. Trial insertion to ensure that the appropriately sized device will fit and that cancellous graft packed into the disc space has not obstructed the pathway. E. Structural graft in place anteriorly with cancellous graft packed in the remaining portion of the disc space. F. Postoperative sagittally reconstructed CT scan demonstrating bone graft anteriorly, posteriorly, and within a titanium TLIF cage. (D–F, Courtesy of Synthes Spine.)
Compression and Posterolateral Grafting

- With the implant in place, distraction is released from the spinous processes or pedicle screws. Compression is then applied to the pedicle screw construct and the locking nuts are finally tightened.
- Compression both loads the anterior implant and restores lordosis to the spine.
- The contralateral spinous processes, lamina, facet joint, and transverse processes should then be decorticated (ideally the transverse processes were decorticated at the time of screw insertion).
- Morselized graft can then be placed into the contralateral interlaminar, facet, and intertransverse regions (TECH FIG 5).

- The interspinous ligament, if preserved, will serve to prevent graft migration into the exposed portion of the spinal canal and foramen.
- Some surgeons may also wish to place graft on the ipsilateral side in the intertransverse region, but care must be taken to avoid allowing graft to enter the spinal canal or compress the exiting nerve root.
- Final AP and lateral fluoroscopic images should be obtained.

Closure

- Before closure, final hemostasis should be obtained and the neurologic elements inspected to ensure that no graft material has fallen into the spinal canal.
- A Valsalva maneuver can also be performed to confirm the integrity of the dural sac.
- A standard layered closure over a drain is then carried out.

POSTERIOR LUMBAR INTERBODY FUSION

- Most of the technique for PLIF is similar to that described above for TLIF, except that a bilateral and more medial approach to the interbody space is used.
- This section describes the PLIF procedure by highlighting the differences between the TLIF and PLIF techniques.

- As noted in the exposure section, two PLIF exposure options are available (TECH FIG 6):
  - Extensive resection including wide laminectomy with bilateral complete facetectomies
  - Limited resection using bilateral laminotomies and medial facetectomies
The decision to use the wide laminectomy with total facetectomies is affected by several considerations:
- It provides maximal exposure and minimizes the amount of neural retraction necessary to place the interbody grafts or implants. This is essentially a bilateral TLIF.
- It should be strongly considered when fusing levels with a smaller interpedicular distance, such as in patients of short stature and in the upper lumbar spine.
- It results in iatrogenic instability and therefore must be supplemented with pedicle screw instrumentation. Even with pedicle screws, a bilateral PLIF represents a more unstable situation. In patients with poor bone quality, the pedicle screws can loosen and lead to instability of the construct, with possible cage migration.
- It eliminates the ability to fuse the facet joints posteriorly and reduces the host bone contact area available for the posterolateral fusion.
- Limited resection using bilateral laminotomies and medial facetectomies:
  - Preserves the segment’s biomechanical stability by preserving the spinous processes, the interspinous ligaments, and most importantly the lateral half of the facet joints and associated pars interarticularis
  - Must be employed for cases in which posterior instrumentation is not being used
  - May be difficult in patients with a tall disc space as there may not be enough room for passage of the larger interbody graft required without more extensive resection of the facets
  - Should only be attempted by surgeons very familiar with the PLIF procedure as additional neural retraction is necessary, with a consequent higher risk of neurologic injury
- After the exposure, pedicle screws are inserted and disc space distraction is applied as described for the TLIF procedure.

The PLIF procedure can be performed without pedicle screws if one uses the limited resection technique during exposure and care is taken not to destabilize the segment.

**Laminotomy and Partial Facetectomy**
- If the partial resection technique is being used, a laminotomy is performed by using curettes to detach the ligamentum flavum from each of the adjacent lamina as well as the superior articular process of the caudal vertebra.
- Kerrison rongeurs are then used to remove lateral portions of the adjacent lamina and the medial half of the superior and inferior articular processes.
- This process should be repeated bilaterally and should result in working windows for approaching the disc space on each side of spinal canal.
- When using the limited resection technique, care should be taken to preserve the spinous process, interspinous ligaments, lateral pars, and lateral half of the facet joints.
- As in the TLIF procedure, the exiting and traversing nerve roots need to be identified and appropriate caution used to avoid traumatizing these sensitive neurologic structures during the procedure. To minimize root injury, one should remove enough lateral bone to be able to access the disc space without major retraction of the traversing root.
- The wide laminectomy and bilateral facetectomy technique simply involves enlarging the above approach.
- Resection of the spinous process and interspinous ligaments medially will improve the ability to retract the thecal sac toward the midline.
- For a maximally sized working window, total facetectomies can be performed to allow for more lateral access to the disc space (see Fig 1A).
- After exposure, the posterolateral annulus can be accessed through the previously described triangular zone cephalad to the pedicle of the inferior vertebra, medial to the exiting nerve root, and lateral to the traversing nerve root and thecal sac (see Tech Fig 2C).
- Epidural veins are carefully coagulated and divided in the same way as described for the TLIF procedure.

**Disc Space Preparation**
- Disc space preparation is performed in an identical fashion as described above for the TLIF procedure except that bilateral annular windows are created somewhat more medially than for a TLIF.
- The thecal sac and traversing nerve root are mobilized medially, and a combination of shavers, curettes, and rongeurs is used to perform a thorough discectomy down to exposed endplate.
- In noninstrumented PLIF procedures, achieving adequate interbody graft contact area is critical to reduce the risk of graft subsidence.
- Closky et al demonstrated that in patients of average bone density and size, interbody graft contact area should exceed 6.2 cm² or an area roughly 2.5 × 2.5 cm.
### PEARLS AND PITFALLS

#### Indications
- As in all lumbar fusion surgeries, clinical success will depend largely on proper patient selection.
- Fusions performed primarily for discogenic back pain have a limited success rate, and realistic expectations will enhance patient satisfaction with the procedure.
- Revision procedures with extensive epidural scarring are technically challenging and benefit from a more lateral approach to the disc space to minimize retraction of neurologic elements typically surrounded by fibrous tissue.

#### Interbody access and preparation
- Distraction techniques are used to neutralize the alignment of the adjacent endplates as much as technically feasible.
- Concave endplates may require use of an osteotome or box chisel to facilitate access to the disc space and allow for placement of a properly sized graft.
- An array of interbody preparation instruments, including offset curettes, must be available to facilitate comprehensive removal of endplate cartilage and disc material.
- Since achieving an interbody fusion is critical to the success of the procedure, adequate time and effort must be spent in disc space preparation. The surgeon must not rush interbody preparation.
- To avoid serious endplate violation, care must be taken to maintain a parallel trajectory to the disc space when working with instruments in the interbody region.

#### Neurologic injury
- Identifying the location of the exiting nerve root is a vital step in the procedure and should occur before incising the annulus.
- Insufficient laminectomy can result in poor visualization and excessive neural retraction with inadvertent neurologic injury.
- Exiting nerve roots with a more acute angle of takeoff from the thecal sac can result in a smaller triangular working zone and should be gently retracted laterally.
- Medial retraction of the thecal sac and traversing nerve root should be minimized and must never cross the midline.
- Neurologic retraction should be released frequently to allow for reperfusion of these sensitive structures.
- Free run electromyographic monitoring can provide live feedback and help reduce the risk of neurologic injury from overzealous neurologic retraction.
- Great care must be taken to account for the dura and neurologic elements every time that an instrument or graft is inserted into the disc space.
- Should significant difficulties arise such as obstructing anomalous neural anatomy, major epidural bleeding, or a complex dural tear, one must be willing to abandon the interbody portion of the fusion rather than risk causing a catastrophic injury.
Epidural bleeding

- Epidural bleeding can be troublesome in the posterior annular region, and use of hemostatic agents such as Gelfoam, Floseal, or Surgiflo should be strongly considered.
- Great care must be taken to identify the neurologic structures when using bipolar cautery.
- Should a dural tear occur, it should be repaired as soon as technically possible, as reduced intrathecal pressure will produce engorgement of the epidural veins with significantly more bleeding.

Graft placement

- Bony resection must allow sufficient access to the interbody region to allow placement of an adequately sized graft.
- Graft type should be chosen carefully in situations where access to the disc is limited or a tall disc space exists.
- Due to their narrower widths, rectangular grafts or cages can be inserted more easily into a tall disc space than cylindrical grafts, which require a larger transverse exposure.
- Fluoroscopy and offset impactors should be used during graft insertion to facilitate optimal final implant position.

POSTOPERATIVE CARE

- The patient is typically mobilized out of bed the day after surgery.
- Postoperative bracing is typically not required for the TLIF or instrumented PLIF procedures but can be used according to surgeon preference.
- Most physicians prefer to use a thoracolumbosacral orthosis during the postoperative period for noninstrumented PLIF procedures.
- Serial radiographs are used to assess for fusion.

OUTCOMES

- Fusion rates for the PLIF and TLIF procedures are similar, with studies finding rates of obtaining a solid arthrodesis varying between 89% and 100%. Several recent larger studies have reported fusion rates above 95%. 7,10,11
- While clinical success rates vary between studies, most series report similar outcomes with PLIF and TLIF as for anterior interbody and combined anterior and posterior fusion procedures.
- Most of the studies on PLIF and TLIF using visual analog scale (VAS) and Oswestry Disability Index (ODI) scores as outcome measures demonstrate an overall patient satisfaction rate of about 80% with the procedure. 4,17,8,14
- Longer-term studies indicate that the results of PLIF and TLIF procedures tend to be durable once a solid arthrodesis has been achieved.

COMPLICATIONS

- Neurologic injury is an uncommon complication of PLIF and TLIF and has been reported to occur in between 0% and 4% of patients. Many of these injuries represent a neuropraxia due to excessive nerve root retraction and resolve spontaneously.13,15
- Dural tears are a more common complication and have historically been reported to occur in 0.5% to 18% of PLIF and TLIF procedures.
- The dural tear rate appears to be significantly lower with the TLIF procedure compared to the PLIF, likely related to the fact that less neural retraction is necessary when using the TLIF’s more lateral approach to the disc space. 3
- More recent studies demonstrate a trend toward much lower rates of dural tears in both PLIF and TLIF procedures, with a reported incidence in the range of 1% to 5%.
- Implant migration or failure is a rare complication in the TLIF procedure but has been reported to occur in up to 2.4% of cases in which a noninstrumented PLIF is performed. Properly sizing the interbody implants and fully packing the disc space with graft material can help reduce the risk of this complication.
- Other complications of posterior lumbar fusions that are not specific to the PLIF and TLIF procedure include wound infection, excessive bleeding, pedicle screw malposition, and epidural hematoma.

REFERENCES

DEFINITION

- Anterior thoracic approaches provide a means of decompression, stabilization, and fusion for a variety of spinal pathologies, such as deformity, trauma, infection, tumors, and disc herniations.

ANATOMY

- The thoracic vertebral bodies are heart-shaped in the anteroposterior plane.
  - The thoracic pedicles are oval and are larger superoinferiorly than mediolaterally.
  - The average height is 8 to 15 mm and the average width is 3 to 10 mm.
  - The medial cortex is the thickest; however, there is no epidural space between the medial cortical edge and the dura.16
  - The facet joints are situated more anteriorly and articulate superiorly and inferiorly with a rib. As the transition from the thoracic to lumbar spine occurs, the thoracic vertebrae begin to resemble the lumbar vertebrae and the facets change from a frontal orientation to one that is more lateral.

PATHOGENESIS

Intervertebral Disc Herniation

- Seventy-five percent of thoracic disc herniations occur between T8 and L1. They are classified as central, centrolateral, lateral, or paramedian.
  - Most herniations occur central or centrolateral and are often calcified.
- The spinal canal in the thoracic spine is relatively small.
  - Neurologic consequences occur from direct anterior compression of the spinal cord from a herniated disc. There can be posterior displacement of the cord and local vascular insufficiency.

Infection

- The mechanism of spinal infections is controversial. Proposed routes of infection include hematogenous spread from other infected foci, local extension from nearby infections, and direct inoculation.
  - The two proposed routes of hematogenous spread are venous and arterial.
  - Advocates of venous hematogenous spread argue that organisms are carried to the spine via the plexus of Batson, similar to the mechanism of tumor metastasis.5
  - Proponents of arterial hematogenous spread note that the metaphyseal bone near the anterior longitudinal ligament is an area where infections typically begin. This region has an end-arteriole network that is susceptible to bacterial seeding.19

Tumor

- Most spine tumors are of metastatic origin. The spinal column is the most frequent site of skeletal metastasis.18
- Malignant cells are carried to the spine through the valveless extradural venous plexus of Batson.2,8 A recent anatomic model suggests that malignant cells can also metastasize through the segmental arteries.20

Trauma

- The articulation of the vertebral column, ribs, and sternum makes the thoracic spine relatively stable.1
- High-energy injuries are frequently required to produce injury to the thoracic spine.
- Forces associated with injury are axial compression, flexion, lateral compression, flexion–rotation, shear, flexion–distraction, and extension.

NATURAL HISTORY

Intervertebral Disc Herniation

- Wood et al described 20 patients with asymptomatic thoracic disc protrusions followed by magnetic resonance imaging (MRI).21 All patients remained asymptomatic at an average of 26 months, and most disc herniations were smaller or unchanged on repeat MRI.
  - It is unknown how often asymptomatic thoracic herniations become symptomatic.
- Brown et al reported on 55 patients with 72 thoracic disc herniations.3 Fifty-four were treated initially with conservative therapy and 15 eventually required surgery. Nine of 11 patients with lower extremity complaints went on to have surgery. Two patients had myelopathy and were treated surgically. All 55 patients ultimately returned to their previous level of activity.
  - Patients with lower extremity symptoms and myelopathy are likely to require surgical intervention.

Infection

- Vertebral osteomyelitis is rare and accounts for 2% to 4% of all cases of osteomyelitis.
  - Staphylococcus aureus is the most common organism, accounting for almost 50% of pyogenic infections.5
  - The incidence is rising as a result of a growing immunocompromised and elderly patient population, increased intravenous drug abuse, and an increase in invasive diagnostic and therapeutic procedures.
  - Before medical and surgical treatment, spinal osteomyelitis carried a mortality rate of greater than 70%.10 The advent of antibiotics and anterior spinal débridement techniques has reduced mortality to less than 15%.6,13
- Carragee reported on 72 patients were treated nonoperatively with antibiotics.6 Over 33% of them required surgical débridement. Results related to patient age and immune status.
Tumor
- Over 90% of spinal tumors are metastatic lesions with a distant primary source.
- Primary tumors from the breast, prostate, lung, kidney, and thyroid are most likely to metastasize to the vertebral column.18
- Tumors that affect the anterior elements of the spine can be benign or malignant.
- Benign primary tumors that have a predilection for the anterior elements include giant cell tumors and hemangiomas. Malignant tumors that commonly affect the anterior elements include osteosarcomas, chondrosarcomas, myelomas, and lymphomas.15
- Improved diagnostics have allowed for more accurate diagnosis and improved staging.9
- Chemotherapy and radiotherapy have improved survival and local control.14
- Treatment goals include preservation of neural function, spinal stability, margin-free tumor resection, and correction of deformity.

Trauma
- Fractures of the thoracolumbar spine are the most common spinal injuries.
- The thoracic spine configuration of vertebrae, sternum, and ribcage confers an inherent stability.1
- Injuries to this region require significant force, and unstable injuries are usually a result of high-energy injuries such as motor vehicle accidents, falls from heights, and crush injuries.
- Patients can have associated injuries such as pneumothoraces, pulmonary contusions, and vascular injuries.
- Although most thoracic injuries do not involve neurologic deficit, complete neurologic deficits are more common with thoracic spine injuries due to the small neural canal, the tenuous blood supply, and the high energy needed to cause injury.4

PATIENT HISTORY AND PHYSICAL FINDINGS
- Neurologic status is examined.
  - Manual motor testing
  - Pin-prick and light touch sensory examination may help to localize the cord level of injury based on dermatome.
  - Babinski reflex and clonus are upper motor neuron signs.
  - Reflex examination of the patellar and Achilles tendons: hyperactivity is an upper motor neuron sign.

IMAGING AND OTHER DIAGNOSTIC STUDIES
- It is often useful to obtain an MRI and a CT-myelogram preoperatively. MRI is the key radiologic study to confirm the diagnosis and localize pathology. Plain CT scans are helpful in delineating bony anatomy.
- A plain CT scan should be obtained in concert with MRI on every patient with a destructive bony process, such as tumor or infection, to preoperatively assess the degree of bony loss and determine the optimal strategy for reconstruction.
- CT-myelography may be needed if MRI scans cannot be obtained or if quality of the MRI is suboptimal due to patient movement, metal artifact from prior implants, or other factors.
- CT can detail ossification of the posterior longitudinal ligament or ligamentum flavum.
- CT-myelography can also clarify whether cord compression is primarily anterior secondary to a disc fragment, or circumferential due to stenosis.

DIFFERENTIAL DIAGNOSIS
- Spinal tumors
- Infections
  - Transverse myelitis
  - Ankylosing spondylitis
  - Fractures
  - Intercostal neuralgia
  - Herpes zoster
  - Cervical and lumbar herniated discs
  - Disorders of thoracic and abdominal viscera
  - Amyotrophic lateral sclerosis
  - Multiple sclerosis
  - Arteriovenous malformations

NONOPERATIVE MANAGEMENT
Intervertebral Disc Herniation
- In the absence of myelopathy, most patients can be treated conservatively.
- A conservative treatment plan should include nonsteroidal anti-inflammatories, rest, activity modification, and physical therapy focusing on trunk stabilization.3
- Other options include intercostal nerve blocks and pharmacotherapy such as narcotics, tricyclic antidepressants, serotonin-reuptake inhibitors, and certain antiepileptics.

Infection
- Vertebral infections should be treated nonoperatively with culture-specific antibiotics and spinal immobilization.
- Open or CT-guided biopsy can aid in targeting appropriate antibiotic treatment.
- Treatment frequently involves 6 weeks of parenteral antibiotics followed by a course of oral antibiotics.
- An infectious disease consultant can help guide the antibiotic regimen.
- External immobilization with an orthosis can help stabilize the spine, decrease pain, and prevent deformity.
- Bracing is particularly important in patients with greater than 50% destruction of the vertebral body since they are at greater risk for deformity.7
- Response to treatment can be followed clinically with erythrocyte sedimentation rate, C-reactive protein, and a complete blood count.

Tumor
- A multidisciplinary approach including a neuroradiologist, pathologist, oncologist, and spine surgeon is used to treat spinal tumors.
- A CT-guided biopsy can help establish a diagnosis in 76% to 93% of lesions.7,18
- Metastatic lesions that do not compromise spinal stability and without rapid neurologic progression can be managed nonoperatively.18
- Nonoperative treatment can include radiation, chemotherapy, embolization, and bracing.
Most primary spinal tumors cannot be treated nonoperatively.

Trauma
- Most thoracic and thoracolumbar spine injuries can be effectively treated nonoperatively.
- Conservative treatment can include recumbency, bracing, and pain management for patients without neurologic deterioration and with a structurally stable injury.11,17
- Decubitus ulcers, thromboembolism, urinary tract infections, and late pain are complications reported with nonoperative treatment.12

SURGICAL MANAGEMENT
- Indications for discectomy
  - Progressive myelopathy due to anterior compressive lesions
  - Lower extremity weakness or paralysis
  - Radicular pain refractory to conservative therapy
  - Deformity correction
- Indications for corpectomy
  - Fractures with anterior spinal cord compression
  - Metastatic or primary thoracic tumors
  - Osteomyelitis
  - Sequestered disc herniations that have migrated behind the vertebral body
  - Ossification of the posterior longitudinal ligament
- Indications for bone grafting and cage or allograft placement
  - Although somewhat counterintuitive, anterior spinal infections can be successfully managed with allograft, cage, or instrumentation reconstruction if a thorough debridement of infected tissues is performed and postoperative antibiotics are administered
  - Tumor
  - Trauma
  - Degenerative disease
  - Deformity correction (scoliosis, kyphosis)
- Indications for polymethylmethacrylate (PMMA) use
  - Anterior column reconstruction of tumors in patients with a life expectancy of less than 1 year
  - Patients in whom the use of radiation or chemotherapy is anticipated
- Indications for use of solid rod instrumentation
  - Patient under 30 years of age
  - Thoracic and thoracolumbar curves of less than 65 degrees (Cobb angle)
  - Thoracic or lumbar compensatory curves that correct to less than 20 degrees with side bending
  - Hypokyphosis (less than 20 degrees from T5 to T12)
  - Refer to Chapter SP-3 for preoperative planning, patient positioning, and approach discussions.

THORACIC DISCECTOMY
- After elevating the articular ligaments of the costotransverse and costovertebral articulations, the remaining rib head is excised (TECH FIG 1).
- The superior edge of the pedicle of the caudal vertebra is resected with a rongeur to expose the dural tube.
- To find the disc herniation, the surgeon follows the superior edge of the pedicle to the vertebral body and disc space.
- The disc herniation is removed using small angled curettes and pituitary rongeurs.
- Discectomy can be facilitated by removing a small portion (1 to 2 cm) of the adjacent vertebral bodies. If the disc is extremely calcified or has migrated behind the vertebral body, it is helpful to perform hemicorpectomies of the adjacent vertebral bodies.
- The portion of the disc that lies away from the ventral aspect of the spinal cord should be removed first. Once a cavity is created by removing this initial disc and bone, the rest of the disc can be removed into this cavity, ensuring that all forceful maneuvers are directed anteriorly away from the thecal sac.
- We prefer to keep the posterior longitudinal ligament (PLL) intact whenever possible, as its removal often results in substantial epidural bleeding. We will pass an elevator or nerve hook through a rent in the PLL if one is present to ensure adequate decompression from pedicle to pedicle. If the PLL needs to be removed, we use bipolar cautery to cauterize the PLL and then carefully remove it with either a Kerrison or a combination of pituitary rongeur and curette.
**THORACIC OR THORACOLUMBAR CORPECTOMY**

- The posterior aspect of the vertebral body is identified.
- Discectomy is performed above and below the level of the corpectomy.
- The lateral annulus is incised using a no. 10 blade to the anterior midline.
- An elevator is then used to separate the disc from the endplates.
- Discectomy is completed using curettes and rongeurs.
- Attention is turned to the vertebrectomy. Using a 4-mm burr, the surgeon removes most of the bone from the vertebral body.
- Corpectomy is completed by removing the remaining bone with a rongeur (TECH FIG 2).
- Depending on the nature of the pathology, the PLL may need to be removed for the purposes of decompression.
- For retropulsed fracture fragments, the fragments are first thinned using a high-speed 4-mm ball-tipped burr.

Then a thin, sharp curette is used to peel the fragments away from the dura and into the created trough.

- It is important to work quickly but carefully at this point as there can be a significant amount of epidural bleeding.
- The posterior cortical fragments are removed from the contralateral (deep) side of the canal first so that the bulging dura will not obscure the rest of the fragments.
- Decompression is adequate when the dura can be seen bulging into the corpectomy trough and the spinal canal has been decompressed throughout its complete width.

**Plating**

- A flat surface is prepared for the plate by removing lateral endplate prominences and rib heads with a high-speed burr.
- Using an awl insertion guide, a posterior bicortical thoracic bolt is placed at the cephalad and caudal fixation levels.
- The trajectory should be parallel to the endplate and angled slightly anteriorly to avoid penetrating the canal (TECH FIG 3A).
- If sagittal correction or interbody graft placement is needed, distraction is performed on the endplates using a lamina spreader.
- A correct-length plate is applied over the bolts without extending into the adjacent disc spaces (TECH FIG 3B,C). Nuts are applied loosely to secure the plate to the posterior bolts.
- Using a drill or awl, correct-length anterior screws are placed angling slightly posteriorly.
- In general, bicortical screws are preferred because the cancellous bone of the vertebral body provides relatively weak purchase, especially in patients with tumors or infections.

**TECH FIG 2** • Corpectomy site.

**TECH FIG 3** • Application of plate and screws. **A.** Osteophytes are removed, and a trajectory is planned parallel to the endplate and angled slightly anteriorly to avoid penetration of the canal. **B.** Nuts secure the posterior bolts, and screws are applied anteriorly. **C.** It is important for the screws to be a safe distance from the dural covering of the spinal cord.
SCREW–ROD INSTRUMENTATION

- Use of an anterior screw–rod construct allows for correction of coronal plane deformity through fusion of fewer spinal motion segments compared with posterior instrumentation.
- The entry position for the anterior vertebral screws is determined based on the location of the vertebral foramen, as this identifies posterior body cortex.
- The surgeon inserts the most cephalad and caudad screws first in the midlateral vertebral body at the same distance from the posterior cortex (TECH FIG 4).
- The screw tips should engage the far cortex of each vertebra and should be directed toward the posterolateral corner of the vertebra.
- The rest of the screws are placed in similar fashion.
- The rods are inserted as directed by the particular system, and alignment is corrected before tightening.

BONE GRAFTING AND CAGES

- It is of utmost importance to prepare an adequate fusion bed.
- A thorough decortication is performed.
- Although placement of the graft on preserved bleeding subchondral endplates is preserved, creating a slot or peg hole in the adjacent vertebral bodies can help to prevent graft extrusion.
- Before graft placement, kyphotic deformity can be corrected by distracting adjacent vertebrae.
  - Extreme care must be taken to avoid injury to the adjacent endplates during distraction, especially in patients with osteoporosis or other states with compromised bone quality (tumors, infections).
- After the graft has been anchored, compression locks the graft in position.
- If tricortical iliac crest bone is used, we prefer to have the cortical smooth surface face the spinal canal.
- Single-level corpectomy defects can be supported with tricortical iliac crest grafts, whereas larger defects are better stabilized with autogenous fibular strut grafts or shaft allografts.
- Depending on the size of the patient, humeral shafts often provide the best fit in the thoracic spine.
- For cage placement, the ends of the cage can be trimmed to create the necessary cage configuration (TECH FIG 5A).
  - Alternatively, stackable cages (eg, those made of PEEK) can be measured to fit the space.
- The packed cage is implanted between the distracted adjacent endplates (TECH FIG 5B).
- The cage is stabilized when the distraction is released.
- Bone graft should be packed in and around the cage.

Polymethylmethacrylate

- PMMA may be used in patients with spinal tumors who have poor life expectancy, or who are unlikely to heal anterior bone grafts due to poor bone quality or healing potential.
POSTOPERATIVE CARE

- Chest tubes remain until output is less than 150 mL over 24 hours.

COMPLICATIONS

- The exiting nerve root can be injured while removing the pedicle.
- Vascular injury
- Intercostal neuralgia
- Atelectasis
- Neurologic injury
- Wrong-level surgery
- Significant bleeding can be encountered when entering the epidural space.

REFERENCES

DEFINITION
- Lumbar disc degeneration is an age-related process heralded by a loss of disc height and gradual changes to the biochemical structure and biomechanical behavior of the intervertebral disc.
- Disc degeneration is not painful in most individuals, but in some patients, the degenerative changes do become painful and lead to the clinical entity known as degenerative disc disease (DDD). It is unclear why disc degeneration is painful in some but not in most.
- The etiology of DDD is multifactorial, including genetic and environmental determinants.
- “Discogenic pain” is the term used to describe pain due to a degenerative disc.

ANATOMY
- The intervertebral disc is composed of the outer annulus fibrosus and the inner nucleus pulposus (FIG 1A).
- The vertebral endplate is composed of cancellous bone in the center and strong, dense, cortical bone along the periphery.
- MRI provides information about the extent of hydration within the disc nucleus. The degenerated disc nucleus will have low signal characteristics (appear dark) on T2-weighted MRI images (FIG 1B).
- Dark discs on MRI do not necessarily correlate with symptomatic low back pain.

PATHOGENESIS
- Various mechanisms have been proposed to explain disc degeneration with age:
  - Reduced nutrition and waste transport
  - Decreased concentration of viable cells
  - Loss of matrix proteins, proteoglycans, and water
  - Degradative enzyme activity
  - Fatigue failure of the matrix
  - Herniated nucleus pulposus
- Alterations to the vertebral endplate microenvironment such as venous pooling and reduced oxygen tension are additional factors.
- Nicotine has known detrimental effects on the intervertebral disc, perhaps via these mechanisms.
- Several factors have been implicated in the generation of discogenic pain: altered disc structure and function, release of inflammatory cytokines, and nerve ingrowth into degenerated discs, which under normal conditions are only minimally innervated in the outermost portion of the annulus.

NATURAL HISTORY
- Radiographic findings of disc degeneration typically appear around age 30.
- Posttraumatic disc herniations, vertebral endplate injuries, and genetic factors may predispose patients to earlier presentation.
- As structural changes occur within the intervertebral disc, associated changes in the vertebral body endplate become apparent:
  - Anterior, lateral, or posterior osteophyte formation
  - Schmorl nodes, cystic cavities, along the endplate can be visualized
  - Endplate sclerosis
- The degenerative changes at the level of the disc, bony endplate, and ultimately the posterior facet-joint complex ultimately restrict motion at the affected level or levels. At this stage, patients will typically complain more of back stiffness and soreness rather than pain. Neurogenic claudication due to narrowing of the spinal canal and spinal stenosis typically becomes more limiting than complaints of back pain.
- The final stage in the natural history of disc degeneration is autofusion.
- Patients should be counseled that disc degeneration itself is an inevitable process of aging and that any back pain experienced could, but may not necessarily, be associated with the disc degeneration.
- The overwhelming majority of patients have only occasional episodes of low back pain. Long-term disability resulting from DDD is rare.

PATIENT HISTORY AND PHYSICAL FINDINGS
- No pathognomonic history or physical examination findings exist for the diagnosis of lumbar DDD.
- Discogenic back pain is typically worst in situations in which an axial load is applied to the lumbar spine, as in prolonged sitting or standing with a forward-bent posture (ie, washing dishes, vacuuming, shaving, or brushing teeth).
- Conversely, positions such as side-lying (ie, the fetal position) or floating erect in water place the least amount of strain across the intervertebral disc and should therefore provide some pain relief.
- Leg pain (in the absence of neural compression), if present, is nonradicular and “referred” in that it does not follow lumbar dermatomes into the lower leg and is not typically associated with loss of motor power, reflex changes, numbness, or tingling.
- Patients will occasionally describe a discrete traumatic disc injury in which they first experienced back pain. Imaging studies that depict an old endplate fracture above or below a degenerative disc help corroborate this history.
- Loss of truncal musculature fitness from abdominal wall hernias, obesity, and prior abdominal wall surgery (ie, rectus
muscle transfer procedures) may worsen discogenic back pain.

- Other causes of back pain should be sought in the history, physical examination, and imaging studies, including muscular strain, spondylolysis or spondylolisthesis, herniated nucleus pulposus, compression fracture, pseudarthrosis, tumor, and discitis.
- Patients with isolated DDD by definition should have a normal neurologic examination.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Standing plain radiographs
  - Lateral radiographs allow for measurement of the intervertebral disc height and allow comparison to other lumbar intervertebral discs (FIG 2A).
  - Anteroposterior (AP) radiographs allow for determination of asymmetric, coronal plain disc degeneration, which may be a precursor to lumbar degenerative scoliosis.
  - Flexion-extension radiographs may be helpful in diagnosing an occult spondylolisthesis or spondylolysis.
  - MRI provides excellent visualization of the discs, the degree to which they have degenerated, and the relationship of the discs to the adjacent endplate and surrounding neurologic structures (FIG 2B).
  - Provocative discography attempts to reproduce the patient’s typical back pain by pressurizing the disc with normal saline. The patient needs to be awake to provide subjective feedback as to the quality and intensity of the pain. Architectural changes to the disc are inferred by contrast administered with the saline.
  - CT discography provides more detailed information about the disc morphology after contrast administration (FIG 2C).

- Normal laboratory tests, including complete blood count, erythrocyte sedimentation rate, and C-reactive protein, can help rule out a disc space infection; severe disc degeneration can sometimes mimic infection radiologically.

DIFFERENTIAL DIAGNOSIS

- DDD
- Discitis
- Pyogenic vertebral osteomyelitis

NONOPERATIVE MANAGEMENT

- DDD is analogous to hip and knee osteoarthritis in that the intervening cartilage (in the case of the disc: collagen, water, and proteoglycans) fails under compressive loads.
- Weight reduction and activity modification (avoidance of exacerbating activities) may be effective first-line treatments.
- Nonsteroidal anti-inflammatory medications
- Acupuncture or massage therapy
- Physical therapy with aquatic or dry land exercises
- Gentle pelvic traction
- Methylprednisolone (Solu-Medrol) taper
- Epidural injections
- Narcotic medications for severe episodes of pain

SURGICAL MANAGEMENT

- Indications
  - Discogenic back pain refractory to nonoperative management
  - Discitis with pyogenic vertebral osteomyelitis refractory to nonoperative management
  - Spinal deformity requiring radical discectomy
  - A thorough and complete discectomy improves the effectiveness of anterior interbody fusion by creating a wide surface area of exposed bone.
Interbody reconstruction and fusion can be accomplished by a variety of methods, including structural autogenous bone graft (iliac crest or fibula), structural allograft (ie, femoral or humeral ring, femoral head, machined bone dowel), or synthetic device (titanium, PEEK, carbon-fiber, composite) packed with cancellous bone or collagen sponges impregnated with bone morphogenic protein 2 (BMP-2).

Regardless of the method used, prerequisites are that the interbody spacer be strong enough to resist intervertebral compressive loads and provide an appropriate biologic environment for healing.

The particular interbody fusion device of choice (eg, Bagby-Kuslich [BAK; Zimmer Spine, Warsaw, IN], lumbar-tapered [LT] cage [Medtronic Sofomor Danek, Memphis, TN], Bengal carbon fiber cages [DePuy Spine, Raynham, MA]) is inserted with instruments designed for proper implantation.

BMP-2 has been approved by the U.S. Food and Drug Administration for anterior interbody application and has been shown to increase the fusion rate when compared to iliac crest bone graft.5

Preoperative Planning

Plain radiographs, MRI, or CT scans should be carefully evaluated for undiagnosed spondylolysis or spondylolisthesis, which may alter the surgical plan.

Templates can be used with plain radiographs or MRI scans to gauge the size of the final implant to be used.

Oversized implants can lead to undesired stretch on neurologic structures and reduced motion of lumbar disc replacements.

The level of the confluence of the common iliac veins into the inferior vena cava and the bifurcation of the aorta can be located on the axial MRI scans.

At L5-S1 the pubic symphysis occasionally precludes appropriate visualization and instrumentation of the disc space in patients with a deep-seated L5-S1 relative to the pelvis. Evaluation of the lateral radiograph with the pubis on the film is critical to visualize the trajectory into the disc space and avoid this miscalculation.

Positioning

See Chapter SP-4.

The patient is placed over an inflatable pillow over a 1-inch-thick foam pad, which is placed on the mattress of the operating table. The pillow allows for modulation of lordosis throughout the procedure and the foam pad props the patient up, allowing the arms to be tucked posteriorly, out of the plane of the spine during imaging.

Positioning over the break in the table allows for increased lordosis if needed.

The use of fluoroscopic C-arm imaging is crucial for appropriate patient and implant positioning. It is helpful to verify that adequate fluoroscopic imaging of operative landmarks can be achieved after the patient is positioned but before the incision is made.

Approach

See Chapter SP-4 on anterior lumbar approach.

Anterior retroperitoneal approaches will typically allow access to the lumbar discs from L2-3 to the sacrum.

The renal vessels limit more proximal extension of the exposure.

Lateral exposures to the lumbar spine are required for access to the L2 vertebra and above.
Chapter 17  ANTERIOR LUMBAR INTERBODY FUSION, DISC REPLACEMENT, AND CORPECTOMY 4637

ANTEOR LUMBAR RADICAL DISCECTOMY

Exposure

- Identify the intervertebral disc and mark the midline with a spinal needle or screw placed into the vertebral body (we prefer not to place a needle into the disc space because this may create unwanted disc injury) (TECH FIG 1A).
- Use AP and lateral fluoroscopic imaging to check the midline. The midline marker also serves to verify the spinal level.
- At L5-S1, retract the left common iliac artery and vein to the patient’s left and the right common iliac artery and vein to the right. At levels above L5-S1, the aorta and inferior vena cava must be mobilized to the patient’s right.
- The great vessels can be held in their retracted position using handheld Hohmann retractors, custom-designed pins, or K-wires, all of which can be advanced directly into the vertebral bodies (virtually eliminating the risk of vessel migration into the field of interest) (TECH FIG 1B).
- Alternatively, stainless-steel vein retractors or radiolucent retractors can be fixed to the arms of an abdominal retractor system (Omnif) or floating, Endo-ring-type retractor system. These blade retractors have the disadvantage of allowing vessel migration into the field by sliding under the retractor blades as motion occurs during the procedure. The advantage of the radiolucent retractors is that better visualization of the operative field is possible with fluoroscopy. In addition, blade-type retractors can be easily manipulated during the procedure without having to reinsert into the vertebral body.
- Attempt to retract the vessels as far lateral as you can to allow for the widest possible view of the intervertebral disc. Poor visualization at this stage will compromise the quality of the discectomy and any ensuing interbody device placement.

Removing the Disc

- Using a 10-blade on a long handle, incise the intervertebral disc starting laterally along the superior endplate and move toward midline. Always move away from the vessels to avoid an accidental lateral plunge into the great vessels. The blade should be inserted between the cartilage endplate and bone if possible, and we use both hands on the knife shank for optimal control and coordination (TECH FIG 2AB).
- A large, sharp Cobb elevator is then used to release as much of the cartilaginous endplate as possible from the superior and inferior endplates. By angling the Cobb blade toward the bone and pronating and supinating the hand, almost the entire disc (annulus and nucleus) can be removed, as if peeling an orange in one large piece (TECH FIG 2C).
- Long-handled no. 2 and no. 3 Cobb curettes are used to remove the remaining disc, taking the dissection all the way to the posterior longitudinal ligament (TECH FIG 2D). Systematic removal of endplate cartilage enhances thorough removal. Thus, start anteriorly on the superior endplate and move posteriorly. Then start anteriorly on the inferior endplate and move posteriorly.
- The curette will function much more effectively if it is used as a cutting instrument rather than a scraper. For this reason, we prefer that curettes be sharp, nonangled, and used with a pronating–supinating motion with the edge of the curette between the cartilage endplate and the endplate bone.
- The posterior longitudinal ligament is not routinely removed, but the posterolateral corners of the disc space must be thoroughly débrided of disc material for several reasons:
  - Periphery of the endplate is the strongest bone and therefore provides the most stable support of an interbody device.
  - Disc material that is left over can be pushed posteriorly into the epidural space, causing an iatrogenic disc herniation during implant insertion.
  - If anterior decompression of the neural foramen is one of the goals of surgery, visualization and removal of a herniated disc or disc–osteophyte complex will not be possible without proper visualization in this region.
The lateral extent of the discectomy is determined by the width of the device to be inserted, but care must be taken to maintain the width of the discectomy posteriorly as the natural tendency is to remove less disc laterally in the posterior portion of the disc space.

A lamina spreader can be gently distracted in the anterolateral interbody region to gain enhanced visibility of the posterior disc space (TECH FIG 2E).

Removal of a posterior or foraminal disc herniation can be accomplished by passing an angled Kerrison rongeur posteriorly and into the neuroforamen. Identification of the ventral aspect of the dura enhances the safety of this maneuver (TECH FIG 2F).

Epidural bleeding can be brisk during posterior disc removal, but thrombin-soaked Gelfoam gauze and removal of intervertebral distraction can be used to control it.

**TECH FIG 2 • A, B.** Direction of movement of the surgical blade. At L5-S1 the surgical field is within the bifurcation of the great vessels, so the surgical knife should always be directed toward the midline and inferiorly—away from vascular structures. At L4-5 and above, the vascular structures are retracted to the patient’s right, and therefore movements with the knife blade are directed to the patient’s left and inferiorly. C. A large Cobb is used between the disc cartilage and the vertebral body to remove as much as possible in one large piece. (continued)
Once the discectomy has been completed, disc space distractors are inserted to gauge the size of the final implant (TECH FIG 3A). Appropriate distractor size can be gauged by comparing the operative level with a normal disc above or below. In addition, the interface between the distractor and the bony endplate should be less than 1 mm. This ensures good interference fit of the final device.

For threaded devices such as the LT cage, a cannulated guide channel is inserted over the disc distractors. This working channel serves to prevent inadvertent migration of the great vessels into the disc space.

Endplate reamers are then inserted to appropriate depth as determined by lateral fluoroscopic imaging (TECH FIG 3B). Care should be taken to aim the reamer for the midportion of the disc space posteriorly on lateral fluoroscopy rather than through one endplate or the other.

Asymmetric reaming will result in excessive removal of one endplate compared to another and the final implant will be more likely to fail in subsidence. Because the reamer tends to follow the path of least resistance, an exceptionally sclerotic endplate will predispose one to asymmetric reaming by this mechanism.

Final threaded implants are then screwed into the appropriate depth and orientation (TECH FIG 3C,D). The first cage (in a dual-cage system) is inserted in the same trajectory as the reamers, and lateral fluoroscopic imaging during cage placement ensures that the cage is not placed too anteriorly or posteriorly. The cage should not
be inserted beyond the depth of the reamer or else the threads will strip and the cage will lose a large percentage of its fixation strength. 
- Saving the C-arm image of the final reamer depth allows the surgeon to reference this image when inserting the cage.
- The second cage is inserted using the first cage as a reference for trajectory and depth. Final images should be true AP and lateral projections showing the cage devices to be in good position. Overlapping pedicles on the lateral image will appear sharp, confirming true lateral positioning (TECH FIG 3E,F).

**LUMBAR TOTAL DISC REPLACEMENT**

**Determining Implant Size**
- Determine midline and the appropriate spinal level by inserting a bone screw, which will serve as a reference throughout the case. Obtaining true AP and lateral images is critical to ensure that the remainder of the instruments and devices can be referenced off these radiographic landmarks (TECH FIG 4A).
- Once the discectomy is completed, a sizing guide, or “lollipop,” is used to ascertain the size of the implant to be used (TECH FIG 4B). These guides vary in depth and width to conform to the size of the vertebral endplate.
- The endplate of S1 is often more shallow in the AP dimension than L5, and this may necessitate the use of a smaller implant at this level.
- The largest footprint that is still covered by the vertebra is chosen. This helps to ensure that the final device will be supported by the greatest percentage of peripheral cortical bone.
- The height and lordosis of the final implant are determined by trial wedges that fit into the interbody location (TECH FIG 4C–E). The vertebral endplates should be flush with the trials.
Implant Placement
- Grooves for a central keel or for fixation teeth are then cut. Make sure the central groove is in the midline and that the trajectory for the grooves is directly posterior and not angled (TECH FIG 5A,B).
- The final implant is then inserted (TECH FIG 5C,D). Double-check that the implant is the correct size and is inserted in the correct orientation regarding lordosis. It can be helpful to break the bed or inflate the lumbar pillow to get the disc implant started in a particularly collapsed disc. Once the implant is halfway into the disc space, the lordosis should be removed so that the implant will move easily into the posterior portion of the disc (TECH FIG 5E,F).

ANTERIOR LUMBAR CORPECTOMY

Vertebra Removal
- The indications for anterior corpectomy in the lumbar spine are lumbar burst fracture, catastrophic failure of lumbar disc replacement or interbody device (ie, vertebral fracture), lumbar vertebral osteomyelitis, correction of kyphosis, and vertebral body malignancy.
- In cases of corpectomy for vascular tumors, pre-operative embolization should be performed (TECH FIG 6A).
- In cases of corpectomy, lumbar radical discectomies are performed above and below the vertebral body to be removed (see discectomy technique above).
TECH FIG 6 • A. Pre-embolization angiogram depicting the aortic bifurcation in a 65-year-old patient with metastatic renal cell carcinoma to the L4 vertebra. Note the degree of vascularity of the L4 vertebral body. B. Postembolization angiogram depicting a striking reduction in contrast entering the L4 vertebral body. Small embolization coils are seen in the vascular network surrounding the vertebral body. C. Anterior disectomy enables the surgeon to use a large rongeur to gain access to the edge of the vertebra and thereby remove the vertebral body bone.

- This enables the surgeon to become oriented to the midline and also to judge the depth and width of the corpectomy to be performed.
- The discectomy space also allows the surgeon to use a large rongeur efficiently to remove the vertebral body (TECH FIG 6B).
- Retractors should be placed above and below the entire vertebra to be removed so there is an unobstructed view for the surgeon and the assistants. The vertebral body bleeds more rapidly than the endplates, so the assistants need to be able to visualize the operative field to suction effectively.
- A Leksell rongeur can be used to remove all of the vertebral body back to the level of the posterior cortex. If this needs to be removed, angled curettes are used to develop the plane behind the vertebra, starting at the disc space. Kerrison punches or angled curettes are then used to lift the posterior cortex off the ventral dura.
- Healthy vertebral body bone should be saved for interbody fusion.

Filling the Interbody Space

- Once the corpectomy is completed, bone graft or an interbody device is contoured to fit into the defect. The wooden end of a cotton-tipped applicator can be cut to the length of the defect and can then be used as a size gauge for the final interbody device. This is particularly useful when cutting and contouring a bone graft because calipers and rulers do not always fit easily into the central portion of the corpectomy defect to give an accurate height measurement.
- Check the height of the corpectomy defect with the wooden applicator throughout its entire depth, from anterior to posterior. Keep in mind that the shape of the corpectomy site may be lordotic, and thus the bone graft or implant needs to be fashioned appropriately.
- Allograft strut grafts such as femoral head, humerus, or femoral shafts can be cut using an oscillating saw to fit snugly into the interbody space. The advantages of allograft are it can be packed with morselized autogenous bone, it has a similar modulus of elasticity to host vertebral bone, and it will become osseointegrated over time. Autogenous tricortical iliac crest and autogenous fibula have the greatest healing potential but are also associated with significant harvest site morbidity.
- Metal cages generally are the easiest to fashion to fit the corpectomy space and can be packed with morselized corpectomy bone (TECH FIG 7A). The disadvantages are their expense and relatively reduced surface area at the endplate for fusion compared to bone.
- The width of the corpectomy should be kept as narrow as possible without compromising decompression or removal of pathologic bone (TECH FIG 7B).
- Allows bone ingrowth from the corpectomized vertebral body into the interbody bone graft.
- Enhances the stability of the interbody strut.
- A bone screw with a washer can be used above and below large defects as an “anti-kickout” buttress for allografts (TECH FIG 7C).
Chapter 17  ANTERIOR LUMBAR INTERBODY FUSION, DISC REPLACEMENT, AND CORPECTOMY 4643

TECH FIG 7 • A,B. AP and lateral postoperative radiographs of a patient in whom posterior element resection followed by fusion and instrumentation with pedicle screws was performed as a first stage, followed by complete anterior corpectomy and reconstruction with a cylindrical titanium mesh cage packed with autogenous bone graft. An anterior side plate was applied as the lateral vertebral body wall was completely removed. C. The corpectomy strut device should fit snugly against the cut edge of the vertebral body to promote side-to-side fusion from host bone to strut graft. D. Intraoperative image of anterior allograft reconstruction after corpectomy, irrigation, and débridement of the L3 vertebra in a 62-year-old man with L3 vertebral body destruction from pyogenic vertebral osteomyelitis. 4.5-mm cortical screws with washers are used to prevent allograft kickout.

PEARLS AND PITFALLS

Use of a pulse oximeter on the left great toe provides real-time feedback to the surgeon about perfusion to the distal extremity during great vessel retraction.

- There should be a low threshold for prophylactic inferior vena cava filter placement in patients with venous injuries requiring repair, as pulmonary embolism, although rare, carries potentially catastrophic consequences.

Perforation of the cancellous vertebral body endplates with Cobb curettes or the lamina spreader increases the likelihood of implant subsidence.

- Early (less than 2 weeks) implant malpositions or migrations can be easily revised as the anterior tissue planes are still preserved.

Epidural bleeding can be effectively controlled quickly with thrombin-soaked Gelfoam gauze and release of any disc space distractors.

- Overdistraction of the disc space with a lumbar disc replacement implant will result in compromised motion and may be associated with new postoperative leg pain related to stretch injury to the lumbosacral nerve trunks.

Marking the location of the dorsalis pedis and posterior tibial pulses with a marking pen facilitates reassessment of pulses in the postoperative setting when lower extremity swelling is more prevalent.
have significantly improved fusion rates and clinical outcomes compared to patients in whom the cages were packed with iliac crest bone graft.

In a prospective, randomized trial comparing Charite lumbar disc replacement to stand-alone anterior lumbar interbody fusion with titanium cages and iliac crest bone graft (control group), a significantly greater percentage of patients undergoing disc replacement were satisfied with their procedure versus the control group at 2-year follow-up.

- Hospital stay was significantly shorter in the disc replacement group compared to controls.
- However, at 2 years there was no statistical difference between the disc replacement group and the control group with respect to pain or disability.
- Clinical outcomes and flexion-extension range of motion correlate with surgical technical accuracy of lumbar disc replacement.

COMPLICATIONS
- Most complications associated with anterior lumbar discectomy, interbody fusion, disc replacement, and corpectomy are approach-related.
- The most common complications of anterior lumbar interbody fusion are pseudarthrosis and device failures such as migration or breakage.
- The complications of lumbar disc replacement depend on the exact type of device being inserted but generally can be categorized as follows:
- Device failures: metal endplate breakage, core dislodgement or fracture, polyethylene degradation
- Bone-implant failures: subsidence, vertebral body fracture, implant migration or dislocation
- Iatrogenic deformity: kyphosis, scoliosis
- Host response: osteolysis, heterotopic ossification
- Infection
- Revision approaches to the anterior lumbar spine carry six times the risk of major bleeding or thromboembolic complications. Preoperative intravenous filter insertion, ureteral stenting, and percutaneous venous access wires are critical to reduce these risks.

OUTCOMES
- Level IV evidence reported by Tropiano et al showed significant improvements in back pain, radiculopathy, and disability at mean of 8.7 years after insertion of the Prodisc lumbar disc replacement.
- Anterior lumbar interbody fusion with titanium cages and iliac crest bone graft has been shown to yield significantly greater fusion rates (97%) versus allograft dowels packed with iliac crest bone graft (48%).
- Patients undergoing anterior lumbar fusion with the titanium cages packed with BMP-2-impregnated collagen sponges have significantly improved fusion rates and clinical outcomes compared to patients in whom the cages were packed with iliac crest bone graft.

POSTOPERATIVE CARE
- As soon as the patient emerges from anesthesia, a complete neurologic examination and brief history should be performed. Specifically, patients should be asked if they have any new leg pain. If present, CT myelography or plain CT scans should be obtained to ensure that no bone, disc material, or portion of an implanted device is impinging on the lumbar nerve roots.
- Nasogastric tubes for the first 12 to 24 hours help to minimize abdominal wall distention and postoperative ileus.
- Patients are encouraged to walk on postoperative day 1.
- Lumbar corsets or abdominal binders are prescribed at the discretion of the surgeon and may reduce the tension on the abdominal incision in the early postoperative period.
- Return to heavy manual labor is restricted in patients undergoing anterior interbody fusion until the fusion is solid. Fine-cut CT scans are useful in documenting solid fusion if there is doubt on AP, lateral, or flexion-extension radiographs.
- Manual labor should be restricted in patients undergoing disc replacement until the bone–prosthesis interface is judged to be stable. In nonkneelded total disc replacement devices requiring porous ingrowth for definitive fixation, such as the Charite (DePuy Spine, Raynham, MA), at least weeks out of work is recommended.

COMPLICATIONS
- Most complications associated with anterior lumbar discectomy, interbody fusion, disc replacement, and corpectomy are approach-related.
- The most common complications of anterior lumbar interbody fusion are pseudarthrosis and device failures such as migration or breakage.
- The complications of lumbar disc replacement depend on the exact type of device being inserted but generally can be categorized as follows:
- Device failures: metal endplate breakage, core dislodgement or fracture, polyethylene degradation
- Bone-implant failures: subsidence, vertebral body fracture, implant migration or dislocation
- Iatrogenic deformity: kyphosis, scoliosis
- Host response: osteolysis, heterotopic ossification
- Infection
- Revision approaches to the anterior lumbar spine carry six times the risk of major bleeding or thromboembolic complications. Preoperative intravenous filter insertion, ureteral stenting, and percutaneous venous access wires are critical to reduce these risks.

REFERENCES


DEFINITION
- Adult scoliosis is a coronal deformity of the spine, typically also involving axial and sagittal plane abnormalities.
- Adult scoliosis may be categorized by patient presentation.
  - One group, predominantly defined by lumbar stenosis and neurogenic claudication with degenerative deformity, has surgical management typically achieved by posterior lumbar procedures.
  - A second group, categorized by progressive deformity, with or without back pain, is more frequently treated with combination anterior and posterior procedures that may involve the thoracic spine to achieve surgical goals.
- While the surgical principles and techniques used to address these different categories are similar, important variations exist.

ANATOMY
- Anatomic characterization of adult spinal deformity involves the coronal, sagittal, and axial planes.
  - Lumbar degenerative scoliosis is characterized by loss of lordosis and intervertebral disc height, as well as listhesis in the anteroposterior, lateral, or rotary direction (FIG 1A,B).
  - Long curves, typically the result of a preexisting spinal deformity, may involve the entire thoracolumbar spine and may be associated with a significant rotational component (FIG 1C,D).

PATHOGENESIS
- Adult scoliosis develops either as the progression of a spinal deformity that was present in adolescence, or as the development of a deformity related to other spinal disorders.
  - The progression of the adolescent spinal deformity is related to increasingly unbalanced forces in the axial skeleton over time.
  - De novo adult deformity is commonly the result of degenerative disease and may also be related to osteoporotic fragility fractures of the vertebrae, resulting in a deformity frequently associated with spinal stenosis and mechanical back pain.

NATURAL HISTORY
- The progression of an adolescent deformity is often seen as a long thoracolumbar curve in the adult.
  - Curves that reach a magnitude of more than 50 degrees are more likely to progress, resulting in symptom exacerbation.
  - As patient age increases, curve flexibility decreases.
  - Lumbar degenerative curves typically involve fewer segments and may be limited to the lumbar spine.
- Degeneration and deformity can cause central, lateral recess, and neural foraminal stenosis as a result of:
  - Loss of intervertebral height
  - Hypertrophy of facet joints
  - Buckling of the ligamentum flavum
  - Compression deformities
  - Neurogenic claudication, as well as radiculopathy and back pain, may result.

PATIENT HISTORY AND PHYSICAL FINDINGS
- Determining the reason for the patient’s presentation is the first step in establishing the goals of surgical treatment.
- Patients with extensive thoracolumbar deformity may present with concerns related to curve progression with an impact on:
  - Balance
  - Ambulation
  - Pain
  - Cosmesis
- Patients with lumbar degenerative scoliosis classically present with complaints of neurogenic claudication.
  - Hip and knee flexion contractures, related to the typical forward-flexed ambulation that limits the symptoms of neurogenic claudication, may be found (FIG 2).
  - Major focal neurologic abnormalities are unusual in this patient group, although relatively mild degrees of weakness in the tibialis anterior and extensor hallucis longus are not uncommon.
- Physical examination should include the following:
  - Assessment of sagittal balance based on lateral observation of the patient standing with knees extended. A plumb line is dropped from the ear and the deviation (anterior or posterior shift) at the greater trochanter is measured, as is the regional (lumbar) lordosis and (thoracic) kyphosis. An upright posture with head over trunk and trunk over pelvis is a critical treatment goal.
  - Assessment of coronal balance based on posterior observation of the patient standing. A plumb line is dropped from the occiput and the deviation (leftward or rightward shift) at the sacrum is measured. A centered posture reduces gait abnormality.
  - The clinician should observe and palpate the vertical relationship of the right and left acromions with the patient standing. Shoulder asymmetry may indicate coronal postural compensation to maintain upright stance.
  - The clinician should observe and palpate the vertical relationship of the right and left iliac crests with the patient standing on the right, left, and both legs. Pelvic obliquity may be a primary or compensatory mechanism with spinal deformity.
  - Assessment of hip and knee range of motion. Longstanding sagittal plane deformities, as well as neurogenic claudication, may result in hip and knee flexion contractures.
  - Focal findings may be uncommon, but a thorough neurologic examination must be performed.
IMAGING AND OTHER DIAGNOSTIC STUDIES

Radiographs

- Standing posteroanterior (PA) radiographs on 36-inch cassettes characterize the spinal deformity by:
  - The magnitude of primary and compensatory curves, by the Cobb method (FIG 3)
  - Coronal balance: the relationship between the C7 plumb line and center of S1 on PA views (FIG 4)

- The apical vertebrae (most laterally deviated; FIG 5A)
- The stable vertebra (caudal vertebra that is transected by the z axis; FIG 5B)
- Rotary and lateral listhesis
- Standing lateral radiographs on 36-inch cassettes characterize the spinal deformity by:
  - Regional lordosis and kyphosis (FIG 6)
  - Sagittal balance; the relationship between the C7 plumb line and center of S1 on lateral views (FIG 7)
  - Anterolisthesis or retrolisthesis

FIG 1 • A,B. Degenerative lumbar scoliosis in PA (A) and lateral (B) radiographs. Lateral, rotary, and anterolisthesis are seen, with significant loss of disc height, osteophyte formation, and subchondral sclerosis. The coronal deformity is limited to the lumbar region. C,D. A long scoliosis involving the lumbar and thoracic regions, associated with rotational deformity, shown in PA (C) and lateral (D) radiographs.

FIG 2 • Neurogenic claudication is frequently associated with this gait abnormality. A forward-flexed posture may provide postural relief of posterior foraminal stenosis but typically alters the sagittal balance, as depicted here. Hip and knee flexion contractures may be associated.

FIG 3 • The Cobb method is used to measure the coronal deformity. Vertebral endplates (or the margins of pedicles) are used to extend lines as depicted for each of the curves involved. Lines orthogonal to these are then compared to determine the scoliosis angle. Vertebrae are typically selected to maximize the Cobb angle on each measurement.
Coronal balance is evaluated on the standing PA radiograph. A virtual plumb line is dropped from the center of C7. The lateral distance between that plumb line and the center of S1 is then measured. (Left to right) Negative coronal decompensation, coronal compensation, and positive coronal decompensation. CSVL, center sacral vertical line.

The apical vertebra is defined as that which is most deviated laterally on the PA radiograph. The stable vertebra is defined as the caudal vertebra that is transected by the vertical plumb line extending from the center of S1 on the standing PA radiograph. CSVL, center sacral vertical line.
Right- and left-bending PA radiographs (FIG 8) are used to:

- Evaluate spinal flexibility
- Determine the structural or nonstructural nature of the curve
- Supine traction radiographs may also be used to evaluate curve flexibility.

**CT Scans**

- Axial CT images, reformatted in the plane of the superior endplates of each vertebra, may be used to measure pedicle dimensions for preoperative planning.
- Plain radiographs and CT images can be used to assess the degree of bone loss and tailor the reconstructive techniques to the bone quality of the patient.

**MRI**

- MRI is used to assess neurologic compression (FIG 9) as well as the status of the disc, ligamentum flavum, and other soft tissues.

**Dual-Energy Radiographic Absorptiometry**

- Dual-energy radiographic absorptiometry (DEXA) is often performed for patients with identified risk factors:
  - History of fracture as an adult or fracture in a first-degree relative
Part 9 SPINE • Section III THORACOLUMBAR SPINE SURGERY

- White race
- Advanced age
- Smoking
- Low body weight
- Female gender
- Dementia
- Poor health or general fragility

Provocative Tests
- Discography can be useful to assess for painful segments, particularly in the lower lumbar spine.
- Facet blocks have been employed to determine levels that should be included, or need not be included, in the fusion. This may be particularly relevant at the lumbosacral junction.20

NONOPERATIVE MANAGEMENT
- A physical therapy regimen may be tried, focusing on:
  - Stretching and core-strengthening exercises
  - Postural training
  - Gait training
  - Resolution of hip and knee flexion contractures
  - General conditioning
- Nonsteroidal anti-inflammatory medications may be used if safely tolerated

SURGICAL MANAGEMENT
- The treatment of adult scoliosis is complex because of the global nature of the spinal deformity and the multiple causes of this disorder.
- Efficiency, safety, and effectiveness in meeting surgical goals are each optimized by a well-designed procedure.

Preoperative Planning
- Preoperative planning is instrumental to a successful treatment algorithm; avoiding both short- and long-term complications is paramount.
- In 1968, the complications associated with surgical correction of adult deformity were estimated to include:31:
  - 5% risk of death
  - 6% risk of major neurologic deficit
  - 20% risk of correction loss
  - 10% risk of deep infection
  - 40% risk of major medical complication

FIG 8 • Bending radiographs aid in determining the flexibility of the spinal curves and are also used to determine the structural or nonstructural nature of the curves.

FIG 9 • MRI is particularly useful in evaluating patients with neurologic symptoms such as claudication. It is used to assess neurologic compression as well as the status of the disc, ligamentum flavum, and other soft tissues.
With advances in surgical and anesthetic techniques, neurophysiologic monitoring, and improvements in perioperative management, these risks have been significantly decreased.

The patient with adult scoliosis may carry a myriad of co-morbidities that may increase the risk of a spinal operation or even contraindicate it. A complete preoperative assessment of those considering surgical treatment provides the opportunity to minimize risks by optimizing health status.

Modifiable conditions that affect surgical risk include:
- Tobacco smoking
- History of asthma or chronic obstructive pulmonary disease
- Coronary or cerebrovascular disease
- Diabetes
- Nutritional deficiency
- Osteoporosis
- Depression
- Current significant life stressors

Collaboration with consulting medical specialists who are trained in perioperative management is an important technique to optimize outcomes for patients with adult scoliosis.

Anesthesia colleagues familiar with this surgical course may also reduce risks.

Certain medical considerations directly affect the selection of surgical techniques for a patient with adult scoliosis.
- Assessment of bone quality plays a critical role in the design of the operation.
- Osteoporosis is the rule, not the exception.

**Approach**

Posterior surgical approaches are typically used for the treatment of adult deformity correction.

Anterior surgery may be used alone in isolated cases but is more frequently combined with posterior surgery to augment the deformity correction, reconstruction, or both.

Anterior exposure allows the soft tissue releases that are often required for adequate deformity correction.

**General Procedures**

**Fixation Strategies for Osteoporotic Bone**

- Spinal instrumentation with pedicle screw fixation is less effective in osteoporotic bone.
- Trabecular bone is predominantly affected by osteoporosis.
- Since pedicle screws have cortical contact limited to the pedicle isthmus, a “windshield wiper” mode of failure typically leads to screw loosening.
- Fixation strategies for osteoporotic bone are targeted toward:
  - Taking advantage of the relatively stronger cortical bone
  - Augmenting the fixation of a pedicle screw within the existing trabecular bone
- Bone-implant interface complications in the osteoporotic spine can be reduced by various methods.
  - Sublaminar wires and pediculolaminar fixation take advantage of the cortical bone composition of the posterior spinal lamina (FIG 10).
  - Fixation of pedicle screws within osteoporotic trabecular bone may be improved by polymethylmethacrylate (PMMA) cement augmentation.
    - Fluoroscopy is used to visualize the placement of 2 to 3 cc of PMMA per pedicle to ensure that cement does not migrate to the neural elements.

**Fusion and Bone Grafting**

- Establishment of a solid fusion is critical.
- The pseudarthrosis rate in one large series of adult deformity patients after long fusion procedures was 24%.
- Statistically significant risk factors for pseudarthrosis in that study included:
  - Thoracolumbar kyphosis
  - Hip osteoarthritis
  - Use of a thoracoabdominal (versus paramedian) approach
  - Positive sagittal balance greater than 5 cm
  - Age greater than 55 years
  - Incomplete sacropelvic fixation

These risk factors emphasize the importance of surgically establishing the proper mechanical environment, including overall sagittal balance and appropriate fixation.

**Bone Graft Selection**

- Appropriate graft selection may reduce pseudarthrosis risk.
- Bone grafts and alternatives may serve multiple roles in the surgical treatment of adult scoliosis; fusion-promotion and deformity-correction techniques both may influence graft selection.

**Calcium sulfate paste may also be used; this has the theoretical advantage of becoming replaced by bone over time.**

- Modified pedicle screws may also be used, including conical screws, hydroxyapatite-coated screws, and expandable screws.

**PEDICLE SCREW ELECTION AND PLACEMENT**

- Screw pullout strength is improved when high insertional torque is achieved:
  - Undertapping (or not tapping) the screw path
  - Using tapered screws. These are limited by the absolute restriction that they cannot be reversed or backed out; such an action would remove the screw’s contact with the bone.
  - Using larger-diameter screws. Increased cortical contact may increase insertional torque but may increase the risk of pedicle fracture as well.
  - Using longer screws: Bicortical purchase can increase screw pullout strength but may pose the possibility of injury to abdominal or vascular structures.

**FIG 10 • Fixation strategies for osteoporotic bone may include the use of multiple fixation points in a vertebra. Such instrumentation, as depicted here, incorporates pedicle screw and laminar hook instrumentation at the same vertebral level.**
An anterior interbody graft may need to be structural to correct a deformity.

- If a structural graft is used anteriorly first, it is with the anticipation that further deformity correction at that segment will be limited by posterior manipulation.
- Anterior structural interbody grafts can be instrumental in preventing a kyphosis when the convexity of a deformity is compressed in a reduction maneuver.
- Structural grafts can be placed with a bias toward the concavity in order to assist in the deformity correction.
- Structural interbody grafts serve a critical role in supplementing the stability of a reconstruction, particularly at the caudal end of a construct, at the lumbar–sacral junction.
- Morselized grafts may allow for deformity correction by subsequent posterior manipulation.

Our typical strategy is as follows:

- Use structural grafts at the caudal end of the construct (two to four levels).
- Overzealous posterior manipulation can cause loosening or displacement of an anterior structural graft.
- Use morselized graft rostrally.
- Subsequent deformity correction during the posterior procedure will be limited mainly to those levels with morselized (or no) anterior graft.

**INTERBODY GRAFT MATERIALS**

- Graft selection is guided by:
  - The goal of fusion success
  - The potential utility of structural roles for the graft
  - The risk of potential complications and other shortcomings
  - Costs
- Interbody grafts may be composed of:
  - Bone (autograft or allograft)
  - Metal
  - Carbon fiber
  - PEEK
  - Other synthetic material
- To reduce the risk of graft subsidence, a graft with a modulus of elasticity similar to that of the native bone can be employed.
  - Iliac crest autograft is typically the best modulus match but is associated with well-established harvest-related morbidity.
  - In osteoporosis, we have used allograft harvested from the iliac crest of a donor, which offers:
    - A relatively high proportion of trabecular to cortical bone compared to a long bone allograft, and an improved modulus match
    - More rapid biologic incorporation of trabecular grafts
  - Carbon fiber and PEEK interbody cages offer a lower (and more closely matched) modulus compared to metal cages; we typically avoid metal cages in the reconstruction of osteoporotic spinal deformities.
- Autograft remains the gold standard material for establishing a solid arthrodesis but has shortcomings:
  - Morbidity of iliac crest autograft harvest
  - Chronic donor-site pain
  - Postoperative hematoma, infection
  - Nerve or vessel injury
  - Iliac graft harvest may be undesirable when iliac instrumentation is planned.
- Autograft may be insufficient for an extensive thoracolumbar fusion.
- Autograft alternatives include allograft products, synthetics, and bone morphogenetic proteins (BMP).
- The fusion efficacy of BMP-2 has recently been demonstrated in patients with adult spinal deformity.
- Seventy adult patients underwent scoliosis fusion with anterior or posterior BMP-2 application, with either local bone graft only (posterior) or no bone graft (anterior), obviating rib, iliac crest, or other autograft harvest morbidity.
- Fusion rates were satisfactory, with 96% anterior fusion success and 93% posterior fusion success.

**BONE MORPHOGENETIC PROTEIN**

- Attention to certain surgical techniques reduces the risk of complications and may also improve efficacy.
- The risks associated with the use of BMP in the cervical spine include:
  - Complications related to soft tissue swelling
  - Inappropriate bone formation
  - Accelerated graft resorption
- In the lumbar spine, there also have been reports of undesirable effects, including:
  - Inappropriate bone formation around neural elements
  - Postoperative radiculitis
  - Accelerated resorption of interbody grafts, increasing the risk of pseudarthrosis, has also been reported in a study of single-level uninstrumented anterior lumbar interbody fusion.
- Structural allograft with appropriate doses of BMP at the lower two to four levels in adult thoracolumbar fusions can, however, be used with minimal risks of complications.
- Example: BMP-augmented transforaminal lumbar interbody fusion (TLIF)
  - Care is taken to reduce the risk of inappropriate bone formation.
  - These steps may help ensure maintenance of the BMP and limit the BMP from affecting adjacent tissues:
    - Irrigate before the placement of the BMP packed cage, not afterward.
    - Pack the BMP sponge entirely within the cage, avoiding “overstuffing.”
    - Place additional sponge only anterior to the cage.
    - Use a repairable “trapdoor” annulotomy.
  - A three-sided annular flap is created, hinging medially, such that when the flap is held open with sutures at its corners, it augments the protection of the thecal sac.
  - After discectomy and placement of BMP, anterior graft, and TLIF cage, the annulotomy is repaired with suture and augmentation of the closure with an adjuvant sealant.

**Sagittal Balance**

- The single most important principle in the surgical treatment of adult scoliosis is achieving and maintaining a proper sagittal balance.
- Balanced spinal posture with neutral positioning:
  - Provides for decreased energy requirements with ambulation
  - Limits pain and fatigue
  - Improves cosmesis and patient satisfaction
  - Limits complications associated with unresolved (or new) deformities
FUSION LEVEL SELECTION

- Sagittal balance must be achieved.
- Functional problems must be avoided.
- Presenting symptoms can guide level selection.
  - Discography can be useful to assess for painful segments, particularly in the lower lumbar spine, that may be incorporated in the fusion.
  - Facet blocks have been employed to determine levels that should be included or need not be included. This may be particularly relevant at the lumbosacral junction.20

RODRIGUETHI

- 36-inch standing PA and lateral
- PA (left and right) bending views, to determine if the main curves are structural
  - If the Cobb angle is greater than 25 degrees on side-bending radiographs, then it is considered to be a structural curve.25
  - Curve magnitude and flexibility and the apical vertebral translation of the thoracic and lumbar curves are measured.
  - The relationship between the C7 plumb line and the center sacral vertical line is considered.
  - Radiographic signs of degenerative disease are categorized.
  - Listhesis (rotary and lateral) are noted. Degenerative segments often are associated with stenosis; this must be considered in the treatment algorithm.

FUSION TO THE SACRUM

- Extension of the fusion to the sacrum for the adult scoliosis patient is an important and controversial subject. There is no consensus as to the best strategy for all clinical scenarios, but certain guidelines and lessons have been developed.
  - There is a relatively high rate of pseudarthrosis (and other complications) after L5–S1 fusion.11,19 For these reasons, in part, some have advocated avoiding fusion to the sacrum whenever possible.3
  - Certain scenarios do require lumbosacral fusion:
    - Symptomatic L5–S1 spondylolisthesis
    - Other instability
    - Oblique take-off with over 15 degrees of scoliosis at the L5–S1 segment often requires reduction and fusion for adequate correction of deformity.
    - For correction of lumbar hypolordosis to achieve proper sagittal balance
  - The risk of pseudarthrosis at the lumbosacral junction can be limited by:
    - Employing combined approaches to perform a meticulous 360-degree fusion at the L5–S1 segment
    - BMP may be applied to further increase the chances of solid arthrodesis.
    - Anterior instrumentation has been advocated:
      - Fixed-angle plates
      - Vertebral body compression screws
      - Isolated posterior instrumentation may be satisfactory if good bicortical purchase is achieved with sacral screws, with high insertion torque.
    - Additional fixation is required, however, in many cases, and iliac screws or Galveston technique fixation satisfies this need.
  - Recently, the use of allograft with BMP and posterior pedicle fixation, without iliac fixation, has been used successfully due to the speed of healing, with the caveat that this depends on the length of fusion.

Specific Management Strategies by Diagnosis

Degenerative Lumbar Scoliosis

- The patient with adult lumbar scoliosis typically has some component of back pain and may also present with radiculopathy or claudication.
- For the typical patient presenting with stenosis complaints, decompression of the neural elements is a priority.
- Deformity correction with proper sagittal balance also is a critical goal of surgery.
  - Loss of lumbar lordosis is associated with increased pain.37
  - Restoration of proper sagittal balance is the most important factor associated with clinical outcome.13
- The typical patient presents with hypolordosis and varying degrees of scoliosis, typically associated with relatively flexible thoracic compensatory curves less than 30 degrees or no thoracic curve (FIG 11A,B).
  - Common radiographic findings include:
    - Degenerative disease, most commonly at L5–S1
    - Rotatory subluxation at L3–L4 (FIG 11C,D)
    - Obliquity at L4–L5 (FIG 11E,F)
  - The choice of surgical approach for the treatment of lumbar adult scoliosis depends on:
    - The levels of the pain-generating segments
    - The flexibility of the curve
    - The coronal obliquity of the distal vertebrae
    - The extent of the curve
  - While in situ fusion may be an option for patients with small-magnitude deformity and poor bone quality, typically restoration of lordosis and coronal realignment are desired (FIG 12). This can be accomplished with a variety of methods, many of which require restoration of anterior height.

TLIF for Deformity Correction and Reconstruction

- TLIF may achieve these goals with a posterior-only approach.
- To assist in correction of the deformity, the cage may be biased to the concavity of the scoliosis to address the coronal plane.
- After facetectomy and posterior compression, lordosis can be restored.
  - In general, a posterior interbody technique (posterior or thoracic lumbar interbody fusion) is less effective than an anterior interbody approach for restoring lordosis.
  - The use of an operating table that produces extension of the lumbar spine (Jackson) to maximize positional lordosis is critical.
- The decision of the levels to include in the treatment of a degenerative lumbar deformity may be determined by a variety of influences.
  - It can be useful to preoperatively determine which segments contribute to a patient’s pain.
  - The apex of the deformity is included (typically L3 or L4).
  - Levels that are severely degenerated may also be included, particularly if they exhibit lateral or rotary listhesis.
- There is no general consensus as to where a lumbar construct should terminate cranially, but it should be at least at a stable end vertebra (ie, the cranial-end level of the fusion construct should be bisected by the center sacral line on a lateral radiograph).
- If the goal is to treat neurogenic claudication, relieve stenosis, and prevent future progression, a short-segment construct (often L2–L5) is sufficient if adequate lordosis is attained and the cranial and caudal vertebralae are well balanced.
In many scenarios, however, such as when the Cobb angle is from L1 to L5, it is necessary to continue the fusion cranially past the thoracolumbar junction. When this is the case, one should take care not to end the fusion at the thoracolumbar junction or at the apex of the thoracic kyphosis.

Extending the fusion to the thoracolumbar junction provides fixation into the more stable rib-bearing vertebrae and is more likely to terminate within the sagittal plumb line, reducing the risk of instrumentation failure or junctional kyphosis. A frequent decision-making dilemma is where to end the caudal end of the fusion reconstruction.

FIG 11 • A, B. Radiographs of a patient with degenerative lumbar scoliosis. Rotatory and lateral listheses are seen on the PA view (A) and the typical hypolordosis is seen on the lateral view (B) preoperatively. C, D. Lumbar radiographs of a typical patient with degenerative scoliosis limited to the lumbar region. The lateral listhesis is seen at L3–L4 (C) as well as the typical loss of lumbar lordosis (D). In another patient, obliquity at L4–L5 is seen in the preoperative PA radiograph (E), with focal loss of disc and neuroforaminal height seen on the preoperative lateral radiograph (F).

FIG 12 • A, B. After decompression of the patient in Figure 11A,B, spinal reconstruction is achieved with recreation of coronal (A) and sagittal (B) balance. C, D. In the patient in Figure 11E,F, postoperative reconstruction after decompression of the neural elements recreates lumbar lordosis to achieve proper sagittal balance.
Accepted indications to fuse to the sacrum include:
- Spondylolisthesis or previous laminectomy at L5–S1 (FIG 13A)
- Stenosis requiring decompression at L5–S1
- Severe degeneration
- An oblique take-off (above 15 degrees) of L5 (FIG 13B)

Fusions to the sacrum in adults with lumbar scoliosis have been found to:
- Require more additional surgery than those to L5
- Have more postoperative complications
- On the other hand, fusions to L5 have been associated with:
  - A 61% rate of adjacent segment disease
  - An associated shift in sagittal balance
- When fusion to the sacrum is performed, iliac fixation should be considered, particularly if the fusion includes more than three levels (FIG 13C,D).
- Augmentation of the lumbosacral reconstruction with interbody fusion at L5–S1:
  - Improves biomechanical stability
  - Reduces the risk of lumbosacral pseudarthrosis
- A structural graft at L5–S1 can:
  - Recreate lordosis, partially restoring sagittal balance
  - Diminish stenosis by restoring intervertebral height
- Hip and knee flexion contractures can be common in this group, with patients accustomed to ambulating with flexed posture.
  - A flexion contracture at the hip limits the patient’s ability to extend the sagittal plumb line posterior to the hips.
  - It may be necessary to address the patient’s hip pathologies before planning any surgical correction of a spinal deformity.

Thoracic and Lumbar (Double-Curve) Scoliosis
- Patients with double major adult scoliosis may present with axial skeletal pain.
- Complaints of progressive deformity may be manifested as:
  - Changes in balance
  - Gait abnormalities
  - Alterations in cosmesis
- The surgical treatment of double-curve scoliosis often combines anterior and posterior procedures (FIG 14).
  - Long deformities that are relatively inflexible may require anterior releases to accomplish effective reduction and fusion with posterior surgery.
  - In part because of the typical degeneration in adult patients, fusions into the caudal lumbar spine are more frequently required.
  - Bending films determine whether the lumbar flexibility is adequate for the scoliosis to “bend out” (see Fig 8).
    - Curve stiffness is related to both patient age and curve magnitude.
    - Flexibility decreases by 10% with every 10-degree increase in coronal deformity beyond 40 degrees.
    - Flexibility decreases by 5% to 10% with each decade of life.
- The correction of a double-curve deformity can be accomplished with a variety of methods. The primary goal of achieving a proper sagittal balance must be emphasized. Reduction of the coronal and rotational deformities follows in priority, with the goal of establishing coronal balance and reduction of rib asymmetry for enhanced cosmesis and patient satisfaction, if possible.
Analogous to the design of the operation for adult lumbar deformities, the decision of whether to extend the fusion to the sacrum may be difficult.

Lumbosacral fusion is recommended when:

- Decompression of L5–S1 stenosis is required
- There is a fixed obliquity over 15 degrees at L5–S1 (see Fig 13B)
- Long fusions to the sacrum increase the risk of pseudarthrosis and reoperation. These may be minimized by anterior augmentation and iliac fixation, as previously discussed (see Fig 14).
- The cranial end of the fusion should include the thoracic curve and should not stop caudal to any structural aspect of it.
- All fixed deformities and subluxations should be included in the fusion.

Rod cross-links increase the stiffness of long constructs and are recommended (see Fig 14C). They should be avoided at the thoracolumbar junction; however, where they may increase the risk of pseudarthrosis.

Vertebral derotation

Curve stiffness may limit the surgeon’s ability to reduce the rotational deformity in the adult population.

For relatively flexible rotational deformities, rotational reduction can be achieved with effective improvement in trunk symmetry, which can significantly improve patient satisfaction (Fig 15).

Additional release maneuvers may be necessary in stiff curves, including thoracoplasty, concave rib osteotomies, and aggressive facetectomies.

PEARLS AND PITFALLS

**Reduction of complications associated with BMP**

- The surgeon should minimize the dose of BMP specific to each application.
- The surgeon should minimize diffusion of the protein from the site of desired action.
- Meticulous hemostasis should be achieved before BMP implantation; a postoperative hematoma may provide an avenue for the spread of the protein.
- Wound irrigation should be performed before BMP implantation, not afterward.
- The BMP should be contained within a rigid structure to limit compression of the implant, to prevent pressure-induced diffusion.
- A barrier should be created between the protein implant and sensitive tissues. Thrombin glue has been used to seal the epidural space from the BMP.
- Hemostatic sponges and suction drains may permit protein to migrate to adjacent tissues and should not be placed adjacent to the protein implant.

**Prevention of adjacent-segment disease**

- The preoperative status (or health) of the segment or disc is the greatest predictor for the development of adjacent segment disease.
- For the population with adult scoliosis, where some identifiable degenerative disease is nearly ubiquitous, this is particularly relevant.
- The surgeon should not end a fusion adjacent to a severely degenerated disc.
- The surgeon should not end a fusion adjacent to a segment with fixed obliquity or subluxation.
- The surgeon should preserve the supra-adjacent facet.
- The surgeon should preserve the intraspinous and the supraspinous ligaments.
- The surgeon should not violate the cranial disc space with pedicle screws.
POSTOPERATIVE CARE

- If a brace is used, it must be custom-molded postoperatively, after surgical deformity correction is accomplished.
- Application of a preoperatively molded brace is counterproductive and should be avoided.
- Postoperative physical therapy regimen should focus on:
  - Range-of-motion and flexibility improvement, often in response to chronic hip and knee loss of motion or contractures
  - Gait training, to include balance rehabilitation
  - General conditioning

REFERENCES

DEFINITION
- The use of autogenous bone graft is considered by most surgeons to be the gold standard for achieving fusion in the spine.
- Autogenous bone graft can be used at any spinal level, anterior or posterior.
- The posterior ilium is most frequently harvested for non-structural, cancellous bone graft.
- Tricortical, structural bone grafts for cervical interbody fusions are typically harvested from the anterior ilium.

ANATOMY
- Anterior ilium
  - The anterior ilium has a concave anterosuperior surface.
  - The anterior iliac crest becomes its thickest (iliac tubercle) 2 to 3 cm posterior to the anterior superior iliac spine (ASIS) (FIG 1A).
- The lateral femoral cutaneous nerve typically courses medial to the ASIS; however, it can infrequently cross lateral to the ASIS and be at risk for injury (FIG 1B).
- Posterior ilium
  - The posterior iliac crest thickness ranges from 14 to 17 mm.
  - The superior cluneal nerve passes over the iliac crest 7 to 8 cm lateral to the posterior superior iliac spine (PSIS) and is at risk for injury with a lateral incision (FIG 1C).
  - The superior gluteal artery exits from the greater sciatic foramen (FIG 1D).

SURGICAL MANAGEMENT
Positioning
- A roll or bump of towels or a blanket beneath the ipsilateral ischial tuberosity can facilitate access to the anterior iliac crest.

FIG 1 • A. Ideal anterior iliac crest bone graft is obtained 2 to 3 cm posterior to the anterior superior iliac spine. B. The lateral femoral cutaneous nerve generally traverses medial to the anterior superior iliac spine. C. The superior cluneal nerves cross the posterior iliac crest 8 cm anterior to the posterior superior iliac spine. D. The superior gluteal artery exits from the greater sciatic foramen.
SURGICAL APPROACH

Anterior Iliac Crest
- A skin incision is made parallel to the iliac crest and is centered over the iliac tubercle.
- The incision is carried down to the bone of the crest and the muscles are elevated subperiosteally to expose the wing of the ilium (TECH FIG 1).
  - The tensor fascia latae, gluteus medius, and gluteus minimus originate from the lateral aspect of the ilium. These muscles are innervated by the superior gluteal nerve.
  - The abdominal muscles are also attached to the iliac crest and are segmentally innervated. The incision over the crest is, therefore, internervous and safe.

Posterior Iliac Crest
- The posterior superior iliac crest is palpable under the skin dimple in the superomedial aspect of the gluteal region.
  - A vertical incision over the PSIS is made to minimize injury to the cluneal nerves.
  - An oblique or curved incision may be made over the posterior iliac crest. The cluneal nerves cross the iliac crest 7 to 12 cm anterolateral to the PSIS; therefore, the incision should be made medial to this cutaneous innervation.
  - The subcutaneous tissue is divided to the level of the iliac crest.
  - Using Bovie cautery, the iliac crest is incised.
  - The muscles are elevated subperiosteally from the posterolateral surface of the ilium.
  - The gluteus maximus, medius, and minimus originate from the lateral surface of the ilium. The superior gluteal nerve innervates the gluteus medius and minimus and the inferior gluteal nerve innervates the gluteus maximus.
  - The paraspinal musculature is innervated segmentally.

Posterior Iliac Crest: Midline Skin Incision
- A midline spine incision may be extended distally and the posterior iliac crest approached laterally under the skin and subcutaneous fat. This avoids the use of a second skin incision.
- The fascia overlying the PSIS is incised on the medial surface, where it is more robust; this facilitates fascial closure upon completion of the bone graft harvesting.
- The PSIS is exposed on its outer surface with the aid of electrocautery via a subperiosteal dissection.

ANTERIOR TRICORTICAL ILIAC CREST BONE GRAFT
- After exposure of the anterior iliac crest, an oscillating saw can be used to make parallel cuts through the inner and outer table (TECH FIG 2A).
- Curved osteotomes can be used to make longitudinal cuts in the inner and outer tables to complete the tricortical bone graft harvesting (TECH FIG 2B,C).
POSTERIOR ILIAC CREST BONE GRAFT

Corticocancellous Strips

- After exposure of the posterior iliac crest, adequate visualization can be obtained with the use of a Taylor retractor.
- Caution should be taken to avoid penetrating the sciatic notch and potentially injuring the superior gluteal artery.
- The removal of bone in the vicinity of the sciatic notch can weaken the thick bone that forms the notch, resulting in pelvic instability.
- It is important to stay cephalad to the sciatic notch and remove bone only from the false pelvis. The false or greater pelvis is the portion of pelvis that lies cephalad to the pelvic brim, which defines the inner diameter of the pelvis.
- For a landmark, an imaginary line dropped anteriorly from the PSIS with the patient in the prone position can be used as the caudal limit of bone removal (TECH FIG 3A).
- Using a straight osteotome, multiple corticocancellous vertical strips can be cut from the iliac crest edge. A curved osteotome can be used to complete the cuts distally (TECH FIG 3B,C).
- After removal of the corticocancellous strips, gouges or curettes can be used to harvest additional cancellous bone (TECH FIG 3D).

Uncapping the Posterior Superior Iliac Spine

- With a rongeur, an osteotome, or both, the cap of the PSIS can be removed, allowing for harvesting of the cancellous bone between the two tables (TECH FIG 4A).
- Using a curette or gouge, the cancellous graft is then harvested through this window (TECH FIG 4B).

**TECH FIG 3** • A. Line directed anteriorly from the posterior superior iliac spine marks the caudal safe zone for bone grafting to avoid injury to the contents of the sciatic notch. B,C. Using osteotomes, several corticocancellous strips can be created from the posterior iliac crest. D. The void left after posterior bone graft harvesting.
Several graft site techniques have been described to improve cosmesis and function and to potentially reduce the onset of chronic dysesthesias.

Malleable bone cement contoured to the void can be used, particularly when structural bone graft has been harvested (TECH FIG 5A).

Crushed allograft bone chips can also be packed into the ilium between the inner and outer table, allowing for bone reconstitution.

After filling the defect with allograft or demineralized bone matrix, malleable polymerized lactide sheets can be contoured to the defect to allow for reconstitution of the external iliac anatomy (TECH FIG 5B).

**TECH FIG 4 •** A. The cap of the posterior superior iliac spine can be removed to expose cancellous bone. B. After removal of the cap of the posterior superior iliac spine, cancellous bone is exposed for harvesting (arrow).

**TECH FIG 5 •** A. After bone graft harvest, cement can be molded to fit the void left from the harvest. B. A mesh sheet can be used to traverse the bone graft void to restore the crest.
PEARLS AND PITFALLS

| Posterior iliac crest exposure | Preservation of the outer table spares the nociceptors located in the posterior perios- teum. Also, preserving the most distal portion of the iliac crest can allow for placement of iliac screws ipsilateral to the site of harvest if desired. |
| Lateral femoral cutaneous nerve | The lateral femoral cutaneous nerve passes 2 to 3 cm medial to the anterior superior iliac spine. Avoiding this area can minimize the risk of injury and meralgia paresthetica. |
| Superior cluneal nerves | The superior cluneal nerves cross the posterior cortex 8 cm lateral to the posterior iliac spine. Injury to these nerves can cause numbness to the posterior buttocks and occasion- ally painful neuromas. Vertical incisions are preferred. |
| Superior gluteal artery | Special care should be taken when working near the sacral notch. The superior gluteal artery exits the sacral notch and can be injured if graft is taken too close to the notch. If injured, this vessel may retract into the pelvis and cause significant hemorrhage. |

COMPLICATIONS

- Donor site pain is common after bone graft harvesting.
  - Most symptoms resolve within 3 months.
  - Chronic donor site pain persists beyond 3 months and can be debilitating.
- Anteriorly, nerves at risk for injury include the lateral femoral cutaneous, ilioinguinal, and iliohypogastric.
  - Injury to the lateral femoral cutaneous nerve may give rise to meralgia paresthetica (paresthesias along the lateral thigh). The ilioinguinal nerve may be injured when the abdomi- nal wall is retracted medially from the anterior iliac crest. The nerve may be compressed beneath the retractor on the inner part of the wall of the ilium. Ilioinguinal neurologic in- jury is characterized by pain radiating from the iliac toward the inguinal and genital areas.
- Posteriorly, nerves at risk for injury include the cluneal, su- perior gluteal, and sciatic.
  - The sciatic nerve may be injured when the dissection is ex- tended down to the sciatic notch. A surgical instrument such as an osteotome may be passed deep to the sciatic notch to cause this injury. The bony rim of the notch should be pallated before the dissection is carried to this area.
  - Injury to the cluneal nerves gives rise to numbness to the buttocks or, more rarely, painful cluneal neuromas.
  - Injury to the superior gluteal artery is rare but may occur with bone graft harvesting too close to the sciatic notch, or via inappropriate placement of retractors or elevators.
- If cut, the superior gluteal artery may retract into the pelvis.
  - If the superior gluteal vessel is lacerated, it can be com- pressed locally and exposed for ligation or clipping. A finger may be used to apply direct pressure to the vessel, against the bone.
  - If the bleeding vessel is still not accessible, the area should be packed and then accessed anteriorly via a retroperitoneal or transperitoneal approach.
  - Arterial occlusion by embolization or by use of a Fogerty catheter is another option.
- The deep circumflex iliac artery, the iliolumbar artery, or the fourth lumbar artery may cause troublesome bleeding when working on the inner table of the ilium.
- A hernia through the iliac bone graft donor site may occur after the removal of a full-thickness bone graft from that site. Symptoms may appear as an iliac swelling, sometimes associated with pain or symptoms of bowel obstruction. Strangulated hernia and valvulae are very rare occurrences.
- Fracture
  - Removal of a large quantity of bone graft from the poste- rior ilium may disrupt the mechanical keystone effect of the sacroiliac joint and the posterior sacroiliac ligament, causing instability.
  - The ensuing instability transfers the stress forces to the pelvic ring, causing fractures of the superior and inferior pubic rami.
  - Patients with such instability may develop symptoms indistinguishable from other spinal disorders. History of clicking or thudding, as well as pain in the thigh and gluteal re- gion, is characteristic.
  - Anteriorly, bone resection less than 3 cm from the ASIS may result in an avulsion fracture of the ASIS from the at- tached muscle groups (sartorius, tensor fascia lata).
  - The incidence of infection of the bone graft site ranges from 1% to 5%.
- Careful subperiosteal dissection can limit hematoma for- mation. Hemostasis after bone graft harvesting with clotting agents (Gelfoam) should be used to limit hematoma formation.
- The harvesting of tricortical grafts, particularly in thin pa- tients, can result in a cosmetic deformity. Careful closure of fascial attachments should be performed to minimize soft tis- sue defects.

REFERENCES

Acetabulum (continued) reconstruction

THA, revision with acetabular bone loss and, 833, 834f

THA, revision with femoral bone loss and, 827

rotation, TIO and, 1548, 1548f

THA, uncemented and component implantation of, 758–759, 758f

THA and malignant lesion, 800–801, 800f

revision, with well-fixed components and, 2568–2569, 2569f

TIO and, 1540

Acetaminophen, 2110

Achilles tendinopathy

Achilles tendinopathy

Achilles lengthening, 4490–4495, 4490f–4495f

Acetaminophen, 2110

Achilles tendon (AT)

Achilles tendon ruptures, chronic allograft reconstruction of, 4412–4416 complications of, 4414, 4415f

Achilles tendon rupture, 4417–4418

Achilles tendon repair

Achilles tendon ruptures

Achilles tendon repairs

Achilles tendon tears

Achilles tendinoplasty

Achilles tenotomy

Achilles tendinitis

Achilles tendon repair

Achilles tendon rupture
Acquired lesions, hand, 2994–2996, 2994
Acromial process fracture, ORIF of, 3245, 3246
ACL reconstruction, for skeletally immature ACL.
AC joint. See Acromioclavicular joint
ACL. See Anterior cruciate ligament
ACL reinsertion, for skeletally immature patient, 1168–1176
complications, 1176
outcomes, 1176
pears and pitfalls of, 1175
physical findings, 1172–1173, 1172f, 1173f
postoperative care, 1176
surgical management of, 1170–1171, 1171f
techniques for, 1172–1175, 1172f, 1173f, 1175f
transphyseal-sparing reconstruction, 1174–1175, 1175f
Acquired lesions, hand, 2994–2996, 2994f
postoperative care, 114
reconstruction, of, 102–115
outcomes of, 114–115
pathogenesis of, 102
patient history of, 102–103
pears and pitfalls of, 114
physical findings of, 102–103
portals and, establishing, 118
postoperative care of, 114
reconstruction of, 102–115
repair of, 102–115
surgical management of, 105–106, 105f
Weaver-Dunn procedure, modified for, 110–111, 110f, 111f
reduction, arthroscopic, 116–120
complications of, 120
outcomes of, 120
postoperative care for, 120
techniques for, 118–120, 118f, 119f, 120f
separations, 116
anatomy and, 116
diagnostic studies for, 116–117
differential diagnosis of, 117
imaging of, 116–117, 117f
nonoperative management of, 117
pathogenesis of, 116
patient history of, 116
physical findings for, 116
surgical management of, 117
TightRope fixation, 116–120
complications of, 120
outcomes of, 120
postoperative care for, 120
techniques for, 118–120, 118f, 119f, 120f
Acromioplasty, 3124–3133
clavicular, 3128–3129, 3128f
closure and, 3131, 3131f, 3132f
complications of, 3133
outcomes of, 3133
pears and pitfalls of, 3132
postoperative care of, 3133
Actinomycin D, Ewing sarcoma, 1715
Adhesive neuralgia
Adhesive capsulitis, nerve wrap procedures, 2564, 2564f
Adhesiolysis, flexor tendons, 2564, 2564f
Adhesive capsulitis, nerve wrap procedures, peripheral to minimize, 3939
Adhesive capsulitis, nerve wrap procedures, barrier procedures, 3933–3940
complications of, 3939–3940
fetal umbilical vein wrap of tarsal tunnel for, 3938, 3938f
nerve wrap procedures, peripheral to minimize adhesive capsulitis, 3939
neurawrap application procedure for, 3937–3938, 3937f
outcomes of, 3939
pears and pitfalls of, 3939
postoperative care of, 3939
contractures, 1310
differential diagnosis of, 1312
natural history of, 1310
nonoperative management of, 1312
pathogenesis of, 1310
surgical management of, 1312
lengthening, pediatric, 1314, 1314f,
1322–1325
completions/wand care and, 1325
complications of, 1325
diagnostic studies for, 1322
differential diagnosis and, 1322
exposure and, 1323, 1323f
ilopsoas tenotomy and, 1324, 1324f
imaging and, 1322
myotomy and, 1323, 1323f
outcomes of, 1325
pathogenesis and, 1322
patient history and, 1322
physical findings and, 1322
postoperative care of, 1325
reconstruction, 2057, 2057f
release, pediatric, 1310–1315
complications of, 1315
diagnostic studies for, 1312
imaging and, 1312, 1312f
outcomes of, 1315
patient history and, 1310–1312
pears and pitfalls of, 1315
physical findings and, 1310–1312
postoperative care of, 1315
psosas lengthening and, 1313, 1313f,
1314f
Adductor longus, groin pain related to, 238–241
complications of, 241
open adductor longus tenotomy for, 240, 241f
outcomes of, 241
pears and pitfalls of, 241
postoperative care of, 241
Adductor muscle group (medial thigh) anatomy, 2000, 2001f
resection, 2000–2004
complications, 2004
exposure, 2002, 2002f
imaging for, 2000–2002, 2001f
incision, 2002, 2002f
indications/contraindications, 2000
outcomes, 2004
pears and pitfalls, 2004
postoperative care, 2004
soft tissue reconstruction and, 2003–2004, 2004f
staging studies for, 2000–2002,
2001f
tumor resection and, 2002, 2003f
vascular reconstruction and, 2003–2004, 2004f
Adhesiolysis, flexor tendons, 2564, 2564f
Adhesive capsulitis, nerve wrap procedures, peripheral to minimize, 3939
Adhesive neuralgia
barrier procedures, 3933–3940
complications of, 3939–3940
fetal umbilical vein wrap of tarsal tunnel for, 3938, 3938f
nerve wrap procedures, peripheral to minimize adhesive capsulitis, 3939
neurawrap application procedure for, 3937–3938, 3937f
outcomes of, 3939
pears and pitfalls of, 3939
postoperative care of, 3939
Adhesive neuritis
revision nerve release for, 3935–3936, 3935f, 3936f
vein wrap procedure for, 3936–3937, 3936f, 3937f
definition, 3933
diagnostic studies, 3934
differential diagnosis, 3934
imaging, 3934, 3934f
natural history, 3933–3934
nonoperative management, 3934
patient history, 3934
physical findings, 3934
surgical management, 3935
Adhesive neuritis, 3933
anatomy, 3933
definition, 3933
natural history, 3933–3934
pathogenesis, 3933
Adolescent idiopathic scoliosis (AIS), 1458.
AKA.
AIN.
Agility TAA, 4093–4101.
Akin osteotomy, 3512–3514.
Allograft, 2941. See also Femoral head allograft
bulk, replacement, revision TKA with femoral bone loss, distal femoral replacement, 966–967, 966f, 967f
distal femoral, revision TKA with femoral bone loss, 946, 947f
humeral head
fixation of, 3121, 3121f
osteotomy of, 3120
iliac crest, bilateral osteotomy, upper and, 914, 914f
morselized revision TKA with femoral bone loss, 945
revision TKA with femoral bone loss, distal femoral replacement, 964
proximal femur, fluted stems used with, 820–821, 821f
reconstruction and preparation of, segmental bone defect, 1984
revision TKA with extensor mechanism repair and placement of, 992, 992f
revision TKA with extensor mechanism repair and preparation of, 991, 991f
structural, 4274–4286
harvesting graft, 4278, 4278f
hemi-talus reconstruction of medial OLT, 4280–4285
implanting graft, 4278–4279, 4278f, 4279f
medial malleolar osteotomy, 4275–4277, 4276f, 4279–4280
reduction/closure, 4279–4280
revision TKA with femoral bone loss, 946, 946f
site preparation for, 4277–4278, 4277f
vascularized fibular grafts and preparation of, 1978
Allograft cartilage transplantation, 322–328
anatomy, 322
comparisons, 328
definition, 322
diagnostic studies, 322–323
differential diagnosis, 323
femoral condyle osteochondral, 324–327, 324f, 325f, 326f, 327f
imaging, 322–323, 323f
natural history, 322
outcomes, 328
pathogenesis, 322
patient history, 322
pears and pitfalls, 328
physical findings, 322
postoperative care, 328
surgical management, 323–324, 323f
Allograft prosthetic composite (APC) bone division and, 1789, 1790f
hemiarthroplasty and, 1790–1791
postoperative care and, 1790
Allograft reconstruction of AT rupture, chronic, 4412–4416
comparisons in, 4416
outcomes for, 4416, 4416f, 4416f
pears and pitfalls for, 4415
postoperative care and, 4415
techniques for, 4414–4415, 4414f, 4415f
MCL tears, isolated chronic, 378–379, 379f
segmental bone defect, 1982–1990
Allograft screw fixation, lateral ankle ligament reconstruction using, 4331–4339
complications of, 4339
outcomes of, 4339
pears and pitfalls of, 4338–4339
postoperative care of, 4339
wound closure for, 4338
Amifluridine, adhesive neuralgia, 3934
Amputations. See specific amputations
Analgesia
multimodal, perioperative pain control, 2110, 2110r
preemptive, 2109–2110, 2109r
Anconeus, anatomy, 3054–3055
Anconeus fascia transfer, split, LCL reconstruction, 3395–3397, 3396f, 3397f, 3398f
Anderson-McBryde technique, 3677, 3677f
Anesthesia
additives, 2107–2108, 2108r
airway management and, 2108
arthroscopic capsular release postrelease manipulation under, 132, 132f
general complications of, 2111–2112, 2111r
PONV and, 2111, 2111r
postanesthetic injuries and, 2111–2112
urine retention and, 2111
local, 2107–2108, 2108r
monitoring and, 2108
perioperative complications of, 2112–2113
regional complications of, 2112
equipment for, 2108–2109, 2109f
hemorrhagic complications of, 2112
infectious complications of, 2112
local anesthetic toxicity and, 2112
nerve injury and, 2112
regional, for upper extremity procedures, 2104–2108, 2104f, 2105f, 2106f, 2107f, 2108r
continuous nerve blocks and, 2107
elbow surgery and, 2105–2106, 2106f
shoulder surgery and, 2104–2105, 2105f
supplementing nerve blocks and, 2106
toxicity, 2112
tor upper extremity surgery, 2102–2113
complications of, 2111–2113, 2111r
equipment and, 2108–2109, 2109f
informed consent and, 2110
pain management and, 2109–2110, 2109r, 2110r
selection, 2104, 2104r
Ankylosis synovialis bone cyst (ABC), 1345–1350
complications, 1350
definition, 1345
differential diagnosis, 1346–1347
imaging, 1346, 1346f
natural history, 1345
nonoperative management, 1347
outcomes, 1350
pathogenesis, 1345, 1345f
patient history, 1345–1346
pears and pitfalls, 1350
physical findings, 1345–1346
postoperative care, 1350
surgical management, 1347–1349, 1347f, 1348f, 1349f
Ankyloblepharon blepharophimosis syndrome, 1349
Ankyloblepharon–cleft lip–cleft palate syndrome, 1349
Angiography
AKA, 2063
axillary space, 1827, 1827f
Ankle arthroscopy, 4216–4221

Ankle anatomy and, 4216, 4216f, 4217f
ankle dislocator placement, 4219–4220, 4219f, 4220f
anteri portal placement, 4218, 4218f
complications, 4221
definition, 4216
deltoid ligament reconstruction, 4356, 4356f
differential diagnosis, 4216
nonoperative management and, 4216–4217
outcomes, 4221
pears and pitfalls, 4220–4221
posterior coaxial portals, 4218, 4219f
postoperative care, 4221
surgical management and, 4217–4218, 4217f

Ankle arthroscopy

Ankle replacement, STAR
Ankle joint
medial malleolar fracture surgical management, 1137
physical findings, 1135
operative management of, 1134–1143
outcomes, 1143
definition, 1134
diagnostic studies, 1135–1136
differential diagnosis, 1136
distal malleolar fracture surgical management and, 1138–1139, 1138f, 1139f
fibular fracture fixation and, 1141
imaging, 1135–1136, 1136f
medial malleolar fracture surgical management and, 1140, 1140f
natural history, 1135
nonoperative management, 1136–1137, 1137f
operative management of, 1134–1143
complications and, 1143
outcomes and, 1143
pathogenesis, 1135
patient history, 1135
physical findings, 1135
postoperative care, 1143
surgical management, 1137
alternative techniques for, 1141
pears and pitfalls of, 1142, 1142f
for techniques for, 1138–1141, 1138f, 1139f, 1140f, 1141f
Tillaux fracture surgical management and, 1139, 1139f
triplane fracture surgical management and, 1140–1141, 1140f, 1141f

Ankle joint

Ankle replacement, STAR
anatomy, 4007
approach, 4008–4009, 4009f
complications of, 4021
definition, 4007
diagnostic studies, 4007–4008, 4008f
differential diagnosis, 4008
imaging, 4007–4008, 4008f
implanting talar component for, 4014–4018, 4014f–4019f
natural history, 4007
nonoperative management, 4008
outcomes of, 4020–4021
pathogenesis, 4007
patient history, 4007
pears and pitfalls of, 4020
physical findings, 4007
positioning, 4008
postoperative care of, 4020
preoperative planning, 4008
surgical management, 4008–4020
talar preparation for, 4012–4014, 4012f–4014f
tibial preparation for, 4010–4012, 4010f–4012f

Ankle valgus, pediatric
anatomy, 1304, 1304f
definition, 1304f
diagnostic studies, 1305
differential diagnosis, 1305–1306
guided growth for, 1307, 1307f
hemiepiphysodesis for, 1304–1309, 1308f
medial malleolar screw, 1306, 1306f
outcomes of, 1308
pears and pitfalls of, 1308
postoperative care of, 1308
physical findings, 1305
natural history, 1304, 1305f
nonoperative management, 1306
osteotomy, supramalleolar, 1307
pathogenesis, 1304, 1305f
patient history, 1304–1305
physical findings, 1304–1305
surgical management, 1306
Anterior calcaneus, lateral column
grafting options for, 4558, 4558f
graft insertion in, 4560, 4560f
definition, 4554
corpectomy limits, evaluating and, 4557, 4558
anterior cervical plating and, 4560
postoperative care of, 4560
Anterior cervical corpectomy and fusion with instrumentation, 4534–4561.
See also Cervical spine anterior cervical plating and, 4560
surgical corpectomy techniques and, 4557, 4557f
complications of, 4560–4561
grafting options for, 4558, 4558f
definition, 4554
endplate preparation for, 4558–4559, 4559f
graft insertion in, 4560, 4560f
graft sizing and, 4559, 4559f
outcomes of, 4560
Anterior cervical disectomy and fusion (ACDF).
See also Cervical spine anatomy and, 4543–4544, 4543f
complications, 4553
definition, 4543
with instrumentation, 4546–4551, 4546f, 4547f, 4548f, 4549f, 4550f, 4551f, 4552f
outcomes, 4553
pears and pitfalls, 4553
postoperative care, 4553
Anterior cruciate ligament (ACL)
anatomy, 341, 350, 350f, 357, 1168
injuries, 341
diagnostic studies for, 342
differential diagnosis of, 342
imaging of, 342, 342f
natural history of, 341, 1168–1169
nonoperative management of, 342–343
pathogenesis of, 341, 1168, 1168f, 1169f
physical findings of, 341–342
surgical management of, 342f, 343, 343f
outcomes of, 345
pears and pitfalls of, 345–349
postoperative care of, 346, 346f
wound closure for, 348
tears, definition of, 350
Anterior interbody arthrodesis with instrumentation
open thoracic, for scoliosis, 1433
for scoliosis, 1431–1441
complications of, 1441
outcomes of, 1441
pears and pitfalls of, 1440
postoperative care and, 1441

reconstruction, anatomic double-bundle, 350–356
anatomy and, 350, 350f
biomechanical studies for, 350
complications, 356
diagnostic arthroscopy and, 352, 352f
diagnostic studies for, 350–351
differential diagnosis and, 351
femoral tunnel, anteromedial and, 353, 353f
femoral tunnel, posterolateral and, 352, 352f
fixation and, 354, 354f
graft choice for, 354, 354f
graft passage for, 354, 354f
imaging and, 350–351
nonoperative treatment and, 351
outcomes of, 355–356
patient history of, 350
pears and pitfalls of, 355
physical findings of, 350
postoperative care of, 355
surgical treatment and, 351, 351f
tibial tunnels and, 353, 353f
reconstruction, multiple-ligament-injured knee, 395
reconstruction of, for skeletally immature patient, 1168–1176
repair, revision, 357–364
anatomy and, 357
arthroscopy and, 360, 360f
complications of, 364
definition of, 357
diagnostic studies and, 358–359
differential diagnosis and, 359
graft passage and tensioning for, 362, 362f
graft preparation for, 361
imaging and, 358–359, 358f
natural history and, 357
nonoperative management and, 359
notchplasty and, 360, 360f
outcomes of, 364
pathogenesis and, 357
pears and pitfalls of, 363
physical findings and, 357–358
postoperative care of, 363–364
surgical management and, 359, 359f
tibial tunnel bone grafting for, 363
tunnel placement for, 361–362, 361f
two-incision technique for, 362–363, 363f
repair, single-bundle, 341–349
arthroscopy for, 345
complications of, 349
femoral tunnel placement for, 346–347, 347f
graft passage and fixation for, 347, 348f
hamstring tendon graft harvesting and, 344, 344f
outcomes of, 349
patellar tendon graft harvesting and, 343, 343f
pears and pitfalls of, 348–349
postoperative care of, 349, 349f
tibial tunnel placement for, 346, 346f
wound closure for, 348
TEARS, definition of, 350

Anterior osteotomy, supramalleolar, 1307
osteotomy, supramalleolar, 1307
surgical management, 1306
Anterior interosseous syndrome

Anterior interosseous nerve (AIN), 2666

Anterior tibial osteotomy, OLT, 4271–4273

Anterograde IMN

Aortic bifurcation, 1855

AO/OTA classification, distal femur fracture, 3237, 3240, 3237f, 3240f

Anterior interosseous nerve (AIN), 2666 anatomy, 2666

Anterior interosseous syndrome anatomy and, 2666
decompression, 2666–2671 complications of, 2670 extensile exposure and, 2667–2668, 2668f limited incision, 2669, 2669f outcomes of, 2670 pears and pitfalls of, 2669 postoperative care of, 2670 definition, 2666 diagnostic studies, 2667 differential diagnosis, 2667 imaging, 2667 natural history, 2666 nonoperative management, 2667 pathogenesis, 2666 patient history, 2666–2671 physical findings, 2666–2667 surgical management, 2667

Anterior reconstruction, TES and, 1850, 1852f

Anterior tibial osteotomy, OLT, 4271–4273 additional technique, 4273 pears and pitfalls of, 4273 trap door for, 4271–4272, 4271f, 4272f, 4273f


Antibiotic spacers, 846, 846f

Hip reimplantation surgery and removal of, 855, 855f

Antiprotrusio cage, THA, revision with acetabular bone loss, 836–842

AO classification, tibial plateau fractures, lateral, 623, 623f

AO/OTA classification, distal femur fracture, 587, 587f, 587f

Aortic bifurcation, 1855

thoracolumbar-lumbar spine, 1436–1439, 1437f, 1438f, 1439f, 1440f thorascopic, 1433–1436, 1433f, 1434f, 1435f, 1436f

Arthrodesis. See also Knee arthrodesis; specific types of arthrodesis anterior interbody, with instrumentation, for scoliosis, 1431–1441 closing wedge, toe deformity, 3723, 3723f

CMC joint, thumb, 2770–2775 complications of, 2776 outcomes of, 2776 pears and pitfalls of, 2774 postoperative care of, 2775, 2775f techniques for, 2772–2773, 2772f, 2773f variations of, 2774

DIP joint, 2752–2764 complications of, 2764 diagnostic studies for, 2753 differential diagnosis of, 2753 fixation methods for, additional, 2762 imaging for, 2753 outcomes of, 2764 patient history and, 2753 pears and pitfalls of, 2764 physical findings for, 2753 plate fixation for, 2762, 2763f postoperative care of, 2764 screw fixation, compression for, 2763, 2763f techniques for, 2755–2757, 2756f, 2757f

elbow, 3462–3466 four-corner, 2809–2811, 2809f, 2811f
glenohumeral, 3256–3260 bone grafting and, 3259, 3259f complications of, 3260 definition of, 3259f diagnostic studies for, 3256 exposure for, 3257, 3258f imaging for, 3256 outcomes of, 3260 patient history and, 3256 pears and pitfalls of, 3260 performing, 3258, 3258f, 3259f physical findings for, 3256 postoperative care for, 3260 hand, 2752–2764 definition of, 2752 Lambrinudi, 1604–1605, 1604f

MCF joint, 2752–2760 complications of, 2764 diagnostic studies for, 2753 differential diagnosis of, 2753 fixation methods for, additional, 2762 imaging for, 2753 outcomes of, 2764 patient history and, 2753 pears and pitfalls of, 2764 physical findings for, 2753 plate fixation for, 2762, 2763f postoperative care of, 2764 screw fixation, compression for, 2763, 2763f techniques for, 2759–2761, 2759f, 2760f, 2761f, 2762f

Penny’s modified Lambrinudi, 1603–1604, 1603f, 1604f

PIP joint, 2752–2764 complications of, 2764 diagnostic studies for, 2753 differential diagnosis of, 2753 fixation methods for, additional, 2762 hammertoe correction with, 3702–3704, 3702f, 3703f, 3704f imaging for, 2753 outcomes of, 2764
Arthrodesis (continued) patient history and, 2753
pearls and pitfalls of, 2764
physical findings for, 2753
plate fixation for, 2762, 2763/f
postoperative care of, 2764
screw fixation, compression for, 2763, 2763/f
techniques for, 2758, 2758/f
plate fixation, PIP, DIP, MCP joint, 2762, 2763/f
posterior, CI-C2, 1405–1406, 1405/f, 1406/f
radiocarpal, wrist arthrodesis, limited and, 2813
revision first MTP arthrodesis and fixation of, 3654
revision first MTP joint, 3650–3655
scapulothoracic, 3316–3322
wrist, complete, 2817–2821
anatomy and, 2817
complications of, 2821
fusion with Steinmann rods for, 2819–2820, 2820/f
osteoynthesis, plate/screw and, 2818–2819, 2819/f
outcomes of, 2821
pearls and pitfall of, 2820
postoperative care of, 2821
wrist, limited, 2808–2815
anatomy and, 2808
complications of, 2815
definition of, 2808
four-corner, using circular plate, 2810–2811, 2811/f
complications for, 2863
psychosocial, 2862/f
management, 2862/f
meniscal, 2862/f
management, 2862/f
Arthroscopic evaluation
scaphoid fracture, 2871–2872
scapholunate dissociation, 2871–2872
with radiocarpal arthritis, 2871–2872
Arthroscopic meniscectomy, 263–273
anatomy, 263–266, 264/f, 265/f
complications of, 273
definition, 263, 263/f, 264/f
postoperative care, 268
diagnostic studies, 268
differentiation diagnosis, 268
imaging, 268
natural history, 266–267
outcomes, 272–273
partial
meniscal cyst decompression and, 271
meniscal tears, bucket-handle, 270–271, 270/f
meniscal tears, conventional, 269, 269/f
meniscus, discoid lateral, 271, 271/f
pathogenesis, 266, 267/f
patient history, 267–268
pearls and pitfalls, 272, 272/f
physical findings, 267–268
postoperative care, 272
Arthroscopic posterior reconstruction.
See also Reconstructive surgery
complications of, 273
posterior shoulder instability, recurrent, 3087–3089, 3088/f, 3089/f
Arthroscopic radial styloidectomy, 2464
Arthroscopic RASL procedure, 2464–2465
Arthroscopic reduction, AC joint, 116–120
comparisons of, 120
outcomes of, 120
postoperative care for, 120
techniques for, 118–120, 118/f, 119/f, 120/f
Arthroscopic reduction/fixation
distal radius styloid fracture, 2172–2181
complications of, 2181
metaphyseal comminution for, 2178–2180, 2178/f, 2179/f
outcomes for, 2181
pearls and pitfalls of, 2180–2181
postoperative care for, 2181
techniques for, 2176, 2176/f
three-part, 2177–2180, 2177/f, 2178/f, 2179/f
ulnar styloid fracture, 2172–2181
techniques for, 2180, 2180/f
Arthroscopic bursectomy, for snapping scapula syndrome, 3298–3299, 3298/f
Arthroscopic capsular release anterior, shoulder loss of motion, 129–130, 130/f
elbow loss of motion, 176–177, 176/f, 177/f
posterior, shoulder loss of motion, 130–131, 131/f
shoulder loss of motion, 125–133
anterior capsular release and, 129–130, 130/f
complications for, 133
outcomes for, 133
pearls and pitfalls for, 132–133
portals, establishing for, 129, 129/f
posterior capsular release and, 130–131, 131/f
postoperative care for, 133
postreconstruction manipulation under anesthesia for, 132, 132/f
Arthroscopic capsular treatment, shoulder instability, posterior, 27–28, 27/f
Arthroscopic classification of carpal instability, 2172, 2173/f
dysplasia, 270–271, 270/f
complications of, 183
outcomes of, 182–183
pearls and pitfalls of, 182
postoperative care of, 182, 182/f
techniques for, 181–182, 181/f
LTT, 2463–2464, 2463/f, 2464/f
LTIL, 2463–2464, 2463/f
OC/D, 159–160, 160/f
percutaneous pinning and, 2464, 2464/f
arthritic hands, wrist, 2921, 2921/f
shoulder DJD, 130–144
SLIL, 2463–2464, 2463/f
postoperative care of, 2462
Arthroscopic decompression, 3327–3328, 3327/f
Arthroscopic drilling, OCD, pediatric, 1177–1182
complications of, 1182
hinged lesions and, 1180, 1180/f
intact lesions and, 1179–1180, 1180/f
outcomes of, 1182
pearls and pitfalls of, 2862
postoperative care of, 2862
thermal shrinkage and, 2463, 2463/f
Arthroscopic dislocation
complications of, 2862
laser/radiofrequency-assisted, 2860–2861, 2860/f
mechanical, 2859–2860, 2859/f, 2860/f
outcomes of, 2862, 2862/f
Arthroscopic dorsal capsule repair and, 2877–2872, 2779/f, 2780/f, 2781/f
Arthroscopic epicondylitis, 116, 161/f
pearls and pitfalls of, 2465
postoperative care of, 2465
SLIL disruptions, 2459–2466
complications of, 2466
outcomes of, 2465–2466
pearls and pitfalls of, 2465
postoperative care of, 2465
techniques for, 2462–2463, 2462/f
Arthroscopic excisional epidermal inclusion cyst pearls and pitfalls of, 3020
postoperative care of, 3020
Arthroscopic lateral release, knee, 422–425
complications for, 425
outcomes of, 424–425
pearls and pitfalls of, 424
postoperative care of, 424
techniques for, 424, 424/f
Arthroscopic meniscectomy, 263–273
anatomy, 263–266, 264/f, 265/f
complications of, 273
definition, 263, 263/f, 264/f
diagnostic studies, 268
differential diagnosis, 268
imaging, 268
natural history, 266–267
postoperative care, 272
Arthroscopic posterior reconstruction.
See also Reconstructive surgery
complications of, 273
posterior shoulder instability, 3087–3089, 3088/f, 3089/f
Arthroscopic radial styloidectomy, 2464
Rehabilitation, 2181
Arthroscopic RASL procedure, 2464–2465
Arthroscopic reduction, AC joint, 116–120
comparisons of, 120
outcomes of, 120
postoperative care for, 120
techniques for, 118–120, 118/f, 119/f, 120/f
Arthroscopic reduction/fixation
distal radius styloid fracture, 2172–2181
complications of, 2181
metaphyseal comminution for, 2178–2180, 2178/f, 2179/f
outcomes for, 2181
pearls and pitfalls of, 2180–2181
postoperative care for, 2181
techniques for, 2176, 2176/f
three-part, 2177–2180, 2177/f, 2178/f, 2179/f
ulnar styloid fracture, 2172–2181
tech...
Arthroscopic saucerization, discoid lateral meniscus, pediatric, 1184–1185, 1184f, 1185f
Arthroscopic stabilization, AC joint injury, 112–114, 112f, 113f
Arthroscopic subacromial decompression, 3127, 3127f
Arthroscopic synovectomy, 256–262.
See also Synovectomy
complications of, 262
definition, 256
diagnostic, 258, 258f
outcomes of, 262
pearls and pitfalls of, 262
postoperative care of, 262
techniques for, 258–261, 259f, 260f, 261f
Arthroscopic treatment
biceps tendinopathy, 57–66
complications of, 66
outcomes of, 65–66, 65f
pearls and pitfalls of, 64
postoperative care of, 65
biceps tenotomy, 64
bony tenodesis, 61–62, 62f, 63f
cam impingement, 218–219, 218f
chondral injuries, 155–165
outcomes of, 164–165
pearls and pitfalls of, 164
postoperative care of, 164
coracoid impingement, 91–101
anchor placement and, 98–99, 98f
complications of, 101
outcomes of, 101
pearls and pitfalls of, 100
portals and visualization for, 94, 95f
postoperative care of, 100–101
suture passage/knot tying and, 99, 99f
cutting block technique, 72, 72f
ebrow loss of motion, 171–178
complications of, 178
outcomes of, 178
pearls and pitfalls of, 178
postoperative care of, 178
epicondylitis, 184–189
complications of, 189
diagnostic, 187, 187f
ECRB, 187–188, 188f
outcomes of, 189
pearls and pitfalls of, 189
postoperative care of, 189
FAI, 213–221
complications of, 221
diagnostic, 216, 216f
outcomes of, 221
pearls and pitfalls of, 219–220
postoperative care of, 220–221, 220f
LR, 2638–2642
ligamentum teres lesion, 211, 211f
LTIL disruptions, 2459–2466
complications of, 2466
outcomes of, 2465–2466
pearls and pitfalls of, 2465
postoperative care of, 2465
OCD, 155–165
outcomes of, 164–165
pearls and pitfalls of, 164
postoperative care of, 164
OS acetabuli, 217, 218f
pincer impingement, 216–217, 217, 217f,
pulvinar lesion, 211, 211f
rotator cuff tear, 81–89
scapulothoracic disorders, 134–136
pearls and pitfalls of, 136
portals for, 135, 135f
resection for, 136, 136f
shoulder instability, anterior, 14–22
additional enhancing techniques for,
20–21, 21f
anchor first technique for, 20
complications of, 22
outcomes of, 22
pearls and pitfalls of, 22
postoperative care of, 22
suture first technique for, 18–20, 19f, 20f
shoulder instability, multidirectional, 30–37
complications of, 37
diagnostic, 32–33, 33f
knot tying and, 35
landmarks for, establishing, 32, 32f
multiple techniques and, 33, 34f
outcomes of, 36, 36f
pearls and pitfalls of, 36
portal closure for, posterior, 35, 35f
portals for, establishing, 32, 32f
postoperative care of, 36
preparation for repair and, 33, 33f
rotator interval closure and, 35
shoulder instability, posterior, 24–29
capsular repair for, 27–28, 27f
complications of, 28
definition of, 24
diagnostic, 26, 26f
glenoid preparation for, 27, 27f
labral repair for, 27–28, 27f
outcomes of, 28
pearls and pitfalls of, 28
portal placement for, 26, 26f
postoperative care of, 28
repair completion and, 28, 28f
suture anchor placement for, 27, 27f
SLAP tear, 38–43
complications of, 42–43
outcomes of, 42, 42f
pearls and pitfalls of, 42
postoperative care of, 42
type I, 39
Type II, 39–41, 39f, 40f, 41f
type III, 41
type IV, 42
SLR disruptions, 2459–2466
complications of, 2466
outcomes of, 2465–2466
pearls and pitfalls of, 2465
postoperative care of, 2465
soft tissue tenodesis, 63–64, 63f
subacromial impingement, 68–74
complications of, 74
cutting block technique for, 72, 72f
outcomes of, 73–74
pearls and pitfalls of, 73
postoperative care of, 73
subacromial decompression and,
71–72, 72f
techniques for, 70–71, 71f
wound closure and, 73
subscapularis tears, 91–101
anchor placement and, 98–99, 98f
biceps tendon and, 95–96, 96f
bone bed preparation and, 98–99, 98f
complications, 101
outcomes of, 101
pearls and pitfalls of, 100
portals and visualization for, 94, 95f
postoperative care of, 100–101
subcoracoid space and, 96–97, 97f
subscapularis mobilization and,
97–98, 98f
suture passage/knot tying and, 99, 99f
valgus extension overload, 166–170
complications of, 170
diagnostic, 168, 169f
outcomes of, 170
pearls and pitfalls of, 170
postoperative care of, 170
Arthroscopy. See also specific types of
arthroscopy
ACI and assessment with, 315, 315f, 315f
ACL repair, revision, 360, 360f
ACL repair and, 345, 345f
ankle arthrodesis, 4154–4159
closure for, 4158, 4158f
complications of, 4159, 4159f
exposure and, 4156–4157, 4156f, 4157f
fixation of, 4158, 4158f
outcomes of, 4159
pearls and pitfalls of, 4158
postoperative care of, 4158–4159, 4158f
stabilization for, 4158, 4158f
techniques for, 4157, 4157f
traction for, 4156–4157, 4156f, 4157f
distraction, 196, 197f
DRCL repair with, 2544–2549
complications of, 2549
ligament repair and, 2547, 2547f
outcomes of, 2548–2549
pearls and pitfalls of, 2548
postoperative care of, 2548
VR portal for, 2546, 2547f
elbow, 145–154
anatomy and, 145–146, 145f
anterolateral portals for, 150–151, 151f
anteromedial portals for, 149–150, 150f
complications of, 153–154
definition of, 145
diagnostic studies for, 146
imaging of, 146
limb preparation for, 149, 149f
OCID, pediatric, 1144–1148, 1146f, 1147f
Panner’s disease, pediatric, 1144–1148,
1146f, 1147f
patient history for, 146
pearls and pitfalls of, 153
physical findings for, 146
posterior portals for, 152–153, 152f, 153f
postoperative care of, 153
surgical management of, 146–148,
147f, 148f
hand, 2114–2126
anatomy and, 2114–2116, 2114f, 2115f
author’s experience with, 2116–2118,
2116f, 2117f, 2118f
background of, 2114
complications of, 2126
dorsal druiji portal for, 2125
4–5 portal for, 2121
midcarpal radial portal for, 2122
midcarpal ulnar portal for, 2123
nonoperative care of, 2123
nonoperative management and,
2118–2119, 2119f
1–2 portal for, 2122, 2122f
pearls and pitfalls of, 2123
postoperative care of, 2123
6R/6U portals for, 2121
surgical management and, 2119–2121,
2120f, 2120r
3–4 portal for, 2121
volar druiji portal for, 2125
Arthroscopy (continued)

volar ulnar portal for, 2124, 2124f
VR portal, midcarpal for, 2124
VR portal for, 2123

hip, 191–202
anatomy and, 191, 192f
complications of, 201–202
definition of, 191
diagnostic studies and, 193–194
differential diagnosis and, 194
FAL, anterior, 890–891, 890f, 891f
hip distraction, 196, 197f
imaging and, 193–194, 194f
natural history of, 192–193
nonoperative management and, 195
outcomes of, 201
pathogenesis of, 192
patient history of, 193
pears and pitfalls of, 201
physical findings and, 193
portal, anterior for, 198–199, 199f
portal, anterolateral for, 198, 198f
portal, distal anterolateral for, 200, 200f
portal, posterosuleral for, 199, 199f
portals, making for, 197, 197f
postoperative care of, 201
surgical management and, 195–196, 196f
hip soft tissue pathology, 203–212
chondroplasty and, 210, 210f
complications for, 212
labral débridement for, 208
labral repair for, 209–210, 209f
outcomes for, 211–212
pears and pitfalls for, 211
postoperative care for, 211
knee, 248–249, 248f
anatomy, 248–249, 248f
complications, 255
definition, 248
diagnostic, 251–254, 251f, 252f, 253f, 254f
loss of motion for, 415–417, 416f
pears and pitfalls, 254–255
portal placement for, 250–251, 250f
postoperative care, 255
surgical management, 249, 249f
OLT, 4226, 4226f
ORIF assisted, tibial spine fracture, 2263, 2263f
radial styloectomy, 2795–2801
scaphoid nonunion percutaneous treatment and, 2263, 2263f
SLIL, diagnostic wrist, 2468
subacromial, shoulder, 12
subtalar arthrodesis, 4237
TFCC repair, 2520–2526
complications of, 2526
outcomes of, 2526
pears and pitfalls of, 2526
postoperative care of, 2526
TFC tear repair and, 2524, 2524f
TFCC ulnar shortening with, 2857–2862
complications of, 2862
outcomes of, 2862, 2862f
pears and pitfalls of, 2862
postoperative care of, 2862
techniques for, 2861, 2861f
TFC tears repaired with, 2524, 2524f
wrist, 2523, 2523f
TFCC repair, 2523, 2523f
TFCC ulnar radial portal for, 2122
midcarpal ulnar portal for, 2123
nonoperative management and, 2118–2119, 2119f
1-2 portal for, 2122, 2122f
pears and pitfalls of, 2125
postoperative care of, 2125
VR portal, midcarpal for, 2124
VR portal for, 2123

Arthroscopy-assisted reduction/fixation, dorsal, 2245–2248, 2246f, 2247f
Arthroscopy
thumb CMC joint, 2770–2772
diagnostic studies for, 2777–2778
differential diagnosis of, 2778
imaging of, 2777–2778, 2777f
natural history of, 2777
nonoperative management of, 2778
pathogenesis of, 2776
patient history of, 2777
physical findings for, 2777, 2777f
surgical management of, 2778
wrist
definition of, 2791
diagnostic studies for, 2792
differential diagnosis of, 2792
imaging of, 2792
natural history of, 2791
nonoperative management of, 2792
pathogenesis of, 2791
patient history of, 2791, 2791f
physical findings of, 2791, 2791f
surgical management of, 2792
Arthroscopy
anterior, 1789
medial parapatellar approach to, TKA, cemented, 921–922
midvastus approach to, TKA, cemented, 922
open DRUJ, 2145–2146, 2145f, 2146f
palmaris graft for, 2146
subvastus approach to, TKA, cemented, 922
TKA, cemented, 921–922, 922f
Articular cartilage
allograft cartilage transplantation, 322
anatomy, 312–313, 313f
biopsy, 316, 316f
imaging, 313, 314f
injuries
natural history of, 313
nonoperative management, 314
pathogenesis of, 313
patient history of, 313
physical findings of, 313
surgical management, 314–315
valgus extension overload, 169
Articular mass fixation, Goel method, 4591–4592, 4592f
AT. See Achilles tendon
Athletic pubalgia, 231–236
anatomy, 231–232, 231f
complications, 236
definition, 231
diagnostic studies, 233
differential diagnosis, 233
imaging, 232–233, 233f
natural history, 232
nonoperative management, 233
outcomes, 236
pathogenesis, 232
patient history, 232
pears and pitfalls, 236
physical findings, 232, 232f
postoperative care, 236
surgical management, 233–234
Ultrapro hernia system, 234–235, 234f, 235f
Atlantoaxial instability, 4386
Atlas, 1399, 1400f
Augeonous autograft cartilage implantation (ACI), 312–322
anatomy, 312–313, 313f
arthroscopic assessment, 315, 315f, 315t
cartilage biopsy, 316, 316f
cartilage grading system, 320f
complications, 321
defect preparation, 316–317, 316f, 317f
definition, 312, 312f
diagnostic studies, 313, 314f
differential diagnosis, 313–314
graft fixation, peristeum, 317–318, 318f
graft harvest, peristeal, 317, 317f
imaging, 313, 314f
natural history, 313
nonoperative management, 314
outcomes, 320, 321f
pathogenesis, 313
patient history, 313
pears and pitfalls, 319
physical findings, 313
postoperative care, 320
special situations, 318
surgical management, 314–315
Autogenous chondrocytes, implantation, 319, 319f
Autogenous chondrocyte transplantation
anatomy, 4288
complications of, 4296
definition, 4288
diagnostic studies, 4289–4290, 4290f
differential diagnosis, 4290
imaging, 4289–4290, 4290f
natural history, 4289
nonoperative management, 4290–4291, 4290f
outcomes of, 4296
pathogenesis, 4288–4289
patient history, 4289
pears and pitfalls of, 4295
physical findings, 4294–4295
postoperative care of, 4296
surgical management, 4291–4295
approach, 4291–4293
harvesting of chondrocytes, 4293, 4293f
positioning, 4291, 4291f
preoperative planning, 4291
positioning, 4291–4293
4293f
Autograft reconstruction, MCL tears, isolated chronic, 378, 378f
Autografts, 2941
implantation, osteochondral, 163
"plug" transfer, osteochondral, 303–310
AVN. Avascular necrosis (AVN), 782
knee, 329–340
anatomy of, 329, 330f
complications of, 340
definition of, 329, 329f
diagnostic studies for, 333
differential diagnosis of, 333
drilling of, 337–338, 337f, 338f
imaging of, 333
natural history of, 331, 332f
nonoperative management of, 333
outcomes of, 340, 340r
pathogenesis of, 331
patient history of, 332
pears and pitfalls of, 339
physical findings of, 332
postoperative care of, 339
surgical management of, 333–335, 335f
talar
definition of, 4192, 4192f
diagnostic studies for, 4193
differential diagnosis of, 4193
imaging of, 4193, 4193f
nonoperative management of, 4193
pathogenesis of, 4192
patient history of, 4192
physical findings of, 4192
surgical management of, 4193
treatment of, with circular tensioned wire fixators, 4192–4202
AVFs. See Arteriovenous fistula
AVN. See Avascular necrosis
Avulsion repair
hamstring complete, 245, 246f
TPCC, 2142–2143, 2143f, 2144f
Axilla, 1825
Axillary, 3049
Axillary nerve, 1769
resections and, 1795
scapula and, 1777–1778
Axillary space
anatomy, 1825–1826
anterolateral, resection of, 1830
exploration, 1825–1832
anterolateral approach to, 1829–1830, 1830f
pears and pitfalls, 1831
imaging of, 1826–1828
posterior, resection of, 1830, 1831f
resections, 1825–1832
complications of, 1825–1832
indications for, 1826
outcomes, 1832
pears and pitfalls, 1831
postoperative care, 1832
reconstruction following, 1830–1831
sarcomas, 1825, 1826f
staging studies, 1826–1828
surgical management in, 1825, 1828–1829
approach to, 1828–1829, 1828f, 1829f
positioning for, 1828
preoperative planning for, 1828
vessels in, 1825
Axillary vein, 3049
Axillary vessels, 1825
Axis, 1399, 1400f

B
Back. See also Spinal cord
musculature of, 4537, 4538f
Bankart reconstruction, labral, 3119
Bankart repair, 3073–3083
complications, 3083, 3083f
outcomes, 3083
pears and pitfalls of, 3082–3083
postoperative care, 3083
techniques for, 3077–3078, 3078f
T-plasty modification of, 3079, 3079f
Beak triple arthrodesis, 1605, 1605f
Below-knee amputation (BKA), 2067–2071
anatomy, 2067
background, 2067, 2068f
complications, 2071
imaging, 2067, 2068f
indications, 2067, 2068f
outcomes, 2071
pears and pitfalls, 2070
postoperative care, 2071
staging studies, 2067, 2068f
surgical management, 2067
techniques, 2069–2070, 2069f, 2070f
Benign bone cysts, pediatric, 1345–1350
complications, 1350
definition, 1345
differential diagnosis, 1346–1347
imaging, 1346, 1346f
natural history, 1345
nonoperative management, 1347
outcomes, 1350
pathogenesis, 1345, 1345f
patient history, 1345–1346
pears and pitfalls, 1330
physical findings, 1345–1346
postoperative care, 1350
surgical management, 1347–1349, 1347f,
1348f, 1349f
Bennett fractures
closed reduction and percutaneous pinning, 2323–2324, 2323f
CMC joint, surgical management, 2322–2324, 2323f
ORIF, 2324–2325, 2324f, 2325f
Berger capsulodesis, 2477, 2477f
Bennese PAO, 863
correction, 865–866
dissection, 864
fixation, 866, 866f
iliac spine, 864–865, 865f
incision, 864, 864f
iscial, 864, 865f
mobilization, 865–866, 865f
pediatric, 1559–1568
cacetabular displacement and, 1562–1568
acetabular fixation and, 1566–1567, 1566f, 1567f
anatomy and, 1559
complications of, 1568
depth dissection for, 1561–1562, 1561f,
1562f
definition of, 1559
diagnostic studies and, 1559–1560
imaging and, 1559–1560, 1560f
natural history and, 1559
nonoperative management and, 1560
osteoarthritis techniques and, 1562–1565, 1562f, 1563f, 1564f, 1565f
outcomes of, 1568
pathogenesis and, 1559
patient history and, 1559
pears and pitfalls of, 1567
physical findings and, 1559
postoperative care of, 1568
superficial dissection for, 1561
surgical management and, 1560–1561, 1561f
wound closure and, 1567
posterior column cuts and, 864–865, 865f
public, 864–865, 865f
technique, 864–866, 864f, 865f, 866f
wound closure, 866
Biceps
anatomy, 3053
graft, 3130, 3130f
Biceps brachi, anatomy, 3047
Biceps femoris transfer, quadriceps resection
and, 1997
Biceps muscle, distal humerus resection
and, 1811
Biceps tendinopathy
anatomy, 57–58, 57f
arthroscopic treatment, 57–66
complications of, 66
outcomes of, 65–66, 65f
pears and pitfalls of, 64
postoperative care of, 65
definition, 57
diagnostic studies, 58
differential diagnosis, 58–59
imaging, 58, 59f
natural history, 58
nonoperative management, 59, 59f
pathogenesis, 58
patient history, 58
physical findings, 58
surgical management, 59–61, 59f, 60f
Biceps tendon
anatomy, 57–58, 57f
subscapularis tears and, 95–96, 96f
Biceps tenodesis, 59, 59f, 3134–3140
bony, arthroscopic treatment of, 61–62,
62f, 63f
complications, 3140
outcomes, 3140
PCL injuries, 387–389, 387f, 388f, 389f
pears and pitfalls, 3139
postoperative care, 3140
subscapularis repair, 3137, 3137f
Biceps tenotomy, arthroscopic, 64
Bicondylar plateau
anatomy, ORIF and, 613, 614f
ORIF, 613–621
anatomy and, 613, 614f
complications of, 620
definition of, 613, 614f
differential diagnosis of, 615
fixation and, 618–619, 618f, 619f
imaging for, 615, 615f
lateral exposure and, 617, 618f
natural history and, 613
nonoperative management of, 615
outcomes of, 620
pathogenesis and, 613
patient history and, 613–615
pears and pitfalls of, 620
physical findings and, 613–615
posterior approach to, 619, 620f
posteroanterior approach to, 616, 617f
postoperative care for, 620
surgical management of, 616, 616f
BioPro prosthesis, MTP joint
hemiarthroplasty, first, 3624–3625, 3625f
Biopsy
AKA, 2063
axillary space, 1827–1828
BKA, 2067
closed, 1724
distal humerus, 1808–1809, 1814
gluteus maximus, 1876–1877
hip joint, hip disarticulation, 1911
incision, 1725, 1725f
MBD, 1730–1731
musculoskeletal lesion, 1704
Biopsy (continued)

musculoskeletal tumor, 1719–1726
operative planning, 1723, 1723f
sampling error and, 1723
needle, 1724
guided, 1725–1726, 1725f, 1726f
open, 1724
open incisional, 1724
pears and pitfalls, 1726, 1805
pelvic, 1858–1859
hemipelvectomy and, 1894
proximal humerus, 1796f, 1797
pears and pitfalls, 1805
resections for, 1787–1788, 1788f
quadriiceps, 1992
sartorial canal tumor, 2028
scapular, 1779–1780, 1779f
shoulder girdle, 1770
scapular, 1779–1780, 1779f
sartorial canal tumor, 2028
vascularized, scaphoid nonunions, avascular, 2273–2277, 2275f, 2276f
volar wedge, scaphoid nonunion, 2266–2272, 2268f, 2269f, 2270f, 2271f
Bone-ligament-bone reconstruction, SLL, 2488–2494
closure for, 2493
complications for, 2494
dorsal wrist and, approach to, 2491, 2491f
fixation and, 2492, 2493f
graft harvesting and, 2492, 2492f
outcomes for, 2494
pears and pitfalls in, 2493
postoperative care for, 2494
recipient site preparation for, 2492, 2493f
Bone loss. See specific types of bone loss
Bone resection, Agility TAA, 4098, 4098f, 4099f
Bone sarcomas
benign, staging, 1700f, 1701f
biologic behavior, 1695–1698, 1696f
epidemiology, 1695
joint involvement in, 1697, 1698f
limb-sparing surgery, 1738
metastatic, 1697–1698, 1698f
pathophysiology, 1695–1698, 1696f
prognostic factors, 1698–1700
risk factors, 1695
space sarcomas, 2013
staging, 1698–1700, 1699f, 1700f
Bone scan
AKA, 2063
BKA, 2067
gluteus maximus, 1876
hip joint, hip disarticulation, 1911
MBD, 1749–1750, 1751f
musculoskeletal lesion, 1702–1704, 1702f
pelvic, 1858
proximal humerus, resections for, 1787, 1788f
quadriiceps, 1992
sartorial canal tumor, 2028
scapular, 1779
soleus muscle, 2023
tibial osteotomy, upper, 907, 908f
Bone scintigraphy
distal humerus, 1808–1809
proximal humerus, 1796f, 1797
Bone tumors
in children, 1740
cryosurgical ablation, 1757–1764
complications, 1763–1764, 1763f
indications for, 1757–1758
morphologic criteria for, 1758
outcomes, 1762–1763, 1763f
postoperative care, 1762
postoperative fractures and, 1763
surgical management and, 1758
Bony tenodesis, arthroscopic treatment, 61–62, 63f
Boutonnières deformities
anatomy and, 2619–2620, 2619f
definition, 2619
diagnostic studies, 2624–2625
differential diagnosis, 2624–2625
scoliosis, adult, 4651–4652
TAA, failed and, 4214
tarsometatarsal arthrodesis, 3764
TEA and, 3429, 3429f
tibial osteotomy, upper, 914, 914f
tibial tunnel, ACL repair, revision, 363
tibiotalocalcaneal arthrodesis with, 4168–4169, 4169f
vascularized, scaphoid nonunions, avascular, 2273–2277, 2275f, 2276f

joint preparation for, 3658, 3658f
tetralateral head/proximal phalanx reaming for, 3658, 3658f, 3659f
natural history of, 3656
nonoperative management of, 3657
outcomes for, 3663–3664, 3663f
pathogenesis of, 3656, 3656f
patient history of, 3657
pears and pitfalls of, 3663
physical findings for, 3657
postoperative care for, 3663
surgical management of, 3657
Bone block graft augmentation, open posterior, 3096
Bone cement
revision TKA with femoral bone loss, 945
revision TKA with femoral bone loss, distal femoral replacement, 964
Bone cyst
anatomy, 3029, 3029f
complications for, 3035
definition, 3029
diagnostic studies, 3030
differential diagnosis, 3030
distal upper extremity, treatment of, 3029–3034
imaging, 3030, 3030f
natural history, 3029–3030
nonoperative management, 3030
outcomes for, 3034
pathogenesis, 3029
patient history, 3030
pears and pitfalls of, 3034
physical findings, 3030
postoperative care, 3034
surgical management, 3030–3031
Bone graft harvesting. See also Graft harvesting
graft site reconstruction, 4662, 4662f
iliac crest, 4659–4663
anterior tricortical, 4660, 4660f
complications of, 4663
definition of, 4659
graft site reconstruction for, 4662, 4662f
pears and pitfalls of, 4663
posterior, 4661, 4661f, 4662f
surgical approach to, 4660, 4660f
surgical management and, 4659
tibial, 3846, 3846f
Bone grafting
acetabular bone loss, revision TKA
antiprotrusio cage, 839–840, 840f
impaction allografting, 833
calcaneal osteotomy and, 1614–1615, 1614f, 1615f
corpectomy, thoracic spine, 4632–4633, 4633f
ganglion cyst, intraosseous, 3017
glenohumeral arthrodesis, 3259, 3259f
inlay, ORIF for Jones fracture and, 738, 738f
Lapidus procedure with, 3562, 3562f
OCJD, knee, 336–337, 337f
ORIF, distal femur, 598, 598f
percutaneous intramedullary screw fixation with, ORIF for Jones fracture and, 738
preparation for tibiotalocalcaneal arthrodesis, 4183, 4183f
revision TKA with tibial bone loss, 969–974
Salter innominatte osteotomy and, 1519–1520, 1519f, 1520f
scaphoid nonunion percutaneous treatment, 2263, 2264f

Download PDF
I-12 INDEX
bioengineered tissue augmentation, 4318, lateral ankle instability repair with, 4317–4318, 4318f/4319f
Brolstrom Brolstrom-Evans procedure, modified, 4310–4312, 4310f/4312f
Brolstrom technique, modified, lateral ankle reconstruction with, 4301–4313 complications of, 4313
pearls and pitfalls of, 4313
postoperative care of, 4313
suture anchors for, 4304–4310, 4304f/4310f
Bruder’s incisions, injection injury treatment and, hand, 2884–2885, 2884f, 2885f
Bunion, juvenile
anatomy, 1633
definition, 1633
diagnostic studies, 1633–1634
diagnostic imaging, 1633–1634, 1633f
natural history, 1633
nonoperative management, 1634
pathogenesis, 1633
patient history, 1633
physical findings, 1633
surgical correction of, 1633–1636
complications for, 1635–1636
Mitchell bunioectomy for, 1634, 1635f
outcomes for, 1635
pearls and pitfalls for, 1635
postoperative care for, 1635
surgical management, 1634
Bunion, traumatic, repair, turf toe injuries and, 3672, 3672f
Bunion deformity
anatomy, 3501
correction, 3545, 3545f
diagnostic studies, 3501
imaging, 3501, 3501f
surgical management, 3501
Bunionectomy
closing wedge proximal osteotomy with, 3549, 3550f
scarf osteotomy, 3515, 3515f
Bunionette deformity
anatomy, 3730
condylectomy, lateral metatarsal with capsular plication for, 3731, 3731f/3732f
definition, 3730
diagnostic studies, 3730
differential diagnosis, 3730
imaging, 3730
natural history, 3730
nonoperative management, 3730
osteotomy for chevron, 3732
oblique metatarsal shaft, 3732–3734, 3732f/3734f
pathogenesis, 3730
patient history, 3730
physical findings, 3730
surgical correction, 3730–3735 complications of, 3730
outcomes of, 3735
pearls and pitfalls of, 3734
postoperative care of, 3735
surgical management, 3730–3731
Bupivacaine
additives, 2108
shoulder surgery, 2105
Toxicity, 2112
Burn injuries. See also Electrical injuries; Thermal injuries
acute
patient history of, 2962–2963
physical findings of, 2962–2963
surgical management of, 2964
natural history, 2962
partial-thickness, full/deep, escharotomy for, 2965, 2965f
reconstruction, secondary, 2963
considerations in, 2964–2965
Bursectomy. See Arthroscopic bursectomy
Bursoscopy
retrocalcaneal, 4419–4422
shoulder, 12
shoulder loss of motion, 131, 131f
subacromial, shoulder loss of motion, 131, 131f
subdeltoid, shoulder loss of motion, 131, 131f
Butler procedure for overlapping fifth toe, 1637–1638, 1638f
Butter. See Gluteus maximus
Buttockectomy, 1876–1878 complications of, 1878
imaging for, 1876–1877
indicators/contraindications, 1876 outcomes, 1878
postoperative care, 1878
techniques, 1877–1878, 1877f, 1878f
C
C1–C2. See also Cervical spine anatomy, 4386, 4387f
arthrodesis, posterior, 1405–1406, 1405f, 1406f
atlantoaxial instability and, 4586–4594
diagnostic studies, 4589
exposure of, facet joint, 4522
fusion and instrumentation, 4586–4594
Brooks method of wire fixation for, 4592, 4592f
complications of, 4594
exposure and, 4590, 4590f
Gallie method of sublaminar wiring/grafting for, 4593, 4593f
Goel method of articular mass fixation for, 4591–4592, 4592f
Magerl method of transarticular screw fixation for, 4590–4591, 4591f
outcomes of, 4594
pears and pitfalls of, 4593
postoperative care of, 4594
imaging, 4589, 4389f
instability
differential diagnosis of, 4589
history of, 4588–4589
natural history of, 4587–4588, 4588f
nonoperative management of, 4589
pathogenesis of, 4586
physical findings and, 4588–4589
surgical management of, 4589–4590, 4590f
posterior cervical arthrodeses, 1399–1407
Cable graft repair, nerve transaction, complete followed by, 2695, 2695f
Cage implantation, TJA, revision with acetabular bone loss and, 840–841, 840f, 841f
Calcaneal bone block, revision TKA with extensor mechanism repair and, 991, 992f
Calcaneal exostectomy, 4426, 4426f–4427f
Calcaneal fractures
anatomy, 712
complications, 722–723
definition, 712
diagnostic studies, 714–715, 715f
differential diagnosis, 715
imaging, 714–715
lateral approach to, 718–720, 719f, 720f
extensive, 720–722, 720f, 721f
medial/lateral approaches to, simultaneous, 718–720, 719f, 720f
natural history, 714
nonoperative management, 715
open reduction, 718, 718f
outcomes, 722
pathogenesis, 712–714, 713f
physical findings, 714
postoperative care, 722
surgical management, 715–716
surgical treatment of, 712–723
tongue, percutaneous reduction and fixation of, 717–718, 717f
Calcaneal lengthening osteotomy, hindfoot
valgus deformity, 1608–1617
AT/gastrocnemius lengthening in, 1613, 1613f
bone graft interposition and, 1614–1615, 1614f, 1615f
complications of, 1617
exposure in, 1612–1613, 1612f
lateral soft tissue release and, 1612–1613, 1612f
medial cuneiform osteotomy and, 1616, 1616f
medial soft tissue plication and, 1615, 1615f
medial soft tissue plication/exposure/plication in, 1613, 1613f
outcomes of, 1617
pains and pitfalls of, 1616
postoperative care of, 1617, 1617f
Calcaneal malunions
anatomy and, 3849, 3849f, 3859, 3859f
calcaneal osteotomy for, 3859–3867
complications of, 3867
oblique, extra-articular, 3866
oblique, with subtalar arthrodesis, 3863–3864, 3863f, 3864f, 3865f
outcomes of, 3867
pains and pitfalls of, 3867
postoperative care of, 3867
vertically oriented, 3866
Cavus foot, 1647–1648, 1647f
Dwyer lateral closing-wedge, cavovarus, 3888, 3889f
lateral ankle ligament reconstruction, 4338
lateral displacement, cavovarus, 3887f
Calcaneal tunnel placement, lateral ankle ligament reconstruction, 4335, 4335f
Calcaneocuboid joint, triple arthrodesis and exposure/preparation of, 3882, 3882f
Calcaneocuboid joint distraction arthrodesis, lateral column lengthening via, 3828, 3828f–3829f
Calcaneocuboid joint preparation, traditional triple arthrodesis, 3871–3872, 3871f–3872f
Calcaneonaviculacal coalition
anatomy, 3839
definition, 3839
diagnostic studies, 3839
differential diagnosis, 3840
imaging, 3839, 3839f
natural history, 3839
nonoperative management, 3840
pathogenesis, 3839
patient history, 3839
physical findings, 3839
resection, 3839–3842
complications of, 3842
EDB, interposition of, 3841, 3841f
incision for, 3840, 3840f
outcomes of, 3842
pains and pitfalls of, 3842
postoperative care of, 3842
surgical management, 3840
Calcaneonaviculacal coalition, pediatric
anatomy, 1650
definition, 1650
diagnostic studies, 1650
differential diagnosis, 1651
natural history, 1650
nonoperative management, 1651
pathogenesis, 1650
patient history, 1650
physical findings, 1650
resection of, 1650–1654
complications in, 1653
incision/dissection in, 1651, 1651f, 1652f
interposition of fat graft for, 1653, 1653f
Calcaneus
anatomy, 3849, 3849f, 3859, 3859f
cryoablation, 2078–2079
curettage, 2078–2079
Calcar-replacing, TJA and, malignant tumor, 805
Calcific insertionional Achilles tendinopathy
anatomy, 4433, 4433f
definition, 4433
diagnostic studies, 4434
differential diagnosis, 4434
imaging, 4434, 4434f
natural history, 4433
nonoperative management, 4434
pathogenesis, 4433
patient history, 4433–4434
physical findings, 4433–4434
retrocaldaneal decompression, lateral approach, 4435, 4435f
surgical management, 4433–4436, 4434.
See also Achilles tendinopathy
outcomes of, 4436
pains and pitfalls of, 4436
postoperative care of, 4436
Cam, lesion, impingement, 218–219, 218f
Canal of Guyon, surgical approach to, 2086, 2086f
Cannulated headless compression screws, phalangeal condylar fractures, 2396–2399, 2397f, 2398f
Capitate fractures, surgical treatment, 2292, 2292f
Capitate shortening osteotomy
Kienböck disease treatment with, 2310–2311, 2310f, 2311f
technique capitate osteotomy, 2310, 2310f
osteotomy fixation, 2310–2311, 2311f
Capitellar fractures
anatomy and, 3337
definition, 3337, 3337f
diagnostic studies, 3338
differential diagnosis, 3338
imaging, 3338, 3338f
natural history, 3337
nonoperative management, 3338
ORIF of, 3337–3342
complications for, 3342
outcomes and, 3342
pains and pitfalls for, 3341
postoperative care for, 3342
techniques for, 3339–3340, 3339f
pathogenesis, 3337
patient history, 3338
physical findings, 3338
surgical management, 3338–3339
Capitellar-trochlear shear fractures
anatomy and, 3337
definition, 3337, 3337f
diagnostic studies, 3338
differential diagnosis, 3338
imaging, 3338, 3338f
natural history, 3337
nonoperative management, 3338
ORIF of, 3337–3342
complications for, 3342
outcomes and, 3342
pains and pitfalls for, 3341
postoperative care for, 3342
technical care for, 3340–3341, 3340f, 3341f
pathogenesis, 3337
patient history, 3338
physical findings, 3338
surgical management, 3338–3339
Capitulum, 3337
Capsular plication, condylectomy, lateral
metatarsal with, bunionette
deformity, 3731, 3731f, 3732f
Capsular reconstructions, 1774
sternoclavicular dislocation, 3165, 3165f, 3166f
Capsular repair, sternoclavicular dislocation,
3165, 3165f
Capsular treatment, arthroscopic, shoulder
capsulorrhaphy
Capsule repair, 3113, 3113f
Capsulorrhaphy
Capsule repair, 3113, 3113
Capsulorrhaphy
Capsule repair, 3113, 3113f
arthroscopic treatment and, 27–28, 27f
Capsule, anterior, elbow DJD, 181
Capule repair, 3113, 3113f
Capsulorrhaphy
Capsule repair, 3113, 3113f
arthroscopic treatment and, 27–28, 27f
Capsulorrhaphy
Berger, 2477, 2477
Carpal instability, arthroscopic classification
surgical management, 3338–3339
pathogenesis, 3337
distal chevron osteotomy with, 3493–3494,
Berger, 2477, 2477
sternoclavicular dislocation, 3165, 3165
ORIF, 2288–2289, 2288
nonoperative management, 2285
natural history, 2285
imaging, 2285
diagnostic studies, 2285
definition, 2284
subscapularis muscle, 3119
posteroinferior, shoulder throwing injury,
54, 54
subscapularis muscle, 3119
Carpal tunnel release (CTR)
adity, 2657, 2657f
definition, 2657
diagnostic studies, 2658
differential diagnosis, 2658
imaging, 2658
natural history, 2658

nonoperative management, 2658, 2659f
outcomes of, 2664
pathogenesis, 2657
patient history, 2658
pears and pitfalls of, 2664
physical findings, 2638
postoperative care of, 2664
surgical management, 2659–2664
approach, 2659, 2659f
hypotenar fat pad, 2664
open CTR, 2659–2661, 2660f, 2661f
palmaris fat pad, 2664
positioning, 2659
revision release for recurrent carpal,
2663–2664, 2664f
single-incision endoscopic CTR,
2661–2663, 2661f–2663f
two incision endoscopic CTR, 2663
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Carpometacarpal (CMC) joint, 2313.
Cervical myopathy, 4554
pathogenesis, 4516, 1326
rectus femoris transfer for, pediatric, 1316–1321
spinal deformity and, 1448
thumb-in-palm deformity in, correction of, 1338–1363
Cervical laminoplasty
anatomy and, 4568, 4569f/cervical spondylotic myelopathy, 4568–4570
complications, 4575
definition, 4568
dissection, 4571, 4571f/french door, 4568–4575
incision, 4571, 4571f/open, 4568–4575
opening, 4573, 4573f/outcomes, 4575
pears and pitfalls of, 4574–4575
posterior arch reconstruction for, 4574, 4575f
postoperative care, 4575
pearls and pitfalls, 4574–4575
outcomes, 4575
postoperative care of, 4574, 4575f
through preparation, 4571–4572, 4572f/wound closure, 4574
Cervical myopathy, 4534
diagnostic studies, 4554
differential diagnosis, 4555/history, 4554
imaging, 4554
natural history, 4554
nonoperative management, 4555, 4555f/pathogenesis, 4554, 4555f/physical findings, 4554
surgical management, 4556
Cervical radiculopathy, 4543–4544
anatomy, 4562, 4563f/definition, 4562
diagnostic studies, 4544, 4562
differential diagnosis, 4544–4545, 4562/history, 4544/imaging, 4544, 4545f, 4562/natural history, 4544, 4562/nonoperative management, 4545, 4562/pathogenesis, 4544, 4562/patient history, 4562
physical findings, 4544, 4544f, 4562/surgical management, 4545, 4545f, 4562–4564, 4563f/Cervical spondylotic myelopathy, 4543–4544
anatomy, 4562, 4563f/definition, 4562
diagnostic studies, 4544, 4562
differential diagnosis, 4544–4545, 4562/history, 4544/imaging, 4544, 4545f, 4562/natural history, 4544, 4562/nonoperative management, 4545, 4562/pathogenesis, 4544, 4562/patient history, 4562
physical findings, 4544, 4544f, 4562/surgical management, 4545, 4545f, 4562–4564, 4563f/Cerebral palsy (CP)
surgical management, 4545, 4545f/physical findings, 4544, 4544f/patient history, 4562/pathogenesis, 4544, 4562/natural history, 4546/pathogenesis, 4568/patient history, 4568–4569/physical findings, 4568–4569/surgical management, 4570, 4570f/Cervicotoracic junction
anterior approach to, 4507–4508
pearls and pitfalls of, 3813
outcomes of, 3813
complications of, 3813
background, 3809, 3809
surgical management of, 3805–3806
nerve root anatomy, 4519–4520
musculature, 4516, 4517f
femoral lengthening of type 1, 1218–1220, 1218
Charcot foot, minimally invasive realignment surgery of, 3809–3813/background, 3809, 3809f/complications of, 3813
outcomes of, 3813
natural history of, 3802–3803/imaging of, 3804–3805
patient history of, 3803–3804, 3804f
physical findings and, 1553/surgical management and, 1554/Chiari type 1
anterior laminectomy for, 1317
anterior cervical approach to, 4507–4508
anterior cervical decompression and, 4507–4515
posterior approach to, 4516–4522
anatomy of, 4516–4520
osteoligamentous anatomy, 4516–4519, 4518f
pedicle screw fixation, 4581–4582, 4582f/posterior anatomy of, 4516–4520, 4517f, 4518f, 4519f/fusion of, 4576–4584/musculature, 4516, 4517f/nerve root anatomy, 4519–4520
surgical management of, 4520, 4520f/vertebral artery in, 4519f, 4520/posterior approach to, 4516–4522/C1-C2 facet joint exposure and, 4522/occipitocervical region and, 4521, 4521f/pears and pitfalls of, 4522/subaxial spine and, 4521/suboccipital musculature, 4516, 4517f/Cervical spondylotic myelopathy
anterior approach to, 4507–4508/techniques for, 4513, 4514f, 4515f/anterior cervical approach to, 4507–4508/techniques for, 4513, 4514f, 4515f/CFD, femoral lengthening of type 1, 1218–1220, 1218f, 1219f, 1220f/Charcot foot, minimally invasive realignment surgery of, 3809–3813/background, 3809, 3809f/complications of, 3813/outcomes of, 3813
hallux rigidus treatment with, 3598–3604/techniques for, 3602, 3602f/Moberg osteotomy, 3387, 3387f, 3388f/Cholelithotomy, first MTP capsular interpositional arthroplasty, 3609f, 3609f/Chemotherapy. See also specific chemotherapy agents
Ewing sarcoma, 1715/limp-sparing surgery and, 1728/OS, 1707–1709/STS, 1715–1716/Chest wall, resections, 1830
Chevron osteotomy, 3488–3490/See also Distal chevron osteotomy; Proximal chevron osteotomy/anatomy, 4298/bunionette deformity, 3732/comlications, 3490/complications of, 4300 definition, 4298/diagnostic studies, 4298/imaging, 4298/natural history, 4298/outcomes, 3490/outcomes of, 4300/arthrodesis, 3805–3806/physical findings and, 3794–3801/pathogenesis, 4298/definition, 4298/surgical management, 4298/external fixation and, 3799/natural history, 3795/osteotomy techniques for, 3488–3489, 3489f, 3489f/chondral osteotomy, 3488–3489, 3489f, 3489f/Chiari type 1
Chondral injuries, 295, 295f
abrasion arthroplasty, 160, 161f
anatomy, 155–156, 155f
arthroscopic débridement, 159–160, 160f
arthroscopic treatment, 155–165
outcomes of, 164–165
pears and pitfalls of, 164
postoperative care of, 164
definition, 155
diagnostic studies, 156–157
differential diagnosis, 157
imaging, 156–157, 157f
internal fixation, 162, 163f
loose body removal, 159–160, 160f
microfracture arthroplasty, 160, 161f
natural history, 156
nonoperative management, 157
osteochondral autograft implantation, 163
pathogenesis, 156
patient history, 156
physical findings, 156
surgical management, 157–159, 158f, 159f
Chondrocytes, implantation of autogenous, 319, 319f
See also Autogenous chondrocyte transplantation
Chondroplasty
hip, arthroscopy for soft tissue pathology of, 210, 210f
microfracture, 295–302
additional considerations for, 300, 300f
anatomy of, 299, 299f
complications of, 302
definition of, 295
diagnostic arthroscopy and, 298, 298f
diagnostic studies for, 296–297
differential diagnosis of, 297
imaging of, 296–297, 296f
initial preparation of, 298, 298f
natural history of, 295–296
nonoperative management of, 297
outcomes of, 301–302, 301f
pathogenesis of, 295, 295f
patient history of, 296
pears and pitfalls of, 300
physical findings of, 296
postoperative care of, 300–301, 301f
surgical management of, 297, 297f
techniques for, 299, 299f
Chondrosarcomas, 1709–1709f
clear cell, 1711, 1713f
clinical characteristics, 1709–1711, 1712f
dedifferentiated, 1711, 1713f
grading, 1711, 1712f
mesenchymal, 1711, 1713f
microscopic characteristics, 1711, 1712f
physical examination, 1709–1711
prognosis, 1711, 1712f
radiographic findings, 1711, 1712f
scapular, 1776
treatment, 1711
variants, 1711, 1713f
Chopart amputation, 2072–2080
anatomy and, 2072
background, 2072, 2073f
complications, 2080
imaging, 2072
indications, 2072, 2074f
outcomes, 2079–2080
postoperative care, 2079
staging studies, 2072
surgical management, 2072–2075
techniques, 2077–2078, 2077f
Chopart joint fusion, equinocavovarus deformity management with, 3901–3903, 3902f
Chronic exertional compartment syndrome (CECS), 443–451.
See also Compartment syndrome
anatomy, 443–444, 443f
compartment fasciotomy (CCS) and, 446–447, 447f
posterior, 448, 449f
single-incision lateral approach for, 446, 446f
complications, 451
definition, 443
diagnostic studies, 445
differential diagnosis, 445
diagnoscopically assisted compartment release, 449–450, 450f
tour-compartment fasciotomy, 447–448, 448f
imaging, 445
natural history, 444
nonoperative management, 445
outcomes, 451
pathogenesis, 444, 444f
patient history, 444–445
pears and pitfalls, 451
physical findings, 444–445
postoperative care, 451
surgical management, 445
Chronic pain, management of, 2110
Clavilis, STS, 1716
Clavicle
acromioplasty, 3128–3129, 3128f
anatomy, 3177
fractures and, 3181, 3181f
distal, excision, AC joint injury repair and, 109, 109f
medial
anatomy of, 3170, 3170f
atraumatic disorders, 3171
atraumatic disorders, differential diagnosis of, 3171–3172
diagnostic studies, 3171
imaging, 3171, 3171f
nonoperative management of, 3172
ostearthritis in, 3170
surgical management of, 3172, 3172f
traumatic disorders, 3171
traumatic disorders, differential diagnosis of, 3171–3172
ostearthritis of, 3170
resection, 3128–3129, 3128f
distal, direct, 77–78, 77f
distal, indirect, 77–78, 77f
medial, 3166, 3166f
Clavicle excision, distal, 3124–3133
closure and, 3131, 3131f, 3132f
complications of, 3133
outcomes of, 3133
pears and pitfalls of, 3132
postoperative care of, 3133
Clavicle excision, medial, 3170–3176
atraumatic disorders and, 3173, 3173f
complications in, 3176
definition of, 3170
dissection in, 3172, 3173f
harvesting of tendon and, 3174, 3174f
incision in, 3172, 3173f
outcomes in, 3176
pears and pitfalls in, 3176
postoperative care for, 3176
wound closure and, 3175, 3175f
Clavicle fractures
definition, 3177
diagnostic studies, 3177
differential diagnosis, 3177
fracture compression and, 3187, 3187f
fracture reduction and, 3186, 3186f
imaging, 3177
intramedullary fixation, 3181–3190
butterfly fragment management and, 3188, 3188f
clavicle preparation and, 3185, 3185f
complications of, 3190
dissection in, 3184, 3184f
fracture compression and, 3187, 3187f
fracture reduction and, 3186, 3186f
incision in, 3184, 3184f
outcomes of, 3190
pears and pitfalls of, 3189
pin insertion and, 3186, 3186f
pin positioning, final and, 3187, 3187f
pin removal in, 3189, 3189f
postoperative care of, 3189, 3189f
wound closure and, 3188, 3188f
natural history, 3177, 3177f
nonoperative management, 3177–3178
pathogenesis, 3177
patient history, 3177
physical findings, 3177
plate-and-screw fixation anterior, 3179
superior, 3178–3179, 3178f, 3179f
plate fixation, 3177–3179
complications of, 3179
outcomes of, 3179
pears and pitfalls of, 3179
postoperative care for, 3179
surgical management, 3178, 3178f
Clavicular head, subcoracoid muscle transfer of, 3055–3056, 3055f, 3056f
Claw deformity of fingers, tendon transfers of, 2720–2721, 2721f
Clinodactyly, 3722–3724
Claw deformity of fingers, tendon transfers, 3056–3056
Closed reduction
distal radius fracture, 2165
femur fractures, pediatric, 1095–1098
complications of, 1098
outcomes of, 1098
pears and pitfalls of, 1097–1097f
postoperative care of, 1098, 1098f
radial head/neck fractures, pediatric, 1058–1065
techniques for, 1061–1062, 1061f, 1062f
Closed reduction and external fixation, femoral shaft fractures, pediatric, 1099–1105
AO/SYNTHES technique for, combination clamp, 1101–1102, 1102f
AO/SYNTHES technique for, modular frame, 1103, 1104f
AO/SYNTHES technique for, multipin clamps, 1102–1103, 1103f
complications and, 1105
diagnostic studies for, 1099
EBI DFS XS fixator technique for, 1100–1101, 1100f, 1101f
imaging for, 1099, 1099f
outcomes and, 1105
pears and pitfalls for, 1104
postoperative care for, 1104f, 1105
Closed reduction and percutaneous fixation femoral neck fractures, 521–532
  technique for, 525–526, 525f
  hip fractures, pediatric, 1090–1091, 1090f, 1091f
Closed reduction and percutaneous pinning of Bennett fractures, 2323–2324, 2323f
  distal femoral physeal fracture, pediatric, 1118–1119, 1118f, 1119f
ORIF of displaced lateral condyle fractures of humerus, pediatric, 1038, 1038f
  of Rolando fractures, 2323–2324, 2323f
supracondylar fractures of humerus, pediatric, 1050–1057
anatomy, 1050, 1051f
  closed-pin technique for, 1056, 1056f
  complications, 1056f
  definition, 1050
  diagnostic studies, 1051, 1052f
  differential diagnosis, 1051
  imaging for, 1051, 1052f
  lateral entry pin technique for, 1054, 1054f
  complications in, 1055
  natural history and, 1050
  nonoperative management for, 1051
  outcomes, 1057
  pathogenesis, 1050
  patient history and, 1050–1051
  pearls and pitfalls, 1057
  physical findings and, 1050–1051
  postoperative care for, 1057
  surgical management for, 1051–1053, 1053f
  techniques for, 1053–1056, 1054f
  1053f, 1056f
Closed reduction and percutaneous screw fixation, distal femoral physeal fracture, pediatric, 1120, 1120f
Closed reduction and pinning, metacarpal fracture, 2369–2371, 2370f, 2371f
Closing wedge proximal osteotomy
complications of, 3532
  outcomes of, 3532
  pearls and pitfalls of, 3531
  postoperative care of, 3531–3532, 3532f
  supramalleolar osteotomy with, 3968–3970, 3968f–3970f
surgical management, 3549–3551
  approach, 3549
  positioning, 3549, 3549f
  preoperative planning, 3549
  soft tissue release/bunionectomy, 3549, 3550f
  technique, 3550–3551, 3550f–3551f
Clubfoot, 1661
  Achilles tenotomy for, percutaneous, 1668–1670, 1669f, 1670f, 1671f
  anatomy, 1661, 1662f, 1674
  complex, correcting, 1667–1668, 1667f, 1668f
  definition, 1674
  diagnostic studies, 1662, 1676
  differential diagnosis, 1662, 1676
  imaging, 1662, 1663f, 1676
  natural history, 1661, 1674
  nonoperative management, 1662–1664, 1663f, 1664f, 1676
  pathogenesis, 1674
  patient history, 1661–1662, 1662f
  1674–1676, 1675f
  physical findings, 1661–1662, 1662f, 1674–1676, 1675f
  Ponseti casting for, 1663–1666, 1665f, 1666f
  surgical management, 1664, 1676
Clubfoot, resistant
posterior lateral release for treatment of, 1674–1681
  complications in, 1681
  fixation in, 1680, 1680f
  incision in, 1677, 1677f
  lateral soft tissue release and, 1679, 1679f
  medial soft tissue release and, 1678–1679, 1678f
  outcomes and, 1681
  pears and pitfalls in, 1681
  posterior soft tissue release and, 1678, 1678f
  postoperative care and, 1681
  realigning bones of foot in, 1679, 1680f
  repair of tendons in, 1680
  posteroomedial release for treatment of, 1674–1681
  complications in, 1681
  fixation in, 1680, 1680f
  incision in, 1677, 1677f
  lateral soft tissue release and, 1679, 1679f
  medial soft tissue release and, 1678–1679, 1678f
  outcomes and, 1681
  pears and pitfalls in, 1681
  posterior soft tissue release and, 1678–1679, 1678f
  postoperative care and, 1681
  realigning bones of foot in, 1679, 1680f
  repair of tendons in, 1680
Clubfoot deformity, residual
  anatomy, 1682–1683, 1682f
  definition, 1682, 1682f
  diagnostic studies, 1684–1685
  differential diagnosis, 1685
  imaging, 1684–1685, 1684f
  natural history, 1683, 1683f
  nonoperative management, 1685
  pathogenesis, 1683
  patient history, 1683–1684, 1684f
  physical findings, 1683–1684, 1684f
  surgical management, 1685
  tibialis transfer for, anterior, 1682–1690
  complications of, 1690
  full, 1686–1687, 1686f, 1687f, 1688f
  outcomes of, 1690
  pears and pitfalls of, 1689, 1689f
  postoperative care of, 1690, 1690f
  split, 1688–1689
CMC joint, See Carpometacarpal joint
CMT, See Congenital muscular torticollis
Cole osteotomy, equinovarus deformity management with, 3903, 3903f
Common peroneal nerve (CPN)
  anatomy, 453–454, 454f
  injuries, 453–457
  anatomy and, 453–454, 454f
  background of, 453
  diagnostic studies for, 455
  imaging of, 455
  nonoperative management of, 455
  pathogenesis of, 454
  patient history of, 454–455
  pears and pitfalls of, 457
  physical findings for, 454–455
  postoperative care of, 457
  techniques for, 456, 456f
Compartment fasciotomy, 446–447, 446f, 447f
  CECS, 446–450, 446f, 447f, 448f, 449f, 450f
  four-, 447–448, 448f
  posterior, posteroomedial incision for, 448, 449f
Compartment syndrome, 660
  anatomy and, 2873–2876, 2875f
  arm, decompression for, 2878, 2878f
definition, 2875
  diagnostic studies, 2877
  differential diagnosis, 2877
digital decompression for, techniques of, 2880, 2880f
  surgical decompression for, 2875–2881
forearm decompression for dorsal, 2879, 2879f
decompression for volar, 2879, 2879f
decompression for, 2875–2881
hand decompression for, techniques of, 2879–2880, 2880f
  surgical decompression for, 2875–2881
imaging, 2877
  natural history, 2876–2877, 2962
  nonoperative management, 2878
  pathogenesis, 2876, 2962
  patient history, 2877, 2963, 2963f
  physical findings of, 2877, 2877f, 2963, 2963f
  surgical decompression, 2875–2881
  complications of, 2881
  outcomes of, 2881
  pears and pitfalls of, 2881
  postoperative care of, 2881, 2881f
  surgical management, 2878, 2964
Completion osteotomy, 1565, 1565f
Component fixation, TKA, cemented, 928–929, 929f
Compress system, 1739
Computed tomography (CT)
  AKA, 2061, 2062f
  axillary space, 1826, 1827f
  BKA, 2067
  distal humerus, 1808–1809
  gluteus maximus, 1876
  hip hemiarthroplasty, 784
  hip joint, hip disarticulation, 1911
  musculoskeletal lesion, 1701, 1702f, 1704
ORIF
  distal femur, 586, 586f
  sacrum/SI joint, 491, 491f
  PAO, 863
  pelvic, 1858, 1858f
  hemipelvectomy and, 1894
  popliteal space, 2018, 2019f
INDEX

proximal humerus, 1796f, 1797
proximal tibia, 1954, 1955f
quadriceps, 1992
sartorial canal tumor, 2028
soleus muscle, 2023, 2024f
space sarcomas, 2013
Conduit repair, 2696, 2696f
Condylar fractures, patterns, 2392, 2392f
Condyle, femoral, osteochondral allograft implantation, 324–327, 324f, 325f, 326f, 327f
femur, bone cuts and, TKA, cemented, 125, 125f
fixation, ORIF of distal femur and, 593–594
posterior, resection, UkA and, 899, 900f
Condyleyotomy, lateral metatarsal, buttonette derotom, 3731, 3731f, 3732f
Congenital dislocation of knee (CDK) anatomy, 122f
definition, 1224, 1224f
diagnostic studies, 1225
differential diagnosis, 1225
tension reconstruction, 1227–1228, 1228f
imaging, 1225, 1225f
natural history, 1224
nonoperative management, 1225, 1225f
pathogenesis, 1224
patient history, 1224–1225, 1224f
physical findings, 1224–1225, 1224f
surgical management, 1225–1226, 1226f
surgical repair of irreducible, 1224–1229
complications and, 1229
minimally invasive quadriceps tenotom and, 1226–1227, 1227f
outcomes and, 1229
pears and pitfalls of, 1228
percutaneous quadriceps recession and, 1226, 1226f
postoperative care and, 1229
Congenital femoral deficiency, pediatric anatomy, 1202, 1203f
definition, 1202
diagnostic studies, 1204
differential diagnosis, 1204
imaging, 1204, 1205f
natural history, 1202
nonoperative management, 1205, 1205f
pathogenesis, 1202
patient history, 1202–1204
physical findings, 1202–1204
surgical management, 1205–1207, 1206f, 1207f
treatment of, 1202–1223
 complications and, 1222–1223
femoral lengthening of type 1 CFD and, 1218–1220, 1218f, 1219f, 1220f
outcomes and, 1222
pears and pitfalls, 1220
postoperative care for, 1221–1222
superhip procedure for, 1208–1212, 1209f, 1210f, 1211f, 1212f
superknee procedure for, 1213–1217, 1213f, 1214f, 1215f, 1216f, 1217f
techniques for, 1208–1220
Congenital lesions, hand, 2992–2993, 2992f, 2993f, 2994f
Congenital muscular torticollis (CMT), 1392–1393
differential diagnosis, 1394
natural history, 1393
nonoperative management, 1394
pathogenesis, 1392–1393
patient history, 1393–1394
physical findings, 1393–1394, 1393f
surgical management, 1394–1395
Congenital pseudarthrosis, tibial anatomy, 1251
definition, 1251
diagnostic studies, 1251–1252
differential diagnosis, 1252
imaging, 1251–1252, 1252f
natural history, 1251
nonoperative management, 1252
pathogenesis, 1251
patient history, 1251, 1251f
physical findings, 1251, 1251f
surgical management, 1252, 1253f
iliac crest bone graft and, 1253
preparation of fibula and, 1254
preparation of tibia and, 1253, 1254f
techniques for, 1253–1255, 1254f, 1255f
Williams rod and repair of, 1251–1257, 1255f, 1256f
complications and, 1257
outcomes and, 1257
pears and pitfalls, 1256, 1256f
postoperative care for, 1256–1257, 1257f
Congenital trigger thumb.
See also Trigger finger.
AI pulley to correct, release of, 1366–1370
surgical treatment of, complications for, 1370
exposure and, 1368, 1368f
open, 1368, 1368f, 1369f
outcomes for, 1370
patients and, 1368
postoperative care for, 1370
natural history, 1366
definition, 1366
diagnostic studies, 1367
differential diagnosis, 1367
imaging, 1367
natural history, 1366
nonoperative management, 1367
pathogenesis, 1366
patient history, 1366–1367, 1367f
physical findings, 1366–1367, 1367f
surgical management, 1367–1368
Contractions
adductor, 1310
differential diagnosis of, 1312
natural history of, 1310
nonoperative management of, 1312
pathogenesis of, 1310
surgical management of, 1312
translation of, 2968–2969, 2968f, 2969f, 2970f
burn, pathogenesis, 2962
diagnostic studies, 2964
differential diagnosis, 2964
distal upper extremity, surgical treatment of, 2961–2971
flexion, TKA, cemented and, 927
iliopsoas differential diagnosis of, 1312
nonoperative management of, 1312
surgical management of, 1312
imaging, 2964
nonoperative management, 2964
psas, 1310
natural history of, 1310
pathogenesis of, 1310
release, 2963
considerations in, 2964–2965
surgical management, 2964–2965
surgical treatment complications of, 2971
outcomes of, 2971
pears and pitfalls of, 2970
postoperative care of, 2970–2971
thumb-in-palm deformity and release of, 1361, 1361f, 1362f
Coracoclavicular ligament, preparation, 118
Coracoclavicular ligament reconstruction
AC joint injury, 106–108, 106f, 107f, 108f, 109f
Coracoclavicular stabilization, AC joint, 116–120
complications of, 120
outcomes of, 120
postaloperative care for, 120
techniques for, 118–120, 118f, 119f, 120f
Coracoid, preparation, 118, 118f
Coracoid fixation, 3104–3105, 3104f, 3105f
Coracoid impingement anatomy, 91f
arthroscopic treatment, 91–101
anchor placement and, 98–99, 98f
complications, 101
outcomes of, 101
pears and pitfalls of, 100
outcomes for, 94, 95f
postaloperative care of, 100–101
suture passage/knot tying and, 99, 99f
definition, 91
diagnostic studies, 93
differential diagnosis, 93
imaging, 93, 93f
natural history, 92
nonoperative management, 93
pathogenesis, 91–92, 92f
patient history, 92–93
physical findings, 92–93
surgical management, 93–94, 94f
Coracoid osteotomy, genial bone loss, 3102–3103, 3102f, 3103f
Coracoid process fracture, ORIF of, 3246, 3246f
Coracoid recession, 3134–3140
complications, 3140
outcomes, 3140
pears and pitfalls, 3139
postoperative care, 3140
Coreoplasty, subscapularis repair, 3138, 3138f
Corona mortis, 1856
Coronoid fracture, ORIF, 3380–3381, 3381f
Corpectomy
lumbar spine, anterior, 4634–4644,
4642f, 4643f
thoracic, 4631, 4631f
anterior, 4628–4633
bone grafting/cages for, 4632–4633,
4633f
complications of, 4633
pears and pitfalls of, 4633
postoperative care of, 4633
screw-rod instrumentation for, 4632, 4632f
thoracolumbar, 4631, 4631f
Corticotomy
metatarsal lengthening in
revision hallux valgus surgery and, 311, 328f, 328f
Coughlin drill holes, hamstring autografting/augmentation, lateral ankle instability, 4328, 4328f
Coxa vara, developmental anatomy, 1577
definition, 1577
Degenerative arthritis, elbow
definition of, 444

diagnostic studies of, 3445–3446
imaging of, 3445–3446, 3445f
implantation in, 3449–3450, 3449f, 3450f
lignet repair and, 3450, 3450f
management of, 3444–3452
nonoperative management of, 3445–3456
pathogenesis of, 3444, 3444f
patient history and, 3444–3445
physical findings for, 3444–3445
postoperative care of, 3451
surgical exposure for, 3448, 3448f
surgical management of, 3446–3448, 3447f
triceps management and, 3448–3449, 3449f
triceps repair and, 3451, 3451f
wound closure and, 3451

Degenerative disc disease (DDD), lumbar,
4634
diagnostic studies for, 4635

differential diagnosis of, 4635
imaging of, 4635, 4636f
natural history of, 4634
nonoperative management of, 4635
pathogenesis of, 4634
patient history of, 4634–4635
physical findings for, 4634–4635
surgical management of, 4635–4636

Degenerative joint disease (DJD)
elbow
anatomy and, 179
arthroscopic débridement, 179–183, 182f
arthroscopic débridement, techniques for,
181–182, 181f
capsular release for, 181
capsulectomy, anterior for, 181
débridement, posterior for, 181
definition, 179
diagnostic studies for, 179
differential diagnosis of, 179–180
imaging of, 179, 179f
natural history of, 179
nonoperative management of, 180
pathogenesis of, 179
patient history of, 179
physical findings of, 179
portal placement, anterior for, 181, 181f
portal placement, posterior for, 181
surgical management of, 180, 180f
hip, 744
shoulder
anatomy and, 138, 138f
arthroscopic débridement for, 138–144
arthroscopy, diagnostic, 141
capsulectomy for, 141–142, 141f
débridement of, 141
definition of, 138
diagnostic studies for, 139
differential diagnosis of, 139
glenoidplasty for, 138–144
glenoidplasty for, techniques of, 142, 142f
imaging of, 139, 140f
natural history of, 139
nonoperative management of, 139
osteophyte removal, inferior for, 141
pathogenesis of, 138–139
patient history of, 139
physical findings of, 139
release for, 141–142, 141f
subacromial decompression, 143
surgical management of, 139–140, 140f
synovectomy for, 141

Deltoid
anatomy, 3046, 3046f
reconstruction, Revision Agility TAA and,
4110–4112, 4110f

Deltoid ligament
anatomy, 3437, 3434, 3434f
deficiency, 3437
diagnostic studies for, 3438
differential diagnosis of, 3438
imaging of, 3438, 3438f
natural history of, 3437
nonoperative management of, 3438
pathogenesis of, 3437
patient history of, 3437–3438
physical findings of, 3437–3438
surgical management of, 3438–3439, 3439f

diagnostic studies, 3435
differential diagnosis, 3435
imaging, 3435, 3435f
natural history, 3434
nonoperative management, 3435
pathogenesis, 3435
patient history, 3434–3435
physical findings, 3434–3435
reconstruction, 3437–3438
complications of, 3432
minimally invasive, 3439–3451, 3439f,
3450f, 3451f
outcomes of, 3432
peucenous longus graft tendon harvesting
for, 3451, 3452f
postoperative care of, 3452
surgical management, 3433–3436, 3436f

Deltoid ligament reconstruction
definition, 3434
lateral ankle, techniques for, 4361–4365,
4361f, 4362f, 4363f, 4364f
medial ankle, 4354–4366
arthroscopy for, 4356, 4356f
complications for, 4366
outcomes for, 4366
pears and pitfalls of, 4366
postoperative care for, 4366
techniques for, 4357–4360, 4357f,
4357f, 4358f, 4359f, 4360f

Deltoidplasty
anatomy, 3046, 3046f

Denervation
full, wrist, 2792–2793, 2792f, 2793f
partial, wrist, 2792
wrist complications of, 2794
outcomes of, 2794
postoperative care of, 2794

Dermofasciectomy, Dupuytren disease,
2989, 2989f

Developmental dislocation of hip (DDH).
See also Hip dislocation
anatomy and, 1493, 1493f, 1502
definition, 1493, 1502
diagnostic studies, 1495–1496, 1502–1503
differential diagnosis, 1496
imaging, 1495–1496, 1495f, 1502–1503,
1503f
natural history, 1494, 1502
nonoperative management, 1496,
1496f, 1503
open reduction for, anterior approach to,
1493–1501
anterior hip exposure and, 1497–1498,
1497f, 1498f
complications of, 1501
outcomes of, 1501

INDEX I-21
Developmental dislocation of hip (continued) postoperative care of, 1501 proximal femoral shortening osteotomy and, 1499–1500, 1500/\text{f techniques, 1498–1499, 1498/\text{f}, 1499/\text{f}} open reduction for, medial approach to, 1502–1507 capsulorrhaphy and, 1505 capsulotomy/acetabular exposure and, 1504–1505, 1505/\text{f} casting and, 1506, 1506/\text{f} closure and, 1505 complications of, 1507 deep dissection and, 1504, 1504/\text{f} hip reduction and, 1505 incision/initial dissection and, 1503, 1504/\text{f} outcomes of, 1507 pearls and pitfalls of, 1506 postoperative care of, 1506–1507, 1506/\text{f} pathogenesis, 1493–1494, 1494/\text{f}, 1502 patient history, 1494–1495, 1502 physical findings, 1494–1495, 1494/\text{f}, 1502 Salter innominate osteotomy, 1517 surgical management, 1496, 1496/\text{f}, 1503 Diagnostic arthroscopy ACL reconstruction, anatomic double-bundle, 352, 352/\text{f} epicondylitis and elbow, 187, 187/\text{f} knee, 251–254, 251/\text{f}, 252/\text{f}, 253/\text{f}, 254/\text{f} microfracture chondroplasty, 298, 298/\text{f} MPFL, 429 osteochondral autograft “plug” transfer, 306 shoulder, 10–12, 11/\text{f}, 12/\text{f}, 26, 26/\text{f}, 32–33, 33/\text{f} shoulder DJD, 141 shoulder throwing injury, 48–49, 49/\text{f} synovectomy, 258, 258/\text{f} valgus extension overload, 168, 169/\text{f} Diaphyseal defect, hemipelvectomy and division of sacrum from, 1908, 1908/\text{f} Diaphyseal defect, spondylolisthesis, high-grade and routine revision without, 1483–1486, 1484/\text{f}, 1485/\text{f}, 1486/\text{f} Diaphyseal forearm fractures anatomy, 2127–2129, 2127/\text{f}, 2128/\text{f} definition, 2128/\text{f} diagnostic studies, 2130, 2131/\text{f} differential diagnosis, 2130 imaging, 2130 natural history, 2129 nonoperative management, 2131 ORIF, 2127–2138 anterior approach to radius and, 2132, 2132/\text{f} anterior approach to ulna and, 2135–2136, 2135/\text{f} complications of, 2138 fracture reduction/fixation and, 2136, 2136/\text{f} outcomes of, 2138 pearls and pitfalls of, 2137 posterior approach to radius and, 2134–2135, 2134/\text{f} posterior approach to ulna and, 2136 postoperative care of, 2138 pathogenesis, 2129 patient history, 2129–2130 physical findings, 2129–2130, 2130/\text{f} surgical management, 2131–2132 Diastasis, repair, turf toe injuries, 3670–3671, 3670/\text{f}, 3671/\text{f} Disc herniation lumbar spine definition of, 4595 diagnostic studies for, 4596 differential diagnosis of, 4596 history of, 4596 imaging of, 4596 natural history of, 4595–4596 nonoperative management of, 4596 pathogenesis of, 4595 physical findings of, 4596 surgical management of, 4596–4597, 4597/\text{f} thoracic spine nonoperative management of, 4629 Discoid lateral meniscus, pediatric anatomy, 1183 definition, 1183 diagnostic studies, 1183 differential diagnosis, 1184 imaging, 1183, 1183/\text{f} meniscalplasty, 1183–1186 alternative techniques for, 1185, 1185/\text{f} arthroscopic saucierization and, 1184–1185, 1184/\text{f}, 1185/\text{f} complications of, 1186 pearls and pitfalls of, 1185 postoperative care for, 1186 techniques, 1184–1185, 1184/\text{f}, 1185/\text{f} natural history, 1183 nonoperative management, 1184 pathogenesis, 1183 patient history, 1183 physical findings, 1183 surgical management, 1184 Disc replacement, lumbar, anterior, 4634–4644, 4640/\text{f}, 4641/\text{f} Displaced lateral condyle fractures of humerus, pediatric, ORIF, 1035–1041 anatomy of, 1035, 1035/\text{f}, 1036/\text{f} closed reduction/percutaneous pinning for, 1038, 1038/\text{f} complications of, 1041 definition of, 1035 diagnostic studies and, 1036, 1037/\text{f} differential diagnosis and, 1036 exposure and, 1039, 1039/\text{f} fixation and, 1040, 1040/\text{f} fracture reduction and, 1039–1040, 1039/\text{f} imaging and, 1036, 1037/\text{f} natural history of, 1035–1036 nonoperative management of, 1036–1037 outcomes of, 1041 pathogenesis of, 1035 patient history and, 1036 pearls and pitfalls, 1040 physical findings and, 1036 postoperative care for, 1041 surgical management of, 1037–1038, 1037/\text{f} techniques for, 1038–1040, 1038/\text{f}, 1039/\text{f}, 1040/\text{f} Distal biceps tendon, anatomy, 2550 Distal biceps tendon disruptions. See also Biceps definition, 2530 diagnostic studies, 2550 Endobutton, 2551–2552, 2551/\text{f} imaging, 2530 natural history, 2550 nonoperative management, 2550 one-incision technique, 2530–2553 complications of, 2533 outcomes of, 2533
Distal chevron osteotomy. See also Femoral osteotomy.
crouch gait, pediatric, 1339–1344, 1340f
complications of, 1344
distal segment reduction and, 1342, 1342f
articular surface and, stabilizing, 600, 600f
bone grafting and, 598, 598f
soft tissue preparation and, 594, 594f
locking plates for, 599, 599f
locking plates for, plate placement and, 594, 595f, 601, 601f
postoperative care of, 602
pathogenesis and, 582
nonoperative management of, 587
natural history and, 582
pelvis and pits of, 601–602
physical findings and, 582–583
positioning for, 589, 590f
postoperative care for, 602
preoperative planning for, 588–589, 589f
reduction of shaft to distal segment in, 594
surgical management of, 587–590, 587f, 587f, 588f, 589f
temporary bridging external fixation for, 591, 591f, 592f
percutaneous, epiphysiodesis, 1238–1243
postoperative care of, 3499
patient history and, 3491
pathogenesis, 3491
outcomes of, 3499
resection with endoprosthetic reconstruction, 1929–1952
anatomy, 1929–1931, 1929f
anterior approach, 1942–1946, 1942f
background, 1929
complications, 1949–1952, 1949f
imaging, 1941–1944, 1943f
indiactions for, extending, 3501–3504
lateral soft tissue release, 3482–3483, 3482f
outcomes, 3504
pears and pits of, 3504
postoperative care, 3504, 3504f
soft tissue closure, 3503, 3503f, 3504f
tumor reconstruction prosthesis for, 967
Distal femur replacement allograft, bulk, 966–967, 966f, 967f
revision TKA with femoral bone loss, 962–968
Distal femoral osteotomy. See also Femoral osteotomy.
closure and, 1117–1118, 1117f
closed reduction and, 1117
natural history, 1117f
ORIF for, 1120, 1120f
pathogenesis, 1116
patient history, 1116, 1117f
physical findings, 1116, 1117f
postoperative care, 1121
surgical management, 1117–1118, 1118f
complications of, 1121
outcomes of, 1121
pears and pits of, 1121
radiographs for, extending, 3501–3504
lateral soft tissue release, 3482–3483, 3482f
outcomes, 3504
pears and pits of, 3504
postoperative care, 3504, 3504f
soft tissue closure, 3503, 3503f, 3504f
surgical management of, 3504f
techniques for, 3501–3502
Distal chevron osteotomy. See also
Osteotomy
bone preparation, 3502–3503, 3502f, 3503f
complications of, 3504
definition, 3501
hallux valgus, 3481–3487
anatomy and, 3481
complications of, 3487
definition of, 3481
diagnostic studies for, 3482
differential diagnosis of, 3482
imaging of, 3482
nonoperative management of, 3482
pathogenesis of, 3481
patient history of, 3481
pears and pits of, 3485
physical findings for, 3481
postoperative care of, 3486, 3486f
surgical management of, 3482
techniques for, 3483–3486, 3484f, 3484f, 3485f
indications for, extending, 3501–3504
lateral soft tissue release, 3482–3483, 3482f
outcomes, 3504
pears and pits of, 3504
postoperative care, 3504, 3504f
soft tissue closure, 3503, 3503f, 3504f
surgical management of, 3504f
techniques for, 3501–3502
Distal chevron osteotomy, biplanar
anatomy
complications of, 3499
definition, 3491
diagnostic studies, 3492, 3492f, 3493f
differential diagnosis, 3492
imaging, 3492, 3492f, 3493f
natural history, 3491
nonoperative management, 3492–3493
outcomes of, 3499, 3499f
pathogenesis, 3491
patient history, 3491–3492
pears and pits of, 3498
physical findings, 3491–3492
postoperative care of, 3499
surgical management, 3493–3498
approach, 3493, 3493f
capsulorrhaphy, 3497–3498, 3497f
capsulotomy, 3493–3494, 3494f
medial/dorsal metatarsal head exposure, 3494, 3494f
osteotomy, 3493–3497, 3495f, 3496f
positioning, 3493
preoperative planning, 3493
Distal interphalangeal (DIP) fracture-dislocations
anatomy and, 2445
definition, 2445
diagnostic studies, 2446–2447
differential diagnosis, 2447
imaging, 2446–2447, 2446f
natural history, 2445
nonoperative management, 2447
operative treatment, 2445–2451
complications of, 2451
extension-block pinning of mallet fractures and, 2448, 2448f
outcomes of, 2451
pears and pitfalls of, 2451
pinning of non-bony mallet fractures and, 2449, 2449f
postoperative care of, 2451

Sauvé-Kapandji procedure for, outcomes of, 2837f
Sauvé-Kapandji procedure for, pears and pitfalls of, 2838
Sauvé-Kapandji procedure for, postoperative care of, 2838
Sauvé-Kapandji procedure for, techniques, 2842–2845, 2842f, 2843f, 2844f, 2845f
surgical management of, 2841–2842, 2842f
arthroscopy, open, 2145–2146, 2145f, 2146f
bridge plating of distal radius fractures and, 2222
degeneration diagnostic studies for, 2832
differential diagnosis of, 2833
imaging of, 2832, 2832f
nonoperative management of, 2833
pathogenesis of, 2831
patient history of, 2832
physical findings, 2832, 2832f
surgical management of, 2833–2834, 2833f, 2834f
diagnostic studies, 2529, 2537–2538, 2538f
dislocations, 2139
disorders, 2840
dissociation, surgical management, 2226, 2226f, 2227f
Galeazzi fractures complications for reduction/stabilization of, 2147–2148
diagnostic studies for, 2141–2142
differential diagnosis of, 2142
imaging of, 2141–2142, 2141f
natural history of, 2139–2140
nonoperative management of, 2142
outcomes for reduction/stabilization of, 2147
pathogenesis of, 2139
patient history of, 2140–2141
pears and pitfalls for reduction/
stabilization of, 2147
physical findings for, 2140–2141, 2140f
postoperative care for reduction/
stabilization of, 2147
reduction/stabilization following, 2139–2148
surgical management of, 2142
TFC avulsion repair and, 2142–2145, 2143f, 2144f
imaging, 2529, 2529f, 2537–2538, 2538f
instability definition of, 2528
differential diagnosis of, 2529, 2538
natural history of, 2529, 2537
nonoperative management of, 2529, 2538
pathogenesis of, 2528–2529
patient history of, 2529, 2537
physical findings of, 2529, 2537
surgical management of, 2529, 2538–2539, 2539f
reconstructive techniques for, 2536–2544
definition of, 2536
Herbert, modified, 2539, 2539f
Hui-Linscheid, 2476–2478, 2540f, 2541f, 2542f
pears and pitfalls of, 2478, 2543f
resection arthroplasty, 2831–2839
complete, Darrach procedure for, 2834–2836, 2835f, 2836f
complications of, 2838
definition of, 2831
hemiresection-interposition technique for, 2836–2837, 2836f, 2837f
matched, 2837, 2837f
outcomes of, 2838
pears and pitfalls of, 2838
postoperative care of, 2838
Shuck test, 2140f, 2141, 2141f
Distal radius. See also Radius
anatomy, 2162, 2162f, 2172, 2198, 2198f
GCTs, bone, 3032, 3032f
resection, wide en bloc extra-articular, 3033f
Distal radius fractures anatomy and, 2162, 2162f
bridge plating, 2218–2223
anatomy and, 2218
approach for, 2220–2221, 2220f
articular fixation for, 2221–2222, 2222f
closed reduction maneuver of Agee for, 2219, 2219f
complications of, 2223
definition of, 2218
DRUJ management for, 2222
indications for, 2222–2219, 2219r
outcomes of, 2222
pears and pitfalls of, 2222
plate fixation for, 2221–2222, 2222f
plate insertion for, 2220–2221, 2220f
postoperative care of, 2222–2223
surgical management and, 2218–2219, 2219f
closed reduction of, 2165, 2165f
definition, 2162
diagnostic studies, 2163, 2185–2187, 2199, 2207–2208, 2218
differential diagnosis, 2163, 2200, 2208
dorsal plate fixation, 2198–2205
anatomy and, 2198, 2198f
complications of, 2205
definition, 2198
dorsal intramedullary device for, 2203, 2203f
outcomes of, 2203
pears and pitfalls of, 2204
postoperative care of, 2205
radial intramedullary device for, 2204
surgical management of, 2200–2201, 2200f, 2201f
techniques for, 2201–2203, 2201f, 2202f, 2203f
external fixator application for, bridging, 2167–2168, 2167f, 2168f
external fixator application for, nonbridging, 2168–2169, 2169f
fragment-specific fixation, 2183–2197
anatomy and, 2183–2184, 2184f
complications of, 2197
dorsal approach to, 2189, 2189f
free articular fragment support with buttress pin for, 2195, 2195f
outcomes of, 2197
pears and pitfalls for, 2196
postoperative care of, 2196–2197
radial column fixation with radial pin plate for, 2190–2191, 2191f
surgical management of, 2187–2188
ulnar corner/dorsal wall fixation for, 2192–2193, 2192f, 2193f
volar approach to, extensile, 2189, 2189f
volar approach to, limited-incision, 2188, 2189f
volar rim fracture and, 2193–2194, 2194f
volar-ulnar approach to, 2190, 2190f
imaging, 2163, 2163f, 2185–2187, 2186f
2199, 2199f, 2207–2208, 2208f
2218
Distraction arthroplasty, (continued) foot ring application for, 3946, 3946f, 3947f
outcomes of, 3951
pools and pitfalls of, 3950
posterior care of, 3950–3951
tibial base frame application for, 3944, 3944f, 3945f
wound dressing for, 3949, 3949f
Distraction osteogenesis, 1258
DJD.
Distraction osteotomy, 1258
DJD.
Docking technique, LCL reconstruction, 3398
Dorsal block pinning, of PIP joint fracture-dislocations, 2404–2409
complications in, 2409
outcomes for, 2409
pools and pitfalls for, 2408
postoperative care for, 2409
Dorsal capsular release, LCL repair and, 3716–3717, 3716f
Dorsal cheilectomy, hallux rigidus, 3944, 3944f
completion of, 3956
complications of, 3957
exposure and, 3954, 3954f
incision and, 3954, 3954f
outcomes of, 3956–3957
pools and pitfalls of, 3956
postoperative care of, 3956, 3957f
resection and, 3955, 3955f, 3956f
Dorsal plate fixation. See also Plate fixation
distal radius fracture, 2198–2205
anatomy and, 2198, 2198f
complications of, 2205
definition, 2198
Dorsal radiocarpal ligament (DRCI) anatomy, 2544, 2544f
arthroscopic, repairs, 2544–2549
complications of, 2549
Dorsal radiocarpal ligament repair and, 2547, 2547f
outcomes of, 2548–2549
pools and pitfalls of, 2548
postoperative care of, 2548
VR portal for, 2546, 2547f
Dorsal radiocarpal ligament surgery, 2546
Dorsal radiocarpal ligament (DRCI) anatom...
DJD

anatomy and, 179
arthroscopic débridement, 179–183, 182f
arthroscopic débridement, techniques for, 181–182, 181f
capsular release for, 181
capsulectomy, anterior for, 181
débridement, posterior for, 181
definition, 179
diagnostic studies for, 179
differential diagnosis of, 179–180
imaging of, 179, 179f
natural history of, 179
nonoperative management of, 180
pathogenesis of, 179
patient history of, 179
physical findings of, 179
portal placement, anterior for, 181
portal placement, posterior for, 181
surgical management of, 180, 180f

extensors, 3054–3055
flexor pronator muscle group, 3055
flexors, 3053–3054
joint structures, 3052
landmarks, 3051

LCL reconstruction of, 3392–3399
ligaments, 3052
loss of motion
anatomy and, 171–172, 171f, 172f
anterior capsular release for, 176, 176f
arthroscopic treatment of, 171–178
definition of, 171
diagnostic studies for, 173
differential diagnosis of, 173
imaging of, 173, 174f
intraoperative splinting for, 177, 177f
natural history of, 172, 173f
nonoperative management of, 173–174
pathogenesis of, 172
patient history of, 172–173
physical findings of, 172–173
portal establishment in contracted elbow and, 175, 176f
posterior capsular release for, 176–177, 177f
surgical management of, 174–175, 175f
unlar nerve release/transposition for, 177
wound closure for, 177, 177f
medial side of, 3413, 3414f
muscles, 3030–3035
nerves, 3053
osteoarthritis, 3400
osteology, 3049–3050
surgical approaches to, 3062–3071
alternative, indications/recommendations, 3071f
anterior, 3071, 3072f
anterolateral, 3067–3068
Boyd, 3068–3069, 3069f
distal Kocher, modified, 3068, 3068f
lateral, 3067–3069
medial, 3069–3070, 3070f
olecranon osteotomy, 3067, 3067f
overview of, 3042
posterior, 3062–3067
regional anesthesia for, 2105–2106, 2106f
triceps-preserving, 3066–3067
triceps-reflecting, 3063–3066, 3064f
triceps-reversing, 3106f
triceps-splitting, 3062–3063, 3063f, 3064f
topographical regions of, and corresponding musculature, 3051–3052

trauma
anatomy and, 3433
definition of, 3433
diagnostic studies for, 3434
differential diagnosis of, 3434
elbow replacement for, 3433–3443
imaging for, 3434, 3434f
natural history of, 3433
nonoperative management of, 3434
pathogenesis of, 3433
patient history for, 3433–3434, 3433f
physical findings for, 3433–3434, 3433f
surgical management of, 3434–3435, 3435f
traumatic conditions
complications of, 3461
definition of, 3453
diagnostic studies for, 3453, 3454f
differential diagnosis of, 3454
imaging of, 3453, 3454f
interposition arthroplasty for, 3455–3458, 3455f, 3457f
nonoperative management of, 3454
outcomes for, 3460–3461
pathogenesis of, 3453, 3453f
patient history and, 3453
physical findings for, 3453
postoperative management of, 3460
surgical management of, 3453–3461, 3454–3455, 3455f
total elbow replacement for, 3458–3459, 3458f, 3459f
vessels, 3052–3053

Elbow arthrodesis, 3462–3466
background, 3462
diagnostic studies, 3462
imaging, 3462
patient history, 3462
pears and pitfalls, 3465
physical findings, 3462
postoperative care, 3463
surgical approach, 3463
surgical management, 3462–3463
techniques, 3463, 3464f, 3465f

Elbow contracture, extracapsular
anatomy and, 3406
definition, 3406
diagnostic studies, 3407
differential diagnosis, 3407
imaging, 3407f
lateral columnar release for, 3406–3411
anterior release and, 3409, 3409f
complications of, 3411
outcomes of, 3411
pears and pitfalls of, 3410
posterior release and, 3408–3409, 3408f
postoperative care of, 3410–3411, 3411f
surgical approach, 3408
natural history, 3406
nonoperative management, 3407
pathogenesis, 3406
patient history, 3406–3407
physical findings, 3406–3407
surgical management, 3407–3408

Elbow contracture, extrinsic
anatomy and, 3413, 3414f
diagnostic studies, 3413
imaging, 3413
nonoperative management, 3413
release, medial over-the-top approach to, 3413–3419
anterior capsule and, exposing, 3413–3417, 3416f
bone spurs and, exposing, 3417, 3417f
closure and, 3418, 3418f
complications of, 3419
definition of, 3413
medial fascia and, exposing, 3415, 3415f
outcomes of, 3418–3419
pears and pitfalls of, 3418
posterior capsule and, exposing, 3417, 3417f
postoperative care for, 3418
ulnar nerve and, exposing, 3415, 3415f
ulnar nerve and, transposition, 3417
surgical management, 3413–3415, 3415f

Elbow dislocation, simple
classification, 3369
definition, 3369
diagnostic studies, 3370
etiology, 3369
hinged external fixation, 3375, 3375f
imaging, 3370
management, 3369–3376
complications of, 3376
nonoperative, 3370–3371
outcomes of, 3375–3376
pears and pitfalls of, 3375
postoperative care for, 3375
surgical, 3371–3372
pathoanatomy, 3369, 3370f
patient history, 3369–3370, 3371f
physical findings, 3369–3370, 3371f
ulnar collateral ligament reconstruction for, lateral, 3374, 3374f
ulnar collateral ligament repair for, lateral, 3372–3373, 3372f, 3373f

Elbow fracture-dislocations
with complex instability
anatomy and, 3377, 3377f
definition of, 3377
diagnostic studies for, 3378
differential diagnosis of, 3378
imaging of, 3378, 3378f
lateral exposure and, 3380, 3380f
natural history of, 3378
nonoperative management of, 3378, 3379f
ORIF of, 3377–3384
ORIF of, complications and, 3384
ORIF of, outcomes and, 3384
ORIF of, pears/pitfalls for, 3383–3384
ORIF of, postoperative care and, 3384
pathogenesis of, 3378, 3378f
patient history and, 3378
persistent instability and, 3383
physical findings for, 3378
surgical management of, 3379–3380, 3379f, 3379f, 3379b, 3380f
LCL repair and, 3382–3383, 3382f

Elbow replacement
for acute trauma, 3433–3443
bone preparation in, 3438–3439, 3438f
complications of, 3442
dissection in, 3435, 3436f
implant insertion/tensioning in, 3439–3440, 3440f
incision in, 3435, 3436f
outcomes of, 3442–3443
pears and pitfalls of, 3442
postoperative care of, 3442
triceps management and, 3436–3437, 3437f
triceps reattachment in, 3440, 3440f
wound closure and, 3441

for traumatic conditions, 3458–3459, 3458f, 3459f

Electrical injuries
definition, 2961
diagnostic studies, 2964
differential diagnosis, 2964
Electrical injuries (continued)

- distal upper extremity, surgical treatment
  - imaging, 2964
- nonoperative management, 2964, 2964f
- pathogenesis, 2961
- second-look procedure for, 2967–2968, 2968f
- surgical management, 2964–2965
- surgical treatment
  - complications of, 2971
- outcomes of, 2971
- pearls and pitfalls of, 2970
- postoperative care of, 2970–2971

Endoectomy, vaso-occlusive diseases of

- En bloc corpectomy, 1850
- En bloc laminectomy, 1849–1850

Endochondroma

- anatomy, 3029, 3029f
- complications for, 3035
- definition, 3029
- diagnostic studies, 3030
- differential diagnosis, 3030
- distal upper extremity, treatment of, 3029–3034
- imaging, 3030, 3030f
- metacarpal
curette of, 3031
-excision of, 3031
-natural history, 3029–3030
-nonoperative management, 3030
-outcomes for, 3034
-pathogenesis, 3029
-patient history, 3030
-pears and pitfalls of, 3034
-physical findings, 3030
-postoperative care for, 3034
-proximal phalangeal
curette of, 3031, 3031f
-excision of, 3031, 3031f
-surgical management, 3030–3031

Endobutton, distal biceps tendon disruption,

- proximal tibia, 1732, 1734f
-scapula, 1734, 1735f
-shoulder, 1737
-skeletally immature patient, 1735, 1736f
techniques, femoral, 1924–1925, 1924f, 1925f
-total femur, 1731–1732, 1733f
total humerus, 1734
-types of, 1731–1735

Endoprosthetic replacement, proximal humerus, 1797

- Endoprosthetic replacement, resections with, proximal humerus, 1793–1806
-anatomic considerations, 1793–1795
-imaging of, 1795–1797, 1796f
-indications for, 1793, 1794f
-staging studies for, 1795–1797
techniques, 1797–1801, 1798f, 1802f

Endoprosthetic replacement, total humerus, 1803

- Endoprosthetic replacement, proximal humerus, 1793–1806
-technical pearls, 1797–1801, 1802f

Endoprosthetic reconstruction, 1728–1739.

- See also Reconstructions; Resection with endoprosthetic reconstruction
calcaneus, 1734
-clinical results following, 1737, 1738f
-complications, 1737–1738
distal femur, 1731, 1733f
-distal humerus, 1814
-elbow, 1734
-expandable implants, 1735, 1736f
-future trends for, 1738–1739
-guidelines, 1737
-hip, 1731, 1732f, 1737
-history of, 1728–1731, 1729f
-implants, 1728, 1730f
-intercalary, segmental bone defect
-reconstruction and, 1988
-knee, 1737
-long-term survival rates, 1737, 1738f
-modularity, hand, 1728–1729, 1730f
-modular systems, 1729–1731, 1731f
-nontumorous condition, 1736–1737
-outcome, 1739
-patient selection, 1735–1737
-proximal humerus, 1732, 1734f
-total humeral, 1803

Epineural repair, nerve transection, complete followed, 2694, 2694f

Equinocavovarus foot deformity

- anatomy and, 3891–3892
-definition, 3891, 3891f
-diagnostic studies, 3893–3894
-differential diagnosis, 3894
-imaging, 3893–3894, 3893f, 3895f
-management, 3891–3899
-Chopart joint fusion, triple for,
- 3901–3903, 3902f
-Cole osteotomy for, 3903, 3903f
-complications of, 3910
-dorsiflexion metatarsal osteotomy for,
- 3906, 3906f
-Dwyer osteotomy for, 3903–3904,
- 3904f
-hindfoot equinus soft tissue correction,
- 3904–3905, 3905f
-Jones procedure for, modified,
- 3899–3901, 3900f
-outcomes of, 3908–3910, 3908f, 3909f
-overview of, 3896
-pears and pitfalls of, 3907
-postoperative care of, 3908
-Russell-Hibbs procedure for, 3906,
- 3907f
-Steindler procedure for, 3896–3897,
- 3896f
-surgical, 3895, 3895f, 3896f
-T-Sport, 3897–3899, 3897f–3899f
-natural history, 3892
-nonoperative management, 3894–3895
-pathogenesis, 3892
-patient history, 3892–3893
-physical findings, 3892–3893
-Equinovarus deformity, 1626
-Equinus, 1334
-hindfoot, correction of, 3904–3905,
- 3905f
-ESCR, See Extensor pollicis longus

Equinovarus foot deformity

- anatomy and, 3891–3892
-definition, 3891, 3891f
-diagnostic studies, 3893–3894
-differential diagnosis, 3894
-imaging, 3893–3894, 3893f, 3895f
-management, 3891–3899
-Chopart joint fusion, triple for,
- 3901–3903, 3902f
-Cole osteotomy for, 3903, 3903f
-complications of, 3910
-dorsiflexion metatarsal osteotomy for,
- 3906, 3906f
-Dwyer osteotomy for, 3903–3904,
- 3904f
-hindfoot equinus soft tissue correction,
- 3904–3905, 3905f
-Jones procedure for, modified,
- 3899–3901, 3900f
-outcomes of, 3908–3910, 3908f, 3909f
-overview of, 3896
-pears and pitfalls of, 3907
-postoperative care of, 3908
-Russell-Hibbs procedure for, 3906,
- 3907f
-Steindler procedure for, 3896–3897,
- 3896f
-surgical, 3895, 3895f, 3896f
-T-Sport, 3897–3899, 3897f–3899f
-natural history, 3892
-nonoperative management, 3894–3895
-pathogenesis, 3892
-patient history, 3892–3893
-physical findings, 3892–3893
-Equinovarus deformity, 1626
-Equinus, 1334
-hindfoot, correction of, 3904–3905,
- 3905f
-ESCR, See Extensor pollicis longus

Equinovarus foot deformity

- anatomy and, 3891–3892
-definition, 3891, 3891f
-diagnostic studies, 3893–3894
-differential diagnosis, 3894
-imaging, 3893–3894, 3893f, 3895f
-management, 3891–3899
-Chopart joint fusion, triple for,
- 3901–3903, 3902f
-Cole osteotomy for, 3903, 3903f
-complications of, 3910
-dorsiflexion metatarsal osteotomy for,
- 3906, 3906f
-Dwyer osteotomy for, 3903–3904,
- 3904f
-hindfoot equinus soft tissue correction,
- 3904–3905, 3905f
-Jones procedure for, modified,
- 3899–3901, 3900f
-outcomes of, 3908–3910, 3908f, 3909f
-overview of, 3896
-pears and pitfalls of, 3907
-postoperative care of, 3908
-Russell-Hibbs procedure for, 3906,
- 3907f
-Steindler procedure for, 3896–3897,
- 3896f
-surgical, 3895, 3895f, 3896f
-T-Sport, 3897–3899, 3897f–3899f
-natural history, 3892
-nonoperative management, 3894–3895
-pathogenesis, 3892
-patient history, 3892–3893
-physical findings, 3892–3893
-Equinovarus deformity, 1626
-Equinus, 1334
-hindfoot, correction of, 3904–3905,
- 3905f
-ESCR, See Extensor pollicis longus
Ewing sarcoma, 1711–1715
chemotherapy, 1715
clinical characteristics, 1711–1712, 1714f
microscopic characteristics, 1714
natural history, 1714
physical examination, 1711–1712, 1714f
radiation therapy, 1715
radiographic findings/evaluation, 1712–1714
staging, 1714
surgical treatment, 1715
treatment, combined multimodality, 1714–1715

Excision types. See also specific types of excision
intralesional, 1705, 1705f
marginal, 1705, 1705f
musculoskeletal tumor, 1705, 1705f
radical, 1705, 1705f
wide (en bloc), 1705, 1705f

Exostectomy, lateral wall, 3853–3854, 3854

Expandable endoprosthesis, 1740, 1741

Extensile exposure
treatment, combined multimodality, staging, 1714
radiographic findings/evaluation, 1712–1714
radiation therapy, 1715
natural history, 1714
microscopic characteristics, 1714
chemotherapy, 1715
wedge (en bloc), 1705, 1705f

distal femoral, implantation of, invasive, 1741, 1742
implantation of, surgical technique for, imaging and, 1740, 1741f
implantation of, surgical technique for, 1743–1745, 1744f
hip, subluxation of, 1747f, 1748
imaging and, 1740, 1741f
implantation of, surgical technique for, 1743–1745
pears and pitfalls, 1746
implant breakage, 1748
invasive, 1741, 1742f, 1742t, 1743
lengthening, 1741–1743, 1742f, 1742t, 1745
LLD and, 1743
loosening, 1747f, 1748
minimally invasive, lengthening, percutaneous, 1745
noninvasive, 1741, 1742f, 1742t, 1743
outcomes, 1746
outgrowth of extending, 1748
patient information and, 1746
periprosthetic fractures, 1748
positioning, 1743
postoperative care, 1746
prosthetic lining, 1743
proximal femoral, implantation of, surgical technique for, 1745
proximal humerus, implantation of, surgical technique for, 1745
proximal tibial, implantation of, surgical technique for, 1745
Rephysis noninvasive, 1739
shortening/lengthening, unplanned, 1747f, 1748
shoulder, subluxation of, 1747f, 1748
skeletal maturity and, 1740, 1741f, 1743
staging studies, 1740
stiffness, 1748
subluxation, 1748
surgical management and, 1740–1743
Extensile exposure
pronitor/anterior interosseous syndrome, 2667–2668, 2668f
revision TKA with, tibial tubercle osteotomy reattachment with screws and, 2649
osteotomy reattachment with wire and, 2649
osteotomy reattachment with wire and, 2649
outcomes of, 984
pathogenesis of, 980
patient history and, 984
pears and pitfalls of, 2649
physical findings for, 2649
postoperative care of, 2649
surgical management of, 981, 981f
revision TKA with, V-Y quadruplasty, 2649

Extension osteotomy.
Extensor carpi radialis brevis (ECRB), 2722
Extensor carpi radialis longus (ECRL), 2722
arthroscopic lateral, release, 187–188, 188

tendon transfer, rheumatoid disorder, 2615
wrist extension restoration, 2724, 2724

Extension osteotomy.
Kirschner wire with, 2768
staple fixation with, 2768, 2768f
tension band fixation with, 2768

Extensor digitorum communis (EDC), 3718

Extensor digitorum proprius (EDP), 2590, 2590f

Extensor pollicis longus (EPL), 2587, 2723

Extensor mechanism.
revision TKA to correct stiffness and, 994, 994f
revision TKA with extensile exposure and, 980, 980f
revision TKA with extensor mechanism repair, 989
proximal tibia, reconstruction of, 1960, 1960f, 1961f, 1962f

Extensor mechanism repair.
revision TKA, 989–993
allograft placement and, 992, 992f
allograft preparation and, 991, 991f
anatomy and, 989
approach to, 990, 990f
calcaneal bone block and, 991, 992f
closure and, 990
complications of, 993
definition of, 989
diagnostic studies for, 989, 989f
differential diagnosis of, 989
imaging for, 989, 989f
natural history and, 989
nonoperative management of, 989–990
outcomes of, 993
pathogenesis and, 989
patient history and, 989
pears and pitfalls of, 993
physical findings and, 989
postoperative care of, 993
primary repair and, 991, 991f
surgical management of, 990, 990f
tibial preparation and, 991, 991f
wound closure and, 993, 993f

Extensor pollicis longus (EPL), 2587, 2723
EIP, transfer, 2590, 2590f
tendon transfer, 2590
Extensor indicis proprius (EIP), transfer, 2590
Extensor indicis proprius, tendon transfer, rheumatoid disorder, 2614

Extensor mechanism.
anatomy
revision TKA to correct stiffness and, 994, 994f
revision TKA with extensile exposure and, 980, 980f

Extensor mechanism repair.
revision TKA, 989–993
allograft placement and, 992, 992f
allograft preparation and, 991, 991f
anatomy and, 989
approach to, 990, 990f
calcaneal bone block and, 991, 992f
closure and, 990
complications of, 993
definition of, 989
diagnostic studies for, 989, 989f
differential diagnosis of, 989
imaging for, 989, 989f
natural history and, 989
nonoperative management of, 989–990
outcomes of, 993
pathogenesis and, 989
patient history and, 989
pears and pitfalls of, 993
physical findings and, 989
postoperative care of, 993
primary repair and, 991, 991f
surgical management of, 990, 990f
tibial preparation and, 991, 991f
wound closure and, 993, 993f

Extensor pollicis longus (EPL), 2587, 2723
EIP, transfer, 2590, 2590f
tendon transfer, 2590
Extensor indicis proprius (EIP), transfer, 2590
Extensor indicis proprius, tendon transfer, rheumatoid disorder, 2614

Extensor mechanism.
anatomy
revision TKA to correct stiffness and, 994, 994f
revision TKA with extensile exposure and, 980, 980f

Extensor mechanism repair.
revision TKA, 989–993
allograft placement and, 992, 992f
allograft preparation and, 991, 991f
anatomy and, 989
approach to, 990, 990f
calcaneal bone block and, 991, 992f
closure and, 990
complications of, 993
definition of, 989
diagnostic studies for, 989, 989f
differential diagnosis of, 989
imaging for, 989, 989f
natural history and, 989
nonoperative management of, 989–990
outcomes of, 993
pathogenesis and, 989
patient history and, 989
pears and pitfalls of, 993
physical findings and, 989
postoperative care of, 993
primary repair and, 991, 991f
surgical management of, 990, 990f
tibial preparation and, 991, 991f
wound closure and, 993, 993f
Charcot arthropathy of midfoot, 3799, 3800f
Charcot foot realignment surgery with, 3810–3811, 3811f
hinged, elbow dislocation, simple, 3375, 3375f
knee arthropathy, 1010–1011, 1011f, 1012f
midfoot arthropathy with, 3779–3782, 3779f–3782f
ORIF, talus and, 708–709, 709f
pelvis, 462–474
after-shock sheeting, circumferential pelvic, 467, 467f
anatomy and, 462
anterior iliac crest, open technique, 467–468, 468f
anterior iliac crest, percutaneous technique, 470, 470f
complications of, 474
definition of, 462
diagnostic studies for, 463–464
differential diagnosis of, 464–465
frame application/reduction and, 471, 472f
imaging for, 463–464, 464f, 465f
natural history of, 462–463
nonoperative management of, 465
outcomes of, 474
pathogenesis and, 462, 462f, 463f
patient history and, 463
pears and pitfalls of, 474
pelvic antishock clamp, 472, 472f, 473f
physical findings, 463
postoperative care for, 474
supra-acetabular technique, 470, 471f
surgical management of, 465–466, 466f, 466f

Charcot arthropathy of midfoot, 3799, 3800f
Charcot foot realignment surgery with, 3810–3811, 3811f
hinged, elbow dislocation, simple, 3375, 3375f
knee arthropathy, 1010–1011, 1011f, 1012f
midfoot arthropathy with, 3779–3782, 3779f–3782f
ORIF, talus and, 708–709, 709f
pelvis, 462–474
after-shock sheeting, circumferential pelvic, 467, 467f
anatomy and, 462
anterior iliac crest, open technique, 467–468, 468f
anterior iliac crest, percutaneous technique, 470, 470f
complications of, 474
definition of, 462
diagnostic studies for, 463–464
differential diagnosis of, 464–465
frame application/reduction and, 471, 472f
imaging for, 463–464, 464f, 465f
natural history of, 462–463
nonoperative management of, 465
outcomes of, 474
pathogenesis and, 462, 462f, 463f
patient history and, 463
pears and pitfalls of, 474
pelvic antishock clamp, 472, 472f, 473f
physical findings, 463
postoperative care for, 474
supra-acetabular technique, 470, 471f
surgical management of, 465–466, 466f, 466f

F
FAL. See Femoroacetabular impingement
False pouch reconstruction/imbrication, 2647–2648, 2648f
Fascial layers, 1767–1769
Fascicular repair, group, nerve transaction, complete followed by, 2695, 2695f
Fasciectomy, medial epicondylar, 2635–2636, 2635f, 2636f
Fasciectomy, medial epicondylar, 2635–2636, 2635f, 2636f
Fasciomyotomy, closure, 668, 669f
compartment
CECS, 446–450, 446f, 447f, 448f, 449f, 450f
dual-incision lateral approach for anterior/lateral, 446–447, 447f
posterior, posteromedial incision for, 448, 449f
single-incision lateral approach for anterior/lateral, 446, 446f
extensive, Dupuytren disease, 2989–2990, 2989f
forearm, 2965–2967, 2966f, 2967f
four-compartment, 447–448, 448f
hand, 2965–2967, 2966f, 2967f
leg, for acute compartment syndrome, 660–670
anatomy and, 660, 660f, 661f
closure and, 668, 669f
closure for, 668, 669f
complications, 670
definition, 660
diagnostic studies and, 663–664
differential diagnosis of, 663–664
double-incision technique for, 665, 666f
imaging and, 663–664
muscle débridement, 668
natural history and, 662
nonoperative management and, 664
one-incision technique for, 667, 668f
outcomes and, 668–670
pathogenesis and, 660–662
patient history and, 662–663
pears and pitfalls for, 669
physical findings and, 662–663, 663f
postoperative care and, 669
surgical management and, 665
open, lateral epicondylar, 2639–2640, 2639f, 2641f
open palm, Dupuytren disease, 2987
partial, Dupuytren disease, 2987–2988, 2988f
percutaneous, Dupuytren disease, 2987, 2987f
Fassier-Duval telescoping nailing, OL, techniques for, 1288–1291, 1288f, 1289f, 1290f, 1291f
FCR. See Flexor carpi radialis
FCU. See Flexor carpi ulnaris
FDG-PET. See Fluorine-18 2-fluoro-2-deoxy-D-glucose-positron emission tomography
FDL transfer. See Flexor digitorum longus transfer
Felons
anatomy, 2603, 2603f
diagnostic studies, 2589
digital revascularization/replantation and repair of, 2894
finger, 2588, 2588t
imaging, 2589
slip, MCP joint traumatic subluxation reconstruction with, 2589
f tenosynovectomy, 2603–2607
compliances of, 2607
outcomes of, 2607
pears and pitfalls of, 2607
postoperative care of, 2607
techniques for, 2605, 2605f
tenosynovitis, 2603–2604
thumb, 2588, 2588t
External fixation. See also Closed reduction and external fixation
Agility TAA, 4096–4097, 4097f
ankle arthropathy with, 4132–4137, 4132f–4137f
Charcot arthropathy of midfoot, 3799, 3800f
Charcot foot realignment surgery with, 3810–3811, 3811f
hinged, elbow dislocation, simple, 3375, 3375f
knee arthropathy, 1010–1011, 1011f, 1012f
midfoot arthropathy with, 3779–3782, 3779f–3782f
ORIF, talus and, 708–709, 709f
pelvis, 462–474
after-shock sheeting, circumferential pelvic, 467, 467f
anatomy and, 462
anterior iliac crest, open technique, 467–468, 468f
anterior iliac crest, percutaneous technique, 470, 470f
complications of, 474
definition of, 462
diagnostic studies for, 463–464
differential diagnosis of, 464–465
frame application/reduction and, 471, 472f
imaging for, 463–464, 464f, 465f
natural history of, 462–463
nonoperative management of, 465
outcomes of, 474
pathogenesis and, 462, 462f, 463f
patient history and, 463
pears and pitfalls of, 474
pelvic antishock clamp, 472, 472f, 473f
physical findings, 463
postoperative care for, 474
supra-acetabular technique, 470, 471f
surgical management of, 465–466, 466f, 466f

Felons
anatomy, 2906, 2907f
definition, 2906, 2906f
diagnostic studies, 2907
differential diagnosis, 2907
imaging, 2907
incision/drainage of, 2909–2910, 2910f
natural history, 2906–2907
nonoperative management, 2907
pathogenesis, 2906
patient history, 2907
physical findings, 2907
surgical management, 2907–2908
surgical treatment, 2906–2911
compliances of, 2910
pears and pitfalls of, 2910
postoperative care of, 2910
Femoral anteverision, 1187, 1187f
diagnostic studies, 1188, 1188f
differential diagnosis, 1189
imaging, 1188, 1188f
natural history, 1187
nonoperative management, 1188
patient history, 1187–1188, 1188f
physical findings, 1187–1188, 1188f
surgical management, 1187–1189, 1189f
Femoral bone loss
revision TKA with, augments and
anatomy of, 942, 942f
bone cement and, 945
complications of, 948
definition of, 942
diagnostic studies for, 943
differential diagnosis of, 943
distal femoral allograft for, 946, 947f
imaging for, 943
metal augments for, 944–945, 945f
morselized allograft for, 945
morselized autograft for, 945
natural history of, 943
nonoperative management of, 943
outcomes of, 948
pathogenesis of, 942–943, 943f
patient history and, 943
pears and pitfalls of, 947–948
physical findings for, 943
postoperative care for, 948
surgical management of, 944, 944f
techniques for, 944–947, 945f
revision TKA with, distal femoral
anatomy and, 962
bone cement for, 964, 964f
bulk allograft replacement, 966–967,
966f, 967f
bulk femoral head reconstruction and,
965, 965f, 966f
complications of, 968
definition of, 962
diagnostic studies for, 962–963
differential diagnosis of, 963
femoral component in, 964, 965f
imaging for, 962–963
metal augments for, 964, 965f
morselized allograft for, 964, 964f
natural history of, 962
nonoperative management of, 963
outcomes of, 968
pathogenesis of, 962
patient history and, 962
pears and pitfalls of, 967–968
physical findings and, 962 postoperative care of, 968
surgical management of, 963–964
tumor reconstruction prosthesis for,
967
Femoral bone loss, revision THA
fluted stems
anatomy and, 815, 816f, 816f
complications of, 822
diagnostic studies for, 817
differential diagnosis of, 817
imaging for, 817
internal fixation for, 819–820
natural history of, 815
nonoperative management of, 817
open reduction for, 819–820
osteotomy for, 819–820, 820f
outcomes of, 821–822
pathogenesis of, 815
patient history and, 815–817, 816f
pears and pitfalls, 821
physical findings, 815–817
postoperative care for, 821
routine revision with diaphyseal defect,
819
routine revision without diaphyseal
defect, 818, 818f, 819f
surgical management of, 817–818
techniques for, 818–821
proximal femoral replacement, 823–830
acetabular reconstruction and, 827
anatomy of, 823
closure, 828, 828f
complications of, 829–830
definition of, 823, 823f
diagnostic studies for, 824
differential diagnosis of, 824
exposure and, 826, 826f
imaging, 824
limb length determination and, 827
natural history of, 823
nonoperative management of, 824
outcomes of, 828–829
pathogenesis of, 823
patient history for, 823–824
pears and pitfalls, 828
physical findings for, 823–824
postoperative care, 828
surgical management of, 824–825, 825f
techniques, 826–828, 826f, 828f
total femur replacement and, 827
Femoral condyle
ostechondral allograft implantation,
324–327, 324f, 325f, 326f, 327f
TKA, cemented, 923, 926f
Femoral condyle
osteotomy, MBD, 2034
surgical management of, 2039–2041,
2040f, 2041f
Femoral head
anatomy, ORIF and, 514, 514f
determining center of, TKA, using
navigation and, 935, 935f
osteoncrosis, 770–772
cephalomedullary nail fixation and,
528–529, 528f, 529f
complications of, 531–532
definition of, 521, 522f
diagnostic studies for, 522
differential diagnosis of, 523
fixation, minimally invasive with sliding
hip screw and, 530–531, 530f, 531f
imaging for, 522
natural history of, 521
nonoperative management of, 523
outcomes of, 531
pathogenesis for, 521
patient history for, 521–522
pears and pitfalls of, 531
physical findings for, 521–522
postoperative care for, 531
surgical management of, 524–525, 524f
Watson-Jones approach to, 526–528,
527f
Femoral nerve, 1855
Femoral osteotomy, 869–876, 874, 875f
See also Osteotomy
anatomy, 869
approach, 872–873, 872f
blade channel placement, 873, 873f
blade insertion, 874–875, 874f
complications, 876
correction and plate placement, 875, 875f
definition, 869
diagnostic studies, 869
imageing, 869, 870f
natural history, 869
outcomes, 876
pathogenesis, 869
patient history, 869
pears and pitfalls, 876
physical findings, 869
postoperative care, 876
preoperative care, 876
proximal femoral replacement, 871, 871f
proximal femoral osteotomy, DDH open
resection and, 1499–1500, 1500f
surgical management, 869–870, 871f
techniques, 871–875, 871f, 872f, 873f,
874f, 875f
Femoral physis, epiphysiosis of,
1240–1241, 1240f, 1241f
Femoral shaft fractures, pediatric anatomy, 1090, 1091
closed reduction and external fixation of, 1099–1105
AO/SYNTHES technique for, combination clamp, 1101–1102, 1102f
AO/SYNTHES technique for, modular frame, 1103, 1104f
AO/SYNTHES technique for, multipin clamps, 1102–1103, 1103f
complications and, 1105
diagnostic studies for, 1099
EBI DFS XS fixator technique for, 1100–1101, 1100f, 1101f
imaging for, 1099, 1099f
outcomes and, 1105
pears and pits for, 1104
postoperative care for, 1104f, 1105
definition, 1099, 1106
differential diagnosis, 1099, 1106
IMN, flexible of, 1106–1110
complications and, 1110
diagnostic studies for, 1106
imaging for, 1106, 1106f
outcomes and, 1109
pears and pits, 1109
postoperative care for, 1109
retrograde, 1107–1108, 1108f, 1109f
nonoperative management, 1099, 1107
pathogenesis, 1099, 1106
patient history, 1099, 1106
physical findings, 1099, 1106
submuscular plating of, 1111–1114
complications and, 1114
implant selection/preparation for, 1111–1112, 1112f
internal fixation for, 1112–1113, 1112f, 1113f
outcomes for, 1114
pears and pits, 1114
postoperative care for, 1114
provisional reduction for, 1111, 1111f
surgical management, 1099–1100, 1107, 1107f, 1111
Femoral stems
fluted, hip reimplantation surgery, two-stage with uncremented tapered, 857, 857f
porous-coated, hip reimplantation surgery, two-stage with uncremented extensively, 856, 856f
Femoral stump, 2053–2056, 2056f
Femoral triangle space, 2011, 2012f,
tumors, surgical resection, 2014–2015, 2015f
Femoral tunnel
anteromedial, ACL reconstruction, 353, 353f
posterolateral, ACL reconstruction, 352, 352f
Femoral tunnel placement, ACL repair, 346–347, 347f
Femoracetabular impingement (FAI), 1569. See also Acetabulum; Impingement test
anatomy, 213
anter anatomy and, 887, 887f
anter incision treatment of, 887–894
anter incision treatment of, techniques for, 890–893, 890f, 891f, 892f, 893f
complications of, 894
definition, 887
diagnostic studies, 888–889
differential diagnosis of, 889
imaging of, 888–889, 888f
natural history of, 887
nonoperative management of, 889
outcomes of, 894
pathogenesis of, 887
patient history and, 887–888
pears and pits of, 893
physical findings for, 887–888
postoperative care of, 894, 894f
surgical management of, 889–890, 889f
arthroscopic management, 213–221
complications of, 221
diagnostic, 216, 216f
outcomes of, 221
pears and pits of, 219–220
postoperative care of, 220–221, 220f
definition, 213, 877
diagnostic studies, 214–215
differential diagnosis, 215
hip dislocation and, surgical, 877–885
closure, 884, 884f
complications, 885
diagnostic studies for, 878
diagnostic differential, 878
imaging for, 878, 878f
natural history of, 877–878
nonoperative management, 878
outcomes, 885
pears and pits, 884–885
physical findings for, 877–887
physical findings of, 877–887
postoperative care, 885
surgical management, 878–879, 879f
techniques for, 879–881, 879f, 880f, 881f
imaging, 214–215, 214f
intra-articular surgery for, 881–883, 882f, 883f
MFCA anatomy and, 877
natural history, 214, 877
nonoperative management, 215
pathogenesis, 213–214, 213f, 877, 877f
patient history, 214
physical findings, 214
pincer, arthroscopic management, 216–217, 217f
surgical management, 215, 215f, 215f
Femur. See also Congenital femoral deficiency, pediatric anatomy
anterograde IMN and, 569
osteotomy and, 869
anterograde IMN, 569–571
physical findings and, 566
pathogenesis and, 566
replacement in, 570
surgical management, 566–570
anatomic anatomy and, 566
complications of, 580
definition of, 569
diagnostic studies for, 570–571
differential diagnosis of, 571
distal interlocking screw placement for, 578–579, 578f, 579f
fracture reduction and, 575–576, 576f
guidewire placement in, 575–576, 576f
imaging for, 570–571
measurement and, 577
nail placement for, 577
natural history and, 570
nonoperative management of, 571
outcomes of, 579–580
pathogenesis and, 569–570
patient history and, 570
percutaneous method of nailing for, 574–575, 574f, 575f
physical findings and, 570
piriform fossa entry and, 573–574, 573f
postoperative care for, 579
proximal interlocking screw placement for, 577
reaming and, 577
soft tissue dissection and, 573
surgical management of, 571–573, 572f
trochanteric entry and, 573–574, 573f,
575–576, 576f
bone cut, TKA, using navigation and, 939, 939f
cementing, TKA, cemented and, 751–752, 752f
condyle, bone cuts and, TKA, cemented, 925, 926f
exposure, TKA, un cemented and, 579, 759f
hip hemiarthroplasty and, lateral approach to, 788–790, 789f, 790f
hip resurfacing and, 776–778, 776f, 777f
lengthening of
 lilzarov method for, 1264–1265, 1265f
monoplanar fixator for, 1265–1266, 1266f
preparation, TKA, un cemented and, 759–760, 759f
removal, revision TKA with removal of
well-fixed components and, 977–978, 978f
retrograde IMN, 558–567
alternative techniques, 567f
anatomy and, 558, 559f
approach to, 562
classification of, 559–561, 559f, 559f,
560f, 561f
complications of, 567
contraindications for, 561
definition of, 558
diagnostic studies for, 558–559
fracture reduction and, 563
guardwire and, passing, 563
guardwire placement and, 563
imaging for, 558–559
nail placement and, 564, 565f
outcomes of, 567
pathogenesis and, 558
patient history and, 558
pears and pits of, 566
physical findings and, 558
positioning for, 562
postoperative care for, 566–567
preoperative planning for, 561–562, 562f
reaming and, 564, 564f
relative indications for, 559–561, 559f,
559f, 560f, 561f
screw fixation and, 565
starting hole and, creating/reaming, 563
surgical management of, 559–562, 559f,
559f, 560f, 561f
wound closure and, 566
rotational, bone cut, TKA, using navigation and, 938–939, 938f
SCFE and, 1569
THA, cemented and preparation of, 750, 750f
THA, un cemented and component
implantation of, 760, 760f
THA and, malignant lesion, 801–802,
801f, 804–805, 804f
trial size/augments, choosing, revision TKA and, 1000–1001, 1001f
valgus osteotomy of
cannulated blade plate for, 1585–1586, 1585f, 1586f
cannulated blade plate for, 1586–1587, 1586f, 1587f
Femur fractures, pediatric. See also Distal femoral physeal fractures, pediatric anatomy, 1095
  closed reduction for, 1095–1098
  complications of, 1098
  outcomes of, 1098
  pears and pitfalls of, 1097–1098
  postoperative care, 1098, 1098f
definition, 1095
diagnostic studies, 1095
differential diagnosis, 1095
imaging, 1095, 1096f
nonoperative management, 1096
pathogenesis, 1095
patient history, 1095
physical findings, 1095
spica casting for, 1095–1098
  complications of, 1098
  outcomes of, 1098
  pears and pitfalls of, 1097–1098
  postoperative care, 1098, 1098f
  traditional, 1096–1097, 1096f, 1097f
walking, 1097, 1097f
surgical management, 1096
  techniques for, 1096–1097, 1097f, 1097f
Fetal umbilical vein wrap, tarsal tunnel, 3938, 3938f
FHL. See Flexor hallucis longus tendon
FHL tendon transfer
Achilles tendinosis treated with complications of, 4453
  outcomes of, 4453
  pears and pitfalls of, 4453
postoperative care of, 4453
Achilles tendon rupture, chronic/neglected, anatomy, 4447, 4447f
definition, 4447
diagnostic studies, 4447, 4449f
differential diagnosis, 4447–4448
imaging, 4447, 4448f
natural history, 4447
nonoperative management, 4448
pathogenesis, 4447
patient history, 4447
physical findings, 4447
surgical management, 4448–4452
  approach, 4448
  augmentation for Achilles tendinosis, 4449–4452, 4449f–4452f
  positioning, 4448, 4448f
preoperative planning, 4448
Fibula
anatomy, 1964, 1964f
  vascularized grafts and, 1974–1976, 1975f
  congenital pseudarthrosis, tibial and, 1254
  fixation, ORIF of pilon and, 680
  flap harvest, vascularized graft, 1978, 1978f
  groove deepening, indirect, peroneal tendon dislocation, chronic, 4480–4482, 4481f, 4482f
  imaging, 1964, 1965f
  vascularized grafts and, 1976
  ORIF of ankle and, 690–691, 690f, 691f, 694f, 694f
  plating of, posterior, 694, 694f
  reduction, ORIF of pilon and, 680
resections, 1964–1973
  background, 1964
  complications, 1973
  imaging, 1964, 1965f
  indications, 1964
  outcomes, 1973
  pears and pitfalls, 1973
Fingertips, anatomy, 2932, 2932f
First MTP capsular interpositional arthroplasty
anatomy, 3606
compliances of, 3611
definition, 3606
diagnostic studies, 3606
differential diagnosis, 3606–3607
imaging, 3606, 3607f
natural history, 3606
nonoperative management, 3607
outcomes of, 3611
pathogenesis, 3606
patient history, 3606
physical findings, 3606
pearls and pitfalls of, 3610
surgical management, 3607–3610, 3608f–3610f
  approach, 3607
  cheileotomy/phalangeal osteotomy, 3609, 3609f
  exposure and capsulotomy, 3608, 3608f
First MTP capsular interpositional (continued) interposition arthroplasty, 3609–3610, 3610f
positioning, 3607
preoperative planning, 3607
First MTP joint arthrodesis, 3627–3631 anatomy and, 3643, 3643f complications, 3631 crossed-screw technique, 3643–3648 alternative technique for, 3647 complications of, 3648 outcomes of, 3648 pearls and pitfalls of, 3648 postoperative care of, 3648 in situ arthrodesis and, 3645–3647, 3646f, 3647f
definition, 3627, 3643 diagnostic studies, 3644–3645 differential diagnosis and, 3645 using dorsal titanium contoured plate, 3629–3630, 3629f, 3630f hallux rigidus treatment with, 3632–3642 complications, 3642 internal fixation of, 3640–3643 joint alignment and, 3639, 3639f joint exposure and, 3637, 3637f joint resection/dissection of, 3638, 3638f
metatarsal head preparation and, 3638, 3638f
outcomes of, 3641–3642 pearls and pitfalls of, 3641, 3641f postoperative care of, 3641, 3641f proximal phalangeal preparation and, 3639, 3639f imaging, 3644–3645, 3644f natural history and, 3644 nonoperative management and, 3645 outcomes, 3630 pathogenesis, 3643–3644 patient history and, 3644 pearls and pitalls, 3630 physical findings and, 3644 postoperative care, 3630, 3630f
in situ, crossed-screw fixation, 3645–3647, 3646f, 3647f
surgical management and, 3645
Fixation. See also specific types acatubal, Bernese PAO and, 1566–1567, 1567f
all-inside, technique, meniscal repair with, 279, 279f
Bernese PAO, 866, 866f Chiarri medial displacement osteotomy, 1556, 1556f, 1557f condyle, ORIF of distal femur and, 593–594 fibular fracture, pediatric, 1141
humeral head allograft, 3121, 3121f malleolus, posterior, 693, 693f
minimally invasive, with sliding hip screw, ORIF and, 530–531, 530f, 531f Moberg osteotomy, 3589, 3589f, 3590f nail, cephalomedullary, ORIF and, 528–529, 528f, 529f
ORIF, bicortical plate, 618–619, 618f, 619f
osteofy, TIO and, 1549, 1549f pelvic, spinal, 493, 500, 500f proximal chevron osteotomy, 3547, 3547f scaphoid nonunion percutaneous treatment, 2264, 2264f
scoliosis, adult, 4651, 4651f syndesmosis, 694, 694f
Flaps cross-finger, fingertip amputation, 2935–2936, 2936f
Flexor digitorum profundus anatomy, 2650, 2650f, 3055 tendon transfers, 2721 Flexor digitorum superficialis anatomy, 2650, 2650f, 3055 tendon transfer, rheumatoid disorder, 2614–2615, 2615f
ulnar slip excision, A1 pulley release for trigger finger with/without, 2630–2636 Flexor hallucis longus (FHL) tendon, 4462 augmentation Achilles tendon ruptures, chronic, 4401–4403, 4402f, 4403f IAT treatment with, 4437–4442 IAT treatment with, techniques for, 4440, 4440f graft attachment for, IAT treatment and, 4440, 4440f harvesting, 4465
Achilles tendons ruptures, chronic, 4403 IAT treatment and, 4440, 4440f talocalcaneal coalition excision and, 1639 Flexor muscles, distal humerus resection and, 1811 Flexor tendon disruptions, acute definition, 2555 natural history, 2556 nonoperative management, 2556–2557 pathogenesis, 2553–2556 patient history, 2556 physical findings, 2556, 2556f repair, 2555–2559 complications of, 2559 outcomes of, 2559 pears and pitfalls of, 2559 postoperative care of, 2559 primary, in zone II, 2557–2558, 2558f, 2559f surgical management, 2557
Flexor tendons adhesiolysis, 2564, 2564f anatomy, 2553, 2555f, 2570, 2570f, 2603, 2603f diagnostic studies, 2556, 2562, 2571 differential diagnosis, 2556 digital revascularization/replantation and repair of, 2894
imaging, 2536, 2562, 2571
injuries, 2561
differential diagnosis of, 2562, 2571 natural history of, 2561–2562, 2570 nonoperative management, 2562, 2571 pathogenesis of, 2561, 2570 patient history of, 2562, 2570–2571 physical findings of, 2562, 2570–2571 surgical management, 2563, 2563f, 2571 tenolysis following, 2561–2569 reconstruction, staged, 2570–2576 complications of, 2576 definition of, 2570 outcomes of, 2576 pears and pitfalls of, 2574–2575, 2574f, 2575f
postoperative care of, 2575–2576 stage 2 of, 2572–2574, 2573f
stage 1 of, 2571–2572, 2572f
stage 1 of, alternative to, 2574, 2574f
tenolysis for, 2574
pathogenesis, 3262, 3275
patient history, 3262, 3276, 3276f
physical findings, 3262, 3263f, 3276, 3276f
total shoulder arthroplasty, 3261–3273
comparisons of, 3273, 3286
outcomes of, 3273, 3286
pears and pitfalls of, 3272, 3285
postoperative care of, 3272–3273,
3286, 3286f
techniques for, 3271, 3272f, 3279–3280,
3280f, 3281f
Glenohumeral instability
anatomy, 3116, 3117f
anterior capsulolabral reconstruction for,
3079–3080, 3079f, 3080f
definition, 3116
imaging for, 3256
physical findings for, 3256
postoperative care for, 3256
ORIF and posterior approach to, 3251,
3252, 3252f
stability, 3073, 3073f
Glenohumeral joint
anatomy, 3073, 3073f, 3256, 3256f, 3275
arthrodesis, 3256–3260
bone grafting and, 3259, 3259f
definition of, 3256
diagnostic studies for, 3256
exposure for, 3257, 3258f
imaging for, 3256
outcomes of, 3260
physical findings for, 3256
postoperative care for, 3256
patient history and, 3256
pearls and pitfalls of, 3260
performing, 3258, 3258f, 3259f
postoperative care for, 3260
Bankart procedure for, 3077–3078, 3078f
T-plasty modification of, 3079, 3079f
definition, 3256
postoperative care for, 3256
stability, 3073, 3073f
surgical management, 3256–3257, 3257f
Glenohumeral muscles.
See also specific muscles
anatomy, 3046–3047, 3046f
Glenoid
anatomy, 3100–3101
arthroscopy and preparation of, 27, 27f
exposure, 3103–3104, 3103f, 3104f,
3110–3111, 3110f, 3111f
neck
ORIF of, posterior approach to,
3245–3245, 3245f
ORIF of, superior approach to, 3245,
3245f
preparation, 3104–3105, 3104f, 3105f,
3111, 3111f
differential diagnosis, 3102, 3108–3109
pathogenesis, 3074
resection, 1767
nonoperative management, 3109
natural history of, 3107–3114
management of, instability with,
3107–3114
Glenoid bone loss, instability with
anatomy, 3107, 3107f
definition, 3100, 3100f, 3107
diagnostic studies, 3101, 3101f, 3108
differential diagnosis, 3102, 3108–3109
glenoid bone graft for, 3107–3114
capsule repair and, 3113, 3113f
compartments of, 3114
Glenoid resurfacing, biologic
Glenoidplasty, shoulder DJD, 138–144
Glide pin positioning, hip screw, sliding,
551–552, 552f
Greater arc injuries
Gracilis tendon reconstruction, hamstring
Graft
ACL reconstruction, 354, 354f
ACL repair, revision, 361, 362, 362f
ACL repair and passage/fixed of,
347, 348f
anterior cruciate ligament, 347, 348f
lateral knee ligament passage for,
3436, 3436f, 3437f, 3438f
meniscus
medial, 287, 287f
rhomboid, 290–291, 290f
osteochondral autograft “plug” transfer
outcomes of, 306, 307f
insertion of, 309, 309f
Graft fixation, ACI peristem, for,
317–318, 318f
Graft harvesting
ACI peristem, 317, 317f
bone-ligament-bone reconstruction and,
SLIL, 2492, 2492f
FCR, for thumb CMC joint, 2315–2317,
2316f
hamate, 2440–2441, 2441f
hamstring, ACL repair and, 344, 344f
iliac crest bone, 3111–3112, 3112f
long thoracic nerve palsy, pectoralis major transfer for,
3131, 3131f
osteochondral autograft “plug” transfer
outcomes of, 306, 307f
insertion of, 309, 309f
Index I-37
Greater arc injuries (continued)

natural history, 2513–2514
operative treatment, 2513–2519
combined dorsal/sural approach to, 2518, 2518f
complications of, 2519
dorsal approach to, 2515–2517, 2516f, 2517f
outcomes of, 2519
pears and pitfalls of, 2519
postoperative care of, 2519
pathogenesis, 2513, 2514f
patient history, 2514
physical findings, 2514
surgical management, 2515
Great toe fusion, hallux valgus correction, revision, 3575

Groat
anatomy, 238, 238f
flap, 2952–2953, 2952f, 2955–2956, 2955f, 2956f
Groin injury, 221–232, 231f, 238.
See also Athletic pubalgia

Groin pain
aductor longus-related, 238–241
complications of, 241
open adductor longus tenotomy for, 240, 241f
outcomes of, 241
pears and pitfalls of, 241
postoperative care of, 241
anatomy and, 238, 238f
definition, 238
diagnostic studies, 239
differential diagnosis, 239
imaging, 239, 239f
natural history, 238
nonoperative management, 239–240
pathogenesis, 238
patient history, 238–239
physical findings, 238–239
surgical management, 240, 240f
Groove deepening, indirect
fibular, peroneal tendon dislocation, chronic, 4480–4482, 4481f, 4482f
peroneal tendon dislocation, chronic, 4477–4483
complications of, 4483
outcomes of, 4483
pears and pitfalls of, 4483
postoperative care of, 4483
Groove deepening, ulnar sesseous, ECU subluxation, 2648, 2648f
Groove-deepening procedure (Trap Door technique), peroneal tendon dislocation repair/reconstruction with, 4472–4473, 4473f–4474f
Growing rod instrumentation, for EOS, 3612–3622
complications of, 3612–3622
outcomes of, 3621, 3621f
pears and pitfalls of, 3619–3620, 3620f
postoperative care of, 3620–3621, 3620f
imaging, 3585–3586, 3586f, 3592–3593, 3593f, 3594f, 3599f, 3600f, 3601f, 3605f, 3613f, 3613f, 3633f, 3633f
microfracture treatment for, 3598–3604, 3603f
HemiCAP, arthroscopic resurfacing for, 3612–3622
complications of, 3612–3622
outcomes of, 3621, 3621f
pears and pitfalls of, 3619–3620, 3620f
postoperative care of, 3620–3621, 3620f
imaging, 3585–3586, 3586f, 3592–3593, 3593f, 3594f, 3599f, 3600f, 3601f, 3613f, 3613f, 3633f, 3633f
microfracture treatment for, 3598–3604, 3603f
MTP joint arthrodesis, first for, 3632–3642
complications of, 3632–3642
internal fixation of, 3640, 3640f
joint alignment and, 3639, 3639f
joint exposure and, 3637, 3637f
joint resection/dissection of, 3638, 3638f
metatarsal head preparation and, 3638, 3638f
outcomes of, 3641–3642
pears and pitfalls of, 3641, 3641f
postoperative care of, 3641, 3641f
proximal phalangeal preparation and, 3639, 3639f
natural history, 3585, 3592, 3598–3599, 3612, 3612f, 3623, 3632
nonoperative management, 3586, 3586f,
3594, 3600f, 3601f, 3601f, 3613f, 3613f
pathogenesis, 3585, 3592, 3598, 3612, 3623, 3623f, 3632, 3633f
patient history, 3585, 3592, 3599, 3613, 3613f, 3623, 3633
physical findings, 3585, 3592, 3599, 3613, 3613f, 3623, 3633
surgical management, 3586–3587, 3587f,
3594, 3600–3601, 3601f, 3601f, 3613f–3614, 3614f, 3624, 3624f,
3636–3637, 3636f, 3636f, 3637f
complications of, 3604
outcomes of, 3604
pears and pitfalls of, 3604
postoperative care of, 3604, 3604f
2nd toe closure for, 3603, 3603f
Hallux valgus
anatomy and, 3505, 3505f, 3536,
3553–3554, 3553f, 3554f, 3564, 3564f
definition, 3505, 3536, 3553, 3564
diagnostic studies, 3506, 3506f,
3537–3538, 3555
differential diagnosis, 3538, 3555, 3566
distal chevron osteotomy, 3481–3487
elementary case example, 3566–3571, 3567f–3571f
imaging, 3506, 3537–3538, 3537f, 3538f,
3555, 3566, 3566f
lateral soft tissue release, 3482–3483,
3482f, 3483f
Ludloff osteotomy and, 3529–3530
natural history, 3536, 3554, 3564, 3565f
nonoperative management, 3506, 3538,
3553, 3566
opening-wedge osteotomy, proximal metatarsal, 3553–3557, 3556f
pathogenesis, 3505, 3536, 3554,
3554f, 3564
patient history, 3505–3506, 3505f, 3506f,
3536–3537, 3564, 3565, 3566f
physical findings, 3505–3506, 3505f,
3506f, 3536–3537, 3555
surgical management, 3506, 3538–3539,
3539f, 3555, 3566
Hallux valgus correction
Mau osteotomy for, 3536–3544
closure and, 3542, 3542f
complications of, 3543, 3543f, 3544f
medial capsullorrhaphy and, 3540, 3540f
MTP joint release, first and, 3539, 3539f
outcomes of, 3542–3543
pears and pitfalls of, 3542
postoperative care of, 3542
techniques of, 3540–3541, 3540f, 3541f
minimally invasive, 3505–3511
techniques for, 3505–3509, 3507f
revision, 3506–3507
complications of, 3576
dorsal opening-wedge osteotomy for,
3574–3575, 3574f
great toe fusion for, 3575
Lapidus procedure for, 3572–3573,
3572f, 3572f
Ludloff metatarsal osteotomy for, 3573,
3573f, 3574f
outcomes of, 3576
pears and pitfalls of, 3575
postoperative care of, 3575
SERI technique, 3505–3511
complications of, 3510–3511
outcomes of, 3510, 3511f
pears and pitfalls of, 3509–3510, 3509f,
3510f
postoperative care for, 3510, 3510f
techniques for, 3507–3509, 3507f
Hallux valgus repair
complications of, 3528
with distal soft tissue procedure, 3521–3528
lateral joint structure release and, 3521–3522, 3521f, 3522f
medial joint capsule preparation and, 3522–3524, 3523f, 3524f
Hamstring autografting/augmentation lateral ankle instability, 4322–4330 lateral ankle ligament instability biotenodesis screw technique for, 4328, 4328f complications of, 4330 Coughlin drill holes in bone for, 4328, 4328f gracilis reconstruction through drill holes and, 4324–4328, 4325f, 4326f, 4327f Myerson minimal incision technique and, 4329, 4329f outcomes of, 4329–4330 pears and pitfalls of, 4332 postoperative care of, 4329

Hamstring injury, proximal, 243–247 anatomy and, 243 complications of, 247 definition of, 243 diagnostic studies for, 243–244 differential diagnosis of, 244 hamstring complete avulsion repair for, 245, 246f imaging of, 243–244, 244f natural history of, 243 nonoperative management of, 244 outcomes of, 246–247 pathogenesis of, 243 patient history of, 243 pears and pitfalls of, 246 physical findings of, 243 postoperative care of, 246 surgical management of, 245, 245f


Hamstrings tendon_AT ruptures, management of, 4406–4410 complications in, 4410 outcomes for, 4410 pears and pitfalls for, 4410 postoperative care for, 4410

Hand acquired lesions, 2994–2996, 2994f, 2995f, 2996f anatomy, 2081, 2081f, 2114–2116, 2114f, 2115f, 2917, 2917f, 2992 arthrodesis in, 2752–2764 definition of, 2752 arthroscopy, 2114–2126 author’s experience with, 2116–2118, 2116f, 2117f, 2118f background of, 2114 complications of, 2126 dorsal drill portal for, 2125 4-5 portal for, 2121 midcarpal radial portal for, 2122 midcarpal ulnar portal for, 2123 nonoperative management and, 2118–2119, 2119f 1–2 portal for, 2122, 2122f

pearls and pitfalls of, 2125 postoperative care of, 2125 6R/6U portals for, 2121 surgical management and, 2119–2121, 2120f, 2120r 3–4 portal for, 2121 volar dorsi portal for, 2125 volar ulnar portal for, 2124, 2124f VR portal, midcarpal, 2123 VR portal for, 2123

compartment syndrome surgical decompression for, 2875–2881 surgical decompression for, techniques of, 2879–2880, 2880f congenital lesions, 2992–2993, 2992f, 2993f, 2994f deep space anatomy of, 2912, 2912f deep space infections of, 2915, 2915f midpalmar, 2914, 2915f Parona’s, 2915 surgical treatment, 2912–2916 thenar, 2914, 2914f definition, 2081 fasciotomy, 2965–2967, 2966f, 2967f injection injuries anatomy of, 2882 Brumer’s incisions for, 2884, 2884f Brumer’s incisions for, modified, 2885, 2885f complications of, 2887 definition of, 2882 diagnostic studies for, 2883 differential diagnosis of, 2883 imaging of, 2883 midaxial incisions for, 2884, 2884f natural history of, 2883, 2883f nonoperative management of, 2883 outcomes of, 2885–2886, 2886f pathogenesis of, 2882 patient history of, 2883 pears and pitfalls of, 2885 physical findings for, 2883 postoperative care of, 2885, 2886f surgical management of, 2883 surgical treatment of, 2882–2887 nerve injury, 2691–2692 diagnostic studies for, 2693 differential diagnosis of, 2693 imaging of, 2694, 2694f nonoperative management of, 2693 patient history of, 2692, 2692f physical findings of, 2692, 2692f surgical management of, 2693

nerve transection, complete, 2691–2698 approach to, 2693–2694, 2694f cable graft repair following, 2695, 2695f complications of, 2698 conduit repair following, 2696, 2696f epineural repair following, 2694, 2694f group fascicular repair following, 2695, 2695f nerve grafting following, 2691–2698 outcomes of, 2697–2698 pears and pitfalls of, 2697 postoperative care of, 2697 primary repair following, 2691–2698 vascularized nerve graft repair following, 2696, 2696f

septic arthritis anatomy of, 2917, 2917f diagnostic studies for, 2918 differential diagnosis of, 2919 imaging of, 2918, 2918f natural history of, 2918
Hip exposure (continued)

Hip flexion-interval rotation, 756. See also Flexion

Hip fractures, pediatric, 1088–1094
anatomy, 1088, 1088f
closed reduction and percutaneous fixation for, 1090–1091, 1090f, 1091f
complications, 1094
definition, 1088
diagnostic studies, 1089
differential diagnosis, 1089
imaging, 1089, 1089f
natural history, 1088
nonoperative management, 1089
ORIF for
fixed angle plate/screws, 1092, 1092f
pin/screw, 1091, 1091f, 1092f
outcomes, 1094
pathogenesis, 1088
patient history, 1088–1089, 1089f
pears and pitsfals, 1094
physical findings, 1088–1089, 1089f
postoperative care, 1094
surgical management, 1089–1090, 1089f, 1090f

Hip hemiarthroplasty, 782–796
anatomy, 782
anterolateral (Watson-James) technique, 795
cemented technique, 794–795
complications, 795, 796f
definition, 782, 782f, 783f
diagnostic studies, 783–784
diagnostic imaging, 783–784
lateral approach, 786–791
acetabular retractor placement and, 788
dissection for, 787–788, 788f
femoral broaching and, 789, 789f
femoral head removal/implant sizing and, 789, 789f
femoral reaming and, 789–789f
femoral stem placement and, 790, 790f
implant placement completion and, 790–791, 791f
incision for, 786, 787f
preparation of surgical site for, 786, 786f
proximal dissection for, 786–787, 787f
trial prosthesis evaluation and, 790, 790f
wound repair/closure and, 791, 791f
natural history, 783
nonoperative management, 784
outcomes, 796
pathogenesis, 782–783, 783f
patient history, 783
pears and pitsfals, 795–796
physical findings, 783
posterior approach, 792–793
completion of procedure, 793, 794f
component placement and, 793, 794f
dissection for, 792–793, 792f
incision for, 792–793, 792f
site preparation for, 793, 793f
postoperative care, 796
surgical management, 784–786
approach, 786
positioning and, 785–786, 785f
preoperative planning and, 784–785
techniques, 786–791
THA, uncremented and, 756
anterior dislocation in, 1913, 1913f
blood supply, 860
capsule incision, 1914, 1914f
capsule reconstruction, 2056, 2056f
DDJ, 744
femoral circumflex arteries, 860
flexed position, 860
groin muscles divided from, 1913, 1913f
iliopectineal arch, 860
imaging, 1860, 1911
THA, cemented and, 745
posterior muscle division in, 1914, 1914f
range of motion, 860, 860f
staging studies, 1911
Hip reduction, DDH open reduction and, 1505
Hip reimplantation surgery, 853–858
acetabular reimplantation and, 856, 856f
anatomy, 852
antibiotic spacer removal and, 855, 855f
complications, 857
definition, 853
diagnostic studies, 853–854
hip exposure and, 855, 855f
imaging, 853–854, 854f
natural history, 853
outcomes, 853
pathogenesis, 853
patient history, 853
pears and pitsfals, 857
physical findings, 853
postoperative care, 857
surgical management of, 854, 854f
techniques, 853–857
two-stage, 853–857
with uncremented extensively porous-coated femoral stems, 856, 856f
with uncremented tapered fluted femoral stems, 857, 857f
Hip resurfacing, 763–780
complications, 780
definition, 763
gluteal navigation system used for, 772–778
acetabular landmarks, acquiring and, 774–775, 774f
femoral landmarks, acquiring and, 776–778, 776f
femoral preparation and, 778, 778f
insertion of acetabular cup and, 774f, 775–776
patient positioning and, 772–773
pelvis registration and, 773, 773f
repositioning patient and, 774, 774f
osteonecrosis of femoral head technique, 770–772
stem cementing and, 771–772, 771f
femoral preparation and, 770–771, 770f
outcomes, 779–780
pears and pitsfals, 778–779
posterolateral approach, 767–770
acetabular preparation and, 768, 768f
femoral broaching and, 770, 770f
exposure and, 767–768, 767f
femoral head resurfacing and, 768, 768f
inserting the guide pin and, 768, 769f
wound closure, 770, 770f
postoperative care, 770
surgical management, 763–767
approach, 766–767, 766f
indications/contraindications for, 763
preoperative planning, 766, 766f
special considerations, 763–766, 766f
systems, 763, 764f
THA, 767–778
Hip screw, sliding, glide pin positioning for, 553–552, 552f
HMRS. See Howmedica Modular Replacement System
Hook nail deformity, 2929
Howmedica Modular Replacement System (HMRS), 1729
HTO. See Tibial osteotomy, upper
Hui-Linscheid reconstruction, 2476–2478, 2476–2478, 2450f, 2541f, 2542f
Humeral bone loss, glenohumeral instability with
diagnostic studies for, 3118
differential diagnosis of, 3118
Hill-Sachs lesion exposure and, 3120, 3120f
humeral head allograft fixation and, 3121, 3121f
humeral head allograft osteotomy and, 3120
humeral head osteotomy and, 3120, 3120f
imaging of, 3118, 3118f
labral inspection and, anterior, 3119
labral inspection Bankart reconstruction and, 3119
labral repair and, 3121
management of, 3116–3122, 3116–3123
management of, complications for, 3122
management of, outcomes for, 3122
management of, pears and pitsfals for, 3122
management of, postoperative care for, 3122
natural history of, 3116–3117
nonoperative management of, 3118
pathogenesis of, 3116
patient history for, 3117–3118
physical findings for, 3117–3118
subscapularis muscle capsulotomy and, 3119
subscapularis muscle release and, 3119
subscapularis reapproximation and, 3121
surgical management of, 3118–3119
Humeral head lateralis dorsi transfer and fixation to, 3148–3150, 3148f, 3149f
osteotomy, 3120, 3120f
Humeral head allograft fixation, 3121, 3121f
osteotomy, 3120, 3120f
Humeral resurfacing, glenohumeral arthritis, 3266–3269, 3267f, 3268f
Humeral shaft, anatomy, 3226, 3234
Humeral shaft fractures anatomy and, 3226, 3234
definition, 3226, 3234
diagnostic studies, 3227, 3235
differential diagnosis, 3227, 3235
imaging, 3227, 3235, 3235f
IMN antegrade, 3237–3240, 3237f, 3240f
retrograde, 3240–3241
intramedullary fixation, 3234–3242
complications of, 3242
outcomes of, 3242
pears and pitsfals of, 3241
postoperative care of, 3241–3242
natural history, 3226, 3234
nonoperative management, 3227, 3235
pathogenesis, 3226, 3234
patient history, 3226–3227, 3234–3235
physical findings, 3226–3227, 3234–3235
plate fixation, 3226–3233
anterolateral approach to, 3228–3229, 3228f
complications of, 3233
fracture nonunion and, exposure of, 3230
fracture reduction and, 3230, 3230f
medial approach to, 3231, 3231f
outcomes of, 3233
pelves and pitfalls of, 3232
plate application and, 3231, 3231f
posterior approach to, 3229, 3229f
postoperative care of, 3232, 3232f
reduction, 3230, 3230f
surgical management, 3227–3228, 3228f,
3235–3237, 3237f
positioning for, 3236–3237, 3237f
Humerus. See also Supracondylar fractures of
humerus, pediatric
diaphysis, 1816
lesions, 1816–1824
MBD in
complications, 1824
exposure and, 1821, 1823f
imaging of, 1816
mechanical reconstruction and, 1819,
1821, 1821f, 1823f
outcomes, 1824
position and, 1821, 1823f
postoperative care, 1824
soft tissue reconstruction and, 1819, 1822f
staging studies for, 1816
surgical management of, 1816–1824,
1817f
surgical management of, pears/pitfalls,
1824
tumor removal and, 1818–1819,
1819f, 1820f
tumor removal in, 1821, 1823f
type III metastases, 1819–1821, 1823f
type I metastases, 1818–1819, 1818f,
1820f
type I metastases, 1818–1819, 1818f
wound closure and, 1819, 1822f
osteology, 3043–3044, 3044f
resections, 1767, 1781–1783, 1782f
skeletal reconstruction following, 1772–1773, 1772f
surgical approaches to, 3058–3062
anterior, 3058–3060, 3059f
posterior, 3060–3061, 3060f
posterior, modified, 3061–3062, 3061f
TEA and, 3429, 3429f
TEA and preparation of, 3425, 3426f
total, resect, 1803
tumors arising from, 1767
Hunter rod, 4465–4466, 4465f, 4466f
Hypothoracic fat pad, 2664
Hypothoracic space infections, 2915, 2915f

I

IAM. See Intra-articular malunion
IAT. See Insertional Achilles tendinosis
Hosfamide, STS, 1716
IGHL. See Inferior glenohumeral ligament
Iliac artery
common, 1855
external, 1855–1856
internal, 1856
resection, 1862–1865, 1863f, 1864f,
TIP, 1544–1545, 1544f, 1545f
Iliac crest
allograft, tibial osteotomy, upper and,
914, 914f
anatomy, 4659, 4659f
anterior tricortical, bone graft harvesting of,
4660, 4660f
bone graft harvesting, 4659–4663
complications of, 4663

INBONE™ total ankle arthroplasty
anatomy, 4072
complications of, 4084
definition, 4072
diagnostic studies, 4072–4073
differential diagnosis, 4073
imaging, 4072–4073
natural history, 4072
nonoperative management, 4073
outcomes of, 4084
pathogenesis, 4072
patient history, 4072
pears and pitfalls of, 4083–4084
physical findings, 4072
postoperative care of, 4084
surgical management, 4073–4074
approach, 4074
positioning, 4073–4074
preoperative planning, 4074
techniques, 4074–4083
approach, 4074, 4074f
closure, 4083
component implantation, 4080–4083,
4080f–4083f
intramedullary alignment, 4076–4077,
4076f, 4077f
tibialani alignment, 4074–4075, 4075f
tibialani joint preparation, 4077–4079,
4078f, 4079f
Infection. See also specific infections
anesthesia and, regional, 2112
Revision Agility TAA, 4119–4122
complications of, 4122
diagnostic studies for, 4119
differential diagnosis of, 4119
imaging of, 4119, 4119f
implant reinsertion and, 4120–4121,
4121f
implant removal and, 4120, 4120f
nonoperative management of, 4119
outcomes of, 4122
patient history of, 4119
pears and pitfalls of, 4122, 4122f
physical findings for, 4119
nonoperative management of, 4119
postoperative care of, 4122
surgical management of, 4119–4120
thoracic spine
nonoperative management of, 4629
pathogenesis of, 4629
Inferior capsular shift, 3073–3083
anterior, 3080–3082, 3081f, 3082f
complications, 3083, 3083f
outcomes, 3083
pears and pitfalls of, 3082–3083
postoperative care, 3083
Inferior glenohumeral ligament (IGHL),
3044–3045
Inflammatory arthritis. See also Arthritis
MCP joint and
anatomy of, 2729–2730, 2729f
definition of, 2729
diagnostic studies for, 2732
anterior, 2732, 2732f
differential diagnosis of, 2731
exposure for, 2732, 2732f
tensor tendon centralization for,
2729–2735
imaging of, 2732
natural history of, 2730–2731
nonoperative management of, 2731,
2731f
pathogenesis of, 2730, 2730f
patient history of, 2731
physical findings of, 2731
surgical management of, 2731–2732,
2732f
Inflammatory arthritis (continued)
syndromes with, 2729–2735
syndrome for, techniques of, 2733, 2733/3

tendon realignment for, 2733, 2733/3
Informed consent, anesthesia and, for upper extremity surgery, 2110
Infrapatellar contracture syndrome (IPCS), 420
Infraspinatus capsular tenodesis, open
Infrapatellar contracture syndrome (IPCS), 420
Inguinal canal, 1856
Initial assessment, musculoskeletal lesion, 1704–1705
Injection injuries, hand
Intracapsular fractures, 4424–4431
Infrapatellar contracture syndrome (IPCS), 420
Intercondylar fractures
diagnostic studies, 3329
imaging, 3329, 3329/
ORIF, 3329–3335
complications of, 3334
intercondylar fracture and, 3332–3333, 3332/
physical findings, 3329
shortening and, 3333, 3334/
surgical management, 3329–3330, 3330/
Interdigital nerve, uniportal endoscopic
Intermetacarpal ligament, sagittal band
Interference screw fixation
Interbody fusion
lumbar, anterior, 4634–4644, 4639/
640, 4640/4
for spondylolisthesis, high-grade, 1480–1487
Interosseous wire fixation, phalangeal
fracture, extra-articular, 2386, 2386/
Interphalangeal joints
septic arthritis in aspiration and, 2919
surgical drainage of, 2920, 2920/
surgical approach to, 2083, 2083/
Interposition arthroplasty
elevator, traumatic conditions of, 3453–3458, 3453/3458
first MTP capsular interpositional
arthroplasty, 3609–3610, 3610/
PRC with, 2806, 2806/
Interspinous wiring, posterior cervical
fusion, 4577–4580, 4577/4578, 4578/
4579/8, 4580/8
Intra-articular débridement, shoulder
Intra-articular malunion (IAM), 2452
Intra-articular surgery
FAI, 881–883, 882/8, 883/
parapatellar arthroscopy, medially with, revision TKA and, 997–998, 998/
Intramedullary alignment, INBONE™ total ankle arthroplasty with, 4076–4077, 4076/7
Intramedullary fixation
antero-posterior, of humeral shaft fractures, 3236–3240, 3237/7, 3238/
of clavicle fractures, 3181–3190
butterfly fragment management and, 3188, 3188/
clavicle preparation and, 3185, 3185/
complications of, 3190
dissection in, 3184, 3184/
fracture compression and, 3187, 3187/
fracture reduction and, 3186, 3186/
incision in, 3185, 3184/
outcomes of, 3190
pears and pitfalls of, 3189
pin insertion and, 3186, 3186/
pin positioning, final and, 3187, 3187/
pin removal in, 3189, 3189/
postoperative care of, 3189, 3189/
wound closure and, 3188, 3188/
closed, radial neck fracture, pediatric, 1070–1071, 1070/
1071, 1071/
1072, 1072/
forearm shaft fracture, pediatric, 1026–1034
anatomy of, 1026, 1026/
closure/dressing/splinting/aftercare for, 1032, 1032/
complications of, 1034
definition of, 1026
diagnostic studies for, 1027–1028, 1028/
differential diagnosis of, 1028
distal radial entry point for, 1029–1030, 1029/
1030, 1030/
final rotation/cutting of radial nerve for, 1032
imaging of, 1027–1028, 1027/
natural history of, 1026
nonoperative management of, 1028
outcomes of, 1034
pathogenesis of, 1026
patient history and, 1026–1027
pears and pitfalls of, 1030
physical findings and, 1026–1027
postoperative care of, 1033
proximal ulna entry point for, 1032, 1032/
surgical management of, 1028–1029, 1029/
techniques for, 1029–1033, 1029/
3216/
of humeral shaft fractures, 3234–3242
complications of, 3242
outcomes of, 3242

INDEX
pears and pitfalls of, 3241
postoperative care of, 3241–3242
nail, elastic, tibial fractures, pediatric, 1126–1127, 1126f, 1127f
of proximal humerus fractures, 3209–3216
complications and, 3216
entry site reaming and, 3214
fragment reduction and, 3213, 3213f
guide wire placement and, 3213–3214
interlocking screw, 3214–3215, 3215f
K-wire placement and, 3212, 3212f
nail insertion and, 3214, 3214f
pears and pitfalls in, 3215–3216
postoperative care for, 3216
ailure, 3215
retrograde, of humeral shaft fractures, 3236–3237, 3240–3241
Intramedullary nailing (IMN).
See also specific types of intramedullary nailing
definition, 642
screw placement with tibiotalocaneal arthrosis, 4167–4168, 4168f
tibial, 642–658
complications of, 658
distal metaphyseal, fractures, 656, 657f
outcomes of, 657
pears and pitfalls of, 657
postoperative care of, 657
proximal metaphyseal, fractures, 653–656, 654f, 655f, 656f
surgical approach to, 647–653, 647f, 648f, 649f, 650f, 651f, 652f, 653f
Intramedullary reduction
closed, radial neck fracture, pediatric, 1070–1071, 1070f, 1071f, 1072f, 1073f
radial neck fracture, pediatric, 1066–1074
complications of, 1073, 1073f
outcomes of, 1073
Intramedullary rod insertion
long, knee arthrodesis and, 1009–1010, 1009f
short, knee arthrodesis and, 1010
IPCS. See Infrapatellar contracture syndrome
Ischial osteotomy, 864, 865f
anterior, 1562, 1562f
Ischiurn, TIO, 1546–1547, 1547f
Isograft, 2941

J
Johnson & Johnson Gateway. See Ultrapro hernia system
Joint contractures. See also Contractures
MCP
release of post-traumatic, 2972–2982
release of post-traumatic, techniques for, 2973–2977, 2975f, 2977f
PIP
release of post-traumatic, 2972–2982
release of post-traumatic, techniques for, 2978–2980, 2978f, 2979f, 2980f
Jones fracture
anatomy, ORIF and, 734, 736f
ORIF of, 734–739
anatomy and, 734, 736f
complications of, 739
definition of, 734, 735f
diagnostic studies for, 734
differential diagnosis of, 734
imaging for, 734
inlay bone grafting without internal
fixation for, 738, 738f
natural history and, 734
nonoperative management of, 734–735
outcomes of, 739
pathogenesis and, 734
patient history and, 734
pears and pitfalls of, 739
percutaneous intramedullary screw
fixation for, 736, 736f, 737f
percutaneous intramedullary screw
fixation for, with bone graft, 738
physical findings and, 734
postoperative care of, 739
surgical management of, 735–736, 736f
Jones procedure, cavovarus, 3889, 3890f
Jones procedure, modified
Kapandji technique, percutaneous pinning of
distal radius fracture, 2165–2166, 2165f
Kienböck disease
anatomy, 2293, 2295f
osteochondral, 2305–2306, 2305f
complications of, 2312
definition, 2305
diagnostic studies, 2296–2297
differential diagnosis, 2298
dorsal distal radius' vascular anatomy,
differential diagnosis of, 2304
surgical management for, 2298–2299, 2299f
volar approach to, 2299, 2300f
surgical management, 2298–2299, 2299f,
2306–2311, 2306f–2311f
capitate shortening osteotomy, 2310–2311, 2310f, 2311f
vascular bundle, implantation, 2309–2310, 2310f
vascularized grafts, 2307–2309,
2307f–2309f
Kirschner wire, extension osteotomy with, 2768
Kirschner wire fixation
multiple, 1579, 1580f
percutaneous, phalangeal fracture,
extra-articular, 2384–2385, 2385f,
2386f
phalangeal fracture, extra-articular,
2384–2385, 2385f, 2386f
scaphoid nonunion, 2271
wrist arthrodesis, limited using,
2809–2810, 2809f
Knee, 1929, 1929f. See also Congenital
dislocation of knee
anatomy, 413
TKA, cemented and, 918, 919f
TKA, revision with tibial bone loss and,
950, 950f
TKA, using navigation and, 933
UKA and, 895
vascular, 950, 950f
arthroscopic lateral release, 422–425
complications of, 425
outcomes of, 424–425
pears and pitfalls of, 424
postoperative care of, 424
techniques for, 424, 424f
AVN, 329–340
anatomy of, 329, 330f
complications of, 340
definition of, 329, 329f
diagnostic studies for, 333
differential diagnosis of, 333
drilling of, 337–338, 337f, 338f
imaging of, 333
natural history of, 331, 332f
nonoperative management of, 333
outcomes of, 340, 340f
pathogenesis of, 331
patient history of, 332
pears and pitfalls of, 339
physical findings of, 332
postoperative care of, 339
surgical management of, 333–335, 335f
exposure, TKA, cemented and, 922,
922f, 923f
loss of motion, 413–420
anatomy and, 413
arthroscopic evaluation for, 415–417,
416f
complications and, 420
definition of, 413
diagnostic studies for, 414
differential diagnosis and, 414
imaging and, 414
natural history and, 413
nonoperative management for, 414, 415f
open surgical treatment for, 417–418,
417f, 418f
outcomes for, 419–420
pathogenesis of, 413, 413f, 414f
physical findings and, 413–414
postoperative care for, 418–419
surgical management for, 414–415
MCL injuries, repair of acute/chronic,
375–380
ODC, 329–340
anatomy of, 329, 330f
bone grafting of, 336–337, 337f
complications of, 340
definition of, 329, 329f
diagnostic studies, 332–333
differential diagnosis of, 333
imaging of, 332–333, 332f
natural history of, 331
nonoperative management, 333
outcomes, 339

INDEX I-45
Knee (continued)
pathogenesis of, 329–331, 330f
patient history of, 331–332
pearls and pitfalls of, 339
physical findings of, 331–332
postoperative care of, 339
primary fixation of, 336–337, 337f
surgical management of, 333–334, 334f
transchondral drilling of intact, 335–336, 335f
pain, 422
anatomy and, 422
definition of, 422
diagnostic studies for, 422
differential diagnosis of, 422–423
imaging of, 422, 423f
natural history of, 422
nonoperative management of, 423
patient history of, 422
physical findings of, 422
surgical management of, 423, 423f
proximal tibia, 1953, 1958, 1958

Knee arthrodesis, 1004–1015
anatomy and, 1004, 1004f
bone loss, strategy for substantial, 1013–1014, 1013f
complications, 1015
definition, 1004
diagnostic studies, 1005
differential diagnosis, 1005
external fixation, 1010–1011, 1011f, 1012f
imaging, 1005, 1005f
intramedullary rod insertion and long, 1009, 1009f
short, 1010
natural history, 1004
nonoperative management, 1005
outcomes, 1015
pathogenesis, 1004
patient history, 1005
pearls and pitfalls, 1014
physical findings, 1005
plating, 1012, 1012f
postoperative care, 1014–1015
surgical management, 1005–1008
approach to, 1008, 1008f
hardware considerations for, 1006–2764
positioning for, 1008, 1008f
preoperative planning for, 1006, 1006f

Knee arthroscopy, 248–255
anatomy, 248–249, 248f
complications, 253
definition, 248
diagnostic, 251–254, 251f, 252f, 253f, 254f
pearls and pitfalls, 254–255
portal placement for, 250–251, 250f
postoperative care, 255
surgical management, 249, 249f

Knee injuries, multiple-ligament anatomy of, 392
bone-ACL reconstruction for, 395
classification of, 393, 393f
complications of, 400
definition of, 392
diagnostic studies for, 393
differential diagnosis of, 393
imaging of, 393
management of, 392–401
multiligament reconstructions for, 398–399
natural history of, 392
nonoperative management of, 393–394
outcomes of, 400
patient history of, 393
PCL reconstruction, double-bundle for, 396–397, 397f
pearls and pitfalls of, 399–400
physical findings of, 393
postoperative management of, 400
surgical management of, 394–395
two-tailed reconstruction, modified for postero-lateral corner, 397–398

Kocher approach
ORIF, of radial head/neck fractures, 3348, 3348f
radial head replacement, 3350, 3350f
Kocher-Langenbeck approach, ORIF, acetabular posterior wall, 506–508, 506f, 507f
Krackow suture technique, modified, AT
repair, open, 4370–4371, 4371f
K-wires
distal radius fracture fixation, with/ without external fixation, 2162–2170
complications for, 2170
outcomes for, 2170
pears and pitfalls in, 2169
postoperative care for, 2169–2170
phalangeal condylar fracture, 2396–2399, 2397f, 2398f
coronal shear, 2399
triplane, 2400, 2400f

Kyphectomy, in spina bifida, 1424–1430
closure for, 1424–1430
complications and, 1430
decancellation and, 1427, 1428f
horizontal resection for, 1428, 1428f
incision and lumbar dissection for, 1426–1427, 1426f
lower extremity hyperfusion and, 1429
outcomes and, 1430
pears and pitfalls for, 1430
pedicle screw placement for, 1427, 1427f
postoperative care for, 1430
rod placement for, 1428–1429, 1428f, 1429f
thoracic dissection for, 1427

Kyphosis
anatomy, 1424, 1424f
definition, 1427–1428
surgical management, 1425–1426, 1425f

L
Laboratory studies, musculoskeletal lesion, 1704
Labral, Bankart reconstruction, 3119
Labral débridement. See also Débridement
hip, arthroscopy for soft tissue pathology of, 208, 208f
Labral inspection, anterior, 3119
Labral repair, 3121
arthroscopic treatment and, 27–28, 27f
hip, arthroscopy for soft tissue pathology of, 209–210, 209f
Labral repair, open posterior, 3092
Labral support (shell) procedure
anatomy and, 1532
definition, 1532, 1532f

Perthes disease, 1532–1539
arthrography and, 1535, 1535f
complications of, 1539
deep dissection for, 1536
graft collection for, 1536, 1536f, 1537f
incision/superficial dissection for, 1536, 1536f
outcomes of, 1538, 1538f
pears and pitfalls of, 1538
postoperative care for, 1538
shelf creation in, 1537, 1537f
trough creation for, 1536, 1536f, 1537f
Labrum, 3045
Lag screw fixation, phalangeal fractures, extra-articular, 2387–2388, 2387f, 2388f
Lag screws, phalangeal condylar fracture, triplane, 2400, 2400f
Laminoplasty, cervical, 4568–4575
Lapidus procedure
anatomy, 3559
complications of, 3563
definition, 3559
diagnostic studies, 3559–3560
differential diagnosis, 3560
hallux valgus correction, revision, 3572–3573, 3572f, 3573f
imaging, 3559–3560
natural history, 3559
nonoperative management, 3560
outcomes of, 3563
pathogenesis, 3559
patient history, 3559
pears and pitfalls of, 3563
physical findings, 3559
postoperative care of, 3563
surgical management, 3560
positioning, 3560
preoperative planning, 3560
techniques, 3560–3563
bone grafting, 3562, 3562f
closure, 3563
distal soft tissue procedure, 3561, 3561f
intraoperative radiographs, 3562, 3562f
metatarsus primus varus correction, 3560–3561, 3561f
stabilization, 3561–3562, 3562f
tarsometatarsal joint preparation, 3560–3561, 3561f

Latarjet procedure, for glenoid bone loss
instability with, 3100–3106
complications of, 3106
coracoid fixation and, 3104–3105, 3104f, 3105f
coracoid osteotomy/preparation and, 3102–3103, 3102f, 3103f
glenoid exposure and, 3103–3104, 3103f, 3104f
glenoid preparation and, 3104–3105, 3104f, 3105f
outcomes of, 3106
pears and pitfalls of, 3105, 3105f
postoperative care of, 3106

Lateral ankle injuries, 4301
anatomy, 4301, 4301f
diagnostic studies, 4302, 4302f
differential diagnosis, 4302
imaging, 4302, 4302f
natural history, 4301
nonoperative management, 4302–4303
pathogenesis, 4301
patient history, 4301–4302, 4302f
physical findings, 4301–4302, 4302f
surgical management, 4302f, 4303f
Lateral ankle instability, chronic anatomy, 4340–4346.

Lateral ankle instability repair definition, 4340.

Lateral ankle ligament pathology, 4340–4345.

Lateral ankle ligament sprains, 4331.

natural history, 4332.

imaging, 4332.

physical findings, 4332.

postoperative care of, 4332.

natural history of, 4332.

pathogenesis of, 4332.

physical findings for, 4332.

surgical management of, 4332.

natural history of, 4332–4333.

pathogenesis of, 4332.

surgical management of, 4332–4333.

Lateral ankle reconstruction.

outcomes of, 4329–4330.

postoperative care of, 4329.

natural history of, 4331–4332.

nonoperative management of, 4332.

pathogenesis of, 4332.

patient history of, 4332.

physical findings for, 4332.

surgical management of, 4332–4333.

postoperative care of, 4332–4333.

Lateral ankle instability repair:

postoperative care of, 4329.

natural history of, 4331.

pathogenesis of, 4332.

patient history of, 4332.

physical findings for, 4332.

surgical management of, 4332.

natural history of, 4332–4333.

postoperative care of, 4332–4333.

postoperative care of, 3399.

split anconeus fascia transfer for,

3395–3397.

natural history of, 3399.

nonoperative management of, 3399.

pathogenesis of, 3399.

patient history of, 3399.

physical findings for, 3399.

surgical management of, 3399.

natural history of, 3399–3406.

postoperative care of, 3399.

postoperative care of, 3399.

natural history of, 3409.

pathogenesis of, 3409.

patient history of, 3409.

physical Findings for, 3409.

surgical approach for, 3409.

Lateral column lengthening anatomy, 3823.

complications of, 3831.

postoperative care of, 3823–3824.

natural history, 3823.

nonoperative management, 3824.

pathogenesis of, 3833.

natural history of, 3835–3836.

pathogenesis for, 3835–3836.

positioning, 3835–3836.

preoperative planning, 3824, 3824.

Lateral epicondylitis (LE), 184.

See also Epicondylitis arthroscopic treatment of, 2638–2642.

complications for, 2642.

outcomes for, 2642.

postoperative care for, 2642.

natural history, 184, 2638.

nonoperative management, 186, 2638.

natural history, 184, 184.

postoperative care for, 2642.

natural history, 184, 2638.

nonoperative management, 186, 2638.

open treatment of, 2638–2642.

outcomes for, 2642.

natural history, 185, 2638.

natural history, 185.

pathogenesis, 2638.

postoperative care for, 2642.

natural history, 185, 2638.

natural history, 185.

pathogenesis, 2638.

postoperative care for, 2642.

natural history, 185, 2638.

natural history, 185.

pathogenesis, 2638.

postoperative care for, 2642.

natural history, 185, 2638.

natural history, 185.

pathogenesis, 2638.

postoperative care for, 2642.

natural history, 185, 2638.

natural history, 185.

pathogenesis, 2638.

postoperative care for, 2642.

natural history, 185, 2638.

natural history, 185.

pathogenesis, 2638.

postoperative care for, 2642.

natural history, 185, 2638.

natural history, 185.

pathogenesis, 2638.

postoperative care for, 2642.

natural history, 185, 2638.

natural history, 185.

pathogenesis, 2638.

postoperative care for, 2642.

natural history, 185, 2638.

natural history, 185.

pathogenesis, 2638.

postoperative care for, 2642.

natural history, 185, 2638.

natural history, 185.

pathogenesis, 2638.

postoperative care for, 2642.

natural history, 185, 2638.
INDEX

Lunotriquetral interosseous ligament (LTIL) anatomy, 2501–2502
augmentation, 2501–2512
outcomes of, 2512
pains and pitfalls of, 2511
postoperative care of, 2512
diagnostic studies, 2503
imaging, 2503
injuries, 2501, 2501f, 2502f
differential diagnosis, 2503
natural history, 2502
nonoperative management, 2503–2504
pathogenesis, 2502, 2503t
patient history, 2502–2503
physical findings, 2502–2503
surgical management, 2504
kinematics, 2501–2502
reconstruction, extensor carpi ulnaris strip, distally based with, 2508–2510, 2508f, 2509f, 2510f
repair, 2501–2512
direct, 2504–2507, 2504f, 2505f, 2506f, 2507f
outcomes of, 2512
pains and pitfalls of, 2511
postoperative care of, 2512
Lunotriquetral ligament (L.TIL) disruptions anatomy and, 2459
arthroscopic débridement, 2463–2464, 2463f, 2464f
arthroscopic evaluation, 2459–2466
complications of, 2466
outcomes of, 2465–2466
pains and pitfalls of, 2465
postoperative care of, 2465
techniques for, 2462–2463, 2462f
arthroscopic radial styloidectomy, 2464
arthroscopic RASL procedure, 2464–2465, 2465f
arthroscopic treatment, 2459–2466
complications of, 2466
outcomes of, 2465–2466
pains and pitfalls of, 2465
postoperative care of, 2465
definition, 2459
diagnostic studies, 2460
differential diagnosis, 2460–2461
fusion, 2464–2465, 2465f
imaging, 2460
natural history, 2459–2460
nonoperative management, 2461
pathogenesis, 2459
patient history, 2460
physical findings, 2460
surgical management, 2461–2462, 2462f
Lymphangioma, 2992–2993
Lymphatics, axial space, 1825
Lymph nodes, shoulder girdle and, 1770

M
Maestro prosthesis, 2824–2828, 2825f, 2826f, 2827f, 2828f, 2829f
Magerl method, transarticular screw fixation, 4590–4591f
Magnetic resonance imaging (MRI)
AKA, 2061, 2062f
axillary space, 1826, 1827f
BKA, 2067, 2068f
distal humerus, 1808–1809, 1809f
gluteus maximus, 1876
hip hemiarthroplasty, 784
hip joint, hip disarticulation, 1911
musculoskeletal lesion, 1701–1702, 1702f
PAO, 863
pelvic, 1838, 1858f
hemipelvectomy and, 1894
pooriletal space, 2018, 2019f
proximal humerus, 1796f, 1797
resections for, 1787, 1788f
sartorial canal tumor, 2028, 2029f
soleus muscle, 2023, 2024f
space sarcomas, 2031
stabilization osteotomy, upper, 907
Malignant bone tumors, 1706–1715
chondrosarcomas, 1709–1711
Ewing sarcoma, 1711–1715
GCT, 1715
Mires scoring system, 800, 800
Malignant fibrous histiocytoma (MFH), 1717f
histologic pattern, 1717
surgical management, 1716–1717
telangiectatic transformation, 1717
Malignant lesions anatomy and, 1788f
posterior
surgical management of, 4105, 4105
postoperative care of, 4109
pearls and pitfalls of, 4109
outcomes of, 4109
open repair of lateral, 4106, 4106
open repair of acute medial, 4105, 4105f
open repair of late medial, 4107–4109, 4107f
open repair of lateral, 4106, 4106f
outcomes of, 4109
patient history of, 4104
pains and pitfalls of, 4109
physical findings for, 4104
postoperative care of, 4109
surgical management of, 4105, 4105f
Malleolar medial fractures, pediatric of, 1140, 1140f
ORIF of ankle and, 691–692, 692f
posterior fixation of, 693, 693f
ORIF of ankle and, 693, 693f
Malunions, 2452. See also specific malunions
Malunited ankle, percutaneous osteotomy for, 3995–3999
background, 3995
complications of, 3999
outcomes of, 3999, 3999f
pains and pitfalls of, 3998
surgical management, 3995–3998
external fixation application, 3998, 3998f
positioning, 3995
technique, 3995–3997, 3996f, 3997f
Marcaine, wrist denervation, 2791
“Mason-Allen”-type construct, rotator cuff repair, double-row, 84–87, 85f, 86f, 87f
Matrix production, musculoskeletal lesion, 1705
Mau osteotomy definition, 3536
hallux valgus correction using, 3536–3544
closure and, 3542, 3542f
complication of, 3543, 3543f, 3544f
medial capsulorrhaphy and, 3540, 3540f
MTP joint release, first and, 3539, 3539f
outcomes of, 3542–3543
pains and pitfalls of, 3542
postoperative care of, 3542
complications of, 3543

MBD. See Metastatic bone disease
MCL. See Medial collateral ligament
MCP joint. See Metacarpophalangeal joint
Mechanical reconstruction humeral, 1821, 1823f
MBD and, 1819, 1821f
MBD, pelvic, 1887–1888, 1887f
Medial antebrachial cutaneous nerve, 1808
Medial closing wedge osteotomy, supramalleolar osteotomy with, 3973, 3973f, 3974f
Medial collateral ligament (MCL) anatomy, 375
complex, 3052
injuries, knee
anatomy and, 375
definition of, 375
diagnostic studies for, 376
differential diagnosis of, 376
imaging of, 376, 376f
isolated chronic, allograft reconstruction of, 378–379, 379f
isolated chronic, autograft reconstruction of, 378, 378f
mid-medial approach to, incision/dissection for, 377
natural history of, 375
nonoperative management of, 376–377
pathogenesis of, 375
patient history of, 375–376
physical findings of, 375–376
repair of acute/chronic, 375–380
surgical management of, 377
tibial-sided isolated, acute repair of, 377, 377f
Medial column osteotomy, cavus foot surgical treatment and, 1644–1645, 1644f, 1645f
Medial displacement calcaneal osteotomy. See also Calcaneal osteotomy
PTTD, stage II, 3814–3821
complications of, 3821
outcomes of, 3821
pains and pitfalls of, 3821
postoperative care of, 3821
techniques, 3817, 3817f
Medial epicondyle. See also Epicondyle anatomy, 263f.

Extraction of, from elbow joint, 1045

Medial epicondylectomy, cubital tunnel release, in situ and, 2681, 2681f

Medial epicondyle fractures, pediatric, ORIF, 1042–1045

anatomy of, 1042, 1042f

anatomical screw for, 1044, 1044f

complications of, 1045

definition of, 1042

diagnostic studies for, 1043

differential diagnosis of, 1043

extraction of medial epicondyle from elbow joint and, 1045

imaging for, 1045

natural history of, 1042

nonoperative management of, 1043

outcomes of, 1045

pathogenesis of, 1042, 1042f

patient history and, 1042–1043

physical findings and, 1042–1043

postoperative care for, 1045

surgical management of, 1043, 1043f

suture fixation for, 1045

techniques for, 1044–1045

Medial epicondylitis

definition, 2634

diagnostic studies, 2634

differential diagnosis, 2634

fasciectomy, 2635–2636, 2635f, 2636f

imaging, 2634

natural history, 2634

nonoperative management, 2634

open debridement of, 2634–2637

complications for, 2637

outcomes for, 2637

pearls and pitfalls for, 2637

postoperative care for, 2637

ostectomy, partial, 2635–2636, 2635f, 2636f

pathogenesis, 2634

patient history, 2634

physical findings, 2634

surgical management, 2634–2635, 2635f

Medial fascia, exposing, elbow contracture release and, extrinsic, 3415, 3415f

Medial femoral circumflex artery

(MFCA), 877

Medial gastrocnemius flap, proximal tibia, reconstruction of, 1807

Medial malleolar osteotomy, structural

Medial gastrocnemius flap, proximal tibia, 1042

Medial femoral circumflex artery

(MFCA), 877

Medial femoral epicondyle fractures, pediatric, ORIF, 1042–1045

anatomy of, 1042, 1042f

cannulated screw for, 1044, 1044f

complications of, 1045

definition of, 1042

diagnostic studies for, 1043

differential diagnosis of, 1043

extraction of medial epicondyle from elbow joint and, 1045

imaging for, 1045

natural history of, 1042

nonoperative management of, 1043

outcomes of, 1045

pathogenesis of, 1042, 1042f

patient history and, 1042–1043

physical findings and, 1042–1043

postoperative care for, 1045

surgical management of, 1043, 1043f

suture fixation for, 1045

techniques for, 1044–1045

Medial epicondylitis

definition, 2634

diagnostic studies, 2634

differential diagnosis, 2634

fasciectomy, 2635–2636, 2635f, 2636f

imaging, 2634

natural history, 2634

nonoperative management, 2634

open debridement of, 2634–2637

complications for, 2637

outcomes for, 2637

pearls and pitfalls for, 2637

postoperative care for, 2637

ostectomy, partial, 2635–2636, 2635f, 2636f

pathogenesis, 2634

patient history, 2634

physical findings, 2634

surgical management, 2634–2635, 2635f

Medial gastrocnemius muscle group, 1461–1471

ankle arthroplasty, 1465, 1465f

bone grafting, 1468–1469, 1469f

complications of, 1471

derive insertion, 1468

evidence case, 1469, 1470f

indication, 1465, 1465f

indication for, 1464

outcomes, 1471

nail placement, 1467, 1474f

nail selection, 1466–1467

outcomes for, 1471

pearls and pitfalls of, 1470–1471, 1471f

plantar incision, 1466, 1466f

positioning, 1464

postoperative care for, 1471

preoperative planning, 1464, 1464f

Melanoma of hand

anatomy, 268

compli9cations of, 3009

diagnostic studies, 3005–3006

differential diagnosis, 3006

imaging, 3005–3006

natural history, 3005

nonoperative management, 3006

outcomes of, 3009

pathogenesis, 3004, 3005f

patient history, 3005

pearls and pitfalls of, 3008

physical findings, 3005

postoperative care of, 3009

surgical management, 3006–3008

approach, 3008

coverage and reconstruction, 3008

cutaneous melanoma, 3007, 3007f

nail matrix melanoma, 3007–3009, 3008f

positioning, 3008

preoperative planning, 3008

Meniscal cyst decompression, arthroscopic meniscectomy, partial, 271

Meniscal injuries

nonoperative management, 268

pathogenesis, 266, 266f

surgical management, 268–269, 268f, 269f

Meniscal repair, 274–282

all-inside fixation technique, 279, 279f

all-inside suture fixation technique, 280, 280f

anatomy, 274, 274f

biological augmentation methods, 280–281, 281f

complications, 282

definition, 274

diagnostic studies, 275–276

differential diagnosis, 276

imaging, 275–276, 275f

inside-out technique, 277, 278f

natural history, 274

nonoperative management, 276

outcomes, 282

outside-in technique, 278, 279f

pathogenesis, 274

patient history, 274–275

pearls and pitfalls, 281

physical findings, 274–275

postoperative care, 281–282

surgical management, 276–277, 276f, 277f

Meniscal tears

bucket-handle, arthroscopic meniscectomy, partial, 270–271, 270f

conventional, arthroscopic meniscectomy, partial, 269, 270f

repair of, 274–282

Meniscus transplant, 284–294

anatomy, 284, 284f

complications, 294

definition, 284

diagnostic studies, 285–286

differential diagnosis, 286

imaging, 285–286, 285f

lateral meniscus and, delivery/fxation of, 289–290, 289f

lateral meniscus approach for, 288, 288f

lateral meniscus graft preparation for, 287, 287f

medial meniscus and, delivery/fxation of, 292–293, 292f

medial meniscus approach for, 291–292, 291f

medial meniscus graft preparation for, 290–291, 290f

natural history, 284–285

nonoperative management, 286

outcomes, 293–294

pathogenesis, 284

patient history, 285

pearls and pitfalls, 293

physical findings, 285

postoperative care, 293

surgical management, 286–287, 286f, 287f

tibial preparation for, 288, 288f, 291–292, 291f
Meniscectomy. See Arthroscopic procedures
Menisci, anatomy, 263–266, 264f, 265f
Meniscoplasty, discoid lateral meniscus,
Metacarpals
Metacarpal malunion
Metacarpal head fractures, ORIF, 2375, 2376–2377,
Mepivacaine, toxicity, 2112
Meniscus. See also Discoid lateral meniscus,
pediatric
anatomy, 284, 284f
discoid lateral, arthroscopic partial excision of,
 scholarly preparation for, 287, 287f
meniscal transplant and, 288–290, 288f, 289f, 290f
medial
 scholarly preparation for, 290–291, 290f
meniscal transplant and, 291–293, 291f, 292f
Mepivacaine, toxicity, 2112
Metacarpal fractures
anatomy, 2365, 2365f
closed reduction and pinning, 2369–2371, 2370f, 2371f
 definition, 2365
diagnostic studies, 2366
differential diagnosis, 2366
imaging, 2366
natural history, 2365–2366
nonoperative management, 2366, 2366f
operative treatment, 2365–2377
 complications of, 2377
 outcomes of, 2377
 pears and pitfalls of, 2376–2377
postoperative care of, 2377
ORIF, 2371–2374, 2372f, 2373f, 2374f
pathogenesis, 2365
patient history, 2366
physical findings, 2366
surgical management, 2366–2369, 2367f, 2368f, 2369f
Metacarpal head fractures, ORIF, 2375, 2375f, 2376f
Metacarpal malunion
anatomy and, 2452, 2452f
definition, 2452
diagnostic studies, 2453
differential diagnosis, 2453
imaging, 2453
natural history, 2452
nonoperative management, 2453
osteofromies for, 2452–2458
 complete, for rotational and angular malunions, 2456, 2456f
 complications of, 2458
condylar advancement, 2457, 2457f
 incomplete, for angular correction, 2454–2456, 2455f
 outcomes of, 2458
 pears and pitfalls of, 2458
postoperative care of, 2458
pathogenesis, 2452f
 patient history, 2452
 physical findings, 2452
 surgical management, 2453, 2454f
Metacarpals
 anatomy, 2452, 2452f
 enchondroma, 3031
 surgical approach to, 2084, 2084f

Metacarpophalangeal (MCP) joint
anatomy, 2949–2955, 2959f, 2972–2930, 2972f, 2973f
arthrosis, 2972–2973
nonoperative management of, 2973–2974
pathogenesis of, 2972–2973
surgical management of, 2973–2974, 2974f
arthrodesis, 2972–2974
 complications of, 2974
 diagnostic studies for, 2973
 differential diagnosis of, 2973
 fixation methods for, additional, 2972
 imaging for, 2973
 outcomes of, 2974
 patient history and, 2973
 pears and pitfalls of, 2974
 physical findings for, 2973
 plate fixation for, 2972, 2976f
postoperative care of, 2974
 screw fixation, compression for, 2973,
 techniques for, 2975–2979, 2979f,
 2979f, 2979f, 2979f
 arthroplasty, silicone implant, 2978–2980, 2978f, 2979f
 complications of, 2978
 diagnostic studies for, 2978
 differential diagnosis of, 2978
 dislocation, 2979
 imaging, 2978, 2979f
 index through small finger, arthrodesis for,
 2979, 2979f, 2979f
 extensor tendon centralization for,
 2979–2983
 inflammatory arthritis and,
 anatomy of, 2979–2983, 2979f
 definition of, 2979
 diagnostic studies for, 2983
 differential diagnosis of, 2983
 exposure for, 2983, 2983f
 extensor tendon centralization for,
 2983–2989
 imaging of, 2983
 natural history of, 2983–2989
 nonoperative management of, 2983, 2984f
 pathogenesis of, 2983–2989
 primary repair of, 2983, 2983f
 sagittal band reconstruction to deep
 transverse intermetacarpal ligament
 and, 2983, 2984f
 surgical management of, 2984–2989
 surface replacement arthroplasty, 2984–2987
 complications of, 2984
 outcomes of, 2985–2987
 pears and pitfalls of, 2985
 postoperative care of, 2985
 techniques for, 2985–2987, 2987f, 2988f
 surgical approach to, 2985–2987, 2987f
 preoperative planning, 2984–2985
approach, 2986
positioning, 2985
thumb arthrodesis for, 2979–2981, 2979f,
 2979f, 2979f, 2979f,
 thumb-in-palm deformity and, 1363–1364, 1364f
Metaizeau technique, radial neck fracture,
pediatric, 1070–1071, 1070f, 1071f,
1072f, 1073f
Metaphyseal comminution, distal radius
 styloid fracture arthroscopic reduction/fixation and, 2178–2180,
2178f, 2180f
Metaphyseal cone augmentation, TKA,
revision with tibial bone loss and, 957–958, 957f
Metaphyseal fractures, fixation, micrometric
 blade plate technique for,
2389–2390, 2389f, 2390f
Metastatic bone disease (MBD)
bioysis, 1750–1751
distal femur, surgical management of,
2041–2043, 2041f, 2042f, 2043f,
2044f, 2045f
femoral diaphysis, surgical management of, 3659–3660, 3659f, 3660f, imaging of, 3657
femoral lesion, 2034, 2034f, 2040f, 2041f
femoral type III metastases
humeral, 1819–1821
pall and pitfalls, 1824
type I metastases
humeral, 1818–1819, 1818f, 1820f
pall and pitfalls, 1824
Metatarsal anatomy, 3577
lengthening
anatomy and, 3577
definition of, 3577
hallux valgus surgery, revision for, 3577–3583
proximal, opening-wedge osteotomy, 3553–3557, 3556f
revision first MTP joint arthrodesis and distal first, 3632, 3652f
shortening, pathogenesis of, 3577
Metatarsalgia
diagnostic studies, 3578, 3578f
differential diagnosis, 3578
imaging, 3578, 3578f
natural history, 3577
nonoperative management, 3578
patient history, 3577, 3577f
physical findings, 3577, 3577f
surgical management, 3578, 3579f
Metatarsal head
MTP joint arthrodesis, first and, 3638, 3638f
reaming, 3658, 3658f, 3659f
surface measurements, HemiCap and, 3661, 3661f
surface preparation, HemiCap and, 3617, 3617f
Metatarsal head resection, lesser, 3738–3740, 3739f
Metatarsal osteotomy
distal horizontal, 3720, 3720f
dorsiflexion first, 3906, 3906f
Ludloff, hallux valgus correction, revision, 3572–3573, 3572f, 3573f
proximal chevron, 3546, 3546f
Metatarsal shaft, osteotomy of oblique, 3732–3734, 3733f, 3734f
Metatarsophalangeal (MTP) joint, 3650.
See also First MTP joint arthrodesis; Hallux rigidus; Revision first MTP joint arthrodesis
anatomy, 3623, 3623f
angular deformity, isolated, 3722
diagnostic studies, 3623
first
anatomy of, 3627, 3627f, 3643, 3643f
deformity, 3656–3657
diagnostic studies, 3627, 3627f
imaging of, 3627
Mau osteotomy and lateral release of, 3539, 3539f
natural history, 3627
nonoperative management of, 3627
pathogenesis, 3627
patient history, 3627
physical findings, 3627
surgical management of, 3627
first, bone-block distraction complications of, 3664
contouring graft and, 3660, 3660f, 3661f
definition of, 3656
diagnostic studies for, 3657
graft insertion/fixation and, 3661, 3661f, 3662f
iliac crest bone block and, harvesting, 3659–3660, 3659f, 3660f, imaging of, 3657
joint preparation for, 3658, 3658f
metatarsal head/proximal phalanx reaming for, 3658, 3658f, 3659f
natural history of, 3656
nonoperative management of, 3657
outcomes of, 3663–3664, 3663f
pathogenesis of, 3656, 3656f
patient history of, 3657
pall and pitfalls of, 3663
physical findings for, 3657
postoperative care for, 3657
surgical management of, 3657
first, bone-block distraction of, 3656–3664
hallux, arthrodesis, 3740, 3740f
hemiarthroplasty of first, 3623–3626
BioPro prosthesis for, 3624–3625, 3625f
complications of, 3626
outcomes of, 3626
pall and pitfalls of, 3626
postoperative care of, 3626
imaging, 3623
Lapidus procedure with correction of, 3560–3561, 3561f
Methotrexate
limb-sparing surgery and, 1728
OS, 1709
STS, 1716
MFCA. See Medial femoral circumflex artery
MFH. See Malignant fibrous histiocytoma
MGHl. See Middle glenohumeral ligament
MHE. See Multiple hereditary exostoses
Microdecompression, lumbar, 4606, 4606f
Microdissection, nerve tumor, distal upper extremity, 3026
Microfracture
hallux rigidus treatment with, 3598–3604
techniques, 3603, 3603f
OLT, 4222–4228
complications of, 4228
lesion preparation and, 4226, 4227f
outcomes of, 4228
pall and pitfalls of, 4228
postoperative care of, 4228
techniques, 4227, 4227f
Microfracture arthroplasty chondral injury, 160, 161f
OCD, 160, 161f
Microfracture chondroplasty, 295–302
additional considerations, 300, 300f
anatomy, 295
assessment, 299, 299f
complications, 302
definition, 295
diagnostic arthroscopy, 298, 298f
diagnostic studies, 296–297
differential diagnosis, 297
imaging, 296–297, 296f
initial preparation, 298, 298f
microfracture techniques, 299, 299f
natural history, 295–296
nonoperative management, 297
outcomes, 301–302, 301f
pathogenesis, 295, 295f
patient history, 296
pall and pitfalls, 300
physical findings, 296
postoperative care, 300–301, 301f
surgical management, 297, 297f, 297t
Microsurgical revascularization
vaso-occlusive diseases of hand, 2903, 2903f
vasospastic diseases of hand, 2903, 2903f
pelvic lesions imaging, 1752
physical examination, 1752
proximal femur, surgical management of, 1752, 1752f
pathological fractures, impending and, 1752, 1752f
pelvic lesions imaging, 1879, 1880f
mechanical reconstruction, 1887–1888, 1887f
resection, 1881–1882, 1884f, 1885–1887, 1885f, 1886f
soft tissue reconstruction, 1888, 1889f
surgical management of, 1879–1890, 1881f
surgical management of, outcomes of, 1889–1890
tumor removal, 1885–1887, 1885f, 1886f
wound closure, 1888, 1889f
physical examination, 1752
proximal femur, surgical management of, 3036–3039, 3036f, 2037f, 2038f, 2039f
quality of life and, 1749
radiation therapy, 1752–1754
adjuvant, 1754
staging studies, 1749–1751, 1751f
surgical management of, 1879–1890, 1881f
failure rate, 1749
femoral lesion, 2034–2046
general considerations for, 1749–1756
humeral lesions and, 1816–1824
indications, 1749, 1816
pall and pitfalls, 1756
postoperative care, 1754
preoperative planning/concerns and, 1751–1752
principles of, 1752–1754, 1754f, 1755f
survival, 1749
Midfoot arthrodesis

Charcot arthropathy of, surgical stabilization of nonplantigrade, 3794–3801
comlications in, 3800–3801
external fixation and, 3799, 3800
internal fixation and, 3799
outcomes and, 3800–3801
pears and pitfalls for, 3800
postoperative care for, 3800
surgical steps in, 3799
Charcot foot deformity
anatomy of, 3802, 3802f, 3803f
diagnostic studies for, 3804–3805
differential diagnosis of, 3805
imaging of, 3804–3805
natural history of, 3802–3803
nonoperative management of, 3805
pathogenesis of, 3802
physical findings for, 3803–3804, 3804f
surgical management of, 3805–3806

Midfoot arthrodesis

Minifragment screws, phalangeal condylar fractures, 2396–2399, 2397f, 2398f

Minilimb, ankle arthrodesis

Minilimb, ankle arthrodesis, 4146–4152

Minilimb arthrodesis, ankle arthrodesis

Minilimb technique, ankle arthrodesis

articular surfaces and, preparation of, 4149–4150, 4149f
comlications of, 4152, 4152f
exposure of joint for, 4148–4149, 4148f
outcomes of, 4152, 4152f
postoperative care of, 4152, 4152f
site/screw placement for, 4150–4151, 4150f
visualization of joint for, 4148–4149, 4148f

Minicondylar blade plate technique, metaphyseal fracture fixation, 2389–2390, 2389f, 2390f

Mini-inflammatory grafting, proximal, plantaris tendon, 4454–4457

Mobi plication, shoulder throwing injury, 3588

Moberg advancement flap, finger tip amputation, 2934, 2934f

Moberg osteotomy, 3585–3591

See also Osteotomy

approach, 3587, 3587f, 3588f
cheilectomy, 3587, 3587f, 3588f
closure, 3589, 3589f, 3590f
comlications of, 3591
fixation, 3589, 3589f, 3590f
outcomes of, 3591
pears and pitfalls of, 3591
postoperative care of, 3591
proximal phalanx, 3588, 3588f, 3589f

Mobility total ankle arthroplasty

anatomy of, 4055
comlications of, 4071
definition, 4056
diagnostic studies, 4057, 4057f
differential diagnosis, 4057
imaging, 4056, 4057f
natural history, 4056
nonoperative management, 4057
outcomes of, 4071
pathogenesis, 4056
patient history, 4056–4057
physical findings, 4056–4057
surgical management, 4057–4058

Morton neuroma, 3743–3750

See also Neuroras

anatomy, 3743, 3743f, 3751
definition, 3743, 3751
diagnostic studies, 3744–3745, 3751
differential diagnosis, 3745, 3751
imaging, 3744–3745, 3751
natural history, 3744, 3751
nonoperative management, 3745, 3745f
nonsurgical management, 3751
pathogenesis, 3743–3744, 3751
patient history, 3744, 3751
physical findings, 3744, 3744f, 3751
revision, excision, 3743–3750
comlications of, 3749–3750
outcomes of, 3749–3750
pears and pitfalls of, 3749
postoperative care of, 3749
primary interdigital, 3747–3748, 3747f, 3748f
revision interdigital, 3748–3749, 3749f
surgical management, 3743–3747, 3746f, 3747f, 3751–3752
posteoperative care of, 3752
primary interdigital, 3752–3754

Multiple plication, arthroscopic treatment, shoulder instability, multidirectional, 33, 34f

Multiple hereditary exostoses (MHE)
anatomy, 1380
definition, 1380
diagnostic studies, 1381–1382, 1381f
differential diagnosis, 1382
forearm osteotomy, 1380–1385
comlications of, 1385
exotist excision in, 1383, 1383f, 1384f
outcomes of, 1383
pears and pitfalls of, 1385
postoperative care of, 1385
radial head excision in, 1384, 1384f
ulnar tethering release and, 1383, 1383f, 1384f
imaging, 1381–1382, 1381f
natural history, 1380
nonoperative management, 1382
pathogenesis, 1380
patient history, 1380–1381, 1381f
physical findings, 1380–1381, 1381f
surgical management, 1382–1383
Multiple ligament injuries, knee, management of, 392–401
Multiple percutaneous osteotomies. See also Osteotomy
OI, 1284–1293
comparisons of, 1293
outcomes of, 1293
pearls and pitfalls of, 1293
postoperative care for, 1293
techniques for, 1288–1291, 1288f, 1290f, 1291f
Muscle reconstruction
distal humerus, 1813, 1813f
proximal humerus, 1803
Muscular dystrophy, spinal deformity
and, 1448
Musculotaneous nerves anatomy, 3053
resections and, 1795
scapula, 1777–1778
Musculoskeletal lesion biopsy, 1704one and, 1705
evaluation of patient with, 1700–1705
imaging, 1701–1704, 1704f
angiography, 1702f, 1704
bone scan, 1702–1704, 1702f
CT, 1701, 1702f, 1704
MRI, 1701–1702, 1702f
PET, 1704
radiography, 1701
venography, 1702f, 1704
initial assessment, 1704–1705
laboratory studies, 1704
matrix production, 1705
presenting symptoms, 1700–1701
staging studies, 1701–1704
Musculoskeletal tumors
biopsy, 1719–1726
preoperative planning, 1723, 1723f
sampling error and, 1723
compartmentalism, 1719, 1721f, 1722f
diagnostic studies, 1719, 1722f
overview, 1695–1718
pathogenesis, 1719
preoperative evaluation, 1695–1718
pseudocapsules, 1719, 1720f
surgical management, 1705–1706, 1723, 1723f
considerations for, 1716–1718
excision types, 1705, 1705f
limb-sparing surgery, 1706, 1706f
preoperative planning, 1723, 1723f
surgical procedures and, 1705–1706
surgical resection, 1706
technique, 1716–1718, 1716f
Musculotendinous junction repairs, 3291
Myelomeningocele, spinal deformity and, 1448–1449
Myerson minimal incision
technique, hamstring autografting/augmentation, lateral ankle ligament instability, 4329, 4329f
Myopathy, cervical, 4354
N
Nail anatomy, 2906, 2907f
Nail matrix squamous cell carcinoma, 3007, 3008f
Nail injury
repair, 2924–2931
reconstruction, 2924–2931
complications of, 2931
definition of, 2924
outcomes of, 2931
postoperative care of, 2931
techniques for, 2929, 2929f
Nail matrix squamous cell carcinoma
study, 3007, 3008f
analysis, 2906
comparison of, 2931
definition of, 2924
examination of, 2906
images of, 3007f
strategies for, 2907
Tattoo, 2906
Nail injuries
CPN, 453–457
LFCN, 453–457
Nerve injuries in continuity
anatomy, 2799
definition, 2799
diagnostic studies, 2801
Nerve injury
anesthesia and, regional, 2112
hand/wrist/forearm, 2691–2692
diagnostic studies for, 2693
differential diagnosis of, 2693
images of, 2692
nonoperative management of, 2693
patient history of, 2692, 2692f
physical findings of, 2692, 2692f
surgical management of, 2693
Nerve lesions, resection, 2804, 2804f
Nerves, anatomy, 2691
Nerve transection, complete
definition, 2691
hand/wrist/forearm approach to, 2693–2694, 2694f
cable graft repair following, 2695, 2695f
complications of, 2698
conduit repair following, 2696, 2696f
epineurial repair following, 2694, 2694f
group fascicular repair following, 2695, 2695f
nerve grafting following, 2691–2698
outcomes of, 2697–2698
pearls and pitfalls of, 2697
postoperative care of, 2697
primary repair following, 2691–2698
vascularized nerve graft repair following, 2696, 2696f
natural history, 2691–2692, 2692f
Nerve tumors
definition, 3022
distal upper extremity
anatomy of, 3022, 3022f
diagnostic studies for, 3023
differential diagnosis of, 3023
enucleation, 3025, 3025f
imaging of, 3023, 3024f
microdissection for, 3026
natural history of, 3022
nerve conduits for, 3025, 3026f
nerve grafts for, 3025, 3026f
nerve repairs for, 3025, 3026f
nonoperative management of, 3023–3024
pathogenesis of, 3022
patient history of, 3022–3023
physical findings of, 3022–3023, 3023f
surgical management of, 3024
surgical treatment of, 3022–3028
lipofibromatous hamartoma, 3027, 3027f
surgical treatment complications of, 3028
outcomes of, 3028
pearls and pitfalls of, 3028
postoperative care of, 3028
Neuralgia, adhesive, 3933–3940
Neuraplasty application procedure, adhesive
neuralgia, 3937–3938, 3937f
Neuritis, plantar fascia release for, 3912–3913

Neurolysis
  external, 2803, 2803f
  internal, 2802–2803, 2802f

Neuromas
  definition, 3925
  foot/ankle
    anatomy and, 3925
    diagnosis of, 3926
    differential diagnosis of, 3926
    dorsomedial cutaneous nerve and, 3929, 3929f
    imaging of, 3926
    natural history of, 3925, 3926f
    nonoperative management of, 3926–3927
    pathogenesis of, 3925, 3925f
    patient history of, 3925–3926
    peroneal nerve resection/burial and, 3928–3929, 3928f, 3929f
    physical findings for, 3925–3926
    planter nerve, and medial, 3930, 3930f
    postoperative care of, 3931
    saphenous nerve resection/burial and, 3930, 3930f
    sural nerve resection/burial and, 3927–3928, 3927f, 3928f
    surgical management of, 3927
    tibial nerve and, 3930
    transection/burial of, 3925–3926
    transaction/burial of, complications for, 3931–3932, 3931f, 3932f
    transaction/burial of, outcomes for, 3931
    transection/burial of, pears and pitfalls for, 3931
  Neurovascular bundle
    resections and, 1795
    scapula and, 1776
    shoulder girdle, 1768–1769
  Neurovascular structures, distal humerus, 1807

Nonarticular scapular fractures
  anatomy and, 3243, 3243f
  definition, 3243
  diagnostic studies, 3243
  differential diagnosis, 3243
  imaging, 3243
  natural history, 3243
  nonoperative management, 3244
  ORIF of, 3243–3247
  acromial process fracture and, 3245, 3245f
  complications for, 3247
  coracoid process fracture and, 3246, 3246f
  outcomes for, 3247
  pears and pitfalls for, 3247
  posterior approach to glenoid neck and, 3244–3245, 3245f
  postoperative care for, 3247
  superior approach to glenoid neck and, 3245, 3245f
  pathogenesis, 3243
  patient history, 3243
  physical findings, 3243
  surgical management, 3244, 3244f
  Notchplasty, 1866, 1867f
  ACL repair, revision, 360, 360f
  Nuclear imaging, axillary space, 1826–1827

O

Obturator nerve, 1855

Occipitocervical arthrodesis
  with iliac graft, posterior cervical arthrodeses, pediatric and, 1403, 1403f, 1404f
  with rib graft, posterior cervical arthrodeses, pediatric and, 1404, 1405f
  Occipitocervical fusion and instrumentation, Cl-C2, 4586–4594
  Brooks method of wire fixation for, 4592, 4592f
  complications of, 4594
  exposure and, 4590, 4590f
  Gallea method of sublaminar wiring/grafting for, 4593, 4593f
  Goel method of articular mass fixation for, 4591–4592, 4592f
  Magel method of transarticular screw fixation for, 4590–4591, 4591f
  outcomes of, 4594
  pears and pitfalls of, 4593
  postoperative care of, 4594
  Occipitocervical region, posterior approach, 4521, 4521f
  Occiput-C2, posterior cervical arthrodeses, 1399–1407
  OCL syndrome: Osteochondritis dissecans
    OL. See Osteogenesis imperfecta
    Olercanon
      anatomy, 3362
      fossa, deepening of, valgus extension overload for, 170, 170f
      resection, 3403, 3403f
      spur removal, posteromedial, 169, 169f
      Olercanon fracture-dislocations, plate and screw fixation for, 3366–3367, 3366f, 3367f
      Olercanon fractures
        definition, 3362, 3362f
        diagnostic studies, 3363
        differential diagnosis, 3363
        imaging, 3363
        natural history, 3362
        nonoperative management, 3363
        ORIF of, 3362–3368
        complications and, 3368
        pears and pitfalls for, 3368
        plate and screw fixation for, 3365–3366, 3365f, 3366f
        postoperative care for, 3368
        tension band wiring for, 3363–3364, 3363f, 3364f, 3365f
        pathogenesis, 3362
        patient history, 3362
        physical findings, 3362
        plate and screw fixation for, 3365–3367, 3365f, 3366f, 3367f
        surgical management, 3363
    Olercanon osteotomy, 3067, 3067f
    OLT. See Osteochondral lesions of talus
    Oncological resection, 1728
    One-incision technique, distal biopses tendon disruption, 2550–2553
    complications of, 2553
    outcomes of, 2553
    pears and pitfalls of, 2553
    postoperative care of, 2553
    Open curettage. See also Curettage
    ganglion cyst, intraosseous, 3017
    Open fractures, Gustilo and Anderson grading system, 674, 674f
    Opening-wedge osteotomy
      dorsal, hallux valgus correction, revision, 3574–3575, 3574f
      proximal metatarsal
        complications of, 3557
        hallux valgus, 3553–3557, 3556f
        outcomes of, 3557
        postoperative care of, 3557
      supramalleolar, medial, 3938, 3958f
      Open lengthening, AT, pediatric, 1619–1625
      complications and, 1625
      modified sliding, 1623, 1623f
      outcomes and, 1625
      pears and pitfalls, 1624
      postoperative care for, 1625
      sliding, 1622–1623, 1622f
      Z-, 1623–1624, 1624f
      Open posterior humeral-based capsular shift, 3090–3091, 3090f, 3091f, 3092f
      Open reduction
        calcaneal fractures, 718, 718f
        radial head/neck fractures, pediatric, 1058–1065
        techniques for, 1063–1064, 1064f
        sacrum, posterior approach to, 496–497, 496f
        SI joint, posterior approach to, 496–497, 496f
        supracondylar fractures of humerus, pediatric, 1046–1049
        anatomy, 1046
        complications, 1049
        definition, 1046
        outcomes, 1048
        patient history for, 1046
        pears and pitfalls, 1048
        physical findings for, 1046
        postoperative care for, 1048
        surgical management, 1046
        techniques for, 1047–1048, 1047f, 1048f
        THA, revision with femoral bone loss, 819–820
        of thumb MCP joint dislocations, 2333–2336, 2335f
      Open reduction–anterior approach to DDH, 1493–1501
        anterior hip exposure and, 1497–1498, 1497f, 1498f
        complications of, 1501
        outcomes of, 1501
        pears and pitfalls of, 1500–1501
        postoperative care of, 1501
        proximal femoral shortening osteotomy and, 1499–1500, 1500f
        techniques, 1498–1499, 1498f, 1499f
        supracondylar fractures of humerus, pediatric and, 1047–1048, 1047f, 1048f
      Open reduction, medial approach to, DDH, 1502–1507
        capsulorrhaphy and, 1505
        capsulotomy/acetabular exposure and, 1504–1505, 1505f
        casting and, 1506, 1506f
        closure and, 1505
        complications of, 1507
        deep dissection and, 1504, 1504f
        hip reduction and, 1505
        incision/initial dissection and, 1503, 1504f
        outcomes of, 1507
        pears and pitfalls of, 1506
      Open reduction and internal fixation (ORIF)
        acetabular posterior wall, 503–512
        anatomy and, 503
        complications of, 511–512
        definition of, 503, 504f
        diagnostic studies for, 505
        differential diagnosis of, 505
        fracture reduction and, 508–509
        fracture site débridement/exposure and, 508
        imaging of, 505
        internal fixation and, 509–510, 509f
Open reduction and internal fixation (continued)
diagnostic studies for, 734, 735f
differential diagnosis of, 734
imaging for, 734
inlay bone grafting without internal fixation for, 738, 738f
natural history and, 734
nonoperative management of, 734–735 outcomes of, 739
pathogenesis and, 734
patient history and, 734
 pearls and pitfalls of, 739
percutaneous intramedullary screw fixation for, 736, 736f, 737f
percutaneous intramedullary screw fixation for, with bone graft, 738
physical findings and, 734
postoperative care of, 732
physical findings and, 724–725
pathogenesis and, 724
nonoperative management of, 725
natural history and, 724
inlay bone grafting without internal fixation for, 727, 727f
diagnostic studies for, 725, 726f, 727f
differential diagnosis of, 725
imaging for, 725, 726f, 727f
lateral incision for, 728, 728f
medial incision for, 728, 728f
natural history and, 724
nonoperative management of, 725
outcomes of, 732
pathogenesis and, 724
patient history and, 724–725
 pearls and pitfalls of, 732
 physical findings and, 724–725
 postoperative care of, 732
 provisional reduction for, 729–731, 729f,
 730f, 731f
diagnostic studies for, 725, 726f, 727f
partial phallectomy and, modified with tension band and, 610, 610f
anatomy and, 1044–1045
definition of, 1044
diagnostic studies for, 1045
complications of, 1045
definition of, 1044
diagnostic studies for, 1043
differential diagnosis of, 1043
 extraction of medial epicondyle from elbow joint and, 1045
imaging for, 1043
natural history of, 1042
nonoperative management of, 1043
outcomes of, 1045
pathogenesis of, 1042, 1042f
 patient history and, 1042–1043
 pearls and pitfalls of, 1045
 physical findings and, 1042–1043
 postoperative care for, 1045
 surgical management of, 1043, 1043f
 suture fixation for, 1045
 techniques for, 1044–1045
 metacarpal fracture, 2371–2374, 2372f,
 2373f, 2374f, 2377f
of nonarticular scapular fractures, 3243–3247
acromial process fracture and, 3245, 3246f
complications for, 3247
coracoid process fracture and, 3246, 3246f
outcomes for, 3247
 pearls and pitfalls for, 3247
 posterior approach to glenoid neck and, 3244–3245, 3245f
 postoperative care for, 3247
 superior approach to glenoid neck and, 3245, 3245f
of olecranon fractures, 3362–3368 complications and, 3368
 pearls and pitfalls for, 3368
 plate and screw fixation for, 3365–3366, 3366f, 3367f
 postoperative care for, 3368
 tension band wiring for, 3363–3364, 3363f, 3364f, 3365f
 patellar, 604–611
 anatomy and, 604, 605f
 approach to, 606
 complications of, 611
 definition of, 604
 diagnostic studies for, 605, 606f
 differential diagnosis of, 605
 imaging for, 605, 606f
 interfragmentary screws without tension banding for, 609, 610f
 natural history and, 604
 nonoperative management of, 605
 outcomes of, 611
 partial phallectomy and, 610, 610f
 pathogenesis and, 604
 patient history and, 604–605
 physical findings and, 611
 postoperative care for, 611
 preoperative planning for, 606
 surgical management of, 605–606
 tension band and, modified with cannulated screws, 608, 609f
 tension band wiring for, 607–608, 607f, 608f
 peritrochanteric hip fracture, 547–557
 anatomy and, 547
 blade plate insertion for, 552–553, 553f
 complications of, 556f, 557
 definition of, 547
 diagnostic studies for, 547
differential diagnosis of, 548
fracture preparation for, 551–552, 552f
fracture reduction for, 550, 551f
 glide pin positioning for sliding hip screw and, 551–552, 552f
 imaging for, 547, 548f
 implant insertion and, 552–553, 553f
 incision for, 550
 natural history and, 547
 nonoperative management of, 548
 outcomes of, 556
 pathogenesis and, 547
 patient history and, 547
 pearls and pitfalls of, 554–555, 555f
 physical findings and, 547
 postoperative care for, 555–556, 556f
 surgical management of, 548–549, 549f, 550f
 wound closure for, 554
 phalangeal condylar fracture, 2392–2403
 bicondylar, 2399–2400, 2399f, 2400f
 complications of, 2403
 outcomes of, 2403
 pearls and pitfalls of, 2401
 postoperative care of, 2401–2403, 2402f
 triplane, 2400, 2400f
 pilon, 671–686
 anatomy and, 671
 anterolateral approach to, 678, 679f
 anteromedial approach to, 677–678, 677f, 678f
 articular fixation and, 681–682, 681f
 arthrotomy and, 681–682, 681f
 complications of, 685–686
 definition of, 671
 diagnostic studies for, 674, 675f
 differential diagnosis of, 674
 extra-articular fixation and, 682, 682f
 extra-articular reduction and, 682, 682f
 fibula and, reduction/fxation of, 680
 imaging for, 674, 675f
 natural history and, 673
 nonoperative management of, 674
 outcomes of, 684–685
 pathogenesis and, 671–673, 672f, 673f
 patient history and, 673–674
 pearls and pitfalls of, 683–684
 physical findings and, 673–674, 674r
 posterolateral approach to, 680
 posteromedial approach to, 680
 postoperative care of, 684
 surgical management of, 674–676, 675f, 676f, 677f
 wound closure/care and, 683, 683f
 of PIP joint fracture-dislocations, 2420–2429
 cerclage wire technique for, 2427–2428, 2427f, 2428f
 closure for, 2429
 complications and, 2429
 exposure for, 2424–2425, 2424f, 2425f
 fracture and joint reduction for, 2425–2426
 mini-fragment fixation and, 2426, 2426f
 outcomes for, 2429
 pearls and pitfalls for, 2429
 postoperative care for, 2429
 splinting for, 2429
 pisiform fracture, 2289
 of proximal humerus fractures, 3200–3207
anatomic plating for, 3204–3206, 3204f,
 3205f, 3206f
 complications of, 3207
 outcomes of, 3207
 pearls and pitfalls of, 3206
 postoperative care for, 3207
 of radial head/neck fractures, 3343–3351,
 3381–3382, 3382f
 Boyd approach to, 3347, 3348f
 closure for, 3350
 complications and, 3351, 3351f
 fixation and, 3350, 3350f
 Köcher approach to, 3348, 3348f
 pearls and pitfalls for, 3350
 postoperative care for, 3350
 results for, 3350
 of Rolando fractures, 2326, 2326f, 2327f
 of sacrum, 487–502
 anatomy and, 487, 488f, 489f
 anterior approach to, 497, 497f
 complications for, 502
 diagnostic studies for, 490–491, 491f, 492f
 iliosacral screw placement and, 498–499,
 498f, 499f
 imaging for, 490–491, 490f, 491f
 natural history of, 487–489
 nonoperative management for, 491–492, 492f, 493f
 outcomes and, 501
 pathogenesis of, 487
Osteochondral lesions of talus (OLT) (continued)
diagnostic studies, 4222, 4259, 4274
differential diagnosis, 4223–4224, 4259–4260, 4274
hemi-talus reconstruction of medial, 4280–4285
approach, 4280–4281, 4281f
axial realignment, 4283–4285, 4284f
closure, 4285
harvesting graft, 4281–4283, 4282f
implanting/Securing graft, 4283, 4283f
preoperatively for, 4280, 4280f
site preparation, 4281, 4281f
imaging, 4223, 4233f, 4242f, 4259, 4260f, 4274
microfracture for, 4222–4228
complications of, 4228
lesion preparation and, 4226, 4227f
outcomes of, 4228
pears and pitsfalls of, 4228
postoperative care of, 4228
technique(s), 4227, 4277
natural history, 4222, 4259, 4274
nonoperative management, 4224, 4260, 4274–4275
osteochondral transfer for, 2000C3
hemi-talus reconstruction of medial, differential diagnosis, 4223–4224, diagnostic studies, 4223, 4259
imaging, 4223, 4223f, 4242f, 4259, 4260f, 4274
microfracture for, 4222–4228
postoperative care of, 4269, 4270
physical findings, 4223, 4259, 4274
pathogenesis, 4222, 4259, 4274
outcomes of, 4269, 4286
structural allograft, 4274–4286
surgical management, 4224–4226, 4225
subchondral cyst-associated, 4227
postoperative care, 4224
arthroscopic treatment, 155–165
arthroscopic débridement, 159–160, 160f
anatomy, 155–156, 155f
abrasion arthroplasty, 160, 161f
anterior, 155–156, 155f
arthroscopic débridement, 159–160, 160f
arthroscopic treatment, 155–165
outcomes of, 164–165
pears and pitsfalls of, 164
postoperative care of, 164
definition, 155
diagnostic studies, 156–157
differential diagnosis, 157
imaging, 156–157, 157f
internal fixation, 162, 163f
knee, 1284–1340
anatomy of, 323f, 329
bone grafting of, 336–337, 337f
complications of, 340
definition of, 322f, 329
diagnostic studies, 332–333
differential diagnosis of, 333
imaging of, 332–333, 332f
natural history of, 331
nonoperative management, 333
outcomes, 339
pathogenesis of, 329–331, 330f
patient history of, 331–332
pears and pitsfalls of, 339
physical findings of, 331–332
postoperative care of, 339
primary fixation of, 336–337, 337f
surgical management of, 333–334, 334f
transchondral drilling of, 335–336, 335f
lesions, drilling for, 161–162, 161f
loose body removal, 159–160, 160f
microfracture arthroplasty, 160, 161f
natural history, 156
nonoperative management, 157
osteochondral autograft implantation, 163
pathogenesis, 156
patient history, 156
physical findings, 156
surgical management, 157–159, 158f, 159f
Osteochondritis dissecans (OCD), pediatric anatomy, 1144, 1177
arthroscopic drilling, 1177–1182
complications of, 1182
outcomes of, 1182
pears and pitsfalls of, 1181
postoperative care for, 1181–1182
techniques for, 1179–1181, 1180f, 1181f
definition, 1144, 1177
diagnostic studies, 1144, 1177–1178
differential diagnosis, 1144, 1178
elbow arthroscopy for, 1144–1148
complications of, 1148
mini-, 1147, 1147f
outcomes of, 1148
pears and pitsfalls of, 1147
postoperative care of, 1148
techniques for, 1145–1147, 1146f, 1147f
hinged lesions, arthroscopic drilling of, 1180, 1180f
imaging, 1144, 1145f, 1177–1178, 1178f
intact lesions, arthroscopic drilling of, 1179–1180, 1180f
natural history, 1144, 1177
nonoperative management, 1144–1145, 1145f, 1178
pathogenesis, 1144, 1177
patient history, 1144, 1177
physical findings, 1144
surgical management, 1145, 1145f, 1178–1179, 1179f
techniques for, 1143–1147, 1146f, 1147f, 1178–1181, 1180f, 1181f
unstable lesions, arthroscopic drilling of, 1181, 1181f
Osteochondroplasty, limited open, FAI, anterior, 891–893, 892f
Osteonecrosis, femoral head, 770–772
acetabular, arthroscopic management of, 217, 218f
chemotherapy, 1707–1709
chondroplastic, 1707
microscopic characteristics, 1707, 1708f
natural history, 1707–1709, 1708f
osteoelastic, 1707
parosteal, 1709, 1710f
radiographic characteristics, 1707, 1708f
surgery, 1709
limb salvage, 1709
treatment strategy, 1709
trigonum pathology, 4257, 4257f
variants, 1709
Osteosynthesis
plate/screw, wrist arthrodesis, complete and, 2818–2819, 2819f
tibial plateau fractures, lateral, 626, 627f
Osteotomy
ankle varus-type osteoarthritis, 3965, 3965f
Blount’s disease, 1232–1235, 1233f, 1234f
calcaneal, 1646–1647, 1646f, 1647f
closing wedge, 1279–1280, 1280f, 1281f
toe deformity, 3723, 3723f
closure, cubitus varus correction, pediatric and, 1077, 1078f
completion, 1565, 1565f
coracoid, 3102–3103, 3102f, 3103f
corrective
distal radius malunion, 2234–2243
radial diaphyseal malunion, 2149–2155, 2152f, 2153f
ulnar diaphyseal malunion, 2149–2155, 2153f
Cuneiform, medial, 1616, 1616f
distal chevron osteotomy with, 3495–3497, 3495f, 3496f
dorsal extra-articular, distal radius malunion, 2237–2238, 2237f, 2238f, 2239
dorsal opening-wedge, halluc valgus correction, revision, 3574–3575, 3574f
femoral neck, THA, cemented and, 748, 748f
fixation
cubitus varus correction, pediatric and, 1077, 1078f
TIO and, 1549, 1549f
humeral head, 3120, 3120f
humeral head allograft, 3120, 3120f
intra-articular, distal radius malunion, 2241, 2242f
Palmaris longus (PL), 2723
anatomy, 3054
graft harvest, 2530, 2530f
tendon transfer, 2711
thumb extension and, 2726, 2727f
Palsy. See also specific palsies
nerve, severity of, 2716
Panner’s disease, pediatric
anatomy, 1144
definition, 1144
diagnostic studies, 1144
differential diagnosis, 1144
elbow arthroscopy for, 1144–1148
complications of, 1148
mini-, 1147, 1147f
outcomes of, 1148
pears and pitfalls of, 1147
postoperative care of, 1148
techniques, 1145–1147, 1146f, 1147f
imaging, 1144, 1145f
natural history, 1144
nonoperative management, 1144–1145,
pathogenesis, 1144
patient history, 1144
physical findings, 1144
surgical management, 1145, 1145f
techniques for, 1145–1147, 1146f, 1147f
PAO. See Periacetabular osteotomy
Parapatellar arthrotomy. See also Arthrotomy lateral, ORIF of distal femur and, 592–593, 593
medial, with complete intra-articular release, revision TKA and, 997–998, 998f
Parona’s space infections, 2915
Paronychia, acute/chronic
anatomy, 2906, 2907f
definition, 2906
diagnostic studies, 2907
epiphyseal marsupialization for, 2909, 2909f
imaging, 2907
incision/drainage of, 2908, 2908f
natural history, 2906–2907
nonoperative management, 2907
pathogenesis, 2906
patient history, 2907
physical findings, 2907
surgical management, 2907
surgical treatment, 2906–2911
complications of, 2910
pears and pitfalls of, 2910
postoperative care of, 2910
Patella. See also Proximal patellar realignment, pediatric anatomy, ORIF and, 604, 605f
ORIF of, 604–611
removal, revision TKA with removal of
well-fixed components and, 978, 978f
TKA, cemented and, 930
arthroscopy, medial parapatellar
approach to, 921–922
preparation for, 925–926, 927f
TKA, using navigation and, 940
Patellar advancement, 1342, 1342f
Patellar instability, pediatric, 1149–1155
anatomy, 1149, 1149f
definition, 1149
diagnostic studies, 1150
differential diagnosis, 1150
imaging, 1150, 1151f
medial patellofemoral ligament reconstruction for, 1152–1153, 1153f
medial patellofemoral ligament repair for, 1152, 1152f
medial patellofemoral ligament repair on femoral side for, 1154, 1154f
natural history, 1150
nonoperative management, 1150–1151
pathogenesis, 1149–1150
patient history, 1150
physical findings, 1150
postoperative care of, 1155
Roux-Goldthwaite patella tendon hemitransfer and, 1154, 1154f
surgical management, 1151, 1151f
complications of, 1155
Galeazzi procedure for, 1153, 1153f
outcomes of, 1155
pears and pitfalls of, 1154
techniques for, 1152–1154, 1152f, 1153f
Patellar tendon, graft harvesting, ACL repair and, 343, 343f
Patella tendon, anatomy, 402
Patella tendon tears anatomy, 402
chronic, reconstruction of, 404, 404f
definition, 402
diagnostic studies, 402
differential diagnosis, 402
imaging, 402
natural history, 402
nonoperative management, 402
pathogenesis, 402
patient history, 402
physical findings, 402
repair
acute, 402–406
acute, techniques for, 403, 403f, 404f
augmentation procedures for, 405, 405f
chronic, 402–406
complications of, 406
outcomes of, 405–406
pears and pitfalls of, 405
postoperative care of, 405
surgical management, 402
Patellofemoral joint, 1156
disorders
definition of, 435
diagnostic studies for, 437–438
imaging of, 437–438, 438f
natural history of, 436, 436f
nonoperative management of, 436
pathogenesis of, 435–436, 436f
patient history of, 436–437, 437f
physical findings of, 436–437, 437f
surgical management of, 438
instability/dislocation, 1156
pain, 422
Patellofemoral ligament, medial, reconstruction, 1158, 1159f
PCL. See Posterior cruciate ligament
Pectoralis major
anatomy, 3047, 3288, 3288f
repair, 3288–3292
complications of, 3292
using drill holes, 3290–3291, 3290f,
3291f
musculotendinous junction, 3291
outcomes of, 3292
pears and pitfalls of, 3292
postoperative care of, 3292
using suture anchors, 3291, 3291f
ruptures, 3288
diagnostic studies for, 3289
differential diagnosis of, 3289
imaging of, 3289, 3289f
natural history of, 3288–3289
INDEX I-61

Periacetabular osteotomy (PAO), 859–868.

Percutaneous pinning

Percutaneous osteotomy, malunited ankle

Pericapsular osteotomies. See also Osteotomy

Peroneal nerve

Deep, resection/burial, 3928, 3928f
superior, resection/burial, 3928–3929, 3928f, 3929f

Peroneal retinaculum repair, superior, calcaneal malunion, 3856, 3856f

Peroneal tendon, anatomy, 4458

natural history, 4458

definitive, 4477

differential diagnosis, 4479
imaging, 4479, 4479f, 4480f
indirect groove deepening, 4477–4483
complications of, 4483
fibular, 4480–4482, 4481f, 4482f
outcomes of, 4483
pears and pitfalls of, 4483
postoperative care of, 4483

Peroneal retinacular tear repair/reconstruction

anatomy, 4468

complications of, 4476

definition, 4468
diagnostic studies, 4470, 4470f
differential diagnosis, 4470
imaging, 4470, 4470f
natural history, 4469, 4469f
nonoperative management, 4470
outcomes of, 4476

pathogenesis, 4468–4469, 4468f, 4469f

patient history, 4469–4470, 4469f

pears and pitfalls of, 4476

physical findings, 4469–4470, 4469f

postoperative care of, 4476

surgical management, 4470–4475
approach, 4471
groove-deepening procedure, 4472–4473, 4473f–4474f

large-diameter drill bit used in, 4474–4475, 4475f
positioning, 4471
preoperative planning, 4471
superior peroneal retinaculaplasty, 4471–4472, 4471f
technique, detailed, 4472, 4472f

Peroneal tendon rupture, type III, repair of, 4461

Peroneal tendinopathy, chronic

AT rupture, management of, 4410–4411
complications in, 4410
outcomes for, 4410
pears and pitfalls for, 4410
postoperative care for, 4410

Peroneal tendinopathy tears

anatomy, 4458

diagnostic studies, 4459
differential diagnosis, 4459
imaging, 4459, 4459f
natural history, 4458

nonoperative management, 4459
pathogenesis, 4458

patient history, 4458–4459, 4458f

physical findings, 4458–4459, 4458f

repair, 4458–4461

complications of, 4461

outcomes of, 4461

pears and pitfalls of, 4461

postoperative care of, 4461

surgical management, 4459–4460, 4460f
type I, repair of, 4460, 4460f

type II, repair of, 4460
type III, repair of, 4461

Peroneal tenosynovitis

for calcaneal malunions, 3856

Peroneus brevis tendon transfer
cavovarus, 3886, 3887f

Peroneus longus, graft tendon harvesting,
deltoid ligament reconstruction, 4351, 4352f

Perthes disease (Legg-Calvé-Perthes disease)
anatomy, 1583
diagnostic studies, 1533–1534

valgus osteotomy and, 1583

differential diagnosis, 1534

valgus osteotomy and, 1583
differential diagnosis of pediatric, 1543
 imaging, 1533–1534, 1534f

Pearls and pitfalls for, 1532–1539
arthrography and, 1535, 1535f

complications of, 1539

deep dissection for, 1536
graft collection for, 1536, 1536f, 1537f
traction/superficial dissection for, 1536, 1536f

outcomes for, 1538, 1538f

pears and pitfalls of, 1538

postoperative care for, 1538

shelf creation in, 1537, 1537f

trophic creation for, 1536, 1536f, 1537f

valgus osteotomy and, 1538

natural history, 1533, 1533f, 1533f

valgus osteotomy and, 1538

natural history of pediatric, 1541

nonoperative management, 1534
valgus osteotomy and, 1538

nonoperative management of pediatric, 1543, 1543f

pathogenesis, 1532

valgus osteotomy and, 1538

pathogenesis of pediatric, 1541

patient history, 1533

valgus osteotomy and, 1583

patient history of pediatric, 1542

physical findings, 1533

valgus osteotomy and, 1583

physical findings of pediatric, 1542

surgical management, 1534–1535

valgus osteotomy and, 1583–1584

valgus osteotomy and, 1584f

Periarticular osteotomy (PAO), 859–868.

See also Osteotomy

anatomy, 859–861, 860f

Bernese, 863, 1559–1568

technical for, 864–866, 864f, 865f, 866f

complications, 867–868

definition, 859
diagnostic studies, 862–863
imaging, 862–863, 862f, 863f

natural history, 861

outcomes, 867

pathogenesis, 861

patient history, 861–862

pears and pitfalls, 866–867

physical findings, 861–862

postoperative care, 867

surgical management, 863

Periarticular reconstruction.

See also Reconstructions

THA, malignant lesion, 803–804, 803f

Periarticular resection, 1865–1866, 1865f
Perthes disease (continued)
surgical management of pediatric,
1543–1544, 1544f
valgus osteotomy for, 1583–1588
complications of, 1588
definition of, 1583
exposure and, 1585, 1585f
femoral, using cannulated blade plate,
1585–1586, 1586f, 1587f
femoral, using noncannulated blade
plate, 1586–1587, 1586f, 1587f
outcomes of, 1587–1588
pears and pitfalls of, 1587
postoperative care of, 1587
Pfannenstiel approach, ORIF, symphysis,
480, 480f
Phalangeal, proximal
encondroma, 3031, 3031f
MTP joint arthrodesis, first and
preparation of, 3639, 3639f
Phalangeal condylar fractures.
See also Condylar fractures
anatomy and, 2392, 2394
bicondylar, ORIF for, 2399–2400, 2399f,
2400f
coronal sheer, dorsal/volar, 2399
definition, 2392
diagnostic studies, 2394
differential diagnosis, 2395
imaging, 2394
natural history, 2394
nonoperative management, 2395
oblique, percutaneous reduction/fixation of,
2396–2397, 2397f, 2398f
ORIF, 2392–2403
complications of, 2403
outcomes of, 2403
pears and pitfalls of, 2401
postoperative care of, 2401–2403, 2402f
pathogenesis, 2392–2394
patient history and, 2394
percutaneous reduction/fixation,
2396–2399, 2397f, 2398f
physical findings, 2394, 2394f
surgical management, 2395–2396, 2395f,
2396f
triplane, ORIF for, 2400, 2400f
Phalangeal fractures, extra-articular
anatomy, 2378, 2378f
definition, 2378
diagnostic studies, 2380
differential diagnosis, 2380
imaging, 2380
natural history, 2379
nonoperative management, 2380–2381
operative treatment, 2378–2392
complications of, 2391–2392
interosseous wire fixation for, 2386,
2386f
Kirschner wire fixation, percutaneous
for, 2384–2385, 2385f, 2386f
lag screw fixation for, 2387–2388,
2387f, 2388f
metaphyseal fracture fixation and,
2389–2390, 2389f, 2390f
other methods for, 2390, 2390f
outcomes of, 2391
pears and pitfalls of, 2391
plate fixation for, 2388, 2388f, 2389f
postoperative care of, 2391
pathogenesis, 2378–2379, 2379f
patient history, 2379–2380, 2379f
physical findings, 2379–2380, 2379f,
2380f
surgical management, 2381–2383, 2382f,
2383f, 2384f
Phalangeal malunion, osteotomies for,
2452–2454
complete, for rotational and angular
malunions, 2456, 2456f
complications of, 2458
condylar advancement, 2457, 2457f
incomplete, for angular correction,
2454–2456, 2455f
outcomes of, 2458
pears and pitfalls of, 2458
postoperative care of, 2458
Phalanges, anatomy, 2452, 2452f
Phalux
middle, shaping articular surface of, VPA
and, 2434
proximo
tosteoeste, 3588, 3588f, 3589f
reaming, 3658, 3658f, 3659f
revision first MTP joint arthrodesis and
proximoal, 3652, 3652f
Phallectomy, partial, ORIF, patellar and,
610, 610f
Phemister, limb deformity corrected with,
1274
Physial bar
anatomy, 1244, 1244f
closure and, 1249
cranioplast interposition and, 1249
definition, 1244
differential diagnosis, 1245
diagnostic studies, 1245
natural history, 1244
nonoperative management, 1245–1246
pathogenesis, 1244
patient history and, 1244–1245
physical findings, 1244–1245
resection, 1248, 1248f
surgical management, 1246, 1246f
techniques for, 1247–1249, 1247f,
1248f, 1249f
Physical examination, resection, 1770
Pigmented villonodular synovitis (PVNS),
256–258. See also Synovitis
Pilon
anatomy, ORIF and, 671
articular fixation of, ORIF and,
681–682, 681f
articular reduction of, ORIF and,
681–682, 681f
extra-articular fixation of, ORIF and,
682, 682f
extra-articular reduction of, ORIF and,
682, 682f
ORIF of, 671–686
anatomy and, 671
anterolateral approach to, 678, 679f
anteromedial approach to, 677–678,
677f, 677f
articular fixation and, 681–682, 681f
articular reduction and, 681–682, 681f
complications of, 685–686
definition of, 671
diagnostic studies for, 674, 675f
differential diagnosis of, 674
extra-articular reduction and, 682, 682f
fibula and, reduction/fixation of, 680
imaging for, 674, 675f
natural history and, 675
nonoperative management of, 674
outcomes of, 674–685
pathogenesis and, 671–673, 672f, 673f
patient history and, 673–674
pears and pitfalls of, 683–684
physical findings and, 673–674, 674f
posterolateral approach to, 680
postero medial approach to, 680
postoperative care of, 684
surgical management of, 674–676, 675f,
676f, 677f
wound closure/care and, 683, 683f
Pilon fractures, 671–673, 672f
PIP joint, nonoperative management of,
2413, 2413f
PIN. See Posterior interosseous nerve
Pincer impingement, 216–217, 217f
arthroscopic management, 217, 218f
Pincer nail deformity, 2929–2930, 2930f
PIP joint. See Proximal interphalangeal joint
Pinform fractures, ORIF, 2289
PL. See Palmaris longus
Plafond, 671
fractures, 671–673, 672f
Plantar fascia release, distal tarsal tunnel
release with
anatomy, 3911–3912, 3911f
complications of, 3918
definition of, 3911
diagnostic studies, 3913
differential diagnosis, 3913
imaging, 3913
natural history, 3912
nonoperative management, 3913–3914
outcomes of, 3918
pathogenesis, 3912
patient history, 3912–3913
pears and pitfalls of, 3918
physical findings, 3912–3913
neuritis/distal tarsal tunnel syndrome,
3912–3913
plantar fasciitis, 3912
postoperative care of, 3918
surgical management, 3914–3917, 3915f,
3917f
approach, 3914
complete release, 3915–3916, 3915f
conduits for neuromas of calcaneal
branches with, 3917, 3917f
extensive nerve scarring present,
3916–3917, 3917
positioning, 3914
preoperative planning, 3914
prior incomplete/failed releases, 3916
Plantar fasciitis, plantar fascia release for,
3912
Plantar fasciotomy, endoscopic
anatomy, 3920
complications of, 3924
definition, 3920
diagnostic studies, 3920
differential diagnosis, 3920–3921
imaging, 3920
natural history, 3920
nonoperative management, 3921
outcomes of, 3924
pathogenesis, 3920
pears and pitfalls of, 3923
physical findings, 3920
postoperative care of, 3924
surgical management, 3921–3923
anesthesia for, 3921–3922
completion of procedure, 3923
Plantaris tendon

Plantaris longus tendon, reconstruction of

Plate-and-screw fixation, superior, clavicle

Plate fixation

anatomy, 4454, 4454

extensive

proximal mini-invasive grafting, 4454–4457

imaging, 4455
distal, harvesting of, 4456, 4457

segmental bone defect reconstructions,

arthrodesis

of humeral shaft fractures, 3226–3233

dedicated midfoot system, 3775–3778,

of clavicle fractures, 3177–3179

Charcot foot realignment surgery with,

bridge plating and, 2221–2222, 2222f

Charcot foot realignment surgery with,

Phalangeal fractures, extra-articular, 2388,

3226

fracture reduction and, 3230, 3230

postoperative care and, 4238

patient history of, 4238

set-up for, 3922

hallux rigidus treatment with, techniques

ankle, 4128–4132, 4128f

PIF, DIP, MCP joint, 2762, 2763f

bridge plating and, 2221–2222, 2222f

Charcot foot realignment surgery with, 3810

of clavicle fractures, 3177–3179

complications of, 3179

postoperative care for, 3179

of humeral shaft fractures, 3226–3233

anterolateral approach to, 3228–3229,

3228f

complications of, 3233

fracture nonunion and, exposure of, 3230

fracture reduction and, 3230, 3230f

medial approach to, 3231, 3231f

outcomes of, 3233

pearls and pitfalls of, 3232

plate application and, 3231, 3231f

posterior approach to, 3229, 3229f

postoperative care of, 3232, 3232f

midfoot arthrodesis with, 3767–3774,

3768f–3775f

phalangeal fractures, extra-articular, 2388,

3238f, 2389f

proximal chevron osteotomy with,

3545–3548

lateral joint structures for, 3546, 3546f

pearls and pitfalls of, 3548

postoperative care of, 3548

skin/capsular incision for, 3545, 3545f

postoperative care of, 3232, 3232f

posterior ankle impingement syndrome

(PAIS). See also Ankle

anatomy, 4229, 4229f

and, 4243, 4243f

associated lesions, evaluation of,

4248–4249, 4249f

complications of, 4233

débridement of soft tissue for, 4247, 4247f

definition, 4229, 4243

diagnostic studies, 4230, 4244–4245

differential diagnosis, 4231, 4245

endoscopic treatment, posterior approach,

4243–4249

complications of, 4249

outcomes of, 4249

pearls and pitfalls of, 4249

postoperative care of, 4249

imaging, 4230, 4230f, 4244–4245, 4244f

natural history, 4229–4230, 4244

nonoperative management, 4231, 4245

OS trignon resection for, 4247–4248,

4248f

outcomes of, 4233

pathogenesis, 4229, 4230f, 4243–4244,

4244f

patient history, 4230, 4244

pearls and pitfalls of, 4233

physical findings, 4230, 4244–4245

postoperative care, 4243, 4244

postoperative care/rehabilitation, 4241,

2022

outcomes, 4222

surgical management, 4231–4232, 4232f,

4245–4246, 4245f

positioning, 4231

posterior ankle endoscopy, 4232, 4232f

posterolateral approach, 4231

posterior cervical arthrodesis, pediatric,

1399–1407

anatomy, 1399, 1400f

complications, 1407

definition, 1399

diagnostic studies, 1401–1402, 1401f

differential diagnosis, 1402

imaging, 1401–1402, 1401f

natural history, 1400

nonoperative management, 1402

occipitocervical arthrodesis with iliac graft

and, 1403, 1403f, 1404f

occipitocervical arthrodesis with rib graft

and, 1404, 1405f

outcomes, 1407

pathogenesis, 1399–1400

Complications of, 4249, 4249f

Posterior cervical foraminotomy, 4562–4567.

See also Cervical spine,

Foraminotomy

adequate decompression in, confirmation of,

4566, 4566f

complications of, 4567

definition, 4562

osteotomy, 1400

differential diagnosis, 1402

pearls and pitfalls of, 4233

physical findings, 4230, 4244–4245

postoperative care, 4231, 4231f

postoperative care/rehabilitation, 4241,

2022

outcomes, 4222

surgical management, 4231–4232, 4232f,

4245–4246, 4245f

positioning, 4231

posterior ankle endoscopy, 4232, 4232f

posterolateral approach, 4231

posterior cervical arthrodesis, pediatric,

1399–1407

anatomy, 1399, 1400f

complications, 1407

definition, 1399

diagnostic studies, 1401–1402, 1401f

differential diagnosis, 1402

imaging, 1401–1402, 1401f

natural history, 1400

nonoperative management, 1402

occipitocervical arthrodesis with iliac graft

and, 1403, 1403f, 1404f

occipitocervical arthrodesis with rib graft

and, 1404, 1405f

outcomes, 1407

pathogenesis, 1399–1400

Complications of, 4249, 4249f

Posterior cervical foraminotomy, 4562–4567.

See also Cervical spine,

Foraminotomy

adequate decompression in, confirmation of,

4566, 4566f

complications of, 4567

definition, 4562

osteotomy, 1400

Complications of, 4249, 4249f

Posterior cervical foraminotomy, 4562–4567.

See also Cervical spine,

Foraminotomy

adequate decompression in, confirmation of,

4566, 4566f

complications of, 4567

definition, 4562

osteotomy, 1400

Complications of, 4249, 4249f

Posterior cervical foraminotomy, 4562–4567.

See also Cervical spine,

Foraminotomy

adequate decompression in, confirmation of,

4566, 4566f

complications of, 4567

definition, 4562

osteotomy, 1400

Complications of, 4249, 4249f

Posterior cervical foraminotomy, 4562–4567.

See also Cervical spine,

Foraminotomy

adequate decompression in, confirmation of,

4566, 4566f

complications of, 4567

definition, 4562

osteotomy, 1400

Complications of, 4249, 4249f

Posterior cervical foraminotomy, 4562–4567.

See also Cervical spine,

Foraminotomy

adequate decompression in, confirmation of,

4566, 4566f

complications of, 4567

definition, 4562

osteotomy, 1400

Complications of, 4249, 4249f

Posterior cervical foraminotomy, 4562–4567.

See also Cervical spine,

Foraminotomy

adequate decompression in, confirmation of,

4566, 4566f

complications of, 4567

definition, 4562

osteotomy, 1400

Complications of, 4249, 4249f

Posterior cervical foraminotomy, 4562–4567.
Posterior cervical foraminotomy (continued) 

discs to in, 4566

exposure and, 4564, 4564f

inferior articular facet resection in, 4565, 4565f

outcomes of, 4567

pearls and pitfalls of, 4567

postoperative care of, 4567

superior articular facet resection in, 4565, 4565f

wound closure in, 4566

Posterior cervical fusion, with instrumentation, 4576–4584

complications of, 4583–4584

interspinous wiring and, 4577–4580, 4577f, 4579f, 4580f

outcomes of, 4583

pearls and pitfalls of, 4583

posterior soft tissue release and, 1679, 1679f

medial soft tissue release and, 1678–1679, 1678f

outcomes and, 1681

pearls and pitfalls in, 1681

posterior soft tissue release and, 1678, 1678f

postoperative care and, 1681

realigning bones of foot in, 1679, 1680f

repair of tendons in, 1680

Posterior lateral rotatory instability (PLRI), 3392

Posterior lateral rotatory instability release, for clubfoot, resistant, 1674–1681

complications in, 1681

fixation in, 1680, 1680f

incision in, 1677, 1677f

lateral soft tissue release and, 1679, 1679f

medial soft tissue release and, 1678–1679, 1678f

Posterior tibial tendon dysfunction (PTTD) 

anatomy, 3814

débridement, 3818–3819, 3818f

diagnostic studies, 3815

differential diagnosis, 3815

FDI transfer for stage II, 3814–3821

complications of, 3821

outcomes of, 3821

pearls and pitfalls of, 3821

postoperative care of, 3821

techniques of, 3818–3819, 3818f

imaging, 3815, 3816f

medial displacement calcaneal osteotomy for stage II, 3814–3821

complications of, 3821

outcomes of, 3821

pearls and pitfalls of, 3821

postoperative care of, 3821

techniques of, 3817, 3817f

natural history, 3814, 3815f

nonoperative management, 3815

pathogenesis, 3814, 3814f

patient history, 3815

physical findings, 3815

plantarflexion osteotomy of medial cuneiform and, 3819–3821, 3820f

surgical management, 3815–3816

Postero lateral arthrodesis. See also Arthrodesis for spondylolisthesis, 1474–1481

bone graft and, 1478

closure and, 1478

complications of, 1479

decompression and, 1477

depression and, 1477

exposure and, 1477, 1477f

instrumentation and, 1477

outcomes of, 1479

pearls and pitfalls of, 1478

postoperative care of, 1478–1479, 1479f

rod placement and, 1478, 1478f

Postero lateral corner (PLC) 

anatomy, 381, 382f

injuries

advancement for, 386, 386f

anatomy and, 381, 382f

augmentation of, 385, 386f

biceps tenodesis technique for, 387–389, 387f, 388f, 389f

complications of, 390

diagnosis studies, 383

differential diagnosis of, 384

direct primary repair of, 385, 385f

exposure for, 384–385, 385f

history of, 382–383

imaging of, 383, 383f

management of, 381–390

natural history of, 382

nonoperative management of, 384

outcomes of, 390

pathogenesis of, 381–382

pearls and pitfalls of, 390

physical findings of, 382–383

postoperative care of, 390

reconstruction of, 386

surgical management of, 384

Postero lateralis cutaneous nerve

anatomy, 1803

proximal humerus, 1803

resection with endoprosthetic reconstruction and, 1959, 1959f

shoulder girdle, 1771
Proximal chevron osteotomy
Proximal crescentic osteotomy, hallux valgus
Prosthetic reconstruction, resection with,
Proximal femur, 859–860
capsule/soft tissue closure, 3548, 3548
bunion deformity, 3545
plate fixation with, 3545–3548
submuscular plating, femoral shaft fracture,
pediatric, 1111, 1111/
Proximal chevron osteotomy
capsule deforrtiy, 3545
submuscular plating, femoral shaft fracture,
pediatric, 1111, 1111/
Proximal crescentic osteotomy, hallux valgus
Prosthetic reconstruction, resection with,
Proximal femur, 859–860
capsule/soft tissue closure, 3548, 3548/
fixation, 3547, 3547/
metsartal, 3546, 3546/
plate fixation with, 3545–3548
lateral joint structures for, 3546, 3546/
pelvic and pittfalls of, 3548
postoperative care of, 3548
skin/capsular incision for, 3545, 3545
Proximal femoral replacement
THA, revision with femoral bone loss, 823–830
definition of, 823, 823/
techniques, 826, 826/
THA and, 805–806, 805/
Proximal femur, 839–860
allograft, fluted stems used with, 820–821
iliopsoas tenotomy and, 1324, 1324
Proximal hamstring.
reconstruction and, 1969, 1969/
tumor removal and, 1968, 1968/
type I, 1968, 1968/
type II, 1968, 1968/
resections, wound closure and, 1969, 1969/
Proximal hamstrings. See also Hamstrings
muscle group (posterior thigh)
anatomy, 1322
definition, 1322
lengthening, pediatric, 1314, 1314/
completion/wound care and, 1325
compliactions of, 1325
diagnostic studies for, 1322
differential diagnosis and, 1322
exposure and, 1323, 1323/
iliosposa tenotomy and, 1324, 1324/
imaging, 1918–1919
MBI’s, 2034
surgical management of, 2036–2039,
2036f, 2037f, 2038f, 2039f
pathogenesis of, 1187
resection with endoprosthetic
reconstruction, 1917–1927
background, 1917, 1918/
complications, 1927
endoprosthetic reconstruction techniques,
1924–1925, 1924f, 1925f
indications for, 1917–1918, 1919f, 1920f
outcomes, 1927
pears and pittfalls, 1927
postoperative care, 1927
soft tissue reconstruction techniques,
1925–1926, 1926f
surgical management of, 1919
techniques, 1920–1926
tumor resection techniques, 1920–1922,
1921f, 1922f, 1923f
rotational osteotomy, pediatric, 1187–1194
complications of, 1194
definition of, 1187
distal, 1193
LCDC plate for, 1193
blade plate placement and, 1199, 1199/
guided wire placement and, 1198, 1198/
patient history and, 1196–1197
natural history of, 1196
imaging for, 1197
patient history and, 1196–1197
surgical management of, 1197
postoperative care, 1197, 1197 /
resection, 1190
resections, wound closure and, 1196, 1196/
surgical technique for, 1191
surgical technique for, 1191
performing osteotomy and, 1199, 1199/
incision for, 1322
peroperative care for, 1201, 1201f
surgical management and, 1197, 1197/
Proximal fibula. See also Fibula
reconstruction and, 1969, 1969f
tumor removal and, 1968, 1968f
type I, 1968, 1968f
type II, 1968, 1968f
resections, wound closure and, 1969, 1969f
Proximal humerus fractures
anatomy, 1329
indications, 1329
integrated screw, 543, 543f, 544f
natural history and, 533
nonoperative management of, 534–535
outcomes of, 545–546
pathogenesis for, 533
patient history and, 533–534
pears and pithfalls for, 545
physical findings and, 533–534
portal acquisition/protection and,
539–540, 540f
positioning for, 537, 537f
postoperative care of, 545
precision portal placement/trajectory
control and, 539, 539f
preoperative planning of, 535–537,
536f, 537f
single-screw/single-device designs for,
542, 542f
surgical management of, 535–537, 535f,
536f, 537f
two-screw construction, 542, 542f
wound closure, 544
Proximal humerus, anatomy, 1329
anatomy, 1323, 1323f
outcomes of, 1325
pathogenesis and, 1322
physical findings and, 1322
postoperative care of, 1325
techniques for, 1324, 1324f
natural history, 1322
Proximal humerus. See also Humerus
anatomy, 1786, 1787f, 1816, 3191, 3191f,
3200–3201, 3217, 3217f
biopsy, 1787–1788, 1788f, 1796f, 1797f
endoprosthetic reconstruction, 1732, 1734f
expandable prosthesis, implantation of,
surgical technique for, 1745
fracture, pediatric, 1084–1085, 1084f
imaging, 1795–1797, 1796f
innervation, 3209–3210
limb-sparing procedures for, 1793
muscle reconstruction, 1803
osteology, 3209, 3209f
prosthetic reconstruction, 1803
resection
alglofl ag prosthesis composite and,
1786–1792
classification system for, 1793, 1794f
complications, 1791
dual suspension technique, 1797–1801,
1803f
imageing of, 1787–1788
indications, 1786
outcomes, 1792
patient history and, 1786–1787
physical findings, 1786–1787
postoperative care, 1791–1792
staging studies for, 1787–1788
surgical management of, 1788, 1789f
techniques, 1797–1801, 1798f, 1802f
techniques for, 1789–1791
total humeral, 1803
type I, 1801–1803, 1804f
type V, 1803, 1805f
resection with endoprosthetic replacement,
1793–1806
anatomic considerations, 1793–1795
imageing and, 1795–1797, 1796f
indications for, 1793, 1794f
staging studies for, 1795–1797
soft tissue reconstruction, 1801
1793, 1794f
anatomy, 1323, 1323f
outcomes of, 1325
pathogenesis and, 1322
physical findings and, 1322
postoperative care of, 1325
techniques for, 1324, 1324f
natural history, 1322
Proximal humerus fractures (continued)
surgical wound closure for, 3223
trial reduction for, 3222, 3222f
tuberosity mobilization for, 3219–3220, 3220f
imaging, 3192–3193, 3193f, 3201, 3210, 3218, 3218f
intramedullary fixation of, 3209–3216
comlications and, 3216
entry site reaming and, 3214
fragment reduction and, 3213, 3213f
guidewire placement and, 3213–3214
interlocking screw, 3214–3215, 3215f
K-wire placement and, 3212, 3212f
nail insertion and, 3214, 3214f
pears and pitfalls of, 3215–3216
postoperative care for, 3216
tuberosity, 3215
natural history, 3192, 3192f, 3210, 3217
nonoperative management, 3193, 3201, 3218
open reduction and suture fixation for, 3204, 3204f
ORIF, 3200–3207
anatomic plating for, 3204–3206, 3204f, 3205f, 3206f
complications of, 3207
outcomes of, 3207
pears and pitfalls of, 3206
postoperative care for, 3207
pathogenesis, 3192, 3201, 3210, 3210f, 3217
patient history, 3192, 3201, 3210, 3217
percutaneous pinning for, 3191–3199
complications of, 3199
outcomes of, 3198–3199
pears and pitfalls of, 3198
postoperative care of, 3198
physical findings, 3192, 3201, 3210, 3217
surgical management, 3193–3195, 3194f, 3201–3202, 3202f, 3210–3211, 3211f, 3218–3219, 3219f
surgical neck fractures, percutaneous pinning for, 3195–3196, 3195f, 3196f
tuberosity fractures and, isolated, fixation of, 3202, 3203f
tuberosity fractures and, three-part greater, percutaneous pinning for, 3196–3197, 3196f
Proximal interphalangeal (PIP) fracture-dislocations
anatomy and, 2420, 2420f, 2436–2437, 2436f
classification, 2420–2421, 2421f
definition, 2420, 2436
diagnostic studies, 2405–2406, 2422, 2423
differential diagnosis, 2406, 2422, 2438
dorsal block pinning, 2404–2409
extension block pinning, 2407–2408, 2408f
closure for, 2442
compliations of, 2443
fracture site preparation for, 2439–2440, 2440f
graft fixation for, 2441–2442, 2442f
harvesting hamate graft for, 2440–2441, 2441f
outcomes of, 2443
pears and pitfalls of, 2443
postoperative care of, 2443
imaging, 2405–2406, 2422, 2422f, 2438, 2438f
natural history, 2405, 2421, 2437, 2437f
nonoperative management, 2406, 2406f, 2412–2413, 2422–2423, 2438
ORIF, 2420–2429
techniques for, 2424–2429, 2424f, 2425f, 2426f, 2427f, 2428f
pathogenesis, 2404–2405, 2420–2421, 2421f, 2437, 2437f
postoperative care of, 2424, 2424f, 2437, 2437–2438
physical findings, 2405, 2405f, 2421–2422, 2421f, 2437–2438
surgical management, 2407, 2423–2424, 2423r, 2438–2439
Proximal interphalangeal (PIP) joint anatomy, 2404, 2404f, 2410–2411, 2411f, 2420, 2420f, 2436–2437, 2436f, 2736, 2744, 2744f, 2752, 2972, 2973f
arthrits, 2752–2753
nonoperative management of, 2753–2754
pathogenesis of, 2752–2753
surgical management of, 2754–2755, 2756f
arthrosis, 2752–2764
complications of, 2764
diagnostic studies for, 2753
differential diagnosis of, 2753
fixation methods for, additional, 2762
hammertoe correction with, 3702–3704, 3702f, 3703f, 3704f
imaging for, 2753
outcomes of, 2764
patient history and, 2753
pears and pitfalls of, 2764
physical findings for, 2753
plate fixation for, 2762, 2763f
postoperative care of, 2764
screw fixation, compression for, 2763, 2763f
techniques for, 2758, 2758f
arthroplasty, silicone implant, 2740–2741, 2741f
complications of, 2742
definition, 2736
diagnostic studies, 2737, 2737f
differential diagnosis, 2737
imaging, 2737, 2737f
injuries, 2404
anatomy and, 2410–2411, 2411f
definition of, 2410, 2410f
diagnostic studies for, 2412
differential diagnosis of, 2412
dynamic external fixation of, 2410–2419
dynamic external fixation of, complications and, 2417
dynamic external fixation of, outcomes and, 2417
dynamic external fixation of, pearls and pitfalls for, 2417
dynamic external fixation of, postoperative care for, 2417
dynamic external fixation of, techniques for, 2414–2418, 2414f, 2416f, 2417f
imaging of, 2412, 2413f
nonoperative management of, 2412–2413, 2413f
pathogenesis of, 2411, 2411f
patient history for, 2422
physical findings for, 2411–2412
surgical management of, 2413–2414
joint contractures, post-traumatic definition of, 2972
diagnostic studies for, 2973–2974
differential diagnosis of, 2974
Index

Q
Quadriceps
- resections, 1991–1999
- background, 1991
- biceps femoris transfer and, 1997
- complications, 1999
- imaging, 1992
- indications, 1991, 1992r
- limited, 1994
- outcomes, 1998–1999
- pearls and pitfalls, 1998
- position, 1994
- postoperative care/rehabilitation and, 1999
- residual large defects and, 1997
- semitendinosus muscle transfer and, 1997
- soft tissue defects and, 1997
- soft tissue reconstruction and, 1997
- staging studies, 1992
- snip, revision TKA and, 998, 999f
- turnover, revision TKA with extensive exposure, V-Y quadroplasty and, 986, 987f

Quadriceps recession, percutaneous, CDK and, surgical repair of irreducible, 1226, 1226f

Quadriceps tendon ruptures acute
- repair of, 407–412
- repair of, complications, 412
- repair of, musculotendinous/midtendinous area, 410, 410f
- repair of, outcomes, 412

Quadriceps tendon rupture, using tendon graft, 2113

Quadriceps tenotomy, mini-open, CDK and, surgical repair of irreducible, 1226–1227, 1227f

R
RA. See Rheumatoid arthritis
Radial artery, elbow and, 3052
Radial collateral ligament (RCL)
disruptions of, thumb MCP joint, 2342–2348
anatomy of, 2342
arthroscopic and open primary repair of, 2342–2348

Radial diaphyseal malunions
anatomy and, 2149, 2149f
definition, 2149
diagnostic studies, 2150–2151
differential diagnosis, 2151
imaging, 2150–2151, 2150f
natural history, 2150
nonoperative management, 2151
osteotomy, corrective, 2149–2155
complications of, 2155
dorsal approach to, 2152, 2153f
outcomes of, 2155
pearls and pitfalls of, 2154
postoperative care of, 2153
reduction, plating, bone grafting in, 2153–2154, 2153f
volar approach to, 2152, 2152f
pathogenesis, 2149–2150
patient history, 2150
physical findings, 2150
surgical management, 2151, 2151f

Radial diaphyseal nonunions
anatomy and, 2156, 2156f
definition, 2156
diagnostic studies, 2157
differential diagnosis, 2157
imaging, 2157, 2157f
natural history, 2156
nonoperative management, 2157
operative treatment, 2156–2161
complications of, 2161
outcomes of, 2161
pearls and pitfalls of, 2161
postoperative care of, 2161
pathogenesis, 2156
patient history, 2156–2157

Pears and pitfalls of, 2806
postoperative care of, 2807
radial styloectomy, 2805, 2805f
reduction assessment for, 2805
wound closure, 2806
wrist degeneration and diagnostic studies for, 2803
differential diagnosis of, 2803
imaging of, 2803
pathogenesis of, 2802, 2802f
physical findings for, 2802
surgical management of, 2803

Proximal tibia
anatomy, 1953
bone cut, TKA, using navigation and, 939–940, 939f, 940f
epiphysiodesis, 1238–1243
extensor mechanism, 1953
- reconstruction of, 1960, 1960f, 1961f, 1962f
- knee joint, 1953
- exposure of, 1958, 1958f
- mapping, TKA, using navigation and, 936, 936f, 937f
- medial gastrocnemius flap, reconstruction of, 1960, 1960f, 1961f, 1962f
- popliteal trifurcation, 1953
- resection with endoprosthesis reconstruction, 1953–1963
- anatomy, 1953
- background, 1953
- complications, 1963
- extensor mechanism, reconstruction and, 1960, 1960f, 1961f, 1962f
- incision, 1956, 1956f
- knee joint, exposure of, 1958, 1958f
- outcomes, 1963
- pears and pitfalls, 1963
- popliteal fossa, exploration of, 1957, 1957f
- postoperative care, 1963
- prosthetic reconstruction, 1959, 1959f
- proximal tibia removal, 1958, 1958f
- staging studies, 1954–1955, 1955f
- surgical management for, 1955
- techniques, 1956–1962
- vascular bundle, detachment of, 1957, 1957f
- tibiofibular joint, 1953
- Proximal tibial osteotomy, supramalleolar osteotomy with, 1954

Pseudarthrosis. See Congenital pseudarthrosis, tibial
Pseudo-aneurysms, 2994. See also Aneurysms
Pseudocapsules, musculoskeletal tumor, 1719, 1720f

Psoas
anatomy, 1310, 1311f
- contractures, 1310
- natural history of, 1310
- pathogenesis of, 1310
- intramuscular lengthening of, TIO and, 1545
- lengthening, 1313, 1313f, 1314f
- PT. See Pronator teres
- PTT. See Posterior tibial tendon

Pubis
anatomy, 1879
- imaging, 1860
Radial diaphyseal nonunions (continued) physical findings, 2156–2157 plate fixation for treatment of, 2158–2160, 2159f, 2160f compression, 2160, 2160f surgical management, 2157–2158

Radial dysplasia, pediatric anatomy, 1376, 1376f definition, 1376 diagnostic studies, 1377 imaging, 1377 natural history, 1376–1377 nonoperative management, 1377 pathogenesis, 1376 patient history, 1377 physical findings, 1377, 1377f radial deviation of wrist and, release of, 1378, 1378f reconstruction, 1376–1379 complications of, 1379 outcomes of, 1379, 1379f pearls and pitfalls of, 1378 postoperative care for, 1379 surgical management, 1377

Radial forearm, flap, 2951–2952, 2952f, 2954–2955, 2955f

Radial head anatomy, 3343, 3344f, 3352, 3352f Monteggia fractures and management of, 3388, 3388f replacement, 3352–3361 common extensor split and, 3355, 3355f, 3356f completion of, 3359 complications of, 3361 definition of, 3352 diagnostic studies for, 3353 differential diagnosis of, 3353 imaging and, 3353 Kocher approach to, 3350, 3350f lateral soft tissue closure and, 3358, 3358f natural history of, 3352 nonoperative management of, 3353 outcomes of, 3360–3361 pathogenesis of, 3352 patient history and, 3352–3353 pearls and pitfalls of, 3360 physical findings and, 3352–3353 postoperative care of, 3360 radial head/neck preparation and, 3356, 3356f, 3357f surgical approach to, 3354, 3355f surgical management of, 3353–3354, 3354f techniques for, 3357, 3357f

Radial head excision, 1384, 1384f


Radial neck fractures, pediatric anatomy, 1058, 1066f definition, 1066, 1066f diagnostic studies, 1067, 1067f, 1068f, 1068t differential diagnosis, 1068 imaging, 1067, 1067f, 1068f, 1068t intramedullary reduction techniques for, 1066–1074, 1070–1071, 1070f, 1071f, 1072f, 1073f complications of, 1072, 1072f outcomes of, 1073 natural history, 1066–1067 nonoperative management, 1068 pathogenesis, 1066, 1067f patient history, 1067 percutaneous joystick techniques for, 1066–1074 complications of, 1072, 1073f outcomes of, 1073 pearls and pitfalls of, 1073 techniques for, 1069–1070, 1069f, 1070f physical findings, 1067 postoperative care, 1073 surgical management, 1068, 1068f techniques for, 1069–1071, 1069f, 1070f, 1071f, 1072f, 1073f


Radial nerve palsy anatomy and, 2722–2723, 2722f definition, 2722 diagnostic studies, 2723 differential diagnosis, 2723 imaging, 2723 natural history, 2723 nonoperative management, 2723 pathogenesis, 2722 patient history, 2723 physical findings, 2723 surgical management, 2723 tendon transfers, 2722–2728 complications of, 2728 finger extension, 2724–2725, 2725f, 2726f finger extension/thumb abduction, 2727 outcomes of, 2728 pearls and pitfalls of, 2727–2728 postoperative care of, 2728 thumb extension, 2726, 2727f wrist extension, 2724, 2724f

Radial styloid, arthritis and, 2795

Radial styloidectomy anatomy, 2795–2796, 2795f arthroscopic, 2795–2801 complication/neck ext, 2801 outcomes of, 2801 pearls and pitfalls of, 2800 postoperative care of, 2800 techniques for, 2800, 2800f definition, 2795 open, 2795–2801 complications of, 2801 outcomes of, 2801 pearls and pitfalls of, 2800 postoperative care of, 2800 techniques for, 2799, 2799f PRC, 2805, 2805f Radiation therapy adjuvant, MBD, 1754 Ewing sarcoma, 1715 MBD, 1752–1754 STS, 1716 Radiulopathy, cervical, 4543–4544 Radiocarpal arthodesis, 2813 Radiography, plain AKA, 2061, 2062f axillary space, 1826 BKA, 2067, 2068f chondrosarcomas, 1711, 1712f distal humerus, 1808–1809
Resection with endoprosthetic reconstruction

supra-acetabular metastatic lesion,

outcomes, 2026

indications, 2023

background, 1953

dual suspension technique, 1979–1801, 1803f

femoral, 1920–1922, 1921f, 1922f, 193f

Tikhoff-Linberg, 1766

Reconstruction with endoprosthetic reconstruction
distal femoral, 1929–1952

anatomy, 1929–1931, 1929f

anterior approach, 1942–1946, 1942f, 1944f, 1945f/19f

background, 1929


imaging, 1931–1934, 1932f, 1933f

indications, 1930f, 1931

longitudinal lateral approach, 1942

longitudinal medial approach, 1935–1941, 1937f, 1939f, 1941f

outcomes, 1949

patient history/physical findings and, 1931, 1931f

pearls and pitfalls, 1948

postoperative care, 1947

staging studies, 1931–1934, 1932f, 1933f

surgical management, 1934–1935, 1934f, 1935f

proximal femur, 1917–1927

background, 1917, 1918f

complications, 1927

diagnostic reconstruction techniques, 1924–1925, 1924f, 1925f

imaging for, 1918–1919

indications for, 1917–1918, 1919f, 1920f

outcomes, 1927

pearls and pitfalls, 1927

postoperative care, 1927

soft tissue reconstruction techniques, 1923–1924, 1923f

staging studies for, 1918–1919

surgical management of, 1919

techniques, 1920–1926

tumor resection techniques, 1920–1922, 1921f, 1922f, 1923f

proximal humerus, 1793–1806
classification system for, 1793, 1794f
dual suspension technique, 1797–1801, 1803f

diagnostic reconstruction techniques, 1793–1806

anatomic considerations, 1793–1795

imaging of, 1795–1797, 1796f

indications for, 1793, 1794f

staging studies for, 1795–1797

techniques, 1797–1801, 1798f, 1802f

Resection with endoprosthetic reconstruction, distal humerus, 1807–1815

complications, 1815
diagnostic studies, 1808–1809

imaging, 1808–1809

indications/contraindications, 1808

outcomes, 1814–1815, 1814f

postoperative care, 1814

surgical management, 1810

Resurfacing arthroplasty.

See also Arthroplasty

Artelon, 2786, 2786f, 2787f

pyrocarbon, 2787, 2787f

thumb CMC joint, 2784–2790

Artelon, 2786, 2786f, 2787f

compartments, 2790

outcomes of, 2790

pearls and pitfalls of, 2789

postoperative care of, 2789–2790

pyrocarbon, 2787, 2787f

Retinacular graft reconstruction, ECU subluxation

2647, 2647f

Retinacular sling reconstruction

alternate, ECU subluxation, 2647, 2647f

ECU subluxation, 2646, 2646f

Retinacularplasty. See Superior peroneal retinacularplasty

Retrocerebrial bursoscopy, 4419–4422

completions/wound closure for, 4421

complications, 4422

outcomes, 4422

pearls and pitfalls, 4421

portal placement/exposure and, 4420, 4420f

postoperative care, 4422

resection/decompression for, 4420–4421, 4421f

Retrocerebral débridement, IAT, 4439, 4439f

Retrocerebral decompression, calcific insertion and tendinopathy, 4435, 4435f

Retrograde IMN

femoral, 558–567

alternative techniques, 567f

anatomy and, 558, 559f

approach to, 562

classification of, 559–561, 559f, 559f,
560f, 561f

complications of, 567

contraindications for, 561

definition of, 558

diagnostic studies for, 558–559

fracture reduction and, 563

guardwire and, passing, 563

guardwire placement and, 563

imaging for, 558–559

nail placement and, 564, 565f

outcomes of, 567

pathogenesis and, 558

patient history and, 558

pearls and pitfalls of, 566

physical findings and, 558

positioning for, 562

postoperative care for, 566–567

preoperative planning for, 561–562, 562f

reaming and, 564, 564f

relative indications for, 559–561, 559f,
559f, 560f, 561f

screw fixation and, 565

starting hole and, creating/reaming, 563

surgical management of, 559–562, 559f,
559f, 560f, 561f, 562f

wound closure and, 566

flexible, femoral shaft fracture, pediatric, 1107–1108, 1108f,

fractures, 3240–3241

Retroversion, humeral, 3221, 3221f

Rett syndrome, spinal deformity and, 1449

Revascularization

definition, 2888

digital, 2888–2898

arterial repair for, 2894–2895, 2895f, 2895f

bone fixation for, 2893–2894, 2893f

complications of, 2898

diagnostic studies for, 2890

tendon repair for, 2894

flexor tendon repair for, 2894

imaging for, 2890, 2890f

natural history and, 2888

nerve repair for, 2895, 2896f

outcomes of, 2897–2898, 2897f

pathogenesis and, 2888

patient history and, 2889–2890

pearls and pitfalls of, 2897

physical findings and, 2889–2890, 2890f,

preparation of amputated part for, 2891–2892, 2891f

preparation of stump for, 2892–2893, 2892f
Revision Agility TAA, 4102–4122. See also Total ankle arthroplasty

anatomy and, 4102

definition, 4102

infection, 4119–4122

definition, 4102

anatomy and, 4102

natural history, 4103–4104, 4104

malleolar fracture, 4104–4109

nonoperative management of, 4119

outcomes of, 4122

patient history of, 4119

pains and pitfalls of, 4122

physical findings for, 4109

postoperative care of, 4122

surgical management of, 4119–4120

ligament instability, 4109–4113

complications of, 4113

deltoid reconstruction for, 4110–4112, 4110

diagnostic studies for, 4109

differential diagnosis of, 4110

imaging of, 4109

nonoperative management of, 4110, 4110f

outcomes of, 4113

pathology of, 4119

pains and pitfalls of, 4113

postoperative care of, 4113

reconstruction of lateral, 4112–4113

surgical management of, 4110

malleolar fracture, 4104–4109

complications of, 4109

diagnostic studies for, 4104

differential diagnosis of, 4104

imaging of, 4104, 4104f

nonoperative management of, 4104–4105

open repair of acute medial, 4105, 4105f

open repair of late medial, 4107–4109, 4107f

open repair of lateral, 4106, 4106f

outcomes of, 4109

patient history of, 4104

pains and pitfalls of, 4109

physical findings for, 4104

postoperative care of, 4109

surgical management of, 4105, 4105f

natural history, 4103–4104, 4104f

pathogenesis, 4102–4103, 4103f

prosthesis subsidence, 4113–4119

complications of, 4119

diagnostic studies for, 4114

differential diagnosis of, 4114

imaging of, 4114, 4114f, 4115f

nonoperative management of, 4114

outcomes of, 4119

patient history of, 4113–4114

pains and pitfalls of, 4118

physical findings of, 4113–4114

postoperative care of, 4119

surgical management of, 4114–4115

talar, 4115–4117, 4116f

tibial component, 4118, 4118f

Revision first MTP joint arthrodesis, 3650–3655

anatomy and, 3650

case studies of, 3653, 3653f

complications, 3654–3655

definition, 3650

diagnostic studies for, 3651

using dorsal titanium contoured plate, 3652

fixation of arthrodesis and, 3654

hallux positioning and, 3654

imaging for, 3651

metatarsal and, distal first, 3652, 3652/

nonoperative management and, 3651

outcomes, 3651

pathogenesis of, 3650, 3650f, 3651f

patient history and, 3650

pains and pitfalls, 3654

phalanx and, proximal, 3652, 3652/

physical findings for, 3650

postoperative care, 3654

surgical management and, 3651

Revision THA. See also Total hip arthroplasty

with acetabular bone loss, antiprotrusio

cage, 836–842

acetabular exposure and, 832, 832f

anatomy and, 836

acetabular preparation and, 832, 833

acetabular reconstruction and, 827

acetabular bone loss, impaction

cage implantation and, 840–841, 840f

compliations, 842

definition of, 836

diagnostic studies for, 836

differential diagnosis, 836

definition of, 836

complications, 842

surgical management, 836

natural history of, 831

complications, 835

nonoperative management of, 832

natural history of, 831

pathogenesis of, 836

patient history/physical findings, 836

physical findings and, 834–842

postoperative care, 842

reconstructive technique, intraoperative
determination, 839, 839f

surgical management, 837–838, 837f

techniques for, 837–841

trabecular metal augmentation and, 839–840, 840f

with acetabular bone loss, impaction

allografting, 831–835

acetabular bone reconstruction and, 833, 833f

acetabular exposure and, 832

acetabular grafting and, 832, 833f

anatomy of, 831, 831f

bone grafting preparation and, 832, 833f

cemented cup insertion and, 834, 834f

complications of, 835

definition of, 831

diagnostic studies for, 831–832

differential diagnosis of, 832

imaging and, 831–832

natural history of, 831

nonoperative management of, 832

outcomes of, 835

pathogenesis of, 831

patient history and, 831

pains and pitfalls, 835

physical findings for, 831

postoperative care of, 835

surgical management of, 832

techniques, 832–834

with femoral bone loss, proximal femoral

osteotomy, 819–820

natural history of, 816

nonoperative management of, 817

open reduction for, 819–820

osteotomy for, 819–820, 820f

outcomes of, 821–822

pathogenesis of, 815

patient history and, 815–817, 816f

pains and pitfalls, 821

physical findings, 815–817

postoperative care for, 821

routine revision with diaphyseal
defect, 819

routine revision without diaphyseal
defect, 818, 818f, 819f

surgical management of, 817–818

techniques for, 818–821

with well-fixed components, 2564–2570

acetabular reconstruction and, 2568–2569,

2569f

anatomy and, 2564, 2564f

approach to, 2566–2567, 2566f

complications, 2570

definition of, 2564, 2564f

diagnostic studies for, 2565, 2566f

treated trochanteric osteotomy, 2567–2568,

2567f

imaging for, 2565, 2566f

natural history of, 2565

outcomes of, 2570

pathogenesis of, 2565, 2565f

pains and pitfalls, 2570

physical findings, 2565

postoperative care, 2570

surgical management of, 2565–2566

techniques for, 2566–2569

Revision TKA

with extensile exposure, tibial tubercle

osteotomy, 980–984

anatomy and, 980, 980f

definition of, 980

diagnostic studies for, 981

imaging of, 981

natural history of, 980–981

osteotomy reattachment with screws and,

984, 984f

osteotomy reattachment with wire and,

983, 983f

outcomes of, 984

pathogenesis of, 980

patient history and, 981
pools and pitfalls of, 984
physical findings for, 981
postoperative care of, 984
surgical management of, 981, 981f
with extensor exposure, V-Y quadruplasty, 986–988
complications of, 988
definition of, 986
outcomes of, 988
pools and pitfalls of, 987
postoperative care for, 987–988
quadriceps turnndown and, 986, 987f
standard approach to, 986
tibial tubercle osteotomy and, 986–987
V-Y quadricepsplasty and, 987, 987f
with extensor mechanism repair, 989–993
allograft placement and, 992, 992f
allograft preparation and, 991, 991f
anatomy and, 989
approach to, 990, 990f
calcaneal bone block and, 991, 992f
complications of, 993
definition of, 989
diagnostic studies for, 989, 989f
differential diagnosis of, 989
imaging for, 989, 989f
natural history and, 989
nonoperative management of, 989–990
outcomes of, 990
pathogenesis and, 989
patient history and, 989
pools and pitfalls of, 993
physical findings and, 989
postoperative care of, 993
primary repair and, 991, 991f
surgical management of, 990, 990f
tibial preparation and, 991, 991f
wound closure and, 993, 993f
with femoral bone loss, augments
anatomy of, 942, 942f
cement bone and, 945
complications of, 948
definition of, 942
diagnostic studies for, 943
differential diagnosis of, 943
distal femoral allograft for, 946, 947f
imaging for, 943
metal augment for, 944–945, 945f
Morchesized allograft for, 945
morselized allograft for, 945
natural history of, 943
nonoperative management of, 943
outcomes of, 948
pathogenesis of, 942–943, 943f
patient history and, 943
pools and pitfalls of, 947–948
physical findings for, 943
postoperative care of, 948
structural allograft for, 946, 946f
surgical management of, 944, 944f
techniques for, 944–947, 945f, 946f, 947f
with femoral bone loss, distal femoral
replacement, 962–968
anatomy and, 962
bone cement for, 964, 964f
bulk allograft replacement, 966–967, 966f, 967f
bulk femoral head reconstruction and, 965, 965f, 966f
complications of, 968
definition of, 962
diagnostic studies for, 962–963
differential diagnosis of, 963
femoral component in, 964, 965f
imaging for, 962–963
metal augment for, 964, 965f
morselized allograft for, 964, 964f
natural history of, 962
nonoperative management of, 963
outcomes of, 968
pathogenesis of, 962
patient history and, 962
pools and pitfalls of, 967–968
physical findings and, 962
postoperative care of, 968
surgical management of, 963–964
tumor reconstruction prosthesis for, 967
with removal of well-fixed components,
975–977
anatomy and, 975
complications of, 979
definition of, 975
diagnostic studies for, 975
differential diagnosis of, 975
exposure and, 976
femoral component removal and,
977–978
imaging for, 975
nonoperative management of, 975
patella component removal and, 972f, 978
pathogenesis of, 975
patient history and, 975
pools and pitfalls of, 979
physical findings and, 975
stemmed implant removal and, 979
surgical management of, 976, 976f
tibial component polyethylene removal and,
976, 977f
tibial component removal and, 977, 977f
stiffness correction with, 994–1003
anatomy and, 994, 994f
closure and, 1001, 1002f
complications of, 1003
component removal and, 999, 999f
definition of, 994
diagnostic studies and, 995–996
physical findings and, 995
femoral trial size/augments and,
choosing, 1000–1001, 1001f
imaging and, 995–996, 996f
natural history of, 995
nonoperative management of, 996
outcomes of, 1002, 1003
parapatellar arthroscopy, medial with
complete intra-articular release and,
997–998, 998f
pathogenesis of, 994–995
patient history and, 995
pools and pitfalls of, 1002
physical findings of, 995
postoperative care of, 1002
quadriceps snip and, 998, 999f
surgical management of, 996–997, 997f
thibal platform for, creating, 1000, 1000f
tibial resection and posterior release in,
999, 1000f
trialing and, 1001, 1002f
with tibial bone loss, bone grafting for,
969–974
anatomy and, 969
complications of, 974
definition of, 969
diagnostic studies for, 969
differential diagnosis of, 969–970
imaging of, 969, 970f
impaction grafting and, 971, 971f, 972f
natural history and, 969
nonoperative management of, 970
outcomes of, 974
pathogenesis and, 969
patient history and, 969
pools and pitfalls of, 973
physical findings for, 969
postoperative care of, 974
structural femoral head allograft and,
972, 973f
surgical management of, 970, 970f
with tibial bone loss, metal augment for
anatomy of, 949–950, 950f
approach to, 953, 954f
block or step augment, medial/lateral and,
956, 956f
complications of, 960–961
component explanation and, 954
definition of, 949
diagnostic studies for, 952
differential diagnosis of, 953
full-width wedge augment and, 956, 956f
hemil wedge augment, medial/lateral and,
954, 955f
imaging for, 952, 952f
metaphyseal cone augmentation and,
957–958, 957f
natural history of, 951–952
nonoperative management of, 953
outcomes of, 960
pathogenesis of, 950–951
patient history and, 952
pools and pitfalls of, 959
physical findings and, 952
postoperative care for, 960
surgical management of, 953
techniques for, 953–959, 954f, 955f,
956f, 957f, 958f, 959f
trabecular metal augmentation, free and,
958, 958f, 959f
Rheumatoid arthritis (RA)
definition, 2608, 3420
diagnostic studies, 3420–3422, 3421f
differential diagnosis, 3422
forefoot, 3736
diagnostic studies for, 3736
differential diagnosis of, 3736–3737
imaging of, 3736, 3737f
natural history of, 3736
nonoperative management of, 3737
pathogenesis of, 3736
patient history and, 3736, 3736f, 3737f
physical findings for, 3736, 3736f, 3737f
surgical management of, 3737, 3737f
imaging, 3420–3422, 3420f, 3421f
MCP joint, 2744–2746
natural history, 2608–2609, 3420
nonoperative management, 3422
pathogenesis, 2608, 3420
patient history, 3420
physical findings, 3420
PIP joint, 2744–2746
surgical management, 3422–3423
anesthetic considerations for, 2102, 2102f
TEA for, 3420–3422
assembly in, 3429, 3429f
bone graft in, 3429, 3429f
cementing in, 3428, 3428f
complications of, 3432
exposure in, 3424, 3424f
humeral component in, 3429, 3429f
humeral preparation in, 3425, 3426f
impaction in, 3429, 3429f
incision in, 3424, 3424f
outcomes of, 3432
pools and pitfalls of, 3431
postoperative care of, 3432
trial reduction in, 3428, 3428f

INDEX I-75
Rheumatoid arthritis (RA) (continued)

triceps reattachment and, 3430, 3430f
ulnar nerve transposition and, 3431, 3431f
ulnar preparation in, 3427, 3427f
wound closure and, 3431, 3431f

Rheumatoid disorders. See also specific disorders

Boutonnière deformities and, 2621–2623, 2621f
nonoperative management of, 2625
surgical management of, 2625–2628
diagnostic studies, 2610
differential diagnosis, 2610
imaging, 2610, 2610f
natural history, 2608–2609
nonoperative management, 2610
pathogenesis, 2608
patient history, 2609
physical findings, 2609, 2609f
surgical management, 2611–2614, 2611f, 2612f, 2613f, 2614f
Swan-neck deformities and, 2622–2623, 2622f
nonoperative management of, 2625
surgical management of, 2625–2628
tendon transfer treatment, 2608–2618
anatomy and, 2608
brachioradialis, 2616, 2616f
complications of, 2618
ECRB, 2615
ECRL, 2615
EPL, 2616, 2617f
extensor indicis proprius, 2614
flexor digitorum superficialis, 2614–2615, 2615f
outcomes of, 2618
pearls and pitfalls of, 2617
postoperative care of, 2618

Rheumatoid forefoot reconstruction, 3736–3742
complications, 3742
hallux MTP arthrodesis and, 3740, 3740f
hammer toe correction and, 3738, 3738f
metatarsal head resection and, lesser, 3738–3740, 3739f
outcomes, 3742
pearls and pitfalls of, 3741
postoperative care, 3742, 3742f
Rhomboiids, anatomy, 3045
Rhomboid transfer, trapezius palsy, 3304, 3304f, 3305f
Rolando fractures
closed reduction and percutaneous pinning, 2323–2324, 2323f
CMC joint, surgical management, 2323–2324, 2323f
external fixator applied for comminuted, 2328, 2329f
ORIF, 2326, 2326f, 2327f
Ropivacaine
additives, 2108
nerve blocks and, continuous, 2107
shoulder surgery, 2105
toxicity, 2112
Rotator cuff
anatomy, 81, 82f, 3124
disease, 81
glenohumeral arthritis with intact, surgical treatment of, 3261–3273
glenohumeral arthritis with irreparable, surgical treatment of, 3275–3287
surgical approach to, 3145–3147, 3146f
Rotator cuff repair
arthroscopic subacromial decompression and mini-open, 3127, 3127f
biceps graft in, 3130, 3130f
closure and, 3131, 3131f, 3132f
complications of, 3133
double-row
with “Mason-Allen”-type construct using medial screw-in suture anchors/lateral pulshock anchors, 86–87, 86f, 87f
with “Mason-Allen”-type construct using screw-in suture anchors, 84–86, 85f
graft, freeze-dried cadaver, 3130, 3130f
open, 3127–3129, 3127f, 3128f, 3129f
clavicular resection/acromioplasty in, 3128–3129, 3128f
incision/dissection in, 3127–3128, 3127f
tear repair in, 3129, 3129f
outcomes of, 3133
pears and pitfalls of, 3132
posterosuperior, 3124–3133
postoperative care of, 3133
tendon transfers, local and, 3131, 3131f, 3132f
Rotator cuff tears, 3124
anatomy and, 81, 82f
arthroscopic treatment, 81–89
complications of, 88–89
outcomes of, 88
pears and pitfalls of, 87
postoperative care of, 87–88
techniques for, 84–87, 85f, 86f, 87f
definition, 81
diagnostic studies, 83, 3125
differential diagnosis, 83, 3126
imaging, 83, 3125, 3125f
irreparable posterosuperior
anatomy of, 3141–3142, 3141f
definition of, 3141
diagnostic studies for, 3143–3144
differential diagnosis of, 3144
imaging of, 3143–3144, 3143f
lattissimus transfer for, 3141–3151
lattissimus transfer for, complications of, 3151
lattissimus transfer for, outcomes of, 3151
lattissimus transfer for, pears and pitfalls of, 3150
lattissimus transfer for, postoperative care and, 3151
lattissimus transfer for, wound closure and, 3150, 3150f
natural history of, 3143
nonoperative management of, 3144
pathogenesis of, 3142–3143, 3142f
patient history and, 3143
physical findings for, 3143
surgical management of, 3144–3145, 3145f, 3145r
natural history, 82, 3124
nonoperative management, 83–84, 3126
pathogenesis, 81–82, 3124
patient history, 82–83, 3124–3125
physical findings, 82–83, 3124–3125
surgical management, 84, 3126, 3126f
Rotator interval closure, 35
Russel-Hibbs procedure, equinocavovarus foot deformity management with, 3906, 3907f
open reduction, posterior approach to, 496–497, 496f
ORIF of, 487–502
anatomy and, 487, 488f, 489f
anterior approach to, 497, 497f
complications for, 502
diagnostic studies for, 490–491, 491f, 492f
iliosacral screw placement and, 498–499, 498f, 499f
imaging for, 490–491, 490f, 491f
natural history of, 487–489
nonoperative management for, 491–492, 492f, 493f
outcomes and, 501
pathogenesis of, 487
patient history and, 489
pears and pitfalls, 500–501
pelvic fixation, spinal, 500, 500f
physical findings for, 489, 489f
posterior approach to, 495–497, 495f, 496f
postoperative care and, 501
sacral nerve root decompression and, 500
surgical management for, 493–495, 493f, 494f
Sacrum
anatomy, ORIF and, 487, 488f, 489f
fractures, u-shaped, 493–494, 494f
hemipelvectomy and division of diaphragm from, 1908, 1908f
imaging, 1859, 1859f
nerve decompression, 493, 493f
ORIF of sacrum/SI joint and, 500
open reduction, posterior approach to, 496–497, 496f
ORIF of, 487–502
anatomy and, 487, 488f, 489f
anterior approach to, 497, 497f
complications for, 502
diagnostic studies for, 490–491, 491f, 492f
iliosacral screw placement and, 498–499, 498f, 499f
imaging for, 490–491, 490f, 491f
natural history of, 487–489
nonoperative management for, 491–492, 492f, 493f
outcomes and, 501
pathogenesis of, 487
patient history and, 489
pears and pitfalls, 500–501
pelvic fixation, spinal, 500, 500f
physical findings for, 489, 489f
posterior approach to, 495–497, 495f, 496f
postoperative care and, 501
sacral nerve root decompression and, 500
surgical management for, 493–495, 493f, 494f
Saddle prosthesis
reconstruction with, 1866, 1867f, 1868f
resection with, 1866, 1867f, 1868f
Sagittal balance, scoliosis, surgical management and, 4652–4653
Sagittal band reconstruction, intermetacarpal ligament, deep transverse, 2600, 2600f
Salter innominata osteotomy, 1517–1522.
See also Osteotomy
anatomy and, 1517
bone graft and, harvesting, 1519, 1519f
bone graft and, placing, 1520, 1520f
complications of, 1521
Scaphoid nonunions (continued) volar-wedge bone grafting, 2266–2272 complications of, 2272
distal radius bone graft for, 2268–2270, 2268f, 2269f, 2270f, 2271f outcomes of, 2272 pearls and pitfalls of, 2271 postoperative care of, 2272 Scaphoid-trapezium-trapezoid (STT) fusion, volar wedge bone grafting, 2266–2272 anatomy and, 2472, 2473f, 2488, 2488f, 2495, 2495f augmentation, 2467–2471 complications of, 2467 outcomes of, 2471 pearls and pitfalls of, 2470–2471 postoperative care of, 2471 bone-ligament-bone reconstruction of, 2488–2494 closure for, 2493 complications for, 2494 dorsal wrist and, approach to, 2491, 2491f fixation and, 2492, 2493f graft harvesting and, 2492, 2492f outcomes for, 2494 pearls and pitfalls in, 2493 postoperative care of, 2494 recipient site preparation for, 2492, 2493f diagnostic studies, 2467
diagnostic wrist arthroscopy, 2468
differential diagnosis, 2467 imaging, 2467, 2467f injury, 2467
diagnostic studies for, 2489
differential diagnosis of, 2489–2490 imaging of, 2489, 2489f natural history, 2488–2489 nonoperative management of, 2490
diagnosis for, 2489 pathological bone scan, 1779
harvesting of, 2489f
natural history of, 2488–2489
nonoperative management of, 2490
pathological bone scan, 1779
patient history, 2489
physical findings, 2489
surgical management, 2487, 2489
surgical management of, 2490–2491, 2490f, 2491f nonoperative management, 2468
repair, 2467–2471 complications of, 2471
direct, 2468–2470, 2469f
direct, with dorsal capsulodesis, 2468–2470, 2469f
outcomes of, 2471
pearls and pitfalls of, 2470–2471 postoperative care of, 2471
surgical management, 2468
ears, 2488
Scapholunate joint, preparation/reduction, 2498, 2498f nonoperative management of, 2474, 2474f pathogenesis, 2472, 2480, 2481f, 2495 patient history, 2472, 2472–2473, 2473f physical findings, 2472–2473, 2474f scaphoid reduction/association and, 2492
complications of, 2487
Scapholunate ligament (SLIL) disruptions anatomy and, 2459 arthroscopic debridement, 2463–2464, 2463f, 2464f arthroscopic evaluation, 2459–2466 complications of, 2466 outcomes of, 2465–2466 pearls and pitfalls of, 2465 postoperative care of, 2465 arthroscopic radial styloidectomy, 2464f arthroscopic RASL procedure, 2464–2465, 2465f arthroscopic treatment, 2459–2466 complications of, 2466 outcomes of, 2465–2466 pearls and pitfalls of, 2465 postoperative care of, 2465 definition, 2459 diagnostic studies, 2460
differential diagnosis, 2460–2461 imaging, 2460 natural history, 2459–2460 nonoperative management, 2461
pathogenesis, 2459
patient history, 2460
physical findings, 2460
surgical management, 2461–2462, 2462f Scaphotrapezial, palmer, 2484, 2484f
Scapula anatomy, 1776–1778, 3249, 3250f, 3293, 3293f, 3316 key structures in, 1776–1778 axillary nerve and, 1777–1778 axillary vessels and, 1776–1777 chondrosarcomas, 1776 exposure, 3314, 3314f forerquarter amputation, 1776, 1838, 1838f lever, anatomy, 3045 limb-sparing surgery, 1778, 1778f contraindications for, 1778–1779 long thoracic nerve palsy pectoralis major transfer and, 3314, 3314f musculoskeletal nerves and, 1777–1778 neuromuscular junction and, 1776–1777 nonarticular, anatomy, 3243, 3243f osteology, 3042–3043, 3043f
preparation, 3314, 3314f radial nerve and, 1778 resections, 1767 angiography, 1779 biopsy, 1779–1800, 1779f bone scan, 1779 complications, 1784–1785 CT, 1779 endoprosthetic reconstruction with, 1776–1783
extra-articular total, 1781–1783, 1782f imaging, 1779–1780 indications for, 1778–1779 intra-articular, 1782–1783, 1783f MRI, 1779
outcomes, 1784, 1784f
postoperative care, 1784 radiography, 1779
skeletal reconstruction following, 1772–1773, 1772f staging studies for, 1779–1780 surgical management for, 1780, 1780f, 1781f sarcomas, 1769 SSN and, 1777 subscapular nerves and, 1778 tendon attachment, 3314, 3314f thoracodorsal nerve and, 1778 Tikhoff-Linberg resections, 1776, 1777f, 1781–1783, 1782f tumors, 1776 winging, 3308–3309 Scapular fractures, intra-articular anatomy and, 3249, 3250f definition, 3249 diagnostic studies, 3249 differential diagnosis, 3249 imaging, 3249, 3250f natural history, 3249 nonoperative management, 3249 ORIF of, 3249–3255 anterior approach to glenoid cavity for, 3252, 3253f complications and, 3255 fixation techniques for, 3253, 3253f, 3254f outcomes for, 3255 pearls and pitfalls for, 3254 posterior approach to glenoid cavity for, 3251, 3252f
postoperative care for, 3254–3255
superior approach to glenoid cavity for, 3252, 3252f
pathogenesis, 3249
patient history, 3249
physical findings, 3249
surgical management, 3249–3251, 3251f
Scapulectomy, 1767
open partial superomedial, for snapping scapula syndrome, 3299
partial superomedial, for snapping scapula syndrome, 3299
Scapulothoracic arthrodesis, 3316–3322
anatomy and, 3316
bony preparation, 3318, 3319f
chest tube placement, 3321, 3321f
complications, 3321–3322
definition, 3316
diagnostic studies, 3317
differential diagnosis, 3317
exposure, 3318, 3318f
imaging, 3317
outcomes, 3321
pathogenesis, 3316, 3316f
pears and pitfalls, 3321
plate fixation, 3320, 3320f
postoperative care, 3321, 3321f
reduction in, 3320, 3320f
semipermanent plate placement in, 3319, 3319f
wire passage in, 3319, 3319f
wound closure, 3321, 3321f
Scapulothoracic disorders
anatomy, 134
arthroscopic treatment, 134–136
pears and pitfalls of, 136
portals for, 135, 135f
resection for, 136, 136f
complications, 135
definition, 134
diagnostic studies, 134
differential diagnosis, 134
imaging, 134
natural history, 134
nonoperative management, 134
outcomes, 135
pathogenesis, 134
patient history, 134
physical findings, 134
postoperative care, 135
surgical management, 134–135, 135f
Scapulothoracic dysfunction
natural history, 3316
nonoperative management, 3317
pathogenesis, 3316, 3316f
patient history, 3316–3317
physical findings, 3316–3317
surgical management, 3317–3318, 3317f
Scapulothoracic muscles, 3045–3046.
See also specific muscles
Scarf osteotomy, 3515–3520.
See also Osteotomy
bunionectomy, 3515, 3515f
complications, 3520
outcomes, 3520
pears and pitfalls, 3519
postoperative care, 3519–3520
soft tissue release, 3515, 3515f
surgical management, 3515
techniques for, 3516–3518, 3516f, 3517f, 3518f, 3519f
SCFE. See Slipped capital femoral epiphysis
Sciatic nerve, 1855
imaging, 1859, 1860f
Sciatic notch, imaging, 1859, 1860f
pedicle screw instrumentation for, 1414–1423, 1423f
complications of, 1423
lumbar, placement, 1421
outcomes of, 1423
pears and pitfalls of, 1422
placement of, 1417
postoperative care of, 1423
thoracic, placement, 1420–1421, 1421f
thoracic exposure and, 1420, 1420f
physical findings, 1409, 1442–1443, 1442f
rod placement and, 1422, 1422f
segmental hook for, 1414–1423
complications of, 1423
outcomes of, 1423
pears and pitfalls of, 1422
placement of, 1416–1418, 1418f, 1419f
postoperative care of, 1423
surgical management, 1410–1411, 1410f, 1411f, 1416–1417, 1443–1444, 1444f
thoracic, 1431–1432
thoracoscopic release and fusion for, 1442–1447
complications of, 1447
outcomes of, 1447
pears and pitfalls of, 1446
postoperative care and, 1446–1447
techniques and, 1444–1445, 1445f, 1446f
Screw fixation. See also specific types of screw fixation
ankle arthrodesis with, 4128–4132, 4128f–4132f
Charcot foot realignment surgery with, 3812, 3812f
distal biceps tendon disruption, 2552
interlocking, proximal humerus fracture, 3214–3215, 3215f
intraosseous compression, scaphoid nonunion, 2268–2270, 2268f, 2269f, 2270f, 2271f
lag, phalangeal fractures, extra-articular, 2378–2388, 2387f, 2388f
midfoot arthrodesis with, 3767–3774, 3768f–3775f
percutaneous
limb deformity corrected with, 1274
seamless fractures, 3678–3679, 3678f
percutaneous intramedullary bone graft with, 738
ORIF for Jones fracture and, 736, 736f, 737f, 738
posterior cervical fusion and lateral mass, 4580–4581, 4581f
retrograde IMN, femoral, 565
transarticular, 4590–4591, 4591f
Screw fixation, compression, arthrodesis, PIP, DIP, MCP joint, 2763, 2763f
Second-look procedure, electrical injury, 2967–2968, 2968f
Segmental bone defects
anatomy of, 1982
imaging, 1982–1983
patient history and, 1982, 1983f
physical findings and, 1982, 1983f
reconstruction
allograft preparation and, 1984
allografts for, 1982–1990
complications, 1989–1990
intercalary endoprosthetic reconstruction and, 1988
intramedullary fixation and, 1985–1988, 1985f
natural history, 1408–1411, 1411f
diagnosis, 1410–1411, 1410f
Scoliosis, pediatric, 1408
anatomy and, 1414–1416, 1414f, 1415f, 1415r, 1416f
lumbar spine, 1415–1416, 1416f
thoracic spine, 1414–1415, 1415f, 1415r
anterior interbody arthrodesis with instrumentation for, 1431–1441
complications of, 1441
open thoracic, 1433
outcomes of, 1441
pears and pitfalls of, 1440
postoperative care and, 1441
thoracolumbar-lumbar spine, 1432f, 1432f, 1438f, 1438f, 1440f
thoracoscopic, 1433–1436, 1433f, 1434f, 1435f, 1436f
congenital, 1409
definition, 1414, 1431
diagnostic studies for, 1431–1432, 1443
differential diagnosis, 1410, 1416, 1443
idiopathic, 1408
anatomy of, 1431
differential diagnosis of, 1432
natural history, 1431
nonoperative management of, 1432
pathogenesis of, 1431
surgical management of, 1432–1433, 1432f, 1433f
imaging for, 1416, 1431–1432, 1431f, 1433f, 1443f
natural history, 1408–1409, 1442
neuromuscular, 1409
anatomy and, 1448, 1448f
definition of, 1448
differential diagnosis of, 1450
imaging for, 1450
natural history of, 1448–1449
nonoperative management of, 1450
pathogenesis of, 1448–1449
patient history and, 1449–1450, 1449f
physical findings and, 1449–1450, 1449f
surgical management of, 1450–1452, 1450f, 1451f, 1452f
unit rod instrumentation for, 1448–1452
unit rod instrumentation for techniques of, 1452–1455, 1452f, 1453f, 1454f, 1455f, 1456f
nonoperative management, 1410, 1416, 1443
pathogenesis, 1442
patient history, 1409, 1442–1443, 1442f
Segmental bone defects (continued)

outcomes, 1989

pears and pitfalls, 1989


postoperative care, 1989

resection and, 1984

segmental prosthesis for, 1982–1990

surgical management, 1983–1984, 1984f
techiques for, 1984


staging studies, 1982–1983

Segmental hook, for scoliosis, 1414–1423

complications of, 1423

pears and pitfalls of, 1422

placement of, 1416–1418, 1418f, 1419f

postoperative care of, 1423

Segmental prosthesis, reconstruction and,

segmental bone defect, 1982–1990

Sesamoid bones, anatomy, 3674, 3674f

Sesamoidectomy, tibial, 3681–3687

Sesamoid fractures

anatomy and, 3674, 3674f
definition, 3674
diagnostic studies, 3676
differential diagnosis, 3676
imaging, 3676, 3676f

internal fixation of, 3674–3680

Anderson-McBryde technique of grafting and,

and, 3677, 3677f

complications for, 3680

outcomes for, 3679–3680, 3680f

pears and pitfalls for, 3679

percutaneous screw, 3678–3679, 3678f

postoperative care for, 3679

natural history, 3675

nonoperative management, 3676

pathogenesis, 3675, 3675f

patient history, 3675–3676

physical findings, 3675–3676, 3675f

surgical management, 3676–3677

SGHL. See Superior glenohumeral ligament

Shoulder AC and, 3044, 3044f

anatomy, 7, 125–126, 3042–3049,

3073–3074, 3073f

capsuloligamentous, 3044–3045, 3045f

labral, 3044–3045, 3045f

anterior, anatomy, 14, 14f

surgical approaches to, 3056, 3057f

arthroscopic capsular release, 12

DJD

anatomy and, 138, 138f

arthroscopic débridement for, 138–144

arthroscopic, diagnostic, 141

capsulotomy for, 141–142, 141f

débridement of, 141

definition of, 138

diagnostic studies for, 139
differential diagnosis of, 139

glenoidplasty for, 138–144

glenoidplasty for, techniques of, 142, 142f

imaging of, 139, 140f

natural history of, 139

nonoperative management of, 139

osteophyte removal, inferior, 141

pathogenesis of, 138–139

patient history of, 139

physical findings of, 139

release for, 141–142, 141f

subacromial decompression, 143

surgical management of, 139–140, 140f

synovectomy for, 141

endoprosthetic reconstruction, 1737

expandable prosthesis, subluxation of,

1747f, 1748

glenohumeral muscles, 3046–3047, 3046f

injuries
diagnostic studies for, 7–8

differential diagnosis of, 8

imaging of, 7–8

natural history of, 7

nonoperative management of, 8

pathogenesis of, 7

patient history of, 7

physical findings of, 7

surgical management of, 8, 8f

instability, definition, 3073

ligaments, 3044–3045, 3045f

loss of motion

anatomy and, 125–126

arthroscopic capsular release of, 125–133

arthroscopic capsular release of,
techniques for, 129–132, 129f, 130f,

131f, 132f

bursoscopy for, 131, 131f
definition, 125
diagnostic studies for, 127
differential diagnosis of, 127

imaging of, 127, 127f

natural history of, 126

nonoperative management of, 127–128

pathogenesis of, 126, 126f

patient history of, 126–127

physical findings for, 126–127

surgical management of, 128, 128f

multiple joint muscles and, 3047–3048

osteology, 3042–3044

clavicle and, 3042, 3042f

humerus and, 3043–3044, 3044f

scapula and, 3042–3043, 3043f

posterior, anatomy, 24

scapulothoracic muscles, 3045–3046

sternooclavicular joint in, 3044

surgery

overview of, 3042

regional anesthesia for, 2104–2105, 2105f

surgical approaches to, 3056–3058

anterior, 3056, 3057f

anterior superior, 3056–3057, 3057f

posterior, 3058, 3058f

veins, 3049

Shoulder arthroscopy, 7–13

anatomy and, 7

arthroscopic insertion for, 9, 9f

complications, 13

definition, 7

diagnostic, 10–12, 11f, 12f, 26, 26f,

32–33, 33f

DJD, 141

outcomes, 13

pears and pitfalls, 13

portal, anterior establishing, 10, 10f

portal placement for, 9, 9f

postoperative care, 13

setup for, 9, 9f

subacromial, 12

Shoulder fractures, pediatric, 1080–1087

anatomy, 1080, 1080f

complications, 1087

definition, 1080

diagnostic studies, 1081, 1081f
differential diagnosis, 1081

imaging, 1081, 1081f

natural history, 1080–1081, 1080f

nonoperative management, 1082

outcomes, 1087

pathogenesis, 1080

patient history, 1081

pears and pitfalls, 1086

physical findings, 1081

postoperative care, 1087, 1087f

proximal humerus fracture, 1084–1085,

1084f

sternooclavicular fracture-dislocations,

posterior, 1085–1086, 1085f, 1086f

surgical management, 1082–1083, 1082f,

1083f

Shoulder girdle

abductor mechanisms in, 1767

anatomy, 1766, 1767–1769, 1767f

examination of, 1786–1787

fascial layers, 1767–1769

forequarter amputation, 1766

lumbosacral surgery

biopsy site, 1770

chest wall involvement and, 1770
contraindications for, 1770
indications for, 1769–1770
infection and, 1770
lymph nodes and, 1770
nerve involvement and, 1770
vascular involvement and, 1770
neurovascular bundle, 1768–1769
resections around, 1766–1774
extent of, 1766, 1768f
guidelines for, 1767–1769
historical background on, 1766
imaging of, 1770–1771, 1771f
indications for, 1769–1770
outcomes of, 1774, 1774f
previous, 1770
skeletal reconstruction following, 1772–1773, 1772f
surgical classification system, 1766–1767
surgical management and, 1770–1771
tumor resection/reconstruction in, 1766
postoperative care of, 22
outcomes of, 22
complications of, 28

Shoulder instability, anterior.

See also Shoulder

anatomy and, 14, 14f
arthroscopic treatment, 14–22
additional enhancing techniques for, 20–21, 21f
anchor first technique for, 20
complications of, 22
outcomes of, 22
pearls and pitfalls of, 22
postoperative care of, 22
suture first technique for, 18–20, 19f, 20f
definition, 14
diagnostic studies, 15–16
differential diagnosis, 16
imaging, 15–16, 16f
natural history, 15
nonoperative management, 16
pathogenesis, 14, 15f
patient history, 15
physical findings, 15
surgical management, 16–18, 16f, 16t, 17f, 18f
Shoulder instability, multidirectional anatomy, 30
arthroscopic treatment, 30–37
complications of, 37
diagnostic, 32–33, 33f
knot tying and, 35
landmarks for, establishing, 32, 32f
multiple plication and, 33, 34f
outcomes of, 36, 36f
pearls and pitfalls of, 36
portal closure for, posterior, 35, 35f
portals for, establishing, 32, 32f
postoperative care of, 36
preparation for repair and, 33, 33f
rotator interval closure and, 35
definition, 30
diagnostic studies, 30–31
imaging, 30–31, 31f
natural history, 30
nonoperative treatment, 31
pathogenesis, 30
physical findings, 30
surgical treatment, 31–32, 31f
Shoulder instability, posterior, 3085–3098.

See also Shoulder

anatomy and, 24
arthroscopic treatment, 24–29
capsular repair for, 27–28, 27f
complications of, 28
definition of, 24
diagnostic, 26, 26f
glenoid preparation for, 27, 27f
labral repair for, 27–28, 27f
outcomes of, 28
pears and pitfalls of, 28
portal placement for, 26, 26f
postoperative care of, 28
repair completion and, 28, 28f
suture anchor placement for, 27, 27f
definition, 24
diagnostic studies, 24
differential diagnosis, 25
imaging, 24, 25f
natural history, 24
nonoperative management, 25
pathogenesis, 24
patient history, 24
physical findings, 24
recurrent
anatomy of, 3085
arthroscopic posterior reconstruction of, 3087–3089, 3088f, 3089f
bone block graft augmentation, open
posterior, 3096
complications of, 3097
definition of, 3085, 3085f
diagnostic studies for, 3086
differential diagnosis of, 3086
glomerous osteotomy, open posterior, 3093–3095
3093f, 3095f, 3096f
imaging of, 3086, 3086f
infraspinatus capsular tenodesis for, open
posterior, 3093, 3093f, 3094f
nonoperative management of, 3086–3087
open posterior humeral-based capsular shift for, 3090–3091, 3090f, 3091f, 3092f
open posterior labral repair for, 3092
outcomes of, 3097–3098
pathogenesis of, 3085
patient history of, 3085–3086, 3086f
pears and pitfalls of, 3096–3097
physical findings for, 3085–3086, 3086f
postoperative care of, 3097
surgical management of, 3086–3087
3085f, 3086–3087
surgical management, 23, 25f
Shoulder throwing injuries
anatomy, 44
definition, 44
diagnostic studies, 46
differential diagnosis, 47
imaging, 46, 47f
management, 44–56
arthroscopy, diagnostic for, 48–49, 49f
capsulotomy, posteriorinferior for, 54, 54f
complications of, 56
Intra-articular derangement for, 50
mini-plication of anterior capsule for, 52, 53f
nonoperative, 47, 47f
outcomes of, 56
pears and pitfalls of, 55
physical findings, 48–49, 49f
postoperative care for, 48, 48f
nonoperative management of, 55–56
SLAP repair for, 49–52, 50f, 51f, 52f
natural history, 45–46
pathogenesis, 44–45, 45f
patient, 46, 46f
physical findings, 46, 46f
SI joint. See Sacroiliac joint
Slipped capital femoral epiphysis (continued)
imaging and, 1595, 1595f
natural history of, 1595
nonoperative management of, 1595
outcomes of, 1598–1599
pathogenesis of, 1595
patient history and, 1595
physical findings and, 1595
postoperative care of, 1598, 1599f
surgical management of, 1595–1596, 1596f
surgical management, 1590
Smith-Peterson anterior approach
modified, septic hip anterior drainage, 1512, 1512f, 1513f
ORIF, femoral head fracture, 516–518, 516f
techniques for, 4508–4510, 4509f
superficial dissection for, 4508, 4509f
positioning for, 4508
incision in, 4508, 4509f
extending the exposure and, 4510
deep dissection for, 4509, 4510f
SNAC. See Scaphoid nonunion advanced collapse
Snapping hip, 222–230.
See also Hip anatomy, 222, 222f
complications, 229–230
definition, 222
diagnostic studies, 224
differential diagnosis, 224
iliospos release, endoscopic for, 225–227,
iliotibial band tenoplasty and, 227, 227f, 228f
imaging, 224, 224f
natural history, 223
nonoperative management, 224
outcomes, 224
pathogenesis, 222–223, 223f
patient history, 223–224
pears and pitfalls, 228, 229f
physical findings, 223–224
postoperative care, 229
surgical management, 224–225
Snapping scapula syndrome, 3293–3300.
See also Scapula anatomy and, 3293, 3293f
arthroscopic bursectomy, 3298–3299, 3298f
complications, 3300
definition, 3293
diagnostic studies, 3294
differential diagnosis, 3294
imaging, 3294, 3295f
natural history, 3293–3294
nonoperative management, 3294
open decompression, 3296–3297, 3296f,
3297f
outcomes, 3299–3300
pathogenesis, 3293, 3294f
patient history, 3294
pears and pitfalls of, 3299
physical findings, 3294
postoperative care, 3299
scapulectomy for, partial superomedial, 3299
surgical management, 3295, 3295f
Soft tissue balancing
TKA, cemented and, 927
TKA, using navigation and, 940
closure, distal chevron osteotomy, 3503, 3503f, 3504f
detachment, 1789
distal chevron osteotomy and, 3501–3503, 3503f, 3504f
plication, medial, calcaneal lengthening osteotomy and, 1613, 1613f, 1615, 1615f
release of, 1613, 1613f, 1615, 1615f
THA, cemented and balance of, 750–751, 751f
THA, uncemented and repairing, 752–753, 752f
THA, uncemented and tension of, 760–761, 761f
Soft tissue coverage, fingertip amputation, 2932–2940
complications of, 2940
outcomes of, 2940
pears and pitfalls of, 2939
postoperative care of, 2939
Soft tissue expansion, in AT reconstruction, 1513
Soft tissue coverage, fingertip amputation, 1789
Soft tissue sarcomas (STS)
biologic behavior, 1695–1698, 1696f
common, 1715–1716
chemotherapy for, 1715–1716
radiation therapy for, 1715–1716
surgical management of, 1716
treatment of, 1715–1716
epidemiology, 1695
metastatic, 1697–1698
pathophysiology, 1695–1698, 1696f
prognostic factors, 1698–1700
risk factors, 1695
staging, 1698–1700, 1699f
Soft tissue tenodesis, arthroscopic treatment, 3549, 3550f
Soleus muscle
anatomy, 2023
imaging, 2023
resection, 2023–2027
and, 2023
background, 2023
complications, 2027
gastrocnemius muscle and, 2024, 2024f
imaging for, 2023, 2024f
indications, 2023
outcomes, 2026f, 2026t, 2027, 2027f
pears and pitfalls, 2027
postoperative care/rehabilitation, 2027
reconstruction, functional after, 2023, 2023f
spinal cord. See also specific spinal cord sections
spinal deformity caused by, 1424–1430
spina bifida, kyphectomy in, 1424–1430
Spina bifida
articulating antibiotic spacer and, 847–848
implant placement and, 848–849, 849f
spacer creation and, 848, 848f
nonarticulating antibiotic spacer block and, 849, 850f
resection arthroplasty and, 843–852
anatomy of, 843, 844f
approach to, 847, 847f
complications, 852
definition of, 843
diagnostic studies for, 844–845
differential diagnosis of, 845
imaging for, 844–845, 845f
natural history of, 843
nonoperative management of, 845
outcomes, 851
pathogenesis of, 843, 844f
patient history for, 844
pears and pitfalls, 850, 850f
physical findings, 844
positioning for, 847
postoperative care and, 851
preoperative planning for, 846–847, 846t
surgical management of, 845–847, 846t
techniques for, 847–850
Spine
anatomy, 2021–2013, 2012f
imaging, 2013–2014
surgical resection, 2011–2017
complications, 2017
defemoral triangle space, 2014–2015, 2015f
imaging and, 2013–2014
indications, 2013
outcomes, 2017
pears and pitfalls, 2017
popliteal space tumors, 2016, 2016f
postoperative care, 2017
sartorial canal tumors, 2015, 2015f
staging studies, 2013–2014
surgical management of, 2014
Spastic hip disease, 1322
surgical management, 1322–1323
Spica casting
femur fractures, pediatric, 1095–1098
complications of, 1098
outcomes of, 1098
pears and pitfalls of, 1097–1098
postoperative care of, 1098, 1098f
traditional, femur fractures, pediatric, 1096–1097, 1096f, 1097f
walking, femur fractures, pediatric, 1097, 1097f
Spina bifida, kyphectomy in, 1424–1430
closure for, 1429, 1429f
complications and, 1430
decancellation and, 1427, 1428f
horizontal resection for, 1428, 1428f
incision and lumbar dissection for, 1426–1427, 1426f
lower extremity hypoperfusion and, 1429
outcomes and, 1430
pears and pitfalls for, 1430
pedicle screw placement for, 1427, 1427f
postoperative care for, 1430
rod placement for, 1428–1429, 1428f, 1429f
thoracic dissection for, 1427
Spinal cord. See also specific spinal cord sections
spondylolisthesis and, 1480–1481
Subcoracoid muscle transfer, of clavicular
subaxial spine, posterior approach, 4521
Subacromial impingement
Subacromial decompression, 71–72, 72
Subacromial, bursoscopy, shoulder loss of
Styloidectomy
Subacromial bursoscopy, shoulder loss of
Submuscular plating, femoral shaft fracture,
Subdeltoid bursoscopy, shoulder loss of
Subscapularis muscle
Subcoracoid space, subscapularis tears and,
Sublaminar wiring/grafting, Gallie method,
Sternocleidomastoid (SCM) muscle
Subdeltoid bursoscopy, shoulder loss of
Subscapularis muscle
Subacromial, bursoscopy, shoulder loss of
Subcoracoid muscle transfer of
clavicular head, 3055–3056, 3055f, 3056f
Subcoracoid space, subscapularis tears and,
Subdeltoid bursoscopy, shoulder loss of
Subcoracoid muscle transfer of, clavicular
Subcoracoid muscle transfer, of clavicular
Subcoracoid muscle, posterior approach, 4521
Subchondral cysts, 4227
Subclavian artery, 3049
Subcoracoid muscle transfer, of clavicular
head, 3055–3056, 3055f, 3056f
Subcoracoid space, subscapularis tears and,
surgical management, 70
Sublaminar wiring/grafting, Gallie method,
Subclavian wiring/grafting, Gallie method,
Submuscular plating, femoral shaft fracture,
tibial bone graft harvesting for, 3846,
wound closure for, 3846
TAA using TNK implant and, 4090,
Subtalar arthroscopy, 4251–4258
Sublaminar wiring/grafting, Gallie method,
Subacromial impingement
Subacromial decompression, 71–72, 72
Subacromial impingement
anaomy, 68
arthroscopic treatment, 68–74
complications of, 74
cutting block technique for, 72, 72f
outcomes of, 73–74
pears and pitfalls of, 73
postoperative care of, 73
subacromial decompression and, 71–72

Subscapularis muscle
Subacromial impingement
anaomy, 68
arthroscopic treatment, 68–74
complications of, 74
cutting block technique for, 72, 72f
outcomes of, 73–74
pears and pitfalls of, 73
postoperative care of, 73
subacromial decompression and, 71–72
techniques for, 70–71, 71f
wound closure and, 73
definition, 68
diagnostic studies, 69
differential diagnosis, 69
imaging, 69, 69f
natural history, 68
nonoperative management, 70
pathogenesis, 68
patient history, 68–69
physical findings, 68–69
surgical management, 70
Subaxial spinous posterior approach, 4521
Subchondral cysts, 4227
Subclavian artery, 3049
Subcoracoid muscle transfer, of clavicular
head, 3055–3056, 3055f, 3056f
Subcoracoid space, subscapularis tears and,
Subdeltoid bursoscopy, shoulder loss of
Sublaminar wiring/grafting, Gallie method,
Subclavian wiring/grafting, Gallie method,
Submuscular plating, femoral shaft fracture,
tibial bone graft harvesting for, 3846,
wound closure for, 3846
TAA using TNK implant and, 4090,
Subtalar arthroscopy, 4251–4258
Sublaminar wiring/grafting, Gallie method,
Subacromial impingement
Subacromial decompression, 71–72, 72
Subacromial impingement
anaomy, 68
arthroscopic treatment, 68–74
complications of, 74
cutting block technique for, 72, 72f
outcomes of, 73–74
pears and pitfalls of, 73
postoperative care of, 73
subacromial decompression and, 71–72
techniques for, 70–71, 71f
wound closure and, 73
definition, 68
diagnostic studies, 69
differential diagnosis, 69
imaging, 69, 69f
natural history, 68
nonoperative management, 70
pathogenesis, 68
patient history, 68–69
physical findings, 68–69
surgical management, 70
Subaxial spinous posterior approach, 4521
Subchondral cysts, 4227
Subclavian artery, 3049
Subcoracoid muscle transfer, of clavicular
head, 3055–3056, 3055f, 3056f
Subcoracoid space, subscapularis tears and,
Subdeltoid bursoscopy, shoulder loss of
Sublaminar wiring/grafting, Gallie method,
Subclavian wiring/grafting, Gallie method,
Submuscular plating, femoral shaft fracture,
tibial bone graft harvesting for, 3846,
wound closure for, 3846
TAA using TNK implant and, 4090,
Supracondylar fractures of humerus, pediatric closed reduction and percutaneous pinning, 1050–1057
- anatomy, 1050, 1051f
- closed-pin technique for, 1056f
- complications, 1057
- definition, 1056
- diagnostic studies, 1057
- differential diagnosis, 1057f
- imaging for, 1057
- lateral entry pin technique for, 1057
- natural history and, 1055f
- nonoperative management for, 1051
- outcomes, 1057
- pathogenesis, 1050
- patient history and, 1050–1051
- pearls and pitfalls, 1057
- physical findings and, 1050–1051
- postoperative care for, 1057
- surgical management for, 1051–1053, 1053f
- techniques for, 1053–1056, 1054f, 1055f, 1056f
- open reduction, 1046–1049
- anatomy, 1046
- complications, 1049
- definition, 1046
- outcomes, 1048
- patient history for, 1046
- pearls and pitfalls, 1048
- physical findings for, 1046
- postoperative care for, 1048
- surgical management, 1046
- techniques for, 1047–1048, 1047f, 1048f
- open reduction of, 1046–1049

Supracondylar humeral osteotomy, cubitus varus correction with, pediatric, 1075–1079
- anatomy and, 1075
- complications of, 1079
- definition of, 1075
- diagnostic studies for, 1075
- exposure and, 1077, 1077f
- imaging for, 1075, 1076f
- natural history and, 1075
- nonoperative management for, 1075
- osteotomy closure/fixation and, 1077, 1078f
- outcomes of, 1079
- pathogenesis of, 1075
- patient history and, 1075
- pearls/pitfalls of, 1078
- physical findings and, 1075
- postoperative care of, 1078f
- surgical management for, 1075–1076, 1076f
- techniques for, 1077–1078, 1077f, 1078f
- wound closure and, 1078

Supramalleolar osteotomy, ankle, 869–870, 871
- fasciotomy, leg, for acute compartment syndrome, 665
- femoral osteotomy, 869–870, 873f
- foot amputation, 2047–2049
- forequarter amputation, 1833, 1836f
- hemipelvectomy
  - anterior flap, 1903, 1903f, 1904f
  - posterior flap, 1893, 1895f
- hip disarticulation, 1911–1912
  - AKA stump and, 2054–2055, 2054f
- hip dislocation, surgical, 878–879, 879f
- anterior, 889–890, 889f
- fasciotomy, leg, for acute compartment syndrome, 665
- femoral osteotomy, 869–870, 871f
- foot amputation, 2047–2049
- for AKAs, 2072–2075
- pelvis, 465–466, 465f, 466f
- tibia, 632–633, 633f
- FAI, 878–879, 879f
- anterior, 889–890, 889f
- femoral osteotomy, 869–870, 871f
- foot amputation, 2047–2049
- for AKAs, 2072–2075
- pelvis, 465–466, 465f, 466f
- tibia, 632–633, 633f
- FAI, 878–879, 879f
- anterior, 889–890, 889f
- fasciotomy, leg, for acute compartment syndrome, 665
- femoral osteotomy, 869–870, 871f
- foot amputation, 2047–2049
- for AKAs, 2072–2075
- pelvis, 465–466, 465f, 466f
- tibia, 632–633, 633f
- FAI, 878–879, 879f
- anterior, 889–890, 889f

Surgical management. See also specific types of surgical management
- AKA, 2063, 2063f
- ankle amputation, 2047–2049
- anterograde IMN, femoral, 571–573, 572f
- axillary space, 1827, 1828–1829
- approach to, 1828–1829, 1828f, 1829f
- positioning for, 1828
- preoperative planning for, 1828
- BKA, 2067
- calcaneal fractures, 715–716
- cephalomedullary nailing, proximal femur, 535–537, 535f, 536f, 537f
- Chopart amputation, 2072–2075
- cryosurgical ablation and, bone tumor, 1758
- Ewing sarcoma, 1715
- excision types, musculoskeletal tumor, 1705, 1705f
- expandable prosthesis and, 1740–1743
- external fixation, pelvic, 465–466, 465f, 466f
- tibia, 632–633, 633f
- FAI, 878–879, 879f
- anterior, 889–890, 889f

Surface replacement arthroplasty
- MCP joint, 2744–2751
  - complications of, 2751
  - outcomes of, 2750–2751
  - pearls and pitfalls of, 2750
  - postoperative care of, 2750
  - techniques for, 2747–2748, 2747f, 2748f
- PIP joint, 2744–2751
  - complications of, 2751
  - outcomes of, 2750–2751
  - pearls and pitfalls of, 2750
  - postoperative care of, 2750
  - techniques for, 2748–2750, 2749f, 2750f
- Surgical classification systems, shoulder girdle resection, 1766–1767
- Surgical management. See also specific types of surgical management
  - AKA, 2063, 2063f
  - ankle amputation, 2047–2049
  - anterograde IMN, femoral, 571–573, 572f
  - axillary space, 1827, 1828–1829
  - approach to, 1828–1829, 1828f, 1829f
  - positioning for, 1828
  - preoperative planning for, 1828
  - BKA, 2067
  - calcaneal fractures, 715–716
  - cephalomedullary nailing, proximal femur, 535–537, 535f, 536f, 537f
  - Chopart amputation, 2072–2075
  - cryosurgical ablation and, bone tumor, 1758
  - Ewing sarcoma, 1715
  - excision types, musculoskeletal tumor, 1705, 1705f
  - expandable prosthesis and, 1740–1743
  - external fixation, pelvic, 465–466, 465f, 466f
  - tibia, 632–633, 633f
  - FAI, 878–879, 879f
  - anterior, 889–890, 889f
  - fasciotomy, leg, for acute compartment syndrome, 665
  - femoral osteotomy, 869–870, 871f
  - foot amputation, 2047–2049
  - for AKAs, 2072–2075
  - pelvis, 465–466, 465f, 466f
  - tibia, 632–633, 633f
  - FAI, 878–879, 879f
  - anterior, 889–890, 889f
Surgical management (continued) humeral MBD in, 1816–1824, 1817f, 1817f
MBD in, pearls/pitfalls of, 1824 knee arthrodesis, 1005–1008 liposarcoma, 1717–1718 Lisfranc amputation, 2072–2075 MBD
Thoracic spine
anatomy, 4628

pedicle screw placement and, 1420–1421, 1420f
posterior exposure of, 1408–1413
fusion, 1413
combinations of, 1421f
closure for, 1413
incision for, 1411–1412, 1411f, 1412f
outcomes and, 1413

Thoracic spine, pediatric
anatomy, 4628

osteoarthritis, 2770, 2776
arthrodesis, 2320–2321
resection arthroplasty, 2776–2783
APL suspensionplasty and, 2781, 2781f, 2782f
complications of, 2783
definition of, 2776
LRTI, using FCR tendon, 2778–2779
outcomes of, 2778–2781
Arтелon, 2786, 2786f, 2787f
complications of, 2790
outcomes of, 2790

Thoracic spinal, pediatric
anatomy, 4628

trauma

natural history of, 4628
nonoperative management of, 4629
pathogenesis of, 4628

induction, 4629

postoperative care of, 2320–2321

prognosis and, 2320

injuries, differential diagnosis, 4629
physical findings, 4629

anterior, of, 4537, 4537f, 4538f, 4539f
posterior approach to, 4537–4542

complications of, 4542, 4542f

midline, 4540–4541, 4540f, 4541f
paraspinal, 4542, 4542f
parasphenial, 4542, 4542f

posterior approach to, 4524–4528, 4524f,
4525f, 4526f, 4527f, 4528f
corpectomy, 4631, 4631f

anterior, 4628–4633
bone grafting/cages for, 4632–4633, 4633f
complications of, 4633

pearls and pitfalls of, 4633
postoperative care of, 4633

screw rod instrumentation for, 4632, 4632f
diagnostic studies, 4629
disectomy, 4630, 4630f
disc herniation
natural history of, 4628

nonoperative management of, 4629
pathogenesis of, 4628
imaging, 4629

infection
natural history of, 4628
nonoperative management of, 4629
pathogenesis of, 4628

trauma

natural history of, 4629

nonoperative management of, 4630
pathogenesis of, 4628
tumor

natural history of, 4629
nonoperative management of, 4629–4630
pathogenesis of, 4628

Thoracic spine, pediatric
anatomy, 1408, 1409f, 1442
scoliosis and, 1414–1415, 1415f

antero posterior interbody arthrodesis with instrumentation, for scoliosis, 1433–1436, 1433f, 1434f, 1435f, 1436f
diagnostic studies, 1409–1410, 1410f

exposure of, pedicle screw placement and, 1420, 1420f
imaging, 1409–1410, 1410f
kyphectomy in spine bifida and dissection of, 1427
Thumb-in-palm deformity
anatomy, 1358, 1358f
augmentation of weak muscles and, 1362–1363, 1362f, 1363f
complications, 1365
in CP, correction of, 1358–1365
definition, 1358
diagnostic studies, 1359
differential diagnosis, 1359
imaging, 1359
natural history, 1358
nonoperative management, 1359
outcomes, 1365
pathogenesis, 1358
patient history, 1358
pearls and pitfalls of, 1364–1365
physical findings, 1358, 1359
postoperative care, 1365
release of contractures and, 1361, 1361
postoperative management of, 1364–1365
patient history, 1358
natural history, 1358
imaging, 1359
differential diagnosis, 1359
diagnostic studies, 1359
in CP, correction of, 1358–1365
complications, 1365
surgical management, 1360, 1360
thumb MCP joint and, stabilization of,

RCL disruptions in chronic volar instability, 2331–2341
arthrodesis, 2337–2339, 2337
imaging of, 2332–2333, 2332
history of, 2332
nonoperative management of, 2333–2343
complications for management, 2336–2337, 2336f, 2337f
dislocations, 2331–2341
anatomy of, 2331–2332, 2331f
complications of, 2340–2341
definition of, 2331
diagnostic studies for, 2332–2333
differential diagnosis of, 2333
history of, 2332
imaging of, 2332–2333, 2332f
natural history of, 2332
nonoperative management of, 2333–2334, 2334f
outcomes of, 2340
pathogenesis of, 2332
pearls and pitfalls of, 2340
physical examination of, 2332
surgical management of, 2334–2335
techniques for management, 2336–2337, 2336f, 2337f

UCL disruptions in anatomy of, 2342
arthroscopic and open primary repair of, 2342–2348
complications and, 2346
definition of, 2342
diagnostic studies of, 2343–2344
differential diagnosis of, 2344
imaging of, 2343–2344
natural history, 2349–2350
nonoperative management of, 2344
pathogenesis of, 2342, 2343f
patient history of, 2343
physical findings for, 2343
repair of acute, 2345–2346, 2345f,
2346f
surgical management of, 2344

UCL instability of anatomy and, 2349
complications and, 2357
definition, 2349
diagnostic studies of, 2350
differential diagnosis, 2350
imaging, 2350
natural history, 2349–2350
nonoperative management of, 2350
pathogenesis of, 2342, 2343f
patient history of, 2343
physical findings for, 2343
reconstructing, using tendon graft, 2354–2356, 2354f, 2355f
surgical management, 2350–2351

Tibia. See also Congenital pseudarthrosis, tibia
Agility TAA and component insertion of, 4099, 4099f
anatomy, 435, 435f, 642, 643f
external fixation and, 629, 631f
revision TKA with tibial bone loss and, 969
tibial osteotomy, upper and, 905, 906f
base frame application, ankle arthritis, 3944, 3944f, 3945f
bone cut and upper, TKA, cemented,
bone graft harvesting, 3846, 3846f
cuts, total ankle shell allograft and, 4002, 4002f
external fixation, 629–641
anatomy and, 629, 631f
ankle-spanning fixator for tibial pilon fracture and, 639, 639f
complications of, 641
definition of, 629, 630f
diagnostic studies for, 632
imaging for, 632, 633f
knee-spanning fixator for tibial plateau fracture and, 638, 638f
monolateral four-pin frame application for tibial shaft fracture and,
634–635, 635f, 636f
monotube four-pin frame application for tibial shaft fracture and,
636–638, 637f
natural history and, 630–631
outcomes of, 641
pathogenesis and, 629–630, 631f
patient history and, 632
pearls and pitfalls of, 640
physical findings and, 632, 632f
pin insertion technique for, 634, 634f
postoperative care of, 640–641
surgical management of, 632–633, 633f
two-pin fixator for tibial fractures and,
639, 640f

IMN, 642–658
complications of, 658
outcomes of, 657
pearls and pitfalls of, 657
postoperative care of, 657
surgical approach to, 647–653,
647f, 648f, 649f, 650f, 651f,
652f, 653f

injuries
diagnostic studies for, 642–643
imaging of, 642–643
natural history of, 642
nonoperative management of, 643–644, 644f
pathogenesis of, 642
patient history of, 642
physical findings of, 642
surgical management of, 644–647, 645f,
646f, 646f, 647f
lengthening of ilizarov method for, 1261–1263, 1261f,
1262f, 1263f
monoplanar fixator for, 1266–1267, 1267f
meniscal transplant and preparation of lateral, 288, 288f
medial, 291–292, 291f
mobility total ankle arthroplasty with preparation of, 4060–4063, 4060f–4063f
ORIF of ankle and, 692, 693f
pediatric anatomy of, 1626
deformity of, 1626
diagnostic studies for, 1627
imaging of, 1627
nonoperative management of, 1627
surgical management of, 1627–1629, 1628f
platform, creating, revision TKA and, 1000, 1000f
posterior, anatomy of, 3814
prosthesis subsidence, Revision Agility TAA and, 4118, 4118f
recutting of, and posterior release, revision TKA, 999, 1000f
removal, revision TKA with removal of well-fixed components and, 977, 977f
resection of
HINTEGRA ankle arthroplasty and, 4025–4026, 4025f
TAA using Salto prosthesis and, 4045–4046, 4045f, 4046f, 4047f
4048f
UKA and, 897–898, 898f
revision TKA with extensor mechanism release and preparation of, 991, 991f
STAR ankle replacement and, 4010–4012, 4010f–4012f
TKA, cemented and preparation of, 923
Tibial anchor region osteotomy, TAA using TKN implant and, 4089, 4089f
Tibial bone loss
revision TKA with, bone grafting for, 969–974
anatomy and, 969
comparisons of, 974
definition of, 969
diagnostic studies for, 969
differential diagnosis of, 969–970
imaging of, 969, 970f
impaction grafting and, 971, 971f, 972f
natural history and, 969
nonoperative management of, 970
outcomes of, 974
pathogenesis and, 969
patient history and, 969
pears and pitfalls of, 973
physical findings for, 969
postoperative care of, 974
structural femoral head allograft and, 972, 973f
surgical management of, 970, 970f
revision TKA with, metal augments anatomy of, 949–950, 950f
approach to, 953, 954f
block or step augment, medial/lateral and, 956–962, 956f
comparisons of, 960–961
component explanation and, 954
definition of, 949
diagnostic studies for, 952
differential diagnosis of, 953
full-width wedge augment and, 956, 956f
hemiwedge augment, medial/lateral and, 954, 955f
imaging for, 952, 952f
metaphyseal cone augmentation and, 957–958, 957f
natural history of, 951–952
nonoperative management of, 953
outcomes of, 960
pathogenesis of, 950–951
patient history and, 952
pears and pitfalls of, 959
physical findings and, 952
postoperative care for, 960
surgical management of, 953
techniques for, 953–959, 954f, 955f, 956f, 957f, 958f, 959f
trabecular metal augmentation, free and, 958, 958f, 959f
Tibial calcaneal arthrodesis, 4194–4196, 4195f
Tibial fractures, distal metaphyseal, 653–656, 654f
proximal metaphyseal, 653–656, 654f
Tibial fractures, pediatric, 1122–1129
anatomy, 1122, 1122f
cutting nails for, 1127, 1127f
definition, 1122
differential diagnosis, 1123
external fixation, 1124–1125, 1125f
imaging, 1123
intramedullary nail fixation, elastic, 1126–1127, 1126f, 1127f
natural history, 1122
nonoperative management, 1123, 1123f
pathogenesis, 1122
patient history, 1122–1123
physical findings, 1122–1123, 1122f
plate fixation, 1125, 1125f
postoperative care of, 1128
surgical management, 1123–1124, 1124f
complications of, 1128–1129
outcomes of, 1128–1129
pears and pitfalls of, 1128, 1128f
techniques for, 1124–1128, 1124f
1125f, 1125f, 1125f, 1127f
wound closure for, 1127, 1127f
Tibialis anterior tendon, anatomy, 4484
differential diagnosis, 4484
tibialis anterior tendon ruptures anatomy, 4484
definition, 4484
diagnostic studies, 4484
differential diagnosis, 4484
extensor hallucis longus transfer to medial cuneiform for, 4485–4487, 4485f
imaging, 4484
natural history, 4484
nonoperative management, 4485
pathogenesis, 4484
patient history, 4484
reconstruction, 4484–4487
complications of, 4487
outcomes of, 4487
pears and pitfalls of, 4487
postoperative care of, 4487
surgical management, 4485
Tibialis tendon transfer, split for clubfoot deformity, residual, 1688–1689
to peroneus brevis, 1629–1630, 1629f, 1630f
Tibialis transfer, anterior, for clubfoot deformity, residual, 1682–1690 complications of, 1690
full, 1686–1687, 1686f, 1687f, 1688f
outcomes of, 1690
pears and pitfalls of, 1689, 1689f
postoperative care of, 1690, 1690f
split, 1688–1689
Tibial osteotomy proximal, 3984
supramalleolar, 3983–3984, 3984f
supramalleolar osteotomy with, 3971–3973, 3972f
TAA using TKN implant and, 4086–4087, 4087f
varus-type osteoarthritis, ankle, 3964, 3964f
Tibial osteotomy, upper, 905–917.
See also Distal tibial osteotomy, pediatric; Osteotomy anatomy, 905, 906f
arthroscopy, 909, 909f
bone grafting, 914, 914f
closure, 914, 915f
complications, 916, 916f, 917f
cutting/opening osteotomy and, 912, 913f
definition, 905
diagnostic studies, 907, 908f
differential diagnosis, 907
imaging, 907, 908f
initial dissection, 910, 910f
natural history, 905
nonoperative management, 907
outcomes, 915, 915f
pathogenesis, 905
patient history, 906–907
pears and pitfalls, 915
physical findings, 906–907
placing guide pins and, 911–912, 911f
plate fixation, 913, 914f
postoperative care, 915
surgical management, 907–909
approach to, 909
positioning for, 909, 909f
preoperative planning for, 909
techniques, 909–915
Tibial physis, epiphysiosis of, 1240–1241, 1240f, 1241f
Tibial plateau fractures, lateral, 622–628
anatomy, 622
anterolateral approach to, 624, 624f
complications, 628
definition, 622
diagnostic studies, 623
differential diagnosis, 623
imaging, 623
meniscal repair, 626
natural history, 622
nonoperative management, 623
osteosynthesis, 626, 627f
outcomes, 627–628
pathogenesis, 622
patient history, 622–623
pears and pitfalls, 627
physical findings, 622–623
posterolateral approach to, 625, 625f
postoperative care, 627
reduction, 625, 625f
reduction of impacted segments, 625, 625f
surgical management, 623–624, 623f, 623f, 624f, 624f
Tibial polyethylene, removal, revision TKA with removal of well-fixed components and, 976, 977f
Tibial sesamoidectomy, 3681–3687
osteotomy reattachment with wire and, 983, 984f
outcomes of, 984
pathogenesis of, 980
patient history and, 981
pains and pitfalls of, 984
physical findings for, 981
postoperative care of, 984
surgical management of, 981, 981f
revision TKA with extensile exposure, V-Y quadruplasy and, 986
soft tissue release before, initial, 981, 982f
Tibial tubercle transfer, 435–442
ankle arthrodesis, 4171, 4173
osteoarthrosis
arthroscopic-assisted management of, ORIF, arthroscopy-assisted management of, nonoperative management, 1162
ORIF, arthroscopy-assisted management of, complications, 1166
outcomes and, 1166
pains and pitfalls, 1166
postoperative care, 1166
repair with, 1163–1165, 1163f, 1164f, 1165f
techniques for, 1163–1166, 1163f, 1164f, 1165f
pathogenesis, 1161
patient history, 1161–1162
physical findings, 1161–1162
spine repair for, 1163–1165, 1163f, 1164f, 1165f
surgical management, 1162–1163, 1163f
techniques for, 1163–1166, 1163f, 1164f, 1165f
Tibial tendon transfer, pediatric, split posterior, 1626–1632
complications of, 1632
through interosseous membrane to lateral cuneiform, 1630–1631
through interosseous membrane to peroneus brevis, 1631
outcomes of, 1631
pains and pitfalls of, 1631
postoperative care of, 1631
split tibialis tendon transfer to peroneus brevis and, 1629–1630, 1629f, 1630f
Tibial tubercle advancement, 1343, 1343f
Tibial tubercle osteotomy, 983, 983f
osteoarthritis
reattachment and with screws, 984, 984f
with wire, 983, 983f
revision TKA with extensile exposure, 980–984
anatomy and, 980, 980f
complications of, 984
definition of, 980
diagnostic studies for, 981
imaging of, 981
natural history of, 980–981
osteoarthritis reattachment with screws and, 984, 984f
osteoarthrosis
ankle arthrodesis, 4171, 4173
blade plate fixation
bone graft preparation, 4183, 4183f
bony excision, 4182, 4182f
closure, 4186
fixation, 4183, 4185f–4186f
incision, 4182, 4182f
outcomes of, 4191
pains and pitfalls of, 4191
positioning, 4182, 4182f
postoperative care of, 4181
preoperative planning, 4181
preparing articular surfaces, 4183, 4183f
stabilization, 4184–4185, 4184f–4185f
tibialcalcanear arthrodesis, 4186–4190, 4187f–4190f
diagnostic studies, 4162–4163, 4181
imaging, 4162–4163, 4163f, 4164f, 4181, 4181f
lateral blade plate fixation, 4173–4178
blade plate insertion for, 4175–4176, 4176f
closure of, 4176
complications of, 4178
osteoarthritis of fibula for, 4175, 4175f
outcomes of, 4177
pains and pitfalls of, 4176–4177, 4176f, 4177f
postoperative care of, 4177, 4177f
subtalar joint preparation for, 4175
tibialtalar joint preparation for, 4175, 4175f
natural history, 4161, 4180
nonoperative management, 4163–4164, 4164f, 4181
osteoarthrosis, 4171
pathogenesis, 4161, 4179–4180, 4180f
patient history, 4161–4162, 4180–4181, 4180f
physical findings, 4161–4162, 4161f, 4162f, 4180–4181, 4180f
surgical management, medullary nail, 4164–4171
ankle arthroplasty, 4165, 4165f
bone grafting, 4168–4169, 4169f
complications of, 4171
end cap insertion, 4168
easy case, 4169, 4170f
incision, 4165, 4165f
indications/contraindications, 4164
intramedullary nail screw placement, 4167–4168, 4168f
nail placement, 4167, 4167f
nail selection, 4166–4167
outcomes of, 4171
pains and pitfalls of, 4170–4171, 4171f
plantar incision, 4166, 4166f
positioning, 4164
postoperative care of, 4171
preoperative planning, 4164, 4164f
TightRope fixation
AC joint, 116–120
complications of, 120
outcomes of, 120
postoperative care for, 120
techniques for, 118–120, 118f, 119f, 120f
coracoclavicular ligament/coracoid preparation for, 118, 118f
guide pin passage for, 119, 119f
suture passage for, 119, 119f
suture tying for, 120, 120f
Tikhoff-Linberg resections, 1766
proximal humerus, 1793
scapular, 1776, 1777f, 1781–1783, 1792f
Tillaux fractures, pediatric, 1139, 1139f
TIO. See Triple innominate osteotomy
Tissue necrosis, cryoblation-induced, 1757
TKA. See Total knee arthroplasty
TLIF. See Transforaminal lumbar interbody fusion
TM joint. See Thumb metacarpal joint
TNK ankle
anatomy, 4085
definition, 4085, 4085f
TNK implant, TAA using, 4085–4092
complications of, 4092
incision of, 4086
outcomes of, 4091–4092, 4091f, 4092f
pears and pitfalls of, 4091
postoperative care of, 4091
subtalar arthrodesis and, 4090, 4090f
talar osteotomy and, 4087, 4088f
tibial anchor region osteotomy and, 4089, 4089f
tibial osteotomy and, 4086–4087, 4087f
trial/setting for, 4089, 4090f
wound closure for, 4090
Tobramycin, spacer insertion, 846
Toe(s)
Tongue fractures
Total ankle arthroplasty (TAA).
scapular, 1776, 1777f
proximal humerus, 1793
anatomy and, 4208, 4208f
wound closure for, 4090
incision of, 4213–4214, 4214f
bone grafting for, 4213
decortication of, 4213
diagnostic studies for, 4209–4210
differential diagnosis of, 4210
imaging of, 4209–4210, 4210f
natural history of, 4209
nonoperative management of, 4210
pathogenesis of, 4208–4209
patient history of, 4209
physical findings for, 4209
posterior blade plate for salvage of, 4208–4215
posterior blade plate for salvage of, complications in, 4215
posterior blade plate for salvage of, outcomes in, 4215
posterior blade plate for salvage of, pears and pitfalls in, 4215
posterior blade plate for salvage of, postoperative care of, 4215, 4215f
surgical management of, 4210–4212, 4211f, 4212f
infected, revision/removal in, 4212–4213, 4213f
removal, 4212–4213, 4213f
Salto prosthesis for, 4042–4054
anatomy of, 4042–4043, 4042f, 4043f
closure of, 4050
complications of, 4051–4054, 4051f, 4052f, 4053f, 4054f
definition of, 4042
definitive component insertion and, 4050, 4050f
diagnostic studies of, 4043–4044
differential diagnosis of, 4044
imaging of, 4043–4044
natural history of, 4043
nonoperative management of, 4044
outcomes of, 4051
pathogenesis of, 4043
patient history of, 4043
pears and pitfalls of, 4050–4051
surgical management of, 4044–4045, 4045f
talar preparation and, 4048–4049, 4048f, 4049f
tibial resection and, 4045–4046, 4045f, 4046f, 4047f, 4048f
trial component insertion and, 4049–4050
TNK implant, 4085–4092
complications of, 4092
incision of, 4086
outcomes of, 4091–4092, 4091f, 4092f
pears and pitfalls of, 4091
postoperative care of, 4091
subtalar arthrodesis and, 4090, 4090f
talar osteotomy and, 4087, 4088f
Tibial osteotomy and, 4086–4087, 4087f
trial/setting for, 4089, 4090f
wound closure for, 4090
Total ankle shell allograft reconstruction, 4000–4005. See also Allograft;
Ankle allograft preparation/cuts and, 4003, 4003f
anatomy and, 4000
closure, 4004, 4004f
complications, 4005
definition, 4000
diagnostic studies for, 4001
differential diagnosis, 4001
distraction of ankle joint and, 4002, 4002f
graft fixation/placement and, 4003, 4003f
imaging and, 4001, 4001f
natural history and, 4000
nonoperative management, 4001
outcomes, 4004–4005, 4005f
pathogenesis, 4000
patient history and, 4000–4001
pears and pitfalls, 4001
physical findings and, 4000–4001
postoperative care, 4004
postoperative plans, 4004, 4004f
surgical management, 4001
talar cuts and, 4002, 4002f
tibial cuts and, 4002, 4002f
Total elbow arthroplasty (TEA), for RA, 3420–3432
assembly in, 3429, 3429f
bone graft in, 3429, 3429f
cementing in, 3428, 3428f
complications of, 3432
exposure in, 3424, 3424f
humeral component in, 3429, 3429f
humeral preparation in, 3425, 3426f
impaion in, 3429, 3429f
incision in, 3424, 3424f
outcomes of, 3432
pears and pitfalls of, 3431
postoperative care of, 3432
trial reduction in, 3428, 3428f
triceps reattachment and, 3430, 3430f
ulnar nerve transposition and, 3431, 3431f
ulnar preparation in, 3427, 3427f
wound closure and, 3431, 3431f
Total en bloc spondylectomy (TES), 1846–1853
antero reconstruction and, 1850, 1850f
approach, 1846
blunt dissection around vertebral body and, 1850, 1851f
complications, 1853
cutting pedicles and, 1849, 1849f
exposures, 1849, 1849f
outcomes, 1853
pears and pitfalls, 1853
posterior instrumentation and, 1850, 1852f
surgical management, 1853
spinal cord dissection and, 1850, 1851f
T-saw guide and, 1849, 1849f
Total femur
anatomy, 1917, 1918f
imaging, 1918–1919
replacement, THA, revision with femoral bone loss and, 827
resection with endoprosthetic reconstruction, 1917–1927
background, 1917, 1918f
complications, 1927
endoprosthetic reconstruction techniques, 1924–1925, 1924f, 1925f
indications for, 1917–1918, 1919f, 1920f
Total femur (continued) outgrowth, 762–763
pearls and pitfalls, 1927
postoperative care, 1927
soft tissue reconstruction techniques, 1925–1926, 1926f
surgical management of, 1919
techniques, 1920–1926
tumor resection techniques, 1920–1922, 1921f, 1922f, 1923f
Total hip arthroplasty (THA)
cemented, 744–755
total hip arthroplasty (THA)
techniques, 1920–1926
surgical management of, 1919
soft tissue reconstruction techniques, postoperative care, 1927
outcomes, 1927
preoperative planning, 745–747, 746f
postoperative care, 753–754
pearls and pitfalls, 753
patient history, 744–745
pathogenesis, 744
leg length, intraoperative assessment and, 751–752, 752f
femoral component, cementing, 751–752, 752f
femoral neck osteotomy and, 748, 748f
femoral preparation and, 749, 749f
hip dislocation and, 748, 748f
imaging, 745
implant selection for, 746, 746f
distal femur mapping and, 752–753, 752f
indications, 745
leg length, intraoperative assessment and, 748, 748f
natural history, 744
nonoperative management, 745
outcomes, 754, 754f
pathogenesis, 744
patient history, 744–745
pearls and pitfalls, 753
soft tissue findings, 756
positioning, 747
postoperative care, 753–754
preoperative planning, 745–747, 746f
reconstruction assessment and, 750–751, 751f
soft tissue balance and, 750–751, 751f
soft tissue repair and, 752–753, 752f
surgical management, 745–747
techniques, 754–756
temporary fixation for, 746–747, 746f
wound closure and, 752–753, 752f
malignant lesion, 798–807
anatomy and, 798
calcaneal osteotomy and, 805
complications of, 807
definition of, 798
diagnostic studies for, 799
differential diagnosis of, 799
imaging for, 799
long-stem cemented femoral components and, 804–805, 804f
natural history of, 798–799
nonoperative management of, 799–800
outcomes, 807
pathogenesis and, 798
patient history and, 799
pearls and pitfalls, 806
periacetabular reconstruction and, 803–804, 803f
physical findings and, 799
postoperative care of, 807
proximal femur replacement and, 805–806, 805f
surgical management of, 800–803, 800f, 800r, 801f, 802f
techniques for, 803–806
acetabular component implantation, 758–759, 758f
acetabular exposure and, 757, 757f
acetabular preparation and, 758, 758f
anatomy, 756
closure, 761
complications, 761–762
definition, 756
diagnostic studies, 756
differential diagnosis, 756
femoral component implantation, 760, 760f
femoral exposure and, 759, 759f
femoral preparation and, 759–760, 759f
imaging, 756, 756f
leg length determination and, 760–761, 761f
natural history, 756
nonoperative management, 757
outcomes, 761–762
pathogenesis, 756
patient history, 756
pearls and pitfalls, 761
physical findings, 756
postoperative care, 761
soft tissue tension and, 760–761, 761f
surgical management, 757
Total hip replacement, 1873
Total knee arthroplasty (TKA)
cemented, 918–932
anatomy and, 918, 919f
arthroplasty and, 921–922, 922f
bone cuts and, 923–926, 923f, 924f, 925f, 926f
chamfer bone cut and, 925, 926f
closure for, 930
complications, 931–932
compartment fixation and, 928–929, 929f
compartment insertion and, 928
definition of, 918
diagnostic studies for, 919
differential diagnosis of, 919
distal femur bone cut and, 924–925, 925f
exposure and, 921, 921f
femoral condyle bone cut and, 925, 926f
femoral exposure and, 921–925, 925f
femoral head center and, determining, 921
femoral condyle bone cut and, 925, 926f
femoral exposure and, 921–925, 925f
femoral neck osteotomy and, 923, 923f
femoral preparation and, 921, 921f
imaging for, 919
infection and, 931–932
instability and, 932
knee joint exposure and, 922, 922f, 923f
natural history of, 918
nerve injury and, 932
nonoperative management of, 920
osteoysis and, 932
outcomes, 931
patellar preparation and, 925–926, 927f
patella tracking and, 930
pathogenesis and, 918
patient history and, 918–919
pearls and pitfalls, 930–931
physical findings, 918–919
postoperative care, 931
preparation of tibia and, 923
soft tissue and ligament balancing, 927
surgical management of, 920–921, 921f
techniques for, 921–930
trial reduction and, 928, 928f
upper tibial bone cut and, 924, 924f
vascular injury and, 932
navigation used for, 933–941
anatomy, 933
ankle center and, determining, 937, 937f
bone cuts and, 937–940, 938f, 939f, 940f
closure and, 940
component implantation and, 940
definition of, 933
distal femur mapping and, 935–936, 935f, 936f
exposure and, 934
femoral head center and, determining, 935, 935f
initial alignment and deformity, assessment of, 937
limb alignment and, 940
outcomes, 941
patella and, 940
pearls and pitfalls, 941
postoperative care, 941
proximal tibia mapping, 936, 936f, 937f
soft tissue balance and, 940
surgical management, 933–934, 934f
techniques, 934–940
tracker pin placement and, 934–935, 934f
Total shoulder arthroplasty for glenohumeral arthritis with intact rotator cuff, 3261–3273
complications of, 3273
outcomes of, 3273
pearls and pitfalls of, 3272
postoperative care of, 3272–3273
techniques for, 3271, 3272f
for glenohumeral arthritis with irreparable rotator cuff, 3275–3287
complications of, 3286
outcomes of, 3286
pearls and pitfalls of, 3285
postoperative care of, 3286, 3286f, 3287–3288, 3280f, 3281f
Trabecular metal augmentation free, TKA, revision with tibial bone loss and, 958, 958f, 959f
THA, revision with acetalbular bone loss and, 839–840, 840f
Transchondral drilling, OCD lesion, 335–336, 335f
Transforaminal lumbar interbody fusion (TLIF), 4616–4627. See also Lumbar spine anatomy, 4616, 4617f
complications, 4627
contraindications, 4618
definition, 4616
indications, 4617–4618, 4617f
nonoperative management, 4618
outcomes, 4627
pathogenesis, 4616–4617
pearls and pitfalls of, 4626–4627
postoperative care, 4627
scoliosis, 4653–4656, 4655f, 4656f, 4657f
surgical management, 4618–4619, 4618f
techniques for, 4619–4624, 4620f, 4621f, 4622f, 4623f, 4624f
Transmetatarsal amputation, techniques, 2075–2076, 2076f
Transosseous excision, vascular tumors, hand, 2999, 3000f
Trap door technique. See Groove-deepening procedure
Trapezial fractures, surgical treatment, 2293, 2293f
Trapezium fractures, surgical treatment, 3045, 3301, 3301f
Trapezius palsy anatomy and, 3301, 3301f
comparisons, 3306
definition, 3301
diagnostic studies, 3303
differential diagnosis, 3303

I-94
INDEX I-95

Eden-Lange procedure for, 3301–3306
exposure, 3304, 3304f
imaging, 3303
levator transfer, 3305, 3305f
natural history, 3301–3302
nonoperative management, 3303
outcomes, 3306
pathogenesis, 3301
patient history, 3302–3303, 3302f
physical findings, 3302–3303, 3302f
postoperative care, 3306
rhomboid transfer, 3304, 3304f, 3305f
surgical management, 3303, 3303f
wound closure, 3305, 3305f
Trapezoid fractures, surgical treatment, 2293
Triangular fibrocartilage (TFC), tears
arthroscopic repair of, 2524, 2524f
open repair of peripheral, 2524, 2525f
open repair of peripheral, with styloid fracture, 2525, 2525f
Triangular fibrocartilage complex (TFC), 2141
anatomy, 2520, 2520f, 2857, 2857f
arthroscopic repair, 2520–2526
complications of, 2526
outcomes of, 2526
pctc and pits of, 2526
postoperative care of, 2526
TFC tear repair and, 2524, 2524f
wrist, 2523, 2523f
débridement, arthroscopically assisted, 2857–2862
complications of, 2862
laser/radiofrequency-assisted, 2860–2861, 2860f
mechanical, 2859–2860, 2860f, 2860f
outcomes of, 2862, 2862f
pctc and pits of, 2862
postoperative care of, 2862
definition, 2520
diagnostic studies, 2522
foveal, avulsion, arthroscopically assisted repair of, 2142–2145, 2143f, 2144f
imaging, 2522, 2522f
injuries, 2536
differential diagnosis of, 2522
natural history of, 2521, 2521f
nonoperative management of, 2523
pathogenesis of, 2520–2521, 2536–2537
patient history for, 2521–2522
physical findings for, 2521–2522
surgical management of, 2523, 2523f
open repair, 2520–2526
complications of, 2526
outcomes of, 2526
pctc and pits of, 2526
postoperative care of, 2526
TFC tear repair and, 2524–2525, 2525f
reconstruction, palmaris graft for, 2146
repair, 2145–2146, 2145f, 2146f
tears
definition of, 2857
diagnostic studies for, 2858
differential diagnosis of, 2858
imaging of, 2858, 2858f
natural history of, 2857–2858
nonoperative management of, 2858
pathogenesis of, 2857, 2857f
patient history of, 2858
physical findings of, 2858
surgical management of, 2858–2859
ulnar shortening, arthroscopically assisted, 2857–2862
complications of, 2862
outcomes of, 2862, 2862f
pctc and pits of, 2862
postoperative care of, 2862
techniques for, 2861, 2861f
Triceps
degenerative arthritis of elbow and, managing, 3448–3449, 3448f, 3451, 3451f
element replacement and, 3436–3437, 3437f, 3440, 3440f
TEA and reattachment of, 3430, 3430f
Triceps brachii, anatomy, 3047–3048
elbow and, 3054
Triceps-preserving surgical approaches, 3066–3067
Triceps-reflecting surgical approaches, 3063–3066, 3064f, 3065f
Bryan-Morrey posteroomedial, 3063–3065, 3064f
Mayo modified extensile Kocher, 3066
osteoanconeal flap, 3065, 3065f
Triceps-splitting surgical approaches, 3062–3063, 3063f, 3064f
posterior, 3062, 3063f
tendon-reflecting, 3062–3063, 3064f
Tricortical graft, fixation of, glenoid and, 3112–3113, 3112f, 3113f
Trigger finger
Al pulley release complications of, 2636
outcomes of, 2636
pctc and pits of, 2656
percutaneous, 2654–2656, 2654f, 2655f
postoperative care of, 2656, 2656f
Al pulley release for open, 2652–2654, 2652f, 2653f, 2654f
with/without flexor digitorum superficialis ulnar slip excision, 2650–2653
definition, 2650
diagnostic studies, 2651
differential diagnosis, 2651
imaging, 2651
natural history, 2650
nonoperative management, 2651–2652, 2651f
pathogenesis, 2650
patient history, 2650–2651
physical findings, 2650–2651
surgical management, 2652
Trigonal process, resection, 4247–4248, 4248f
Trigonum patholgy, OS, 4257, 4257f
Triplane fractures, pediatric, 1140–1141, 1140f, 1141f
Triple arthrodesis
pediatric, 1600–1607
anatomy and, 1600
Beak, for severe cavus deformity, 1605, 1605f
complications of, 1607
definition of, 1600
diagnostic studies and, 1601
differential diagnosis and, 1601
imaging and, 1601
inlay grafting method in, for valgus deformity, 1606, 1606f
Lambrinudi, 1604–1605, 1604f
hip dysplasia, 1540–1544
iliac osteotomy and, 1544–1545, 1544f
psoas intramuscular lengthening and, 1545
INDEX

I-96

Triple innominate osteotomy (TIO) (continued)
ubis, 1545, 1546f
wound closure and, 1549
Triketral fractures, ORIF, 2289
T-saw guide, TES, 1849, 1849f
Tscherner and Gotzen grading system, closed fractures, 674, 674f
T-Spott technique, equinocavovarus deformity management with, 3897–3899, 3897f–3899f
Tuberosity fractures, isolated, fixation of, 3202, 3203f
Tuberosity fractures, three-part greater, percutaneous pinning, 3196–3197, 3196f
Tumor reconstruction, prosthesis, 967

see also specific tumors
limb salvage and, 1735–1736
thoracic spine
natural history of, 4629
nonoperative management of, 4629–4630
pathogenesis of, 4628
Turf toe injuries. see also Toe(s)

U
UBC. See Unicameral bone cyst
UCL. See Unlar collateral ligament
UKA. See Unlar collateral ligament
Ulna
anatomy, 2127–2128, 2224, 2225f
lateral, 2864–2865, 2864f
artery, elbow and, 3052
diaphyseal fracture ORIF and, 2135–2136, 2135f
distal, 2224, 2224f
osteology, 3050, 3051f
surgical approach, 2088–2089, 2089f
TEA and preparation of, 3426, 3427f
Ulna fracture fixation, Monteggia fractures
and, 3389, 3389f
Ulna head hemiarthroplasty, 2851–2853, 2852f
Ulna head implant arthroplasty anatomy, 2849
complications of, 2856
definition, 2849
diagnostic studies, 2849
diagnostic imaging, 2849
natural history, 2849
nonoperative management, 2849
outcomes of, 2856
pathogenesis, 2849
patient history, 2849
pears and pitsalls of, 2856
physical findings, 2849
postoperative care of, 2856
surgical management, 2850–2855, 2850f–2855f
approach, 2850
construcitonal radiounlar joint arthroplasty, 2854–2855, 2854f, 2855f
partial ulna head replacement arthroplasty, 2851, 2851f
positioning, 2851
preoperative planning, 2851, 2851f
ulna head hemiarthroplasty, 2851–2853, 2852f

Ulner collateral ligament (UCL)
disruptions of, thumb MCP joint, 2342–2348
anatomy of, 2342
arthroscopic and open primary repair of, 2342–2348
definition of, 2342
diagnostic studies of, 2343–2344
diagnostic imaging of, 2343–2344
natural history of, 2342–2343
nonoperative management of, 2344
pathogenesis of, 2342, 2343f
patient history of, 2343
physical findings for, 2343
repair of acute, 2345–2346, 2345f, 2346f
surgical management of, 2344
instability, of thumb MCP joint
anatomy and, 2349
complications and, 2357
definition, 2349
diagnostic studies, 2350
diagnostic imaging, 2350
natural history, 2349–2350
nonoperative management, 2350
outcomes and, 2356–2357
pathogenesis, 2349
patient history, 2350
pears and pitsalls of, 2356
physical findings, 2350
postoperative care for, 2356
reconstructing, 2349–2357
reconstructing, using tendon graft, 2351–2354, 2351f, 2352f, 2353f
surgical management, 2350–2351

Unlar collateral ligament reconstruction, lateral, elbow dislocation, simple, 3374, 3374f
Unlar collateral ligament repair, lateral, elbow dislocation, simple, 3372–3375, 3372f, 3373f
Unlar corner fixation, fragment-specific fixation and, 2192–2193, 2192f, 2193f
Ulner diaphyseal malunions
anatomy and, 2149, 2149f
definition, 2149
diagnostic studies, 2150–2151
differential diagnosis, 2151
imaging, 2150–2151, 2150f
natural history, 2150
nonoperative management, 2151
postoperative care, 2150–2155
approach to, 2153, 2153f
complications of, 2155
outcomes of, 2155
pears and pitsalls of, 2154
postoperative care of, 2155
reduction, plating, bone grafting in, 2153–2154, 2153f
pathogenesis, 2149–2150
patient history, 2150
physical findings, 2150
surgical management, 2151, 2151f

Ulner diaphyseal nonunions
anatomy and, 2156, 2156f
definition, 2156
diagnostic studies, 2157
differential diagnosis, 2157
imaging, 2157, 2157f
natural history, 2156
nonoperative management, 2157
postoperative care, 2156–2161
complications of, 2161
outcomes of, 2161
pears and pitsalls of, 2161
postoperative care of, 2161
pathogenesis, 2156
patient history, 2156–2157
physical findings, 2156–2157
plate fixation for treatment of, 2158–2160, 2159f, 2160f
compression, 2160, 2160f
surgical management, 2157–2158

Ulner fractures
diagnostic studies, 2225–2226
distal, ORIF for comminuted intra-articular, 2223
imaging, 2225–2226, 2225f
natural history, 2224, 2225f
ORIF
complications of, 2232
outcomes of, 2232
postoperative care of, 2232
pathogenesis, 2224
surgical management, 2226–2229, 2226f, 2227f, 2228f

Ulner head fractures
anatomy and, 2224, 2224f
ORIF, 2224–2232
incision/exposure in, 2229–2230, 2229f
techniques for, 2231, 2231f
surgical management, 2228

Ulner impaction syndrome
definition, 2864
diagnostic studies, 2866–2867
differential diagnosis, 2867
imaging, 2866–2867, 2866f
natural history, 2865
nonoperative management, 2867
pathogenesis, 2865, 2865f, 2865f
patient history, 2865–2866
physical findings, 2865–2866
surgical management, 2867–2868

Ulner metadiaphyseal fractures
anatomy and, 2224, 2225f
ORIF, 2224–2232

Ulner neck fractures
distal, ORIF for, 2232, 2232f
surgical management, 2228–2229, 2228f
Ulnar nerve

- anatomy, 2716, 3053
- resection, 1810–1811
- exposing, elbow contracture release and, extrinsic, 3415, 3415f
- release/transposition, elbow loss of motion, 177
- TEA and transposition of, 3431, 3431f
tethering, release, 1383, 1383f, 1384f
- transposition, elbow contracture release and, extrinsic, 3417

Ulnar nerve at Guyon’s canal

- anatomy, 2671, 2672f
- compression, 2671–2675
differential diagnosis, 2674
- natural history of, 2672
- nonoperative management of, 2674
- pathogenesis of, 2671–2672, 2673f, 2673f
- patient history of, 2672–2673
- physical findings in, 2672–2673
- surgical management of, 2674
decompression, 2671–2675
- complications of, 2675
- outcomes of, 2675
- pearls and pitfalls of, 2675
- postoperative care of, 2675
- techniques for, 2674–2675, 2675f
diagnostic studies, 2673–2674
exploration of, 2674–2675, 2675f
- imaging, 2673–2674

Ulnar nerve palsy

- anatomy and, 2716
- definition, 2716
- diagnostic studies, 2716–2717, 2717f
- natural history, 2716
- nonoperative management, 2717
- pathogenesis, 2716
- patient history, 2716–2717
- physical findings, 2716–2717, 2717f
- surgical management, 2717–2718
- tendon transfers, 2716–2722
- claw deformity of fingers and, 2720–2721, 2721f
- complications of, 2722
- flexor digitorum profundus, 2721
- outcomes of, 2722
- pearls and pitfalls of, 2721
- postoperative care of, 2721–2722
- thumb adduction restoration, 2718–2720, 2719f, 2720f

Ulnar osseous groove, ECU subluxation and deepening, 2648, 2648f

Ulnar shaft fractures

- distal, ORIF for, 2232, 2232f
- surgical management, 2228–2229, 2228f

Ulnar shortening

- osteotomy, 2864–2873
- anatomy and, 2864–2865, 2864f
- AO compression device for, 2871, 2871f
- author’s preferred technique for, 2868–2870, 2868f, 2869f, 2870f
- complications of, 2873
- osteochondroma, 2871–2872, 2872f
- outcomes of, 2873
- pearls and pitfalls of, 2872–2873, 2872f
- postoperative care of, 2873

TFCC, arthroscopically assisted, 2857–2862
- complications of, 2862
- outcomes of, 2862, 2862f

Ulnar slip excision, flexor digitorum superficialis, A1 pulley release for trigger finger with/without, 2650–2656

Ulnar styloid fractures

- anatomy and, 2172, 2224, 2225f
- arthroscopic reduction/fixation of, 2172–2181
- complications for, 2181
- metacarpal comminution for, 2178–2180, 2178f, 2179f
- outcomes for, 2181
- pearls and pitfalls for, 2180–2181
- postoperative care for, 2181
- techniques, 2176, 2176f, 2180, 2180f
- definition, 2172
- diagnostic studies, 2173–2174
differential diagnosis, 2174
- imaging, 2173–2174, 2174f
- natural history, 2172–2173
- nonoperative management, 2174
- ORIF, 2224–2232
- techniques for, 2230, 2231f
- pathogenesis, 2172
- patient history, 2173
- physical findings, 2173
- surgical management, 2174–2175, 2175f, 2226, 2227f
- TFC tear open repair, peripheral with, 2525, 2525f

Ulnar styloid nonunion

- ORIF, 2231
- surgical management, 2228, 2228f

Unicameral bone cyst (UBC), 1345–1350

- imaging, 1346, 1346
- definition, 1345
- natural history, 1345
- nonoperative management, 1347
- outcomes, 1350
- pathogenesis, 1345
- patient history, 1345–1346
- pearls and pitfalls, 1350
- physical findings, 1345–1346
- postoperative care, 1350
- surgical management, 1347–1349, 1347f, 1348f, 1349f

Unicondylar knee arthroplasty (UKA), 895–904

- anatomy and, 895
- balancing flexion and extension gaps, 899f
- complications, 903–904, 903f
- definition, 895
- diagnostic studies, 895–896
differential diagnosis, 896
- drilling, 898–899, 899f
- exposure, 897, 897f
- final component in, inserting/cementing, 901f, 902f
- imaging, 895–896, 895f
- natural history, 895
- nonoperative management, 896
- outcomes, 902–903, 903f
- pathogenesis, 895
- patient history, 895
- pearls and pitfalls, 902
- physical findings, 895
- posterior condyle resection and milling, 899, 900f
- postoperative care, 902, 902f
- surgical management, 896–897, 897f
- techniques, 897–902
- templating, 898–899, 899f
tibial resection, 897–898, 898f
- trial bearing, 901, 901f
- trial component, 901, 901f
- Unit rod instrumentation, 1448–1457

- for neuromuscular scoliosis, 1448–1457
- completion/wound closure for, 1455, 1455f, 1456f
- complications of, 1457
- exposure and, 1452
- Luque wire passage and, 1453, 1453f
- outcomes of, 1454
- pearls and pitfalls of, 1456
- pelvis preparation and, 1452, 1452f
- postoperative care of, 1457
- rod selection/insertion and, 1454–1455, 1454f, 1455f

Upper cervical spine, 1399

- instability, 1400–1402

Upper extremity surgery

- anesthetic considerations for, 2102–2113
- background of, 2102
- complications of, 2111–2113, 2111f
- equipment and, 2108–2109, 2109f
- informed consent and, 2110
- pain management and, 2109–2110, 2109f, 2110r
- preoperative evaluation of, 2102–2103, 2102r, 2103f, 2103r
- regional anesthesia and, 2104–2108, 2104r, 2105f, 2106f, 2107f, 2108f
- selection of anesthesia and, 2104, 2104f
- trauma, 2102–2103
- pediatric, anesthetic considerations for, 2103, 2103f, 2103r

Ureter, 1856

Urethography, retrograde, ORIF, sacrum/SL joint, 491

Urine retention, anesthesia and, 2111
primary incision/excision on volar side for, 2343, 2433/4
volar plate, detachment and, 2433, 2433/4
volar plate, securing and, 2435, 2435/6
volar plate, transposing and, 2434, 2434/5
Volar plating, distal radius fracture, 2206–2216
anatomy and, 2206–2207, 2206/f
complications of, 2216
definition of, 2206
fixed-angle, 2209–2214, 2210f, 2211f, 2212f, 2213f, 2214f
fixed-angle, using plate as reduction tool, 2213, 2215f
outcomes of, 2216
pears and pitsalls of, 2215–2216
postoperative care of, 2216
Volar radial (VR) portal, arthroscopy
DRCI repair, 2546, 2547/f
hand/wrist, 2123
hand/wrist midcarpal, 2124
Volar rim fragment, fragment-specific fixation
and, 2193–2194, 2194/f
Volar wrist. See also Wrist
ganglion cyst, 3016–3017, 3016
VPA. See Volar plate arthroscopy
VR portal. See Volar radial portal
V-Y advancement, Achilles tendon ruptures, chronic, 4398–4405
complications of, 4405
outcomes of, 4405
pears and pitsalls of, 4404
postoperative care of, 4404
V-Y advancement flap
lateral, finger tip amputation, 2935, 2935/f
volar, fingertip amputation, 2935, 2935/f
V-Y lengthening, Achilles tendon ruptures, chronic, 4400–4401, 4401/f
V-Y quadricepsplasty, 987, 987/f
V-Y quadruplasty, revision TKA with extensive exposure and, 986–988
complications of, 988
definition of, 986
outcomes of, 986
pears and pitsalls of, 987
postoperative care for, 987–988
quadricepss turndown and, 986, 987/f
standard approach to, 986
tibial tubercle osteotomy and, 986
V-Y quadricepsplasty and, 987, 987/f
pathogenesis, 3707
patient history, 3707–3708, 3708/f
pears and pitsalls of, 3712
physical findings, 3707–3708, 3707/f
postoperative care of, 3713, 3713/f
surgical management, 3708–3711, 3709/f–3711/f
approach, 3708
exposure of metatarsal, 3709–3710, 3709/f–3710/f
fixation of mobile fragment, 3711, 3711f
osteotomy and bony slice extraction, 3710, 3710f–3711/f
positioning, 3708
preoperative planning, 3708, 3709/f
Williams rod, congenital pseudarthrosis
repair with, tibial, 1251–1257, 1254, 1255/f
Wiltse osteotomy, 1281.
Wagner plate fixation.
Wagner type osteotomy, 859.
Watson-Jones approach, ORIF, 526–528, 527/f
Weber clamp reduction, ORIF, symphysis, 480, 481/f
Weil lesser metatarsal shortening osteotomy
anatomy, 3707
complications of, 3713
definition, 3707
diagnostic studies, 3708
differential diagnosis, 3708
imaging, 3708, 3708/f
natural history, 3707
nonoperative management, 3708
outcomes of, 3712–3713
dorsal druji portal for, 2125
4-5 portal for, 2125/f
midcarpal radial portal for, 2122
midcarpal ulnar portal for, 2123
nonoperative management and, 2118–2119, 2119r
1-2 portal for, 2122, 2122/f
pears and pitsalls of, 2123
postoperative care of, 2125
68/6U portals for, 2121
surgical management and, 2119–2121, 2120f, 2120r
TFCC and, 2523, 2523/f
3-4 portal for, 2121
volar druji portal for, 2125
volar ulnar portal for, 2124, 2124/f
VR portal, midcarpal for, 2124
VR portal for, 2123
arthrosis
definition of, 2791
diagnostic studies for, 2792
differential diagnosis of, 2792
imaging of, 2792
natural history of, 2791
nonoperative management of, 2792
pathogenesis of, 2791
patient history of, 2791, 2791/f
physical findings of, 2791, 2791/f
surgical management of, 2792
definition, 2081
degeneration, 2802–2803, 2802/f
natural history of, 2817
patient history of, 2817
physical findings of, 2817
wrist implant arthroplasty and, 2823–2824, 2825/f
denervation, 2791–2794
complications of, 2794
full, 2792–2793, 2792/f, 2793/f
outcomes of, 2794
partial, 2792
pears and pitsalls of, 2794
postoperative care of, 2794
extension restoration, 2724, 2724r
innervation, 2791
ligament injuries
natural history of, 2808
pathogenesis of, 2808
patient history of, 2808
physical findings of, 2808
nerve injury, 2691–2692
diagnostic studies for, 2693
differential diagnosis of, 2693
imaging of, 2693
nonoperative management of, 2693
patient history of, 2692, 2692/f
physical findings of, 2692, 2692/f
surgical management of, 2693
nerve transection, complete
approach to, 2693–2694, 2694/f
cable graft repair following, 2695, 2695/f
complications of, 2698
cordur repair following, 2696, 2696/f
epineural repair following, 2694, 2694/f
group fascicular repair following, 2695, 2695/f
nerve grafting following, 2691–2698
outcomes of, 2697–2698
pears and pitsalls of, 2697
postoperative care of, 2697
primary repair following, 2691–2698
vascularized nerve graft repair following, 2696, 2696/f
nerve transection in, complete, 2691–2698
Wrist (continued)
proximal row, anatomy, 2802
septic arthritis
anatomy of, 2917, 2917f
arthroscopic débridement for, 2921, 2921f
aspiration of, 2920
diagnostic studies for, 2918
differential diagnosis of, 2919
imaging of, 2918, 2918f
natural history of, 2918
nonoperative management of, 2919
pathogenesis of, 2917–2918, 2918f
patient history of, 2918
physical findings of, 2918
surgical drainage, open of, 2921–2922, 2922f
surgical management of, 2919
surgical treatment of, 2917–2923
surgical treatment of, techniques for, 2919–2922, 2920f, 2921f, 2922f
surgical approaches, 2081–2089
pearls and pitfalls of, 2089
surgical management, 2082
Wrist extensor tendon disruption, traumatic, repair following, 2578–2587
complications of, 2587
outcomes of, 2587
pearls and pitfalls of, 2586–2587
postoperative care of, 2587
suture techniques for, 2582, 2582f
techniques for, 2584–2586, 2585f, 2586f
Wrist flexion deformity
anatomy, 1371
definition, 1371
diagnostic studies, 1372
differential diagnosis, 1372
FCU transfer for, 1371–1375
complications of, 1374–1375
outcomes of, 1374
pearls and pitfalls of, 1374
postoperative care of, 1374
imaging, 1372
nonoperative management, 1372
pathogenesis, 1371
patient history, 1371–1372
physical findings, 1371–1372
surgical management, 1372–1373, 1373f
Wrist implant arthroplasty, 2822–2830
anatomy and, 2823, 2823f
complications of, 2830
definition, 2822–2823, 2822f
Maestro prosthesis, 2824–2828, 2825f, 2826f, 2827f, 2828f, 2829f
outcomes of, 2829–2830, 2830f
pathogenesis and, 2823, 2823f
pearls and pitfalls of, 2829
postoperative care of, 2829
wrist degeneration and, 2823–2824, 2823f

X
Xenograft, 2941

Z
Z-plasty, 2964–2965, 2964f, 2965f
contractures bands, release of, 2968–2969, 2968f, 2969f
Z-plasty flaps, 2954, 2958, 2958f